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International Civil Aviation Organization
AMENDMENTS

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**RECORD OF AMENDMENTS AND CORRIGENDA**

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(ii)
Secondary surveillance radar (SSR) is a major system for surveillance purposes in most air traffic control (ATC) systems. One of the important updates was the standardization of Mode S systems in 1985. Mode S has a data link capability which is part of the aeronautical telecommunication network (ATN).

The purpose of this document is to describe all the system characteristics not only of the ground station but also the airborne transponder. This document should be read together with Annex 10 for the relevant Standards and Recommended Practices (SARPs).

Several chapters describe Mode S surveillance and communications functions, including the implementation aspects of Mode S, interference considerations and the Mode S subnetwork of the ATN.

There is a specific chapter on Mode S extended squitter concept, technique and applications. The Mode S extended squitter system is subject to patent rights from the MIT Lincoln Laboratory. On 22 August 1996, MIT Lincoln Laboratory issued a notice in the Commerce Business Daily (CBD) of its intent not to assert its rights as patent owner against any and all persons in the commercial or non-commercial practice of the patent, in order to promote widest possible use of the Mode S extended squitter technology. Further, by letter to ICAO dated 27 August 1998, MIT Lincoln Laboratory confirmed that the CBD notice was provided to satisfy ICAO requirements for a statement of patent rights for techniques that are included in SARPs, and that “the patent holders offer this technique freely for any use”.

This document consists for the most part of material developed by the Secondary Surveillance Radar Improvements and Collision Avoidance Systems Panel (SICASP).

Comments on this manual from States and other parties outside ICAO concerned with SSR systems development and provision of services would be appreciated. Comments should be addressed to:

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Montreal, Quebec
Canada H3C 5H7
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GLOSSARY

**Aircraft address.** A unique combination of 24 bits available for assignment to an aircraft for the purpose of air-ground communications, navigation and surveillance.

Note.— The aircraft address is also referred to as the Mode S address or the aircraft Mode S address.

**All-call.** An intermode or Mode S interrogation that elicits replies from more than one transponder.

**All-call (Mode A/C-only).** An intermode interrogation that elicits replies from Mode A/C transponders only. Mode S transponders do not accept this interrogation.

**All-call (Mode A/C/S).** An intermode interrogation that elicits Mode A/C replies from Mode A/C transponders and all-call replies from Mode S transponders that are currently not in the lockout state.

**All-call (Mode S-only).** A Mode S interrogation that elicits all-call replies from Mode S transponders that are currently not in the lockout state.

**Altitude.** The vertical distance of a level, point or an object measured above mean sea level.

**Antenna (electronically scanned, E-Scan).** An SSR antenna consisting of a number of planar arrays or a circular array of radiating elements. A beam former unit allows it to electronically steer the beam to the desired azimuth angle by applying phase shifting. The antenna elements may either be active or passive, depending on the order in which the beam former and transmitter(s) are set up.

**Antenna (hog-trough).** An SSR antenna comprising a horizontal linear array of radiating elements installed in an extended corner reflector assembly (resembling in shape a hog-trough). The linear array is usually of sufficient length to give an azimuth beam width of between 2° and 3° and the hog-trough reflector achieves typically between ± 40° and 45° vertical beamwidth. For special purposes shorter arrays can be used. These have increased azimuth beam width.

**Antenna (large vertical aperture, LVA).** An SSR antenna comprising two-dimensional array radiating elements. A typical LVA consists of a number of columns (each consisting of a vertical linear array designed to produce beam shaping in the vertical plane) arranged in a horizontal linear array to produce between 2° and 3° azimuth beamwidth. Typically, LVA antennas are a pre-requisite for monopulse SSR systems.

**Antenna (linear array).** An antenna consisting of a “battery” or array of radiating elements in a straight line. The desired radiation characteristic of the antenna is obtained by the varied distribution of radio frequency energy in amplitude or phase so as to produce the shaped “beam” or wave front.

**Antenna (sum and difference).** A hog-trough or LVA antenna which is electrically split into two halves. The two half-antenna outputs are added in phase at one output port (sum, \( \Sigma \)) and added in antiphase at a second output port (difference, \( \Delta \)) to produce output signals which are sensitive to the azimuth angle of arrival of received signals, enabling an off-boresite angle for the signal source to be obtained.

**Antenna (reflector).** An antenna producing the beam by a method analogous to optics. In most cases the “reflector” surface of the antenna is illuminated by a radio frequency source (e.g. a radio-frequency “horn” assembly). The dimensions of the reflector antenna both in the horizontal and vertical plane, together with the characteristics of the illuminating source, determine the shape and magnitude of the radar beam produced.

**Antenna elevation (tilt).** An angle between the direction of maximum gain of the antenna and the tangent to the surface of the earth. A distinction is sometimes made between electronic (radio signal) and mechanical tilt, especially for SSR LVA antennas. In this case the mechanical tilt may be zero while the antenna is radiating at the electronic tilt of 3°.
Antenna (omnidirectional). An antenna with the same gain in all directions. In earlier side-lobe suppression systems, this antenna type was often used for transmitting the $P_2$ pulse and sometimes also for transmission of the $P_1$ pulse ($^4\text{SLS}$). Modern omnidirectional antennas for ground SSR use include a “notch” coinciding with the peak of the main beam.

Antenna diversity. For an installation with a top-end mounted antenna, the selection of the Mode S transponder reply transmission path is based on a comparison of the interrogation signals received on two channels.

Beam sharpening. A technique applied to the LVA antenna to decrease the runlength of SSR replies. The reduced runlength is required to improve the resolution capabilities of the extraction system. On the interrogation path, a part of the power of the $P_2$ pulse is transmitted through the interrogate ($P_1$-$P_3$) pattern to raise the peaks of the control pattern. The crossover points may be raised by about 9 dB thus reducing the effective beamwidth. On the reply path, the sum and difference receivers are used to compare the incoming signal. The plot runlength will be adjusted by tuning the amplifier.

Beamwidth. An angle subtended (either in azimuth or elevation) at the half-power points (3 dB below maximum) of the main beam of an antenna.

Boresight. A main lobe electrical (radio) axis of an antenna.

Bracket decode. A decoding of the $F_1$ - $F_2$ framing pulses (nominal interval 20.3 µs) without regard to the content of the data pulses between these framing pulses.

Capability report. An indication provided by the capability (CA) field of an all-call reply and a squitter transmission of the communications capability of the Mode S transponder (see also “data link capability report”).

Chip. A 0.25 µs carrier interval following possible data phase reversals in the $P_6$ pulse of Mode S interrogations (see “data phase reversal”).

Closeout. A command from the Mode S ground station that terminates a communication transaction.

Code. A combination of data bits contained in signals transmitted by an SSR transponder in reply to an SSR interrogator.

Code train. A sequence of bracket (framing) and information pulses in an SSR Mode A or Mode C reply.

Comm-A. A 112-bit interrogation containing the 56-bit MA message field. This field is used by the uplink SLM and broadcast protocols.

Comm-B. A 112-bit reply containing the 56-bit MB message field. This field is used by the downlink SLM, ground-initiated and broadcast protocols.

Comm-B Data Selector (BDS). The 8-bit BDS code in a surveillance or Comm-A interrogation determines the register whose contents are to be transferred in the MB field of the elicited Comm-B reply. The BDS code is expressed in two groups of 4 bits each, BDS1 (most significant 4 bits) and BDS2 (least significant 4 bits).

BDS1 code. The BDS1 code is defined in the RR field of a surveillance or Comm-A interrogation.

BDS2 code. The BDS2 code is defined in the RRS subfield of the SD field of a surveillance or Comm-A interrogation when DI=7. If no BDS2 code is specified (i.e. DI≠7), it signifies that BDS2 = 0.

Comm-C. A 112-bit interrogation containing the 80-bit MC message field. This field is used by the extended length message (ELM) uplink protocol for uplink data transfer and by the downlink ELM protocol for the transfer of segment readout commands.

Comm-D. A 112-bit reply containing the 80-bit MD message field. This field is used by the extended length message (ELM) downlink protocol for downlink data transfer and by the uplink ELM protocol for the transfer of technical acknowledgements.

Control antenna. An SSR antenna having a polar diagram which is designed to “cover” the side lobes of the main interrogating antenna. It is used to radiate a control pulse which, if it exceeds in amplitude the associated interrogation signal at the input to the transponder, will cause the transponder to inhibit responses to the interrogation pulses. Modern SSR antennas have the control elements built into the main array. The control antennas is also known as the SLS (side-lobe suppression) antenna.

Control pattern. A polar diagram of the control antenna. Modern integrated SSR antennas have a “modified cardioid” beamshape.

Control pulse. A pulse ($P_2$ for Modes A and C, $P_3$ for Mode S) transmitted by the ground equipment (SSR interrogator) in order to ensure side-lobe suppression.
Cone of silence. A gap in coverage above a radar due to the limitations of the antenna performance at high elevation angles.

Correlation criteria. A number of pulse repetition intervals over which range correlation of replies must be achieved in a sliding or moving window extractor before the presence (or tentative presence, subject to further tests) of a plot can be declared.

Correlated tracks. Tracks which have been correlated with a flight plan (sometimes this term applies only to tracks for which the Mode A code has been correlated with a call-sign in the code/call-sign list i.e. flight plan association).

Data link capability report. Information in a Comm-B reply identifying the complete Comm-A, Comm-B, ELM and ACAS capabilities of the aircraft installation.

Data phase reversal. A 180° phase shift which precedes a chip in a Mode S interrogation (see “chip”) and is used to encode a binary ONE. The absence of the phase reversal encodes a binary ZERO.

Dead time. A period of time during which an SSR transponder is inhibited from receiving signals after a valid interrogation is received and a reply transmitted. The term is also used to describe the time after the normal range for returns and before the next transmission from an interrogator or from a primary radar system.

Defruiter. Equipment used to eliminate unsynchronized replies (fruit) in an SSR ground system.

Defrutiing. A process by which aircraft replies accepted by the interrogator-responser are tested by means of storage and a comparator for synchronism with the interrogation-repetition frequency. Only replies which are in synchronism (correlate on a repeated basis in range) will be output from the defruiter. Other replies are rejected as “fruit” or false.

Degarbling. A process of separating (and possibly validating) garbled SSR replies. (See “Garbling”.)

Delta theta. A number of azimuth count pulses (ACPs) as measured from the plot leading edge to the plot trailing edge in a sliding window plot extractor. Also known as azimuth extension or plot run length.

Difference pattern. A receive (1 090 MHz) characteristic of a monopulse SSR antenna, obtained by connecting in antiphase the signals (replies) received by two partial antennas. The difference pattern has a minimum in the main radiation direction of the antenna and an amplitude and phase characteristic which varies as a function of angle of arrival of the received signal. Used in conjunction with the sum output of the antenna, it enables the off-boresight angle to be found.

Downlink. Associated with signals transmitted on the 1 090 MHz reply frequency channel.

DPSK. Binary differential phase shift keying (DPSK) modulation which uses phase reversals preceding chips to denote binary ONEs and the absence of a phase reversal to denote binary ZEROS.

En-route radar. A surveillance radar for the traffic passing through the area of control. Typically, the range of such a radar is approximately 370 km (200 NM) and the information renewal rate for a mechanically rotating antenna is 8 to 12 seconds.

ERP. Effective radiated power (ERP) is the transmitted power enhanced by the gain of the antenna less the losses in cables, rotary joints, etc.

Extended length message (ELM). A series of Comm-C interrogations (uplink ELM) transmitted without the requirement for intervening replies, or a series of Comm-D replies (downlink ELM) transmitted without intervening interrogations.

Extended length communication protocol. A procedure to exchange digital data using extended length messages.

False plot. A radar plot report which does not correspond to the actual position of a real aircraft (target), within certain limits.

Far field monitor (FFM). See remote field monitor.

Field. A defined number of contiguous bits in an interrogation or reply.

Flight status (FS) field. A field of a Mode S reply indicating whether the aircraft is airborne, whether it is transmitting the Mode A/C SPI code and whether it has recently changed its Mode A identity code.

Framing pulses. Pulses which “frame” the information pulses (code) of SSR Mode A and C replies (described as F1 and F2 respectively). Also known as “bracket pulses”.
**Fringe (inner and outer).** A minimum and maximum range respectively for a successful plot detection.

**Fruit.** A term applied to unwanted SSR replies received by an interrogator which have been triggered by other SSR interrogators. Fruit is the acronym of False Replies Unsynchronized In Time, or False Replies Unsynchronized to Interrogator Transmission.

**Garbling.** A term applied to the overlapping in range and/or azimuth of two or more SSR replies so that the pulse positions of one reply fall close to or overlap the pulse positions of another reply, thereby making the decoding of reply data prone to error.

**Gain (of antenna).** A measure for the antenna of the increased (effective) transmitted power density radiated in a particular direction as compared to the power density that would have been radiated from an isotropic antenna (expressed in dB).

**Ground-initiated Comm-B protocol (GICB).** A procedure initiated by a Mode S ground station for eliciting a Comm-B message from a Mode S airborne installation.

**Hit.** A reception by the aircraft equipment (transponder) of one usable set of interrogation pulses as evidenced by a reply code return (i.e. receipt of 2 interrogation pulses and 1 control pulse).

**Improved interrogation side-lobe suppression (I^2SLS).** A technique whereby interrogation pulse \( P_1 \) is transmitted via both the main beam and the control beam of the SSR antenna, so that a transponder in a side-lobe direction more reliably receives a \( P_1-P_2 \) pulse pair.

**Interlace.** A repeating series of SSR interrogation modes. The interlace pattern may be determined either on a p.r.p. (pulse-repetition period) to p.r.p. basis or on an antenna rotation to antenna rotation basis. It may also be made on a combined p.r.p./antenna basis.

**Interleave.** A condition where two or more pulse trains become superimposed in time so that their pulse time spacing can be distinguished and the correct codes established.

**Intermode interrogations.** Interrogations that consist of 3 pulses \( (P_1, P_2 \), and \( P_6) \) and are capable of eliciting replies a) from both Mode A/C and Mode S transponders or b) from Mode A/C transponders but not from Mode S transponders (see “All-call”).

**Interrogation.** See “Mode”.

**Interrogator repetition frequency (IRF).** An average number of interrogations per second transmitted by the radar. See also “Pulse repetition frequency”.

**Interrogator side-lobe suppression (ISLS).** A method of preventing transponder replies to interrogations transmitted through the ground antenna side lobes.

**Interrogator.** A ground-based (normally) transmitter element of an SSR system.

**Interrogator-responder.** A ground-based combined transmitter-receiver element of an SSR system.

**Interrogator identifier (II).** One of the codes (1 to 15) used to identify a Mode S ground station using the multisite protocols.

**Lobing (antenna pattern).** A process whereby, due to interference of two waves, one direct and one reflected, differences in phases cause larger or smaller amplitudes than expected for free space, causing differences in signal amplitudes.

**Lockout state.** A state in which a Mode S transponder has been instructed not to accept certain all-call interrogations. Lockout is deliberately induced by command from the Mode S ground station.

**Mode A/C transponder.** Airborne equipment that generates specified responses to Mode A, Mode C and intermode interrogations but does not reply to Mode S interrogations.

**Mode S.** An enhanced mode of SSR that permits selective interrogation and reply capability.

**Mode S ground station.** Ground equipment that interrogates Mode A/C and Mode S transponders using intermode and Mode S interrogations.

**Mode S interrogations.** Interrogations consisting of three pulses \( (P_1, P_2 \) and \( P_6) \) that convey information to and/or elicit replies from Mode S transponders. Mode A/C transponders do not respond to Mode S interrogations because they are suppressed by the \( (P_1-P_2) \) pulse pair.

**Mode S transponder.** Airborne equipment that generates specified responses to Mode A, Mode C, intermode and Mode S interrogations.
**Mode.** SSR interrogation mode as specified in Annex 10, Volume IV, Chapter 2.

**Monopulse.** A technique wherein the amplitudes and/or phases of the signals received in overlapping antenna lobes are compared to estimate the angle of arrival of the signal. The technique determines the angle of arrival of a single pulse, or reply, within an antenna beamwidth. The angle of arrival is determined by means of a processor using the replies received through the sum and difference patterns of the antenna. The monopulse technique is generally termed “monopulse direction finding”.

**Monopulse plot extractor.** A plot extractor using monopulse direction-finding techniques. See also plot extractor.

**Moving window detector.** A radar signal processing device which stores radar returns over a given number of pulse repetition periods (the number depending upon the so-called moving window size) and uses these for the automatic detection of radar targets. Also known as sliding window detector.

**Multisite Comm-B protocol.** A procedure to control air-initiated Comm-B message delivery to Mode S ground stations that have overlapping coverage and that are operating independently (see “multisite protocol”).

**Multisite directed Comm-B protocol.** A procedure to ensure that a multisite Comm-B message closeout is effected only by the particular Mode S ground station selected by the Mode S airborne installation.

**Multisite protocol.** Procedures to control message interchange between a Mode S transponder and Mode S ground stations with overlapping coverage and that are operating independently. Multisite protocols allow only a single Mode S ground station to close out a message interchange, thereby assuring that independent operation of Mode S ground stations does not cause messages to be lost.

**Non-selective Comm-B protocol.** A procedure to control air-initiated Comm-B message delivery to Mode S ground stations operating alone or in overlapping coverage with operations coordinated via ground communications.

**Over-interrogation.** Interference in the operation of a secondary radar system due to the fact that the number of interrogations exceeds the capacity of the transponder (a preset value). The action of the transponder is an automatic reduction in transponder receiver sensitivity.

**Overlapping targets.** A condition where radar replies overlap each other in range and/or azimuth. (See also “Garbling”.)

**Parrot.** A fixed transponder referred to as the Position Adjustable Range Reference Orientation Transponder and used as a field monitor. (See “Remote field monitor”.)

**Plot combiner.** A signal processing device for the combination of PSR and SSR data ascertained as having originated from the same target. Targets failing to meet pre-defined combination criteria will be output as “PSR only” or “SSR only” plots in place of “combined plots”.

**Plot extractor.** Signal processing equipment which converts PSR or SSR video into an output data message suitable for transmission through a data transmission medium or possibly to further data processing equipment. (See “Plot filter”.)

**Plot filter.** Signal processing equipment which filters out radar plot data positively identified as stationary by a rotation scan-to-scan correlation process.

**Plot resolution.** A separation in range and azimuth between two plots, for which the quality of the information of one plot is not affected by the presence of the other plot.

**Plot run length.** The number of azimuth count pulses between the first and last detection of a plot presence in a sliding window plot extractor (see also “Delta theta”).

**Polar diagrams.** Horizontal or vertical radiation patterns for a radar antenna whereby the relative gain is plotted as a function of the relative azimuth (horizontal polar diagram) or as a function of the relative elevation angle (vertical polar diagram). Polar diagrams for LVA antennas are measured separately on uplink and downlink with respect to the main beam axis.
**Pulse repetition frequency (PRF).** An average number of pulses/interrogations per second transmitted by the radar (see "Stagger"). Also known as pulse recurrence frequency.

**Pulse train.** A sequence of framing and information pulses in the coded SSR reply.

**Pulse position modulation (PPM).** Modulation technique used for Mode S replies where a pulse transmitted in the first half of the bit position interval represents a binary ONE, whereas a pulse transmitted in the second half represents a binary ZERO.

**Quantized video (QV).**

Secondary:
A pulse generated within a plot extractor on detection of $F_1$, $F_2$ pulses, synchronized to the plot extractor timing.

Monopulse:
Analogue video converted to digital words synchronized to the monopulse plot extractor master clock timing.

**Quantum.** Range unit used for quantization of the range information. Also known as range bin or range cell.

**Radar reinforcement.** In combined PSR/SSR plot extractors, the term is applied to the successful association of a primary plot with an SSR plot. Also known as plot combination. If successful association is achieved, the plot extractor generates an SSR message in which an additional bit, radar reinforcement, is set; the remaining primary radar plot information may be merged or it may be discarded.

**Raw video.** Unprocessed, analogue PSR or SSR video information.

**Receiver side-lobe suppression (RSLS).** A method, using two (or more) receivers to suppress aircraft replies which have been received via side lobes of the main beam of the antenna.

**Remote monitoring and control system (RMCS).** A system which allows manual or automatic reconfiguration of a radar system. The RMCS will also give an overall indication of the system status (equipment operational, equipment in standby, faults, etc.). The RMCS equipment may have a terminal either at the station level or at the ATC centre level and often at both levels.

**Reply.** A pulse train received at an SSR ground station as a result of successful SSR interrogation.

**Reply code, reply pulse train.** See “Code train”.

**Reply preamble.** A sequence of four pulses, each with a duration of 0.5 microsecond, indicating the beginning of a Mode S reply.

**Residual errors.** Errors in position which exist between the corrected positions of an object (measured position minus systematic error) and the corresponding trajectory.

**Resolution.** Ability of a system to distinguish between two or more targets in close proximity to each other both in range and bearing (azimuth).

**Respondor.** A ground-based receiver part of the SSR. The complete equipment is generally known as the interrogator/respondor.

**Ring-around.** Continuous reception of replies to interrogations by the side lobes of the ground antenna. This normally occurs only at short ranges, usually due to the non-existence of a side-lobe suppression mechanism or the improper functioning of this mechanism, at either the interrogator or the transponder side.

**Round reliability.** A probability of receipt of a correct reply, resulting from either an SSR interrogation or a PSR transmission.

**Secondary surveillance radar (SSR) system.** A radar system which transmits coded interrogations to aircraft transponders in various modes and receives coded replies.

**Secondary surveillance radar (SSR) transponder.** A unit which transmits a response signal on receiving an SSR interrogation. The term is a derivative of the words transmitter and responder.

**Side lobes (antenna).** Lobes of the radiation pattern of an antenna, which are not part of the main or principal beam. Radar systems can have sufficient sensitivity via
side lobes for successful detection of aircraft (particularly for SSR, but also for PSR). Special precautions are necessary to protect against these false plots.

**Side-lobe suppression (SLS).** A mechanism in an SSR transponder activated by the transmission (radiation) of a control pulse ($P_2$ or $P_3$) of amplitude greater than the antenna side-lobe signals-in-space, which will enable the transponder to prevent itself from replying to the side-lobe interrogation signals.

**Squitter.** The spontaneous periodic transmission by a Mode $S$ transponder (nominally once per second) of a specified format to permit passive acquisition by Mode $S$ interrogators with broad antenna beams (e.g. ACAS).

**Stagger.** Deliberate, controlled variation of the pulse repetition frequency of the SSR to prevent aircraft plots due to second-time-around replies.

**Standard length communication protocol.** A procedure to exchange digital data using Comm-A interrogations and/or Comm-B replies.

**Sum pattern.** Normal radiation pattern for the main directional beam of an antenna. Contrasts with the “difference-pattern”, where parts of the radiating elements of the antenna are switched in anti-phase to produce signals proportional to the amount by which the source is off the boresight of the sum pattern.

**Suppression.** A deliberate inhibition of a transponder’s ability to accept or reply to interrogations.

**Surveillance interrogation.** A 56-bit Mode $S$ interrogation containing surveillance and communications control information.

**Surveillance processing.** A general term covering any processing applied to the target reports after the extraction functions and prior to the data transmission functions. Such processes include filtering, clutter reduction, data rate control and dynamic angle control.

**Surveillance reply.** A 56-bit Mode $S$ reply containing surveillance and communications control information, plus the aircraft’s 4,096 identity code or altitude code.

**Sync phase reversal.** A first phase reversal in the Mode $S$ $P_6$ interrogation pulse. It is used to synchronize the circuitry in the transponder that decodes the $P_6$ pulse by detecting data phase reversals, i.e. as a timing reference for subsequent transponder operations related to the interrogation.

**Tilt.** See antenna elevation.

**Track.** A succession of radar-reported positions for one aircraft sometimes correlated and smoothed by a special tracking algorithm.

**Trailing edge (plot).** The azimuth, for which the extractor/plot processor logic detects the “end of plot”.

**Transponder transaction cycle.** The sequence of Mode $S$ transponder operations required by the reception of an interrogation. The process begins with the recognition of an interrogation and ends either with the non-acceptance of the interrogation or the transmission of a reply or the completion of processing associated with that interrogation.

**Uplink.** Associated with signals transmitted on the 1,030 MHz interrogation frequency channel.

**Validation (code).** Process of correlation of the code information used in SSR Mode A/C systems. Generally two identical codes in two successive replies suffice to validate the code. In Mode $S$, code validation occurs inherently when the reply is decoded (and, if appropriate, error corrected).

Note.—Modern radar systems may provide “smoothed” code information when the so-called validation serves to indicate non-extrapolated code information.
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<th>Definition</th>
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<td>ACAS</td>
<td>Airborne collision avoidance system</td>
<td>LVA</td>
<td>Large vertical aperture</td>
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<td>ADLP</td>
<td>Airborne data link processor</td>
<td>MA</td>
<td>Message Comm-A</td>
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<td>ADS-B</td>
<td>Automatic dependent surveillance-broadcast</td>
<td>MB</td>
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<td>ASAS</td>
<td>Airborne separation assurance system</td>
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<td>Air traffic control</td>
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<td>ATN</td>
<td>Aeronautical telecommunication network</td>
<td>MSP</td>
<td>Mode S specific protocol</td>
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<td>BDS</td>
<td>Comm-B data selector</td>
<td>MTL</td>
<td>Minimum triggering level</td>
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<td>CC</td>
<td>Cross-link capability</td>
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<td>CF</td>
<td>Change field</td>
<td>PRF</td>
<td>Pulse repetition frequency</td>
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<td>Compact position reporting</td>
<td>PRI</td>
<td>Pulse repetition interval</td>
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<td>CRC</td>
<td>Cyclic redundancy check</td>
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<td>Resolution advisory</td>
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<td>DCE</td>
<td>Data circuit-terminating equipment</td>
<td>RDPS</td>
<td>Radar data processing system</td>
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<td>DH</td>
<td>Dataflash header</td>
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<td>Radio frequency</td>
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<td>DS</td>
<td>Data selector</td>
<td>RL</td>
<td>Reply length</td>
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<td>DTE</td>
<td>Data terminal equipment</td>
<td>RNP</td>
<td>Required navigation performance</td>
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<td>EC</td>
<td>Event criterion</td>
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<td>Standard length message</td>
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<td>ELM</td>
<td>Extended length message</td>
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<td>FDPS</td>
<td>Flight data processing system</td>
<td>SPI</td>
<td>Special position identification</td>
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<td>FRUIT</td>
<td>(fruit) False replies from unsynchronized</td>
<td>SR</td>
<td>Service request</td>
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<td></td>
<td>interrogator transmissions in time</td>
<td>SSR</td>
<td>Secondary surveillance radar</td>
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<td>GDLP</td>
<td>Ground data link processor</td>
<td>STC</td>
<td>Sensitivity time control</td>
</tr>
<tr>
<td>GICB</td>
<td>Ground-initiated Comm-B</td>
<td>SVC</td>
<td>Switched virtual circuit</td>
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<tr>
<td>GNSS</td>
<td>Global Navigation Satellite System</td>
<td>TA</td>
<td>Traffic advisory</td>
</tr>
<tr>
<td>HRP</td>
<td>Horizontal radiation pattern</td>
<td>TIS</td>
<td>Traffic information service</td>
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<tr>
<td>II</td>
<td>Interrogator identifier</td>
<td>TLS</td>
<td>Target level of safety</td>
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<td>I^SLS</td>
<td>Improved interrogator side-lobe suppression</td>
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<td>Vertical radiation pattern</td>
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<td>ISLS</td>
<td>Interrogator side-lobe suppression</td>
<td>W/S</td>
<td>Whisper/shout</td>
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Chapter 1

SYSTEM DESCRIPTION AND FUNCTIONAL OBJECTIVES

Note.— Chapters 1 to 8 contain references to SARPs for SSR and SSR Mode S systems which are in Annex 10, Volume IV, dedicated to surveillance radar and collision avoidance systems, Chapters 2 and 3. Chapter 9 contains references to SARPs for the Mode S subnetwork of the ATN, which are in Annex 10, Volume III, Part I, dedicated to digital data communication systems.

1.1 SYSTEM DESCRIPTION

1.1.1 The secondary surveillance radar (SSR) system provides ground-based surveillance of transponder-fitted aircraft and allows data link communication between ground stations and aircraft where both are fitted with appropriate Mode S equipment.

1.1.2 SSR has two basic elements: the SSR interrogator, normally ground-based, and the aircraft SSR transponder. When aircraft are within the antenna beam of the ground station, the ground station’s interrogations elicit replies from transponders.

1.1.3 The system has four modes of interrogation/reply: Mode A, Mode C, Mode S and intermode. Ground stations will either be Mode A/C ground stations, which can interrogate and receive replies only on Mode A/C, or Mode S ground stations, which can interrogate and receive replies on all modes. There are two classes of transponders: Mode A/C transponders, which can respond to Mode A, Mode C and intermode interrogations only, and Mode S transponders, which can respond to all modes. The use of these modes for interrogations and replies is illustrated in Figure 1-1.

1.1.4 The SSR system can provide two categories of service, as illustrated in Table 1-1:

   a) *Mode A/C service:* Range and azimuth surveillance, identification (4 096) codes, altitude reporting; and

   b) *Mode S service:* All Mode A/C services, selective addressing, specific services and full two-way data link, both uplink and downlink.

1.1.5 In a mixed environment with Mode A/C and Mode S ground stations and transponders, the Mode A/C service is always available. Upgrading of ground stations or transponders to Mode S does not prevent the provision of a Mode A/C service, thus ensuring compatibility between Mode A/C and Mode S.

1.1.6 The replies to all modes of interrogation can be used to determine aircraft position by measurement of the range and bearing of the reply.

1.2 SSR MODES

The four modes of SSR provide the following specific functions:

a) *Mode A.* A Mode A interrogation elicits a Mode A reply which supports the following capabilities: a) one of 4,096 codes to allow identification of individual aircraft or groups of aircraft depending upon operational requirements; b) identification on the display, when requested, of an individual aircraft signal by the use of the transponder special position identification (SPI) facility; c) immediate identification of aircraft experiencing a radiocommunication failure or other emergency or unlawful interference (highjacking);

b) *Mode C.* A Mode C interrogation elicits a Mode C reply. All transponders are required to reply to Mode C interrogations. The reply will contain encoded pressure-altitude information. The pressure-altitude source will be analogue or digital.
and the altitude information is provided uncorrected directly to the transponder from the source. Digitized altitude information is automatically derived by an analogue-digital converter connected to the altitude pressure source in the aircraft referenced to the standard pressure setting of 1 013.25 hectopascals. If, for any reason, the transponder cannot load data for altitude report transmission, the reply will consist of framing pulses only. If suitable decoding and display facilities are available, the altitude of those aircraft transmitting altitude information can be displayed;

Note.— Barometric altitude is the reference for vertical separation in ICAO airspace. There are no means to convert geometric height data to pressure-altitude.

c) Mode S. Mode S interrogations (uplink) can be addressed to individual aircraft. This allows the transmission of coded information to the transponder fitted with data link capability. The Mode S reply (downlink) may contain the aircraft’s identity, its altitude, or other data, depending on what is requested by the ground station and depending on the aircraft fit. The Mode S interrogations and replies are protected by a robust error detection/correction scheme which gives high reliability to the information transferred. Mode S transponders are capable of reporting pressure-altitude in either 100-ft or 25-ft increments. Pressure-altitude encoders will report altitude at least in 100-ft increments. However, the capabilities of ground and airborne surveillance systems are significantly improved if the pressure-altitude report is transmitted with 25-ft increments. Most pressure-altitude sources are capable of reporting equal to or finer than 25-ft increments. Therefore, such altitude sources should be used, at least in new installations. However, using a pressure altitude source with a quantization coarser than 25-ft connected to the transponder when the transponder is using the formats for 25-ft increments will make the situation worse. Altitude reports must not be transmitted in 25-ft increments if the pressure-altitude source is not capable of providing 25-ft or better quantization. If the pressure-altitude information is directly provided from the altitude source to the transponder then the transponder will choose the appropriate quantization for altitude report transmission. If digitized altitude information is provided via an on-board data bus the data set should also provide information on the appropriate quantization of altitude report transmission; and

d) Intermode. The Mode A or Mode C all-call intermode interrogation allows a Mode S ground station to interrogate Mode A/C transponders on Mode A or C, without Mode S transponders replying. The Mode A/C/S all-call interrogation causes Mode S transponders to reply with a Mode S reply, indicating their discrete Mode S address. Mode A/C transponders reply with a Mode A or Mode C reply according to the interrogation.

Table 1-1. Service level available as a function of ground station and transponder class

<table>
<thead>
<tr>
<th>Transponder</th>
<th>Ground station</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Ground station</td>
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<tr>
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<td>Mode A/C</td>
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<tr>
<td>Mode A/C</td>
<td>Mode A/C service</td>
</tr>
<tr>
<td>Mode S</td>
<td>Mode A/C service</td>
</tr>
</tbody>
</table>
Figure 1-1. Compatibility between SSR Mode A/C and Mode S
Chapter 2

PERFORMANCE CAPABILITIES

Note.— SSR provides enhanced surveillance of aircraft compared to primary radar. Mode A/C provides, in addition to position reporting, rudimentary data link capabilities to report identity and pressure-altitude. Mode S provides more comprehensive data link capabilities, which are described in later sections.

2.1 OPERATIONAL OBJECTIVES

SURVEILLANCE ENHANCEMENT

Surveillance information

2.1.1 Like primary radar, secondary surveillance radar (SSR) can provide plan position (range and bearing) information. In addition, SSR is able to provide the information described below.

2.1.2 Information from Mode A/C. Mode A replies provide identity codes for aircraft identification purposes. The Mode A code contained in a reply is used to correlate the aircraft identity to the position report. The special position identification (SPI) pulse feature may be used in addition to Mode A codes to validate aircraft identification. Certain emergency conditions can be reported using special Mode A codes, which are exclusively reserved for these purposes. Mode C replies provide pressure-altitude reporting, encoded with 100-ft resolution.

2.1.3 Information from Mode S. In addition to the information described above, a Mode S ground station can obtain some or all of the following information from a Mode S transponder:

a) the unique Mode S address of the aircraft;

b) aircraft “on the ground” status (used to aid processing of SSR replies in conflict alert systems and radar data/flight data processing systems);

c) aircraft identification (in the form specified in item 7 of the ICAO flight plan);

d) aircraft pressure-altitude with 25-ft resolution; and

e) other information through use of the Mode S data link, including Mode S specific services.

The ability to obtain the above information is dependent upon the level of the transponder fitted to the aircraft, except for the first two items which are available from all levels.

Surveillance reliability and integrity

2.1.4 Probability of detection. Due to the use of transponders, received signal levels have a $1/R^2$ relationship to range instead of the $1/R^4$ relationship found with primary radar. Therefore an SSR system is able to achieve a high probability of detection (e.g. greater than 95 per cent) even at long range using relatively low power transmitters and simple receivers. Long range performance is determined by interrogator/receiver and transponder characteristics and not by aircraft size or shape.

2.1.5 False targets. Use of separate frequencies by SSR for interrogation and reply eliminates the false targets seen on primary radar systems due to ground clutter, weather returns and “angels”. Side-lobe replies are prevented by side-lobe suppression (SLS) circuitry in transponders. Further protection can be provided by receiver side-lobe suppression (RSLS) in the ground system. Interrogations and replies received via reflecting surfaces can generate false targets with Mode A/C SSR systems. A number of techniques can be used to minimize this problem. In a full SSR Mode S environment there should be no persistent false targets. This is because the selective interrogation will only be transmitted when the aircraft is within the direct antenna beam and never when the aircraft is in the reflected antenna beam.
2.1.6 Data protection. Protection against corruption of reply code information for Mode A/C SSR depends on frequent repetition of the reply code information as a means of validation. This process can be enhanced with tracking, confidence determination and other similar processes. Protection against corruption of the data contained in Mode S interrogations and replies is provided by cyclic redundancy check (CRC) procedures, which are designed to achieve error rates of less than one undetected error in $10^7$ 112-bit messages. Where tracking and confidence determining processes are employed in the ground system these may be used to assess the validity of the barometric altitude data. For example when both the track and the reply are decodable and all high confidence and the report altitude is greater than a number of flight levels $N$ per scan than the track altitude (where $N$ is a variable parameter dependent on the antenna scan time and the performance envelope of the detected aircraft), then the reported flight level is output with information to indicate that the information is not valid.

2.1.7 Resolution. Surveillance resolution is a measure of the ability of the radar to separate replies from two or more aircraft that are in close proximity. Resolution has an influence on the air traffic control separation standards to be applied within its coverage volume.

2.1.8 Azimuth resolution. The azimuth resolution of Mode A/C SSR ground stations that use “sliding window” signal processing is generally slightly in excess of the antenna azimuth beamwidth. The azimuth resolution of Mode A/C SSR ground stations that use monopulse signal processing can be improved to a fraction of the antenna azimuth beamwidth. A Mode S ground station should experience no resolution problem for any aircraft pair where at least one carries a Mode S transponder.

2.1.9 Range resolution. Mode A/C reply pulse trains from aircraft at similar azimuths may overlap in time if the aircraft are close in range. If the SSR signal processing is unable to resolve the framing pulses, a loss of detection can result. Synchronous garbling can occur if code information pulses from one reply overlap pulse positions from another reply on successive interrogations. Monopulse processing of Mode A/C reply pulse trains offers some improvement over sliding-window processing, as overlapped pulse trains can be separated in most cases on the basis of monopulse off-boresight angle estimates. Mode S is not susceptible to detection losses or code garbling from aircraft close in range because only one Mode S transponder replies to a given selective interrogation.

2.1.10 Accurate position reports. SSR ground stations should be able to provide accurate position reports on targets that are correctly detected. The required accuracy is dependent upon the desired radar separation minima (elements on the establishment of radar separation minima can be found in the Procedures for Air Navigation Services — Air Traffic Management (PANS-ATM, Doc 4444, Chapter 8, 8.7.4)). The conventional sliding-window technique for SSR is able to support current radar separation minima of 18.5 km (10 NM), 9.3 km (5 NM) and 5.6 km (3 NM), depending on the range of the aircraft from the radar. Monopulse and Mode S ground stations are significantly more accurate and therefore may support closer separation at longer range.

Utilization of SSR information

2.1.11 Analog display of SSR reply pulses. The analog video pulse trains of a Mode A/C reply may be displayed on a plan position indicator (PPI), either alone or superimposed on primary radar returns. It should be noted that while analogue SSR systems are able to display the position of aircraft based on the detection of SSR replies, they are not easily able to extract and display the identity (Mode A) and pressure-altitude (Mode C) information in SSR replies. Mode S in general and most monopulse SSR systems do not generate suitable video signals for analogue display.

2.1.12 Display of digitally processed SSR information. SSR plot extractors (SSR digitizers) process all the replies from an aircraft during each scan of the antenna to form a digital target report (“plot”) which can contain aircraft position, identification code and flight level. (Mode S systems may also provide a range of further information.) SSR plot information may be further processed before display in radar data processing systems (RDPS), which may perform monoradar or multiradar tracking, conflict alert processing, minimum safe altitude warning (MSAW) processing, etc. SSR plot information is normally displayed on plan position displays as a plot position symbol which may have an adjacent alphanumeric label providing the SSR identification information and pressure-altitude information.

Volume of coverage

2.1.13 SSR should provide coverage under all weather conditions at all bearings and at all ranges between at least 1.85 km (1 NM) and the maximum operationally required range (typically 370 km [200 NM] for long-range systems and 150 km [80 NM] for short-range systems), and at all operational altitudes up to at least 30 480 m (100 000 ft)
above mean sea level between at least the angles of elevation of 0.5 degree and 40 degrees (or 0.5 degree above the terrain in directions of terrain masking).

2.1.14 Coverage at ground level on airfields may be required for some SSR Mode S data link applications.

Environment

2.1.15 Interference. SSR systems should perform their operational function without degrading the performance of other radio, radar or electronic equipment on board aircraft or on the ground and without being affected by such other equipment.

2.1.16 Aircraft manoeuvres. The probability of detection of manoeuvring aircraft can be reduced because of transponder antenna shielding. This can be alleviated by careful site selection or multiradar processing. Transponder antenna diversity systems will also alleviate the problem.

2.1.17 Coverage in a multiradar environment. SSR system performance in areas with multiple radar coverage should also meet the surveillance reliability and integrity criteria of 2.1.

2.2 TECHNICAL PERFORMANCE CRITERIA

SURVEILLANCE PERFORMANCE CRITERIA

Surveillance reliability and integrity

2.2.1 Detection probability. The probability of detection ($P_D$) is measured inside the volume of coverage. It should be at least 95 per cent everywhere within the volume of coverage. The $P_D$ is influenced by siting and by uplink and downlink power budgets, as well as other factors.

2.2.2 False detection. False targets are mainly caused by main beam reflections (see Figure 2-1), detection through side lobes, which can give rise to ring-around at shorter ranges, and second-time-around replies from aircraft beyond the maximum range that appear to be detected at shorter range. Within any one scan, the false target count should be less than 2 per cent of the total target count. False detection can be reduced by good vertical antenna cutoff, judicious siting, sensitivity time control (STC) and scan-to-scan processing.

2.2.3 Resolution. Resolution problems can give rise to missed detection, inaccurate detection, and Mode A and Mode C code corruption, particularly when targets are near enough to each other to be subject to synchronous garbling.

2.2.4 Detection accuracy. To a first approximation, the detection accuracy can be characterized by the bias and standard deviation in range and azimuth throughout the volume of coverage. Typical figures of standard deviation are 250 m and 0.15 degree for conventional SSR and 100 m and 0.06 degree for monopulse and Mode S ground stations. The data quantization should be consistent with the accuracy. Biases in range and azimuth should be minimized. They should be monitored very carefully, particularly if data from several overlapping radar sites are merged. In particular, the radar north should then be aligned with geographical north to within about 0.1 degree (an azimuth bias of 0.3 degree at 370 km range corresponds to an error of 2 km). In the case of a single radar site, these biases are less important, since the distance between two proximate aircraft will remain correct.

SURVEILLANCE INFORMATION

2.2.5 Mode A and Mode C. Reports with missing or invalid Mode A codes should occur with less than 5 per cent probability in any scan. Reports with missing or invalid Mode C codes should occur with less than 5 per cent probability in any scan for Mode C-equipped targets. Reports with corrupted Mode A codes should occur with less than 2 per cent probability in any scan. Reports with corrupted Mode C codes should occur with less than 2 per cent probability in any scan.

2.2.6 Mode S. The Mode S message undetected error rate should be less than one undetected error in $10^7$ 112-bit messages. This message protection is provided by the CRC provisions included in the Mode S coding.

Ground station capacity

2.2.7 Ground station capacity requirements (maximum number of aircraft per scan) should be specified according to forecast local traffic density. A capacity of 400 aircraft per scan is sufficient for most areas of the world.

Processing and display criteria

2.2.8 Processing and display equipment should be able to handle the specified ground station capacity. They
should not introduce excessive delay (e.g. less than \( \frac{1}{2} \) scan period) between detection and display.

**Test and evaluation methods**

2.2.9 Technical performance criteria can be tested and evaluated by measurements within the ground station itself and by comparing the ground station output with a reference based on test flights employing either an independent means of trajectory determination or trajectory reconstruction, based on non-real-time tracking of recorded radar data.

2.2.10 Details are given in the *Manual on Testing of Radio Navigation Aids* (Doc 8071).
Figure 2-1. False target geometry
Chapter 3

MODE S AND MODE A/C COMPATIBILITY

3.1 SIGNALS IN SPACE

3.1.1 The overriding principle that has been maintained throughout the design and development of the SSR Mode S system has been that Mode S should be entirely compatible with SSR Modes A and C. Such compatibility requires that SSR ground stations operating only on Modes A and C receive valid Mode A and C replies from Mode S-equipped aircraft without modification to the ground equipment and that Mode A/C transponders require no modification to receive surveillance services from a Mode S ground station.

3.1.2 The same carrier frequencies have been adopted for Mode S as those used for Modes A and C (1 030 MHz for interrogations and 1 090 MHz for replies). Special measures have been developed to ensure that the two systems can co-exist on the same frequencies without suffering mutual interference. It was necessary to prevent Mode A/C transponders from being spuriously triggered by the Mode S interrogation signals. This was achieved by beginning each Mode S interrogation with a pair of equal amplitude pulses spaced 2 microseconds apart. This provides a side-lobe suppression (SLS) pulse pair which causes Mode A/C transponders to suppress for 35 plus or minus 10 microseconds. The Mode S interrogation is completed within the nominal suppression period. However, transponders with the minimum allowable suppression time of 25 microseconds will nevertheless detect the end of the Mode S P₆ pulse but will not trigger since the remaining P₆ pulse duration is not long enough to synthesize a Mode A interrogation. An uplink data rate of 4 megabits per second has been selected in order to accommodate both the 24-bit address and enough data for messages within this suppression period. A one-megabit-per-second data rate is used for replies to allow the Mode A/C and Mode S reply pulses to be generated by a single transmitter.

3.2 GROUND STATION

3.2.1 Mode S ground stations interrogate and process replies from both Mode S and Mode A/C transponders. As a result of the signal-in-space compatibility between Mode S and Mode A/C it is possible to implement Mode S ground stations in an evolutionary manner, allowing a gradual transition from a Mode A/C environment to an eventual all-Mode-S environment. As this evolution progresses, the surveillance system will continue to function with any mix of Mode A/C and Mode S ground stations either in a local region or worldwide.

3.2.2 Mode S ground stations have a number of technical characteristics that require tighter tolerances and more capable processing than provided in Mode A/C ground stations. However, the Mode S design is such that each of the technical improvements introduced for Mode A/C surveillance also improves the surveillance of Mode A/C transponders.

3.2.3 An example is the interrogation carrier frequency tolerance. Mode A/C interrogations are transmitted with a carrier frequency tolerance of plus or minus 0.2 MHz. This is adequate for decoding the pulse amplitude modulated signals employed by Mode A/C equipment. The use of differential phase shift modulation in Mode S interrogations requires a carrier frequency tolerance of plus or minus 0.01 MHz.

3.2.4 Another important example is the use of monopulse processing to estimate target bearing. In order to achieve optimum use of channel time for Mode A, Mode C and Mode S interrogations, it is necessary to employ an efficient technique for target bearing estimation. Monopulse bearing estimation allows the target bearing to be determined from a single reply rather than the series of ten or more replies normally required. This monopulse processing technique, which can also be used in Mode A/C ground stations, is essential to Mode S operation. Within a Mode S ground station, monopulse bearing estimation can be used for Mode A/C targets as well as Mode S targets, providing a significant improvement in performance while providing compatibility between the old and new systems.
3.2.5 Two other examples of Mode S features that result in compatible and improved surveillance of Mode A/C transponders include the use of multiple interrogation power levels (commonly referred to as power programming) and the use of improved receiver pulse processing techniques. The monopulse processing required by Mode S ground stations can be applied to existing Mode A/C ground stations as a preliminary step in the evolutionary process of upgrading to Mode S without any loss of compatibility and with measurable improvement in performance.

### 3.3 TRANSPONDER

3.3.1 Mode S transponders also respond to Mode A and C interrogations. Thus, as aircraft become equipped with Mode S transponders they can continue to fly in areas served by Mode A/C ground stations without degrading the surveillance capability of those ground stations. Mode S transponders embody a number of improvements such as tighter transmit frequency and timing tolerances, which are both compatible with and beneficial to Mode A/C surveillance techniques. Mode S transponders may also be associated with a dual antenna installation for diversity operation. Diversity provides improved reliability of the radio link for both surveillance and communications.

3.3.2 The use of the same interrogation and reply frequencies and similar pulse widths permits the sharing of elements between Mode A/C and Mode S functions within the transponder.

### 3.4 OPERATION

Operational compatibility between Mode S and Mode A/C aircraft and ground elements is achieved by the use of intermode and Mode S all-call transactions and by the use of the lockout protocols. Intermode transactions allow Mode S ground stations to simultaneously interrogate both Mode S and Mode A/C transponders in order to determine the Mode S addresses of newly-detected Mode S aircraft. Intermode interrogations are also available which allow the ground station to assure that it receives replies exclusively from either Mode A/C aircraft or Mode S aircraft but not both simultaneously. The lockout protocols permit a Mode S ground station to control a Mode S transponder after its address has been determined so that it replies only to particular subsets of the possible intermode interrogations. The operational compatibility achieved by Mode S and Mode A/C aircraft and ground elements is illustrated in Figure 1-1.
Chapter 4

SSR SYSTEM TECHNIQUES

4.1 SYSTEM POWER CONSIDERATIONS

Note.— Section 4.1.1 examines the complete system, both uplink and downlink with respect to sensitivity and power budget. Sections 4.1.7 and 4.1.10 provide guidance on the parameters relevant for interrogator-receiver installations and for aircraft transponder installations. Values are given in certain instances for a nominal 370 km (200 NM) range system.

The balance between uplink and downlink power budgets

4.1.1 SSR systems for civil aviation applications are normally designed so that the downlink is more sensitive than the uplink, typically by 3 to 6 dB. This ensures that whenever a transponder is triggered by a ground interrogator, there is a very high probability that the resultant reply will be received properly by the associated ground receiver. It is usual to define the maximum uplink range as that range for which the transponder’s received power level is at the minimum triggering level (MTL) of the transponder. MTL is defined as the signal level at which a transponder responds to an interrogation signal or a ground station receiver responds to a reply signal with 90 per cent reply ratio. The transponder MTL is measured at the antenna end of the transmission line. To a first order approximation, the “round trip” reply-to-interrogation ratio at the output of the ground receiver is then assumed to also be 90 per cent (rather than the 81 per cent which it would be if both up and downlinks were each balanced at 90 per cent probability). It should also be noted that this is the probability of a single successful “round trip” interrogation and reply. The actual “probability of detection” at the output of defruiting and plot extraction processing is dependent on sufficient successful single round trip replies from a sequence of interrogations for the processing technique employed.

4.1.2 The SSR system can become saturated and will degrade in performance if transponders are overinterrogated and/or oversuppressed.

4.1.3 Aircraft transponders can receive from and reply to only one ground station at a time, so it is important that they not be “occupied” by having to respond to more stations than absolutely necessary.

4.1.4 An excessive power margin can enable triggering of the transponder by side-lobe interrogations or by false P1-P2 pairs. Unwanted suppressions can then occur which will reduce the availability to reply to other ground stations.

4.1.5 The radar equation applied to SSR is the following:

\[
P_{\text{rec}} = P_{\text{trd}} \frac{G_A G_T}{L_{\text{at}} L_{\text{t}}} \frac{1}{(4\pi)^2} \frac{\lambda^2}{R^2}
\]

where

\( P_{\text{rec}} \) is the received power at the input of the receiver (watts);

\( P_{\text{trd}} \) is the transmitted power at the output of the transmitter (watts);

\( G_A \) is the ground station antenna gain with respect to the isotropic in the direction of the transponder;

\( G_T \) is the transponder antenna gain with respect to the isotropic;

\( L_{\text{at}} \) is the sum of the losses between the interrogator and the antenna;

\( L_T \) is the sum of the cable losses between the antenna and the transponder;
L<sub>at</sub> is the atmospheric attenuation;
λ is the wavelength (metres);
R is the range between the ground station and the transponder antennas (metres).

Note.— The values for G<sub>A</sub> and G<sub>T</sub> to be used in this equation need to be chosen carefully. G<sub>A</sub>, the gain of the ground station antenna, will vary as a function of azimuth and elevation. For reliable operation over the required coverage volume, the gain should not fall below the chosen value over all elevations in this volume at any given range. Furthermore, the gain should not fall below the chosen value over the azimuth beamwidth for which replies are required. These considerations lead to an effective gain value which will be less than the peak gain of the ground station antenna. G<sub>T</sub>, the gain of the transponder antenna, can be expected to be more constant in normal situations, but it will vary with elevation and its effective value will be determined by the aircraft attitude.

4.1.6 The number of replies in a beam dwell is proportional to the beam dwell time and the pulse repetition frequency. The beam dwell time is defined as the beamwidth (in degrees) divided by the antenna scanning rate (in degrees/second):

Number of replies = beamwidth (degrees) PRF (s<sup>–1</sup>)
antenna scanning rate (degrees/s)

THE UPLINK POWER BUDGET

4.1.7 The elements of the uplink are shown as a block diagram in Figure 4-1. Analysis of the uplink is facilitated if the elements common to the ground station (transmitter power, interrogator feeder loss and interrogator antenna gain) are combined to give a term for the effective radiated power (ERP):

\[ \text{ERP}(I) = P_{\text{trd}} \frac{G_A}{L_I} \]

where ERP<sub>(I)</sub> and P<sub>trd</sub> are in watts and G<sub>A</sub> and L<sub>I</sub> are ratios.

The power level received at the antenna of the transponder is given by:

\[ P_{\text{ant}(T)} = \text{ERP}(I) \frac{1}{L_{\text{at}}} \frac{1}{R^2} \frac{\lambda^2}{(4\pi)^2} \]

where P<sub>ant(T)</sub> and ERP<sub>(I)</sub> are in watts, L<sub>at</sub> is a ratio and λ and R are in metres.

If λ = 29.13 cm (f = 1 030 MHz) then the atmospheric loss (which varies with wavelength) can be shown to be 0.0065 dB per nautical mile (1.85 km). If R is in nautical miles, the above equation can be written in a logarithmic form:

\[ P_{\text{ant}(T)} = \text{ERP}(I) - 0.0065 R - 20 \log(R) - 98.05 \]

where P<sub>ant(T)</sub> and ERP<sub>(I)</sub> are in dB above 1 milliwatt (dBm).

Figure 4-2 plots ERP<sub>(I)</sub>, the power required to be radiated by the antenna of the ground station, to provide given power P<sub>ant(T)</sub> at the transponder antenna at range R, for values of R between 18.5 and 555 km (10 and 300 NM). The actual power into the receiver of the transponder is calculated by taking into account the transponder’s antenna gain and cabling loss:

\[ P_{\text{rec}} = P_{\text{ant}(T)} \frac{G_T}{L_T} \]

where P<sub>rec</sub> and P<sub>ant(T)</sub> are in watts and G<sub>T</sub> and L<sub>T</sub> are ratios (linear form).

\[ P_{\text{rec}} = P_{\text{ant}(T)} + G_T - L_T \]

where P<sub>rec</sub> and P<sub>ant(T)</sub> are in dBm and G<sub>T</sub> and L<sub>T</sub> are in dB (logarithmic form).

Figure 4-1 shows atmospheric loss figures for a 370 km (200 NM) range and transponder parameters corresponding to those defined in the standards for worst case limits of transponder performance. The uplink margin is given by the amount the radiated power level exceeds the minimum necessary to trigger the transponder. The uplink margin obtained is determined by transmitter power, antenna gain and feeder loss of the ground station. It should be noted that the last two factors also affect downlink margins.

4.1.8 Mode S data link delivery to aircraft on the airport surface may result in excessive signal dynamic range at the transponder receiver caused by very short minimum ranges. Because of this very large dynamic range, consideration should be given to the use of an auxiliary system with transmitter power programming to match the transmitter power to transponder range.

4.1.9 Allowance must be made for the aircraft transponder to receive interrogations above MTL across a sufficient portion of the ground station antenna beamwidth (nominally 3 dB beamwidth) to enable a sufficient number of replies to be received for subsequent processing (e.g. plot extraction). Depending on the interrogation rate,
antenna turning rate, antenna azimuthal pattern and antenna elevation pattern, this number of replies will require operation to a certain level below the peak gain level of the antenna. This level is typically between 2 and 4 dB down on the peak. Note that the signal levels shown are based on free space propagation. Lobing effects can cause significant variations to these levels.

THE DOWNLINK POWER BUDGET

4.1.10 The elements of the downlink are shown as a block diagram in Figure 4-3. Analysis of the downlink is facilitated if the elements common to the transponder (transmitter power, transponder feeder loss and transponder antenna gain) are combined to give a term for the effective radiated power:

\[
\text{ERP}(T) = P_{\text{trd}} G_T / L_T
\]

where ERP(T) and P_{\text{trd}} are in watts and G_T and L_T are ratios, or in a logarithmic form.

\[
\text{ERP}(T) = P_{\text{trd}} + G_T - L_T
\]

where ERP(T) and P_{\text{trd}} are in dBm and G_T and L_T are in dB.

The power level received at the antenna of the ground station is:

\[
P_{\text{ant}(I)} = \text{ERP}(T) - 0.0090 R - 20 \log(R) - 98.54
\]

where P_{\text{ant}(I)} and ERP(T) are in watts, L_{\text{at}} is a ratio and \( \lambda \) and R are in metres. If \( \lambda = 27.52 \) cm (f = 1 090 MHz) then the atmospheric loss (which varies with wavelength) can be shown to be 0.0090 dB per nautical mile (1.85 km). If R is in nautical miles, the above equation can be written in a logarithmic form:

\[
P_{\text{ant}(I)} = \text{ERP}(T) - 0.0090 R - 20 \log(R) - 98.54
\]

where P_{\text{ant}(I)} and ERP(T) are in dB above 1 milliwatt (dBm).

Figure 4-4 plots ERP(T), the effective radiated power from the antenna of the transponder, and the resultant power at the antenna of the ground station P_{\text{ant}(I)}, as a function of range R, for values of R between 18.5 to 555 km (10 and 300 NM). The actual power into the receiver of the ground station is calculated by taking into account ground station antenna gain:

\[
P_{\text{rec}} = P_{\text{ant}(I)} G_A / L_I
\]

where P_{\text{rec}} and P_{\text{ant}(I)} are in watts and G_A and L_I are ratios.

Figure 4-3 gives atmospheric loss figures for a 370 km (200 NM) range, and transponder power output at the lowest level allowed in the Standards, 24 dBW (250 W). The downlink margin is the amount by which the received power level exceeds the receiver sensitivity level. SSR interrogator/receiver sensitivity has traditionally been defined as the “tangential” sensitivity (see 4.2.22, Receiver sensitivity). In many applications a more realistic figure to use may be the minimum signal-to-noise ratio required for reliable operation of subsequent signal processors (plot extractors). This is particularly true for monopulse systems using sum/difference ratio techniques where there must be an adequate signal-to-noise ratio in the difference channel for maximum range replies.

THE RELATIONSHIP BETWEEN ABSOLUTE POWER LEVELS AND POWER DENSITY LEVELS

4.1.11 In some instances it is convenient to work with power density levels in watts per square metre at various ranges for uplink and downlink signal paths. The received power levels can then be calculated from a knowledge of the effective area of the receiving antenna. The relationships for these calculations are summarized below:

a) for an isotropic antenna transmitting power P_T, the power density at range R metres is \( P_D = P_T/(4\pi R^2) \) W/m^2;

b) if the gain G_T of a transmitting antenna in a given direction is defined as the ratio of the power radiated in that direction to the power radiated in the same direction by a standard (isotropic) antenna, then the power density in that direction is

\[
P_D = G_T P_T/(4\pi R^2) \text{ W/m}^2
\]

Note.— G_T is a dimensionless ratio in the linear form, not a number of dB.

c) using this equation, the power density at any range can be calculated for a given transmitting system;

d) a receiving antenna with a gain G_R has an effective receiving area A_R given by

\[
A_R = G_R (\lambda^2/4\pi) \text{ m}^2 \text{ where } \lambda \text{ is in metres}
\]
e) the power delivered by a matched antenna to its load is then

\[ P_{\text{rec}} = P_D A R W \]

f) substituting from previous equations generates the radar equation for transponder systems

\[ P_{\text{rec}} = P_T G_T G_R \lambda^2/(4\pi R)^2 \]

4.2 GROUND STATION INSTALLATION

SITING

Number of ground stations

4.2.1 In planning the siting of ground stations, care should be taken to ensure that their number is kept to a minimum consistent with the operational requirement.

Effects of obstacles

4.2.2 Natural and artificial obstacles around an SSR site can have detrimental effects due in particular to reflection or diffraction phenomena. It should be emphasized that reflections of the main lobe can cause serious problems such as false targets.

4.2.3 Diffraction phenomena can occur when portions of the beam are obstructed by buildings or other surfaces. Differences between the direct path and the path diffracted by an obstacle perturb the azimuth measurement. Reflection from a non-horizontal ground can cause the image to be displaced in azimuth. Combining of the direct and reflected signals produces a distorted beam shape. It is therefore advisable to avoid large vertical reflecting surfaces within a reasonable distance of the SSR ground station antenna. This distance will depend on the effective cross-section of the reflecting surface and its elevation with respect to the ground station but, as a guide, it is desirable to site the ground station at least 800 m away from large structures.

INTERROGATOR ANTENNA

Horizontal radiation pattern (HRP)

4.2.4 Interrogation pulses are radiated by a directional antenna. For a mechanically rotated antenna the beamwidth in azimuth should be sufficiently narrow, typically between 2 and 3 degrees at the 3 dB point, but it should be noted that there is a minimum number of replies necessary for reliable processing and display. This minimum will depend on the particular processing and display facilities provided. A typical requirement for “sliding window” SSR plot digitizers is 4 to 8 replies per beamwidth on each interrogation mode. Monopulse SSR plot digitizers typically require 2 to 4 replies per beamwidth on each mode. It should also be noted that there is a direct relationship between the desired number of replies per beamwidth, the rate of interrogation, the antenna beamwidth and the rate of rotation of the antenna (see 4.1.6).

4.2.5 The horizontal beamwidth of the antenna is often made as narrow as possible in order to improve azimuth accuracy. For a mechanically rotated antenna, a narrow horizontal beamwidth reduces beam dwell time and therefore reduces the Mode S capacity of the ground station. A good compromise has been found to be of the order of 2.4 degrees.

4.2.6 Azimuth pattern side lobes should be as low as practicable. A level at least 24 dB down from the mainlobe is desirable.

Vertical radiation pattern (VRP)

4.2.7 Interrogation pulses should be radiated on an antenna which provides adequate signal strength between the angles of 0.5 degree and 40 degrees, to the operationally required range and altitude.

4.2.8 Another important characteristic is the ability to lessen the energy directed at the ground. Reflected energy from the earth can have a significant effect on the radiation pattern in space of an SSR antenna. For targets at certain elevation angles, the direct and reflected energy combines in phase, giving a large increase in signal strength, while at certain other angles the signals combine out of phase, causing significant reductions in signal strength. This can have a number of undesirable effects, including:

a) loss of replies from aircraft in regions of reduced signal strength;
b) interrogation of aircraft beyond ranges of operational interest in regions of increased signal strength, possibly interfering with the operation of other ground station receiver systems; and

c) degradation of azimuth accuracy when the magnitude of the reflection is not uniform across the antenna beam. This causes less variation in signal strength on one side of the beam than the other, shifting the effective centre of the beam.

Techniques for achieving reduced low angle radiation

4.2.9 Inherent limitations of small vertical aperture antennas (e.g. “hog-trough antennas”) can be overcome by designing large vertical aperture (LVA) antennas (five wavelengths or more). Practical examples of such antennas have been implemented from superposed columns of dipoles driven by signals of appropriate phase and amplitude. In another design, it is achieved by adding suitable radiating elements to a primary radar antenna and using the reflector to form the pattern in elevation (“integrated antennas”).

Influence of antenna height above ground on vertical radiation pattern

4.2.10 At most sites the vertical radiation pattern will be affected to some degree by reflected energy from the ground. The magnitudes of the peaks and nulls will be dependent on the reflection characteristics of the reflecting ground and the number of peaks and nulls will depend on the height above the reflecting ground surface of the antenna. The peaks and nulls will occur at intervals of approximately \( n\lambda/4h \) radians, where \( \lambda \) is the wavelength, \( h \) is the effective antenna height and \( n \) is odd for peaks and even for nulls. Figure 4-5 illustrates the geometry of reflection, the resultant lobing structure, and the variations in signal strength as a function of range seen by a constant-altitude aircraft. This approximation for calculating peaks and nulls is only valid if the reflecting ground is substantially level out to a range of approximately 2.8 to 5.6 km (1.5 to 3 NM), dependent on antenna height. Sloping ground can tilt the lobing pattern up or down. Careful attention should be paid to site selection and antenna tower height to achieve the best operational performance. Raising the antenna height tends to increase the number of nulls, but reduces the depth of each individual null. This is shown in Figure 4-6 which presents the lobing patterns for a given antenna at effective heights of 8.5 and 25 metres.

Side-lobe suppression (SLS) antenna

4.2.11 The main requirement is that the control pattern covers the directional pattern side lobes and back lobe. Another essential characteristic for proper functioning is that the patterns of the control and directional antennas match in the vertical plane, so that the \( P_1/P_2 \) power ratio can be maintained over all elevation angles. If separate transmitters are used for \( P_1 \) and \( P_2 \) (or \( P_6 \) and \( P_5 \) for Mode S), care must be taken to ensure that the \( P_1/P_2 \) \( (P_6/P_5 \) for Mode S) power ratio in space is maintained at the levels required for side-lobe suppression (Annex 10, Volume IV, Chapter 3, 3.1.1.7.4 and 3.1.2.1.5.2.1).

4.2.12 The best solution to meet these requirements is that SLS and directional antennas be designed in a common assembly. Generally, the SLS pattern is produced by feeding the central part of the directional antenna with suitable amplitude and phase. Back lobes can be covered by a special radiator.

4.2.13 Another solution uses a separate omnidirectional antenna to radiate the SLS pattern. Because of physical constraints, the phase centre of a separate antenna will often be offset from the phase centre of the directional antenna. This causes the ratio between \( P_1 \) and \( P_2 \) to change with target azimuth and elevation angle. Where possible in existing installations and in new installations, such as those that employ integrated feed antennas, the SLS antenna should be mounted on the main antenna and designed to minimize these effects. An offmounted solution should be reserved to upgrade older equipments and should be avoided in new installations.

Monopulse antenna patterns

4.2.14 Monopulse SSR systems require antennas which provide information about the “off-boresight” angle of received signals usually as “sum” and “difference” outputs. A comprehensive description of monopulse signal processing is given in Chapter 5. As monopulse processing uses the relative amplitudes or phases of sum and difference outputs to determine off-boresight azimuth, it is important that these relativities are maintained within appropriate tolerances as a function of off-boresight angle over the elevation angle coverage of the antenna.

Feeder system

4.2.15 The ground station feeder system connects the antenna to the transmitters and receivers and includes rotating joint channels, coaxial cables and RF change-over
units. The characteristics of the feeder system are an important part of the total system, especially with monopulse systems, where the phase and amplitude matching of each channel of the feeder system must be maintained within appropriate tolerances for the type of processing being used.

GROUND STATION TRANSMITTER

Transmitter power

4.2.16 The transmitter power output necessary to achieve a given operational performance objective is highly dependent on the gain and radiation pattern of the antenna with which it is being used. The uplink power budget has been discussed in 4.1.7.

4.2.17 If the control pattern for interrogator side-lobe suppression (ISLS) is not provided by an antenna integrated with the directional antenna, then a different power level may be required to adequately drive the control pattern antenna. Antennas of this type should be avoided for new installations.

4.2.18 Where the full coverage of the system is not required, the interrogator power should be reduced as recommended in Annex 10, Volume IV, Chapter 3, 3.1.1.8.2. It should be noted that digital techniques allow the reduction of transmitted power in predefined azimuth sectors in order to avoid unwanted replies due to reflections, for example.

Techniques for rejecting side-lobe interrogations (ISLS)

4.2.19 Mode A/C transponders are suppressed on receipt of $P_1$-$P_2$ pulse pairs (Annex 10, Volume IV, Chapter 3, 3.1.1.7.4) as shown in Figure 4-7. Mode S transponders are prevented from replying on receipt of $P_3$ pulses which mask the sync phase reversal of $P_6$ (Annex 10, Volume IV, Chapter 3, 3.1.2.10.3.1). $P_2$ or $P_3$ pulses are radiated by the interrogator via a “control” pattern which should cover all side lobes of the directional pattern over the operational angles of elevation. This may demand that the antennas for the directional and control patterns be designed in a common assembly so that the same effective height above the ground can be maintained for both and a constant phase relationship maintained as the directional antenna rotates.

GROUND STATION RECEIVER

Receiver bandwidth and phase characteristics

4.2.20 The bandwidth of the receiver should be adequate to reproduce faithfully the pulses transmitted by the transponder (pulse rise time 0.1 microsecond) and to accommodate the drift in transponder transmitter frequency. Specifically, the minimum over-all receiver bandwidth, which is typically determined by the intermediate frequency (IF) filter, should be at least plus or minus 4 MHz at the 3 dB points.

4.2.21 The phase characteristic of the receiver should be linear within plus or minus 10 degrees over a frequency range of plus or minus 4 MHz to provide faithful detection of Mode A/C reply pulses. However, based on observations of actual Mode A/C transponder reply frequency distributions, prudent filter amplitude and phase bandwidth design should allow for reply carrier frequencies ranging from approximately 1 085 MHz to 1 095 MHz. More stringent receiver amplitude and phase specifications may be required to support the monopulse processing requirements of the ground station (5.2.3).

Receiver sensitivity

4.2.22 Receiver sensitivity has traditionally been defined for the SSR ground station receiver in terms of the tangential sensitivity as determined manually with an oscilloscope. The tangential sensitivity is equal to the amplitude of a pulsed input to the receiver that raises the observed noise amplitude by its own width (i.e. aligns the negative peaks of the noise on the pulse with the positive peaks of the noise alone). This measurement can be made with a linear or non-linear (e.g. logarithmic) receiver transfer function. It is illustrated in Figure 4-8 for a square-law detector. Measured by this method, the receiver should be more sensitive than 85 dBm as indicated in Figure 4-3. This sensitivity, when associated with a suitable antenna and feeder system, is adequate to provide a downlink range of 370 km (200 NM) for transponders having minimum specification output power.

Note.— Caution should be exercised in respect to measuring and using this sensitivity value. The definition is framed in terms of a single pulse response. Where the receiver drives a digital plot extractor it is also necessary to consider the plot extractor requirements in terms of signal-to-noise ratio for reliable defruiting, plot extraction and code validation from a sequence of reply pulse trains.
4.2.23 There are several alternative techniques available for determining the receiver sensitivity. Among these alternatives are:

a) measurement of the receiver mean-square noise power level;

b) measurement of the receiver noise figure; and

c) measurement of the overlap of the probability distributions of noise only and signal plus noise.

Note.— Equipment which passes the simple oscilloscope test may fail accurate quantitative measurements. In current and old equipment, allowances may be made for this if desired but new equipment should meet the more stringent specification.

4.2.24 The mean-square noise power can be determined directly by calibrating the receiver gain, sampling the receiver output in the absence of a reply signal to obtain multiple independent measurements of the instantaneous receiver noise power, and processing the resulting samples statistically to obtain the mean-square value of the Gaussian receiver noise. The tangential sensitivity measured as illustrated in Figure 4-8 is approximately 9 dB greater than the mean-square receiver noise power. That is, a tangential sensitivity of -85 dBm corresponds to a mean-square noise power level of -94 dBm.

4.2.25 The receiver noise figure may be measured directly with any of several commercially-available noise figure measurement instruments that employ calibrated noise sources. The noise figure in dB is approximately equal to 114 – B + N, where B is the 3 dB receiver bandwidth in dB relative to 1 MHz and N is the mean-square noise power in dBm. That is, a mean-square noise of -93 dBm and an effective bandwidth of 10 MHz (10 dB relative to 1 MHz) correspond to a receiver noise figure of 11 dB.

Note.— Noise bandwidth is dependent on filter characteristics and can vary significantly from 3 dB bandwidth.

4.2.26 If the probability distributions of noise-only and of signal-plus-noise are plotted on the same axes for the case where the signal-to-noise ratio is 8 dB, i.e. tangential sensitivity, the area of the noise-only distribution that lies above the point at which the two distributions cross over, and the area of the signal-plus-noise distribution that lies below the point at which the two distributions cross over, will be constant and independent of receiver law. These areas, expressed as a percentage of the total distribution area, are 6.6 per cent and 8.1 per cent respectively and can easily be measured using sampling techniques for automatic monitoring.

4.2.27 It is desirable to have a method of reducing the receiver sensitivity to a pre-set level at the time of transmission of the interrogator pulses, and to increase the sensitivity to a normal level at a pre-set rate.

4.2.28 At 15.36 microseconds (corresponding to 1.85 km [1 NM] plus transponder delay) after pulse P, the gain should normally be reducible to a value between 10 dB and 50 dB below maximum sensitivity. The recovery rate should be adjusted to suit local conditions. A rate of 6 dB for each doubling of range is satisfactory for most applications.

4.2.29 Control of receiver sensitivity in this way has two benefits:

a) it normalizes the amplitude of received signals to make them vary less with range, which reduces the required dynamic range of the receiver, reducing susceptibility to pulse stretching and distortion; and

b) it discriminates against unsynchronized replies arriving from aircraft at long ranges interfering with genuine replies from aircraft at short range.

4.2.30 It should be noted that digital techniques of sectorization allow the use of adequate laws of sensitivity reduction in azimuths where reflections have been identified.

Techniques for rejecting side-lobe replies

4.2.31 If the SSR antenna and rotating joint system are designed to allow reception as well as transmission via the control pattern, then it is possible to recognize replies received via side lobes by virtue of the relative amplitudes of signals from the directional and control channels. This technique provides protection against transponders with faulty ISLS circuitry. Since an important part of the fruit replies is received by the side lobes of the antenna, this technique also allows a great reduction of fruit density seen by the processing.

ADDITIONAL TECHNIQUES FOR COMBATTING REFLECTIONS

Surveillance processing or tracking

4.2.32 Digitizing systems which incorporate surveillance processing or radar tracking based on data
accumulated over a number of antenna rotations can use a number of factors to identify reflections. The main criterion of discrimination is the duplication of codes: if a given identification code can be assigned only once in the coverage area, a false target situation will be recognized when two or more targets report the same identification code.

4.2.33 Generally, the above discriminant is associated with one or more of the following:

- a) comparison of the range of associated reports with the same codes. The wrong one generally has a slightly longer range;

- b) predictions of false targets made by mapping of known reflectors and calculations using the laws of geometric optics;

- c) comparison of amplitude. If a receiver with wide dynamic range is used, the video amplitude (\( \log \Sigma \)) associated with the report can be used as a discriminant. A report with a weaker amplitude is generally typical of a reflection; and

- d) presence of a primary report at the same location. The principle is that the primary radar will not see the reflection seen by the beacon system because of its fourth-power path-loss law.

Additional radiation through auxiliary antennas

4.2.34 This technique makes use of an additional directional antenna to radiate synchronized suppression pairs into the reflection area when the main ground station beam is sweeping the reflecting surface. This assists suppression over a sector determined by the directivity of the additional antenna. In applying this technique, the power radiated from this additional antenna should be kept to the minimum required to overcome the particular reflection problem and within the narrowest possible sector.

Improved interrogator side-lobe suppression (I^2SLS)

4.2.35 It should be noted that this technique will cause suppression periods in transponders over a wide azimuth, which can degrade the probability of transponder reply to interrogations from other SSR stations. Therefore it should not be used unless absolutely necessary.

4.2.36 This technique exploits the characteristic of transponders that requires them not to reply for 35 plus or minus 10 microseconds after suppression by a pair of pulses conforming to Annex 10. Since transponders will not reply to interrogations falling within a suppression period, it is necessary to provide for additional suppression in areas where reflections occur. This can be achieved by radiating P\(_1\) in addition to P\(_2\) on the “control” pattern normally used for side-lobe suppression. Suppression is then assisted throughout the side-lobe region.

4.2.37 Digital techniques of sectorization allow one to minimize these drawbacks by using this technique only in azimuth where reflections have been identified.

Selective interrogation

4.2.38 Systems which selectively interrogate using Mode S capabilities can overcome reflection problems. Reflections can occur during the Mode S all-call acquisition phase, but they can be identified as reflections with a higher level of confidence because two aircraft should never reply with the same Mode S address. The ambiguity can be resolved by surveillance processing as described in 4.2.32. (Surveillance processing is essential in a Mode S implementation to track aircraft so that the selective interrogations can be scheduled at the required azimuths.) Once acquisition has occurred and a track been established, selective interrogations are scheduled only when the antenna is in the direction of the aircraft and never when the antenna is in the direction of the reflector.

REJECTION OF UNWANTED RESPONSES

4.2.39 In an area where a large number of ground stations are deployed, a considerable number of transponder responses, triggered by other ground stations, will be received at any one ground equipment. The responses will be received at recurrent frequencies which will, if carefully planned, be different from that of the ground station receiving the information and will constitute a nuisance called “fruit” (false replies from unsynchronized interrogator transmissions) on the radar display. Defruiting techniques which use storage of received pulses to defruit on a pulse-to-pulse basis should be employed to remove these non-synchronous replies. The defruiting function may also be an integral part of the digital detection process.

4.2.40 As this process relies on the unwanted replies being non-synchronous, it is recommended that interrogation intervals should be able to be varied by small amounts
from interrogation to interrogation. This improves the decorrelation of false reply signals and “second time around” replies which can occur in certain propagation and antenna lobing situations.

**MONITORING OF SSR GROUND STATION**

**Interrogator monitoring**

4.2.41 General. The performance monitoring of the ground station called for in Annex 10 is required to provide responsible personnel with an indication that the equipment is functioning satisfactorily within the system limits prescribed in Annex 10, Volume IV, Chapter 3 and to give an immediate indication of any significant fault developing in the equipment. It is desirable that continuous monitoring is provided for the system parameters listed in 4.2.42 and 4.2.43 and that alarm indications are given in the event of this monitor itself failing. In addition to the test transponder described below, a test target generator should be provided that inputs video test signals into the Mode S system, for the purpose of simulating replies from Mode S-equipped aircraft. This generator can be used to monitor system integrity and can perform checks on garbled preambles, garbled messages, poor reply quality, noisy video, etc.

4.2.42 Pulse intervals. Means should be provided to measure pulse spacing for all modes that are to be employed (Annex 10, Volume IV, Chapter 3).

4.2.43 Interrogator relative radiated pulse levels. When side-lobe suppression is provided, monitoring of this parameter is most important and should be associated with the tolerances indicated in Annex 10.

4.2.44 Other system parameters. Monitoring (or checking on a periodic basis) of the following SSR system parameters is also desirable:

a) **Interrogator radio frequency.** Assuming that a high stability crystal controlled oscillator is used as the frequency control element of the SSR, it will be necessary only on a periodic basis to determine that the tolerance specified in Annex 10, Volume IV, Chapter 3, 3.1.1.1.2, 3.1.1.1.3 and 3.1.2.1.1 are satisfied.

b) **Interrogator pulse duration.** Precise measurement of pulse duration in the interrogator is one means of verifying the transmission of the correct interrogation pattern. A less precise method is the use of a fixed transponder located near the ground station (see monitoring of system operation below). The continued presence of replies from this fixed transponder gives a measure of assurance that the interrogator is functioning properly.

c) **Radiated power.** On-line measurement of transmitter power is one technique for verifying that the ERP limitation recommended in Annex 10, Volume IV, Chapter 3, 3.1.1.8.2 is observed. If implemented, the test monitor should be able to detect transmitter power both above and below normal limits.

d) **Spurious radiation.** Conformance to the requirements of Annex 10, Volume IV, Chapter 3, 3.1.1.11.1 and 3.1.2.11.3.1 need only be monitored on a periodic basis.

e) **Monitor warning location.** The precise location of the monitor warning indication is a matter for determination by the Administration concerned in the light of local circumstances, but should take into account the need to prevent the presentation of erroneous information to the controller without the controller’s knowledge.

**Receiver monitoring**

4.2.45 Receiver sensitivity (see 4.2.22) should be monitored continuously. In receiver systems which employ monopulse and/or RSLS techniques, the sensitivity of all receiver channels should be monitored.

4.2.46 The matching of sensitivity, gain and phase responses of receiver channels employed for monopulse and RSLS techniques should be checked on a periodic basis.

**Monitoring of system operation**

4.2.47 The use of a site monitor installed at a suitable fixed location can provide useful monitoring of overall SSR system operation. Observation of the responses from a fixed site monitor can check range and azimuth accuracy of the processing and display system, in addition to providing a simple test of uplink and downlink operation. It is often useful to provide a capability to delay the fixed site monitor replies so that their displayed range may be adjusted to meet local operational and technical requirements. In addition it may also be useful to adjust the receiver
minimum triggering level threshold and transmitter output power level of the fixed site monitor to provide a monitor of ground station overall performance.

4.2.48 The Mode S site monitor is a remote beacon used for Long Loop testing of the Mode S station. It mostly operates like an ICAO Mode S transponder, with additional capabilities, such as programmable attenuation and range, and specific Mode S protocols. Several site monitors may be deployed in proximity to each interrogator (refer to Manual on Testing of Radio Navigation Aids (Doc 8071), Volume III, for location issues). Site monitors serve as the basis for the overall operational surveillance checks by providing replies from “aircraft” with known identification and position. Overall operational communications checks are performed by loop tests with the site monitor. Since a Mode S station can operate with an SI code, the Mode S site monitor should also handle SI codes to allow loop testing of the Mode S station.

4.2.49 The Mode S site monitor is used for:

a) the on-line testing of the Mode S station — station Long Loop Test performed using interrogations to and replies from the site monitor;

b) the calibration of the Mode S station during the System Setting Up phase, at site installation of the Mode S station — using interrogations to and replies from the site monitor; and

c) the maintenance of the Mode S station, by visualising the site monitor data on the Local Display.

4.2.50 The ability to obtain surveillance data from an adjacent netted interrogator may also be checked using the site monitor. In this case, the local interrogator requests surveillance data on a site monitor of an adjacent interrogator. A surveillance message received in response to the request is checked against stored data to verify correct content.

4.2.51 The site monitor has many characteristics in common with a Mode S transponder. However, there are a number of important differences.

4.2.52 The main differences should be the following:

a) in normal operation, a Mode S interrogator provides surveillance on Mode A/C aircraft using a Mode A/C-only all-call interrogation. This interrogation does not elicit replies from a Mode S transponder. In order to check $P_1 - P_3$ spacing and the shape of the pulses, provision should be made to monitor replies;

b) all-call lockout control for a Mode S transponder depends upon a timeout of 18 ± 2 seconds following the last lockout command. This time delay is undesirable in configuring the site monitor to respond to all-calls. It is desirable to provide a means to command the site monitor in and out of lockout without any time delays;

c) provision should be made in the site monitor for additional delay to be added to the nominal turnaround time to allow the apparent position of the site monitor to be moved from its actual location. This could be used to prevent synchronous garble if two site monitors are mounted on the same tower or to artificially locate the site monitor at a non-interfering place;

d) the site monitor should not generate acquisition squitters in order to eliminate the possibility of a site monitor being acquired by an ACAS unit;

e) the site monitor may be configured to use an internal or an external transmitter source. In either case, the output power should preferably be adjustable in 1 dB steps over a dBm range band enabling to get a nominal received power from a site monitor wherever its location from the sensor;

f) the site monitor receiver MTL should be adjustable in 1 dB steps over a dBm range band so that the receiver gets a 40 dB dynamic range. This variable MTL is provided for different installed ranges as noted in the preceding paragraph; and

g) the site monitor should sense for any failure that causes a continuous transmission of the 1090 MHz carrier. If such is detected, the site monitor transmitter should be disabled, preferably within 100 ms. The purpose of this feature is to prevent site monitor interference with sensor operation if the site monitor fails in such a way as to generate CW.

4.2.53 There are a number of protocols which may be envisaged to control the site monitor, including:

a) the use of Mode S interrogations with particular RR values;

b) the use of Comm-A interrogations with specific MA field values; or

c) the use of an uplink MSP channel 6 containing an SR field of value 2. This service request for this
Chapter 4. SSR System techniques

4.2.54 The site monitor should preferably perform the following checks:

a) **Standard Length Message Test.** A communications loop test using the standard length messages (Comm-A/Comm-B) should be supported by the site monitor. This would test the ability of the sensor to correctly deliver and receive an SLM message. Several solutions may be envisaged, one being to deliver a Comm-A message to the site monitor which could cause the generation of an air-initiated Comm-B message with the same message content. The sensor would then check that the MB field content is the same as the MA field content;

b) **ELM Message Test.** This test should be similar to the SLM test but based on the extended length message protocol;

c) **Alert bit trigger.** The site monitor would set the alert bit (change of the Mode A code) upon reception of a request from the Mode S station. For example, this request could consist of a Comm-A interrogation with a specific MA field value or of an interrogation with a particular RR value. This is to check that the Mode S sensor correctly processes such an event;

d) **Downlink capability report announcement.** The site monitor would trigger a downlink capability report announcement upon reception of a request from the Mode S station. For example, this request could consist of a Comm-A interrogation with a specific MA field value or of an interrogation with a particular RR value. This is to change BDS 1,0 to a test value and to check that the Mode S sensor correctly processes this event;

e) **Flight ID change.** The site monitor would trigger a change of Flight ID upon reception of a request from the Mode S station. For example, this request could consist of a Comm-A interrogation with a specific MA field value or of an interrogation with a particular RR value. This is to change BDS 2,0 to a test value and to check that the Mode S sensor correctly processes this event;

f) **RA broadcast.** The site monitor would trigger an RA broadcast upon reception of a request from the Mode S station. For example, this request could consist of a Comm-A interrogation with a specific MA field value or of an interrogation with a particular RR value. This is to change BDS 3,0 to a test value and to check that the Mode S sensor correctly processes this event; and

g) **II/SI code delivery.** The site monitor should report the II/SI codes on which the site monitor is locked out. This is to check that the Mode S sensor is working with the II/SI codes it has been assigned. This report could be contained in one of the two transponder registers assigned for this purpose (accessed by either BDS code E,1 or E,2) as described in Annex 10, Volume III, Part I, Appendix to Chapter 5. The GICB protocol would be used to extract this register.

4.2.55 The site monitor can provide status information when requested by an interrogation.

4.2.56 The following information is desirable:

a) oscillator out of phase-lock;

b) power failures;

c) inside of enclosure under-temperature;

d) inside of enclosure over-temperature;

e) miscellaneous fault conditions;

f) Mode S All-Call lockout state;

g) transponder failures (receiver, transmitter, squitter, “ADLP” bus, EEPROM, ROM, RAM, altitude failures, etc.); and

h) delay board failures.

4.2.57 The information could be contained in one of the two transponder data registers assigned for this purpose (accessed by either BDS code E,1 or E,2) as described in Annex 10, Volume III, Part I, Appendix to Chapter 5. The GICB protocol would be used to extract this transponder data register.

4.2.58 Controls are required to operate the special features of the site monitor beyond those needed for a Mode S transponder. This includes controls for the transmit power and receiver MTL. Interfaces are needed for inputting information such as altitude and call sign.
4.2.59 It should be possible for the user to programme at least the following operational parameters:

a) Mode S address;
b) site monitor flight level;
c) Mode A (and the test value);
d) flight ID (and the test value);
e) alert bit trigger;
f) BDS 1.0 (and the test value);
g) BDS 3.0 (and the test value);
h) simulated range of the site monitor;
i) power attenuation;
j) receiver triggering level; and
k) turnaround delay.

4.2.60 A range check should be performed when changing any of the operational parameters.

4.2.61 It should be possible to use rechargeable batteries to supply power to the site monitor. A two-hour autonomy is recommended.

Monitor transponder interactions with ACAS

4.2.62 These fixed transponders, also referred to as PARROTs (position adjustable range reference orientation transponders), may also respond to interrogations from airborne collision avoidance system (ACAS) equipped aircraft. It is often useful to encode status information regarding the operation of the transponder into the Mode C reply. However, care should be taken not to use a Mode C code that could be decoded into a valid altitude by ACAS which could result in the generation of spurious traffic advisories (TAs) and resolution advisories (RAs). Refer to Figure 4-9.

4.2.63 Several techniques can be used separately or in combination to prevent or reduce this potential problem.

4.2.64 For PARROTs which employ Mode S transponders, at least one of the following two techniques should be used:

a) set the vertical status bit to “on the ground”. This will minimize the interrogations from ACAS; and

Note.— The PARROT should be configured in that case to respond to All Call and Mode A/C interrogations.

b) if possible, disable the squitter function. This will prevent acquisition by an ACAS, because the Mode S PARROT will not reply to the Mode C-only interrogations of an ACAS and will not announce itself (by squitters) for passive acquisition by the ACAS.

4.2.65 For PARROTs which employ Mode A/C transponders, the following techniques can be used (these techniques are also applicable to Mode S PARROTs):

a) set the Mode C data in the reply from the PARROT to a value which decodes, after allowance for barometric pressure correction, to be always outside the range of altitudes at which ACAS aircraft will fly:

1) at least 150 m (500 ft) below the true (ground) altitude of the PARROT installation, when assuming an atmospheric pressure of 1 013 hectopascals; or

2) at very high altitudes, such as between 24 000 and 37 800 m (80 000 and 126 000 ft);

b) reply code to include C and D reply pulse combinations which decode as illegal Mode C bit combinations:

\[
\begin{array}{cccc}
A & B & C & D \\
X & X & 0 & 0 \\
or & X & X & 5 & 7 \\
or & X & X & 7 & 7 \\
\end{array}
\]

where \( X = 0 – 7 \). Where the Mode C value from a PARROT may change (e.g. to indicate equipment status), this allows for 64 unique status codes. It should be noted however that the design of some commercial transponders prevents the transmission of illegal Mode C bit combinations;

c) introduce a range delay into the transponder reply. This is often used to prevent garbling when the geographical location of the PARROT is on an airway. It has the secondary advantage that, if the delay is large enough, the ACAS unit never sees the “aircraft” as being at close enough range to
generate traffic or resolution advisories. A possible disadvantage is that a PARROT with delay can appear to be in different places on different radars, if more than one radar is able to interrogate the PARROT. Some display systems may have difficulties with this situation. A second disadvantage, where more than one radar is interrogating a site monitor, is that during the delay time the transponder is unavailable to respond to other interrogations, possibly leading to missed replies; and

d) use highly directional antennas with the site monitor (PARROT) installation, to limit reception to a narrow angle in the direction of the radar being monitored. This can reduce the likelihood of ACAS interrogations being received, but may not totally eliminate it.

4.2.66 It is recommended that:

a) for Mode S PARROTS, both techniques described in 4.2.64 a) should be implemented;

b) for Mode A/C PARROTS, either:

1) the technique described in 4.2.65 a) should be implemented, to ensure that Mode C replies decode to altitudes well outside those flown by ACAS-equipped aircraft; or

2) the technique described in 4.2.65 c) should be implemented, to ensure that the apparent range of the PARROT as seen by an ACAS prevents the generation of ACAS advisories.

4.2.67 Similar false aircraft responses may be generated by transponder test facilities, particularly those which test pressure-altitude encoding, unless the test facility is adequately shielded to prevent reception and transmission of signals from/to ACAS-equipped aircraft.

4.3 AIRCRAFT EQUIPMENT INSTALLATION

Nominal Aircraft Equipment Characteristics

4.3.1 A standard aircraft equipment installation is assumed to have the following characteristics:

a) an antenna having performance equivalent to that of a simple quarter-wave antenna;

b) a transponder output power of between 21 and 27 dBW (i.e. 125 to 500 watts) except for transponders used solely below 4 570 m (15 000 ft) or Mode S transponders used in aircraft operating below 4 570 m (15 000 ft) with maximum cruising speed less than 324 km/h (175 kt) which may have a minimum output power of 18.5 dBW (70 watts) at the antenna end of the transmission line (Annex 10, Volume IV, Chapter 3, 3.1.1.7.11.1 and 3.1.2.10.2); and

c) a transponder receiver minimum triggering level (MTL) of –69 to –77 dBm (Annex 10, Volume IV, Chapter 3, 3.1.1.7.5) and a Mode S transponder receiver MTL of –71 to –77 dBm (Annex 10, Volume IV, Chapter 3, 3.1.2.10.1) measured at the antenna end of the transmission line.

Non-Standard Aircraft Installations

4.3.2 An aircraft installation having these characteristics will meet the requirements specified in Annex 10, Volume IV, Chapter 3, 3.1.1.7.5 and 3.1.1.7.11.1. In the event that an aircraft installation has characteristics that differ from those of the assumed system, the effective radiated peak power and the received power level required at the input of the antenna should be comparable to that of the assumed system.

Mode A/C Transponders

Mode A Identification Code Transmission

4.3.3 Mode A identification code interrogations are used to obtain from an aircraft a four-digit octal code which has been manually set in the cockpit. Each digit may have values between 0 and 7, providing 4 096 codes. Coding is by pulse position in accordance with Annex 10, Volume IV, Chapter 3, 3.1.1.6.6. Rules on the use of Mode A codes for ATC are provided in Procedures for Air Navigation Services — Air Traffic Management, PANS-ATM (Doc 4444). Certain codes are reserved for indicating emergency conditions (e.g. 7700 for emergency, 7600 for radio failure, 7500 for unlawful interference).

4.3.4 A special position identification (SPI) pulse may be transmitted with a Mode A reply to further aid in identification of individual aircraft. This pulse is added for
a short period (nominally 18 seconds) upon manual activation by the pilot, upon request of the air traffic controller.

**Mode C pressure-altitude code transmission**

4.3.5 In order to achieve maximum operational benefit from automatic pressure-altitude transmission, the altitude information used by the pilot and that automatically provided to the controller must closely correspond (see Annex 10, Volume IV, Chapter 3, 3.1.1.7.12.2.4). The highest degree of correspondence will be achieved by having aircraft systems that use the same static pressure source, same aneroid unit, and the same static pressure error correction device for both the pilot and the automatically transmitted pressure-altitude data.

4.3.6 If this correspondence is not within the tolerance required in Annex 10, Volume IV, Chapter 3, 3.1.1.7.12.2.4, a facility is required to remove the pressure-altitude information pulses from the reply, which then consists of only framing pulses. The purpose of this requirement is to ensure that inaccurate information pulses are able to be removed while retaining the capability of detection and position determination.

4.3.7 For aircraft installations that are for any reason not able to report pressure-altitude, the transmission of a reply consisting of framing pulses only (Annex 10, Volume IV, Chapter 3, 3.1.1.7.12.2.1) is required in response to Mode C interrogations. The framing pulses alone are useful in certain ground processing equipments for enhancing the detection probability and azimuth accuracy and are essential for ACAS efficiency. For this reason the continued use of transponders that only enable Mode C information and framing pulses to be removed together is discouraged.

4.3.8 The following formats may be accepted by the transponder:

a) ARINC 429 data which is the format normally used by the latest generation of commercial aircraft;

b) ARINC 575 data which is provided by the first generation of Inertial Reference Systems;

c) ARINC 407 for the delivery of synchro altitude data; and

d) Gilham altitude data.

4.3.9 In order to verify that the input altitude is correct the transponder should monitor the following:

a) for ARINC 429 data the Status Matrix field (bits 30 and 31 of the ARINC word) should be monitored to make sure that the value either indicates “Normal Operation” or “Functional Test”. In such a case the information should be considered valid and the transponder should assume that the source delivering the data is operating correctly. In other cases or when the altitude data parity check fails the altitude should be considered as invalid;

b) for synchro altitude data the “synchro flag” input should be monitored. In addition the coarse and fine inputs should also be monitored to detect variations between the two inputs. Misalignments of more than ± 90 degrees should result in the altitude being considered invalid; and

c) installations using the Gilham altitude data should be equipped with at least two independent sources and a Gilham altitude compare function. The transponder should use the information provided by the Gilham altitude compare function to detect invalid altitude. If the altitude is invalid the transponder should declare an “external failure” fault and log this information to its non-volatile RAM.

**Transmission of the “X” pulse**

4.3.10 In Annex 10, Volume IV, Chapter 3, 3.1.1.6.2, the position of the “X” pulse is specified as a technical standard. This pulse position is not used in replies to Mode A or Mode C interrogations (see Figure 4-10). It was originally specified to provide for possible future expansion of the system, but it has subsequently been decided that such expansion should be achieved using Mode S. It is used in some States to validate or invalidate replies by checking the absence of pulse at this position.

**The Mode S transponder**

**General**

4.3.11 The Mode S transponder receives and decodes Mode A/C and Mode S interrogations, recognizing which Mode S interrogations are addressed to it. Each Mode S transponder must be able to recognize the discrete address assigned to the aircraft and the address used both in the Mode S-only all-call interrogations and in the Comm-A broadcast transmissions (see 6.1.4 and 6.4.3). After determining the type of interrogation and the contents of the control fields in the Mode S interrogation, the transponder
formats and transmits the appropriate Mode A/C or Mode S reply. As in the case of a Mode A/C transponder, inputs from an encoding altimeter are required for altitude reporting.

4.3.12 The principal elements of the Mode S transponder, and their interconnection, are depicted in Figure 4-11. Mode S transponders are categorized according to their data link capability into five levels. Level 1 transponders support only the surveillance functions. Levels 2, 3, 4 and 5 transponders permit various levels of data link communications as defined in Annex 10, Volume IV, Chapter 2. Mode S transponders used by international civil air traffic must conform at least to Level 2.

4.3.13 A Level 2 or higher transponder is required for data link, in which case the transponder can be considered to act as a modem. Uplink messages, once verified for correct parity, are available for data link processing. The parity technique is arranged so that recognition of its address is implicit verification that the contents of the interrogation were correctly decoded (see Appendix A). Downlink messages are received from the aircraft data link processing system, incorporated in reply formats and transmitted using the downlink protocols. The transponder does not interpret or modify in any way the contents of such messages.

4.3.14 Mode S transponders intended for international use (Levels 2 or higher) are also capable of transmitting the aircraft identification which requires an appropriate manual input device if this cannot be derived automatically.

Mode S transponders with an extended interface function

4.3.15 Mode S transponders that are used to provide aircraft data and/or communications to ATC ground systems have been specified with all or some of the Mode S subnetwork functionality (see Chapter 9) and some Mode S specific services (see Manual on Mode S Specific Services (Doc 9688)) in the same line replaceable unit (LRU) as the transponder functions. This extra functionality is known as the “Extended Interface Function”.

4.3.16 It is essential that such Mode S transponders are clearly identified as to the data services that they will provide and that the design is such that it allows the comprehensive testing of the transponder, subnetwork, and data service functions, of the combined unit.

4.3.17 Where a GICB service is to be provided, the dataflash service specified in Doc 9688 operating on uplink MSP 6 for requests and downlink MSP 3 for the service provision must be included in the unit to avoid the high data flows on the aircraft bus, which could result from constant monitoring of the serviced GICB registers from outside the unit.

4.3.18 When a Mode S transponder is intended for use in areas requiring enhanced surveillance and other data services, an extended interface function is necessary and the combined “one box” architecture is the preferred solution.

Antenna diversity operation

4.3.19 In order to maintain adequate link reliability, certain aircraft are required to be equipped with a diversity transponder (see Annex 10, Volume IV, Chapter 2). Two antennas (one located on the top and the other on the bottom of the fuselage so that at least one is visible from the ground station) are connected to the transponder. The most common form of the diversity transponder is one that employs two receivers, selection logic, and a switch to connect the transmitter to either antenna (Figure 4-12). The selection logic examines the interrogation as received on each antenna, selects the stronger signal and switches the transmission to the corresponding antenna for the reply. This logic is based on the reasoning that since the interrogation and reply frequencies are separated by only 60 MHz (that is, by about 6 per cent) it is likely that the antenna that provides the stronger signal to the transponder receiver will also provide a stronger return signal to the ground station.

4.3.20 The extent to which the interrogation and reply RF links are, in fact, reciprocal determines the required precision of the amplitude comparison process. Antenna pattern measurements have shown that the links typically track each other to within about 3 dB. Thus, if the received signal on antenna A is 3 dB stronger than the received signal on antenna B, it is likely that a reply on antenna A would be received at the ground station at a greater level than would a reply on antenna B. It also follows that it is not critical to accurately determine which signal is stronger when both of the signals are well above the minimum detection level of the transponder. It is only necessary to carry out a precise amplitude comparison between the two received signals when those signals are both received within about 6 dB above the transponder MTL.

4.3.21 Since the goal of the diversity function is to increase the probability that both the air-air link margin, in the case of ACAS, and the air-ground link margin to the transponder remain adequate as the aircraft manoeuvres,
the antenna selection logic should not favour either the top or the bottom antenna.

4.3.22 The amplitude comparison should only be used to select the reply channel if valid P₁-P₃ or P₁-P₂ pairs have been received on both channels. For example, if Channel A receives a valid pulse pair and Channel B receives either nothing or an invalid pulse pair, Channel A is selected by default. It is also allowable for a transponder to examine more than merely a pair of pulses before making the channel selection (provided of course, that the selection process is completed in time to generate a reply with the proper reply delay). A transponder could, in principle, include two complete Mode S interrogation decoders operating in parallel. In such a transponder, the amplitude comparison would only be used to select the reply channel if complete and valid Mode S interrogations had been accepted on both channels.

4.3.23 If a valid received signal on one channel is delayed by more than Tₐ (where Tₐ for a given transponder may be anywhere between 125 and 375 nanoseconds) relative to a valid received signal on the other channel, the latter signal should be assumed to be a multipath reflection and the channel with the earlier signal, even if weaker, should be selected.

4.3.24 The simultaneity requirement makes it important that the time delays through the two antenna-receiver channels be held to well within 125 nanoseconds of each other to avoid an unwanted bias in the selection process. It follows that it is also desirable to mount the two antennas directly above and below each other. Two antennas mounted on the nose and tail of a large aircraft could be more than 40 m apart. Signals arriving at such an aircraft from the 12 o’clock or 6 o’clock directions would always have apparent relative time delays of more than 125 nanoseconds.

4.3.25 The use of two independent transponders connected to the separate antennas is not permitted. Such an arrangement could be made functionally equivalent to the use of parallel decoders if provision were made for inhibiting replies from the last transponder to decode a valid signal. However, it is difficult to match the sensitivities and time delays of two independent transponders, particularly the delay variation from reply to reply, which is required to be less than 80 nanoseconds for Mode S signals (see Annex 10, Volume IV, Chapter 3, 3.1.2.10.3.8.2).

4.3.26 The use of a switch to periodically alternate the antenna connection from one antenna to another at a preset rate is not permitted. In situations in which only one antenna has an adequate link, such a technique would reduce the round reliability of the transponder by half and result in track drops caused by inadvertent statistical synchronization of the antenna switching rate with the interrogation rate. When both antennas have adequate links, such a technique could unnecessarily increase delay variation from reply to reply.

Data link interface

4.3.27 One possible implementation of a Mode S avionic system comprises a transponder with a separate airborne data link processor (ADLP). In this implementation a level 2 or higher transponder transfers data both to and from the ADLP. Uplink communications capacity implied by the reply rate specification indicates the ability to handle a high short-term data rate to the ADLP. Downlink communications protocols require the transponder to have access to downlink messages within the transponder turnaround time. These requirements can be met in either of two ways.

4.3.28 The transponder can be designed to buffer the content of data link messages internally. This buffer will require approximately 2.5, 3.0, 3.5 or 56.0 kilobytes of storage for a level 2, 3, 4 or 5 transponder respectively, and an interface data exchange capability of approximately 20 kilobytes per second or higher. When a non-real time interface is used, provision must be made for the data link processor to cancel an air-initiated message stored in the transponder message buffer. This requires message numbering if more than one message at a time can be stored.

4.3.29 Another possible implementation is the integration of the ADLP and the transponder in a single unit.

Mode S transponder protocol characteristics

Note 1.— The overall functional logic and flow charts of Mode S transponder processing are presented in the following paragraphs. An explanation of the protocols represented by these diagrams is contained in Chapter 6.

Note 2.— These flow charts represent the functional logic required to handle a particular protocol. They do not represent or imply an implementation of this logic.

4.3.30 Overall functional logic. This logic is illustrated in Figures 4-13A and 4-13B using a representation derived from Petri Nets. Figure 4-13A shows the overall functional logic of Mode S transponder. The particular protocols of Level C in the diagram are described in the relevant flow charts which follow. Figure 4-13B illustrates
the functional logic of the address and parity checking and the Mode S-only all-call processing (Level B of Figure 4-13A). The basic notions required in order to read a Petri Nets representation of a logical structure are presented in Figure 4-14.

4.3.31 Interrogation acceptance. Interrogation acceptance is the decision process made by the transponder that a recognized interrogation should be processed and, if appropriate, a reply transmitted. The logic for interrogation acceptance is presented in Figure 4-15.

4.3.32 Lockout. The lockout protocol defines the transponder processing and time-out of all-call lockout commands. This includes multisite and non-selective. The logic for the lockout protocol is presented in Figure 4-16. A description of this protocol is contained in 6.1.

4.3.33 Basic data protocols. The basic data protocols define transponder action for flight status, alert, on-the-ground and data link capability reporting. The logic for these protocols is presented in Figure 4-17. A description of this protocol is contained in 6.10.

4.3.34 Comm-B protocol. The Comm-B protocol defines the transponder processing for standard length downlink messages. This includes ground-initiated, non-selective air-initiated, multisite air-initiated, multisite directed and broadcast Comm-B messages. A summary of transponder storage is presented in Figure 4-18. An overview of the complete protocol is presented in Figure 4-19. A description of this protocol is contained in 6.5.

Note.—The requirement to process the PC field before the SD field is not fully covered in the figure.

4.3.35 Uplink ELM handling. This protocol defines transponder action for the receipt of individual message segments and the assembly of these segments into a complete uplink extended-length message (ELM). Uplink ELM message handling logic is presented in Figure 4-20. A description of this protocol is contained in 6.6.1.

4.3.36 Uplink ELM reservation and closeout. This protocol defines transponder action for the reservation process that precedes the delivery of a multisite uplink ELM. It also defines closeout action for both multisite and non-selective uplink ELM delivery. Uplink ELM reservation and closeout logic is presented in Figure 4-21. A description of this protocol is contained in 6.6.2 and 6.6.6.

4.3.37 Downlink ELM handling. This protocol defines transponder action for the delivery of individual message segments of a downlink ELM upon receipt of control messages received from a Mode S ground station. Downlink ELM message handling logic is presented in Figure 4-22. A description of this protocol is contained in 6.7.1.

4.3.38 Downlink ELM reservation and closeout. This protocol covers the same function as 4.3.36 for the uplink ELM. Downlink ELM reservation and closeout logic is presented in Figure 4-23. A description of this protocol is contained in 6.7.2, 6.7.5 and 6.7.6.

TRANSPONDER TESTER

4.3.39 A transponder in-flight tester may be provided to indicate normal or faulty operation.

4.3.40 When a tester is used it should not radiate a signal level external to the aircraft stronger than –70 dBm. The test interrogation signal should not exceed an interrogation rate of 450 per second.

4.3.41 The transponder tester should be limited to intermittent use which is no longer than that required to determine the status of the transponder.
Figure 4-1. Uplink margin: effective radiated power equals 79.4 dBm
Figure 4-2. Relationship between power and range at 1030 MHz

\[ P_{\text{ant}}(T) = \text{Power level at transponder antenna} \]
Figure 4-3. Downlink margin: receiver minimum sensitivity power at receiver input
Figure 4-4. Relationship between power and range at 1 090 MHz
Figure 4-5. Effects of surface reflections

Note.— $E_t = \text{Angle of incidence}$

$h_r = \text{Height of antenna above reflecting surface}$

$\lambda = \text{Wavelength}$

$S/N = \text{Signal-to-noise ratio}$
Figure 4-6. Typical antenna lobe structure envelope representing 90 per cent probability of detection
Figure 4-7. Pulse amplitude discrimination in transponder for side-lobe suppression facility

Figure 4-8. Pulse signal on an A-scope with square-law second detector
Figure 4-9. Parrot apparent intruder to ACAS-equipped aircraft

<table>
<thead>
<tr>
<th>Available pulse positions</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Spacing (microseconds)</td>
<td>leading edge to leading edge</td>
</tr>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Designation of pulses</td>
<td>Framing</td>
</tr>
<tr>
<td>Standard</td>
<td>(4 096 codes)</td>
</tr>
</tbody>
</table>

Figure 4-10. SSR transponder reply codes in response to Mode A and C interrogations
Figure 4-11. Mode S transponder
Figure 4-12. Example of diversity transponder
Figure 4-13A. Overall functional logic of Mode S transponder

Note.—Each box of level C may lead to no processing.
Figure 4-13B. Address and parity checking, Mode S only all-call processing
(Level B of Figure 4-13A)
A Petri Network is a place-transition graph where a place is represented by a circle and a transition is represented by an arrow.

A place represents a subset of the state variables of the whole system, and a transition represents an event whose occurrence modifies the state of the system. This event is described by the condition associated to the transition. The global state of the system, at a given time, is described by the set of all places marked with a token (black point). Simulation of the evolution of the system can then be achieved by moving tokens from place(s) to place(s) according to the transition firing rules (defined by the associated condition) described below:
- A transition can be fired if and only if, all its input places are marked with a token and the transition associated condition is realized.
- The result is that the tokens in all input places are removed, and all the output places are marked with a new token.

Note. — For simplicity, a part of the whole diagram may be represented by a box leading, itself, to another Petri Nets representation.

As an example, the possible evolutions of a hypothetical system are described as follows:

Figure 4-14. Basic notions to read a Petri Nets
Notes. — 1. Double borders indicate transponder states.
2. * = Start of transponder transaction cycle, (Mode S).
3. ** = Start of transponder transaction cycle (Mode A/C).
4. $R = \text{Recover from desensitization.}$
5. "Unable to process" indicates that the transponder cannot accept a long interrogation because it is not able to store any additional messages.
Start

UF = 4, 5, 20, 21

No

No effect on lockout state

Yes

DI = 1, 7

Yes

LOS = 1

Yes

IIS = 0

Yes

Start or restart TL timer #IIS

No

No effect on lockout state

Non-selective all-call lockout

Start

UF = 4, 5, 20, 21

No

Yes

PC = 1

Yes

Start or restart T₀ timer

No

No effect on lockout state

Multisite all-call lockout

Note.— For actions of T₀, T₁, and IIS see 6.1.

Figure 4-16. Lockout protocol
Note.— The VS code appears in the VS field of DFs = 0, 16.
The FS code appears in the FS field of DFs = 4, 5, 20, 21.
The $T_c$ timer is specific to the alert function; it is not the uplink ELM timer.
The $T_i$ timer is specific to the SPI function.

Figure 4-17. Basic data protocols
Notes: 1. Double borders indicate transponder states.
2. Each decision diamond is assigned a unique letter. Additional instances of the same decision diamond are represented by a small diamond containing only the letter.
3. The T register indicates that the message has been sent at least once.
4. The B-timer does not expire for an air directed Comm-B message.
5. Follow arrows vertically through action blocks.

Figure 4-18. Transponder storage for Comm-B protocol
Figure 4-19. Comm-B protocol overview
Figure 4-19. Comm-B protocol overview (cont.)
Figure 4-19. Comm-B protocol overview (cont.)
Note 1.— Double borders indicate transponder state.

Note 2.— Clear SET-UP does not clear TAS. TAS is cleared by the receipt of a closeout message.

Figure 4-20. Uplink ELM handling
Chapter 4. SSR System techniques

Figure 4-21. Uplink ELM reservation and closeout

Notes.— 1. "Reservation" indicates that the IIS is stored and the timer is started.
2. "Closeout" indicates that the stored IIS is cancelled, the timer is stopped, TAS is cleared and the set-up is cancelled.
3. "0" indicates termination of the process.
4. Double borders indicate transponder states.

1. Broadcast Comm-A
2. UF = 4, 5, 20, 21
3. PC = 5
4. DI = 1
5. MES = 1, 5
6. MES = 2, 6, 7
7. TRC timer runs
8. IIS matches stored value
9. Closeout

The diagram illustrates the process flow for uplink ELM reservation and closeout, with various decision points and actions indicated by the flowchart. The notes clarify the meanings of certain symbols and terminations in the process.
Note.—Double borders indicate transponder state.

Figure 4-22. Downlink ELM handling
Notes.— 1. "Reservation" indicates that the IIS is stored and the TRD timer is started or restarted.
2. "Closeout" indicates that the stored IIS is cancelled, the timer is stopped, DR is cleared and the message is cancelled.
3. "0" indicates termination of the process.
4. Double borders indicate transponder states.
5. Additional processing for multisite-directed DELM processing is described in 6.6.3.
6. Closeout is only permitted if the D-register is set (see Figure 4-21).
7. The D-register indicates that a message has been sent at least once.
8. The D-register is reset when the D-timer expires.

Figure 4-23. Downlink ELM reservation and closeout
Chapter 5

MONOPULSE SSR

5.1 AZIMUTH MEASUREMENT

Monopulse azimuth measurement, as its name implies, is a technique that allows the measurement of target azimuth to be made on a single pulse within any transponder reply. Thus, compared to typical sliding window azimuth measurement techniques, a significant reduction in pulse repetition frequency (PRF) is possible, improving the SSR environment and reducing interference. Monopulse azimuth measurement is also more accurate, particularly in an interference environment.

5.2 IMPLEMENTATION CONSIDERATIONS

SYSTEM ELEMENTS

5.2.1 A monopulse system consists of the following functional elements: a monopulse antenna, a twin channel monopulse receiver, a monopulse off-boresight angle processor, and a plot extractor, which may include scan-to-scan processing. These elements are not necessarily physically separated.

THE MONOPULSE ANTENNA

5.2.2 Monopulse azimuth measurement techniques usually require two antennas or a split antenna, with each antenna or each section separately fed. One technique uses two beams arranged with their radiation axes parallel and their centres separated horizontally. Except for targets on-boresight, there is a difference in path lengths between the target aircraft and the two antennas. This gives rise to a phase difference between the two received signals which is a function of target angle relative to the antenna boresight (see Figure 5-1). Another technique uses two beams having a common phase centre. It is common practice to combine the two antenna outputs into sum and difference patterns. The resultant signal amplitude patterns are illustrated in Figure 5-2. The sum pattern is used for the interrogation signals, whereas both patterns are used for replies. Figure 5-3 shows how the off-boresight angle of the target can be estimated from the ratio of the amplitude of the difference signal to that of the sum signal ($\Delta \Sigma$) or from a combination of difference and sum channels ($f(\Delta \Sigma)$). The same consideration needs to be given to the vertical radiation pattern (VRP) of a monopulse antenna as to any other SSR antenna. In addition, to ensure accurate off-boresight angle estimation, the ratio between sum and difference patterns should remain as stable as possible for any given off-boresight angle within the 3 dB beamwidth over all practical elevation angles.

THE MONOPULSE RECEIVER

5.2.3 As the monopulse receiver has to deal with a wide dynamic range, it is advantageous to use a logarithmic receiver for the signals to be processed for target detection and code extraction.

5.2.4 With regards to the bearing measurement accuracy, the receiver has to be fitted with two carefully matched channels (sum ($\Sigma$) and difference ($\Delta$)), having stable gain and phase characteristics not only over the dynamic range but also over the possible frequency band of the received signals (at least plus or minus 3 MHz). To limit the beamwidth over which signals are processed, a received side-lobe suppression (RSLS) function is required which needs a third receiver channel (control ($\Omega$)).

THE MONOPULSE PROCESSOR

5.2.5 The output of the monopulse receiver is fed to the monopulse processor for the calculation of the off-boresight angle (OBA) and added to the antenna bearing to determine the azimuth of the aircraft target.
5.2.6 Figure 5-4 shows a possible implementation of a sum/difference ratio monopulse system. After logarithmic amplification, the ratio can be computed by subtraction. The left-right indication is provided by the sign of the phase difference between sum and difference signals.

5.2.7 Figure 5-5 shows a possible realization of a half-angle monopulse processor which generates a single-valued output over the entire range of sum/difference ratios. The output is given by the approximate formula:

\[ f(\Delta, \Sigma) = 2 \arctan(\Delta/\Sigma) \]

THE MONOPULSE EXTRACTOR

5.2.8 The output of the monopulse processor is fed into a special monopulse extractor which permits improved code processing and achieves a reduction of the effects of synchronous garbling. Considerable benefits in code and target detection can be obtained by use of the extra data available from monopulse processors. Further advantages can also be obtained by correlating this data on a scan-to-scan basis and checking the data for consistency. With additional computation this process also allows the removal of most multipath targets.

5.3 POTENTIAL BENEFITS

INCREASED AZIMUTH ACCURACY

5.3.1 Monopulse processing can give an improvement in accuracy relative to a sliding window process, by a factor of two to three times. The improvement is limited by the amplitudes of the multipath signal entering the system as well as by receiver noise.

IMPROVED PERFORMANCE IN THE CASE OF GARBLING REPLIES

5.3.2 The use of the additional information available in a monopulse system allows a very significant improvement in the processing of garbling replies.

REDUCED INTERROGATION RATE

5.3.3 The greater accuracy of the process in both positional measurement and code detection allows smaller correlation windows to be set and fewer repetitions of codes for code validation. Monopulse processing can be reliably expected to detect and decode targets using a minimum of two replies per A/C mode, thus allowing a marked reduction in PRF with consequent benefits in fruit generation and channel occupancy.
Figure 5-1. Monopulse azimuth measurement

Figure 5-2. Sum ($\Sigma$) and difference ($\Delta$) patterns
Figure 5-3. Off-boresight angle as a function of sum and difference channel signals
Note.— OBA signifies off-boresight azimuth.

Figure 5-4. Example of sum/difference processing
Figure 5-5. Example of half-angle processing
Chapter 6

MODE S PROTOCOL CONSIDERATIONS

Note.— In regions of overlapping coverage, Mode S ground stations must coordinate their activities to permit the correct operation of the Mode S surveillance and communications protocols. The multisite protocols provide this coordination with a minimum of ground cooperation through the use of a site identifier in uplink transmissions. The non-selective protocols require ground to ground coordination of ground station activity but are more efficient in the use of channel time. However, the non-selective lockout protocols are not compatible with the Mode S subnetwork protocols.

6.1 ACQUISITION AND LOCKOUT PROTOCOLS

GENERAL

6.1.1 In order to selectively interrogate a Mode S-equipped aircraft, the ground station must know the aircraft’s Mode S address and approximate position. To acquire the addresses of Mode S aircraft each ground station transmits all-call interrogations. A Mode S-equipped aircraft will respond to such an interrogation with its unique address, and it will be added to the ground station’s file of acquired aircraft.

6.1.2 Once acquired, the Mode S-equipped aircraft should be locked out from replying (instructed not to respond) to subsequent Mode S all-call interrogations in order to minimize all-call synchronous garbling. This lockout condition is controlled by the Mode S ground station through Mode S selectively addressed interrogations. If for any reason an aircraft ceases to receive discretely-addressed interrogations containing a lockout command for a period of approximately 18 seconds (corresponding to a few antenna scans), any existing lockout will lapse so that the aircraft may be reacquired by normal Mode S acquisition.

6.1.3 The interrogation used by the ground station to elicit all-call replies depends upon the acquisition technique in effect at that site.

MULTISITE ACQUISITION AND LOCKOUT

6.1.4 Multisite acquisition is carried out by using the Mode S-only all-call interrogation UF = 11. The interrogator code of the interrogating site is contained in the interrogation. Two types of interrogator codes are defined:

a) the interrogator identifier (II) code is used for multisite surveillance and data link coordination. II codes of 1 to 15 are valid (an II code of zero is interpreted as non-selective, see 6.1.13); and

b) the surveillance identifier (SI) code is used only for multisite surveillance. SI codes of 1 to 63 are valid. SI code 0 is not used.

6.1.5 The transponder replies to this interrogation if it is not in a state of lockout to that specific interrogator code. The transponder has a total of seventy-nine independent lockout timers to maintain the lockout state requested by the ground stations (i.e. 16 II and 63 SI lockout timers).

TECHNIQUE TO DETECT NON-SI-CAPABLE TRANSPONDERS

6.1.6 An SI code is composed of the IC field and the CL field. Only transponders complying with at least Amendment 73 (or higher) of Annex 10 will decode the CL field in order to determine if the content of the IC field is an II code or an SI code. Transponders that have not been upgraded to handle an SI code will, by default, consider the content of the IC field as being an II code value. Therefore, if CL is not equal to zero (meaning that the IC field contains an SI code), the non-upgraded transponders will encode the parity sequence of the reply using the “matching” II code rather than the SI code contained in the interrogation.

6.1.7 The interrogator that will receive Mode S-only all-call replies encoded with the “matching” II code will normally reject these replies. The consequence is that
transponders which have not been upgraded to handle SI codes will not be detected by the interrogator operating with an SI code.

6.1.8 The following technique enables the acquisition and detection of non-SI-capable transponders for the transition period.

6.1.9 The interrogator, when operating with an SI code, should be configurable by the user to accept Mode S-only all-call replies for which the “matching” II code has been used to encode the parity sequence.

6.1.10 The target that has sent such replies should be considered as equipped with a non-SI-capable transponder, even if the content of register 10\textsubscript{16} states that the transponder has SI capability.

6.1.11 The interrogator, if operating with an SI code, should be configurable by the user to interrogate targets equipped with non-SI-capable transponders using the Mode S selective protocols foreseen for II code operation. The II code to be used should be the “matching” II code.

6.1.12 The interrogator, if operating with an SI code, should be configurable by the user to either:

a) not lock out non-SI-capable transponders on the “matching” II code; or

b) use intermittent lockout for this “matching” II code.

Note. — This is to allow neighbouring interrogators operating with the “matching” II code to acquire the non-SI-capable transponders.

6.1.13 The interrogator, if operating with an II code, should be configurable by the user to either:

a) not lock out Mode S transponders that do not report the SI capability in register 10\textsubscript{16}; or

b) use intermittent lockout for Mode S transponders that do not report the SI capability in register 10\textsubscript{16}.

Note. — This is to allow neighbouring interrogators operating with an SI code and the “matching” II code to acquire the non-SI-capable transponders.

6.1.14 This technique should only be used to detect aircraft not equipped with SI-code-capable transponders entering mandated SI-code airspace so that appropriate action can be taken (e.g. they can be re-routed out of such airspace).

6.1.15 Some of the data link protocols defined in this chapter require the use of an II code. These protocols cannot be used by an interrogator operating with an SI code.

6.1.16 The data link capability for an interrogator operating with an SI code is therefore limited to unlinked Comm-A, broadcast Comm-A, ground-initiated Comm-B (GICB) protocol, broadcast Comm-B and ACAS downlink transactions. This specifically excludes the use of the air-initiated Comm-B (AICB) protocol.

Note. — The AICB protocol is required for data flash and downlink MSPs.

6.1.17 When the system is operating in the multisite mode, separate interrogation of Mode S and Mode A/C targets can be achieved by the use of the Mode A/C-only all-call, together with the Mode S-only all-call, UF = 11.

6.1.18 As the name implies, the Mode S-only all-call interrogation elicits replies only from Mode S transponders. It is therefore used in conjunction with the Mode A/C-only all-call interrogation (distinguished by a short P\textsubscript{1} pulse). This latter interrogation elicits replies only from Mode A/C transponders and therefore complements the Mode S-only all-call so that Mode A/C and Mode S transponders reply to at most one of the interrogations. This avoids the possibility of having the same aircraft under surveillance as both a Mode A/C and a Mode S aircraft.

6.1.19 One technique for managing the RF channel is for each all-call interrogation to be followed by its own listening window. At the expense of more sophisticated management of the reply processors, an alternative technique obtains the benefit of a shared listening interval by pairing the two all-call interrogations as shown in Figure 6-1. This shared listening interval results in a much more efficient use of the time line. The spacing between the interrogations is such that replies are received simultaneously from a Mode A/C transponder and a Mode S transponder at the same range. This allows enough time for a Mode A/C transponder to recover from the side-lobe suppression caused by the P\textsubscript{1}-P\textsubscript{2} Mode S interrogation preamble before it receives the Mode A/C-only all-call.

Note. — Some States have experienced that certain Mode A/C transponders respond to Mode S-only all-call with Mode A or C and this causes ghost targets (two tracks generated by the same aircraft). When the above combined interrogation technique is used, it is essential that the Mode A/C suppression function perform correctly.
Appropriate testing for the Mode A/C transponder suppression function when interrogated by a Mode S-only all-call is strongly recommended.

6.1.20 The P1 field of an all-call reply, DF = 11, elicited by a Mode S-only all-call interrogation (UF = 11) is encoded using the interrogator code received in the interrogation that elicited the reply. This is composed of the code label (CL) and the interrogator code (IC) fields of the all-call interrogation. This address is used in the encoding of the P1 field in exactly the same manner as the transponder Mode S address is used to generate the AP field. Ground stations operating in the multisite mode decode all-call replies using their own interrogator code as the expected address. All-call fruit replies produced by adjacent ground stations will not be accepted by the local ground station since they would be encoded using a different interrogator code. This rejection of all-call replies by the interrogator code eliminates the possibility of extraneous all-call tracks being formed from Mode S fruit replies.

6.1.21 The use of all-call lockout makes it necessary for ground stations to coordinate surveillance activities in regions of overlapping coverage to ensure that all ground stations are allowed to acquire Mode S aircraft. If ground stations cannot coordinately via ground communications, the transponder multisite lockout feature is employed.

6.1.22 The multisite lockout feature is based upon the use of interrogator codes (II and SI) and multiple transponder lockout timers. The Mode S transponder can be selectively and independently locked out to multisite all-call interrogations originating from up to 78 different interrogator codes. Adjacent sites using different interrogator codes are unaffected by the other sites’ lockout activity and hence can perform acquisition and lockout in a completely autonomous manner. Restrictions on interrogator operations as stated in 8.1.8 must be taken into account.

6.1.22.1 Implementation of SI code capability (Annex 10, Volume IV, Chapter 2, 2.1.5.1.7.1) can be determined by monitoring bit 35 of the Data Link Capability report (register 1.0). This report should be routinely extracted at track acquisition. SI codes cannot be used in a region of airspace until all of the Mode S aircraft are equipped for SI codes. This monitoring should continue after SI codes are put into use to identify any transponder that is not SI-capable. Follow-up action should be initiated for aircraft that are detected that are not equipped with SI codes.

6.1.22.2 The reason that all aircraft must be SI-equipped is that a non-SI code-capable Mode S transponder will misinterpret the SI code contained in the Mode S-only all-call interrogation. The II or SI code included in a Mode S-only all-call interrogation is contained in a 7-bit field composed of the 3-bit Code Label (CL) field and the 4-bit Interrogator Code (IC) field as follows:

CL Coding (in binary):

000 signifies that IC Field contains the II code
001 signifies that IC Field contains SI codes 1 to 15
010 signifies that IC Field contains SI codes 16 to 31
011 signifies that IC Field contains SI codes 32 to 47
100 signifies that IC Field contains SI codes 48 to 63

A transponder that does not support SI codes will not detect the CL field and will therefore interpret the IC field as always containing an II code. This causes the mapping of a set of SI codes into an II code. For example, interrogator codes of II = 1 and SI = 1, 17, 33 and 49 will all have 0001 in the IC field. If an aircraft not equipped for SI codes is operating in a region of overlapping coverage of interrogators with II = 1 and SI = 16, the following interaction will occur:

a) if the aircraft is acquired first by the II = 1 interrogator, the aircraft will be locked out to II = 1. An all-call interrogation from the SI interrogator expressing SI = 17 will not elicit an all-call reply, because the transponder interprets the code as II = 1 and it is locked out to II = 1; and

b) if the aircraft is acquired first by the SI interrogator, the transponder will reply to the SI = 17 all-call interrogation, since it is not locked out to II = 1. The SI interrogator will not be able to lock out the transponder, since the mechanism for II and SI code lockout is entirely different. Therefore, the transponder will not recognize the SI lockout command (and will not change its lockout status to any II code).

Thus with a transponder not equipped with SI code capability, there will never be a loss of surveillance coverage for an interrogator with an II code. Surveillance loss can only happen to the SI code interrogator and then only for a certain combination of II and SI codes.

6.1.22.3 The transition to SI codes is manageable through monitoring compliance to the SI code requirement via the Data Link Capability Report, and (where possible for fixed interrogators) assigning II and SI codes for adjacent interrogators to avoid possible interaction. It is possible to assign more than one SI code to an interrogator on a sector basis. This approach might be useful as another means to avoid interacting SI and II codes. For mobile interrogators, or for fixed interrogators where non-interacting SI and II codes cannot be used, a low rate of lockout
override Mode S-only all-call interrogations by the SI code interrogator can be used to acquire the occasional non-SI code Mode S transponder. Another means for managing this situation is for the interrogators operating with II codes to periodically remove lockout for non-SI equipped Mode S transponders to ensure acquisition by SI interrogators.

**NON-SELECTIVE ACQUISITION AND LOCKOUT**

6.1.23 Addressed interrogations containing II = 0 are not compatible with the Mode S subnetwork protocols. These protocols monitor discrete interrogations for II activity and use non-zero II codes for routing of downlink messages to intended ground addresses. Thus the use of non-selective acquisition (which is based on II = 0) cannot be used with an interrogator that is supporting the Mode S subnetwork. For this reason, II = 0 is no longer authorized for use in normal Mode S acquisition. II = 0 is now reserved for adaptive acquisition in connection with stochastic/lockout override technique (6.2.19).

6.1.24 The protocol (PC) field is used either for lockout or for communication purposes. When the PC field in an interrogation is used for communication purposes, non-selective lockout can be accomplished in the same interrogation by the use of the lockout subfield (LOS) in the special designator (SD) field.

**CLUSTERED INTERROGATOR ACQUISITION AND LOCKOUT**

6.1.25 Interrogators with overlapping coverage using the same interrogator code may be linked via a ground network to coordinate their surveillance and communications activities. This provides the reduced all-call fruit benefit of the non-selective acquisition technique in a form that is compatible with the Mode S subnetwork. Since ground coordination is provided, clustered interrogators may use the non-selective communications protocols.

**STOCHASTIC ACQUISITION**

6.1.26 While Mode S lockout can reduce synchronous garbling on acquisition, it cannot eliminate it completely, nor is it effective in the case where a Mode S ground station resumes operation after a period of inactivity and must therefore acquire many Mode S aircraft simultaneously. These latter cases are handled by a feature called the stochastic acquisition mode. In this mode, the Mode S ground station interrogates using a special all-call interrogation command that instructs aircraft to reply with a specified less-than-unity reply probability. The resulting reduced reply rate means that some all-call replies will be received ungarbled and these aircraft will thus be acquired. Once an aircraft is acquired, it is locked out and hence no longer interferes with the all-call replies from the remaining unacquired aircraft. The process is repeated until all aircraft are acquired.

6.1.27 This form of acquisition uses the Mode S-only all-call interrogation, UF = 11. The specified reply probability is contained in the probability of reply (PR) field and can be selected from the values 1, 1/2, 1/4, 1/8 or 1/16. The transponder will not reply if a lockout condition is in effect. Otherwise, the transponder executes a random process and replies only if the outcome of the random process is consistent with the specified reply probability. For example, if the PR code specifies a reply probability of 1/4, the transponder will generate a random number between zero and one and will reply only if:

a) a lockout condition does not apply; and

b) the generated random number is less than or equal to 0.25.

Note.— The stochastic acquisition technique described in the following paragraphs is only an example. Other modes of stochastic acquisition may be employed.

6.1.28 Implementation can include the following two modes:

a) Initial acquisition mode. This mode is executed after a period of Mode S ground station inactivity. It consists of periodic Mode S-only all-call interrogations (4-6 or more per beam dwell) followed by a listening interval out to the range of interest. These are interspersed with scheduled Mode S intervals to permit discrete interrogation and lockout of Mode S addresses acquired on the previous scan. The minimum probability assignment used for this purpose is a site-dependent parameter chosen to match the Mode S traffic load handled by this site. The programme for reacquisition begins at this lowest probability level and then moves to higher probability levels after several scans in order to reduce the overall acquisition time. Aircraft not acquired initially, as well as all-call garbling situations which occur unexpectedly during normal operation, are handled as described in the following paragraph.

b) Adaptive acquisition mode. Mode S replies received with uncorrectable errors during the all-call listening
interval are grouped together if they correlate in range and azimuth. Groups formed of 3 or more replies per dwell are interpreted as evidence of an all-call synchronous garbling occurrence. A trial Mode S track is initiated at the approximate range and azimuth of the correlated replies. On the next scan, the ground station interrogates using a Mode S-only all-call with a specified reply probability of one half. With high probability, an ungarbled reply will be received from one of the two transponders in the garbling situation during the four or more interrogation opportunities possible during a beam dwell, thereby permitting discrete interrogation and lockout on the following scan. If acquisition is not successful, the trial track will be dropped since the continued garbling situation will lead to the initiation of a fresh trial track. Residual garbling caused by more than two aircraft in the initial garble set will also result in a new trial track. The last aircraft in the garbling set will be acquired by the normal all-call process in use at the site.

**LOCKOUT OVERRIDE**

6.1.29 Lockout override may be used in situations where it is believed that the lockout activities of an adjacent ground station are preventing Mode S acquisition by the local ground station, e.g. the adjacent ground station is inadvertently using the same II code as the local ground station. Use of this mode must be strictly limited since it elicits Mode S all-call replies from acquired as well as unacquired aircraft and therefore can cause a substantial level of Mode S all-call fruit.

6.1.30 An acquisition technique can be defined that combines features of the site-addressed and stochastic acquisition approaches. It uses the Mode S-only all-call, UF = 11, and employs PR codes that define reply probabilities of 1, 1/2, 1/4, 1/8 and 1/16. In this case, the transponder is instructed to disregard the lockout state in making a reply decision. This will of course result in the continued possibility of garbled all-call replies since both acquired and unacquired Mode S aircraft can reply to the all-call interrogations. The stochastic mode is used to handle the resulting garbling.

**COORDINATION BETWEEN ADJACENT GROUND STATIONS**

6.1.31 Techniques for coordinating the activities of clustered interrogators using the same II code are described in 7.4.

### 6.2 MODE S ACQUISITION USING LOCKOUT OVERRIDE

**OPERATIONAL CONCEPT**

6.2.1 Certain interrogators (e.g. mobile military interrogators) may need the identity and other information available via Mode S and may not be in a position to have an assigned II code in order to perform normal Mode S surveillance. A technique for performing Mode S acquisition using lockout override that does not require an assigned II code is described in this section.

6.2.2 An operational concept for Mode S acquisition using lockout override is defined as follows:

a) Routine aircraft surveillance is performed by these interrogators using Mode A/C, primary radar surveillance, or other means. For Mode A/C, monopulse processing must be used to provide current surveillance performance with a lower interrogation rate. The channel time now available is used for Mode S acquisition.

b) On each scan, this type of interrogator schedules a number of Mode S-only all-call interrogations, followed by a listening interval appropriate for the operating range. These interrogations contain a lockout override code that commands Mode S transponders to respond to the interrogation regardless of their lockout state. The resulting synchronous garble is managed through the use of PR = 10 to 12 in the Mode S-only all-call interrogation. These codes command lockout override, together with a reduced probability of reply.

c) Every ungarbled Mode S all-call reply is processed and correlated in range and azimuth to the corresponding Mode A/C or primary radar track. The all-call reply contains the 24-bit aircraft address. This address is used in Mode S discretely addressed interrogations to obtain any supplemental information available from that aircraft. These discretely addressed interrogations do not contain any lockout commands and contain an interrogator code equal to zero. The discrete surveillance replies contain Mode C and Mode A codes which can also be used as further correlation criteria with a Mode A/C track. The interrogator has not modified in any way the lockout state of the aircraft as established by neighbouring Mode S interrogators using the multi-site lockout protocols.
d) The 24-bit aircraft address is stored in the track file and is used for a subsequent update of this supplemental information.

e) The Mode S acquisition status of every aircraft in track is maintained in the track file, with one of the three following characteristics:

1) aircraft address acquired;

2) confirmation that the aircraft is not Mode S equipped, since a prescribed number of interrogations has not resulted in an error-free reply reception or a Mode S preamble detection; or

3) Mode S acquisition in process.

f) In order to minimize all-call fruit, all-call interrogations are only transmitted in beam dwells containing aircraft that are currently in the acquisition process.

CONTROL OF SYNCHRONOUS GARBLE

6.2.3 The above operational concept for Mode S acquisition is based on the use of the lockout override feature. As the name implies, a Mode S-only all-call interrogation carries a code (PR = 8 to 12) that instructs the transponder to reply to this all-call independent of its lockout state. Lockout override would be of limited use by itself since such transmissions would likely result in synchronously garbled Mode S all-call replies from aircraft close in slant range and within the same beam dwell as the aircraft of interest. (The synchronous garble range for a Mode S all-call reply is 9.6 km (5.2 NM).)

6.2.4 Mode S defines a second feature known as “stochastic acquisition” that should be used with lockout override. Stochastic acquisition overcomes synchronous all-call garble by commanding the transponder (via a code in the all-call interrogation, PR = 10 to 12) to respond with a probability less than unity. Available probabilities are 1/4, 1/8 and 1/16. A reply probability of less than one reduces the total number of replies from a set of aircraft in garble range. This increases the likelihood of receiving a single ungarbled reply from an unacquired aircraft. Stochastic acquisition makes it possible to acquire a Mode S aircraft, even in relatively dense environments.

6.2.5 The performance of stochastic acquisition as a function of the number of aircraft in a garble zone and the probability used is presented in Table 6-1. A summary of the performance to be expected with this technique is presented in Table 6-2. The rows of the table indicate the number of aircraft in the garble zone defined by the beamwidth and the 9.6 km (5.2 NM) garble zone for the Mode S all-call reply. Anything over ten aircraft would be an extremely dense case. The columns indicate the maximum and average number of interrogations needed for 99 percent probability of acquisition.

MAXIMUM ALL-CALL INTERROGATION RATE

SARPs limit for a standard Mode S interrogator

6.2.6 The maximum all-call interrogation rate specified in the Mode S system SARPs (Annex 10, Volume IV, Chapter 3, 3.1.2.11.1.1) is 250 per second. This interrogation rate defines the limit of 1 030 and 1 090 MHz interference caused by the all-call interrogation activity of a single Mode S interrogator.

1 030 MHz considerations

6.2.7 The stochastic/lockout override technique uses a standard Mode S-only all-call and, therefore, has the same effect on the 1 030 MHz channel as the all-call generated by a standard Mode S interrogator. From a 1 030 MHz perspective, an interrogator using stochastic/lockout override could operate at the same all-call interrogation rate as a standard Mode S interrogator.

1 090 MHz considerations

6.2.8 A standard Mode S interrogator using lockout can be expected to elicit less than one all-call reply per interrogation. This would yield a maximum of about 250 Mode S all-call replies per second per standard Mode S interrogator.

6.2.9 An interrogator using lockout override will have a higher reply rate to its all-call interrogations, since lockout is not used. Assume an interrogator with a 10 second scan, a 3.6 degree beamwidth and 700 aircraft in track. The average beam loading will be seven aircraft for each of the 100 beam positions per scan. If a stochastic probability of 0.25 is used, there will be an average of around two replies to each all-call interrogation.

6.2.10 On this basis, the total all-call interrogation rate for this example interrogator using lockout override should be limited to about 125 Mode S-only all-call
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interrogations per second to avoid generating any more Mode S fruit than a standard Mode S interrogator.

6.2.11 Different target loadings, beamwidths and scan rates will lead to different operating points. However, the operating principle is to limit total Mode S all-call fruit to no more than the low level generated by a standard Mode S interrogator.

EXAMPLE OF INTERROGATOR USE OF LOCKOUT OVERRIDE

Interrogator characteristics

6.2.12 Following the above assumptions, the interrogator has a beamwidth of 3.6 degrees, a range of 370 km (200 NM) and a scan time of 10 seconds. Using 10 lockout override all-call interrogations per beam dwell leads to an interrogation rate of 100 per second. This is within the interrogation rate allowed by the SARPs, even after adjustment for the higher number of replies produced per interrogation.

Expected performance

6.2.13 Table 6-2 indicates the maximum and average number of interrogations needed to achieve a 99 per cent probability of acquisition. Since 10 interrogations are used per beam dwell, the maximum and average number of scans for acquisition can be determined by dividing the last two columns of Table 6-2 by 10 and rounding up to the next whole scan. The result is shown in Table 6-3.

Simulation results

6.2.14 The acquisition performance for an interrogator with the characteristics of 6.2.13 was estimated via simulation. For the simulation, a traffic density of 10, 25 and 50 aircraft per beamwidth was generated randomly in range and azimuth out to 370 km (200 NM) at an extent of 3 beamwidths. Performance was measured for the aircraft in the centre beamwidth as the interrogator beam scanned through the traffic. The results are presented in Figure 6-2.

6.2.15 An indication of the performance in terms of the number of aircraft acquired is shown in Figure 6-3. Figure 6-3 indicates that for the 10 and 50 aircraft cases, all but one of the aircraft were quickly acquired, but the last aircraft was not acquired even after 20 scans.

Need for an adaptive technique

6.2.16 The simulation results show that while rapid acquisition is provided by lockout override for most aircraft, it may take a long time to acquire all aircraft in a high density environment. Acquisition performance is greatly improved for the acquisition of these aircraft through the use of selective lockout.

Use of II = 0

6.2.17 The development of the Mode S subnetwork algorithms has greatly limited the utility of II code zero. The subnetwork communication protocols require the use of a non-zero II code in order to support downlink routing. Thus II = 0 will not be used when Mode S data link is used with the subnetwork services, even in areas of no overlapping sensor coverage.

6.2.18 Given that II = 0 will not be used in the most dense areas, it would seem that II = 0 could be eliminated for normal acquisition use without restricting Mode S operations.

Adaptive acquisition

6.2.19 For acquiring the last of the aircraft in a garble zone, an adaptive technique using II = 0 operates as follows:

a) all of the acquired aircraft in the beam dwell of the garble zone containing the unacquired aircraft are discretely interrogated and locked out to II = 0;

b) during the following scan, all-call interrogations are transmitted using II = 0, without lockout override; and

c) transponders will unlock to II = 0, 18 seconds after the last lockout command.

6.2.20 The reduced garble density will lead to rapid acquisition of the unacquired aircraft, or a determination that it is not Mode S equipped. Since lockout is used only temporarily and selectively, only a minimum of coordination is required with neighbouring interrogators using lockout override to avoid conflict in the use of lockout to II = 0.
6.3 SURVEILLANCE PROTOCOL

6.3.1 The ground station’s surveillance protocol should routinely elicit Mode C altitude in the Mode S surveillance reply. An additional interrogation to elicit the aircraft Mode A code should be sent a) when the Mode S aircraft is acquired, b) after a prolonged coast period and c) in the case of temporary or permanent alert. An alert condition is reported in the flight status (FS) field of every surveillance and Comm-B reply to indicate a change in Mode A code. If the new code is an emergency code (7500, 7600 or 7700) the alert condition remains active (i.e. it does not time-out). If the new code is not an emergency code, the alert condition resets after 18 (plus or minus 1) seconds.

6.3.2 Knowledge of the current value of the transponder Mode A code is important to the ATC system since a) the code is used to signal emergency conditions and b) it is needed to identify an aircraft in handoffs to non-Mode S facilities. Provision is therefore made in the FS field to notify the ground station any time that the Mode A code is changed.

6.4 UPLINK SLM TRANSFER PROTOCOL (COMM-A)

Note.— Comm-A interrogations are used for the ground-to-air transmission of SLMs. Before any such transfer is initiated, the interrogator has knowledge (from a previous capability report usually obtained when the aircraft is first acquired) of the Comm-A capability of the addressed aircraft.

COMM-A PROTOCOL PRECAUTIONS

6.4.1 If the transponder cannot pass the uplink SLM to the data link processing unit, the transponder will not reply to that Comm-A interrogation, since it cannot output the uplink message. However, a transponder in this state will continue to respond to short surveillance interrogations. In the event of loss of contact with an aircraft when using only Comm-A interrogations, a ground station should transmit one or more short interrogations to determine if interface failure is preventing the transponder from replying. A change of data link capability is announced by the broadcast Comm-A message (see 6.5.22).

6.4.2 If a separate transponder interface is used for ACAS and for the ADLP, the transponder must route selectively addressed Comm-A messages to the appropriate interface based on information in the Comm-A interrogation. Comm-A messages intended for ACAS are identified by DI = 1 or 7, TMS = 0 and the first eight bits of the MA field equal to 05 {HEX}. Messages identified for ACAS (including air-air MU messages) should be delivered to the ACAS interface but not to the ADLP interface. Messages that are not identified for ACAS should be delivered to the ADLP interface but not to the ACAS interface.

COMM-A BROADCAST MESSAGES

6.4.3 Comm-A broadcast messages are intended for the transfer of a message to all aircraft within an azimuth sector. Depending upon operational needs, this sector can be as small as one beamwidth, or as large as a complete antenna rotation. Due to the absence of a transponder reply, the interrogator will not have positive confirmation that this message was received by a particular aircraft. For this reason, broadcast messages should be restricted to information that is re-transmitted periodically in order to ensure a high probability of successful delivery. Comm-A broadcast messages should be transmitted at a rate that allows at least three transmissions within each azimuth sector corresponding to the antenna 3 dB beamwidth. This minimum transmission rate ensures a reasonable probability of delivering the broadcast Comm-A message in one antenna scan.

6.5 DOWNLINK SLM TRANSFER PROTOCOL (COMM-B)

GROUND-INITIATED TRANSFER OF COMM-B MESSAGES

6.5.1 The ground-initiated Comm-B (GICB) protocol allows for the immediate transfer of data required by the ground and the extraction of information stored in the transponder. This information (if available) is contained in the reply to an interrogation specifying the address (Comm-B data selector (BDS) code) of the storage location containing that information. Examples of information obtainable using the ground-initiated Comm-B protocol are data link capability report (6.10.2) and aircraft identification (6.11). An example of a ground-initiated Comm-B message delivery is presented in Table 6-4.

6.5.2 Airborne applications providing downlink data via the GICB protocol will update specific registers at a rate that is consistent with maintaining current information in those registers. A minimum rate of approximately 5 seconds is used to provide for recovery of the GICB register data in the event of a failure that causes the
transponder to lose GICB data. If an interface used to load the GICB registers fails, the data in the registers will become invalid with no indication given to users of these messages. Transponder action in this case should be to clear those GICB registers being updated by this interface, with the exception of the data link capability register (10 {HEX}). This register has a special protocol for failure detection. Upon recovery of this interface, the airborne applications will resume loading data into these registers. Recovery will be completed in approximately 5 seconds.

6.5.3 If the transponder interface used to load the AIS subfield in GICB register 20 {HEX} fails, the transponder should clear the AIS subfield and the AIS bit in the data link capability report. This will cause the transponder to broadcast a change in aircraft identification and a change in data link capability. This action can be independent from the general clearing of the GICB registers if a separate interface is used to load the GICB register 20 {HEX}.

6.5.4 ACAS will normally be provided with a separate transponder interface. The same protocol for clearing GICB registers in the event of an interface failure should be applied separately to the ACAS interface.

6.5.5 Note that the transponder action, in the event of an interface failure, is a function of the type of data transferred by that interface. For example, if GICB and SLM data use separate interfaces, the transponder will be able to provide GICB data even in the event of an SLM interface failure. Since the SLM interface is used by the ADLP to load the data link capability report, failure of the SLM interface will cause this report to indicate zero data link capability even though the transponder is still capable of supporting the transfer of GICB data.

6.5.6 The readout of a GICB can occur at any time, since it is governed by the transmission time of the interrogator(s). These interrogations involve an access to the GICB registers. A second asynchronous activity involving register access is the process of updating the information in the GICB registers. It is important that safeguards be provided to ensure that a register update cannot occur during an access due to a received interrogation. This will avoid the error of providing data from a partially updated register in the reply to a GICB request.

AIR-INITIATED TRANSFER OF COMM-B MESSAGES

6.5.7 An air-initiated Comm-B message waiting for delivery causes the DR code of every surveillance or Comm B reply to be set to a value that indicates that an air-initiated Comm-B message is waiting. To extract the Comm-B message, the ground station will transmit a request for a Comm-B message reply in a subsequent interrogation (RR = 16 and if DI = 7, RRS = 0). Reception of this request code will cause the transponder to transmit the Comm-B message. The Comm-B reply will also continue to contain a downlink request (DR) code equal to ONE. The message will be cancelled and the DR code belonging to this message removed after a Comm-B closeout has been received.

6.5.8 This protocol can result in the reception of more than one Comm-B closeout instruction for a particular message if the interrogation containing the closeout is received by the transponder but the ground station did not receive the reply. The absence of the expected reply will cause the ground station to repeat the interrogation at the next opportunity.

6.5.9 If the transponder has a second air-initiated Comm-B message waiting to be transferred, it indicates its presence to the ground station by sending the appropriate DR code in its reply to the interrogation that delivered the Comm-B closeout acknowledgement to the previous message. Every effort should be made to deliver this closeout within the same beam dwell period as the message delivery in order to permit the announcement of subsequent messages waiting to be delivered. Note that the avionics must not permit a message to be closed out until after it has been read at least once. This prevents the multiple clears that can be received due to a downlink failure from closing out a second waiting message that has not as yet been transferred to the ground station. The possibility of downlink failure also prohibits the ground station from both reading and closing out a Comm-B message in the same interrogation because multiple delivery of such an interrogation could result in the loss of an undelivered Comm-B message.

6.5.10 Multisite transfer of air-initiated Comm-B messages. In a multisite environment, an air-initiated Comm-B message may be read by more than one ground station. In this protocol, any ground station is allowed to read the air-initiated message, but only the ground station that made a prior reservation may close out the message and so remove the indication that a message is waiting.

6.5.11 If it is possible for more than one ground station to service an air-initiated Comm-B message request, the multisite protocol or ground co-ordination must be used to avoid possible loss of messages. Such a loss can occur when (1) a transponder has more than one air-initiated message ready for delivery and (2) the interleaved read and cancel instructions from the multiple sites results in the
following sequence: ground station A has cleared message 1 and has had a downlink failure in reading message 2. This is followed by a cancel from ground station B (intending to cancel message 1) that in fact cancels message 2, which is lost since it has not been successfully read by either ground station.

6.5.12 When the ground station extracts an air-initiated message, normally after having made a reservation, it must check the utility message (UM) field to determine if it is the reserved site for this message. When this is the case, the message will be processed and closed out by this ground station in a subsequent interrogation, before the reservation expires. When another ground station is already reserved for the message, the announcement for this message may be ignored.

6.5.13 In a multisite environment, more than one ground station can attempt to extract an air-initiated Comm-B message. Normally, the first one to attempt to extract the message will be the one that is reserved for processing and closeout of the message.

6.5.14 Multisite closeout of an air-initiated Comm-B message can be accomplished two ways:

a) through coding in the multisite Comm-B subfield (MBS) of the SD field; or

b) through coding in the PC field.

6.5.15 In either case, closeout will be accomplished by the transponder only if the II code of the interrogator that delivers the closeout command matches the II code reserved for that message.

6.5.16 An example of a multisite air-initiated Comm-B message delivery is presented in Table 6-5.

6.5.17 Multisite directed Comm-B delivery. This multisite Comm-B protocol makes it possible for the ADLP to route an air-initiated message to a particular ground station. This capability is important in a multisite environment since it makes it possible for a pilot acknowledgement message to be routed to the ground station that delivered the message being acknowledged.

6.5.18 When a Comm-A message is delivered, the ADLP will receive the SD field along with the message, Comm-A (MA) field, and will thus be able to associate the sending site address in the interrogator identifier subfield (IIS) with the Comm-A message. When a pilot acknowledgement is generated, the ADLP will cause the transponder to reserve the message for the desired site address at the same time that the message is made available for delivery. Thus, even the initial reply indicating that an air-initiated Comm-B message is waiting will show (in the UM field) that a reservation already exists for the desired site. This reservation remains in effect until the message is read and closed out by the reserved ground station, or until the message is cancelled by the ADLP.

6.5.19 Non-selective transfer of air-initiated Comm-B messages. The non-selective protocol is used if: (1) the ground station does not have overlapping coverage with any other Mode S ground station, or (2) it communicates with its neighbouring ground stations to ensure that only one ground station at a time is responsible for Comm-B message transfer. A reservation is not required in the non-selective protocol. Closeout is accomplished through coding of the PC field. An example of a non-selective air-initiated Comm-B message delivery is presented in Table 6-6.

6.5.20 Air-initiated Comm-B error recovery. If a multisite-directed Comm-B message is input to the transponder by the ADLP, this message can only be cleared by (1) the interrogator after a successful delivery or (2) ADLP action after a timeout if the message is not delivered, since multisite-directed message reservations do not time out in the transponder. If the transponder SLM interface fails while a multisite-directed Comm-B message is awaiting delivery, no other Comm-B activity can occur until the multisite-directed message is delivered. An undeliverable multisite-directed message will block any further Comm-B activity by the transponder. This includes the Comm-B broadcast of the change of data link capability report that the transponder will initiate to inform the ground of loss of communication capability because of the SLM interface failure.

6.5.21 In the event of SLM interface failure, the transponder should clear any waiting air-initiated messages and notify the ADLP of this action when the interface operation is restored. Whenever ADLP operation is initiated at power-up or resumed after recovery from a failure, the ADLP should clear the transponder air-initiated Comm-B registers.

6.5.22 The air-initiated Comm-B protocol described above is designed to deliver a Comm-B message initiated on board an aircraft to a single ground station. Certain types of messages may require delivery to more than one ground station. In this case the broadcast Comm-B message protocol is used.
6.5.23 The broadcasting of Comm-B messages should be strictly controlled and limited to those messages that are required to be received by all ground stations that have the aircraft in coverage. For example, a change in the data link capability would be delivered by a broadcast Comm-B message. The broadcast Comm-B message should never be used for messages that are intended to elicit a subsequent response from a ground station. This would result in multiple delivery of the requested response, one from each ground station that reads the broadcast message.

6.5.24 The broadcast Comm-B protocol uses the DR field to signal the presence of a broadcast Comm-B message that is available for delivery. Any ground station in contact with the transponder may read the message using the same coding as for an air-initiated Comm-B message. The key difference is that the ground station cannot clear a broadcast message; the message clears automatically after approximately 18 seconds. During the period when the message is active, it can be read by every ground station in contact with the transponder.

6.5.25 Provision is made in the coding of the DR field to distinguish two different broadcast messages, i.e., broadcast message 1 and broadcast message 2. The transponder will send successive broadcast messages using alternate message codes. This permits the ground station to detect the change in a broadcast message and therefore eliminates the need for the ground station to read the message every scan. Thus, a ground station that has read broadcast message 1 from a particular transponder on one scan can safely avoid reading the same message on subsequent scans (until it times out) since the presence of a new broadcast message will be indicated by DR = 5, i.e., “broadcast message 2 is available”.

6.5.26 Provision is made for an air-initiated Comm-B message to interrupt the delivery of a broadcast Comm-B message. In this case, the broadcast message delivery is resumed for the full 18-second period following the delivery of the air-initiated message. In the case of a queue of air-initiated Comm-B messages, the delivery of a broadcast may take considerably longer than 18 seconds.

6.5.27 The transponder is required by the broadcast protocol to provide a delivery notice to the data link interface upon timeout of a broadcast message. This is used by the ADLP to update its message processing bookkeeping. The transponder can initiate two broadcast messages, (1) a change in transponder capability and (2) a change in aircraft identification. The ADLP is not aware of the presence of these messages. Therefore, it is unnecessary for the transponder to generate delivery notices for these transponder-initiated broadcast messages.

6.6 UPLINK EXTENDED-LENGTH MESSAGE (ELM) PROTOCOL

Note.— The uplink extended-length message (ELM) protocol provides for more efficient transmission of long data link messages by permitting the grouping of up to sixteen 80-bit message segments into a single entity that can be acknowledged by a single reply. Each segment is included in a single Comm-C transmission. The limit of 16 segments refers solely to the manner in which the message is transferred over the link. Longer messages can be accommodated through the use of M-bit sequencing of packets within the Mode S subnetwork.

**Basic Uplink Extended-Length Message Transfer**

6.6.1 Uplink extended-length messages are transmitted using the Comm-C format with three different reply control codes. The three reply control codes designate an initializing segment, intermediate segments and a final segment. (Note that the minimum length of a ground-to-air ELM is two segments since the protocol requires at least an initializing and a final segment.) The transfer of all segments may take place without any intervening air-to-ground replies, as described in the following paragraphs. In this way, channel loading is minimized. Message segments (one per Comm-C interrogation) may be transmitted at any rate up to one per 50 microseconds. This limit on the minimum spacing is required to permit the re-suppression of Mode A/C transponders. Delivery of the message may take place during a single scan or over a few scans depending on the length of the message and the ground station loading. Normally, sufficient time will be available within one scan to permit complete delivery of the message.

**Multisite Uplink ELM Protocol**

6.6.2 The multisite uplink ELM protocol is used to coordinate the activities of multiple ground stations so that only one ground station at a time is reserved for uplink ELM activity. Before beginning an uplink ELM, a ground station uses the multisite protocol to obtain a reservation. It is recommended that a ground station precedes the first downlink ELM delivery from a newly acquired aircraft with a downlink ELM closeout to ensure that the transponder downlink ELM registers are cleared.

6.6.3 A reservation remains in effect for 18 (plus or minus one) seconds from the time of last delivery activity, i.e. the reservation itself or any segment delivery or
acknowledgement request. If delivery activity ceases for more than 18 (plus or minus 1) seconds before delivery is complete, it is assumed that the ground station is no longer in contact and the reservation is cancelled along with any segments that have been delivered up to that point. The transponder is then able to grant a reservation to any other ground station that is currently in contact.

6.6.4 Multisite uplink ELM closeout can be accomplished in either of two ways:

a) through coding in the multisite ELM subfield (MES) of the SD field; or

b) through coding in the PC field and SD fields.

Every effort should be made to deliver the closeout within the same beam dwell period as the completion of message delivery in order to make transponders available to other interrogators for uplink ELM delivery. It is not advisable to attempt the delivery of two uplink ELMs in the same beam dwell. This increases the probability of the second message not being completed.

6.6.5 An example of a multisite uplink ELM delivery is presented in Table 6-7.

6.6.6 The non-selective protocol may be used when only one ground station at a time has the responsibility for delivering an uplink ELM message. No reservation is required. A partially delivered non-selective uplink ELM is not automatically cleared by a timeout. It is recommended that a ground station precedes the first uplink ELM delivery to a newly acquired aircraft with an uplink ELM closeout to ensure that the transponder uplink ELM registers are cleared.

6.6.7 Ground stations with overlapping coverage that do not properly coordinate their communications activity through the use of the multisite protocols or ground coordination may experience the following communications failure modes:

a) a multisite uplink ELM transaction in progress by one interrogator can be interfered with through the action of another interrogator delivering an uplink ELM using the non-selective protocol. The transponder will accept uplink ELM segments as if they were being delivered by a single interrogator using the uplink delivery protocol. In this case, the completed message will be composed of segments from both ground stations; and

b) if an interrogator is delivering segments of an uplink ELM using the non-selective protocol, these segments will be discarded upon the receipt of an initializing segment from a second ground station.

6.7 DOWNLINK EXTENDED-LENGTH MESSAGE (ELM) PROTOCOL

The transfer of an air-to-ground ELM is similar to the ground-to-air process. Differences between the two protocols result primarily from the fact that (1) all channel activity is ground-initiated and (2) the transponder can reply with longer communications formats only when given specific permission by the ground station.

6.7.1 Downlink extended-length messages are transmitted (under ground control) using the Comm-D reply.

6.7.2 When the multisite downlink ELM protocol is used, a ground station obtains a reservation before beginning the readout of a downlink ELM message.

6.7.3 A reservation will time out if 18 (plus or minus one) seconds pass with no delivery activity. The transponder is then able to grant a reservation to another site for transfer of the downlink ELM. Multisite downlink ELM closeout should be accomplished in either of the two ways:

a) through coding in the multisite ELM subfield (MES) of the SD field; or

b) through coding in the PC field and SD fields.

Every effort should be made to deliver the closeout within the same beam dwell period as the message delivery in order to permit the announcement of subsequent messages waiting to be delivered.

6.7.4 An example of a multisite downlink ELM delivery is presented in Table 6-8.
6.7.5 The technique used for air-directed downlink ELM delivery is equivalent to the air-directed Comm-B protocol described earlier.

6.7.6 The non-selective protocol may be used when only one ground station at a time has the responsibility for delivering a downlink ELM message. No reservation is needed. Closeout is accomplished through coding in the PC field.

6.7.7 Over interrogation. If the transponder has a queue of downlink ELMs and the interrogator attempts to extract downlink ELM segments at a higher rate than the transponder can support, the transponder should stop replying as necessary to protect its transmitter. The transponder should not withdraw the announcement of the current downlink ELM while it is recovering, since the recovery time will normally be short compared to an interrogator scan time. Withdrawal of the announcement could lead to unnecessary transactions by the interrogator since any delivered segments of the current downlink ELM would be discarded if the interrogator detected a withdrawal of the announcement.

6.7.8 Response if no message waiting. If the interrogator commands the delivery of a downlink ELM when the transponder has no message waiting for delivery, the transponder should respond with the commanded segments with an MD field of all ZEROs. Failure to respond would result in a repeated request from the interrogator. The receipt of segments containing all ZEROs will indicate to the interrogator that there is no message waiting. This parallels the action taken for the same situation in the Comm-B protocol.

6.7.9 Command for out-of-range segments. When the transponder announces the presence of a waiting downlink ELM in the DR field, it indicates the number of segments of the waiting message. If the ground commands the delivery of segment numbers beyond the maximum announced (but within the transponder reply capability), the transponder should deliver the commanded segments. The segments beyond the announced length should contain all ZEROs in the MD field. This reaction to the error condition avoids repeated requests from the interrogator.

6.7.10 An equivalent error recovery condition, as identified for the multisite-directed Comm-B protocol (6.5.10), applies to the multisite-directed downlink ELM protocol as well. For this reason, the transponder should clear any waiting downlink ELMs in the event of an ELM interface failure and notify the ADLP of this action when the interface operation is restored. Whenever ADLP operation is initiated at power-up or resumed after recovery from a failure, the ADLP should clear the transponder downlink ELM registers.

6.8 ENHANCED COMMUNICATIONS PROTOCOLS

6.8.1 The non-selective communication protocol required that only one interrogator be allowed to provide Comm-B or ELM service to a given transponder. Management of the coverage of the ground interrogators was required to enforce this constraint. One technique for managing the assignment of interrogators is to use a geographical coverage map that defines the coverage area of each interrogator.

6.8.2 The multisite protocol made it possible for the interrogators to make reservations (via the transponder) for Comm-B and ELM transactions. While the transponder participated in this protocol, its role was limited to reporting reservation status. It reported the same status to every interrogator. The interrogators interpreted this status and determined whether or not to proceed with a Comm-B or ELM transaction.

6.8.3 The enhanced protocol adds the transponder capability to treat interrogators individually and to report downlink message waiting and technical acknowledgment as appropriate for each interrogator. This makes it possible for this protocol to perform Comm-B and ELM activity with more than one interrogator at a time and eliminates the need for multisite reservations. The protocol is backward compatible in that it can operate with multiple interrogators, even if they are still using the multisite protocol. It does this by granting simultaneous reservations. Details of the enhanced protocols are contained in the following paragraphs.
ENHANCED COMM-B PROTOCOL

6.8.4 The enhanced Comm-B protocol provides improved capacity through the ability to operate on a concurrent basis with multiple interrogators. This is accomplished by providing sixteen sets of air-initiated Comm-B registers, one for each II code including GICB registers 2 through 4 for the linked Comm-B protocol. Operation in overlapping coverage without the use of multisite reservations is provided by requiring a match of the II code associated with the message transfer with the II code of the message closeout. This prevents a closeout from one interrogator from clearing a message in process to a second interrogator.

6.8.5 This protocol is backward compatible with multisite and non-selective protocols since it can operate correctly with interrogators using the current protocols. This protocol provides increased activity even when operating with multiple interrogators using the current protocol since it can provide for parallel delivery by granting multiple simultaneous reservations.

ENHANCED MULTISITE-DIRECTED COMM-B PROTOCOL

Message initiation

6.8.6 When a multisite-directed message is input to the transponder, it is placed in the Comm-B registers assigned to the II code specified for the message. If the registers for this II code are already occupied (i.e. a multisite-directed message is currently in process to this II code) the new message is queued until the current transaction with that II code is closed out.

Message announcement

6.8.7 In the multisite protocol, the announcement of a waiting Comm-B message for a given II code is made by setting DR code = 1 or 3 and by inserting the destination II code in the IIS subfield of the UM field in the reply to a surveillance interrogation. With the multisite protocol, the same announcement is made to all interrogators since only one message can be in process at a time. The Comm-B message is then read and cleared only by the interrogator using the corresponding II code.

6.8.8 With the enhanced protocol, the same control fields are used. However, the DR and IIS field contents are set specifically for the interrogator that is to receive the reply. For example, if an air-directed message is waiting for an interrogator with II = 2, the surveillance replies to that interrogator contain DR = 1 and IIS = 2. If this is the only message in process, replies to all other interrogators will indicate that no message is waiting.

6.8.9 In addition to permitting parallel operation, this form of announcement enables a greater degree of announcement of downlink ELMs. The announcements for the DELM and the Comm-B share the DR field. Only one announcement can take place at a time due to coding limitations. In case both a Comm-B and a DELM are waiting, announcement preference is given to the Comm-B. In the example above, if a multisite-directed Comm-B was waiting for interrogator II = 2 and a multisite-directed DELM was waiting for interrogator II = 6, both interrogators would see their respective announcements on the first scan, since there would be no Comm-B announcement to interrogator II = 6 to block the announcement of the waiting DELM.

Message closeout

6.8.10 Closeout for the enhanced protocol operates in a similar manner to the other protocols.

Announcement of the next message waiting

6.8.11 The DR field will indicate a message waiting in the reply to an interrogation containing a Comm-B closeout if another multisite-directed message is waiting for that II code, or if an air-initiated message is waiting and has not been assigned to an II code.

ENHANCED MULTISITE AIR-INITIATED PROTOCOL

Message initiation

6.8.12 An air-initiated Comm-B message input into the transponder is stored in the registers assigned to II = 0.

Message announcement and extraction

6.8.13 An air-initiated message will be announced in the DR field of the replies to all interrogators for which a multisite-directed message is not waiting. The UM field of the announcement reply will indicate that the message is not reserved for any II code, i.e. the IIS subfield = 0. When a command to read this message is received from an interrogator with a given II code, the reply containing the message will contain a UM field content indicating that the
message is reserved for that II code. After readout and until closeout, the message is associated with that II code. That is, the message is handled like a multi-directed message for the delivery process. Announcement of this message is therefore no longer made in the replies to other interrogators. If the message is not closed out by the assigned interrogator in 18 seconds, the message reverts back to air-initiated status (i.e. IIS = 0) and the process repeats. To simplify the protocol, only one air-initiated Comm-B message can be in process at a time.

**Message closeout**

6.8.14 The air-initiated message can only be closed out by the interrogator that was assigned most recently to transfer the message. Every effort should be made to deliver this closeout within the same beam dwell period as the message delivery in order to permit the announcement of subsequent messages waiting to be delivered.

**Announcement of the next message waiting**

6.8.15 The DR field will indicate a message waiting in the reply to an interrogation containing a Comm-B closeout if another air-initiated message is waiting and has not been assigned to an II code, or if a multisite-directed message is waiting for that II code.

**Enhanced broadcast Comm-B protocol**

6.8.16 A broadcast Comm-B message is assigned to all 16 II codes. The message remains active for 18 seconds for each II code. The provision for interruption of a broadcast by a non-broadcast Comm-B applies separately to each II code. Thus, it is possible that the broadcast message timeout will occur at different times for different II codes. A new broadcast message cannot be initiated until the current broadcast is timed out for all II codes.

**Storage requirements**

6.8.17 To support the enhanced protocol, the transponder must provide an enhanced Comm-B buffer with the capacity to store a four-segment linked Comm-B message for 16 different ground stations at the same time.

**Note 1.**— Except for the multiple registers required for the 2nd to 4th segments of linked Comm-B messages, the GICB protocol is not affected by the enhanced Comm-B protocol.

**Note 2.**— ACAS messages are announced to all interrogators (by setting DR = 2 or 3) and read out separately from the Comm-B message and are therefore not affected by the enhanced protocol.

**ENHANCED UPLINK ELM PROTOCOL**

**Overview**

6.8.18 The enhanced uplink ELM protocol provides a higher data link capacity by permitting parallel delivery of uplink ELM messages by up to 16 interrogators, one for each II code. Operation without the need for multisite uplink ELM reservations is possible in regions of overlapping coverage for interrogators equipped for the enhanced uplink ELM protocol. The enhanced protocol requires the addition of the IIS subfield in all uplink ELM segments and this requirement is incorporated into the general protocol. Thus the enhanced protocol is fully conformant to the standard multisite protocol and is also compatible with interrogators that are not equipped for the enhanced protocol.

6.8.19 This improved performance is achieved by the enhanced uplink ELM protocol by examining the IIS subfield contained in the first four bits of the MC field of each uplink ELM interrogation. Message segments are sorted on II code and then the standard ELM protocol operates on the resulting segments.

**Message delivery**

6.8.20 The message delivery for the enhanced uplink ELM protocol takes place according to the procedures specified for the standard ELM delivery as contained in Annex 10. This involves the transmission of an initial segment followed by up to fourteen intermediate segments, followed by a final segment. The transponder reassembles the message segments to form the complete message according to the segment number (contained in the NC field) and the II code (contained in the IIS subfield).

**Acknowledgement**

6.8.21 The technical acknowledgment from the transponder to the interrogator contains the received II code to allow the interrogator to verify that it is receiving the correct technical acknowledgment.
Closeout

6.8.22 After the delivery is complete, the interrogator performs closeout in the same manner as in the multisite and non-selective protocol in order to clear the TAS subfield.

Storage requirements

6.8.23 To support the enhanced protocol, the transponder must provide an enhanced uplink ELM buffer with the capacity to store 16 ELM segments from 16 different ground stations at the same time.

ENHANCED DOWNLINK ELM PROTOCOL

Overview

6.8.24 The enhanced downlink ELM protocol provides a higher data link capacity by permitting concurrent delivery of downlink ELM messages to up to 16 interrogators, one for each II code. Operation without the need for multisite downlink ELM reservations is possible in regions of overlapping coverage for interrogators equipped for the enhanced downlink ELM protocol. The enhanced protocol requires the addition of the IIS subfield to the Comm-C interrogation that requests the transfer of downlink ELM segments and this requirement is incorporated into the general protocol. Thus the enhanced protocol is fully conformant to the standard multisite protocol and is also compatible with interrogators that are not equipped for the enhanced protocol.

6.8.25 This improved performance is achieved with the enhanced downlink ELM protocol by providing storage for a 16 segment downlink ELM to each of 16 different interrogators at the same time. Announcement of multisite directed downlink ELM messages is made only in replies to the intended interrogator. The transponder examines the IIS subfield contained in the Comm-C interrogation that delivers the request for segment transfer in order to determine which message buffer to access. The delivery and closeout are performed using the standard downlink ELM protocol.

Announcement

6.8.26 A multisite-directed downlink ELM is announced only in replies to the intended interrogator. A non-directed downlink ELM is announced in the replies to all interrogators that do not have a multisite directed message waiting.

Note.—Other aspects of announcement and delivery of a non-directed downlink ELM are the same as for the air-initiated Comm-B protocol.

Delivery

6.8.27 The segment request subfield (SRS) contained in the MC field is used to request the transfer of downlink segments. The SRS subfield must be accompanied by the IIS subfield in order to identify the II code of the message to be transferred. The IIS must be included with the SRS even though the interrogator may not be equipped for the enhanced protocol. Since the IIS unambiguously identifies the interrogator transmitting the request to send segments, it is possible for the transponder to grant multiple simultaneous reservation to interrogators that are not equipped for the enhanced protocol.

Closeout

6.8.28 After the delivery is complete, the interrogator performs closeout in the same manner in order to clear the downlink ELM message buffers.

Storage requirements

6.8.29 As for the enhanced uplink protocol, the transponder must provide an enhanced downlink ELM buffer with the capacity to store 16 ELM segments from 16 different interrogators at the same time.

MESSAGE PROTOCOL INDEPENDENCE

The Mode S communication protocols are defined in such a way that the Comm-A, Comm-B, uplink ELM, and downlink ELM protocols are completely independent. This means that except for field coding limitations, delivery activity for the different message types can be freely interleaved without restriction. If the multisite protocol is used, it is possible for the Comm-B, uplink ELM, and downlink ELM reservations to be granted to three different sites.

CAPABILITY REPORTING

Note.—The ground system must know the aircraft’s capability in order to accept and provide data link information. This is accomplished through the reporting of capability.
Chapter 6. Mode S protocol considerations

6.10.1 The basic data link capability of the transponder is reported in the CA field, which indicates whether or not the transponder is capable of providing a data link capability report. The CA field also indicates on-the-ground or airborne status of the aircraft, as well as an indication of whether the transponder is announcing a flight status condition or a downlink message waiting. This announcement is intended for Mode S ground stations that perform acquisition via the transponder squitter (e.g. a surface surveillance system).

6.10.2 The data link capability report contains details that inform the ground system of the specific Comm-A, Comm-B, and ELM capability that currently exists on board the aircraft. The capability is updated on board the transponder every second to ensure that the reported capability reflects the current status of the data link avionics equipment.

6.10.3 The data link capability report will normally be read by a ground station immediately after the aircraft is acquired. In addition, any time that the transponder detects a change in communications capability, it causes a transfer of the data link capability report to the ground station as a broadcast Comm-B message. The ADLP will input a current capability report to the transponder every second. The transponder will perform a bit-by-bit comparison of the former and current data link capability reports at least once every four seconds and will generate a broadcast of the current capability if a difference is detected. This also covers the case where the ADLP interface fails, since the current capability will appear to be all zeros.

6.10.4 If the ADLP is incorporated into the transponder, the data link communications capability of the transponder can be provided to the ADLP function by means internal to the transponder. If the ADLP is not incorporated into the transponder, some automatic means must be provided to notify the ADLP of transponder data link capability. One example of an automatic means is the coding of pins in the connector of the cable between the transponder and the ADLP. An automatic means is required to cover the case where a transponder is replaced with one that has a different communications capability.

6.10.5 As a minimum, the capability provided to the ADLP should indicate the design data link communications capability of the transponder. Reporting of dynamic capability changes (e.g. the loss of ELM capability due to an ELM interface failure) is beneficial to the operation of the Mode S data link but it is not a requirement. The interrogator data link protocol is designed to cope with incorrect reporting of transponder capability.

6.11 AIRCRAFT IDENTIFICATION PROTOCOL

6.11.1 All aircraft employ aircraft identification as call signs, which are normally inserted in Item 7 of the ICAO flight plan. Some aircraft (usually general aviation) employ the aircraft registration. Other aircraft (principally those used for air carrier and military flights) employ variable aircraft identification which may be based on the commercial flight number or the military call sign. Although there is provision for eight characters, a maximum of seven should be used in line with the provisions specified for the content of Item 7 of the ICAO flight plan.

6.11.2 Mode S transponders (except level 1) can automatically report this aircraft identification data via the GICB protocol. General aviation aircraft can permanently report the registration as the aircraft identification. Other aircraft can employ a pilot input device to allow manual selection of a) the aircraft identification code for each flight, or b) the aircraft registration for those times when the aircraft is not operating under a commercial flight number or flight plan. The default value of the aircraft identification GICB register should be the aircraft registration number. This should be automatically inserted at transponder initialization and then replaced by a variable call-sign where appropriate.

6.11.3 If the aircraft identification is changed, for instance to correct for an error made in an earlier manual entry, the new aircraft identification is reported to ground stations using the broadcast Comm-B message protocol.

6.12 UTILITY MESSAGE PROTOCOL

6.12.1 The function of the UM field is to report reservation status. If the content of the UM field in a reply is not specified by the interrogation, the UM field contains the site number reserved for multisite Comm-B or Comm-D activity (if any). If both Comm-B and Comm-D
message protocols are in use, the reporting of the Comm-B reserved site takes precedence over the reporting of the Comm-D reserved site.

6.12.2 The specific activity (Comm-B or Comm-D) being reported is defined by the IDS subfield (of the UM field). This is followed by the IIS subfield which gives the site number of the reserved site.

6.12.3 The voluntary reporting of reserved Comm-B and Comm-D sites interrogators eliminates unnecessary attempts by other ground stations to transfer a message if a reservation has already been granted.

6.13 MULTISITE RESERVATION TECHNIQUES

Note.—The consequences of a failure to coordinate data link activity in a multisite environment have been described in the previous sections. This section describes techniques for making and verifying the existence of a multisite communications reservation.

INITIAL RESERVATION REQUEST

6.13.1 A multisite communications (Comm-B, uplink ELM, or downlink ELM) reservation is requested by coding in the SD field of a surveillance or Comm-A interrogation. In order to determine if the reservation was granted, the reservation status subfield (RSS) value must be set in the interrogation to request the site number of the reserved site in the UM field of the elicited reply. For example, if an uplink ELM reservation is requested, a value of RSS = 2 will instruct the transponder to insert the number of the site reserved for uplink ELM transfer into the UM field of the reply.

VERIFYING THE EXISTENCE OF A RESERVATION

6.13.2 Once granted, a multisite reservation lasts for 18 plus or minus 1 seconds. If the reservation and delivery are accomplished in the same beam dwell, no special procedures are required to verify the reservation. If delivery is not completed within 17 seconds, the ground station must ensure that the reservation is still in effect in order to continue the delivery process.

6.13.3 The technique for doing this is to mark the time of the reservation and then renew, if necessary, the reservation request before the reservation times out. The reservation can be renewed as follows:

a) by repeating the action used to make the initial reservation; or

b) for an extended length message transfer by automatically renewing the reservation each time a segment is requested or received.

6.13.4 For case b), successful renewing of the reservation is determined from the receipt of a reply that confirms that the transponder actually received the interrogation expected to renew the reservation. A ground station cannot assume that the transmission of an uplink ELM segment will automatically result in renewing the reservation since it is possible that the interrogation may not be received by the transponder.

6.13.5 After successfully renewing, the ground station can then advance the time of reservation to the latest time that the reservation was renewed and repeat the above actions.

6.14 AIR-AIR CROSS-LINK

PURPOSE

6.14.1 Mode S transponders are equipped with 255 transponder data registers of 56 bits each. These transponder data registers can contain a variety of aircraft state and intent information of interest to ground ATC as well as ASAS. A definition of the contents of these registers is contained in Annex 10, Volume III, Part I, Appendix to Chapter 5.

6.14.2 The technique for extracting transponder data register information over the air-ground link is described in 6.5. The technique used for air-air transfer is described in the following paragraphs.

DS FIELD IN UF = 0

6.14.3 The Comm-B data selector (BDS) is currently defined in the SARPs as the code that specifies the transponder data register to be accessed. The short air-air format UF = 0 contains a data selector (DS) field for the code of the transponder data register whose contents are to be returned in the reply to the UF = 0 interrogation.
6.14.4 This field is not included in the long air-air interrogation UF = 16. This long interrogation is only used for ACAS air-to-air coordination. The reply to this interrogation will always include coordination information in the 56-bit MV field, so cross-link data cannot be carried. In addition, omitting the DS field from the long ACAS interrogation has the desirable effect of completely separating the coordination and cross-link protocols.

CC FIELD IN DF = 0

6.14.5 An indication of a transponder’s ability to support the air-to-air cross-link communications capability is provided in order to allow for a transition phase where not all of the transponders have this capability. A one-bit flag cross-link capability (CC) field is provided in the short air-air reply to indicate the transponder has cross-link capability when this field is set to 1. In operation, an aircraft equipped with ASAS would not attempt a cross-link transaction unless it first interpreted this field. The first transponder register data extracted would be the Mode S specific service capability report so that the ASAS could determine what data was specifically available.

Protocol for Long Reply with Transponder Register Data

6.14.6 The extraction of transponder register data over the air-air link is defined in terms of the reply length (RL) and DS fields in the short air-air interrogation. Note that BDS = 0 does not access a legal transponder data register so it is not permitted. BDS = 0, in fact, accesses the transponder register used for an air-initiated Comm-B.

6.15 ACQUISITION SQUIRTERS

Transmission of Acquisition Squitters

6.15.1 When commanded to report the surface format by type control subfield (TCS) commands, aircraft without automatic means of determining the on-the-ground condition, and aircraft with such means that are reporting airborne status, will transmit acquisition squitters in addition to the surface type extended squitters unless acquisition squitter transmission has been inhibited. This action is taken to ensure ACAS acquisition in the event that the ground station inadvertently commands an airborne aircraft to report the surface type of extended squitter.

6.15.2 If aircraft are commanded to stop emitting surface extended squitters by TCS command, these aircraft will begin to emit the acquisition squitter (if not already doing so). This will reduce the squitter rate from two extended squitters per second to one acquisition squitter per second.

6.15.3 In the event that the transponder generates acquisition squitters while in the surface state, these squitters will be generated using only the top-mounted antenna for aircraft with antenna diversity.

6.15.4 A summary of the acquisition squitter conditions is presented in Table 6-9. In this table, Y indicates that the acquisition squitter is regularly broadcast, and N means that the acquisition squitter is suppressed. The condition of no transmission of any extended squitter can result from (1) initialization with no position, velocity, identity or altitude data available, or (2) a surface squitter lockout command while reporting the surface type of extended squitter.

6.15.5 The CA field of the acquisition (and extended) squitters reports the vertical status as determined by the aircraft. The TCS in SD controls the position format type reported by the transponder, either airborne or surface. These commands affect only the format type reported, they do not change the aircraft determination of its on-the-ground condition and therefore have no effect on the status reported in the CA, FS or VS fields.

6.16 EXTENDED SQUIRTER

Note.— All the aspects of the extended squitter technique are dealt with in detail in Chapter 10, including protocol considerations.

6.17 DATA LINK CAPABILITY FOR AN INTERROGATOR USING AN SI CODE

6.17.1 Some of the data link protocols defined in this section require the use of an II code. These protocols cannot be used by an interrogator operating with an SI code.

6.17.2 The data link activity for an interrogator operating with an SI code is therefore limited to unlinked Comm-A, broadcast Comm-A, GICB, broadcast Comm-B and ACAS downlink transactions. This specifically excludes the use of the AICB protocol.

Note.— The AICB protocol is required for data flash and downlink MSPs.
### Table 6-1. Number of interrogations required for 99 per cent probability of acquisition

<table>
<thead>
<tr>
<th>Number of aircraft in garble zone</th>
<th>0.5</th>
<th>0.25</th>
<th>0.125</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>16</td>
<td>22</td>
<td>40</td>
</tr>
<tr>
<td>3</td>
<td>35</td>
<td>31</td>
<td>46</td>
</tr>
<tr>
<td>4</td>
<td>72</td>
<td>41</td>
<td>53</td>
</tr>
<tr>
<td>5</td>
<td>&gt;100</td>
<td>56</td>
<td>61</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>76</td>
<td>70</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>&gt;100</td>
<td>80</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
<td>93</td>
</tr>
<tr>
<td>9</td>
<td></td>
<td></td>
<td>105</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
<td>121</td>
</tr>
</tbody>
</table>

### Table 6-2. Lockout override acquisition performance (interrogations)

\( p = 0.25 \) (2 to 5 aircraft), \( p = 0.125 \) (6 to 10 aircraft)

<table>
<thead>
<tr>
<th>Number of aircraft in garble zone</th>
<th>Maximum number of interrogations for 99% probability of acquisition</th>
<th>Average interrogations for acquisition</th>
<th>Maximum number of interrogations for 99% probability of acquisition</th>
<th>Average interrogations for acquisition</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>22</td>
<td>5</td>
<td>26</td>
<td>8</td>
</tr>
<tr>
<td>3</td>
<td>31</td>
<td>7</td>
<td>38</td>
<td>13</td>
</tr>
<tr>
<td>4</td>
<td>41</td>
<td>10</td>
<td>54</td>
<td>20</td>
</tr>
<tr>
<td>5</td>
<td>56</td>
<td>13</td>
<td>76</td>
<td>29</td>
</tr>
<tr>
<td>6</td>
<td>70</td>
<td>16</td>
<td>97</td>
<td>38</td>
</tr>
<tr>
<td>7</td>
<td>80</td>
<td>18</td>
<td>114</td>
<td>46</td>
</tr>
<tr>
<td>8</td>
<td>93</td>
<td>20</td>
<td>133</td>
<td>55</td>
</tr>
<tr>
<td>9</td>
<td>105</td>
<td>23</td>
<td>155</td>
<td>66</td>
</tr>
<tr>
<td>10</td>
<td>121</td>
<td>27</td>
<td>181</td>
<td>78</td>
</tr>
</tbody>
</table>
Table 6-3. Stochastic/lockout override acquisition performance (scans)  
\[ p = 0.25 \text{ (2 to 5 aircraft), } p = 0.125 \text{ (6 to 10 aircraft)} \]

<p>| Number of aircraft in the | Maximum number of scans for | Average number of scans for |</p>
<table>
<thead>
<tr>
<th>garble zone</th>
<th>99% probability of acquisition</th>
<th>99% probability of acquisition</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>6</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>7</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>8</td>
<td>9</td>
<td>2</td>
</tr>
<tr>
<td>9</td>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td>10</td>
<td>11</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 6-4. Example of ground-initiated Comm-B delivery

Scenario: Ground station readout of Comm-B message with BDS1 = 3 and BDS2 = 5

<table>
<thead>
<tr>
<th>Interrogation</th>
<th>Reply</th>
<th>Relevant fields</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>S or A</td>
<td>RR = 19 (b)</td>
<td>Readout of Comm-B message with BDS1 = 3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>DI = 7</td>
<td>SD field contains RRS subfield</td>
<td></td>
</tr>
<tr>
<td></td>
<td>RRS = 5</td>
<td>BDS2 of requested Comm-B message</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>MB</td>
<td>Ground-initiated Comm-B message</td>
<td></td>
</tr>
</tbody>
</table>

Notes.—

a) \( S = \) surveillance (\( UF = 4, 5 \)), \( A = \) Comm-A (\( UF = 20, 21 \)), \( B = \) Comm-B (\( DF = 20, 21 \))
b) RR code value equals 16 plus the decimal value of BDS1.
Table 6-5. Example of multisite air-initiated Comm-B delivery

Scenario: Local site interrogator identifier = 4

<table>
<thead>
<tr>
<th>Interrogation (a)</th>
<th>Reply (a)</th>
<th>Relevant fields</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>S or A</td>
<td></td>
<td>S or B</td>
<td>DR = 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>S or A</td>
<td>RR = 16</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>DI = 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>MBS = 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>RSS = 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>IIS = 4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B</td>
<td>DR = 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>IDS = 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(b)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>IIS = 4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>MB</td>
</tr>
<tr>
<td>S or A</td>
<td></td>
<td>S or A</td>
<td>DI = 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>MBS = 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>IIS = 4</td>
</tr>
<tr>
<td>S or B</td>
<td>(c)</td>
<td></td>
<td>DR = 0</td>
</tr>
</tbody>
</table>

Notes.—

a) S = surveillance (UF = 4, 5), A = Comm-A (UF = 20, 21), B = Comm-B (DF = 20, 21)

b) If IIS = 4, the local site is not the reserved site and no further action is taken on the message.

c) If DR = 1 in the reply to a Comm-B closeout, it indicates the presence of another air-initiated Comm-B message.
Table 6-6. Example of non-selective air-initiated Comm-B delivery

<table>
<thead>
<tr>
<th>Interrogation (a)</th>
<th>Reply (a)</th>
<th>Relevant fields</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>S or A</td>
<td>DR = 1</td>
<td>—</td>
<td>Air-initiated Comm-B waiting</td>
</tr>
<tr>
<td>S or B</td>
<td>RR = 16</td>
<td>DR = 1</td>
<td>Readout of air-initiated Comm-B</td>
</tr>
<tr>
<td></td>
<td>DI = 7</td>
<td></td>
<td>No extended data readout</td>
</tr>
<tr>
<td></td>
<td>DI = 7 and LOS = 0</td>
<td></td>
<td>No extended data readout</td>
</tr>
<tr>
<td>B</td>
<td>DR = 1</td>
<td>Air-initiated Comm-B message waiting</td>
<td></td>
</tr>
<tr>
<td></td>
<td>MB</td>
<td></td>
<td>Air-initiated Comm-B message</td>
</tr>
<tr>
<td>S or A</td>
<td>PC = 4</td>
<td>Non-selective Comm-B closeout</td>
<td></td>
</tr>
<tr>
<td>S or B</td>
<td>DR = 0</td>
<td>Comm-B closed out</td>
<td></td>
</tr>
</tbody>
</table>

Notes.—

a) S = surveillance (UF = 4, 5), A = Comm-A (UF = 20, 21), B = Comm-B (DF = 20, 21)
b) The message has not yet been closed out.
c) If DR = 1 in the reply to an air-initiated Comm-B closeout, it indicates the presence of another air-initiated Comm-B message.
### Table 6-7. Example of multisite uplink ELM delivery

Scenario: Multisite delivery of 3-segment uplink ELM by local site with interrogator identifier = 6

<table>
<thead>
<tr>
<th>Interrogation</th>
<th>Reply</th>
<th>Relevant fields</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>S or A</td>
<td></td>
<td>D = 1</td>
<td>Multisite SD field</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MES = 1</td>
<td>Uplink ELM reservation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RSS = 2</td>
<td>Request for uplink ELM reservation status in UM</td>
</tr>
<tr>
<td></td>
<td></td>
<td>IIS = 6</td>
<td>Local site’s interrogator identifier</td>
</tr>
<tr>
<td>S or B</td>
<td>(a)</td>
<td>IDS = 2</td>
<td>Uplink ELM reservation status is in IIS</td>
</tr>
<tr>
<td></td>
<td></td>
<td>IIS = 6</td>
<td>Site 6 (the local site) is the reserved site</td>
</tr>
<tr>
<td>C</td>
<td></td>
<td>RC = 0</td>
<td>Initializing segment delivery</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NC = 2</td>
<td>Announces a 3 segment ELM</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MC</td>
<td>Segment 3 of uplink ELM</td>
</tr>
<tr>
<td>None</td>
<td></td>
<td></td>
<td>Reply not elicited by RC = 0</td>
</tr>
<tr>
<td>C</td>
<td></td>
<td>RC = 1</td>
<td>Intermediate segment delivery</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NC = 1</td>
<td>Indicates MC contains segment 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MC</td>
<td>Segment 2 of uplink ELM</td>
</tr>
<tr>
<td>None</td>
<td></td>
<td></td>
<td>Reply not elicited by RC = 1</td>
</tr>
<tr>
<td>C</td>
<td></td>
<td>RC = 2</td>
<td>Segment delivery and request for technical acknowledgement</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NC = 0</td>
<td>Indicates MC contains segment 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MC</td>
<td>Segment 1 of uplink ELM</td>
</tr>
<tr>
<td>D</td>
<td>(c)</td>
<td>KE = 1</td>
<td>MD contains technical acknowledgement of uplink ELM in TAS</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TAS</td>
<td>Technical acknowledgement of segments 1 to 3</td>
</tr>
<tr>
<td>S or A</td>
<td></td>
<td>DI = 1</td>
<td>Multisite SD field</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MES = 2</td>
<td>Multisite uplink ELM closeout</td>
</tr>
<tr>
<td></td>
<td></td>
<td>IIS = 6</td>
<td>Local site’s interrogator identifier</td>
</tr>
<tr>
<td>S or B</td>
<td></td>
<td></td>
<td>Technical acknowledgement of closeout command</td>
</tr>
</tbody>
</table>

**Notes.—**

a) S = Surveillance (UF = 4, 5), A = Comm-A (UF = 20, 21), B = Comm-B (DF = 20, 21), C = Comm-C (UF = 24), D = Comm-D (DF = 24)

b) If IIS = 6, the local site is not the reserved site and no further action is taken this scan. The IIS subfield is in the UM field.

c) The ground station will resend any segment not acknowledged by TAS.
Table 6-8. Example of multisite downlink ELM delivery

Scenario: Multisite delivery of 2-segment uplink ELM by local site with interrogator identifier = 2

<table>
<thead>
<tr>
<th>Interrogation (a)</th>
<th>Reply (a)</th>
<th>Relevant fields</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>S or A</td>
<td></td>
<td>S or B</td>
<td>DR = 17</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Announces presence of 2-segment downlink ELM</td>
</tr>
<tr>
<td>S or A</td>
<td></td>
<td>DI = 1</td>
<td>Multisite SD field</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MES = 3</td>
<td>Downlink ELM reservation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RSS = 3</td>
<td>Request for downlink ELM reservation status in UM</td>
</tr>
<tr>
<td></td>
<td></td>
<td>IIS = 2</td>
<td>Local site’s interrogator identifier</td>
</tr>
<tr>
<td>S or B</td>
<td></td>
<td>IDS = 3</td>
<td>Downlink ELM reservation status is in IIS</td>
</tr>
<tr>
<td></td>
<td></td>
<td>IIS = 2</td>
<td>Site 2 (the local site) is the reserved site</td>
</tr>
<tr>
<td>C</td>
<td></td>
<td>RC = 3</td>
<td>MC contains request for downlink ELM delivery in SRS</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SRS</td>
<td>Indicates delivery request for segments 1 and 2</td>
</tr>
<tr>
<td>D</td>
<td></td>
<td>KE = 0</td>
<td>Downlink ELM in MD</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NC = 0</td>
<td>Indicates MD contains segment 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MD</td>
<td>Segment 1 of downlink ELM</td>
</tr>
<tr>
<td>D</td>
<td></td>
<td>KE = 0</td>
<td>Downlink ELM in MD</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NC = 1</td>
<td>Indicates MD contains segment 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MD</td>
<td>Segment 2 of downlink ELM</td>
</tr>
<tr>
<td>S or A</td>
<td></td>
<td>DI = 1</td>
<td>Multisite SD field</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MES = 4</td>
<td>Multisite downlink ELM closeout</td>
</tr>
<tr>
<td></td>
<td></td>
<td>IIS = 2</td>
<td>Local site’s interrogator identifier</td>
</tr>
<tr>
<td>S or B</td>
<td></td>
<td>DR = 0</td>
<td>Downlink ELM closed out</td>
</tr>
</tbody>
</table>

Notes.—

a) $S = \text{Surveillance (UF = 4, 5)}$, $A = \text{Comm-A (UF = 20, 21)}$, $B = \text{Comm-B (DF = 20, 21)}$, $C = \text{Comm-C (UF = 24)}$, $D = \text{Comm-D (DF = 24)}$.

b) If IIS = 2, the local site is not the reserved site and no further action is taken this message.

c) If all segments are not successfully received, the ground station will send another SRS requesting redelivery of missing segment(s).

d) If DR = 0 in reply to a Comm-D closeout, it indicates the presence of another air-initiated message (either B or D depending on the value of DR).
Table 6-9. Acquisition squitter transmission requirements

<table>
<thead>
<tr>
<th>Aircraft on-the-ground condition</th>
<th>Acquisition squitter not inhibited</th>
<th>Acquisition squitter inhibited</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No transmission of any surveillance type extended squitter</td>
<td>At least one surveillance type extended squitter transmitted</td>
</tr>
<tr>
<td>Airborne</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Surface</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Airborne or surface</td>
<td>Y</td>
<td>Y</td>
</tr>
</tbody>
</table>

Note.— Y = regular transmission of acquisition squitters

N = acquisition squitter suppressed.
Chapter 6.  Mode S protocol considerations

Figure 6-1. Combined interrogation for site selective acquisition

Legend:
1. Maximum suppression time equals 45 μs.
2. Mode A.
3. Mode C.

Note 1.— It is desirable to provide at least 45 microseconds spacing between the interrogations to ensure that Mode A/C transponders recover from the suppression caused by the Mode S interrogation preamble. The spacing shown is the maximum possible without interfering with the receipt of zero range Mode S all-call replies.

Note 2.— If gain time control is to be used, the spacing of 128 microseconds must be used to provide an identical range zero point for Mode S and SSR replies.
Figure 6-2. Lockout override probability of acquisition

(3.6 degrees beam, 10 seconds scan, 10 all-call interrogations per beam, $p = 0.25$)
Figure 6-3. Stochastic/lockout override number of aircraft acquired

(3.6 degrees beam, 10 seconds scan, 10 all-call interrogations per beam, p = 0.25)
Chapter 7

MODE S IMPLEMENTATION

7.1 EVOLUTION OF GROUND FACILITIES

CONVERSION TO MONOPULSE

7.1.1 As discussed in Chapter 5, the implementation of monopulse ground stations can bring considerable benefits in regions where it is necessary to improve system performance. The introduction of monopulse to ground facilities requires no modification to the aircraft transponders. It does require, however, a monopulse antenna or adaptation of an existing antenna, a twin-channel receiver and a special processor.

ADDITION OF MODE S FEATURES

7.1.2 The principal functions to be added to upgrade a monopulse ground station to Mode S are channel management, Mode S surveillance processing and, if used, data link processing and network management. The step to add these functions can be taken, for instance, when surveillance performance of monopulse alone becomes inadequate or when it is considered desirable to take advantage of the additional capabilities offered by the Mode S data link. As well as improving surveillance performance, the basic Mode S system will allow ATS authorities to offer, and to benefit from, a number of additional services which can be accomplished through use of the Mode S specific services capability. The Mode S system can be further enhanced by the extension of its data link to support full subnetwork operation. The benefits of Mode S surveillance or communications will, of course, increase as the proportion of Mode S-equipped aircraft increases.

ANTENNA REQUIREMENTS

Rotating antenna

7.1.3 In order to support monopulse processing of Mode A/C aircraft, four or more intermode interrogation and reply intervals must be scheduled within the antenna 3 dB beam. The antenna beamwidth and antenna rotation rate determine the intermode interrogation repetition frequency (IRF) and thus the channel time required for Mode A/C operation. The antenna beamwidth together with the antenna rotation rate also determine the dwell time, i.e. the time that an aircraft is illuminated by the main beam and thus the period of time that Mode S activity can take place on a particular scan. Both of these considerations imply the need to avoid extremely narrow beam antennas. An antenna beamwidth of approximately 2.4 degrees has been found to provide a reasonable compromise between azimuth measurement accuracy and Mode S operation.

Electronically-scanned antenna

Note.—An electronically-scanned (E-scan) antenna with the capability of randomly instantaneously pointing in any desired direction is expected to provide many benefits to Mode S operation once the operational use of this type of antenna is validated.

7.1.4 Data link capacity. The effective data link capacity of a rotating beam antenna is limited by the fact that aircraft are often not uniformly distributed in azimuth but bunched in high-density azimuth sectors. This bunching can be as much as 4 to 1 at some locations, i.e. most of the aircraft are in a 90-degree azimuth sector. This means that most of the available Mode S channel time is unused. An E-scan antenna can increase the effective capacity of the data link by utilizing all of the available Mode S time. Further, data link service to a particular aircraft is no longer limited by dwell time.

7.1.5 Data link delivery delay. The inherent delivery delay of a rotating beam antenna is determined by the scan time. This must be taken into account for certain data link functions, e.g. tactical manoeuvre commands. The uplink delivery delay time for an E-scan antenna can be reduced to a small fraction of a second. This improvement applies to downlink transfers only after the announcement has been detected.
7.1.6 Variable surveillance rate. Certain activities, such as monitoring approaches to closely-spaced parallel runways, may require a surveillance update rate higher than that for normal ATC activities. An E-scan antenna can provide a basic surveillance update for all aircraft within coverage, plus a higher update rate for selected aircraft based on operational requirements.

7.1.7 Transmitter duty cycle. Since Mode S aircraft can be accessed at any time by an interrogator with an E-scan antenna, the Mode S data link load can be uniformly handled throughout a scan period, significantly reducing the transmitter duty cycle for a given data link loading.

7.2 STEPS TO FACILITATE UPGRADING OF MONOPULSE SSR TO MODE S

MODE S TRANSMITTER REQUIREMENTS

Note.— Ground station transmitter requirements for Mode S interrogations are more stringent than for Mode A/C interrogations. Consideration should therefore be given to incorporating a Mode S-compatible transmitter at the time that conversion is made to monopulse.

Main-beam transmitter

7.2.1 The transmit power level for a Mode A/C ground station must provide for an effective radiated power (ERP) that gives good link reliability out to its maximum operating range. This power level always includes additional link margin beyond nominal values to allow for link differences between the ground station and individual aircraft. This normally results in an ERP that is higher than necessary for most aircraft. The selective address and re-interrogation features of Mode S permit the use of a Mode S transmit power that is below the nominal Mode A/C interrogation level. This power level can be used for all Mode S aircraft on the initial interrogation attempt for each scan. In most cases, this power level will be sufficient for a successful reply. In cases where a reply is not received after a few attempts, a higher power interrogation can be used for the aircraft. This higher power level can be set at a level above or equal to the nominal Mode A/C interrogation level. This provides improved transmit link margin at an acceptable interference level because this high-power Mode S interrogation is used selectively in exceptional cases. For a given ground station maximum operating range, antenna gain, and traffic and data link load, the required peak power of a Mode S ground station transmitter may be determined by using the uplink power budget equation given in 4.1.7. The short-term transmitter duty cycle for a very high-capacity ground station can be as high as 65 per cent over a 2-millisecond interval.

Auxiliary transmitter

7.2.2 When transmitting Mode S-only all-call interrogations, Mode S side-lobe suppression (SLS) is required to prevent replies from aircraft in the side lobes and back lobes of the interrogation antenna. It should also be used with discretely addressed Mode S interrogations both to a) reduce the amount of time that a nearby transponder is unable to process main-beam interrogations from other ground stations because it is busy processing unwanted side-lobe interrogations from the Mode S ground station, and to b) reduce the probability of a nearby transponder accepting interrogations that are not addressed to it but which may be corrupted by multipath or uplink interference so as to appear to be properly addressed.

7.2.3 Suppression is accomplished by the omnidirectional transmission of a separate pulse, known as the P5 pulse, which overlaps the sync phase reversal within the P6 pulse of the Mode S interrogation causing the transponder to fail to synchronize when the received amplitude of the P5 pulse is comparable to or larger than the received amplitude of P6.

7.2.4 Since the P5 pulse and the P6 pulse are transmitted simultaneously, an auxiliary transmitter is required for transmitting P5. This transmitter can also be used to generate the omnidirectional P2 suppression pulse for non-Mode S interrogations.

7.2.5 Power output relative to main-beam power. The pulses transmitted by the auxiliary transmitter are radiated by a separate control antenna pattern whose gain exceeds the gain of the main antenna pattern in all directions outside of its main beam. The auxiliary transmitter power should be such as to assure that the received power of the P5 pulse exceeds the received power of the P6 pulse by several dB everywhere outside of the main beam of the directional antenna. If the main-beam power is variable, the auxiliary transmitter power should be automatically controlled to follow the main-beam power.

7.2.6 Power and duty cycle. Depending upon operational use, the auxiliary transmitter may be required to provide up to 3 200 watts peak power at the control antenna RF port. The duty cycle of the auxiliary transmitter should be consistent with the interrogation rate of the main beam transmitter. The duty cycle of the auxiliary transmitter is
much lower than the main transmitter since the $P_5$ suppression pulse is much shorter than the $P_6$ pulse. The $P_5$ pulse is approximately $1/20$th the width of a short $P_6$ pulse or $1/40$th the width of a long $P_6$ pulse. Duty cycles given above for the main transmitter can be scaled by these factors.

Amplitude stability

7.2.7 For satisfactory operation, transmitters intended for use with ground stations that handle uplink ELMs should have the ability to transmit the desired number of consecutive ELM segments with an amplitude drop of no more than 2 dB.

Frequency and phase stability

7.2.8 The carrier frequency of all interrogations from Mode S ground stations, Mode A/C as well as Mode S, is required to fall within a frequency band of 1 030 plus or minus 0.01 MHz. This is equivalent to a maximum phase variation of 0.9 degrees over the duration of a 0.25-microsecond interval.

7.2.9 The overall tolerance on the 180-degree phase reversals of the carrier within the $P_6$ pulse is plus or minus 5 degrees over the duration of any 0.25-microsecond interval. Thus, taking into account the possible 0.9 degree error due to carrier frequency mistuning, the phase accuracy of the mechanism used for generating 180-degree phase reversals must be better than 4.1 degrees.

Spurious radiation

7.2.10 Mode S transmissions cannot be synchronized with primary radar transmissions. Therefore, care must be taken in implementing the Mode S transmitter to prevent spurious radiation that could affect the operation of the receiver of a collocated primary radar, particularly one operating at L-band.

Note.— Care must also be taken to prevent spurious radiation from the transmitter of the primary radar from interfering with Mode S operation.

Mode A/C reply processor blanking

7.2.11 Mode S ground stations will normally be configured to perform Mode A/C surveillance and Mode S all-call acquisition in a shared listening interval. Mode S replies may then be detected by the Mode A/C reply processor. In addition, Mode S fruit replies will also be received during the Mode A/C listening interval by interrogators without Mode S capability. In order to prevent possible spurious SSR bracket detections, it is advisable to blank the Mode A/C reply processor for the duration of the Mode S reply. This may be accomplished by detecting the Mode S preamble and blanking the Mode A/C reply processor for a time equivalent to the duration of the Mode S reply.

AZIMUTH PROCESSING

7.2.12 Using monopulse for Mode A/C surveillance permits a reduction in the Mode A/C pulse repetition frequency (PRF) and therefore makes channel time available for Mode S roll-call processing. The reduced Mode A/C PRF means that the replies will not necessarily be received on boresight. Hence, the monopulse processor must have good off-boresight performance. The same characteristic is required for Mode S processing: the initial interrogation is normally scheduled early in the beam dwell of each scan to permit the possibility of multiple interrogations. A monopulse processor intended for Mode S use should have good performance over as wide a portion of the beamwidth as possible (e.g. between the points where the delta-to-sum beam ratio is equal to two).

7.3 GROUND STATION IMPLEMENTATION TECHNIQUES

Note.— The material presented in this section represents one approach to the implementation of a high capacity Mode S ground station but it should be noted that other approaches are possible.

Mode S reply processing

Preamble detection

7.3.1 Mode S replies are detected on the basis of the four-pulse preamble preceding the reply data block. The preamble detector provides accurate time-of-arrival estimation for aircraft ranging and for synchronization of message bit processing and reply decoding.

7.3.2 For replies to roll-call interrogations, channel management (7.3.7) provides to the preamble detector an estimate of the expected reply time and an uncertainty
window. A reply is accepted only if its preamble is detected within this window. Since the reply processor cannot start decoding a new reply when it is still decoding an earlier one, the use of this window minimizes the probability that the reply decoder will miss the desired reply due to Mode S fruit. Care must be exercised in selecting the conditions for preamble detection. If detection conditions are too loose, reply preamble false alarms will result in lost channel time. If detection conditions are too stringent, missed preambles will result in reduced reply probability.

Confidence determination

7.3.3 Since a message bit is transmitted as a pulse in one of two possible positions, depending on whether the bit value is “ZERO” or “ONE”, bit decisions are based primarily on the relative amplitudes of the signals received in these two pulse positions. A receiver channel operating with an associated omnidirectional antenna can determine if a received pulse was received in the antenna main beam or in its side lobes. This side-lobe information is used to help resolve ambiguous situations in which a signal is received in both pulse positions.

7.3.4 Bit decisions are indicated as high-confidence only when a main-beam signal appears in one pulse position, and either no signal or a side-lobe signal appears in the other. Otherwise, they are indicated as low-confidence.

Error detection and correction

7.3.5 Message decoding uses the parity check code described in Appendix A to detect errors in the demodulated message. Since the parity check bits for roll-call replies are combined with the transponder address, the decoder must know the expected address (supplied by channel management) in order to perform error detection.

7.3.6 Whenever a decoded reply contains errors, error correction can be attempted if the total number of low-confidence bits in the reply and the total number of low confidence bits in the 24-bit correction span do not exceed a preset threshold. The use of these thresholds minimizes the possibility of erroneously “correcting” a reply that contains a very large number of errors. Error correction can be successful only if:

a) all errors are confined within a span of 24 contiguous bits; and

b) all errors occur in bits flagged as low-confidence.

Garbling by a single strong Mode A/C reply, which can result in bit decision errors spanning no more than 24 bits, usually results in a correctable error pattern. Thus, with high probability, the Mode S data block will be correctly decoded unless it is garbled by more than one strong Mode A/C reply.

Channel management

Purpose

7.3.7 The channel management function regulates all activity on the RF channels through control of the modulator/transmitter and the Mode A/C and Mode S reply processors. Its principal function is the scheduling of intermode and Mode S interrogations.

7.3.8 To provide surveillance of both Mode A/C and Mode S-equipped aircraft with minimal mutual interference, the RF channels are time-shared between all-call activities and roll-call activities.

7.3.9 One example of a technique for time-sharing the channel is shown in Figure 7-1. This approach divides the channel time line into non-overlapping periods of a) Mode A/C and Mode S all-call activity and b) Mode S roll-call activity. Another approach is to schedule Mode S roll-call interrogations and replies during the all-call period as well as during the roll-call period. This latter approach uses the channel time available between the replies expected from acquired Mode A/C aircraft and thus provides more channel time for Mode S roll-call activity. Care must be taken to avoid repeated use of the same range zone in the Mode A/C and Mode S all-call reply interval in order to permit the acquisition of new aircraft.

7.3.10 An additional approach for time-sharing the channel is to allocate channel capacity to Mode S based upon actual demand rather than the fixed allocation of time between Mode A/C and Mode S that was presented in Figure 7-1. This would give more channel time to Mode A/C activity during periods of low Mode S use since a fixed allocation is based upon peak Mode S demand.

Mode A/C and Mode S all-call scheduling

7.3.11 Mode A/C and Mode S all-call interrogations are scheduled at the beginning of a Mode A/C period as determined by a site adaptation input that defines the ground station time line. To reduce the incidence of fruit
and second-time-around target reports, these interrogations should be pseudo-randomly jittered from the nominal interrogation time.

7.3.12 Following each Mode A/C interrogation, the ground station processes Mode A/C replies for an interval corresponding to the maximum desired coverage range at the current antenna azimuth. When the desired coverage range is short, initiation of the subsequent Mode S interval may be delayed so that reception of replies from longer-range Mode A/C targets does not interfere with roll-call replies in the following roll-call interval. The use of adaptive interrogation power to limit replies to the required operational range minimizes the requirement to delay the subsequent Mode S interval and reduces unnecessary interference on the channel.

7.3.13 In order to conserve channel time, Mode S all-call acquisition is also performed during the Mode A/C listening period. Replies from unacquired Mode S and Mode A/C aircraft may be elicited in one of two ways:

a) through use of the Mode A/C/S all-call interrogation; and/or

b) by using a Mode S-only all-call interrogation followed by a Mode A/C-only all-call interrogation.

7.3.14 The latter approach must be used with the multisite and stochastic acquisition functions because site address and stochastic coding for these functions is contained in format UF=11, the Mode S-only all-call.

Mode S roll-call scheduling principles

7.3.15 Scheduling of Mode S roll-call interrogations and replies occurs under the following principles:

a) Mode S interrogations are addressed only to aircraft within the antenna beam;

b) channel time is allocated to each Mode S interrogation and reply based upon a prediction of aircraft range; and

c) the ground station is able to interrogate an aircraft more than once while it remains in the beam.

The ground station maintains an active target list, comprising those Mode S aircraft that are within the antenna beam, and makes repeated passes through this list, scheduling discretely-addressed Mode S interrogations and replies on a nonconflicting basis. A single aircraft may appear on one or more of the resulting schedules of interrogation and replies, so that multiple surveillance and communication tasks can be accomplished. In the case of a failure to receive a reply, the capability for repeated scheduling of interrogations to an aircraft provides a high overall surveillance/communication reliability.

7.3.16 The principal elements of Mode S roll-call scheduling are illustrated in Figure 7-2. The intervals of time devoted to Mode S roll-call activity are called Mode S roll-call periods. During a Mode S period, one or more roll-call schedules are produced. A schedule is a set of interrogation and reply times that allows the ground station to carry out one interrogation-reply pair per aircraft to some or all of the aircraft on the active target list without providing a second transaction to any aircraft. The interrogations are timed so that non-overlapping blocks of channel time are assigned to each individual interrogation and reply. If insufficient time is available to schedule all aircraft on the list, the time is allocated to aircraft according to a pre-assigned transaction priority.

7.3.17 Roll-call scheduling begins with the first (longest range) aircraft on the list, scheduling an interrogation at the assigned start time of the schedule; next, the expected reply arrival time is computed and a suitable listening period provided. Subsequent aircraft are scheduled by placing their reply listening periods in sequence and computing the corresponding interrogation times. A cycle is completed when the next interrogation, if so scheduled, would overlap the first reply. This interrogation is deferred to start a new cycle.

7.3.18 Several types of transactions must be efficiently combined in forming a Mode S schedule. Since the aircraft on the active target list are in various stages of completion, with respect to Mode S activity, each may require a different kind of transaction. Figure 7-3 a) illustrates a typical cycle comprised of long and short interrogations, coupled with long and short replies.

7.3.19 The cycles shown in Figures 7-3 b) and 7-3 c) illustrate uplink and downlink ELM transactions as well as short and long interrogations.

Channel management organization

7.3.20 General. The five subfunctions that comprise channel management are a) channel control, b) transaction preparation, c) target list update, d) roll-call scheduling and e) transaction update. The data flow paths between these subfunctions and their interfaces with other ground station functions are illustrated in Figure 7-4. An example of one approach to channel management follows.
7.3.21 Interfaces. Channel management receives inputs from surveillance processing, data link management and network management. Surveillance processing provides channel management with the predicted position (azimuth and range) of Mode S aircraft. Data link management provides organized lists of pending uplink messages for each Mode S aircraft. Network management controls the track state to define the kinds of service, both surveillance and communication, to be afforded each aircraft. Channel management has control over the modulator/transmitter unit and the Mode S and Mode A/C reply processors. Channel management communicates with these units by generating interrogation and reply control commands and by receiving Mode S reply data blocks. When an aircraft leaves the beam, a record of channel activity and downlink message content is passed on to the surveillance processing, data link management and network management functions.

7.3.22 Channel control. Channel control monitors the system real-time clock and the antenna pointing direction, assuring that all Mode A/C and Mode S activities take place at the proper time and in the proper sequence. The other four channel management subfunctions are periodically activated by channel control. In addition, channel control regulates the flow of control commands to the modulator/transmitter and to the reply processors, and it directs the transfer of Mode S reply data blocks from the Mode S reply processor to channel management.

7.3.23 Transaction preparation. At regular intervals, channel control directs transaction preparation to provide a list of aircraft about to enter the beam. Transaction preparation consults the surveillance file that contains predicted position, the pending uplink message data placed there by data link management and control information generated by network management. If uplink messages and/or downlink message requests are pending for an aircraft entering the beam, transaction preparation will determine the number and type of transactions required to accomplish these tasks. Transaction preparation creates a list of data blocks, one for each new aircraft, containing a complete specification of the required set of transactions needed to accomplish all pending surveillance and communication tasks.

7.3.24 Target list update. An active target list is updated regularly by the target list update subfunction. The entries on this list are the data blocks which have been formulated by the transaction preparation subfunction. Data blocks on new targets, supplied by transaction preparation, are merged into the list, while old targets, either leaving the beam or completely serviced, are removed. In order to facilitate the computation of a non-conflicting schedule of interrogations and replies, an active target list is arranged in order of decreasing target range.

7.3.25 Roll-call scheduling. As directed by channel control, roll-call scheduling operates on the contents of an active target list to produce Mode S schedules according to the procedures described earlier. If insufficient time remains for a complete schedule (i.e. one transaction per aircraft on the active target list) then the available time is allocated based on transaction priority. The outputs of roll-call scheduling are Mode S interrogation control blocks specifying interrogation time, power level, and data-block contents and reply control blocks specifying expected reply time and address.

7.3.26 Transaction update. If a target enters the beam with several transactions to be carried out, these transactions will normally take place on successive schedules. The transaction update function examines each reply and, if the transaction was successful, modifies the target’s data block so that the next pending transaction will be carried out in the subsequent schedule. If the transaction was unsuccessful, it will be repeated in the next schedule and the next pending transaction delayed to a later schedule. Finally, transaction update indicates the completion of targets for which no further transactions are pending.

SURVEILLANCE PROCESSING

7.3.27 Surveillance processing maintains target files on all Mode A/C and Mode S aircraft within the ground station’s coverage volume. Its principal functions are:

a) to select the Mode S reply to be used for surveillance processing, if more than one reply is available;

b) to edit and correct Mode A/C target reports based upon data from previous scans;

c) to predict next-scan position of Mode S aircraft for interrogation scheduling; and

d) to disseminate surveillance data to ATC users.

7.3.28 The interconnection between the principal subfunctions of surveillance processing is illustrated in Figure 7-5.

Note.— Figure 7-5 does not necessarily imply the order in which processing tasks would take place.
MODE S DATA LINK MANAGEMENT

7.3.29 Data link management regulates the flow of messages on the air-ground link. This is accomplished through the maintenance of a file, called the active message list, which contains a record of all of the pending communications activities. Entries in this file are organized by Mode S address and are used by channel management to determine the number and type of interrogations and replies to be scheduled for an aircraft when it is available in the antenna main beam.

7.3.30 As shown in Figure 7-6 the two major sub-functions of data link management operate to update the active message list. Input processing handles messages received from the ground data link processor (GDLP) and in general is involved with additions of ground-to-air messages to the active message list. Output processing examines the transaction record prepared by channel management. The transaction record together with the contents of the reply messages indicate which communication activities are complete and which transponders, if any, are requesting an air-to-ground message transfer.

Note.— Message priority management is specified in the Mode S subnetwork SARPs (Annex 10, Volume III, Part I, Chapter 5).

NETWORK MANAGEMENT

7.3.31 Purpose. Network management provides for continuity of surveillance and data link services where adjacent ground stations have overlapping coverage. When operating in a network, Mode S ground stations exchange surveillance data to hand off targets between ground stations and to maintain surveillance continuity and rapid target re-acquisition in the event of a temporary link interruption. This multisensor coordination is directed by the network management function, operating under the control of the ground station coverage map.

7.3.32 The coverage map. The extent and type of coverage to be provided by each ground station is controlled by a data file known as the ground station coverage map. In general, two major boundaries are defined by this map:

a) the maximum range at which the ground station is to manage all-call lockout while providing surveillance coverage; and

b) the area in which the ground station is to provide data link coverage.

The coverage map can be implemented in Cartesian coordinates or in a \( \rho - \Theta \) grid as shown in Figure 7-7. For each element of the grid (termed a cell) a ground station priority list is specified, with a lower altitude cutoff defined for each ground station. The position of a ground station in the list specifies its function in that cell. The ground station with the lowest altitude coverage is termed the primary ground station. The primary ground station is responsible for surveillance and communications coverage. The ground station with the next lowest altitude coverage is called the secondary ground station and is responsible for surveillance coverage. Ground stations with higher altitude cutoff are called back-up ground stations and are normally employed to provide coverage in the event of a failure of a primary or secondary ground station. Ground station coverage boundaries are thus defined by a change in ground station ordering between adjacent cells. In clustered operation, coverage maps can be changed dynamically.

7.4 OPERATION OF ADJACENT MODE S GROUND STATIONS

Note.— Coordination is required when adjacent Mode S ground stations have overlapping coverage (Annex 10, Volume IV, Chapter 2, 2.1.2.1.2). This is particularly important where radar coverage crosses national boundaries. The need for this coordination and the technical and administrative procedures for achieving it are described in the following paragraphs.

NEED FOR COORDINATION

7.4.1 Mode S all-call lockout (6.1.1) is used to minimize interference for all-call replies. This means that provision must be made to ensure that acquisition of Mode S aircraft is not denied to a neighbouring ground station with overlapping coverage.

7.4.2 The Mode S data link protocols for air-initiated Comm-B and ELMs also need coordination because only one ground station at a time can perform any one of these protocols with a given Mode S transponder.

7.4.3 For these reasons, care must be exercised when deploying Mode S ground stations to ensure that handoff and communications protocol constraints are met.

ALL-CALL ACQUISITION CONSIDERATIONS

Note.— Three types of Mode S acquisition techniques are described in 6.1, i.e. multisite, non-selective and
clustered. Each technique has different characteristics from the standpoint of required channel time, Mode S all-call fruit generation, and the level of coordination required in a region of multisensor coverage. Recall that the non-selective technique is not compatible with the Mode S subnetwork.

Channel time requirements

7.4.4 Multisite and clustered acquisition require the transmission of the local site’s interrogator identifier (II) code and thus uses the Mode S-only all-call interrogation for Mode S acquisition. This interrogation is used together with the Mode A/C-only all-call interrogation to provide coverage of Mode A/C-equipped aircraft. If separate reply listening intervals were used for Mode S all-call replies and Mode A/C replies, the use of the multisite acquisition mode would imply a significant decrease in the amount of channel time available for Mode S interrogations compared to non-selective acquisition using a single Mode A/C/S all-call interrogation. Ground stations using multisite or clustered acquisition should therefore use the combined interrogation described in 6.1.4 to obtain the benefit of a shared listening interval for Mode S-only and Mode A/C-only all-call replies.

Techniques for minimizing Mode S all-call fruit

7.4.5 Ground stations using the non-selective acquisition technique or a cluster of interrogators with the same II code use a common lockout code. This means that aircraft under Mode S coverage (and lockout) of any one ground station will not reply to the all-call interrogations of any other ground station.

7.4.6 Consider the set of six terminal ground stations shown in Figure 7-8. Each circle defines the maximum range at which each ground station acquires and locks out Mode S aircraft. In order to have reliable operation to the acquisition range, the interrogation power is sufficient to interrogate most aircraft at considerably greater ranges. Thus, aircraft 1 will likely receive all-call interrogations from ground station D even though it is outside of D’s acquisition range. Now assume that all of the ground stations are using non-selective lockout or are clustered interrogators with the same II code. Aircraft 1 will not respond to all-call interrogations from the other ground stations if it is locked out by ground station B. When a common II code is used, aircraft only reply to all-call interrogations when they enter or exit the combined coverage of a set of Mode S ground stations. Thus aircraft 2 will not respond to any all-call interrogations between points x and y. This acquisition technique produces the minimum Mode S all-call fruit.

7.4.7 If the six ground stations in Figure 7-8 are using multisite acquisition, every aircraft will reply to the all-call interrogations of every ground station for which it is in cover and not in a state of lockout. Thus aircraft 1 in Figure 7-8 would respond to the all-call replies of ground stations A, C, D, E and F if it is only locked out to ground station B. Consequently this acquisition technique can produce a significant amount of all-call fruit. It is therefore desirable that, where possible, ground stations A, C, D, E and F perform surveillance on all aircraft in their cover and lock out all-calls.

7.4.8 When the multisite mode is used with en-route ground stations, aircraft able to receive an all-call interrogation beyond the ground station’s maximum range must be at very high altitudes due to the earth’s curvature. This limits the number of such aircraft and thus limits the all-call fruit. For example, an aircraft at 390 km (210 NM) from a ground station with a zero degree screening angle must be above 9150 m (30 000 ft) to receive the all-call interrogation.

7.4.9 The non-selective clustered acquisition technique (which is compatible with the Mode S subnetwork) should be used in high Mode S traffic densities where many terminal ground stations have overlapping coverage. The multisite acquisition mode may be used in any other environment.

Ground station coordination

7.4.10 Need for coordination. Acquisition in a region of overlapping ground station coverage implies the need for some form of coordination between adjacent sites. Aircraft 3 in Figure 7-8 is covered only by ground station F at point i but is in the joint coverage area of D and F at point j. Two options, namely linked and unlinked ground station operation, are available.

7.4.11 Linked ground station operation. If ground stations D and F in Figure 7-8 are in contact via ground communications, F can send D a message giving the range, azimuth, and Mode S address of aircraft 3. This information is sufficient for ground station D to schedule interrogations at the correct location using the proper Mode S address to acquire aircraft 3 without unlocking aircraft 3.
7.4.12 Unlinked ground station operation. Unlinked ground stations will normally use the multisite acquisition technique. Some administrative coordination (see 7.4.16) is required for successful acquisition in overlapped regions. Each ground station needs only use a different interrogator identifier (II) code from any neighbour with which it has overlapping acquisition range coverage. In the situation illustrated, each ground station could be assigned a unique II code. Another acceptable assignment of II codes is shown in Figure 7-9: the six ground stations are assigned only four different II codes. It is only required that unique II codes be assigned to ground stations that share overlapping coverage within the areas in which they acquire and lock out Mode S aircraft. The II code assignment of Figure 7-9 satisfies this requirement in each region of double and triple overlap. The assignment of II codes should be the subject of regional air navigation agreements.

7.4.13 The required number of different II codes does not necessarily increase as the number of ground stations increases. Consider the expanded ground station deployment shown in Figure 7-10. Here five ground stations have been added to the original six, but no additional II codes are required for the overlap regions assumed. If, however, the complexity of the configuration of ground stations is such that satisfactory operation with multisite acquisition cannot be ensured with 15 II codes, then ground station linking becomes necessary.

7.4.14 A more complex II code assignment example is shown in Figure 7-11. In this example interrogators A, B, D, E form a first cluster, C, F, I a second cluster and L, M, N a third cluster. These three clusters show interconnections by ground communications and hence can use the same II code. Note also the possibility of a single interrogator (labelled I in the figure) using different II codes in different sectors in order to achieve compatible operation for the given code assignment.

**The Use of Multiple Interrogator Codes by a Single Interrogator**

7.4.15 If multiple Interrogator Codes are used by a single interrogator, as shown for the interrogator labelled I in Figure 7-11, only two codes are permitted. The codes should be used on a sector basis and to avoid complexity and to limit FRUIT at the sector boundaries, no more than two sectors should be used. The sectors should be defined so that the boundaries do not coincide with busy traffic areas, i.e. along airways. The interrogator codes should be chosen so that both codes can be used in a buffer zone across the sector boundaries so that selectively addressed aircraft can be locked out to Mode S-only all-calls in the buffer zone. Acquisition in the buffer zone should be capable of using all-call replies from both Interrogator Codes in order to avoid setting up duplicate tracks for the same aircraft.

**Data Link When an Interrogator Uses Multiple Interrogator Codes**

7.4.16 When an interrogator is configured to use two Interrogator Codes only one of the Interrogator Codes can be used for full data link activity. Limited data link functions that may be carried out in both sectors include single segment Comm-A, the uplink and downlink broadcast protocols, and also GICB extraction, which includes ACAS RA and Flight Identity extraction. This is to keep down the complexity of the system and avoid the problems of coordinating data link activity across the sector boundaries. This would require great care close to the radar where the sector boundaries could be crossed very quickly, almost on a scan-to-scan basis and could result in lost connections. The resultant re-setting up of channels would involve a large number of transactions and a heavy usage of channel time. All data link activities should be terminated in an orderly way whenever possible, as the aircraft exits the sector designated for full data link.

7.4.17 If ground communications are not available between interrogators D and F in Figure 7-8, interrogator F can make aircraft 3 visible to D by withdrawing its lockout commands to aircraft 3. After the 18-second timeout, aircraft 3 will respond to the acquisition interrogations of ground station D and will be acquired. In order to be certain of a successful handoff, ground station F must periodically unlock all aircraft in the overlap region. This technique is only recommended for limited overlap situations. It must be recognized that this technique results in an increase in Mode S fruit.

**Need for regional coordination**

7.4.18 The assignment of II codes must be coordinated in regions of overlapping ground station coverage at international boundaries to ensure acquisition of Mode S aircraft. The assignment of II codes should be the subject of regional coordination.

**Summary of all-call acquisition considerations**

7.4.19 Non-selective acquisition. Non-selective acquisition is more efficient in the use of channel time and
produces less all-call fruit, but it requires ground communication or cooperative unlocking between ground stations with overlapping coverage and is not compatible with the Mode S subnetwork. Its principal use will be for a ground station with no overlapping coverage that is not supporting the Mode S subnetwork.

7.4.20 Clustered acquisition. Clustered interrogators using a common non-zero II code and ground coordination produce the same level of all-call fruit as the non-selective technique. This is the preferred technique in very high Mode S traffic and interrogator density environments.

7.4.21 Multisite acquisition. Multisite acquisition requires slightly more channel time, produces more all-call fruit, but requires no ground communication with adjacent ground stations. It is the technique of choice anywhere that the non-selective mode is not mandatory.

MODE S DATA LINK COORDINATION CONSIDERATIONS

Note.— Two ways of managing communications use the multisite and non-selective protocols. These techniques differ in the amount of channel time required and in the level of coordination required in a region of multisensor coverage.

Channel time requirements

7.4.22 Except for the enhanced protocols, the use of the multisite technique for air-initiated Comm-B and ELM protocols requires that the interrogator make a reservation when performing a message delivery. For the air-initiated Comm-B, this is performed as part of the delivery process and requires no additional channel activity. For the multisite ELM protocols, the reservation requires a separate interrogation/reply transaction before the ELM delivery begins. This could take place during the surveillance transaction performed each scan and thus might not represent additional channel activity. Lost channel time can definitely occur when a ground station attempts a reservation and finds that the transponder is busy. It must then make another attempt on a subsequent scan.

7.4.23 When the non-selective mode is in use, only one ground station at a time is authorized to provide data link service to a particular aircraft. Therefore, a reservation process is not required, and the channel utilization is more efficient.

Interrogator coordination

7.4.24 In order to use the non-selective communications technique in a region of overlapping coverage, ground stations must be coordinated via ground communications to assure that only one ground station at a time is assigned data link responsibility for a given aircraft.

7.4.25 The only coordination required when using the multisite protocols is for the interrogator identifier (II) codes to be assigned such that interrogators with the same II code never share overlapping coverage (see 7.4.12).

Summary of data link coordination considerations

7.4.26 Non-selective protocols. The non-selective protocols permit more efficient operation than the multisite protocols but require ground communication. Non-selective protocols will be of use for:

a) a ground station with no overlapping coverage; and

b) a cluster of terminal ground stations with no overlapping coverage with any other Mode S interrogators that must use the clustered acquisition technique because of Mode S all-call fruit considerations. Since ground communication is provided for acquisition coordination, it can also be used for communication coordination.

7.4.27 Multisite protocols. The multisite protocols use slightly more channel time than the non-selective protocols but they can be implemented with a minimum of site-to-site coordination. Multisite protocols will be used whenever the non-selective protocols cannot be used, i.e. in the majority of cases.

7.5 EXAMPLE OF OVERALL GROUND STATION OPERATION

7.5.1 A functional block diagram of a Mode S ground station showing the interrelationship of major functions is presented in Figure 7-12. Three different categories of processing are identified in the figure. Pulse processing refers to activities that take place within microseconds. These tasks are usually performed in special-purpose hardware. Beam dwell processing refers to activities that take place within the passage of the antenna beam and thus take place within milliseconds. Scan processing refers to activities that are performed each scan of the radar antenna
and thus take place within seconds. Dwell processing and scan processing are normally implemented in general purpose computers. Experience has shown that the implementation of beam dwell processing requires great care in order to complete channel management and Mode A/C reply correlation tasks within the allotted time.
Figure 7-1. An example of Mode A/C/S time-sharing

*Typically 25-30 ms for a terminal sensor
Note.— The Mode S period illustrated comprises three schedules. The second schedule includes eight transactions, grouped in three cycles of 4, 3 and 1 transactions, respectively.
(a) Cycle containing surveillance and standard length message transactions

<table>
<thead>
<tr>
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<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
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<tbody>
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<td>Surveillance</td>
<td>Surveillance</td>
<td>Surveillance</td>
</tr>
<tr>
<td>Reply</td>
<td>Surveillance</td>
<td>Surveillance</td>
<td>Surveillance</td>
<td>Comm-B</td>
</tr>
</tbody>
</table>

(b) Cycle containing surveillance, uplink standard length message and downlink extended length message transactions

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<th>3</th>
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<td>Surveillance</td>
<td>Comm-C</td>
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<tr>
<td>Reply</td>
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<td>Surveillance</td>
<td>Surveillance</td>
<td>Surveillance</td>
<td>Comm-D</td>
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</table>

(c) Cycle containing surveillance and uplink extended length message transactions

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<th>Type</th>
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<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
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<td>Surveillance</td>
<td>Surveillance</td>
</tr>
<tr>
<td>Reply</td>
<td>Comm-D</td>
<td>Surveillance</td>
<td>Surveillance</td>
</tr>
</tbody>
</table>

Figure 7-3. Examples of Mode S cycles
Note.— The dashed lines from the channel control function indicate the flow of control data.

Figure 7-4. An example of channel management
Figure 7-5. An example of surveillance processing for a Mode S ground station collocated with a primary radar
Figure 7-6. An example of data link management
Each cell specifies
Ground station (G) priority and altitude cutoff (A)

- $G_1, A_1$ → Principal ground station
- $G_2, A_2$ → Alternative (Surveillance)
- $G_3, A_3$ → Backup coverage

Figure 7-7. Example of a coverage map grid structure
Figure 7-8. Overlapping coverage of closely spaced Mode S ground stations
Figure 7-9. Possible interrogator identifier (II) code assignment
(six ground stations)
Figure 7-10. Possible interrogator identifier (II) code assignment (eleven ground stations)
Figure 7-11. Possible interrogator identifier (II) code assignment with netted clusters of ground stations
Figure 7-12. One example of a Mode S ground station functional block diagram
Chapter 8

INTERFERENCE CONSIDERATIONS

8.1 OVERVIEW

8.1.1 Mode S and Mode A/C SSR use the same interrogation and reply frequencies (1 030 MHz and 1 090 MHz). The availability of free time on both of these channels depends, on the one hand, on the number and distribution of aircraft in an airspace illuminated by the antennas of a group of ground stations and, on the other hand, on the interrogation (including the consequent suppression) rates and the number of replies from each aircraft. Since each ground station in the group interrogates independently of the others, it suffers from interference by replies generated in response to interrogations from other ground stations and also from transponders being occupied by other ground stations at the time access is being attempted.

8.1.2 Interference can result in a degradation of the system performance causing lost or wrong information. The reasons for this degradation are mainly transponder occupancy and RF signal distortion. Transponder occupancy is any mechanism that prevents valid signals arriving at the transponder from triggering the desired reply. RF signals on either uplink or downlink can be distorted by other overlapping RF signals which can make correct decoding of wanted signals impossible. The degree of degradation is a function of the channel loading.

8.1.3 Mode A/C transponders can give false information if a Mode C interrogation is converted to an apparent Mode A interrogation by an interference pulse from another interrogation falling in a position 8 microseconds or possibly 13 microseconds after the genuine P₁ pulse. Also, if an interference pulse falls a mode spacing before P₁, a reply will be generated at the wrong range and possibly in the wrong mode. Lost information occurs when the transponder is interrogated when it is either in suppression or in the process of replying to an interrogation from another ground station with overlapping cover.

8.1.4 When Mode S transponders are operating in a Mode A/C-only ground station environment the interference considerations are identical to those for Mode A/C transponders. The introduction of Mode S ground stations into such an environment will, however, result in different interference mechanisms, the effect of which will depend on many factors including the number of Mode S and Mode A/C transponders and the particular Mode S protocol in use.

8.1.5 The interference phenomena are different for uplink and downlink. In an environment where Mode A/C and Mode S equipment are used in the same airspace, the effect of interference is different for each system. For example a Mode A/C transponder is suppressed by a Mode S interrogation while a Mode S transponder will process the interrogations and reply if it is correctly addressed.

8.1.6 SSR system-generated interference can be minimized by a) using the lowest transmitter power level possible, consistent with desired performance and b) ensuring that interrogation rates are as low as possible and are not synchronous with any ground station having overlapping cover. PRF stagger can also be used, thus ensuring that synchronous interference does not take place.

8.1.7 The transponder cannot process incoming RF signals for interrogation acceptance under the following conditions:

a) it is suppressed on its internal aircraft suppression bus due to RF transmission from other avionics equipment;

b) it is in a transaction cycle; or

c) it cannot decode Mode A/C signals when a P₁-P₂ suppression pair has been accepted, until the suppression period is over.
8.1.8 An important consideration in reducing channel activity is assigning the minimum number of interrogators to a region of airspace, consistent with operational requirements. The combination of II and SI codes makes it possible to uniquely identify 78 different interrogators or clusters. This unique identity capacity has been provided to ease the assignment of interrogator codes, especially for the case of mobile interrogators. It must not be allowed to become a reason for over assignment of interrogators in a region of airspace, since this will lower the performance to all users.

8.2 TRANSPONDER OCCUPANCY

GENERAL

8.2.1 A transponder is occupied from the time it detects an incoming signal that causes some action to be initiated, e.g. either a valid interrogation or suppression pair, to the time that it is capable of replying to another interrogation (including turnaround delay, reply time and dead time). For valid interrogations generated by one SSR or Mode S ground station, the occupancy depends on whether:

a) it is in the cover of the main beam only or in the side-lobe cover; or

b) it is an interrogation that does or does not elicit a reply.

IN THE MAIN BEAM OF A MODE S GROUND STATION

8.2.2 Assuming the ground station is also interrogating on Mode A/C, a Mode A/C transponder will be occupied in the normal way to these interrogations but in addition it will be suppressed for every Mode S interrogation made while it is in the beam.

Note.— Mode A/C transponders treat intermode interrogations as conventional Mode A/C interrogations.

8.2.3 A Mode S transponder will be occupied by all Mode S interrogations specifically addressed to it. This includes Mode S-only all-call and broadcast interrogations. It will also be occupied by intermode interrogations with a long $P_4$. It is possible to minimize the transponder occupancy by both types of all-call interrogation by using the lockout protocol.

8.2.4 A Mode S transponder will be occupied by the receipt of main-beam Mode S interrogations addressed to another aircraft. The transponder must fully decode the interrogation to determine the address contained in the message block. Once the transponder determines that the interrogation is intended for another transponder, it will resume normal operation. This activity will nominally require 45 microseconds.

IN THE SIDE LOBES OF A MODE S GROUND STATION

8.2.5 A Mode S transponder will only be occupied by a Mode S interrogation specifically addressed to it. This should not normally happen in the side lobes. The transponder will however be occupied to Mode A/C for the suppression period after the receipt of every $(P_1-P_2)$ pair. However, during and after the receipt of a Mode S side lobe interrogation, the Mode S transponder will not be able to detect valid interrogations which are below the current threshold up to the time of recovery to full sensitivity.

8.2.6 A Mode A/C transponder will be occupied by the normal suppression for Mode A/C and intermode interrogations.

8.2.7 It is important to note that a Mode A/C transponder will be suppressed by every Mode S interrogation, including broadcast and Mode S-only all-call interrogations, made by that ground station.

8.2.8 If selectively addressed Mode S interrogations are transmitted without an accompanying $P_5$ suppression pulse, all transponders receiving the interrogation will be occupied until the interrogation has been fully decoded. If the interrogation is accompanied by a $P_5$ pulse, the transponder is only prevented from decoding other interrogations until the sync phase reversal recognition fails, followed by the receiver recovery time.

SELECTIVE MODE S TRANSPONDER OCCUPANCY

8.2.9 The Mode S protocols provide the facility to lock out the transponder to all types of all-call interrogations requiring a Mode S reply. This can be regarded as permanent occupation of the transponder to that type of interrogation and great care must be exercised to ensure that the use of these protocols does not prevent other ground stations with a need to acquire the transponder through all-call interrogations from doing so.
Chapter 8. Interference considerations

### TABLE OF TRANSPONDER OCCUPANCY FOR DIFFERENT INTERROGATIONS

8.2.10 The total occupancy is made up of several nominal times as listed in Table 8-1. The term “transaction cycle”, defined in Annex 10, Volume IV, Chapter 3, 3.1.2.4 is used for Mode A/C transponders in the same manner as for Mode S transponders. (Note that the time for an additional SPI in a Mode A/C reply is not included.)

**Note.**— The total processing times for all interrogation types are listed in Table 8-2. The items in parentheses are references to the rows of Table 8-1.

### 8.3 CHANNEL LOADING

**GENERAL**

8.3.1 The channel loading is different on the uplink and on the downlink. For conventional SSR systems (Mode A/C) one interrogation is replied to by all transponders receiving that interrogation. Thus, the downlink loading is sometimes considerably higher than on the uplink.

8.3.2 When the selective interrogations of a Mode S ground station are used each selective interrogation normally triggers only one reply. This leads to a more balanced channel loading in terms of number of transmissions. Since the uplink transmission bit rate of 4 MHz is four times greater than on the downlink the total channel occupancy time on the uplink is also only 1/4 of the downlink loading for equivalent transactions.

**UPLINK LOADING**

8.3.3 The uplink channel loading should be measured or defined at the antenna of any aircraft in terms of interrogations per time unit or time occupancy. The loading is dependent on the location of an aircraft, i.e. the distance to a ground station and the flight level, which determines how many ground stations are illuminating it.

8.3.4 Inside the side lobes of a ground station antenna, an aircraft receives continuously all interrogations from the ground station. Since this area is normally controlled by an omni suppression technique, suppression pulses will also be received.

8.3.5 Outside the side lobes the loading is due to the limited effective beamwidth of a rotating antenna dependent on the time when the beam sweeps through an aircraft.

8.3.6 Considering an aircraft being in the effective beam of a Mode S ground station antenna, the channel loading originating from this ground station is a function of the number of aircraft being selectively interrogated and of the degree of activity for surveillance and/or data link purposes. The channel loading is a function of the azimuth but can also vary with time.

8.3.7 The overall loading is dependent on the total number of ground stations interrogating the aircraft, measured during an interval of the order of one minute. This loading value represents a mean value, whereas during such an interval, peak values can be measured that are considerably higher than the mean value.

8.3.8 Since the channel loading is heavily dependent on the scenario, i.e. the number of ground stations, type and number of interrogations, number of aircraft and their type of equipment, etc., only some examples for typical scenarios can be given.

8.3.9 The replacement of a conventional ground station, using sliding window techniques, with a Mode S ground station reduces the Mode A/C interrogation rate due to the use of the monopulse technique. In this case, the all-call interrogation rate is typically between 100 and 150 per second. Assuming an effective beamwidth of 3.6 degrees and an antenna rotation time of 5 seconds, an aircraft located in the main lobe would receive between 5 and 8 all-call interrogations during each scan. Inside the side lobes the aircraft would receive all interrogations, i.e. 100 to 150 per second. When intermode interrogations can be used to acquire Mode S transponders, the same interrogation rate applies.

8.3.10 A Mode S-equipped aircraft may be selectively interrogated during a beam dwell time of 50 milliseconds with up to 15 surveillance or Comm-A interrogations. A 16-segment uplink ELM may be transferred during this time, whereby replies required for ELM delivery reduce the number of the former mentioned interrogations. These figures are derived from the minimum reply rates for Mode S transponders.

8.3.11 From highly loaded scenarios it is known that up to 15 aircraft can be simultaneously within the beam, while typical peak values are about 5 to 8 aircraft. Assuming all aircraft to be equipped with Mode S transponders and high data link activity, the number of Mode S interrogations can be in the order of 100 during a beam
dwell which would produce (in the given example) a peak interrogation rate of 2,000 per second. The maximum repetition rate for selective interrogations is limited to 2,400 per second averaged over a 40 millisecond interval.

8.3.12 For the delivery of an uplink ELM, the interrogation segments are normally transferred closely spaced. Therefore, they represent a higher potential for interference compared with surveillance or Comm-A interrogations.

**DOWNLINK LOADING**

8.3.13 The downlink loading should be measured or defined at the antenna of a ground station. This loading is a function of the number of aircraft within coverage and the number of interrogations from other ground stations interrogating the same aircraft in the same time period.

8.3.14 In the case of surveillance and standard length message transactions, the downlink loading corresponds to the uplink loading since a reply can only be triggered by an interrogation. It should be noted, however, that each Mode S transponder also transmits a squitter reply once each second.

8.3.15 As in a pure Mode A/C environment, all replies triggered by other ground stations are named fruit, so that the Mode A/C and Mode S fruit rate corresponds to the degree of uplink loading in the environment of the ground station where the fruit rate is determined.

**8.4 SSR GARBLING**

8.4.1 SSR replies from transponders can be corrupted by other signals arriving at the same time at the interrogator receivers. Interference that leads to the corruption of the reply is referred to as garble. There are two types of garble:

a) *Asynchronous garble*. The SSR reply is corrupted by a random signal that is not synchronized with the SSR interrogations.

b) *Synchronous garble*. The SSR reply is corrupted by other replies to the same interrogator.

8.4.2 Asynchronous garbling rarely causes corruption of the complete radar plot data for an aircraft. This is because the SSR system transmits several interrogations to each aircraft as the beam sweeps past. It is unlikely that random interference will corrupt all of the replies in the beam. The radar performs an averaging function of the replies that correlates across the beam reducing the impact of any random errors. Also, the radar typically performs scan to scan or track correlation that may have further error correcting functions that depend on the history of the aircraft track in the system. The most common source of signals leading to asynchronous garble is the replies from aircraft responding to other interrogators and airborne collision avoidance systems (ACAS). This is why it is important to operate neighbouring interrogators with different pulse repetition frequencies (PRF) and to operate random PRF stagger functions (in order to ensure that the interrogators remain unsynchronized).

8.4.3 Synchronous garbling occurs when aircraft close to each other in slant range respond to the same interrogation. Depending on the range difference between the aircraft, the reply pulses may overlap or interleave with each other. A standard SSR Mode A or C reply is approximately 1.7 nautical miles long; therefore, aircraft within this range of each other (slant range difference), at similar azimuths (i.e. within the antenna beam width), have a chance of the reply pulses overlapping each other. Because the replies from all aircraft are synchronized to the interrogator, multiple replies across the beam may be corrupted which may cause the reply averaging function of the radar to produce an erroneous result. If the garble situation persists from scan to scan, then the radar track history error correcting functions may also be corrupted. The following may result:

a) incorrect Mode A code for the aircraft;

b) incorrect Mode C (flight level) for the aircraft;

c) code swaps, where the wrong Mode A and/or Mode C data are associated with the aircraft;

d) phantom aircraft, where the overlapping reply pulses form a new aircraft (between the real aircraft) where one does not exist.

8.4.4 Synchronous garbling can occur when aircraft are at similar azimuths and at similar slant ranges, even where there may be large altitude separation, and can persist for several scans. Situations where synchronous garbling can occur include:

a) aircraft stacks where aircraft in the stack are moving around directly above and below each other;

b) groups of gliders riding the same thermal and flying small circuits above and below each other;
c) aircraft flying in the same airway at similar range and speed;

d) aircraft tracks crossing at a coincident range and azimuth;

e) helicopters converging to attend or provide television coverage of events such as concerts, horse racing and motor racing;

f) recreational flying events where multiple aircraft converge.

8.4.5 It is recommended that, for ATC operations based on SSR plot data, an operational objective should be to avoid synchronous garble situations persisting by carefully directing traffic to avoid loss of range and azimuth separation, even where altitude separation is being maintained.

8.4.6 Mode S radar systems employ techniques to avoid synchronous garble. During all-call acquisition, stochastic reply functions are employed to de-garble all-call replies where aircraft are in close proximity to each other. During roll-call surveillance, each aircraft is individually interrogated, thus avoiding synchronous garble.

8.5 RF INTERFERENCE FROM OTHER SYSTEMS

8.5.1 The SSR system requires a 3 dB receiver bandwidth of approximately 8 MHz centred on 1 030 and 1 090 MHz for the airborne transponder and ground SSR receiver respectively. This bandwidth is sufficient to permit significant co-channel interference from transmitters operating on adjacent frequencies. This interference can be minimized by ensuring adequate frequency or spacial separation between the interfering transmitters and the SSR receivers. Two air traffic service (ATS) systems, DME and primary radar, can be the cause of interference. In the case of DME it is advisable to take care in using the DME channels adjacent to the SSR frequencies as transmission on these channels can cause interference to SSR. Some primary radar transmitters make use of two frequencies that if separated by 60 MHz can cause intermodulation products with consequent problems to collocated SSR systems.

8.5.2 Any incoming signal may cause the transponder to miss a valid interrogation. The duration of the interference depends on the signal source, the signal duration on the 1 030 MHz channel and the signal amplitude at the transponder antenna followed by any recovery from desensitization.
Table 8-1. Relevant times for transponder occupancy

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<td>10.8, 11.6 µs</td>
<td>19.75 µs</td>
</tr>
<tr>
<td></td>
<td></td>
<td>21.8 µs</td>
<td>23.8, 24.6 µs</td>
<td>33.7 µs</td>
</tr>
<tr>
<td>a2)</td>
<td>reference 2)</td>
<td>8 µs</td>
<td>11.6 µs</td>
<td>4.75 µs</td>
</tr>
<tr>
<td></td>
<td></td>
<td>21 µs</td>
<td>24.6 µs</td>
<td></td>
</tr>
<tr>
<td>b)</td>
<td><strong>transaction events</strong> 4)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b1)</td>
<td>reply delay</td>
<td>3 µs</td>
<td>128 µs</td>
<td>128 µs</td>
</tr>
<tr>
<td>b2)</td>
<td>reply duration</td>
<td>20.75 µs</td>
<td>64 µs</td>
<td>64 µs</td>
</tr>
<tr>
<td>b3)</td>
<td>transaction cycle: reply</td>
<td>23.75 µs</td>
<td>192 µs</td>
<td>192 µs</td>
</tr>
<tr>
<td>b4)</td>
<td>transaction cycle: no reply</td>
<td></td>
<td>15 µs</td>
<td>29 µs</td>
</tr>
<tr>
<td>c)</td>
<td><strong>dead time</strong></td>
<td>up to 125 µs</td>
<td>up to 125 µs</td>
<td>up to 125 µs</td>
</tr>
<tr>
<td>d)</td>
<td><strong>suppression</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>d1)</td>
<td>signal duration</td>
<td>2.8 µs</td>
<td>—</td>
<td>19.75 µs</td>
</tr>
<tr>
<td>d2)</td>
<td>reference 2)</td>
<td>2 µs</td>
<td>—</td>
<td>4.75 µs</td>
</tr>
<tr>
<td>d3)</td>
<td>suppression interval</td>
<td>35 µs</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>e)</td>
<td><strong>recovery</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>e1)</td>
<td>single pulse, interference</td>
<td>up to 15 µs 3)</td>
<td>up to 15 µs 3)</td>
<td>up to 15 µs 3)</td>
</tr>
<tr>
<td>e2)</td>
<td>interrogation not eliciting a reply</td>
<td>—</td>
<td>—</td>
<td>45 µs</td>
</tr>
</tbody>
</table>

Notes.—

1) Starting at reference.

2) Timespan from the beginning of the signal.

3) Depending on the signal amplitude beginning at the trailing edge of the signal (last pulse).
Table 8-2. Table of transponder processing times

<table>
<thead>
<tr>
<th>Received signals</th>
<th>Total transponder processing time $^{1,2}$</th>
<th>Mode A/C transponder</th>
<th>Mode S transponder</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$P_1P_3P_4$, Mode A</td>
<td>156.75 µs ($a_2+b_3+c$)</td>
<td>156.75 µs ($a_2+b_3+c$)</td>
<td>156.75 µs ($a_2+b_3+c$)</td>
</tr>
<tr>
<td>Mode C</td>
<td>169.75 µs ($a_2+b_3+c$)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$P_1P_3P_4$ short, Mode A</td>
<td>156.75 µs ($a_2+b_3+c$)</td>
<td>26.6 µs ($a_2+e_1$)</td>
<td>39.6 µs ($a_2+e_1$)</td>
</tr>
<tr>
<td>Mode C</td>
<td>169.75 µs ($a_2+b_3+c$)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$P_1P_3P_4$ long, Mode A</td>
<td>156.75 µs ($a_2+b_3+c$)</td>
<td>328.6 µs ($a_2+b_3+c$)</td>
<td>341.6 µs ($a_2+b_3+c$)</td>
</tr>
<tr>
<td>Mode C</td>
<td>169.75 µs ($a_2+b_3+c$)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$P_1P_2$</td>
<td>37 µs ($d_2+d_3$)</td>
<td>47 µs ($d_2+d_3$) for Mode A/C</td>
<td>4.75 µs ($a_2$) for Mode S</td>
</tr>
<tr>
<td>$P_1P_2P_3P_6$</td>
<td>37 µs ($d_2+d_3$)</td>
<td>4.75 µs ($a_2$) $^3$</td>
<td></td>
</tr>
<tr>
<td>$P_1P_2P_3P_6$ correctly addressed,</td>
<td>37 µs ($d_2+d_3$)</td>
<td>321.75 µs ($a_2+b_3+c$)</td>
<td>377.75 µs ($a_2+b_3+c$)</td>
</tr>
<tr>
<td>short reply</td>
<td>long reply</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$P_1P_2P_6$ not addressed</td>
<td>37 µs ($d_2+d_3$)</td>
<td>49.75 µs ($a_2+e_2$)</td>
<td></td>
</tr>
<tr>
<td>no received signal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Squitter, short</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>long</td>
<td>—</td>
<td>189 µs ($b_2+c$)</td>
<td>245 µs ($b_2+c$)</td>
</tr>
</tbody>
</table>

Notes.—

1) Additional effects may occur due to reply rate limiting.

2) The maximum value of dead time (125 µs) is used in the processing times values calculated in the table. Typical values are significantly lower.

3) In this case the incoming RF signal extends beyond this time and other incoming signals will only be decoded if they are sufficiently above the receiver threshold set by the original signal.
Chapter 9

THE MODE S SUBNETWORK OF THE ATN

9.1 CONSIDERATIONS CONCERNING DIGITAL DATA INTERCHANGE

INTERNETWORK ARCHITECTURE

9.1.1 An internetwork data communication architecture (i.e. an architecture composed of multiple interoperating networks) offers the greatest flexibility in design, management and control of each independent subnetwork and allows each subnetwork to be optimized for use in its own environment. The alternative (i.e. one unified subnetwork encompassing all aircraft and ground processing) would impose an unnecessarily high degree of standardization and present formidable management problems. This would be especially undesirable in an environment where various avionics application processors need to exchange data with various ground-based application processors, all operated and controlled by different authorities and organizations.

9.1.2 The aeronautical data communication logical connectivity illustrated in Figure 9-1 may be described as an internetwork architecture.

9.1.3 Data transfer through an aeronautical internetwork environment is supported by three types of data communication subnetworks:

a) avionics subnetworks;

b) ground subnetworks; and

c) air-ground subnetworks.

9.1.4 The transfer of data between two end-systems (i.e. application processors) of the aeronautical data communication system is accomplished through the interconnection of these subnetworks in a manner providing a continuous path between the respective end-systems.

AVIONICS SUBNETWORKS

9.1.5 Modern aircraft will, in general, incorporate one or more internal subnetworks which interconnect the various processes required for the operation of flight systems. These are referred to as avionics subnetworks. In an aircraft equipped for aeronautical data communication, these subnetworks are used to interconnect the aircraft data communication processors (such as the Mode S airborne data link processor (ADLP)) with aircraft application processors (such as data display processors, data entry processors and flight management computers).

9.1.6 In the simplest (i.e. single air-ground subnetwork) case, an aircraft application processor may be connected directly to a dedicated data communication processor (stand-alone operation). Where internetwork operations are desired, each aircraft application processor may have access to one or more data communication processors and thus to their respective air-ground subnetworks.

GROUND SUBNETWORKS

9.1.7 Contemporary ground-based data processing facilities require a similar level of connectivity among the various processors local to that facility. A ground subnetwork provides the required connectivity within such a facility, often in the form of a local area network (LAN). The ground subnetworks also provide interconnection of ground application processors with ground data communication processors (such as the Mode S ground data link processor (GDLP)), in order to access the aircraft-resident end-systems.
9.1.8 In the case of air traffic service (ATS) facilities, the various ground subnetworks will generally have different physical and logical characteristics while serving the common purpose of connecting the various ground application processors supporting air traffic management (ATM), an example of which is shown in Figure 9-1.

9.1.9 The air traffic service facilities will generally be interconnected via ground subnetworks and other data networks may also be interconnected with ATS ground subnetworks.

AIR-GROUND SUBNETWORKS

9.1.10 An air-ground subnetwork serves to interconnect end-systems of ground subnetworks with end-systems of avionics subnetworks. The air-ground subnetwork performs this function by transferring messages to the destination avionics subnetwork from the originating ground subnetwork and by transferring messages from the originating avionics subnetwork to the destination ground subnetwork.

9.1.11 The Mode S data link is one of several air-ground data subnetworks serving the mobile aviation end-system. Other subnetworks include the VHF data link subnetwork and satellite data link subnetwork. An air-ground subnetwork may interconnect with ATS ground networks, as well as with other ground networks.

INTERCONNECTION OF SUBNETWORKS

9.1.12 For messages to be passed between the ground and avionics subnetworks through the air-ground subnetwork, there must be a clearly defined transition from one subnetwork to another. This is provided by an element known as an ATN router.

9.1.13 The interconnection of subnetworks that are physically, logically and administratively separate is performed through the installation of routers at the points of interconnection. Figure 9-1 illustrates how the subnetworks may be interconnected by routers.

9.1.14 The term router refers to the communication element that manages the information flow between the ground subnetworks, between the ground subnetwork and the air-ground subnetwork, and between the air-ground subnetwork and the avionics subnetwork.

MODE S OPERATIONAL GOALS

9.1.15 The operational goals of the Mode S subnetwork may be summarized as follows. It should:

a) support efficient, reliable data communications between:

1) ATS personnel and aircraft flight-deck personnel;

2) ATS computers and aircraft computers;

3) ground personnel and aircraft computers; and

4) flight-deck personnel and ground computers; and

b) conform with ATN standards thus facilitating:

1) cooperative message routing with other aeronautical data communication subnetworks; and

2) sharing of avionics application processors and avionics data entry and display systems with other aeronautical data communications subnetworks.

9.1.16 Mode S also supports the establishment of communications between ground and aircraft stand-alone applications. Stand-alone applications are those operating directly over the Mode S ISO 8208 subnetwork.

9.2 MODE S SUBNETWORK SERVICES PROVIDED

9.2.1 The Mode S air-ground subnetwork primarily provides a connection-oriented communication service between two subnetwork points of attachment (SNPA), one in the aircraft and the other on the ground. This service may be accessed by means of the protocol defined in ISO 8208, and is entirely conformant with the aeronautical telecommunication network (ATN) architecture. In addition, a number of services particular to the Mode S system, known as Mode S specific services, are offered. These may be accessed by means of locally defined special purpose interfaces or, in the case of the GDLP, through the SNPA.
9.2.2 The Mode S subnetwork is composed of the following functional elements: a Mode S transponder (level 2, 3, 4 or 5 defined in Annex 10, Volume IV, Chapter 2) an airborne data link processor (ADLP), a ground data link processor (GDLP), and a Mode S interrogator. The ADLP and GDLP have a standard ISO 8208 interface between the output of the subnetwork and the ATN router(s). Exchanges between the ADLP and GDLP use a modified form of the ISO 8208 protocol to reduce bandwidth requirements over the Mode S air-ground link.

9.2.3 It is not required that the physical boundaries of implemented systems correspond with the functional boundaries defined in SARPs (Annex 10, Volume IV, Chapter 3). For example, both aircraft (or ground-based) elements could be implemented within a single physical unit or, equally, subfunctions defined within one functional element might be implemented within the physical unit of another functional element.

9.2.4 The GDLP and ADLP may be considered as existing at the same level in the communication hierarchy, as can the interrogator and transponder. The ADLP and GDLP provide a subnetwork communication service by making use of the data link service of the interrogator-transponder pair(s).

9.2.5 The Mode S ground interrogator is responsible for operating the Mode S protocols, in conjunction with aircraft Mode S transponders, as defined in Annex 10, Volume IV, Chapter 3. Once acquired by an interrogator (i.e. by identifying its unique 24-bit aircraft address), a suitably equipped aircraft within Mode S coverage may be selectively interrogated for surveillance purposes. The interrogations may include uplink data fields and may invoke replies containing downlink data fields.

9.2.6 The Mode S GDLP provides functionality specific to the Mode S data link, so as to offer both a switched virtual circuit (SVC) communication service and access to Mode S specific services. A single GDLP may exploit the data link service of one or more Mode S interrogators, but due to topology restrictions, a given interrogator may be connected to only one GDLP.

9.2.7 The Mode S transponder operates in accordance with the Mode S protocols as defined in Annex 10, Volume IV, Chapter 3. Mode S selective interrogations (including data link transactions) are addressed to a given aircraft by means of a unique 24-bit aircraft address, allocated and assigned in accordance with Annex 10, Volume III. The aircraft address must be made available to the transponder by a locally defined interface contained in the equipment specification.

9.2.8 The Mode S ADLP provides functionality in the aircraft analogous to that of the GDLP on the ground.

9.2.9 Data link transactions may be carried out using one of two possible protocols over the Mode S link between the Mode S interrogator and the Mode S transponder.

9.2.10 The standard length message (SLM) protocol employs “long” Mode S interrogations and/or replies, each containing a 56-bit message segment. An uplink SLM interrogation is known as a Comm-A, (containing the MA message field), and a downlink SLM reply is known as a Comm-B, (which contains the MB message field). Comm-A interrogations are sent directly to the transponder, under the control of the interrogator, and each one must be acknowledged by a reply from the transponder. Each Comm-B reply must be extracted by an interrogation, under the control of the ground interrogator. The SLM protocol provides for up to four Comm-A (or four Comm-B) segments to be logically linked together. Such a concatenated sequence of Comm-A (or Comm-B) segments is referred to as an SLM frame.

9.2.11 The alternative technique is the extended length message (ELM) protocol. This provides lower overhead and more efficient use of the channel capacity for longer messages that cannot be accommodated in an SLM frame. An uplink ELM transaction is known as a Comm-C (containing an 80-bit MC message field) and a downlink one as a Comm-D (containing the 80-bit MD message field). The ELM protocol provides for up to sixteen Comm-C (or Comm-D) segments to be logically linked together. The interrogations (or replies) containing these segments are transmitted in succession without intervening replies (or interrogations) resulting in very low overhead. The commencement of an ELM transfer is under the control of the ground interrogator and the transfer is acknowledged only after the last segment has been sent. The acknowledgement includes a feature to request retransmission of missing or corrupted segments. A sequence of Comm-C (or Comm-D) segments is known as an ELM frame.

9.2.12 In a typical switched virtual circuit (SVC) data transfer over the Mode S subnetwork, the following operations would take place:
9.2.13 In the description of the data exchange fields, the decimal equivalent of the binary code formed by the bit sequence within a field is used as the designator of the field function.

PACKETS, FRAMES AND USER DATA

9.2.14 User data is the means of carrying application generated messages across the subnetwork to and from end systems. As an example, “an air traffic controller uplinks a clearance message to the pilot”. This message is relayed across the network as user data until it reaches its final destination and becomes an application message. User data can also be used for connection set-up and initialization negotiation for upper layer protocols. In Mode S, user data is delivered across the subnetwork in the form of packets and frames and is not altered in any way.

9.2.15 A packet is the basic unit of communication among devices within the subnetwork. Packets use a set of rules to exchange communication set-up from one device to the next for the means of relaying data across the networks. In the context of the Mode S subnetwork, a Mode S packet is designed to minimize the bandwidth required from the air-ground link. A Mode S packet can be summarized as a record of bytes which contain a packet header specific to the Mode S subnetwork as well as user data information. The relationship between packets and frames relative to the Mode S subnetwork functional elements is presented in Figure 9-2.

9.2.16 A frame is the basic unit of communication among devices within the link layer. Frames (much like packets) use a set of rules to exchange communication information from one link to another. In the context of the Mode S subnetwork a Mode S frame is used as the communication protocol across the RF link between the Mode S transponder and the Mode S interrogator, and can include one to four Comm-A or Comm-B segments, two to sixteen Comm-C segments, or one to sixteen Comm-D segments.

FRAMES

Uplink frames

9.2.17 Up to four Comm-A segments may be logically associated to form an SLM frame. The number of linked Comm-A segments is limited to four because longer linked Comm-A transmissions would result in inefficient utilization of the Mode S link, as well as slow frame delivery. Longer frames can be transferred more efficiently using the ELM protocol.

9.2.18 Each standard length transaction requires an interrogation/reply sequence and hence each such transaction is processed separately by the transponder. Consequently, no assembly/segmentation of linked SLMs is mandatory in the transponder itself, provided the appropriate fields are included in the segments transferred from the transponder to allow the successful re-assembly of linked SLMs by the ADLP.

9.2.19 An uplink ELM frame consists of two to sixteen segments, logically linked by the Mode S ELM protocol. Each uplink ELM segment consists of an 80-bit field containing the 4-bit interrogator identifier (II) code transferring the ELM in the most significant 4 bits, and 76 bits of message data.

Downlink frames

9.2.20 Up to four Comm-B segments may be logically associated to form a downlink SLM frame.

9.2.21 When the Mode S interrogator detects a non-zero linked Comm-B subfield (LBS) code in an air-initiated Comm-B segment, it can proceed immediately with the ground-initiated Comm-B protocol and request the remaining segments of the SLM frame. When it has received all of the segments, it closes out the air-initiated segment that began the linked Comm-B protocol.
9.2.22 A downlink ELM frame consists of one to sixteen segments logically linked by the Mode S ELM protocol. Each segment contains an 80-bit message field.

**XDLP frame processing**

9.2.23 The placement of the Mode S subnetwork packets into SLM and ELM frames is referred to as frame packing. The complementary operation is referred to as frame unpacking. Provision is also made for a number of packets to be transferred between GDLP and ADLP, multiplexed into one SLM or ELM frame. The size of the Mode S packet will determine the framing strategy to be utilized by the originating XDLP.

9.2.24 The user data field is always an integral multiple of bytes in length.

9.2.25 The value of the length parameter (LV) field may be established by frame processing or by the reformatting process, depending on the implementation. Details on the use and calculation of the LV are given in 9.2.99.

9.2.26 The Mode S subnetwork also provides a mechanism known as “multiplexing” to concatenate multiple packets (destined for the same XDLP) into a single frame. Multiplexing may be applied to SVC packets and also Mode S ROUTE packets. However, multiplexing is not applicable to Mode S specific protocol (MSP) packets. This preserves compatibility with the airborne collision avoidance system (ACAS) and provides MSPs with the appropriate priority. Packets from different SVCs may be multiplexed together, but normally only where the SVCs are of the same priority; this is recommended for the GDLP and mandatory for the ADLP. This restriction helps to preserve the sequence of Mode S packets within an SVC.

9.2.27 In general, it is recommended that multiplexing be applied wherever possible in the interest of efficient use of data link capacity. In certain cases, the use of multiplexing might result in increased delivery time (e.g., where a short packet capable of transmission in an SLM is multiplexed into an ELM frame). Therefore, specific decisions on the use of multiplexing on the ground should be made locally.

9.2.28 The protocols defined for frame transfer could result in frame desequencing (e.g., a transponder will always announce a new Comm-B first, even if an ELM is already waiting in the transponder). In order to compensate for such desequencing, a resequencing algorithm has been defined, allowing the correction of a limited amount of desequencing. In order to avoid too many desequenced frames, it is required that the order of SLM and ELM frames be maintained within the XDLP.

**GDLP frame processing**

9.2.29 Prior to being passed to the interrogator for transmission, uplink packets are converted into Mode S frames by the frame processing function. This process must take into account transponder capability, obtained from the data link capability report, as described in 9.3, since not all installations may be capable of processing ELM frames. The reciprocal transformation is performed by the GDLP for downlink packets.

9.2.30 Elements of the GDLP frame processing may be distributed to the Mode S interrogator.

9.2.31 The implementation of multiplexing in the Mode S ground environment (i.e., the GDLP/interrogator functions) must take into account that with rotating antennas, one of the main causes of queue build-up of Mode S packets for transfer to a particular aircraft is the waiting for the antenna beam to illuminate the aircraft. To achieve maximum benefit under these conditions, multiplexing should take place at the interrogator because it alone has the knowledge of the time at which transactions can be performed with the aircraft. When multiplexing is done in the GDLP for a rotating antenna system, the GDLP should control the queue for a particular aircraft to the maximum number of transactions that can be expected to be delivered in a beamwidth. The GDLP should assure that the total number of transactions to all aircraft in a particular beamwidth does not exceed the available time. If a non-rotating antenna (E-scan, omni or sector beam) is used to provide constant access to the aircraft, multiplexing will not be required very often because all aircraft will always be available for a transaction.

9.2.32 A transaction must never be delayed in the expectation of the arrival of another Mode S packet in order to multiplex into a more efficient link transfer frame.

9.2.33 In order to ensure that frames for transfer to a particular transponder are not desequenced by more than the resequencing algorithm in the ADLP can correct, it is necessary for the GDLP to (1) have knowledge of the frame handling algorithms in the interrogator and (2) control the flow of frames for transmission to the transponder accordingly. For example, if an interrogator automatically gives precedence to SLMs, then the GDLP must not send a long queue of SLMs to the interrogator because this could result in long delays (and hence desequencing) for an ELM on the same SVC.
ADLP frame processing

9.2.34 Prior to being passed to the transponder for transfer to the ground, downlink packets are converted to Mode S frames by the frame processing function which includes multiplexing. ADLP frame processing must take into account the transponder capability and must therefore be configurable to work with the characteristics of any transponder with which it is intended to operate.

9.2.35 The ADLP outputs frames to the transponder together with information defining the protocol type and the interrogator intended to extract the downlink frame.

9.2.36 The implementation of multiplexing in the aircraft part of the Mode S subnetwork will be dependent on whether separate ADLP and transponder or a combined ADLP/transponder are used. For most efficient frame packing in the case of separate ADLP and transponder, the ADLP must ensure that only minimum data queuing takes place in the transponder. This will enable the transponder to continue to operate close to its maximum rate. If a combined ADLP/transponder is designed ideally multiplexing should take place immediately prior to the insertion of a frame into the output message buffer.

9.2.37 The Mode S protocols specify that a transponder will always announce SLM frames for transfer to the ground in preference to ELM frames, regardless of the order in which the frames arrive at the transponder. It is essential that the ADLP controls the flow of frames to the transponder in such a way that excessive desequencing does not take place. In order to perform this function efficiently, it is necessary to ensure that long queues of SLMs (which could block an ELM for a long period) are not transferred to the transponder.

PRIORITY MANAGEMENT

9.2.38 For efficient priority management, when a separate ADLP and transponder are used (as described above for multiplexing), only the minimum number of frames should be queued inside the transponder. If long queues are allowed to form in the transponder, management of these queues may become cumbersome since the use of a cancellation function via the transponder interface may be required. In the ADLP, it will be necessary to operate queues for high priority SVCs and for low priority SVCs, as well as a queue for MSPs and another for broadcasts. The broadcast protocol is used to issue a Search Request packet on power up or a system reset and under these conditions the ADLP must ensure that this activity takes priority over all activities other than Mode S specific services.

9.2.39 The GDLP must transfer sufficient frames (if available) to the interrogator for a particular aircraft to ensure optimum utilization of the channel. Otherwise, message queues will need to be maintained in the GDLP to simplify queue priority management.

9.2.40 When a rotating antenna is used by the Mode S interrogator, priority can be handled by maintaining four queues for each aircraft, two for SVCs (one high priority and one low priority), one for MSPs, and one for ground-initiated Comm-B (GICB) requests. In addition, there is a single broadcast queue for all aircraft. The reason for the separate queue for GICB requests is to enable them to be combined with other uplink SLM or surveillance transactions, thus allowing even a low priority SVC to be serviced with the same interrogation that is servicing the GICB request. It is necessary to ensure that ROUTE packets take priority over the two SVCs. This can be achieved by having another separate queue, or by a mechanism which automatically moves ROUTE packets to the head of the high priority SVC queue. With a rotating antenna, the priority handling will be more effective if it is done in the interrogator so that priority decisions can take place at the latest possible time (i.e. immediately prior to the aircraft becoming available in the beam).

9.2.41 When a non-rotating antenna is used by the Mode S interrogator, aircraft are always accessible and message queues should be handled (1) in order of priority and (2) within the priority level by the arrival time of the messages. The priority handling will not be greatly affected by its location, which may be in the GDLP or the interrogator. In the interests of link efficiency, a separate GICB request queue for each aircraft is still advantageous, because it allows the GICB requests to be combined either with a surveillance polling transaction or another uplink data-link transaction if there is one.

DATA EXCHANGE INTERFACES

DTE ISO 8208 interface

9.2.42 The DTE interface with the Mode S subnet-work is referred to in the Mode S subnetwork SARPs (Annex 10, Volume III, Part I, Chapter 5) and in this manual as the DTE/DCE interface. This conforms with the ISO 8208 protocol.

9.2.43 The physical and link layers of the ground DTE/DCE interface are to be capable of interoperating with existing local or wide area subnetworks.
9.2.44 Although DTE address assignment is a local issue, it is necessary to assign DTE addresses in an unambiguous manner in order to ensure the correct operation of the Mode S subnetwork.

9.2.45 A ground DTE will be incorporated into an ATN router or a stand-alone ground end-system, and allocated a DTE address in the range 0 through 255. The following guidelines should be adhered to when allocating ground DTE addresses:

a) a single GDLP may be connected to more than one ground DTE, but due to restrictions in the topology, each DTE may only be connected to a single GDLP; and

b) for Mode S interrogators operating in a clustered manner which are further connected to a single GDLP, the interrogator identifier (II) code allocation may be used to derive the DTE address thus ensuring an unambiguous association.

9.2.46 The mobile DTE address is the 24-bit aircraft address with a sub-address, in the range 0 through 15, which identifies specific DTEs on board an aircraft.

9.2.47 The ISO connection-oriented subnetwork protocol standard is defined in ISO 8208. Table 9-1 lists the different packet types defined by ISO 8208 to support connection-oriented subnetwork service.

9.2.48 In accordance with ISO 8208 the default maximum user data field length is 128 bytes. In addition, other (non-standard) default maximum user data field lengths may be available from the following list: 16, 32, 64, 256, 512, 1024, 2048 and 4096 bytes. The selection of a non-standard default value is a local issue at a DTE/DCE interface and has no influence on the Mode S packet layer protocol, because the exact length of the user data field can be extracted from the data link layer information field of the DTE/DCE interface.

9.2.49 Selection of a non-standard value should be based on (1) the requirement for efficient data transfer across the interface and (2) buffer restrictions in the XDLP, e.g. when the average size of the messages is larger than the default maximum user data field length, a larger default value should be selected to reduce overhead and to increase interface efficiency. This might be the case for the connection to an ATN router, but such a selection will result in larger buffer requirements. On the other hand, for connections to applications which have to transfer only small messages, the maximum length can be reduced to save buffer space. This may be the case for connections to stand-alone applications. For SVCs, this choice applies in common to all logical channels at each DTE/DCE interface. Negotiation of a maximum user data field length on a per SVC basis is only allowed by subscription to the flow control parameter negotiation facility.

### Flow control over the DTE/DCE interface

9.2.50 The flow control mechanism to be used on the DTE/DCE interface is described in the provisions of ISO 8208.

9.2.51 The principal mechanism of flow control is the use of a rotating flow control window. Permission is granted by a receiver of packets for the transmitter to send not more than the number of packets that would fill the flow control window (nominally 2 packets). Once this number has been transferred, if a receiver wishes to allow more packets to flow, then the window must be updated by transfer from the receiver to the transmitter of a revised value for “next expected packet sequence number” denoted P(R), either in a DATA packet, or else in a RECEIVE READY (RR) packet. Conversely, a receiver may prevent the flow of more packets by failing to update the value of P(R).

9.2.52 The flow control window technique is a necessary, but not always sufficient mechanism to provide effective flow control over the DTE/DCE interface, and there are certain conditions where additional measures may be necessary. The most notable cases are as follows:

a) where a packet containing an updated P(R) is lost, permission to send further packets is not received by the transmitter, and the flow of packets ceases; and

b) where insufficient buffer space is available in the GDLP to accommodate packets from open flow control windows on all active SVCs, there is a risk of data loss when DATA packets are transferred within an open window.

9.2.53 In order to overcome the situation in 9.2.52 a), ISO 8208 provides two additional optional procedures. These are either:

a) for the transmitter to start a Window Rotation Timer (T25) each time a packet is transferred across the interface, representing the maximum time that the transmitter will wait for an update to the P(R)
value; upon expiry of the timer, the transmitter either resets the SVC or re-sends all DATA packets in the window; or

b) for the receiver to send at least every Window Status Transmission Timer (T24) time units a flow control (RR, RNR) or DATA packet to carry the current P(R) value to the transmitter.

XDLP implementors should provide at least one of the above procedures to prevent indefinite flow control lockout in the event of packet loss.

9.2.54 In order to overcome a shortage of space as described in 9.2.52 b), ISO 8208 provides a RECEIVE NOT READY (RNR) packet, which allows a receiver to inhibit the flow of packets on an SVC in spite of the fact that the flow control window remains open. The transmission of this packet is optional within ISO 8208, and in implementations where buffer space is adequate to accommodate all packets that could be transferred within the open windows of all SVCs, the transmission of the RNR packet is not required to implement effective flow control on the DTE/DCE interface. The XDLP must, however, be able to act upon a received RNR packet from a DTE, as described by the state tables contained in Annex 10, Volume III, Part I, Chapter 5.

9.2.55 Flow control over the DTE/DCE interface is a local issue, and has no end-to-end significance over the subnetwork. Flow control is required also between the DCE and XDCE, and is provided by the Mode S packet layer protocol. These individual instances of local flow control must be coordinated to ensure that effective congestion management is provided across the entire subnetwork to ensure that packet loss does not occur under normal or congested conditions.

Mode S specific services interface

9.2.56 There are certain additional services provided by the Mode S data link protocols that are not available in the OSI standard protocols. These are the broadcast protocols (uplink and downlink) and the GICB protocol. In addition, a Mode S feature corresponding to a datagram service has been developed for certain real-time applications. This is referred to as a Mode S specific protocol (MSP). Collectively, these services are referred to as Mode S specific services.

9.2.57 Provision is made for Mode S specific services to be accessed by means of one or more special purpose interfaces, routing data directly between applications and the Mode S specific services entity (SSE) of the XDLP. Alternatively an application may access the SSE by means of the DTE/DCE interface.

9.2.58 Access to the SSE must take account of the following factors:

a) the SSE is dedicated mainly to time-critical applications. In this context, it is generally better to tolerate sporadic loss of real time information (that will be replaced with more current data), than to enforce reliable, ordered end-to-end transmission of messages. Enforcing this discipline will put the communication system at risk of failing to keep up with the pace of the application;

b) the Mode S specific services support real time connectionless communication protocols with minimum overhead and do not fit into the basic concept of OSI. Implementing intermediate connection-oriented services between the SSE and its users would require the development of specific protocols, e.g. to ensure the proper end-to-end delivery of broadcast messages; and

c) most applications using Mode S specific services have a high probability of being run on stand-alone end-systems that have a direct connection with the GDLP, rather than communicating across the ATN.

For the reasons stated above, the recommended transport layer for real-time applications is the ISO 8602 connectionless transport service, provided that the associated processing overhead remains compatible with real-time constraints. Note that when used in this manner, the transport protocol does not provide end-to-end error protection.

9.2.59 When connection-oriented intermediate layers are excluded, the responsibility for managing the dialogue between the SSE and its subscribers depends entirely on the applications.

ADLP/transponder interface

9.2.60 The interface between the transponder and the ADLP is a local issue, but will need to support the following information:

a) uplink frames and protocol information;

b) downlink frames and protocol information;

c) control information from the transponder indicating the status of downlink transactions; and
control information to the transponder selectively cancelling incomplete downlink transactions.

GDLP/Mode S interrogator interface

9.2.61 The interface between the GDLP and the interrogator is a local issue, but will need to support the following information:

a) uplink Mode $S$ frames and protocol type from the GDLP;

b) downlink Mode $S$ frames and protocol type from the interrogator;

c) control information from the interrogator, indicating the status of uplink transfers;

d) information from the interrogator on the capability of Mode $S$-equipped aircraft;

e) information from the interrogator on Mode $S$-equipped aircraft within coverage; and

f) information from the GDLP allocating data link responsibility to interrogators for given aircraft.

DCE operations

DCE state transitions

9.2.62 An ISO 8208 packet received from the DTE can cause state transitions, as can a packet received from the XDCE. State transitions are determined by instructions in the state tables. The states of the DCE exist in a hierarchy described in Figure 5-2 of Annex 10, Volume III, Part I, Chapter 5, which is reproduced for convenience as Figure 9-3.

DCE disposition of packets

9.2.63 Packet transfer between the DCE and the XDCE is determined by instructions in the state tables.

Mode $S$ packet layer processing

ISO 8208/Mode $S$ packet mapping

9.2.64 The XDLP maps certain ISO 8208 packets (see Table 9-1) into Mode $S$ packets, based on information provided via the DTE/DCE interface.

Buffer requirements

9.2.65 Requirements for buffers in the ADLP. In order to maintain air-to-ground connectivity utilizing SVCs, buffering for channel management, data storage and processing must be provided. Buffers to operate a channel can be assigned separately for each process (DCE, XDCE, frame processing, reformatting and SSE). Alternatively, a common buffer can be used.

9.2.66 Flow control buffers. In the downlink direction, the flow control window buffer is required in the event that the GDLP is not ready to accept Mode $S$ data packets from the ADLP. In this event, the flow control window buffer of 2 400 (160 x 15) bytes per SVC can be utilized to maintain up to 15 Mode $S$ subnetwork DATA packets of 160 bytes each for a transponder with uplink ELM capability, or 420 (28 x 15) bytes of buffer space for transponders without ELM capability (which utilize a maximum of 28 byte frames). An example of downlink flow control window buffer utilization is provided in Attachment A to Chapter 9.

9.2.67 In the uplink direction, the flow control window buffer is required in the event that the aircraft DTE attached to the ADLP is not able to receive DATA packets from the ADLP. In this case, the flow control window buffer of 2 280 (152 x 15) bytes per SVC can be utilized to maintain up to 15 Mode $S$ subnetwork data packets from the GDLP of up to 152 bytes for a transponder with uplink ELM capability, or 420 (28 x 15) bytes of buffer space for transponders without ELM. An example of uplink flow control window buffer utilization is provided in Attachment A to Chapter 9.

9.2.68 Interrupt data delivery buffers. When it is necessary to deliver data as quickly as possible by bypassing all flow control mechanisms, the ADLP can store two Mode $S$ INTERRUPT packets, (one in the uplink direction and one in the downlink direction) until the receiver of these messages is ready to receive again. A storage space of 35 bytes each (user data plus control information) is required for each SVC.

9.2.69 Resequencing buffer. In the event that packets from the GDLP to the ADLP are received out of sequence, the resequencer will (1) allow for the reordering of these packets or (2) cause the process of the ADCE to request retransmissions from the GDLP if the desequencing resulted from one or more lost packets. For this activity, the ADLP may utilize up to 4 712 (152 x 31) bytes of resequencing buffer space per SVC for a transponder with uplink ELM capability or 868 (28 x 31) bytes of resequencing buffer space for transponders without ELM capability.
9.2.70 **M-bit or S-bit assembly buffer.** When M-bit or S-bit linking of packets is in use within the ADLP, it becomes necessary to buffer message sequences (which indicates more data to follow) until receipt of the final packet in the sequence. The buffer allocation for this purpose should provide sufficient storage for the linking of up to 10 uplink ELM packets. Uplink ELMs can contain a maximum of 152 bytes each, for a total buffer size of 1,520 bytes per SVC in the uplink direction. Each downlink ELM can contain a maximum of 160 bytes, for a total buffer size of 1,600 bytes in the downlink direction.

9.2.71 **Multiplexing buffer.** When multiple Mode S subnetwork packets are awaiting transfer to the same GDLP, it is desirable to multiplex these packets into single frames in order to optimize throughput. In performing multiplexing functions, a variable length list of buffers (local queue of variable length) should be used to hold all packets awaiting transfer to the same GDLP. This variable length buffer is preferred over fixed length buffers since the number of packets that will be queued at any given point in time is unknown. Variable length buffers allow more efficient utilization of the buffer space assigned for multiplexing.

9.2.72 **MSP buffer.** When processing MSP type messages in the ADLP, 1,600 bytes of buffer space are allocated to be shared among all MSP software components. This includes the storing of L-bit linked MSP packet sequences in the uplink direction for all MSP channels.

9.2.73 Resequencing is carried out independently for each SVC. Normally, receipt of a Mode S CALL REQUEST packet implies that a new SVC is to be established, and hence that a new resequencing buffer is required.

9.2.74 When a Mode S CALL REQUEST by GDLP is received by the ADLP, carrying a TC value which is associated with an existing SVC in the ADCE p4 state, the existing association is broken, and the CALL REQUEST placed in a new resequencing buffer in readiness for the establishment of the new SVC.

9.2.75 In the event that a Mode S CALL REQUEST by GDLP is received carrying a TC associated with an existing SVC which is not in the ADCE p4 state, then the CALL REQUEST may be discarded as a duplicate.

9.2.76 **Buffer size rationale for the GDLP.** The GDLP will be required to support and maintain buffer space for two SVCs per Mode S data line-equipped aircraft in the coverage area of the interrogators servicing the aircraft. The rationale for buffering is similar to that of the ADLP. However, the size of these buffers is dependent on the instantaneous maximum number of aircraft that must be serviced by the GDLP. The buffer size allocation for the GDLP may be variable in length (as recommended for the ADLP) or may be of fixed length. Considerations in the choice of the buffer approach to be used are given in the following paragraphs.

9.2.77 The advantages of the variable length buffer approach are that:

a) it permits better utilization of available memory;

b) it allows for memory to be returned to the system when no longer needed; and

c) it supports a flexible allocation of memory resources such that the maximum number of aircraft is limited only by available memory, rather than by a fixed algorithm design limit.

9.2.78 The advantages of the fixed length buffer approach are that:

a) it is very straightforward to implement;

b) it requires only a simple memory management function; and

c) it uses no processing time for dynamic memory management.

Note.— Additional buffer space will be required if DTEs associated with end-systems are supported.

**Channel number pools**

9.2.79 A channel number will be assigned to each ISO 8208 SVC at the DTE/DCE interface. A channel number will also be assigned to each SVC between the GDCE and the ADCE. An association between these channel numbers must be established and maintained.

9.2.80 In order to provide for an unambiguous assignment of channel numbers between the GDCE and ADCE, two pools of channel numbers (temporary and permanent) are used at the GDCE/ADCE interface. The GDCE exclusively allocates temporary channel numbers in the range 1 through 3. The ADCE exclusively allocates permanent channel numbers in the range 0 through 15. The allocation of a permanent channel number by the ADCE either replaces an existing temporary channel number assigned by the GDCE or assigns a permanent channel number to a new SVC set up by the ADCE. In the first
case, the ADCE indicates the replacement to the GDCE in a Mode S CALL ACCEPT by ADLP packet. In the latter case the ADCE indicates the new assignment in a Mode S CALL REQUEST by ADLP packet.

9.2.81 The RECEIVE READY (RR) and RECEIVE NOT READY (RNR) conditions of the state machines indicate the ability of the XDLP to accept or not accept additional DATA packets for a given SVC from its peer entity. The Mode S RR and RNR packets are used to indicate these conditions at the ADCE/GDCE interface. A similar function is performed by the ISO 8208 RR and RNR packets at the DTE/DCE interface. Since there is no direct relationship between the DCE and XDCE state machines, the Mode S RR and RNR packets only relate to control of the XDCE state machine. These Mode S packets do not result in the generation of any corresponding ISO 8208 packets.

9.2.82 Resequencing is carried out independently for each SVC. Normally, receipt of a Mode S CALL REQUEST packet implies that a new SVC is to be established, and hence that a new resequencing buffer is required.

9.2.83 When a Mode S CALL REQUEST by GDLP is received by the ADLP, carrying a temporary channel number (TC) value which is associated with an existing SVC in the ADCE p4 state, the existing association is broken, and the CALL REQUEST placed in a new resequencing buffer in readiness for the establishment of the new SVC.

9.2.84 In the event that a Mode S CALL REQUEST by GDLP is received carrying a TC value associated with an existing SVC which is not in the ADCE p4 state, then the CALL REQUEST may be discarded as a duplicate.

**Processing of M-bit, S-bit and L-bit Sequences**

**M-bit processing**

9.2.85 The M-bit flag set to ONE in the DATA packet indicates that the user data field continues in the subsequent DATA packet. When this flag is set to ZERO, it marks the end of M-bit assembly. All M-bit processing in the Mode S subnetwork is performed as described in ISO 8208. Figure 9-4 illustrates the use of M-bit processing both over the DTE/DCE and ADCE/GDCE interfaces.

9.2.86 The packet size used on the DTE/DCE interface is different from that used on the ADCE/GDCE interface. The latter is dependent on the capability of the transponder. If the transponder is ELM capable, the maximum packet size on the ADCE/GDCE interface will be 160 bytes downlink (including header information) and 152 bytes in the uplink direction. The difference in uplink and downlink ELM maximum packet sizes is due to the II code being inserted into each uplink segment. DATA packets that are greater than this maximum will be candidates for M-bit linking. If the transponder is not ELM capable, then the maximum packet size at the ADCE/GDCE interface will be 28 bytes (including header information), and any DATA packets received greater than the maximum allowed will be M-bit linked.

9.2.87 Any detected error conditions during M-bit processing, such as receiving a DATA packet smaller than the maximum allowed with M-bit set to ONE, will cause a reset to be generated as specified by ISO 8208.

**S-bit processing**

9.2.88 S-bit processing applies to the Mode S CALL REQUEST, CALL ACCEPT, CLEAR REQUEST and INTERRUPT packets only. S-bit linking for the Mode S CALL REQUEST, CALL ACCEPT and CLEAR REQUEST packets is required to transfer user data when the fast select option is in use and the amount of user data is such that the packet length exceeds the size of the available frame. S-bit sequencing is not required for these packets if Fast Select is not in use, nor if the packet can be transferred in a single frame (i.e. ELMs are available).

9.2.89 In the case of INTERRUPT packets, the fast select option is not required in order to allow for S-bit linking, which can be applied to packets greater than 28 bytes (including header information) for non-ELM capable transponders. It should be noted that S-bit processing only applies to non-ELM capable transponders, since the user data size for the CALL REQUEST, CALL ACCEPT and CLEAR REQUEST packet will not exceed 128 bytes, and the user data size for the INTERRUPT packet will not exceed 32 bytes as described in ISO 8208. ELM capable transponders will allow for the maximum packet size to be 160 bytes (including header information) in the downlink direction and 152 bytes in the uplink direction, therefore, these packets can be processed without the use of S-bit linking.

9.2.90 When linking S-bit sequence packets, the F-bit flag is used in conjunction with the S-bit flag in order to
properly link and complete S-bit linked sequenced packets. The F-bit flag is categorized as follows:

a) if S-bit is set to ONE and F-bit is set to ZERO, it identifies that this is the first S-bit linked packet for reassembly and that there will be more following;

b) if S-bit is set to ONE and F-bit is set to ONE, it identifies that this is an intermediate S-bit linked packet for reassembly and that more packet(s) in the S-bit sequences will follow;

c) if S-bit is set to ZERO and F-bit is set to ONE, it identifies the final packet for S-bit linking and that no more packets in this S-bit sequence will follow; and

d) if S-bit is set to ZERO and F-bit is set to ZERO, it identifies that no S-bit reassembly is required for this single packet.

9.2.91 The S-bit reassembly process acts upon packets output from the resequencing process and passes its output to the XDCE state machine. A single packet that is not part of an S-bit sequence (F = 0, S = 0) is handled directly by the XDCE state machine without any need for S-bit reassembly. Upon receipt of the first packet of an S-bit sequence (F = 0, S = 1), the S-bit reassembly process starts a timer that expires after $T_q$ seconds. The packet is stored in an S-bit reassembly buffer specifically for that SVC, while waiting for intermediate packets (F = 1, S = 1) or the final packet (F = 1, S = 0) of the sequence to be delivered from the resequencing process. Upon receipt of the final packet, the entire sequence is passed to the XDCE state machine. If the timer (started upon receipt of the first packet of the sequence) expires before the sequence is complete, the entire sequence is discarded. Release by the resequencing process of an intermediate or final packet of an S-bit sequence with no corresponding first packet indicates an error condition. Any such packets should be discarded by the S-bit reassembly process. When performing S-bit reassembly, any packet that is part of an incomplete S-bit sequence due to the assembly timer expiration ($T_q$) will be discarded. This ensures that packets forming an S-bit sequence will be reassembled in the correct order, and without gaps from missing packets, as a result of the action of the resequencing process.

L-bit processing

9.2.92 L-bit processing applies the Mode S specific services long form MSP packet only. When the user data is too long to fit into a single MSP packet, a sequence of packets can be defined using the L-bit protocol. This protocol indicates that a packet is part of a linked sequence by setting the value of the L-bit to ONE. In addition, each packet contains an L-bit sequence number. The packets are sent in order. The last packet in a sequence is indicated by an L-bit value of ZERO.

9.2.93 L-bit processing will be applied to long form MSP packets that are greater than 28 bytes (including header information) for transponders with no ELM capability, and to packets that are greater than 160 bytes (including header information) in the downlink direction and 152 bytes in the uplink direction for transponders with ELM capability.

9.2.94 The following error conditions during L-bit processing will result in an incomplete sequence causing the entire L-bit sequence to be discarded:

a) receiving a long form MSP packet smaller than the maximum allowed with L-bit set to ONE;

b) processing a long form MSP packet with a duplicate M/SN field; and

c) expiration of the L-bit assembly timer ($T_m$) before a completed L-bit sequence.

Reformatting process

9.2.95 In order to utilize the Mode S data link protocol in an efficient manner, the ISO 8208 SVC packets which are not directed to the SSE are processed prior to transmission over the Mode S data link. They are converted into Mode S packets by the reformatting process, with the aim of reducing the header overhead. This involves some compression of the ISO 8208 header field, and the removal of information which is carried in the Mode S data link protocols.

9.2.96 The major operations performed by the reformatting process may be summarized as follows:

a) the channel identifier field size is reduced from 12 bits in ISO 8208 to 4 bits in the Mode S packets;

b) the Q-bit and the D-bit are not provided in the Mode S packet;

c) the packet type identifier field size is reduced from 8 bits in ISO 8208 to 1 to 8 bits (depending on the packet type) in the Mode S packets; and
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9.2.97 There is a correspondence between the ISO 8208 packet types and the Mode S packet types. For each packet type of Table 9-1 (with the exception of the diagnostic packet) there exists a corresponding packet type within the Mode S subnetwork. The relationship between ISO 8208 packets, Mode S packets and Mode S frames is illustrated in Figure 9-5.

9.2.98 Across the DTE/DCE interface, one packet contained within the data link layer information field will delimit the packet’s length. Therefore, at this interface the exact length of an ISO 8208 packet is known. For reassembling of an ISO 8208 packet received via the Mode S link, information on the length of the user data contained in the ISO 8208 packets must be provided to the receiving reformatter. The Mode S data link layer does not carry any explicit length information. The length of a segment is constant for each segment type and the length of the complete frame is known by the number of segments in the frame. All Mode S packets which transfer user data fields may differ in length, while the last segment of a Mode S frame may be only partially used. The remaining bytes in this segment will be set to 0. This mechanism would generate extra bytes during unpacking. Different solutions are possible to avoid this situation, e.g. (1) explicit transfer of the user data length or (2) indication of the number of bytes used in the last segment. For efficiency reasons, the latter mechanism is used for the coding of the LV parameter.

9.2.99 Computation of the LV parameter is required for the Mode S DATA, CALL REQUEST, CALL ACCEPT, CLEAR REQUEST and INTERRUPT packets. The length of the user data has to be extracted from the corresponding ISO 8208 packets. The total length of the Mode S packets will be calculated by adding the Mode S packet header length. The header length is:

a) 3 bytes for a DATA packet transferred as an ELM and an uplink SLM;

b) 4 bytes for a DATA packet transferred as a downlink SLM;

c) 5 bytes for a CALL REQUEST packet;
d) 5 bytes for a CALL ACCEPT packet;
e) 7 bytes for a CLEAR REQUEST packet; and
f) 3 bytes for an INTERRUPT packet.

9.2.100 Calculation of the LV parameter in SLM frames: Count the total length of the Mode S packet using modulo 7. The result is the value of the LV field if not equal to 0. Equal to 0 indicates that all bytes in the last segment are used and the LV field must be set to 7.

9.2.101 Calculation of the LV parameter in downlink ELM frames: Count the total length of the Mode S packet using modulo 10. The result is the value of the LV field if not equal to 0. Equal to 0 indicates that all bytes in the last segment are used and the LV field must be set to 10.

9.2.102 Calculation of the LV parameter in uplink ELM frames: Determine the number of segments needed to contain the entire packet, at 9.5 bytes per uplink ELM segment. Count the required numbers of odd and even segments separately, but ignore the last segment. Multiply the number of odd segments by 9 and the number of even segments by 10. Subtract the sum of both results from the total packet length. The remainder is the value of the LV field. The above procedure is described by the equation:

\[ LV = \text{INT}[L - \text{INT}(L/9.5)\times9.5 + 0.5] \]

where \( L \) = the total packet length in bytes

\[ \text{INT} = \text{a function that rounds a number down to the nearest integer} \]

If \( LV = 0 \) in the above calculation, it indicates that all bytes of the last segment are used and \( LV \) must be set to 10.

9.2.103 The packet types listed in Table 9-1 enable Mode S subnetwork exchange but do not result in the generation of an ISO 8208 packet.

9.2.104 The Mode S RESET CONFIRMATION packet is required in order to perform a reset of the ADCE/GDCE interface.
XDCE OPERATIONS

Basic functions

9.2.105 Following the reformatting process, Mode S packets are passed through the XDCE, which is a state machine within the XDLP responsible for establishing and maintaining virtual circuits with its peer level process in the ADLP or GDLP. The XDCE controls the transfer of Mode S packets to and from the aircraft. The protocol used to accomplish this is closely patterned after the operation of an ISO 8208 interface. As such, the XDCE operations are essentially the same as those of the DCE.

XDCE state transitions

9.2.106 XDCE state transitions are similar to those of the DCE (9.2.62).

9.2.107 The states of the XDCE exist in a hierarchy in the same way as for the DCE (as illustrated in Figure 9-3), except that states r2, r3 and p5 are omitted.

9.2.108 Certain states (r1, p4 and d1) provide access to subordinate states in the hierarchy. When first entering these “access” states, the XDCE should enter the first state of each subordinate layer, and should be considered to exist both in the access state and the subordinate state simultaneously. For example, this happens:

a) when first entering r1, enter p1 and remain in r1 during subsequent p state transitions;

b) when first entering p4, enter d1 and remain in p4 during subsequent d state transitions;

c) when first entering d1, enter f1, g1, i1 and j1 and remain in d1 during subsequent f, g, i and j state transitions.

The actions to be taken when entering a state should be considered to take a finite amount of time to complete and hence capable of being interrupted by arrival of another packet. In this event, the action to be taken is described in the state transition tables in the Mode S subnetwork SARPs, Annex 10, Volume III, Part I, Chapter 5.

XDCE disposition of packets

9.2.109 Packet transfer is similar to that of the DCE (9.2.63).

SVC call setup and clear procedures

9.2.110 The XDCE never originates a call. Call requests that are received from the local DTE are relayed to the peer XDCE. Requests for call setup from the peer XDCE are relayed to the local DTE.

9.2.111 An SVC is open or in the DATA TRANSFER state when the call is accepted. It is the responsibility of the DTE to handle the situation when a call accept indication or a call clear indication is not received, for a channel in the CALL REQUEST state.

9.2.112 If the ground DTE initiating a call request determines that the call is not required, it will send a clear request using the same temporary channel number (TC) issued in the original call request. If the mobile DTE originated the call request, a clear request from the mobile DTE will contain the channel number (CH) from the call request. In either case, the XDCE will respond to the aborted call request with a clear confirmation.

9.2.113 A call may be cleared at any time by any party. For example, the XDCE may initiate a CLEAR REQUEST packet to the DTE if it has insufficient resources to accept the call. The XDCE may also clear a call in response to an error detected by the DCE.

Data transfer and interrupt procedures

9.2.114 Packet transfer. After an SVC has been set up, the XDCE state machine for this SVC is in state d1 (flow control ready), allowing DATA and INTERRUPT packets to be transferred between peer DCEs through peer XDCEs.

9.2.115 The reception of an ISO 8208 DATA (or INTERRUPT) packet from the local DCE is the external event that triggers the sending of either one or several M-bit sequenced (or S-bit sequenced) Mode S DATA (or INTERRUPT) packets by the XDCE.

9.2.116 The reception of one or more M-bit or S-bit sequenced Mode S packet(s) from the peer XDCE is the external event that triggers the sending of an ISO 8208 packet to the local DCE.

9.2.117 An ISO 8208 packet size larger than the packet size of the associated Mode S packet does not constitute an error. The XDLP will invoke M-bit or S-bit assembly procedures to transfer such packets.
9.2.118 For optimum performance of the Mode S air-ground data transfer, the flow control window size has been set to a value greater than is usual for ISO 8208 networks.

9.2.119 SVC flow control. The receiving XDCE has to explicitly permit the transmission of DATA packets by the sending peer XDCE. In this way, the receiving XDCE can always guarantee that it has enough buffers to contain arriving DATA packets.

9.2.120 The implementation of a flow control mechanism between the DCE and XDCE is a local issue. However, the mechanism applied has to ensure the successful transfer of data between the DCE and the XDCE.

9.2.121 INTERRUPT procedures for SVCs. When an ISO 8208 INTERRUPT packet is received from the local DCE, the XDCE transmits it to the peer XDCE as one or more S-bit sequenced Mode S INTERRUPT packets. The peer XDCE processes the S-bit sequence as one interrupt.

9.2.122 INTERRUPT packets are not subject to flow control (except possibly the local flow control between the DCE and the XDCE) and so may “overtake” DATA packets. The purpose of this feature is to allow the user of an SVC to speedily transmit short messages to the peer user (e.g. for system management purposes). However, potential users should be aware of the limitations of this mechanism with regard to the internal priorities existing in the Mode S data link system. Frames encapsulating Mode S INTERRUPT packets have a lower priority than frames associated with Mode S specific services and Mode S subnetwork management activities. An INTERRUPT packet for a low priority SVC has a lower priority at frame level than a DATA packet on a high priority SVC.

9.2.123 The Mode S RECEIVE READY (RR) packet indicates that the sender of such a packet is ready to receive up to the full window size complement of packets (for this SVC) starting with the packet number PR, where PR is a parameter field in the Mode S RECEIVE READY packet.

9.2.124 The XDCE transmits a Mode S RECEIVE NOT READY (RNR) packet if the incoming channel buffers are filled. This may occur (1) because of an inability to transfer the packets to the remote DTE or (2) if no confirmation has been received from the DTE concerning transferred packets that would allow the clearing of the packets from the buffers.

Resequencing process

9.2.125 Transmission. Acknowledgement of the transmitted sequence number is made as follows:

a) for data packets, acknowledgements are a result of the Mode S packet layer protocols exchange of valid PR values acknowledging the peer XDCE receipt of the Mode S data packet.

b) in the case of non-data packets, acknowledgements are made based on a local and dedicated XDLP protocol (GDLP to interrogator, and ADLP to transponder).

Note.— An acknowledgement of a non-data packet is not a guarantee that the packet has reached its peer packet layer. If the packet is lost, it is the responsibility of the Mode S packet layer protocol to recover from this transmission error.

9.2.126 Reception. The resequencing window, normally, should not store packets. This window begins to fill only if the next expected packet is missing. As soon as the next expected packet is received, it is sent to the XDCE and NESN is incremented.

MODE S SPECIFIC SERVICES PROCESSING

Note.— There are three services to be handled by the specific services entity (SSE): broadcast, GICB and MSP.

Broadcast processing

9.2.127 The broadcast Comm-A protocol was designed to permit a Comm-A message to be delivered efficiently and quickly to a large number of aircraft. A Comm-A interrogation containing the message is transmitted using a 24-bit aircraft address of all ONEs. The transponder recognizes this as a broadcast message and accepts the interrogation, but does not reply. To ensure delivery, the interrogation must be transmitted two or more times per beamwidth. Ground-to-air uses might include information of general interest such as the status of ATC services at a particular terminal or transmission of hazardous weather information.
Note.— A similar protocol referred to as Comm-U is used by the airborne collision avoidance system (ACAS) on the air-air link to announce its presence to other ACAS units to support interference limiting calculations. It is also used by ACAS to broadcast its manoeuvre intent to omnidirectional Mode S receiving stations.

9.2.128 The recommended protocol for uplink broadcast is as follows:

a) a user generates a broadcast request that contains the broadcast message, an indication of the required broadcast area and the duration of the requested broadcast delivery; and

b) a user can cancel a request for broadcast delivery at any time.

9.2.129 The Comm-B protocol is designed to deliver a downlink message to a single interrogator. This is accomplished by the interrogator clearing the message after it is successfully transferred. The broadcast Comm-B protocol indicates its presence to the ground through an indication in surveillance and Comm-B replies. This indication remains set for at least 18 seconds and cannot be reset by an interrogator. This makes it possible for any interrogator in contact to read the message. This protocol is used by the transponder to deliver a change in either the capability report or the aircraft identification.

Note.— A modified form of this protocol is used by ACAS to deliver intent messages to Mode S interrogators.

9.2.130 The recommended protocol for downlink broadcast is as follows:

a) a user sends a subscription message indicating that it wants to receive downlink messages for one or more specified broadcast channels;

b) the ground SSE adds the user to an internal list of downlink broadcast subscribers; and

c) a user can cancel its broadcast subscription at any time.

GICB processing

9.2.131 The GICB protocol was developed to make it possible to deliver real-time information, such as aircraft state data, in an efficient manner to many interrogators, without requiring coordination. The technique used is to provide 255, 56-bit buffers in the transponder, and provide coding in the interrogation to allow the interrogator to specify which (if any) of the buffer contents it wants to have transferred in the reply to that interrogation. Thus only a single transaction is used to transfer the information and no coordination with neighbouring interrogators is required since an interrogator cannot clear or alter the contents of the buffers. Information stored in the buffers must be kept current since the aircraft application loading the buffer does not know when it will be read. The overall operation is very similar to the readout of the altitude code in a surveillance reply.

9.2.132 The recommended protocol for GICB subscription is as follows:

a) a ground user sends a subscription message indicating that it wants to receive GICB data for one or more registers;

b) a ground user can send a GICB request for single or periodic extractions of a given transponder register for a given aircraft;

c) when a GICB has been extracted, the response message is sent to the subscriber by the ground SSE; and

d) the user can cancel an active subscription at any time.

9.2.133 This recommended protocol is intended to minimize the data traffic between the ground SSE and the users. Developers might wish to build upon this minimum protocol and use more sophisticated features.

MODE S SPECIFIC PROTOCOL (MSP)

9.2.134 Requirements for MSPs. Messages transferred in support of certain real-time applications must be transferred with a minimum of delay and overhead. Further, they must not be subject to retransmission in the event of a lost message or one received with a detected error. Real-time applications require that missing messages or messages with detected errors be ignored, since the following messages will contain more recent data. If this retransmission service were applied, old messages would be retransmitted and current messages would be delayed waiting for the delivery process to catch up. The MSP was defined to support these real-time applications by defining a technique to bypass the ISO 8208 protocol and to permit data transfer with a minimum of overhead.
9.2.135 Operating characteristics of MSPs compared to SVCs. As compared to SVCs, the advantages of MSPs are that:

a) they have the potential for shorter delivery time, since they are not subject to flow control (9.2.119);

b) they operate with a total overhead of 1 or 2 bytes per packet; and

c) there is no setup time.

For these reasons, they are well suited to support real-time data transfer.

9.2.136 Before the GDLP transmits a ROUTE packet, the data link capability of the target aircraft must be determined. The DATA LINK CAPABILITY report should be examined in order to avoid sending ROUTE packets to aircraft unable to participate in a data exchange. There are two distinct protocols supported within the Mode S subnetwork, Mode S specific services and ISO 8208. The “Mode S specific services capability” bit in the DATA LINK CAPABILITY report should be checked to verify that the aircraft supports MSP and a non-zero value of the Mode S subnetwork version number (bits 17-23) of the DATA LINK CAPABILITY report should be checked to confirm support for the ISO 8208 services.

9.2.137 However, MSPs are not as reliable as SVCs since:

a) they cannot have subnetwork-wide user addresses;

b) packets may be lost without notification to the sender (e.g. discarded by a flooded XDLP); and

c) the order of packets is not guaranteed.

9.2.138 It is important to note that the speed advantage of the MSPs might be reduced if the messages sent via an MSP channel are too long, since:

a) they may become subject to segmentation and reassembly; and

b) their delivery may require more than one antenna scan.

9.2.139 MSP processing and use. The ground SSE must notify a subscriber of the successful delivery of an uplink MSP to the transponder (i.e. a technical acknowledgement). However, it is recognized that the only certain way to ensure that an MSP message has reached its peer application is through the use of an application acknowledgement.

9.2.140 In general, uplink and downlink MSP channels are simplex and independent. The simplest way to approximate a duplex MSP channel is to match an uplink and a downlink channel, both with the same channel number.

9.2.141 MSP coordination in overlapping coverage. The MSP achieves its bit efficiency (in part) through the use of limited addressing capability. On the uplink, the addressing consists of the MSP channel number. Downlink addressing consists of the MSP channel number, although the II code can be used in a multisite-directed delivery. A second consideration for coordination is that the sequence numbers for L-bit processing (9.2.92) are reset at the beginning of each message transfer, on an MSP channel number basis.

9.2.142 To ensure the correct downlink routing of aircraft request/response messages and the correct assembly of an L-bit sequence (9.2.92), some form of coordination is required between adjacent ground applications using the same MSP channel number. An alternative technique is to have the ground applications (with overlapping coverage) coordinate their activities to ensure that only one application is active with a given aircraft at any one time.

9.2.143 In order to detect delivery errors, applications making use of MSPs may be developed with the ability to build and verify a checksum. For example, one such algorithm is defined in ISO 8073. Upon detection of an error, local procedures could be invoked to notify the user of the error.

MODE S SUBNETWORK MANAGEMENT

Functions performed

9.2.144 Subnetwork management concerns those features which allow the Mode S subnetwork to be configured to achieve optimum performance as well as the allocation of resources to achieve the best use of the system. Subnetwork management within the ADLP is confined to the interrogator link determination function, whereas in the GDLP it is carried out by the subnetwork management entity (SNME).
Interrogator link determination function

9.2.145 A special feature of the ADLP is that it is required to maintain a cross-reference table linking ground DTE addresses to Mode S interrogator identifier (II) codes through which they may be reached. Entries in this table will normally be inserted or deleted by Mode S ROUTE packets uplinked from the ground. When no interrogation has been received from a given interrogator for more than a specified period, entries in the ADLP table relating to this interrogator are removed.

9.2.146 The ROUTE packet contains an optional data field which is intended to be used for the specification of quality of service (QOS) parameters applicable to each entry in the cross reference table. When multiple entries exist in the cross-reference table, selection of the interrogator to reach a specific DTE address may be performed on the basis of the QOS parameters.

SUPPORT FOR DTEs

9.2.147 Introduction. From the point of view of exclusive ATN subnetwork operation, the minimum requirement to operate a Mode S subnetwork is a mobile reporting facility (MRF) (i.e. the MRF is the minimum required subset of the SNME). The MRF enables an ATN router (or a stand-alone end-system having no separate access to air traffic information) to learn which mobile SNPAs are currently reachable. When stand-alone end-systems are in use, the MRF should also determine (from the Mode S data link capability report) which aircraft DTEs are available. In the case of Mode S where the aircraft position information is available, the connected ATN router may be notified with position data by routing initiation and a periodic connectivity report.

9.2.148 The DTEs connected to a GDLP or to an ADLP need to be informed when connectivity changes occur within the Mode S subnetwork. Unless they get this information from another source, the Mode S subnetwork must provide them with the knowledge of which remote DTEs become reachable or unreachable. Ground DTEs (either ATN routers or stand alone DTEs) need to know the DTE addresses of the aircraft in the coverage of the GDLP to which they are connected. The aircraft DTE addresses are built from the 24-bit aircraft addresses plus a sub-address.

9.2.149 Within the ATN environment, the first ISO 8208 SVC established between a ground ATN router and the ATN router of a newly acquired aircraft will always be set up from the ground. The aircraft ATN router deduces from this that a new ground ATN router has become reachable. When the aircraft exits the coverage of a GDLP, the aircraft ATN router needs to be notified about which ground ATN routers have become unreachable. The ADLP must thus provide the aircraft ATN router with the DTE addresses of the ground ATN routers which have become unreachable.

9.2.150 An MRF must be implemented at both the ground and aircraft sides to support connectivity reporting. Such implementations must guarantee the consistency of both XDLP and DTE connectivity databases. The following paragraphs give an example of such an implementation.

Ground MRF example

9.2.151 Overview. On the ground side, the MRF can be considered to be a server, the clients of which are ground DTEs. The dialogue between a ground DTE and the MRF makes use of a connection. For instance, this connection can be a network connection (ISO 8878) relying on an ISO 8208 SVC or a transport connection (ISO 8073) over a connectionless network (ISO 8473) making use of an ISO 8208 SVC. Such a connection is established by the ground DTE.

9.2.152 The GDLP contains a DTE function for the access to the MRF. The GDLP can identify that an ISO 8208 SVC is used to support the dialogue with the MRF based upon the value of the called DTE address used during the SVC establishment. Several ground DTEs may establish a connection with a given MRF. A ground DTE may establish a connection with the MRFs of several GDLPs. A ground DTE and the MRF exchange messages on the established connection in order to maintain the coherence of their reachability databases.

9.2.153 Addressing. The MRF located within a GDLP must be given a DTE address, in order to enable a ground DTE to establish an ISO 8208 SVC. The same DTE address might be used throughout an administration’s implementation of the Mode S subnetwork. The selected address could be within the range 0 to 255 normally reserved for the ground DTEs. An address outside of this range might be used in order to conserve ground DTE addresses, in which case the selected address must be chosen so that it cannot conflict with an aircraft DTE address.

Dialogue between a ground DTE and the MRF

9.2.154 Connection management. The initiator of the connection establishment is always the ground DTE. Using
the called DTE address, the GDLP determines whether the SVC is intended for communication with the MRF or not. When the MRF receives a connection establishment indication, it checks whether it already has a connection established with the calling ground DTE:

a) if it has, the current connection is released and the new connection establishment is accepted; or

b) if not, the MRF may either accept or reject the connection establishment.

9.2.155 When such a connection is first established or later reset, the MRF should start an unsolicited refresh cycle as described in 9.2.158. When such a connection fails, the ground DTE is responsible for trying to reestablish the connection.

9.2.156 Information update. As long as a connection is established between a ground DTE and the MRF and if there is no refresh cycle in progress, the MRF should send “join event” and “leave event” messages to the ground DTE to indicate which aircraft DTEs become respectively reachable or unreachable.

9.2.157 If an error is detected by the ground DTE, it should start a solicited refresh cycle (an example of which is described below). If an error is detected by the MRF, it should start an unsolicited refresh cycle (an example of which is described below).

9.2.158 Refresh cycle example. During a refresh cycle, the MRF sends to a ground DTE a list of all the reachable aircraft DTEs. A solicited refresh cycle is initiated by the ground DTE sending a “Refresh Request” message to the MRF. An unsolicited refresh cycle is initiated by the MRF without receiving a “Refresh Request” message from the ground DTE. Refresh cycles enable a ground DTE and the MRF to synchronize their reachability databases. Refresh cycles are necessary after a connection establishment, a connection reset or the detection of an error. A ground DTE may also initiate periodically a solicited refresh cycle in order to remove any undetected corruption of its reachability database.

9.2.159 A refresh cycle encompasses the following steps:

a) if the refresh cycle is a solicited one, the ground DTE sends a “Refresh Request”;

b) the MRF sends a “Refresh Start” message, which causes the ground DTE to mark every entry in its reachability database;

c) the MRF sends a “join event” message for every reachable aircraft DTE, which causes the ground DTE:

1) to unmark the corresponding entry in its reachability database if it already exists, or

2) to add a new, unmarked entry in its reachability database if it does not already exist; and

d) the MRF sends a “Refresh End” message, which causes the ground DTE to remove from its reachability database all the entries that are still marked.

9.2.160 If the MRF receives a “Refresh Request” message in the middle of the refresh cycle (that is, after sending a “Refresh Start” message, but before sending a “Refresh End” message), the current refresh cycle should be aborted and a new refresh cycle should be initiated. If the ground DTE receives a “Refresh Start” message in the middle of the refresh cycle (that is, after receiving a “Refresh Start” message, but before receiving a “Refresh End” message), the current refresh cycle should be aborted and a new refresh cycle should be initiated. No entry (including the entries added during the aborted refresh cycle) should be removed from the ground DTE’s reachability database. If the ground DTE receives a “leave event” message or an erroneous message in the middle of the refresh cycle, the current refresh cycle should be aborted and a “Refresh Request” message should be sent to the MRF. At the end of the refresh cycle, the MRF and the ground DTE return to the information update state described in 9.2.156.

9.2.161 Message formats. The messages exchanged between a ground DTE and the MRF are transmitted in the user data field of protocol data units (PDUs). The MRF may put several messages in the user data field of a single PDU. The ground DTE should analyze the messages starting from the beginning of the user data field. Each message should be handled before the following one is retrieved. If a message is incorrect, it should be discarded together with the remaining part of the user data field. The MRF may put options into some of the messages. The ground DTE may skip these options when they are present.

9.2.162 “Join event” and “leave event” messages contain at least the following fields:

a) message type;

b) message length;
c) aircraft address; and

d) optionally, time and position of aircraft entry or exit.

9.2.163 “Refresh Request”, “Refresh Start” and “Refresh End” messages contain the following fields:

a) message type; and

b) message length.

**Aircraft MRF example**

9.2.164 **Overview.** On the aircraft side, the MRF reports the loss of reachability of ground DTEs to the aircraft DTE by sending “leave event” messages. A “leave event” is generated when the last entry in the II code-DTE cross-reference table is deleted for a particular DTE address, indicating that this DTE address is no longer reachable via any current Mode S interrogator. The dialogue between the aircraft DTEs and the aircraft MRF makes use of datagrams, e.g. ISO 8208 CALL REQUEST packets with FAST SELECT requested and RESTRICTION ON RESPONSE. The ADLP contains a DTE function for the support of the MRF. An aircraft DTE can identify that an ISO 8208 SVC is used to support the dialogue with the MRF based upon the value of the calling DTE address used.

9.2.165 **Addressing.** The MRF located within an ADLP must be given a DTE address, in order to enable the aircraft ATN router to identify messages used to convey reachability information. A DTE address outside of the range reserved for aircraft DTEs (0 to 15) should be used to conserve these aircraft DTE addresses. The selected address must be chosen so that it cannot conflict with a ground DTE address.

9.2.166 **Message format.** The messages sent by the MRF to an airborne DTE are transmitted in the user data field of PDUs. The MRF may put contiguously several messages in the user data field of a single PDU. The aircraft ATN router should analyze the messages starting from the beginning of the user data field. Each message should be handled before the following one is retrieved. If a message is incorrect, it should be discarded together with the remaining part of the user data field. The MRF may put options into some of the messages. An aircraft DTE may skip these options when they are present.

9.2.167 “Leave event” messages contain at least the following fields:

a) message type; and

b) message length; and

c) ground ATN router address.

**ERROR PROCEDURES**

9.2.168 There are two conditions that cause an XDLP error procedure. These conditions are:

a) a link failure; or

b) the XDCE remaining in a p2, p3, p6, p7, d2 or d3 state for more than a specified time interval.

9.2.168.1 Before declaring a link failure, the GDLP should preferably make additional attempts to uplink a packet since the link failure may only be a temporary state. The link failure with a particular aircraft should be declared once the following conditions are met:

a) the maximum number of attempts to uplink a packet has been reached at the GDLP/radar interface level; and

b) the condition described above is met for each individual radar which is available to uplink data to this particular aircraft.

9.2.168.2 Whatever the cause of an XDLP error procedure, the XDCE detecting the error condition:

a) releases all resources associated with the erroneous SVC;

b) returns to the p1 state; and

c) indicates the error condition to the local DTE.

This error condition is included in an ISO 8208 CLEAR REQUEST packet.

**SUBNETWORK MANAGEMENT ENTITY (SNME)**

9.2.169 The SNME within the GDLP is required to perform a number of tasks including determination of the optimum interrogator for routing of packets to a given aircraft, management of GDCE-ADCE connections and support of the ground ATN router, including notification of connectivity with new aircraft.
9.2.170 The SNME aids system management by providing management processing external to the subnetwork access to some internal GDLP operations. Furthermore, it allows the GDLP to indicate changes in the configuration of the Mode S subnetwork, including the availability of aircraft. Primarily, the SNME will be used for notifying the management entity (typically located in the ATN router) of changes in connectivity, such as when an aircraft enters or leaves coverage of the GDLP due to normal operation or the failure of a component.

9.2.171 To aid the SNME in carrying out its tasks, the interrogator should be responsible for providing the GDLP at least the 24-bit aircraft addresses which are available for data link communication with that interrogator. Furthermore, as aircraft leave the data link coverage area of the interrogator an indication should be sent to the GDLP. Finally, in order to support failure recovery procedures, it may be necessary in a given scenario to provide the SNME with regular reports (or on demand) as to the position of all aircraft within its data link coverage area.

9.2.172 The peer application partners of the SNME are either a system management entity (SME) operated by a Mode S network administrator, or other SMEs operated in the global context of ATN system management.

MANAGEMENT LEVELS

9.2.173 A Mode S subnetwork requires two different levels of management:

a) a network administrator which must be able to (1) locally administer one or several GDLPs and their Mode S interrogators to collect statistics on past or current operations, (2) modify ground data link topology or the list of stand-alone end-systems and (3) reconfigure the network to compensate for the failure of equipment, etc. These activities must be done in conjunction with information and constraints relating to the surveillance part of the Mode S system; and

b) an ATN system management which must have access (less privileged and less detailed) to certain objects associated with the Mode S subnetwork.

Figure 9-6 illustrates the concepts of manager and agent SNME by taking into account these two distinct aspects of Mode S subnetwork management.

INTERACTION BETWEEN THE GDLP AND INTERROGATOR COORDINATION MECHANISMS

9.2.174 In general, neighbouring Mode S interrogators will provide overlapping coverage. In order to prevent mutual interference between such interrogators, special measures are necessary to coordinate their operation. Such a measure might be to allocate each interrogator with overlapping coverage a unique interrogator identifier (II) code, thus ensuring that the multisite protocols alone are adequate to ensure the required coordination. However, it is more probable that ground interrogators will need to be connected by means of a ground network in order to coordinate their operation. The functionality which is needed in such cases is treated as a local issue. It may be distributed between the interrogators, exist as a separate entity, or else be integrated into the GDLP. Consequently, the GDLP may take either a passive or an active role in its interaction with the interrogator coordination mechanism.

9.2.175 The interrogator coordination processing is responsible for determining when an aircraft is within a particular region of coverage and for notifying adjacent interrogators of this event (normally interrogators whose coverage overlaps). This may include notifying the GDLP when a particular aircraft is within a region where data link is possible. In this case the GDLP takes a passive role in its interaction with the interrogator coordination function, in that the GDLP is provided with sufficient information necessary for transferring a particular message from the GDLP to a particular aircraft.

9.2.176 In contrast, the GDLP may take an active role in determining the most appropriate interrogator for a particular uplink transmission. This selection could be based on instantaneous and statistically determined traffic loads and the actual movements of aircraft through a region of space serviced by the GDLP. The GDLP would be responsible for managing the assignment of aircraft to interrogators for data link activity.

USE OF GEOGRAPHIC COVERAGE MAPS

9.2.177 In general, geographic coverage maps are an integral part of the interrogator coordination process used within and between interrogators. These maps define different types of coverage responsibility for each interrogator. These maps will be located at the interrogator site and additionally may be located at some central facility in the event that a centralized interrogator coordination mechanism is
being used. Further, a dedicated coverage map located in this central facility may be used to support the allocation of communications resources over a particular region, including the determination of the most appropriate interrogator to be used for an uplink transmission. If such a coverage map were to be maintained within the GDLP, a regular stream of position data would need to be transferred to the GDLP.

**Handover**

9.2.178 The technical handover of communication responsibility for an aircraft between Mode S interrogators is considered in two cases. In the first case, handover between interrogators serving the same GDLP allows the SVC connections within the subnetwork to be maintained. However, when the aircraft leaves the coverage of all interrogators connected to a GDLP, it is no longer possible to maintain the existing SVC connections and new ones must be established through an alternative GDLP.

9.2.179 The handover of communications between interrogators supporting the same GDLP may be undertaken in order to provide continuity of service as the aircraft flies between areas of interrogator coverage, and to improve resource allocation thus providing better performance. Prior to the initiation of the handover procedure, a decision to hand over has to be made. The handover decision may be based on:

a) performance criteria relating to the actual RF connection, i.e. the transmission quality, the transmitter/receiver power level budget, channel interference;

b) subnetwork directed criteria, such as the actual traffic loading per interrogator, the subnetwork throughput, cost; or

c) operational criteria, such as the position and track of the aircraft.

When a handover is made between two interrogators serving the same GDLP, but having different II codes, it is necessary to transfer a Mode S ROUTE packet in order to update the ADLP’s II code-DTE cross reference table.

Note.— The handover functions that support a single GDLP may be combined with the route determination function.

9.2.180 When an aircraft leaves the edges of coverage provided by the interrogators connected to a GDLP, it is no longer possible to maintain the SVCs established through that GDLP. In the event of no action being taken by the GDLP, those SVCs will eventually be retired after expiration of the appropriate timers in the GDLP, but at the cost of occupying resources (e.g. channel numbers, buffer space). This may degrade the performance available to aircraft still within coverage. Alternatively, the SVCs may be closed down in an organized way before the aircraft flies out of coverage, by means of a subnetwork management process within the GDLP. In order to preserve continuity of communication service with the aircraft, SVCs should be opened through the next GDLP on the aircraft’s flight path prior to leaving the coverage of the GDLP currently in contact with the aircraft (this would be achieved by the ATN router in an ATN environment).

**Subnetwork routing**

9.2.181 In terms of ground topologies, a GDLP is likely to be connected to several interrogators having overlapping coverage. As a consequence, an aircraft could be reachable through more than one interrogator at a given time. The way the GDLP chooses which interrogator to use is not standardized in ICAO SARPs, but it is one of the major issues of any ground subnetwork implementation. Conversely, in the air, an aircraft has to select an appropriate interrogator to downlink a given message. The way this is accomplished is specified in ICAO SARPs. These functions are identified respectively as ground and aircraft routing functions. They are explained with examples in the following paragraphs.

9.2.182 The ground routing function. The aim of the routing function is to decide, for each message directed to a given aircraft, which interrogator(s) to use (uplink routing function). It must also decide which interrogators have the right to perform downlink extractions for this aircraft (downlink routing function). Indeed, in certain topologies, not all interrogators with the aircraft in their coverage have the right to extract downlink messages (Comm-B or Comm-D). For instance, if the aircraft is flying in the overlapping coverage of two interrogators sharing the same II code, only one of these two interrogators has the right to perform extractions for a given aircraft at a given moment. Otherwise, it is possible to mix the extracted segments, even when using the multisite protocol.

9.2.183 According to the ground implementation, the messages to be routed could be either Mode S packets (both SVC and MSP), GICB requests, or Mode S frames (Comm-A, Comm-B, Comm-C or Comm-D). The broadcast requests are not concerned by the routing function, as they are not directed to an aircraft, but to interrogators.
9.2.184 The route determination and selection, and the relaying functions. The routing function could be split into two subfunctions, the route determination and selection function, and the relaying function.

9.2.185 The route determination and selection function must first determine all possible routes (i.e. all interrogators) that provide access to a given aircraft. This could be done by means of acquisition/relinquishment events, sent to the route determination function by an interrogator each time an aircraft enters or leaves its data link coverage. Note that the data link coverage may be a subset of the surveillance coverage. Next, the route determination and selection function must choose from these possible routes, which route will be used for the next message in the uplink direction and which route will be used for the downlink direction (these routes are not necessarily the same). More than one route could be used in either uplink, downlink, or both directions, allowing parallel operation of interrogators. However, this is possible only if permitted by the ground topology. The interrogators involved in the parallel delivery must not use the same Mode S protocol at the same time if they have the same II code or if they are using the non-selective protocol with transponders having a level less than or equal to 4.

9.2.186 The way the route determination and selection function chooses the route(s) is designated the routing policy. This selection could be very simple (e.g. choose the first available route) or it could use routing maps, based on the aircraft position. Other routing policies are also possible (e.g. dynamic load sharing between interrogators). From an implementation point of view, the route determination and selection function could be centralized (for instance in the GDLP or elsewhere), or distributed over several entities (for instance, distributed over all interrogators connected to the same GDLP).

9.2.187 The relaying function is simply required to send each message (related to a particular aircraft) to the interrogator indicated by the route determination and selection function. Therefore, this function is necessarily located within the GDLP. When the route changes (this corresponds to an interrogator handover), some special care must be taken in order to ensure that no message is lost or duplicated. Due to the resequencing algorithm, a limited amount of desequencing could be tolerated during this handover.

9.2.188 Implementation examples. The following paragraphs give two examples of possible implementations.

9.2.189 Centralized solution. Each interrogator has a defined data link coverage area, in which it considers that it is able to perform data link to any aircraft present in this coverage area. When an aircraft enters or leaves this coverage area, the interrogator sends the corresponding acquisition/relinquishment event to the GDLP. Of course, the data link coverage must overlap to ensure continuity of service. The extent of overlapping coverage will depend upon the routing policy.

9.2.190 An example of a simple policy is as follows:

a) only one route is used, both in the uplink and in the downlink;

b) once a route has been selected, it remains active until it breaks; and

c) when a new route needs to be selected, the route to be selected is the most recent available one.

9.2.191 This routing policy is very simple and efficient, provided that the data link coverage area maps are defined according to the operational needs.

9.2.192 Distributed solution. Each interrogator has a data link responsibility coverage map. For each aircraft in this coverage area, the interrogator is responsible for data link service, i.e. it has the right to uplink and downlink messages. A mechanism must be provided to coordinate the interrogators, to ensure that only one interrogator is responsible for a given aircraft at a given time. This mechanism uses an inter-interrogator network. As a consequence, only one route is used, both in the uplink and in the downlink. Once this route has been determined by this inter-interrogator network, a message is sent to the GDLP to indicate the new route.

The airborne routing function

9.2.193 SVC routing. The ADLP could maintain several SVCs with several GDLPs. In this case, it is fundamental that packets belonging to a particular SVC arrive at the GDLP connected to the corresponding DTE. This is achieved by air-directing the frames containing the packets to the interrogators connected to this GDLP (forcing the packets to reach the correct DTE). The correspondence between the II code (identifying an interrogator or a cluster of interrogators) and the GDLP (identified through the ground DTE) is achieved through the II code-DTE cross-referencing table.

9.2.194 In order to avoid delays and/or problems in the SVCs, it is very important that the cross reference table
contains reliable information, reflecting the exact ground resources available. It is the responsibility of the GDLP to provide such information, using ROUTE packet(s) to add or remove II code-DTE address pairs. In particular, the II code-DTE cross-reference table should only contain the downlink route(s), selected by the ground (and not all possible routes, as this will result in unnecessary delays). As a consequence, each time the ground changes the downlink route to one using a different II code, it would be necessary to uplink a ROUTE packet to indicate such a change.

9.2.195 Recovery of II code-DTE cross-reference information after an ADLP reset is accomplished by the aircraft generation of a search request by the ADLP. This request leads all GDLPs in coverage to respond with ROUTE packets to this ADLP.

9.2.196 MSP routing. The routing is much simpler for MSPs. Either the MSP packet (1) will have an II code attached with it and the packet will be multisite-directed to this II code or (2) it will be air-initiated.

9.3 DATA LINK CAPABILITY REPORT

TRANSPONDER CAPABILITY LEVELS

9.3.1 A number of different levels of SSR transponder are defined in Annex 10, Volume IV, Chapter 2, reflecting their data link capability. The basic level of SSR transponder is known as level 2 and is capable of uplink and downlink SLM transactions. Level 3 adds the capability of handling uplink ELM transactions, while level 4 offers both uplink and downlink ELM capability. In order to provide a higher throughput compared to a level 4 transponder, the level 5 transponder provides a higher data link capacity with the added ability to operate with more than one interrogator at a time.

CAPABILITY REPORTING

9.3.2 All Mode S transponders participate in surveillance activities with a Mode S interrogator. The amount and type of data link activity supported by an aircraft Mode S installation is defined by the Mode S data link capability report (Annex 10, Volume IV, Chapter 3). This report is extracted from the transponder by the ground interrogator at surveillance acquisition. This report specifies the aircraft data link capability class, level 2, 3, 4 or 5 and provides additional information regarding the data rates that the aircraft installation can support for these protocols.

9.3.3 The data link capability report also indicates the presence and status of ACAS equipment, the availability of a Mode S specific services capability report as well as information on any DTEs supported by the aircraft.

9.3.4 The transponder capability is used by the ADLP and GDLP to determine an appropriate packet size and Mode S packet protocol for uplink and downlink transmissions. Furthermore, it will be used when carrying out frame processing.

REPORT GENERATION

9.3.5 Within a particular level, the capability of transponders may be expected to vary in terms of peak and average data acceptance and reply rates. This information is required by the ADLP to construct the aircraft data link capability report to the ground system. If the ADLP is not combined with the transponder, this information must be made available by the transponder through a locally defined transponder interface. The approach used for this information transfer must ensure that transponder capability information to the ADLP is automatically updated if a transponder is replaced. An example of an acceptable means for this transfer is to incorporate transponder capability information into pins on the connector of the cable that interfaces the transponder with the ADLP.

9.3.6 If there is a change in the capability report (including the absence of the report from the ADLP due to an interface failure), the Mode S transponder will make the new report available as a broadcast Comm-B message in order to update the data link status for ground interrogators currently providing communications service.

9.3.7 The capability report provides information to the ground on every mobile DTE that is supported by the ADLP. The status of mobile DTE should periodically be made available to the ADLP for inclusion in the capability report. Upon start-up and at regular intervals afterwards, each DTE should send a status message to the ADLP indicating current availability. Existing aircraft buses efficiently support this type of status reporting. One or more missing status reports indicates that a DTE is unavailable. Since the changing of a DTE status bit in the capability report will cause a broadcast Comm-B, careful consideration should be given to the sampling rate of the individual DTE. Upon receiving an indication of a change in DTE availability, the capability report will be broadcast by the transponder. However, to avoid excessive broadcasts due to intermittent
failures, a brief delay of approximately one minute duration should elapse before the status bit of the DTE is changed again.

**INTERROGATOR HANDLING OF INCORRECTLY REPORTED CAPABILITY**

**9.3.8** In designing the data link communications function of a Mode S interrogator, care must be taken to handle the case of an incorrectly reported data link capability, in particular, the case of the reported capability being greater than the actual capability. If an aircraft reports a higher than actual communication capability, this may result in a transponder failing to reply to an addressed interrogation. This can happen when the transponder is not equipped for the service (e.g. an ELM interrogation to a level 2 transponder) or in the case where the interrogator exceeds the communications capacity of the avionics installation. In the latter case, a Mode S transponder will not reply to a data link interrogation if it cannot store the message field of the interrogation.

**9.3.9** Since an incorrectly reported capability can lead to an absence of replies, the interrogator communications function should detect the absence of expected replies to communications interrogations and revert to 56-bit surveillance interrogations that command 56-bit surveillance replies in order to maintain surveillance coverage. The initial transaction on subsequent scans should continue to be surveillance only. After a successful surveillance transaction, additional attempts may be made in the beam dwell to see if the aircraft has recovered its communications capability. Repeated communications failures should lead the interrogator to downgrade the aircraft capability to a level corresponding to the observed reply performance. For example, if the transponder reports level 4 capability but will not respond to downlink ELM transactions and responds to SLMs and uplink ELMs, the interrogator should downgrade the transponder’s capability to level 3.

**9.3.10** When a change in transponder capability is inferred by the above process, this information should be provided to the connected DTEs as an update of the quality of service reported for this aircraft.

**INTERROGATOR CAPABILITY**

**9.3.11** Interrogators with advanced antenna and transmission capabilities will be able to transfer a greater amount of data in a given period of time. The interrogator capability will be used to determine the quality of service (QOS) which is available over a particular subnetwork connection.

**9.4 MODE S SUBNETWORK TIMERS**

**REQUIREMENT FOR TIMERS**

**9.4.1** Unlike a fixed ground network, the Mode S subnetwork must handle the case of continually changing connectivity as aircraft move in and out of the coverage of a given interrogator or GDLP. The normal mode for such a transition is the use of coverage criteria to anticipate the departure from a service area in time to explicitly close the communications circuits. This explicit closure cannot be guaranteed, therefore means must be provided to ensure the eventual timeout of the communications protocols and the release of any associated resources.

**TIMER USE AND RATIONALE FOR TIMER VALUES**

**9.4.2** The timer values listed in Tables 5-1 and 5-13 of Annex 10, Volume III, Part I, Chapter 5 were chosen to satisfy a particular need for the orderly operation of the subnetwork. The need for the timer, the rationale for the selection of its value and its relationship to other timers is explained in the following paragraphs.

**ACTIVE CHANNEL TIMER — Tx**

**9.4.3** Tx timer purpose. This timer is used to trigger action that will determine whether or not an open SVC is still active.

**9.4.4** If the SVC is in the flow control ready state (d1) for more than Tx seconds with no channel activity, the XDLP will initiate a Reject, RR or RNR packet (as appropriate) to determine the activity status of the channel. The Tx timer is reset when the packet is sent. If the aircraft is in coverage, a reply will be received. If the aircraft is no longer in the coverage area of the GDLP that was providing the communication service, a link failure will be declared because the message will not be able to be delivered.

**9.4.5** If the SVC is in the p2, p3, p6, p7, d2 or d3 state when the Tx timer expires, a link failure will be declared immediately.

**9.4.6** When a link failure is declared, the channel is cleared and all resources associated with that channel are released, including the clearing of any undelivered messages.

**9.4.7** Tx timer value. Since channel initiation represents a moderate level of channel activity, it is desirable
to hold an idle channel open during temporary loss of contact between aircraft and interrogator. One outage that can be anticipated is signal loss if the aircraft flies through the zenith cone (also called the cone of silence) of a Mode S interrogator and there are no adjacent interrogators with overlapping coverage serving the active GDLP. Depending upon aircraft speed and altitude and antenna characteristics, it is possible for an aircraft to take several minutes to traverse the zenith cone.

9.4.8 This consideration has lead to the assignment of a Tx value of 300 seconds for the GDLP. A greater value is assigned to the Tx timer for the ADLP (420 seconds) since it is desirable for the GDLP to initiate the action since the Mode S ground-air protocol is somewhat more efficient than the air-ground protocol. This efficiency is a consideration when the aircraft is still in contact and the message is delivered. If the aircraft is out of coverage, then the GDLP will detect a link failure and retire the channel and its resources. At a later time, the Tx timer of the ADLP will expire and lead to a communications attempt. Since the GDLP has already attempted contact and failed, it is almost certain the ADLP will declare a link failure. If for some reason communication is restored by the time the ADLP Tx timer expires, the packet will be transferred to the GDLP. By this time, the referenced SVC will be cleared, so the GDLP will respond with a CLEAR REQUEST to the packet sent by the ADLP.

 CHANNEL RETIREMENT TIMER — Tr

9.4.9 Tr timer purpose. This timer is used to determine when it is possible to reuse a Mode S, SVC channel number.

9.4.10 Use of Tr in channel number assignment. When a channel is closed due to the expiration of the Tx timer, the channel number must not be reused until sufficient time has passed to assure that the channel number has been cleared by the ADLP and the GDLP. After channel clearing resulting from Tx timeout, the ADLP will not allow the channel number to be reassigned for Tr seconds. Permanent channel numbers are assigned only by the ADLP and are interpreted together with the 24-bit aircraft address. For this reason, the Tr timer applies only to the ADLP.

9.4.11 Tr timer value. The Tr timer value must be greater than the value of the Tx timer plus time to allow for channel clearing. Additionally, the accidental simultaneous use of the same channel number will lead to serious protocol and message routing problems. For this reason, a Tr value of 600 seconds has been selected to provide generous margin over the 420-second value of the Tx timer.

 INTERROGATOR INTERROGATION TIMER — Ts

9.4.12 Ts timer purpose. This timer is used by the ADLP to detect the loss of contact with a particular ground interrogator based on the use of the II code.

9.4.13 Use of Ts with the II code-DTE cross-reference table. The ADLP maintains a table that provides a correspondence between the II codes of interrogators currently providing communications service and the DTEs that are reachable via each of these interrogators. The ADLP uses this table to determine the II code to use when it has a message to deliver to a particular DTE. Therefore, it is important that this table reflects the current state of the ground network reachability.

9.4.14 Ts timer value. An aircraft in the coverage area of a Mode S interrogator will be interrogated at least once per antenna rotation (called the scan time). The scan time for Mode S interrogators will be in the range of 4 to 12 seconds. The ADLP receives information on all interrogations (including those only for surveillance) so it has access to the II code contained in every interrogation received by the transponder. The receipt of an interrogation from a particular interrogator will cause the Ts timer associated with its II code to be reset.

9.4.15 If a discrete interrogation containing a particular II code is not received in 60 seconds, the information associated with that interrogator will be deleted from the cross-reference table. The 60-second time limit allows for 5 to 15 scan opportunities for the interrogator to contact the transponder. Mode S interrogators can interrogate an aircraft several times in the beam dwell, so the loss of contact for 60 seconds indicates a loss of coverage by that interrogator.

 INTERROGATOR LINK TIMER — Tz

9.4.16 Tz timer purpose. This timer is used by the ADLP to detect a loss of service in the delivery of a downlink message.

9.4.17 Use of Tz in downlinking Mode S packets. When a Mode S packet is to be downlinked, the ADLP must determine the II code of the interrogator for transferring the message to the addressed DTE. For an SVC, the
ADLP obtains the code from the II code-DTE cross-reference table or uses experience with previous packet transfers. For an MSP, the ADLP uses an II code that is provided by the application that generated the message (obtained via control data from the Mode S specific services interface) or sends the message using the air-initiated protocol if there is no II code specified.

9.4.18 After passing the message to the transponder, the ADLP monitors the progress of the transfer. The timer is started when the message is delivered to the transponder if there are no other messages of this type (SLM or ELM) currently in process. If there are other messages of the same type queued in the transponder, the timer for a particular message starts with the receipt of the delivery notice for the message immediately ahead of the current message.

9.4.19 If the message is not read and closed out by the interrogator in Tz seconds, the ADLP will cancel an SVC downlink transaction to that interrogator and attempt to deliver it via another available interrogator. If the message delivery cannot be performed after all available interrogators have been attempted and timed out, a link failure is declared. For an MSP, failure to deliver the message in Tz seconds will result in cancellation of the message and the generation of a delivery failure notice to the Mode S specific services interface.

9.4.20 Tz timer value. The value for this timer must be as short as practical in order to minimize the time required to deliver a downlink Mode S packet. The value assigned for Tz is 30 seconds.

9.4.21 Tc timer purpose. This timer is used by the ADLP to detect a loss of contact in the delivery of a linked Comm-A message.

9.4.22 Use of Tc in linked Comm-A message delivery. The Mode S protocol defines two types of segmented frame transfers. The extended length message is assembled entirely within the transponder. The assembly of segmented uplink standard length messages (linked Comm-A protocol) is performed by the ADLP. The protocol defines a separate linking process for each of the non-zero II codes. It is possible that a linked Comm-A message could be initiated by an interrogator just as the aircraft was flying out of coverage. For this reason, a timeout is necessary (for each II code) to ensure that a partially delivered message will not be retained and merged with Comm-A segments being delivered later by a different interrogator with the same II code.

9.4.23 Tc timer value. A time-out value of 60 seconds is assigned to this timer. The rationale for this selection is the same as for the value of the Ts timer.

L-BIT DELIVERY TIMER — Tm

9.4.24 This timer is used by the XDLP to detect a loss of contact in the delivery of a sequence of MSP packets being delivered using the L-bit protocol.

9.4.25 Use of Tm in L-bit sequencing. If user data is too long to fit within a single MSP packet, a sequence of packets can be defined using the L-bit protocol. This protocol indicates that a packet is part of a sequence by setting the value of the L-bit to ONE in the long form MSP packet. The packets are sent in order. The last packet in a sequence is indicated by an L-bit value of ZERO. It is possible that an L-bit sequence could be in process when the aircraft flies out of coverage of the interrogator delivering the sequence of packets. For this reason, provision must be made for the XDLP to detect the loss of contact and discard the packets of the incomplete sequence. This must be done to avoid merging these packets with those of a subsequent L-bit sequence of packets. The Tm timer is used for this purpose.

9.4.26 Tm timer value. A timeout of 120 seconds is allowed to complete the delivery of the L-bit sequence. This provides a minimum of 10 to 30 scans to complete the delivery process.

PACKET RESEQUENCING AND S-BIT DELIVERY TIMER — Tq

9.4.27 Tq timer purpose. This timer is used by the XDLP to release packets undergoing resequencing that would otherwise be blocked due to the loss of a packet. The timer is also used to discard any packets in the released set that are part of an incomplete S-bit sequence.

9.4.28 Use of Tq in packet resequencing. In order to gain efficiency in packet delivery, Mode S packets are allowed to become desequenced in the delivery process. The correct packet order is identified by a sequence number that is managed separately for each SVC. The resequencing function detects a missing packet (based on SN number) by noting that a received packet is not labelled with the next SN in sequence. The process holds this packet to allow time for the missing packet(s) to be received. A timeout must be provided to handle the case of a lost packet, otherwise the resequencing process would block the delivery of all subsequent packets. A timer (Tq) is associated with each
detected missing packet. After a timeout of $T_q$ seconds, all packets being held will be released to the state machine. For a DATA packet, this will lead to recovery via the Mode S packet layer protocol, since the detection of a missing packet will lead to the generation of a REJECT packet to the peer process requesting retransmission of the missing packet.

9.4.29 Certain protocol packets (Mode S CALL REQUEST, CALL ACCEPT, CLEAR REQUEST and INTERRUPT) may require S-bit processing if they are carrying user data. The state machine has no basis for determining completeness for these packets and therefore cannot correctly process an incomplete S-bit sequence. For this reason, packets in the released set will be discarded if they are part of an incomplete S-bit sequence.

9.4.30 $T_q$ timer value. A timeout value of 60 seconds is assigned to this timer. The rationale for this selection is the same as for the value of the $T_s$ timer. An additional consideration is that this timer must operate on a shorter time scale than the timers used in the transport and upper layers, in an environment where these protocols are used.

9.5 DCE AND XDCE STATE TABLES

STATE TABLES

9.5.1 The state tables specified in the Mode S subnetwork SARPs (Annex 10, Volume III, Part I, Chapter 5) are based on the ISO 8208 state tables but are modified for use by Mode S packet layer processing. The XDCE state machines are used to provide independence of timer and parameter values used within the subnetwork from those used at the ISO 8208 interface.

DIAGNOSTIC AND CAUSE CODES

9.5.2 Diagnostic and cause codes specified in the state tables are consistent with those of ISO 8208.

9.6 MODE S PACKET FORMATS

DEFINITION OF PACKET FORMATS

9.6.1 The packet formats transferred over the Mode S air-ground data link are simplified versions of the standard ISO 8208 packet formats. This is done to reduce the amount of control data transferred over the air-ground data link. The packet formats contain fields that are byte aligned wherever possible.

SIGNIFICANCE OF CONTROL FIELDS

9.6.2 The control fields are structured to minimize the control overhead. Two unassigned codes remain for possible future use.

9.7 SUBNETWORK SYSTEM IMPLEMENTATION CONSIDERATIONS

FUNCTIONAL TOPOLOGY

9.7.1 The ground topology of the Mode S subnetwork must be implemented to ensure that Mode S packets can be successfully routed between a ground DTE and a mobile DTE, each identified by an unambiguous address.

9.7.2 For uplink packets, the GDLP (the subnetwork management entity) must determine which Mode S interrogator is to transfer the packet to the aircraft. It is possible that a number of interrogators will be capable of transferring the packet. In this case a subnetwork routing algorithm must be used to select the most appropriate path.

9.7.3 For downlink packets, the ADLP is required to use its II code-DTE cross-reference table to determine, for a given destination ground DTE address, the II code of the interrogator through which the packet is to be transferred. The packet is then multisite directed to that II code, either via a specific interrogator, or else via an interrogator within a cluster using that II code. By directing the packet through an interrogator having the specified II code, the subnetwork ensures that the packet reaches the GDLP having connectivity with the required DTE.

9.7.4 In order for the above procedures to operate as intended, the following principles must be observed when designing the ground topology of the Mode S subnetwork:

a) a GDLP may support any number of ground DTEs, within the limit of the ground DTE addressing scheme;

b) a GDLP may be connected to any number of interrogators, either having discrete II codes, or connected into one or more clusters;
c) an interrogator must be connected to only one GDLP (except for a duplicate standby device). This is necessary because the DTE address and/or channel number associated with a packet are not known to the interrogator and so if more than one GDLP were connected to the interrogator, it would have no way to establish which GDLP should receive the packet; and

d) all interrogators within a cluster (i.e. operating with a single II code) must be connected to the same GDLP. This is necessary because when a packet is downlinked, the II code is used to route the packet to a particular GDLP. In a cluster, the same II code is used by several interrogators, so if they were not all connected to the same GDLP, it would not be possible to use the II code to route the packet to the appropriate GDLP.

9.7.5 Taking all the above principles into account, Figure 9-7 illustrates the general ground topology of the Mode S subnetwork.

DTE ADDRESS ALLOCATION

9.7.6 The Mode S subnetwork provides a total of 256 different DTE addresses. These must be allocated to ground DTEs (which are incorporated into ATN routers and/or stand-alone applications) in such a way that no ambiguity is possible on which DTE is referenced by a particular address. Provided that ambiguity does not occur, a particular DTE address may be re-used by other implementations.

9.7.7 A ground DTE connected to a given GDLP will have an associated geographical coverage area determined by the coverage of the interrogators connected to the GDLP in question. In this context, the coverage of the interrogator refers to the area within which the interrogator performs selective interrogations. In practice, the data link coverage may be deliberately constrained to a smaller area than that used for surveillance. However, it will be seen from the following text that it is the area in which selective interrogations are performed (including those for surveillance only) that determines the distance within which a DTE address may be re-used.

9.7.8 Address ambiguity may arise where ground DTEs have overlapping coverage. If an aircraft with active SVCs is within the coverage area of two DTEs using the same address, then packets generated by aircraft applications for one DTE would risk being incorrectly routed to the other DTE. This in turn would cause the packet to arrive at a GDLP not recognizing that SVC with the aircraft, resulting in loss of the packet and the SVC being erroneously cleared.

9.7.9 When an aircraft flies out of the coverage area of a ground DTE, references to the old DTE address in the ADLP tables may be cleared by one of several sequences of events, as described in the following sub-paragraphs. The principal requirement is that in order to generate an ADLP connectivity report (Annex 10, Volume III, Part I, Chapter 5, 5.2.8.2.2) it is necessary for all entries corresponding to a given DTE address to be cleared from the ADLP’s cross-reference table before the DTE address can be re-used. Furthermore, it is important that the channel numbers associated with the old DTE address are made available for re-use as rapidly as possible.

9.7.10 The preferred course of action is for the GDLP to recognize that the aircraft is about to exit its area of coverage and to clear the channel in time. A Mode S ROUTE packet should then be sent to delete the appropriate entries in the ADLP’s cross-reference table. This would result in immediate generation of the ADLP connectivity report and would ensure that the channel number could be re-used at once.

9.7.11 If the aircraft were to leave the coverage area of the DTE before the entries in the II code-DTE cross-reference table had been cleared, the entries would be preserved for as long as the transponder was receiving selective interrogations (including surveillance) from an II code associated with the DTE address. After Ts (60) seconds following cessation of those interrogations, the entries in the cross-reference table would be deleted, at which point the ADLP connectivity report would be generated.

9.7.12 A serious malfunction would arise if the ADLP were to receive a Mode S ROUTE packet containing a re-used DTE address less than Ts (60) seconds after leaving the coverage of another DTE using the same address. In this event, the ADLP’s cross-reference table would not be cleared of all entries for that DTE address during the transition between the two coverage areas, and hence the ADLP connectivity report would not be generated.

9.7.13 If any SVCs from a previous GDLP were not cleared (e.g. if the GDLP had not cleared them before the aircraft exited the coverage), the ADLP would attempt to send a Mode-S RR packet after no activity on an SVC for Tx (420) seconds. Provided there were no appropriate entries in the ADLP’s II code-DTE cross-reference table, a link failure would be declared and the SVC would be cleared immediately. However, the channel number would only be available for re-use after a further Tr seconds delay,
i.e. after a maximum delay of Tx + Tr (1 020) seconds after leaving the DTE coverage area. Such a large delay is undesirable since it may prevent a stand-alone application from opening a channel when needed.

9.7.14 It is recommended that when a GDLP acquires an aircraft at its initial entry into coverage, the first ROUTE packet sent to the aircraft should have the initialization bit set to ONE so as to clear any SVCs from a previous GDLP that were not cleared when exiting its coverage. This use of the initialization bit will prevent any erroneous operation due to DTE address ambiguity.

9.7.15 In order to prevent ground DTE address ambiguity and to ensure that the subnetwork operates as intended, the following principles must be observed:

a) II codes must be allocated to interrogators/clusters so that the time taken to fly between coverage areas (in which any selective interrogations are performed) of interrogators/clusters using the same II code is greater than Ts seconds;

b) all ground DTEs having overlapping coverage must be allocated unique addresses;

c) outside the coverage area of a DTE, its address may be re-used, provided that the time taken to fly between the coverage areas of any two DTEs using the same address is greater than Ts seconds. This is necessary to ensure that all entries corresponding to the DTE address are cleared from the ADLP’s cross-reference table prior to its re-use. (Note that SARPs prohibit re-use until after Tr seconds thus adding an additional margin.);

d) the GDLP should clear all SVCs with an aircraft and issue a Mode S ROUTE packet to remove entries in the ADLP’s cross-reference table prior to an aircraft exiting its area of coverage. This will enable the channel numbers to be re-used as rapidly as possible; and

e) the GDLP should also issue a ROUTE packet with the initialization bit set upon an aircraft first entering the GDLP’s coverage, so as to clear any SVCs inadvertently left open by a previous GDLP using the same DTE address.

COORDINATION OF THE GDLP TO A GROUND DTE

9.7.16 The interface between the GDLP and a ground DTE (including an ATN router) is required to be functionally conformant with the ISO 8208 DTE-DCE interface. However, the form of the physical connection between the GDLP and a ground DTE remains an option at the discretion of implementors. Alternative approaches are discussed in the following sub-paragraphs, although other options are also possible.

9.7.17 The simplest form of physical connection which may be used is a simple point-to-point link directly between the DTE and the DCE. In this case, only a suitable link layer protocol (e.g. ISO 9676) must be provided below the DTE and the connection to the physical medium established.

9.7.18 Alternatively, it may be desirable to connect DTEs to a GDLP by means of a wide area network (WAN) such as an X.25 network. Normally it would not be possible to connect the DTE and/or GDLP directly to such a WAN, since the addressing scheme of the WAN would generally be different from that in use in the Mode S subnetwork. Furthermore, it would not be possible to connect the DCE within the GDLP directly to another DCE forming part of the WAN. The conventional approach to this situation is to embed the ISO 8208 packet for transfer across the DTE-DCE interface of the Mode S subnetwork within an outer packet which carries it across the WAN. This may be achieved by connection of the DTEs and the DCE of the GDLP to the WAN by a device conformant with the WAN protocol. It should be appreciated that in this scenario the DTE and DCE of the subnetwork might be allocated addresses within the WAN bearing no significance to the Mode S subnetwork. In principle, only a single connection might exist over the WAN carrying all SVCs of the subnetwork DTE/DCE interface.

9.7.19 If the network addressing between a GDLP and ground DTEs (an ATN router or stand alone DTE) does not support the Mode S address format, the ISO 8208 called/calling address extension facilities should be used. Likewise, if an alternative addressing scheme is used on an aircraft, i.e. between aircraft DTEs and an ADLP, the ISO 8208 address extension facilities could also be considered. The following sections contain a definitive example, using X121 addressing, describing how these facilities can be used to support different addressing formats.

FORMAT OF THE DTE ADDRESS EXPECTED BY THE GDLP

9.7.20 The ground DTE addresses have a total length of 3 BCD digits. They shall be decimal numbers in the range of 0 to 255 coded in BCD. The mobile DTE addresses have a total length of 10 BCD digits. The 8 most significant digits contain the octal representation of the
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9.31 Aircraft address coded in BCD. The 2 least significant digits identify a sub-address for specific DTEs on board an aircraft and shall be a decimal number in the range of 0 through 15 coded in BCD.

<table>
<thead>
<tr>
<th>3 BCD digits</th>
<th>Aircraft address (8 BCD digits)</th>
<th>DTE sub-address (2 BCD digits)</th>
</tr>
</thead>
</table>

Ground DTE address Mobile DTE address

X121 ADDRESSING SCHEME

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<tr>
<th>0</th>
<th>Country code (3 digit)</th>
<th>Network ID</th>
<th>Client number and other network specific fields</th>
</tr>
</thead>
</table>

DNIC 15 digits maximum

The ground DTE when connected to the GDLP over a packet switching network has an address compliant with the above addressing scheme which doesn’t match the Mode S ground DTE address format.

Note.— The DNIC identifies the network. The fields following the DNIC will enable the identification of the GDLP and the ground DTE when they are connected through a unique packet switching network.

9.7.21 The DTE address expected by the GDLP is not consistent with the X121 addressing scheme. The ISO 8208 protocol nevertheless enables the use of a Called/Calling Address Extension Facility which is proposed for use during the connection establishment phase between the GDLP and a ground DTE over a packet switching network as described in the following paragraphs.

UPLINK PROCESSING

9.7.22 A GDLP which is connected to a ground DTE through a packet switching network should be assigned a unique X121 address from the addressing space of the particular packet switching network it is connected to. Thus, the GDLP will be regarded as a network end-user of the packet switching network. When the ground DTE (a standalone DTE or an ATN router) establishes a virtual circuit with an airborne DTE, the ground DTE should insert the Mode S ground and airborne DTE addresses in the Called/Calling Address Extension Facility field of the CALL REQUEST packet exchanged between the ground DTE and the GDLP. The GDLP is responsible for extracting the Calling and Called DTE address from this extension field in order to reformat the ISO 8208 packet into the associated Mode S packet. In any other ISO 8208 packets exchanged between the GDLP and the ground DTE, the Mode S DTE addresses are absent, because the SVC channel number unambiguously identifies a particular SVC.

DOWNLINK PROCESSING

9.7.23 On the downlink, the GDLP is responsible for extracting the AG (Ground Address) and AM (Mobile Address) fields from a received Mode S CALL REQUEST packet, and for reformatting it into the corresponding ISO 8208 CALL REQUEST packet. It inserts the AG and AM into the address extension facility field of the ISO 8208 CALL REQUEST packet destined for the ground DTE.

CALLED/CALLING ADDRESS EXTENSION FACILITY FIELD CODING

9.7.24 The Called/Calling Address Extension Facility field has to be encoded as described in ISO 8208.

Note 1.— According to the 1990 version of ISO 8208, the facility code shall be set to 0xCB for calling DTE address extension facility, and to 0xC9 for called DTE address extension facility (this is the first byte of the address extension facility field). The second byte is encoded as follows: bits 8-7 = 10 (to indicate that the address is not compliant with X.213 recommendation); bits 6-1 indicate the number of semi-octets of the address field (this number is binary coded). The following octets convey the address field. The address field can contain up to 40 semi-octets coded in BCD. An airborne DTE address will have a length of 10 semi-octets (even number of bytes); a ground DTE address will have a length of 3 semi-octets (odd number of bytes, so the last semi-octet shall be filled with four consecutive ZEROs).

Note 2.— CCITT X25, 1984 is the first version supporting address extension.

Note 3.— Using different networks supporting special features (e.g. address extension) requires the support of the same features by the connecting gateway.

MODE S SPECIFIC SERVICES ACCESS

9.7.25 Local access (air and ground). Local access to the Mode S specific services can be achieved via the alternative interface to the airborne and ground Mode S subnetworks. It is the only means of access in the airborne case.
9.7.26 The interface standards for this alternative interface are not prescribed in the SARPs and can therefore be chosen by the implementer. The protocols chosen should provide the means of transferring every message or instruction needed to support all required functions and have a method of detecting when the function at the other side of the interface is not working. An example of a local ground access application protocol is given in Attachment B to this chapter.

9.7.27 Access via the ISO 8208 interface. On the ground it is possible to access the Mode S specific services via the ISO 8208 interface. Two local DTE addresses are assigned in the ground part of the Mode S subnetwork. One provides access to the SME and the other to the SSE.

9.7.28 When ground access to the Mode S specific services is required, via the ISO 8208 interface, DTE addressing should be used between the function requiring the access and the SSE. The data field should comply with the local ground access protocol (see 9.7.25).

9.7.29 Mode S specific services are designed specifically for supporting near real time applications. The high overheads associated with the OSI protocols employed by the ATN make the ATN unsuitable for such applications. If ATN access is required to the Mode S specific services then a suitable conversion function is required.

**DATA FLOW MANAGEMENT**

9.7.30 Data flows. Several distinct data flows (e.g. SVC, MSP, etc.) are going through a single RF link in the Mode S subnetwork. There will be occasions when an interrogator and/or transponder is unable to handle the volume of data presented and congestion will result. The following paragraphs describe existing flow control and provide an example for congestion management.

9.7.31 SVC congestion management in the XDLP. Packet sequencing and flow control for SVCs are defined in the SARPs. Specifically, the flow control mechanisms defined consist of the implementation of a sliding window protocol between the ISO 8208 DCE and DTE and the Mode S GDCE and ADCE. Each logical state machine is responsible to notify its peer if it is experiencing congestion through the use of an RNR packet. Once the congestion condition has cleared, the peer entity can be notified to continue through the use of the RR packet.

9.7.32 Example of SVC congestion management. An example of SVC congestion management assumes that the frame processor is able to inform the XDCE of the status of the RF media to which it is attached. During those times when RF congestion is experienced, the frame processor could inform the XDCE; the XDCE could inform the DCE of the situation, and an RNR packet could be sent to the DTE, thus halting the incoming data. Conversely, when the RF media is able to continue the data exchange, the frame processor to XDCE to DCE notification could result in the transmission of an RR packet by the DCE, thus continuing the data flow from the DTE.

9.7.33 MSP congestion management in the XDLP. When the frame processor within an XDLP becomes critically congested to the point where the resources needed to handle the traffic load are not available, the link could start to fail (i.e. packets could be lost) unless there is a means to notify the SSE of the congestion condition. If the frame processor can communicate this information, then the data flow can be regulated into and out of the frame processor to ensure its continued functionality.

9.7.34 Example of MSP congestion management. An example of MSP congestion management will assume that the frame processor is able to notify the SSE that it is unable to accept data. The SSE will then inform the MSP application of the situation, thus stopping the data. When the condition that caused the congestion is cleared, a notification from the frame processor to the SSE, and subsequently to the MSP application, is expected.
Table 9-1. ISO 8208 packet types

<table>
<thead>
<tr>
<th>Name</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>CALL REQUEST</td>
<td>Requests channel connection by first party</td>
</tr>
<tr>
<td>CALL ACCEPTED</td>
<td>Affirms second party channel connection</td>
</tr>
<tr>
<td>CLEAR REQUEST</td>
<td>Requests termination of a channel</td>
</tr>
<tr>
<td>CLEAR CONFIRMATION</td>
<td>Second party agrees to channel termination</td>
</tr>
<tr>
<td>DATA</td>
<td>Transfers data</td>
</tr>
<tr>
<td>INTERRUPT</td>
<td>Provides limited data transfer as quickly as possible</td>
</tr>
<tr>
<td>INTERRUPT CONFIRMATION</td>
<td>Acknowledges reception of INTERRUPT packet</td>
</tr>
<tr>
<td>RECEIVE READY</td>
<td>Acknowledges reception of packets for flow control purposes and indicates receiver in a state to receive more packets</td>
</tr>
<tr>
<td>RECEIVE NOT READY</td>
<td>Acknowledges reception of packets and indicates receiver unavailable for further data transfer</td>
</tr>
<tr>
<td>RESET REQUEST</td>
<td>Resets channel (outstanding packets lost)</td>
</tr>
<tr>
<td>RESET CONFIRMATION</td>
<td>Confirms reset has occurred</td>
</tr>
<tr>
<td>RESTART REQUEST</td>
<td>Clears SVCs (and resets PVCs)</td>
</tr>
<tr>
<td>RESTART CONFIRMATION</td>
<td>Confirms restart has occurred</td>
</tr>
<tr>
<td>DIAGNOSTIC</td>
<td>Provides supplementary error information not available in other packet types</td>
</tr>
<tr>
<td>REJECT</td>
<td>Provides explicit request to resend specified packets</td>
</tr>
</tbody>
</table>
Figure 9-1. Example of subnetwork interconnection
Figure 9-2. Relationship of packets and frames
Ready and restart states

Call setup and clearing states

Data transfer states

Interrupt and control states

Note. — States r1, p4 and d1 (shown circled) are states that provide access to the lower levels of the DCE substate hierarchy.
<table>
<thead>
<tr>
<th>DTE Requirement</th>
<th>Pakets on ISO 8208 interface (assuming a user data size of 128 bytes*)</th>
<th>Pakets on ADCE/GDCE interface (assuming a 16 segment downlink ELM transponder with a maximum user data size of 157 bytes*)</th>
<th>Pakets on ISO 8208 interface (assuming a user data size of 128 bytes*)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Send 2 packets, each 128 bytes long and each an entire M-bit sequence</td>
<td>M = 0 128 bytes → M = 0 128 bytes</td>
<td>M = 0 128 bytes → M = 0 128 bytes</td>
<td>M = 0 128 bytes → M = 0 128 bytes</td>
</tr>
<tr>
<td></td>
<td>M = 0 128 bytes</td>
<td>M = 0 128 bytes</td>
<td>M = 0 128 bytes</td>
</tr>
<tr>
<td></td>
<td>M = 1 128 bytes</td>
<td>M = 1 157 bytes</td>
<td>M = 1 128 bytes</td>
</tr>
<tr>
<td></td>
<td>M = 0 20 bytes</td>
<td>M = 0 119 bytes</td>
<td>M = 0 20 bytes</td>
</tr>
</tbody>
</table>

* Only the relevant portion of the headers are shown in the examples.

Figure 9-4. Use of M-bit in the subnetwork packets
Figure 9-5. Conversion of packet formats
Chapter 9. The Mode S subnetwork of the ATN

Figure 9-6. Mode S subnetwork management in an OSI framework

Note 1. The Mode S Management Information Base (MIB) is used to build the less detailed Mode S access MIB.

Note 2. Local management can use the ATN to gain access to the SNME.
Figure 9-7. General ground topology of the Mode S subnetwork
Attachment A to Chapter 9

EXAMPLES OF FLOW CONTROL WINDOW BUFFER UTILIZATION

1. UPLINK FLOW CONTROL WINDOW BUFFER UTILIZATION EXAMPLE

The process of utilizing the flow control window buffer in the uplink direction is described in the following paragraphs. A diagram of this process is presented in Figure 9A-1.

a) The aircraft DTE announces to the ADLP (via the DTE/DCE interface) that it is not ready to receive data packets from the ADLP. This announcement is accomplished by issuing an ISO 8208 RNR packet. Upon receipt of this packet, the ADLP will transition to the DCE flow control transfer state g2 “DTE not ready”.

b) The ADLP will begin utilizing the uplink flow control window buffer to store DATA packets received from the GDLP until the flow control window limit is reached (15 packets).

c) Once the flow control window is full, the ADLP instructs the GDLP not to send any more DATA packets. This is achieved with a Mode S RNR packet. In addition, the ADLP transitions to the ADCE flow control transfer state f2 “ADCE not ready”.

d) Flow control resumes again when an ISO 8208 RR packet is received from the aircraft DTE. This indicates that the DTE is now ready to receive DATA packets. The receipt of this packet causes the ADLP to transition to the DCE flow control transfer state g1 “DTE ready”.

e) The ADLP releases DATA packets to the DTE from the flow control window buffer.

f) The ADLP transitions back to the ADCE flow control transfer state f1 “ADCE ready”, and informs the GDLP of its readiness condition by sending a Mode S RR packet.

2. DOWNLINK FLOW CONTROL WINDOW BUFFER UTILIZATION EXAMPLE

The process of utilizing the flow control window buffer in the downlink direction is described in the following paragraphs. A diagram of this process is presented in Figure 9A-2.

a) The GDLP announces to the ADLP (via the ADLP/transponder interface) that it is not ready to receive data packets from the ADLP. This announcement is accomplished by issuing a Mode S RNR packet. Upon receipt of this packet, the ADLP will transition to the ADCE flow control transfer state g2 “GDLP not ready”.

b) The ADLP will begin utilizing the downlink flow control window buffer to store DATA packets received from the reformatter (via the DTE/DCE interface) until the flow control limit is reached (15 packets).

c) Once the limit is reached, the ADLP instructs the aircraft DTE not to send any more ISO 8208 DATA packets. This is achieved with an ISO 8208 RNR packet. In addition, the ADLP transitions to the DCE flow control transfer state f2 “DCE not ready”.

d) Flow control resumes again when a Mode S RR packet is received from the GDLP. This indicates that the GDLP is now ready to receive DATA packets. The receipt of this packet causes the ADLP
to transition to the ADCE flow control transfer state g1 “GDLP ready”.
e) The ADLP releases DATA packets to the GDLP from the flow control window buffer.
f) The ADLP transitions back to the DCE flow control transfer state f1 “DCE ready”, and informs the aircraft DTE of its readiness condition by sending an ISO 8208 RR packet.
Figure 9A-1. Uplink flow control window buffer utilization

Figure 9A-2. Downlink flow control window buffer utilization
Attachment B to Chapter 9

EXAMPLE OF AN SSE ACCESS APPLICATION PROTOCOL (LOCAL ACCESS)

1. INTRODUCTION

1.1 This appendix describes a possible local access protocol for Mode S specific services both on the ground and in the air. The protocol has been designed to provide for interaction between the SSE and locally connected end-systems.

1.2 The following assumptions have been made regarding the Mode S subnetwork:

a) on the ground, the SSE could be located in the GDLP or the ground station. In the air, the SSE is located in the ADLP;

b) the airborne end-system includes an ARINC-429 concentrator to supply the ARINC-429 labels required for the GICB service;

c) ISO 8208 is not needed to access Mode S specific services on either the ground or in the air;

d) the SSE is dedicated to mainly real time applications. This means that the timeliness of the data is paramount; and

e) end-to-end acknowledgement is not supported by the subnetwork. Applications requiring delivery guarantees must provide their own transaction management.

1.3 Service interactions are described in terms of service primitives. A primitive is an abstract view of protocol information and places no format restrictions on the contents.

1.4 In order to provide a comprehensive service the following primitive parameters are used:

a) aircraft address: 24-bit address of aircraft;

b) flight identity: flight dependent call sign;

c) II code: interrogator identification code used as ground address;

d) request interval: number of seconds between GICB requests;

e) active period: number of seconds for which broadcast remains active;

f) channel number: MSP channel number, Comm-B register number of broadcast identifier;

g) data length: length of data field (MSP only);

h) application data: data (Comm-B register contents, broadcast data, MSP data);

i) channel selection: list of selected broadcast or MSP channels;

j) control data: additional data required to control the service which is not transferred over subnetwork;

k) diagnostic code: used in confirmation primitives to indicate if the transfer was successful or not;

l) application ident: used to distinguish between different applications hosted on the same end-system;

m) request number: used to distinguish between messages from an application when providing technical acknowledgement (confirmation).

Note.— Request numbers must be assigned uniquely. Subfields should be used to distinguish between applications co-located on a single end-system.
2. GICB SERVICE

2.1 There are two aspects to the GICB service:

- the airborne end-system is responsible for the timely update of the Comm-B register contents — which means that the airborne end-system is required to provide the airborne SSE with the required information along with the Comm-B register identifier; and

- the requirement is to allow the ground user to request a GICB schedule.

2.2 A GICB request is for a particular Comm-B register from a particular aircraft. The SSE is responsible for managing all incoming requests to minimize the required interrogations. The GICB request includes the period between required replies.

2.3 The GICB request interrogations only interact with the ADLP so far as they are used to maintain entries in the ADLPs II-code DTE cross-reference table. A GICB interrogation extracts the latest contents of the Comm-B register held in the transponder.

2.4 There are two ways of setting up multiple GICB requests, namely:

- each GICB request is for a single Comm-B register; multiple register schedules are set up by issuing multiple requests, each of which may be cancelled individually; and

- the GICB request primitive could be defined to include all required requests. In this case it needs to be determined if a new GICB request is treated as an additional schedule or a replacement for the old schedule.

2.5 The user interactions required for the GICB service are shown in Figure 9B-1.

2.6 The primitives required for the GICB service are defined as follows:

GICB_request

| Direction: | from application to ground SSE; |
| Contents:  | aircraft address; |
|           | request number; |
|           | request interval; |
|           | channel number. |

GICB_reply

| Direction: | from ground SSE to application; |
| Contents:  | aircraft address; |
|           | request number; |
|           | channel number; |
|           | application data. |

Note. — A time stamp could be added to this primitive to provide an indication of the age of the received data (UTC or indication of time in ground station).

GICB_cancel

| Direction: | from application to airborne SSE; |
| Contents:  | aircraft address; |
|           | request number; |
|           | channel number. |

GICB_update

| Direction: | from application to airborne SSE; |
| Contents:  | channel number; |
|           | application data. |

3. BROADCAST SERVICE

3.1 The user interactions required for the broadcast downlink service are shown in Figure 9B-2.

3.2 Ground users subscribe to broadcast by aircraft address and broadcast identifier. The ground SSE only forwards those broadcast messages for which a subscription is held.

3.3 The primitives are defined as follows:

BDN_subscribe

| Direction: | from application to ground SSE; |
| Contents:  | aircraft address; |
|           | request number; |
|           | channel selection. |

Note. — Subscriptions overwrite previous subscriptions. A null channel selection would cancel all subscriptions. An “all ONEs” would indicate that broadcast from all aircraft should be forwarded.

BDN_request

| Direction: | from application to airborne SSE; |
Contents: data (including identifier).

Note.— Some broadcast downlink, for example data link capability and flight identity are generated by the transponder.

BDN_reply

Direction: from GDLP to application;
Contents: aircraft address;
request number;
channel number;
application data.

Notes.— For broadcast services the channel number is extracted from the application data.

3.4 The user interactions required for the broadcast uplink service are shown in Figure 9B-3. No subscription is required by the airborne end-system; the airborne SSE forwards all received broadcast messages to the SSE interface.

3.5 Uplink broadcast are enabled for a variable period (approximately a period of three complete antenna scans is recommended). Uplink broadcast may be cancelled at any time before the enabled period expires.

3.6 The primitives are defined as follows:

BUP_request

Direction: from application to ground SSE;
Contents: control data;
request number;
active period;
channel number;
application data.

Note.— The control data for broadcast uplink determines which portion of sky is broadcast to; it may include II codes, azimuths and scan times.

BUP_cancel

Direction: from application to ground SSE;
Contents: request number.

BUP_reply

Direction: from airborne SSE to application;
Contents: channel number;
application data.

4. MSP SERVICE

4.1 The user interactions required for the MSP downlink service are shown in Figure 9B-4.

4.2 The ground user subscribes to an MSP channel; only messages which are subscribed to are forwarded to the user. The delivery confirmation message is dependent on successful delivery to the interrogator and not to the end-user.

4.3 Applications making use of the MSP service are ground initiated. If the applications require air initiation of service, for example pilot request for weather data, then the ground application needs to advertise its existence to the airborne application.

4.4 The primitives are defined as follows:

MDN_subscribe

Direction: application to ground SSE;
Contents: aircraft address;
request number;
channel selection.

Note.— Subscriptions overwrite previous subscriptions. A null channel selection would cancel all subscriptions.

MDN_request

Direction: application to airborne SSE;
Contents: request number;
II code;
channel number;
data length;
application data.

MDN_confirm

Direction: from airborne SSE to application;
Contents: request number;
diagnostic code.

Note.— This is a technical acknowledgement that an interrogator has tried to extract the data. It does not guarantee delivery to either the interrogator or the ground application.

MDN_reply

Direction: from ground SSE to application;
4.5 The user interactions required for the MSP uplink service are shown in Figure 9B-5. No subscriptions are used for the airborne service. The ADLP forwards all received MSPs on all Mode S specific services interfaces.

4.6 The required primitive contents are defined as follows:

**MUP_request**
- **Direction:** from application to ground SSE;
- **Contents:** aircraft address; request number; channel number; data length; application data.

**MUP_confirm**
- **Direction:** from ground SSE to application;
- **Contents:** request number; diagnostic code.

Note.— This is a technical acknowledgement that the information has been delivered to the transponder. It does not guarantee delivery to the airborne application.

**MUP_reply**
- **Direction:** from airborne SSE to application;
- **Contents:** aircraft address; request number; channel number; data length; application data.

### 5. SSE MANAGEMENT SERVICE

5.1 In order to support Mode S specific services, the ground end-system needs to obtain certain information concerning potential targets. It is recommended that join and leave events are sent from the ground SSE to the ground applications.

5.2 In addition, the aircraft end-systems need to be informed when an II-code is no longer available for data link communications.

5.3 The primitives are defined as follows:

**SSE_join**
- **Direction:** from ground SSE to application;
- **Contents:** aircraft address; flight identity.

**SSE_leave**
- **Direction:** from ground SSE to application;
- **Contents:** aircraft address; diagnostic code.

**SSE_leave**
- **Direction:** from airborne SSE to application;
- **Contents:** II code; diagnostic code.

Primitives are also required to initiate refresh cycles.
Figure 9B-1. GICB service

Figure 9B-2. Broadcast downlink (BDN) service

Note.—Some downlink broadcast messages are automatically generated by the transponder
Figure 9B-3. Broadcast uplink (BUP) service

Figure 9B-4. MSP downlink (MDN) service
Figure 9B-5. MSP uplink (MUP) service
Attachment C to Chapter 9

ILLUSTRATION OF TIMER FUNCTION

Active channel timer (Tx = 5 minutes for GDLP, 7 minutes for ADLP)

GDLP or ADLP

SVC in d1 state  |  no activity on the channel  |  RR, RNR or Reject packet sending
start of Tx  |  Tx  |  no answer: link failure
                |  no answer: link failure  |  SVC cleared
                |  else: TX = 0

SVC in p2, p3, p6, p7, d2, d3 state  |  no activity on channel  |  SVC cleared
start of Tx  |  Tx

L-bit sequencing timer (Tm = 2 minutes)

GDLP or ADLP

Receipt of first MSP of an MSP sequence  |  second MSP  |  discard the packets
start of Tm  |  Tm

incomplete sequence
Packet re-sequencing and s-bit delivery timer (Tq = 1 minute)

GDLP or ADLP

Scenario example

Packet received at the interrogator interface of the GDLP with SN = i

Packet received with SN = i + 2 not received

Control packet with S-bit processing received with SN = i

Control packet with SN = i + 2 not received

Packet with SN = i + 2 sent to the GDCE

S-bit sequence incomplete

Control packet with S-bit processing received with SN = i + 1

Packet with SN = i + 2 sent to the GDCE

All packets discarded

Channel number assignment timer (Tr = 10 minutes)

ADLP

SVC in d1 or in p2, p3, p6, p7, d2, d3

no activity

SVC clearing

SVC number re-assigned

start of Tx

Tx and link failure

start of Tr

Tr

Interrogator interrogation timer (Ts = 1 minute)

ADLP

Il code in cross reference table

no interrogation received with this Il code

Il code deleted from the cross reference table

start of Ts

Ts
Downlinking Mode S packet timer (Tz = 30 s)

**ADLP**

- **SLM or ELM to be directed**
  - Acknowledgement delivery of previous SLM or ELM
  - Start of Tz
  - Tz

- **Message not read and closed out by the interrogator**
  - Start of Tz
  - Tz

- **Change of interrogator**
  - Start of Tz
  - Tz

- **No more interrogator**
  - SLM or ELM cancelled
  - Delivery failure notice

Link frame cancellation timer (Tc = 1 minute)

**ADLP**

- **Intermediate Comm-A segment received from II = i**
  - Start of Tc
  - Tc

- **No more Comm-A segment**
  - Tc discarded

- **Comm-A sequence associated to II = i**
1. INTRODUCTION

1.1 This appendix describes a possible remote access protocol for Mode S specific services both on the ground and in the air. The protocol has been designed to provide for interaction between the SSE and remote connected end-systems.

1.2 The following assumptions have been made regarding the Mode S subnetwork:

a) on the ground, the SSE is located in the GDLP. In the air, the SSE is located in the ADLP;

b) the airborne end-system includes an ARINC-429 concentrator to supply the ARINC-429 labels required for the GICB service;

c) the ground SSE will be accessible over the GDLP’s ISO 8208 DTE-DCE interface providing access to the Mode S subnetwork and as such will behave as an ISO 8208 DTE having a ground DTE address;

d) data handled by the SSE is real time nature. This means that the timeliness of the data is paramount; and

e) end-to-end acknowledgement is not supported by the subnetwork. Applications requiring delivery guarantees must provide their own transaction management.

1.3 Service interactions are described in terms of service primitives. A primitive is an abstract view of protocol information and places no format restrictions on the contents.

1.4 In order to provide a comprehensive service the following primitive parameters are used:

Identification

a) D_Mode_S_address: 24-bit aircraft address;

b) D_App_id: numerical identifier for ground-based SSE applications;

c) D_Message_type: identifier for each primitive;

Broadcast data

d) D_broadcast: broadcast message sent or received (MA or MB field);

e) D_broadcast_id: broadcast identifier as defined by Mode S Subnetwork SARPs;

f) D_broadcast_no: a number used to correlate a broadcast request or subscription with the associated acknowledgement or data;

g) D_broadcast_prefix: contents of the first 32 bits of an uplink broadcast;

h) D_broadcast_priority: priority property of an uplink broadcast;

i) D_broadcast_duration: duration property of an uplink broadcast;

j) D_broadcast_zone: defines the geographical zone into which an uplink broadcast is to be made;

GICB data

k) D_BDS_code: BDS code identifying a particular GICB register;

l) D_GICB_extracted: MB field;
m) D_GICB_no: a number used to correlate a GICB request with the associated response(s);

n) D_GICB_periodicity: number of seconds for which broadcast remains active and other characteristics of GICB extraction;

MSP data

o) D_MSP_channel: MSP channel number as defined in the Mode S subnetwork SARPs;

p) D_MSP_no: a number used to correlate an MSP request or subscription with the associated acknowledgement or data;

q) D_MSP_ud: MSP user data of 1 to 159 bytes length (uplink: 151 bytes max; downlink: 159 bytes max);

r) D_MSP_ud_length: MSP user data length in bytes;

Diagnostic

s) D_result: indicates status of a response to a request;

Timestamping

t) D_time: absolute time stamp expressed as UTC time since last midnight;

Note.— The ground specific service application and the particular request issued by the application are unambiguously identified by D_App_id, D_broadcast_no, D_GICB_no and D_MSP_no.

2. ASSOCIATION MANAGEMENT

2.1 Association is the means with which the ground system notifies the SSE of the requirement to use the SSE services. An association will be formed between an SSE user and the ground SSE by the establishment of an ISO 8208 SVC between a DTE address at the end system containing the SSE user and an internal DTE address allocated to the ground SSE.

2.2 The ground SSE address will have the format of a ground DTE address, as defined by the Mode S subnetwork SARPs, but may be outside the range permitted for Mode S SVC services. The value of the SSE address will be user assignable and will be set up default to 257.

2.3 The DTE address at the end system of the SSE user will have the format and the range of a ground DTE address as defined by the Mode S subnetwork SARPs. A number of separate SSE user applications may be associated with a single DTE address, and these will be individually identified by use of the D_App_id parameter appearing in service primitives. Thus an SSE user will be unambiguously identified by the combination of its DTE address and D_App_id parameter.

2.4 An association will be established by means of an ISO 8208 CALL REQUEST packet and cleared by means of an ISO 8208 CLEAR REQUEST packet. In the event that either the SSE user or the GDLP SSE receives an INTERRUPT packet they will invoke the ISO 8208 RESET procedure.

3. GICB SERVICE

3.1 There are two aspects of the GICB service:

a) the ADLP is responsible for the timely update of the Comm-B register contents. These data are sent to the ADLP by avionics sub-systems via analogue or digital links. The ADLP gathers and reformats these data (at least a data concentrator is mandatory onboard). This facility is required to feed the transponder BDS registers with the relevant data; and

b) the requirement is to allow the ground user to request a GICB schedule.

3.2 A GICB interrogation extracts the latest contents of the Comm-B register held in the transponder.

3.3 A GICB request is for a particular Comm-B register from a particular aircraft. The SSE is responsible for managing all incoming requests to minimize the required interrogations. The request may be for a single extraction, in which case the M_SSE_GICB_extract_single request is used.

3.4 Alternatively, the user may nominate the period between successive extractions in the D_GICB_extract_periodic request as applicable. The D_time parameter may be optionally used to specify the end time of the extraction but, if not present, the request will be carried out indefinitely.

3.5 Following each subsequent successful extraction, the SSE will issue a response containing the extracted
GICB data in the D_GICB_extracted parameter. The D_time parameter will be set by the SSE to indicate the time of arrival at the interrogator.

3.6 Three cancellation primitives are provided. The user may cancel a particular GICB extraction by sending the M_SSE_GICB_cancel request. The user may also cancel all GICB extractions to a particular aircraft by sending the M_SSE_GICB_cancel_all_bds request. Alternatively, the user may cancel all GICB requests of an application by sending the M_SSE_GICB_cancel_all request.

3.7 The primitives required for the GICB service are defined as follows:

**GICB_extract_single**

*Direction:* from application to ground SSE;
*Contents:* D_Message_type;
D_App_id;
D_GICB_no;
D_Mode_S_address;
D_BDS_code.

*Direction:* from ground SSE to application;
*Contents:* D_Message_type;
D_App_id;
D_GICB_no;
D_Mode_S_address;
D_BDS_code;
D_Result;
D_Time;
D_GICB_extracted.

**GICB_extract_periodic**

*Direction:* from application to ground SSE;
*Contents:* D_Message_type;
D_App_id;
D_GICB_no;
D_Mode_S_address;
D_BDS_code;
D_GICB_periodicity;
D_Time.

*Direction:* from ground SSE to application;
*Contents:* D_Message_type;
D_App_id;
D_GICB_no;
D_Mode_S_address;
D_BDS_code;
D_Result;
D_Time;
D_GICB_extracted.

**GICB_cancel**

*Direction:* from application to ground SSE;
*Contents:* D_Message_type;
D_App_id;
D_GICB_no.

*Direction:* from ground SSE to application;
*Contents:* D_Message_type;
D_App_id;
D_GICB_no;
D_Mode_S_address;
D_Result.

**GICB_cancel_all_bds**

*Direction:* from application to ground SSE;
*Contents:* D_Message_type;
D_App_id;
D_Mode_S_address.

*Direction:* from ground SSE to application;
*Contents:* D_Message_type;
D_App_id;
D_Mode_S_address;
D_Result.

**GICB_cancel_all**

*Direction:* from application to airborne SSE;
*Contents:* D_Message_type;
D_App_id.

*Direction:* from ground SSE to application;
*Contents:* D_Message_type;
D_App_id;
D_Result.

4. BROADCAST SERVICE

4.1 Ground users subscribe to uplink broadcast service by aircraft address and broadcast channel identifier (as defined by the Mode S subnetwork SARPs). The subscription may apply to a particular aircraft (M_SSE_BDN_subscribe request) or, alternatively, to all aircraft handled by the GDLP (M_SSE_BDN_subscribe_all_ac request). The ground SSE forwards received downlink broadcasts to the users in accordance with their subscriptions.

4.2 Subscriptions can be cancelled by issuing an M_SSE_BDN_cancel message (cancellation of a particular
subscription) or, alternatively, an \texttt{M\_SSE\_BDN\_cancel\_all} message (cancellation of all active subscriptions for the ground user).

4.3 The primitives are defined as follows:

\texttt{BDN\_subscribe}

\textit{Direction:} from application to ground SSE;
\textit{Contents:} \texttt{D\_Message\_type; D\_App\_id; D\_Broadcast\_no; D\_Mode\_S\_address; D\_Broadcast\_id.}

\textit{Direction:} from ground SSE to application;
\textit{Contents:} \texttt{D\_Message\_type; D\_App\_id; D\_Broadcast\_no; D\_Mode\_S\_address; D\_Broadcast\_id; D\_Result; D\_Time; D\_Broadcast.}

\texttt{BDN\_subscribe\_all\_ac}

\textit{Direction:} from application to ground SSE;
\textit{Contents:} \texttt{D\_Message\_type; D\_App\_id; D\_Broadcast\_no; D\_Broadcast\_id.}

\textit{Direction:} from ground SSE to application;
\textit{Contents:} \texttt{D\_Message\_type; D\_App\_id; D\_Broadcast\_no; D\_Broadcast\_id; D\_Result.}

\texttt{BDN\_cancel}

\textit{Direction:} from application to ground SSE;
\textit{Contents:} \texttt{D\_Message\_type; D\_App\_id; D\_Broadcast\_no.}

\textit{Direction:} from ground SSE to application;
\textit{Contents:} \texttt{D\_Message\_type; D\_App\_id; D\_Broadcast\_no; D\_Result.}

4.4 No subscription is required by the airborne end-system; the airborne SSE forwards all received broadcast messages to the SSE interface.

4.5 Uplink broadcast requests are enabled for a variable period (approximately a period of three complete antenna scans is recommended). Uplink broadcast may be cancelled at any time before the enabled period expires. Two cancellation primitives are available: \texttt{M\_SSE\_BUP\_cancel} message applies to the cancellation of a particular uplink broadcast request and \texttt{M\_SSE\_BUP\_cancel\_all} message applies to the cancellation of all active uplink broadcast requests of the user.

4.6 The primitives are defined as follows:

\texttt{BUP\_request}

\textit{Direction:} from application to ground SSE;
\textit{Contents:} \texttt{D\_Message\_type; D\_App\_id; D\_Broadcast\_no; D\_Broadcast\_id; D\_Broadcast\_duration; D\_Broadcast\_priority; D\_Broadcast\_zone; D\_Broadcast\_prefix; D\_Broadcast.}

\textit{Direction:} from ground SSE to application;
\textit{Contents:} \texttt{D\_Message\_type; D\_App\_id; D\_Broadcast\_no; D\_Broadcast\_id; D\_Result.}

\texttt{BUP\_cancel}

\textit{Direction:} from application to ground SSE;
\textit{Contents:} \texttt{D\_Message\_type; D\_App\_id; D\_Broadcast\_no; D\_Broadcast\_id; D\_Result.}

\textit{Direction:} from ground SSE to application;
\textit{Contents:} \texttt{D\_Message\_type; D\_App\_id; D\_Broadcast\_no.}
5. MSP SERVICE

5.1 The ground user subscribes to an MSP channel (as defined by the Mode S subnetwork SARPs). Each subscription may apply to a particular aircraft (M_SSE_MDN_subscribe request) or, alternatively, to all aircraft (M_SSE_MDN_subscribe_all_ac request). Only messages which are subscribed to are forwarded to the user.

5.2 The user may cancel a particular subscription (identified by the D_App_id and D_MSP_no parameters) by sending an M_SSE_MDN_cancel message. The user may also cancel its currently active subscription to downlink MSPs by sending an M_SSE_MDN_cancel_all message.

5.3 Applications making use of the MSP service are ground initiated. If the application requires air initiation of service, for example pilot request for weather data, then the ground application needs to advise the airborne application of its existence.

5.4 The primitives are defined as follows:

MDN_subscribe

Direction: application to ground SSE;
Contents: D_Message_type;
D_App_id;
D_MSP_no;
D_Mode_S_address;
D_MSP_channel.

MDN_subscribe_all_ac

Direction: from application to ground SSE;
Contents: D_Message_type;
D_App_id;
D_MSP_no;
D_MSP_channel.

Direction: from ground SSE to application;
Contents: D_Message_type;
D_App_id;
D_MSP_no;
D_Mode_S_address;
D_MSP_channel;
D_Result;
D_Mode_S_address;
D_Time;
D_MSP_ud_length;
D_MSP_ud.

MDN_cancel

Direction: from application to ground SSE;
Contents: D_Message_type;
D_App_id;
D_MSP_no.

Direction: from ground SSE to application;
Contents: D_Message_type;
D_App_id;
D_MSP_no;
D_Result.

MDN_cancel_all

Direction: from application to ground SSE;
Contents: D_Message_type;
D_App_id.

Direction: from ground SSE to application;
Contents: D_Message_type;
D_App_id;
D_Result.
5.5 The user interactions required for the MSP uplink service are shown in Figure 9B-5. No subscriptions are used for the airborne service.

5.6 An uplink MSP request is for transmission of a single MSP packet to a particular aircraft on a specified MSP channel. The request can be cancelled at any time before the packet is transmitted by the interrogator. The user may cancel a particular uplink MSP request by sending an M_SSE_MUP_cancel message or, alternatively, may cancel all its currently active uplink MSP requests by sending an M_SSE_MUP_cancel_all message.

5.7 The required primitive contents are defined as follows:

**MUP_request**

*Direction:* from application to ground SSE;  
*Contents:*  
- D_Message_type;  
- D_App_id;  
- D_MSP_no;  
- D_Mode_S_address;  
- D_MSP_channel;  
- D_MSP_ud_length;  
- D_MSP_ud.

*Direction:* from ground SSE to application;  
*Contents:*  
- D_Message_type;  
- D_App_id;  
- D_MSP_no;  
- D_Mode_S_address;  
- D_MSP_channel;  
- D_Result.

**MUP_cancel**

*Direction:* from application to ground SSE;  
*Contents:*  
- D_Message_type;  
- D_App_id;  
- D_MSP_no.

*Direction:* from ground SSE to application;  
*Contents:*  
- D_Message_type;  
- D_App_id;  
- D_MSP_no;  
- D_Mode_S_address;  
- D_MSP_channel;  
- D_MSP_ud_length;  
- D_MSP_ud.

**MUP_cancel_all**

*Direction:* from application to ground SSE;  
*Contents:*  
- D_Message_type;  
- D_App_id.

*Direction:* from ground SSE to ground SSE;  
*Contents:*  
- D_Message_type;  
- D_App_id;  
- D_Result.

6. SSE MANAGEMENT SERVICE

6.1 In order to support Mode S specific services, the ground end-system needs to obtain information concerning potential targets. To include this information in the SSE services will complicate the protocol considerably and to no useful purpose. The SSE user must separately access the Mobile Reporting Facility (MRF) entity within the T-GDLP and obtain aircraft information using the MRF services.

6.2 The MRF will be remotely accessible to the SSE users over the ISO 8208 DTE-DCE interface providing access to the Mode S subnetwork and as such behave as an ISO 8208 DTE having a ground DTE address. This address will be capable of being configured by the user and will be set up default to 256. Join and leave events are sent from the MRF to the ground applications that have been registered by the MRF, i.e. following system start-up a ground SSE user will attempt to open an SVC to the MRF by issuing a CALL REQUEST to the ground DTE address allocated to the GDLP MRF. In the event that an SVC is not established to an MRF, the user must repeat the attempt at intervals, until an SVC is established.

6.3 To provide SSE users with aircraft availability information, as opposed to mobile DTE information, an additional form of SNPA field must be included in the Join/Leave primitives. The SNPA field incorporates sub-fields “Type, Length, Value”. Type = 1 SNPA fields contain mobile DTE addresses. Type = 2 SNPA field must have Length = 3 bytes, with Value = 24-bit aircraft address. Whenever an aircraft enters or leaves the coverage of the GDLP, the MRF will issue a Join or Leave event, to all connected ground end users, containing a Type = 2 SNPA field, which may be present in isolation or else in combination with one or more Type=1 SNPA fields (depending on the mobile DTE available at present for this particular aircraft).

6.4 The GDLP MRF primitives are defined as follows:

**MRF_join**

*Direction:* from GDLP MRF to application;
### Contents:
- message ID;
- length;
- version;
- lifetime;
- SNPA.

### Direction:
from GDLP MRF to application;

### Contents:
message ID; length.

### MRF_leave

**Direction:** from GDLP MRF to application;

**Contents:** message ID; length.

### MRF_refresh_request

**Direction:** from airborne to application;

**Contents:** message ID; length.

**Note.—** Detailed information can be obtained from Eurocontrol, with the following references:

Chapter 10

EXTENDED SQUITTER, SYSTEM CONCEPT
AND APPLICATIONS

10.1 INTRODUCTION

Note.— The following description is based primarily on the use of GNSS as the navigation source. While this is expected to be the principal source, the message formats for extended squitter permit the reporting of position based on other sources of navigation (such as inertial). The accuracy of the reported position is defined by a figure of merit included in the message.

10.1.1 Mode S extended squitter is a technique that combines the capabilities of the SSR Mode S system with those of automatic dependent surveillance (ADS). This is accomplished by using an extended squitter as the broadcast data link for transferring the aircraft-derived ADS report from the aircraft to airborne or ground users. This type of operation is known as ADS-broadcast (ADS-B). In addition to airborne and surface surveillance, Mode S extended squitter is expected to find application in enhancements to ACAS operation. The extended squitter concept is illustrated in Figure 10-1.

10.2 SYSTEM CONCEPT

10.2.1 In the current Mode S design, each Mode S transponder pseudo-randomly radiates (squitters) its unique Mode S address in an azimuth-omnidirectional pattern once per second. This squitter is a 56-bit transmission of 64 µs duration, broadcast on the Mode S transponder reply frequency (1 090 MHz). Figure 10-2 illustrates the current Mode S squitter. The squitter is used by the airborne collision avoidance system (ACAS) to detect the presence of Mode S-equipped aircraft. In operation, an ACAS listens for squitters, extracts the 24-bit aircraft address contained in the squitter data and uses this address as the basis for discrete interrogation, as required, to perform surveillance on Mode S-equipped aircraft.

10.2.2 This form of squitter is currently in operational use with ACAS. Its performance is well understood from the design and validation of ACAS as well as the substantial experience with ACAS as an operational system.

10.2.3 The Mode S message protocol defines both 56-bit and 112-bit reply formats. The extended squitter approach uses a 112-bit format for squitters, as shown in Figure 10-3. This creates a 56-bit message field for ADS data. All other fields remain the same as in the original short squitter.

10.2.4 In operation, aircraft equipped with a GNSS receiver determine their position and velocity at least once every second. This information is inserted into the 56-bit ADS message field of the long squitter and broadcast twice per second by the Mode S transponder. The current 56-bit short squitter continues to be broadcast for compatibility with ACAS. The short squitter transmission can be omitted if all ACAS equipment is converted to receive the long squitter.

10.2.5 The omnidirectional pattern of extended squitter broadcast makes it possible to support both air-ground and air-air surveillance applications. A key advantage of ADS-B is that the ground station can be relatively simple compared to a current ground SSR.

10.2.6 In addition to the transponder implementation of extended squitter described above, the system concept also includes the capability to transmit extended squitter from a non Mode S transponder device. The rationale for this extended squitter non-transponder (ES/NT) capability is to obtain a lower cost general aviation or surface vehicle extended squitter implementation than would be available by an extended squitter implementation based on a Mode S...
transponder. The extended squitters from a Mode S transponder are identified by a downlink format (DF) code equal to 17. In order to unambiguously identify the extended squitters from ES/NT devices, a DF code of 18 is used. The use of a different DF code format is used to ensure that replies from these ES/NT devices are clearly identified in order to prevent ACAS II from attempting to interrogate them for acquisition or for hybrid surveillance.

10.2.7 The ES/NT devices perform all of the extended squitter functions of the transponder-based implementation, except those that directly depend on Mode S transponder functions. An example of a feature that is not supported is squitter rate and format control by uplink SD field commands via a ground Mode S interrogator.

10.3 DATA LINK

It is intended that extended squitter ground stations be capable of interrogation as well as reception. This capability is needed to support the hybrid surveillance concept (10.5.5) and also for the provision of two-way Mode S data link. This capability can be used to augment the data link service provided by Mode S interrogators, particularly for extending data link coverage down to a low altitude. Another important application is data link service on the airport surface.

10.4 SURVEILLANCE APPLICATIONS

10.4.1 The most important surveillance applications of extended squitter are:

a) air-ground:
   1) en route;
   2) terminal; and
   3) precision runway monitoring (PRM);

b) surface, for runways and taxiways; and

c) air-air;
   1) ACAS hybrid surveillance; and
   2) cockpit display of traffic information (CDTI).

10.4.2 Mode S extended squitter ground stations will perform both surveillance and data link tasks. Surveillance will be principally through the passive reception of position and aircraft type and identification squitter information. Active surveillance will be used to acquire additional information such as aircraft SSR Mode A code.

USE OF SURVEILLANCE STATUS SUBFIELD

10.4.3 In the acquisition squitter, the means to alert the ground of a surveillance or data link condition requiring ground interrogation is the setting of code 7 in the CA field. This indicates that one or more of the following conditions is set in the transponder:

a) an air-initiated message or an ACAS RA is waiting;

b) the SSR Mode A code has been changed (includes emergency); and

c) there is a special position identifier (SPI) condition.

This code is sufficient if the squitter ground station is performing both surveillance and data link services for the aircraft. If the ground station is only performing surveillance (e.g. the aircraft is outside of the assigned data link area of responsibility), then the ground station would waste channel time interrogating aircraft whose CA field was set to seven because of a waiting data link message. To eliminate this possibility, a Surveillance Status Subfield (SSS) is defined in the airborne position squitter. The coding in this field indicates whether there is a surveillance reason to interrogate the aircraft, e.g. surveillance alert or SPI.

10.4.4 The concept for air-ground surveillance for both a terminal area and en route is shown in Figure 10-4. Aircraft determine their positions using GNSS and broadcast these positions via the squitter. The squitter is received by terminal and en-route ground stations. The terminal antenna is shown as a single omni, which is capable of a squitter reception range of 90 to 180 km (50 to 100 NM).

10.4.5 PRM surveillance can be supported using the same antennas used for terminal surveillance, or may use dedicated antennas to provide the required coverage. The accuracy requirement for PRM imposes the use of differential corrections by the GNSS navigation equipment. These corrections are determined on the ground and are transmitted to the aircraft.

10.4.6 For en-route operation, a 6-sector high-gain antenna (with six independent low-noise receivers) is
necessary in order to obtain a 370 km (200 NM) surveillance range. The 6-sector antenna may also be used in high traffic density areas in order to limit the number of aircraft being processed by any one receiver.

SURFACE SURVEILLANCE

10.4.7 Airport surface surveillance is illustrated in Figure 10-5. Aircraft transmit squitters containing their differentially corrected positions while operating on runways and taxiways. These squitters are received by several stations around the periphery of the airport. Two such stations are shown in the figure, but the actual number for each airport will be determined by squitter reception performance in the environment of the airport surface. Measurements have indicated that four stations will provide good coverage for most terminals.

AIR-AIR SURVEILLANCE

ACAS hybrid surveillance

10.4.8 Although it does not affect the collision avoidance function, the availability of position and velocity data in the extended squitters will result in significant improvement to ACAS surveillance.

10.4.9 Extended squitter will reduce the effect of ACAS on the SSR environment through reduced interrogation rates. ACAS will be able to monitor intruders at full range rather than the reduced range currently available to ACAS in high traffic density environments due to the action of interference limiting.

10.4.10 The ACAS ability to support active Mode S interrogations makes it possible for ACAS to obtain additional information from a threat aircraft via readout of registers contained in every Mode S transponder. This capability is termed the ACAS cross-link (see Annex 10, Volume IV, Chapter 3, 3.1.2.8). Cross-link information can provide for enhanced operation of ACAS through the use of intent information to reduce the rate of unnecessary alerts.

CDTI via extended squitter

10.4.11 CDTI enables situational awareness and is feasible for aircraft which are equipped with a 1090 MHz receiver. Such aircraft would listen to extended squitters from nearby aircraft and display their positions and identity on a small cockpit display. A range of 26 km (14 NM) can be supported for CDTI using receivers equivalent to those in ACAS. This range can be extended up to 185 km (100 NM) through the addition of a low-noise front end to the receivers. ACAS aircraft already have 1090 MHz receivers, which would require modifications for increased range, but other aircraft would have to equip in order to realize this benefit. For capacity limitations see 10.8.

OTHER SURVEILLANCE APPLICATIONS

10.4.12 Provided that the independence of navigation and surveillance functions is preserved, extended squitter could be considered as a low-cost means for surveillance:

a) for small terminals which do not qualify for high-cost ground SSR equipment; and

b) for en-route gap filling in mountainous or remote areas.

10.5 INDEPENDENCE OF NAVIGATION AND SURVEILLANCE

POTENTIAL FOR LOSS OF INDEPENDENCE

10.5.1 Traditionally, ATC has required the use of separate and independent systems for communications, navigation and surveillance. This is referred to as the principle of independence. The benefit to aviation is that independence makes it unlikely that an aircraft could lose more than one of its capabilities at the same time. This provides for a robust backup in the event of a failure of one of the systems. For example, loss of navigation capability on board an aircraft can be accommodated through the use of ground vectors provided by an air traffic controller based on ground SSR data.

10.5.2 If used as the sole means of surveillance, ADS-B inherently merges the aircraft navigation and surveillance capabilities. As a consequence, loss of navigation capacity would not be able to be accommodated with ADS-B alone, since ATC would lose surveillance and, therefore, be unable to provide vectors.

10.5.3 In addition to a complete failure of navigation, a second aspect of loss of independence is that an undetected failure of the navigation system that resulted (for example) in a slowly increasing error may not be detected. This can happen since both pilot and ground controller would see the aircraft on its intended course, when, in fact, the actual position of the aircraft could be on a very different course.
10.5.4 Due to loss of independence, ADS-B cannot by itself be considered to be a direct replacement for SSR.

HYBRID SURVEILLANCE

10.5.5 The integration of extended squitter into the SSR Mode S system offers a straightforward way to obtain the benefits of ADS-B while still maintaining independence. This is based on the use of hybrid surveillance.

10.5.6 As the name implies, hybrid surveillance makes use of both passive ADS-B and active SSR surveillance. The technique can be applied to both ground ATC and ACAS surveillance applications. The active surveillance is used to validate the ADS-B reported position, and to take the place of ADS-B if an aircraft loses navigation capability.

HYBRID SURVEILLANCE APPLICATION TO ATC SURVEILLANCE

10.5.7 In operation, an ADS-B ground equipment would detect the presence of a new aircraft under surveillance. At track initiation, the ADS-B station would transmit an addressed interrogation to that aircraft to make an independent assessment of the validity of the reported position. For ground ATC, an estimate of the new track’s two dimensional position is possible. This can be obtained via simple monopulse processing in the event that the ground station has a multisector beam antenna. A second possibility for an ADS-B ground station that has overlapping coverage with one or more neighbouring stations is the use of range-range or time difference multilateration.

10.5.8 If the validity check at track initiation is successful, the aircraft can be maintained on ADS-B and periodically monitored to verify continued correct operation of the navigation system. If a check fails at any time, then the track can be maintained on active surveillance. For ATC, this will likely require the use of increased separation for this aircraft, since a reduction in surveillance performance is likely.

HYBRID SURVEILLANCE APPLIED TO ACAS SURVEILLANCE
(SEE ANNEX 10, VOLUME IV, CHAPTER 4, 4.5.1)

10.5.9 For ACAS, a similar approach to validation at track initiation and monitoring is used. At track initiation, an addressed interrogation is made to determine the aircraft range. This is compared to the relative range determined from a comparison of own and the intruder’s ADS-B position.

10.5.10 Monitoring after acquisition is based on an assessment of the imminence of collision with the intruder. When the intruder is within 3 000 ft, 3 NM or within 60 seconds of these thresholds, re-validation takes place every ten seconds. When the intruder is close in both range and altitude (but not yet a potential threat), full active surveillance is performed every second. Full active interrogation and ACAS surveillance starts well before any collision avoidance advisory is required. Note that a loss of ADS-B capability will not affect the collision avoidance performance of an ACAS II, since this form of ACAS uses range measurements from active interrogations (together with reported altitude) for its surveillance of intruders.

MONITORING BY MODE S INTERROGATORS

10.5.11 The ADS-B messages that are broadcast via extended squitter are also available for readout by a Mode S interrogator using an addressed interrogation and the GICB protocol. This will provide a means to monitor the accuracy of the ADS-B reports when in the cover of a Mode S interrogator.

10.6 EXTENDED SQUITTER ADS MESSAGE TRANSMISSION

EXTENDED SQUITTER TYPES

10.6.1 Extended squitter makes use of five types of squitter:

a) airborne position;

b) airborne velocity information;

c) surface position;

d) aircraft type and identification; and

e) event-driven.

Either the airborne position and velocity squitters, or the surface position squitter are transmitted depending on aircraft location. The aircraft type and identification, and event driven squitters are transmitted as additional squitters in the air and on the ground. The 56-bit acquisition squitter
is retained while airborne (and in certain cases when on the surface, 6.15.3) for continued compatibility with current ACAS equipment.

**REPORTING OF EXTENDED SQUITTER CAPABILITY**

10.6.2 Provision has been made in the data link capability field to identify a transponder with extended squitter capability (bit 34 of transponder data register 10 (HEX)). This is desirable to monitor transponder equipage via narrow-beam Mode S interrogators, since they cannot reliably receive transponder squitters.

10.6.3 Note that each extended squitter transmission contains the aircraft address. This makes it possible to unambiguously associate the data in the various squitter formats with the originating aircraft. An overview of the message structure is provided in Figure 10-6.

10.6.4 The message data for each squitter type is obtained from a defined transponder register. The formats and data sources for the squitter messages are defined in Annex 10, Volume III, Part I, Appendix to Chapter 5.

**AIRBORNE POSITION**

10.6.5 The airborne position message can be considered to provide basic surveillance information. This includes three-dimensional position plus validity time and surveillance status information.

**AIRBORNE VELOCITY**

10.6.6 The airborne velocity message can be considered as a definition of aircraft state. Together with the position message, the information in the velocity squitter provides the complete four-dimensional aircraft state vector. Such state vector information will greatly improve the prediction performance of both airborne and ground-based tracking systems.

**SURFACE POSITION**

10.6.7 The surface position message provides the complete surface state vector in a single message. This is made possible since altitude and vertical rate reporting are not required on the surface. The use of a single squitter type on the surface is important. For the surface application, the majority of the channel activity will be extended squitters. Therefore, use of a single squitter for aircraft state will lead to a higher surveillance capacity.

10.6.8 Selection of the surface format will be based on the use of a “weight on wheels” switch (also referred to as a squat switch). Provision is made in the SD field of an addressed interrogation to command an aircraft to use the surface format. This command times out to prevent an aircraft from remaining in the surface format condition while airborne. Provision is also made in the SD field for a timed command to lock out surface squitters for cases where surface surveillance based on squitter transmissions is not required.

**AIRBORNE/SURFACE STATE DETERMINATION**

10.6.9 Aircraft with automatic means for determining the on-the-ground condition (squat switch) will use this input to determine whether to transmit the surface or the airborne squitter type. Aircraft that do not have a squat switch will report the airborne type, unless commanded by the ground to report the surface type. These commands may also be sent to aircraft with squat switches where they take precedence over the squat switch input. This provision is made to handle the case of a failed squat switch.

10.6.10 These commands can only affect the format type reported, they cannot change the aircraft determination of its on-the-ground condition. Thus, an aircraft without the means to set the on-the-ground condition will continue to report code 6 in the CA field, and an aircraft, that believes it is airborne, with the means to set the on-the-ground condition, will continue to set code 5, independent of the extended squitter format that is emitted.

10.6.11 These commands can be generated by extended squitter surface surveillance ground stations. Surface status will be determined by aircraft position, altitude and ground speed relative to the airport surface.

10.6.12 When an aircraft takes off, the squat switch input or commands from the ground station will cause a change back to the airborne format. Commands to report the surface position type will timeout to prevent continued transmission of the surface format to cover the case of loss of contact with the aircraft after take-off.

**IDENTITY**

10.6.13 The identity squitter provides the aircraft type category, as well as the ICAO identifier (i.e. the aircraft
radio call sign. Type information is useful for visual acquisition and for wake vortex avoidance. The call sign is necessary since it is the operational address of the aircraft. (See Annex 10, Volume IV, Chapter 3, Table 3-7, Character coding for transmission of aircraft identification by data link.)

**EVENT DRIVEN**

10.6.14 The event-driven squitter is intended for the transmission of additional information that may be needed infrequently. This message type is defined principally as a means for accommodating the needs of future ADS-B applications. An example of a possible use of this squitter would be for additional information on the nature of a declared emergency.

**SQUITTER CAPABILITY REPORTING OF VARIABLE SURFACE SQUITTER RATE**

10.6.15 As indicated in 10.6.24, the variable surface squitter rate will be determined outside of the transponder based on position and velocity information. For example, this function may exist in the navigation unit or in the Mode S aircraft data link processor (ADLP). A means is needed to pass this information to the transponder and to notify the ground that this transponder is capable of determining its surface squitter rate. Transponder register 07 (HEX) is defined for this purpose. The airborne process that determines the rate will set the contents of squitter transmission rate subfield (TRS). The TRS information will be read by the transponder to set the surface squitter rate. In addition, the TRS contents will be read by the ground to determine if the aircraft is capable of surface squitter rate determination, or if the rate must be controlled by the ground.

**SURFACE SQUITTER LOCKOUT**

10.6.16 Airports that do not use extended squitter or multilateration for surface surveillance may not need to use the squitters transmitted by surface aircraft.

10.6.17 For this reason, a command has been provided in the SD field for DI=2 of an addressed interrogation to suppress surface squitters for 60 seconds in order to reduce channel occupancy at these airports.

10.6.18 This command has no effect on a transponder that is broadcasting the airborne type of extended squitter. Therefore, aircraft without the means of determining on-the-ground condition must first be commanded to transmit the surface format before they can be placed into a state of squitter lockout. Both of these commands have a specific timeout period. If the surface format command times out first, the aircraft will resume broadcasting the airborne format even if the squitter lockout command has not timed out (since the squitter lockout command has no effect on the transmission of the airborne format). If the squitter lockout command times out first, the aircraft will resume the transmission of surface squitters.

10.6.19 Acquisition squitters will be broadcast during a period of surface squitter lockout, as described in 6.15.2.

**CHANNEL ACCESS TECHNIQUE**

10.6.20 Extended squitters are broadcast using a pseudo-random channel access technique. This is the same technique that is used for the current short squitter that is in operational use in support of ACAS. A pseudo-random technique for extended squitter provides some advantages which are explained below.

10.6.21 **High capacity.** For a high data rate system (like Mode S) it provides higher capacity than other channel access techniques. For example, if a time division multiple access (TDMA) approach were used on 1 090 MHz supporting surveillance to 460 km (250 NM), this would require a 1.5 ms guard time following each 120 µs extended squitter. This would lead to a maximum capacity of approximately 600 aircraft using the one-second update required to support ACAS.

10.6.22 **Compatible with a sector beam antenna.** A pseudo-random channel access technique is compatible with sector antennas that are used in extended squitter ground stations to break up the traffic population and thus reduce the squitter rate to the receiver connected to each sector, which has the effect of increasing the maximum operating capacity.

10.6.23 **Support for multiple update rates.** The pseudo-random approach has the ability to satisfy aviation surveillance users with different update requirements. The ACAS surveillance requirement is for a 1-s update rate out to about 26 km (14 NM). A 5-s update is required for terminal ATC operation for aircraft out to 110 km (60 NM). En-route interrogators currently provide up to a 12-s update rate to a range of 370 km (200 NM). An ACAS receiving extended squitter would operate at a sensitivity level adequate for 26 km (14 NM). This level means that the ACAS squitter receiver would process squitters from a small fraction of the aircraft visible to a terminal or en-route squitter receiver, permitting the ACAS to operate at a
squitter reception level suitable for a 1-s update. The en-
route and terminal receivers operate with a much higher
signal traffic density due to their greater operating range.
While leading to a lower probability of reception of a single
squitter, the multiple squitter opportunities produce a high
probability of an update during the 5-s or 12-s update
period. Both requirements are handled simultaneously by
the same pseudo-random squitter.

**TRANSMISSION RATES**

10.6.24 The airborne position and velocity squitters
are each transmitted pseudo-randomly twice per second
when the aircraft is airborne. When the aircraft is airborne,
the identification squitter is transmitted pseudo-randomly
once every five seconds. On the surface, the surface
position squitter is transmitted pseudo-randomly twice per
second when the aircraft is moving and once per five
seconds when the aircraft is stationary. On the surface, the
identification squitter is transmitted pseudo-randomly once
per five seconds when the aircraft is moving and once per
ten seconds when the aircraft is stationary. A determination
of aircraft motion is made outside of the transponder based
on monitoring the position and velocity data. The result of
this determination is passed to the transponder via
transponder register 07 (HEX).

10.6.25 A squitter may be delayed, but not omitted, if
the transponder is busy with an addressed transaction or
another squitter at the intended time of transmission for an
extended squitter. A delayed squitter will be transmitted at
the next available opportunity.

**Antenna selection**

10.6.26 For aircraft with diversity antennas, each
squitter is transmitted alternately from the top and bottom
antenna when the aircraft is airborne. On the surface, all of
the extended squitters are transmitted using the antenna as
specified in the SAS subfield of the SD field for DI = 2 that
is delivered via an addressed uplink interrogation. The
default is to use the top antenna only. The alternative is to
alternate between the top and bottom antenna.

**Timeout of squitter transponder data registers**

10.6.27 Each of the four transponder data registers
used for regularly scheduled extended squitters (airborne
position, airborne velocity, surface position, aircraft identi-
fication and type) are cleared if they are not updated within
two seconds. This is done to prevent the transmission of
outdated information. This timeout is not required for the
event-driven squitter since it is loaded each time that an
event-driven squitter is to be transmitted.

10.6.28 The internal insertion of data by the tran-
sponder into these registers (e.g. altitude and surveillance
status fields for the airborne position report) does not
qualify as a register update for the purposes of this timeout
condition. Transponder data insertion and squitter trans-
mision continue during a register timeout event.

**Airborne position and velocity**

10.6.29 Extended squitter operates on a channel that
is shared with other users. In the airborne case, the majority
of the activity is due to conventional SSR replies. The rate
of squitter receptions will be influenced by the transmission
rate of the transponder. This rate must be at least once per
second in order to support the update rate required by
ACAS. Since most of the channel activity is background
interference, an increase to an average rate of two per
second for the airborne position and velocity squitters is
used to obtain a higher operating capacity. The effect of this
increase in squitter rate on traffic capacity for a ground-
based receiver is provided in the following paragraphs.

10.6.30 The airborne traffic capacity for a ground-
based extended squitter receiving station is presented in
Figure 10-7 as a function of the number of squitters trans-
mitted per second by each aircraft. The background inter-
ference cases for conventional SSR replies and Mode S
replies to ground or ACAS interrogations are defined in
Table 10-1.

10.6.31 The results shown in Figure 10-7 are for a
station with an omnidirectional antenna and indicate a
capacity that can be supported for each interference case
while providing an update once per 5 seconds with a
probability of greater than or equal to 99.5 per cent. The
traffic capacity shown represents the traffic within 280 km
(150 NM) of the station.

10.6.32 The figure indicates a substantial increase in
capacity through a change from one to two squitters per
second. Further increases in squitter rate offer only a
modest increase in capacity for Cases 1 and 2, indicating
that the improvement in performance offered by an
increased number of squitters per 5 seconds is offset by the
reduced probability of receiving each squitter due to the
increased channel activity. This effect of the increased channel activity is shown in Case 3 where the squitters become the dominant activity at the higher squitter rates. For Case 4, the capacity reaches a peak and then decreases due to the effect of squitter occupancy on the probability of squitter reception.

10.6.33 These effects are shown more clearly in Figure 10-8, which presents the fractional capacity change resulting from one additional squitter per second. The change in squitter rate from one to two per second results in a 67, 70, 83 and 92 per cent increase in capacity for Cases 1 through 4, respectively. An increase to three squitters per second provides an additional improvement of less than 30 per cent. The selected operating point of two squitters per second is seen to represent a reasonable rate for airborne surveillance.

Identity

10.6.34 The identity squitter contains static data (aircraft type and radio call sign). For this reason, it can be transmitted at a lower rate than the position and velocity squitters. Since acquisition of an aircraft may not be considered complete until the identity is received, a squitter rate must be chosen that will not cause a long delay in the reception of identity. A transmission rate of once per five seconds has been selected for this purpose.

Surface position

10.6.35 The required surface position update rate is once per second. Since surface multipath will result in some loss of otherwise ungarbled squitters, a higher than once per second data rate is required. For this reason, the same twice per second transmission rate is used as for the airborne position and velocity squitter.

10.6.36 On the surface, the majority of the channel activity results from squitter transmissions. This follows since:

a) transponders do not respond to conventional SSR or Mode S all-call interrogations while on the surface; and

b) surface squitter receiving stations operate with a very short range. They therefore receive replies from only those aircraft operating near the airport.

10.6.37 For this reason, it is desirable to lower the squitter rate for stationary traffic as a means of increasing surface capacity. The approach used to reduce the squitter rate for surface aircraft is as follows:

a) when the aircraft is moving, emit:
   1) position squitter twice per second; and
   2) identity squitter once per 5 seconds;

b) when the aircraft is stationary, emit:
   1) position squitter once per 5 seconds; and
   2) identity squitter once per 10 seconds;

c) transition to the higher squitter rate occurs when motion is detected on board the aircraft (see Manual on Mode S Specific Services (Doc 9688)); and

d) provide controls in the SD field of an addressed interrogation to prevent a transition to the low rate when the aircraft is in a critical position, e.g. stopped at the entrance to an active runway.

Event-driven

10.6.38 An event-driven squitter is broadcast at a rate and time duration depending upon need. The actual rate and duration will be determined by an application that is generating the messages that are input into the transponder. The transponder will broadcast each message that is input into the event-driven register a single time. A maximum rate of no more than twice per second will be permitted by the transponder.

10.6.39 An example of the use of this squitter would be for additional information on the nature of a declared emergency. In this case, the squitter would likely be broadcast twice per second for the duration of the emergency. It is intended that the average rate of these squitters across the traffic population be low, no more than an average of 0.3 squitters per second per aircraft.

Transponder insertion of barometric altitude

10.6.40 The reliability of barometric altitude in the extended squitter is enhanced if the altitude is inserted into
the airborne position message directly by the transponder, since this ensures that the altitude is based upon the same source. Provision has been made for the direct insertion of barometric altitude into the airborne position messages that contain this information. Since provision is also made in the airborne position formats to transmit GNSS height data, the ATS subfield (Annex 10, Volume IV, Chapter 3, 3.1.2.8.6.8.2) has been included in the extended squitter status transponder data register (transponder data register 07 [HEX]), to suppress the internal insertion of altitude when GNSS height is being used.

10.6.41 The transponder insertion of altitude into the extended squitter position message requires the use of a 12-bit altitude field. This allows the transponder to determine the quantization (25 or 100 feet) and results in a direct transfer of the AC field data (less the M-bit) into the airborne position message.

10.6.42 When the transponder determines that it is time to emit an airborne position squitter, it will (unless inhibited by the ATS subfield) insert the current value of the barometric altitude and surveillance status into the appropriate fields of transponder data register 05 [HEX]. The contents of this register will then be inserted into the ME field of DF=17 and transmitted. Insertion in this manner ensures that (1) the squitter contains the latest altitude and surveillance status at the time of squitter transmission, and (2) ground readout of register 05 [HEX] will yield exactly the same information as contained in the previous squitter.

10.7 OPERATIONAL RANGE

10.7.1 The design baseline for squitter reception range was based on ACAS experience.

10.7.2 For a surface receiver, range improvements relative to ACAS are easily accomplished by the use of improved antenna gain through vertical aperture and the use of horizontal sector beams. A second technique for enhanced range performance that applies to both airborne and ground receivers is the use of a receiver with a reduced noise figure. These improvements produce a conservative extended squitter operating range for a ground station of 90 to 180 km (50 to 100 NM) using an omnidirectional antenna and 370 km (200 NM) using a 6-sector antenna. The use of a low noise front end makes it possible to achieve a 180 km (100 NM) squitter reception range with an airborne receiver using a simple transponder-type omnidirectional antenna.

10.7.3 Antenna characteristics and a link budget for extended squitter receivers are presented in Table 10-2.

10.8 SURVEILLANCE CAPACITY

10.8.1 As indicated in 10.4, extended squitter has the capability to support a number of surveillance applications. The surveillance requirements differ for each of these applications, and thus the capacity must be estimated separately. Capacity estimates are provided in the following paragraphs for each of the following surveillance applications:

a) CDTI, 10-second update, air-air with and without surface aircraft;

b) ACAS, 1- and 2-second update air-air with and without surface aircraft;

c) surface, 1-second update ground-ground; and

d) air-ground, 5-second update air-ground.

ANALYSIS METHODOLOGY

Overview

10.8.2 The technique used to estimate extended squitter surveillance capacity presented in this section is based upon the Poisson probability model for the reception of transponder transmissions. This is the standard analysis technique for estimating the probability of the arrival of randomly generated events in a listening time window.

Interference mechanism

10.8.3 Mode S transponders transmit squitters on 1 090 MHz. This frequency is reserved principally for SSR use so it is shared with activities of the current SSR. The interference events of interest then are SSR replies, and short (56-bit) and long (112-bit) Mode S replies. The length for each of the reply types is as follows:

a) SSR 20.3 µs;

b) 56-bit Mode S 64 µs; and

c) 112-bit Mode S 120 µs.
10.8.4 The interference effect of an individual reply is a function of its length. Thus, the analysis must treat the effect of each reply separately.

**Analysis technique**

10.8.5 The Poisson model is applied separately to each reply type to calculate the probability of an interfering reply in the 120 µs listening window needed to receive a squitter.

10.8.6 For the 112-bit Mode S reply, the probability of receiving zero replies in a 240 µs window is calculated. The window of 240 µs is used, since a squitter may not be correctly received if any part of the squitter is overlapped by a Mode S fruit reply.

10.8.7 The calculation for the 56-bit case is similar, except that a window of 184 µs is used to account for the short Mode S reply.

10.8.8 The SSR interference effect is estimated by calculating the probability of zero or one SSR in a 140.3 µs window. One reply is permitted in the listening window since Mode S has an error correction function that can correct for the effect of a single SSR reply.

10.8.9 The individual probabilities are then multiplied to obtain the probability of successful squitter reception with the assumed fruit rate for each of the reply types.

**CONSERVATIVE ASSUMPTIONS IN THE CAPACITY ESTIMATES**

10.8.10 *Relative signal strength.* It is assumed that all replies are received at a power level stronger than the desired reply. In this respect, this serves to estimate the performance of a desired reply that is being received from an aircraft at maximum range. As aircraft approach the receiver, they will have an amplitude advantage over longer range aircraft. The Mode S reply process is tolerant to lower level overlapping fruit due to the use of pulse position modulation. This means that the apparent fruit rate will drop as an aircraft approaches the receiver, which results in an increase in probability of reception and update rate.

10.8.11 *SSR reply rate.* It is assumed that every SSR interrogation leads to a Mode S reply. In fact, Mode S transponders will not respond to SSR interrogations received from ACAS or a Mode S interrogator.

10.8.12 *Surface squitter rate.* All surface aircraft are assumed to squitter at a rate of 2.2 times per second. The squitter design calls for the reduction of the squitter rate for stationary surface aircraft.

10.8.13 *Altitude screening effect.* Interfering fruit replies are assumed to be received at the same power from aircraft at all altitudes. A top-mounted receiving antenna will in fact provide some shielding from replies from aircraft at lower altitude. This effect will be helpful in overflights of terminals with significant surface traffic.

**SSR INTERROGATION RATE MEASUREMENTS**

10.8.14 A key factor in determining extended squitter capacity is the SSR interrogation rate. Measurements made in several States indicate that the SSR interrogation rate in en-route airspace will generally be low, usually less than 30 interrogations per second. Interrogation rates in the vicinity of terminals are generally higher. They range from 40 interrogations per second for a major isolated terminal to 90 interrogations per second for terminals in high density regions, in close proximity to other terminals. A small number of major terminals in close proximity to areas with military interrogators may experience interrogation rates of up to 200 per second.

**EXPECTED DECREASE IN FUTURE SSR INTERROGATION RATES**

10.8.15 Measurements of SSR interrogation rates in one State indicate a significant decrease in rate over the last 15 years. This is believed to be due to interrogator improvements (interrogator sidelobe suppression, use of minimum required transmit power, etc.). Additional reduction in the SSR interrogation rate can be expected in the future due to the following factors:

a) new SSR interrogators usually employ a monopulse technique that typically operates at a significantly reduced interrogation rate (as little as one-quarter) compared to conventional SSR processing. Mode S interrogators will also provide monopulse SSR processing;

b) a revision was made to ACAS SARPs (SICASP/6, 1997) to lower its SSR interrogation rate to a level more appropriate to the current density of SSR aircraft. The current whisper/shout interrogation pattern is based upon the assumption that most of
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the aircraft are SSR equipped. In fact, in the environments where ACAS operates, most of the aircraft are Mode S equipped. Since Mode S aircraft do not respond to the SSR interrogations from ACAS, the actual density of SSR aircraft is quite low and can be handled by a shorter whisper/shout sequence; and

c) military activity is generally decreasing, resulting in the decommissioning of some interrogators.

10.8.16 The implementation of extended squitter will lead also to a reduction in the SSR fruit rate since more aircraft will become Mode S equipped. Eventually, some ground interrogators could be phased out in areas where extended squitter is the principal mode of surveillance.

MODE S REPLY SOURCES

10.8.17 The Mode S reply rate per aircraft used in the capacity analysis is indicated in Table 10-3. This is intended to reflect a very high level of Mode S activity resulting from Mode S ground interrogators and squitter transmissions. All airborne aircraft are assumed to emit the following Mode S transmissions per second:

a) a total of 4.5 extended squitters (airborne position, velocity, identity and event-driven); and

b) the ground data link activity assumed (four short and two long replies) reflects a very heavy surveillance and data link load. The assumed two long replies per second are equivalent to one 16-segment downlink ELM every other scan, a much higher than expected rate.

10.8.18 In the traffic model, all of the aircraft are assumed to be equipped for extended squitter and all ACAS equipment is assumed to be performing hybrid surveillance.

CDTI CAPACITY ESTIMATE

10.8.19 Estimates of CDTI capacity for the airborne-only case are presented in Figure 10-9. Each aircraft is assumed to transmit a total of 10.5 Mode S replies per second plus the number of SSR replies per second indicated in the right-hand margin. The reception probability indicated is for at least one update in 10 seconds for a position squitter or a velocity squitter.

10.8.20 The expected requirement is a 90 per cent probability of a 10-second update to support CDTI. At this probability level, extended squitter can support from 240 to well in excess of 500 aircraft depending upon the SSR interrogation rate, except in the few terminal areas that exceed an SSR interrogation rate of 90 per second. Expected reductions in SSR interrogation rates will make this capacity available in all terminals in the future.

10.8.21 A 90 per cent probability of a position squitter or velocity squitter leads to a probability of 81 per cent of receiving both squitters in any 10-second interval, and only a 1 per cent probability of receiving no squitters in that interval.

10.8.22 The effect of a very high level of surface traffic is shown in Figure 10-10. It is seen to cause a small reduction in capacity compared to Figure 10-9.

10.8.23 The actual number of expected squitter receptions over 10 seconds is shown in Figure 10-11. The probability of zero receptions is seen to be 0.1, as defined by the operating point. This will lead to an average of slightly more than 2 squitter receptions during the 10-second update interval.

ACAS HYBRID SURVEILLANCE CAPACITY ESTIMATE

10.8.24 Similar extended squitter air-air capacity results are presented in Figures 10-12 to 10-15. Performance in this case is appropriate for ACAS hybrid surveillance. The reduced probability of squitter reception in the highest SSR fruit environment will have the effect of gracefully reducing the update rate.

SURFACE CAPACITY ESTIMATE

10.8.25 SSR activity is not an issue for surface surveillance, since transponders do not transmit SSR replies while on the surface. Ground receivers will be equipped with sector-beam antennas. These ground receivers will see some SSR and Mode S activity from airborne aircraft, but this effect is limited.

10.8.26 The pulse position modulation technique used in Mode S is not affected by signals that are six or more decibels lower than the desired reply. This means that airborne aircraft that are at least twice the range of the most distant surface aircraft (i.e. 11 to 15 km (6 to 8 NM) from
the receiver) will not cause a loss of squitter reception. The effect of these airborne aircraft is modelled by assuming that each squitter receiver sees high level replies from twenty airborne aircraft, each transmitting 10.5 Mode S and 60 SSR replies per second.

10.8.27 The effect of ground multipath is modelled by assuming that an ungarbled reply has a 95 per cent probability of successful reception.

10.8.28 The results of Figure 10-16 indicate that extended squitter can support 250 moving surface aircraft with a 95 per cent probability of a one-second update rate. Five hundred moving aircraft can be supported at 90 per cent probability of a one-second update.

AIR-GROUND CAPACITY ESTIMATE

10.8.29 Table 10-4 presents the capacity per ground station that can be supported with a 99.5 per cent probability of a 5-second update. Performance is shown for omni and sector antenna cases. Figure 10-17 shows the probability of multiple report reception for this operating point. An average of over 4 position or velocity squitters would be received over the 5-second update interval.

SUMMARY OF CAPACITY ESTIMATES

10.8.30 The capacity estimates indicate that extended squitter will have sufficient capacity to meet the requirements of the expected surveillance applications.

SUPPRESSION OF UNNECESSARY EXTENDED SQUIITERS

10.8.31 Aircraft may be equipped with a transponder with extended squitter capability in advance of equipping with an appropriate navigation device to provide lat/lon information for the position messages. The absence of altitude information would result in the generation of extended squitters with message fields of all zeroes. This would result in unnecessary channel occupancy.

10.8.32 Provision has been made to power up the transponder in the acquisition squitter mode only. That is one acquisition squitter per second. Extended squitter operation will only be initiated if a message is loaded into transponder data registers 05 {HEX} (airborne position), 06 {HEX} (surface position), 09 {HEX} (airborne velocity) or 08 {HEX} (aircraft identification and type). A decision is made individually for each of these squitters. The insertion of altitude data into transponder data register 05 {HEX} by the transponder satisfies the minimum requirement for broadcast of the airborne position squitter.

10.8.33 Once a decision is made to broadcast a specific type of extended squitter, this squitter type will continue to be broadcast for 60 seconds if input to its related transponder data register stops being updated. After timeout (10.6.28), this squitter type may contain an ME field of all zeroes. Continued transmission is required so that receiving aircraft will know that the data source for the message has been lost. If the squitter transmission were stopped, receiving aircraft could infer that the aircraft was no longer within reception range.

FUTURE SUPPRESSION OF ACQUISITION SQUIITTER

10.8.34 Airborne aircraft generating extended squitters must continue to transmit acquisition squitters in order to remain compatible with the current ACAS equipment. When all ACAS equipment is converted to receive the extended squitter (as a minimum to read the 24-bit address and the CA field), the acquisition squitter will no longer be required and channel occupancy will be reduced if the acquisition squitter is suppressed. This process will be assisted if the acquisition squitter suppression can be effected without modification to the transponder.

10.8.35 After acquisition squitter suppression has been implemented, the acquisition squitter will continue to be broadcast by transponders if they are not emitting any extended squitters. This is necessary in order to ensure acquisition by an ACAS. Thus, an ACAS will need to retain the ability to receive the acquisition squitter even after that ACAS has been converted to receive the extended squitter.

10.9 DATA LINK CAPACITY FOR EXTENDED SQUIITTER GROUND STATIONS

DATA LINK OVERVIEW

10.9.1 One use of extended squitter for air-ground surveillance is as a replacement for a Mode S interrogator in moderate to low density airspace, i.e. areas that may not
be covered by Mode S interrogators. In order to provide the same service as the Mode S interrogator, the extended squitter station must also provide a two-way data link. This can be readily accomplished since the surveillance function of these stations requires the ability to transmit on 1 030 MHz (for hybrid surveillance) and receive on 1 090 MHz (for squitter reception). Thus, the provision of a two-way data link only requires the addition of a modest data link interface and protocol control function in the extended squitter ground station.

10.9.2 A second important data link application is communications support on the airport surface. If extended squitter is used for surface surveillance, squitter ground stations will be deployed to provide good squitter detection throughout the airport movement area. This coverage can also be exploited for data link purposes. A very responsive two-way data link can be provided in support of surface safety monitoring. Since stationary antennas are used, delivery delay will be very small, equivalent to that of an E-scan interrogator. Interference on 1 030 MHz is minimized for airport surface data link use due to the very short ranges. Field trials have indicated excellent data link performance using a 1 030 MHz transmit power of less than 10 W.

**Capacity considerations for extended squitter ground stations**

**Self interference limit**

10.9.3 The station will not be able to receive squitters while it is transmitting on 1 030 MHz or during the reception of elicited replies on 1 090 MHz, therefore the interrogation rate must be kept low.

**Transponder occupancy limit**

10.9.4 Each Mode S interrogation has the effect of occupying SSR transponders for 35 µs and Mode S transponders (other than the addressed transponder) for 45 µs. The extended squitter stations use omni or sector-beam antennas to transmit Mode S interrogations, as opposed to the narrow-beam (2.4 degree) antennas used by conventional Mode S interrogators. Thus, each Mode S interrogation from an extended squitter station will affect aircraft over a larger region than the same interrogation transmitted using a conventional Mode S interrogator. This leads to the conclusions that:

- a) the interrogation rate must be kept low; and
- b) data link activity must be avoided in high density environments where transponder occupancy is a concern. This latter condition is easily met since (except for the airport surface) Mode S interrogators are already being provided for data link use in high density environments.

10.9.5 Selective use of omni or sector-beam transmissions to airborne aircraft in high density environments may be needed for applications that require access times shorter than available from the rotating beam Mode S interrogator. This is possible provided these interrogations are kept to a low rate.

**Maximum link utilization**

10.9.6 The approach used to achieve these requirements is (like ACAS) to limit two-way data link activity from an extended squitter ground station to a one per cent occupancy of Mode S and SSR transponders. Note that (like ACAS) this one per cent is a maximum that can be generated by all of the data link activity in a region of airspace. In areas where extended squitter stations have overlapping coverage, the joint transponder occupancy caused by all stations must be kept to no more than one per cent.

10.9.7 As extended squitter is implemented, the active interrogation rate of ACAS will be reduced since it will be able to provide surveillance of nearby aircraft via hybrid surveillance. When extended squitter is fully implemented, ACAS will greatly reduce its interrogation activity. At this point, extended squitter stations may be allowed to increase their activity to two per cent, to take advantage of the decreased ACAS link activity.

**Data link interrogation rate limit**

**Omnidirectional antenna station**

10.9.8 A Mode S interrogation occupies a Mode S transponder for 45 µs and an SSR transponder for 35 µs. The longer occupancy time of the Mode S transponder is used to define the allowable interrogation rate. One per cent utilization of a Mode S transponder is equal to 10 ms over a second period. Thus, the maximum interrogation rate is equal to 10 ms/s divided by 45 µs or 220 interrogations per second. A two per cent limit would yield a maximum interrogation rate of 440 per second.
Six-sector antenna station

10.9.9 If a six-sector antenna is used, a higher data rate can be supported since each interrogation only occupies the aircraft covered by the beam that was used for the interrogation. The surveillance benefit of a six-sector antenna compared to an omni antenna has been estimated to be equivalent to a traffic reduction of 2.5. This is due to the division of the traffic population among the six beams, taking into account traffic bunching and antenna sidelobe effects. These are the same considerations that would be used to determine the effective occupancy of Mode S transponders in the coverage area of an extended squitter station transmitting over a six-sector antenna. Therefore, the maximum rates calculated for the omni antenna case can be increased by a factor of 2.5 for the six-sector antenna case. This yields an interrogation rate of 550 and 1 100 interrogations per second for the one and two per cent limits, respectively.

DATA LINK PERFORMANCE

10.9.10 The data link capacity per ground station corresponding to the interrogation rates limits determined above is presented in Table 10-5 for one through four ground stations, using nominal data link operating characteristics. Note that a single six-sector antenna station cannot exceed the omni interrogation limit, even if it has no overlapping coverage with neighbouring stations. This limit is imposed to ensure that a Mode S transponder close to the station is not occupied more than the occupancy limit due to reception of interrogations from the sidelobes of the sector antennas. These estimates indicate that extended squitter ground stations can provide useful data link capacity in regions not served by the high capacity Mode S narrow beam interrogators (each of which has a data link capacity of approximately 60 to 100 kbits/s of user data).

10.9.11 The stationary omni and sector-beam antennas used for extended squitter stations have the property of providing immediate aircraft data link access. In this respect, these antennas offer the same access time performance as an electronically scanned antenna.

10.9.12 Some limited use of these stations might be desirable in high density airspace in order to take advantage of this response time for applications that cannot be served by a scanning beam antenna.

10.9.13 If additional capacity is required beyond the capability of the omni and six-sector beam antennas, it can be provided by antennas with a greater number of sectors or by an overlay of a data link-only electronically scanned antenna.

10.10 TRANSITION ISSUES

10.10.1 In order to achieve a surveillance system that is based on extended squitter, it is necessary to define a transition strategy that will accommodate a mixed environment during the transition from SSR to a full use of extended squitter. In addition, transition aspects related to ACAS need to be addressed specifically.

10.10.2 A number of issues must be addressed in this transition strategy. Significant issues include:

a) potential loss of independence between surveillance, navigation and communication functions;

b) potential compromise of ACAS as an independent collision avoidance system;

c) validation (or at least a reasonableness test) of reported position until reliability of this data is established by experience;

d) surveillance in a mixed ADS-B/SSR environment for ACAS, and ATC airborne and surface surveillance;

e) backup surveillance for loss of GNSS function for individual aircraft due to an equipment malfunction;

f) backup surveillance for loss of GNSS function over an extended area due to interference effects on GNSS operation; and

g) the ability to suppress the creation of tracks on ADS-B reports that contain intentionally incorrect position information (i.e. spoofers).

10.10.3 The basic considerations in the above issues can be stated as validation, backup and operation with mixed equipage.

10.10.4 At the present time, the ATC-related activities that make use of SSR capability are air-ground surveillance of airborne aircraft for ATC surveillance and precision runway monitoring (PRM). In addition, SSR is used for air-air surveillance in support of ACAS. Another use of SSR technology is for the identification of surface aircraft tracks provided by airport surface detection equipment (ASDE).

10.10.5 A strategy for transitioning from an SSR to an extended squitter environment needs to be defined. The strategy should make use of the capabilities of the SSR transponders to support validation, backup and mixed
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10.10.6 A possible transition strategy for validation, backup and operation with mixed equipage is described separately for ACAS, surface surveillance and ground surveillance of airborne aircraft in the following paragraphs.

ACAS TRANSITION TO EXTENDED SQUITTER

Surveillance techniques

10.10.7 ACAS active surveillance. ACAS II equipment performs surveillance by actively interrogating Mode S and Mode A/C transponders within their range of operation (maximum of 30 NM). The ACAS logic uses the measured range and reported altitude in its threat evaluation and manoeuvre selection. Coarse bearing is measured by the aircraft and used for the pilot’s traffic display and as an input to a miss-distance filter.

10.10.8 ACAS hybrid surveillance. Concerns over compromising the ACAS II role of an independent collision avoidance system have been addressed through use of a hybrid surveillance technique (10.4.8).

Validation

10.10.9 Validation of GNSS data that is the basis for the extended squitter report is performed by comparing the relative position obtained by direct interrogation of the intruder aircraft’s transponder with the relative position obtained from the GNSS position of the two aircraft. Passive information is only used after it is validated.

Backup

10.10.10 Hybrid surveillance provides automatic backup in the event of single or multiple loss of GNSS capability. If a passive report is not received at the required time, ACAS will perform active surveillance to obtain an updated position report. This reaction covers short term dropouts as well as long term dropouts due to loss of GNSS functionality.

Mixed equipage

10.10.11 Hybrid surveillance allows ACAS II to handle any mix of extended squitter and SSR-only aircraft. With no extended squitter equipage, ACAS operates using active surveillance just as it does today. With complete equipage, ACAS will only interrogate to obtain surveillance on threatening aircraft. Since most of the aircraft under surveillance by ACAS are non-threatening, extended squitter equipage will result in a significant decrease in ACAS interrogations. Intermediate levels of equipage will lead to a proportionate decrease in ACAS interrogation rates.

SPECIAL CONSIDERATIONS FOR OTHER AIR-AIR APPLICATIONS

Possible applications

10.10.12 In the future, increased use of air-air surveillance data is foreseen for applications other than collision avoidance. These applications will principally be based upon the use of ADS-B data. Applications such as cockpit display of traffic information (CDTI) will provide traffic information in support of enhanced situational awareness, advanced operational procedures, and potential migration to cooperative airspace management. More complex applications such as long range flight path conflict detection and resolution are also under consideration.

Requirements for validation and backup

10.10.13 Requirements for validation and backup will depend upon the specific application. Those applications that involve close range activity, such as PRM (10.10.4), will likely require validation and backup capability. Other applications involving long range operation (e.g. 50 to 100 NM) will be unlikely to require validation and backup for several reasons. For long range operations over water or remote airspace, no validation or backup capability may be available. Note that validation applies to the position data provided by the navigation sources and that revalidation would be required if the navigation source changes.

Background validation using Mode S interrogators

10.10.14 It should be noted that even for the long range oceanic scenario described above, validation is possible before the aircraft leaves ground coverage via a Mode S readout of the extended squitter position and a comparison to
the radar measurement. Any aircraft with a failed extended squitter capability would be detected before it entered the over-ocean track. The probability of failure over the ocean is thus reduced, since aircraft are known to have correctly operating navigation sources before entering the oceanic track.

10.10.15 Background validation by Mode S interrogators is seen as an important technique for maintaining the accuracy of extended squitter reported position data and for gathering statistics on the positional accuracy of extended squitter reports.

SURFACE SURVEILLANCE TRANSITION TO EXTENDED SQUITTER

Surveillance techniques

10.10.16 For surveillance on the airport surface, the positional error must be small compared to the size of an aircraft. This rules out the use of direct range and azimuth measurement, or even range-range multilateration due to the tolerance in the transponder turnaround delay. For this reason, SSR-based surface systems under development use time-difference multilateration, since it is based only on the difference in the receipt of an aircraft transmission at spatially diverse ground stations.

10.10.17 The extended squitter design provides formats for use on the airport surface that are optimized for surface surveillance. These formats include position, velocity, ICAO address and aircraft call sign. The accuracy needed for surface surveillance can be supported by GNSS using local or wide area differential corrections.

Validation

10.10.18 Validation of surface position reports can be performed using multilateration on the extended squitter transmission. Once validated, the passive reports can be used for improved surveillance performance. Multilateration can be performed in the background mode for validated aircraft for periodic revalidation of position.

Backup

10.10.19 The background process of multilateration provides position and identity for short or extended squitter reports that do not contain GNSS position information. A total loss of GNSS service would cause the surveillance system to revert to full multilateration operation. This would result in lower surveillance performance since the position accuracy and update rate will be somewhat degraded and the aircraft will no longer provide velocity information. However, surveillance could continue throughout the loss of GNSS service.

Mixed equipage

10.10.20 With multilateration, the only aircraft requirement for surveillance is a periodic transmission. All Mode S transponders (even those that do not support extended squitter) transmit a short squitter on an average of once per second. This is a high enough rate to support multilateration for surface surveillance. Mode A/C transponders do not squitter, so provision must be made to elicit periodic replies if Mode A/C aircraft are to participate in surface surveillance during the transition period. One approach would be to modify the transponders to generate a reply once per second. However, this is not a feasible approach, since high costs could lead operators and users to resist such a modification. A second approach may be used if only a small percentage of surface aircraft are Mode A/C equipped (i.e. most aircraft are Mode S equipped). This approach is based on the use of the whisper/shout technique also used by ACAS to interrogate only a subset of the Mode A/C aircraft within range. Initial field measurements indicate that this technique may be able to support as many as 15 to 20 Mode A/C surface aircraft.

10.10.21 A Mode S transponder is a required element of an ACAS II installation. In the countries where ACAS is mandated, it is likely that there would be no more than 15 to 20 Mode A/C surface aircraft at busy terminals. This makes the whisper/shout technique a candidate for the means to accommodate Mode A/C transponders during a transition period (provided that it is possible to operate Mode A/C transponders on the surface).

GROUND ATC SURVEILLANCE TRANSITION TO EXTENDED SQUITTER

Surveillance techniques

10.10.22 ATC surveillance of airborne aircraft is currently provided by narrow scanning beam SSRs often collocated with primary radars. SSR intended for terminal area surveillance has a maximum range of 60 to 100 NM and a scan interval of four to six seconds. En-route coverage is provided by SSRs with a maximum range of 200 to 250 NM and a scan interval of eight to twelve seconds.
Chapter 10. Extended squitter, system concept and applications

10.10.23 Different capabilities exist for these SSRs. This includes Mode A/C only capability based on sliding window or monopulse azimuth processing. The newest SSRs have Mode S (and Mode A/C) capability with monopulse azimuth determination. Mode S interrogators are able to support the readout of aircraft information on identity, aircraft state and intent.

10.10.24 The extended squitter technique provides formats for airborne use that are optimized for ATC surveillance. These formats include position, velocity, ICAO aircraft address and aircraft call sign. Provision is made to report the quality of the reported surveillance data based upon the accuracy of the navigation source data.

10.10.25 If a transition is made to extended squitter, squitter receiving stations would be expected to fulfill the functions of/complement current SSR. Squitter stations would have ranges up to 100 NM for terminal areas. Squitter stations would need to provide coverage up to 250 NM in en-route airspace and up to 300 NM as required in remote areas. The squitter stations would be capable of transmitting interrogations in order to obtain additional information from the transponder, such as intent and Mode A code if available.

10.10.26 While these stations would provide omnidirectional coverage, in most cases this would be achieved with an antenna having six to twelve sectors. Operation with such an antenna requires the use of a receiver associated with each antenna sector, with a single transmitter that may be switched between the sectors as required. The use of multiple sectors will be required at high density environments for increased traffic capacity, since each receiver only has to cope with the traffic in one sector. Such an antenna will also be required at en-route stations in order to achieve the antenna gain required for long range operation.

Airspace considerations

10.10.27 The potential for transition of ATC surveillance to extended squitter depends on the type of airspace being covered. The most likely application of extended squitter will be in airspace that does not currently have SSR coverage. This could be in a remote area or low altitude coverage in any airspace.

10.10.28 It is unlikely that ADS-B will replace SSR in any high density airspace for the foreseeable future. A principal consideration is the vulnerability of satellite navigation sources to low level interference. Such an interference event could result in the loss of satellite navigation service over areas measured in tens of kilometres. Providing backup surveillance for large numbers of aircraft will significantly increase the cost of the ADS-B ground station to the point where ADS-B may not be a cost effective replacement for SSR. ADS-B replacement of SSR in high density airspace will likely require the development of a robust satellite navigation source, or the use of an alternate navigation source such as an inertial platform as a backup.

Validation

10.10.29 Position validation can be performed by a single station equipped with a multi-sector antenna. Range would be determined by direct interrogation of the transponder, while bearing would be determined by measuring the relative amplitude of the received signals in the antenna sectors. Analysis indicates that a six-sector antenna can provide a bearing accuracy of around 2 degrees. This should be accurate enough for a reasonableness test in low density airspace, but would not be sufficient for a high density terminal area.

10.10.30 Where provided for backup service (as a minimum in terminal area environments), multilateration can be performed in the background mode for validated aircraft for periodic revalidation of position. When validation is performed by direct interrogation, a technique similar to ACAS hybrid surveillance could be implemented to revalidate aircraft that have flight paths in close proximity to other aircraft.

Backup

10.10.31 Backup surveillance could be provided in terminal area environments using the same multilateration technique described for surface surveillance. As in the surface case, multilateration would require the use of multiple receiving stations. This would be configured as a central station surrounded by three or more outrigger stations. In this configuration, the central station would be an extended squitter ground station with transmit and receive capability and a multi-sector antenna. The outrigger stations would be simple receivers with omnidirectional antennas. At low altitude or in remote areas, backup could be provided by direct interrogation.

10.10.32 If the multilateration system is provided with sufficient capacity, multilateration can provide backup for single aircraft or area failures of GNSS functionality. Where multilateration is not available, aircraft will need to be interrogated at the nominal scan interval. If this direct
interrogation is needed at low altitude or in low density airspace, the additional channel occupancy required by these periodic interrogations must be evaluated.

Mixed equipage

10.10.33 Surveillance on Mode S aircraft that are not equipped with extended squitter can be performed using multilateration on the short squitter, or by direct interrogation.

10.10.34 Surveillance of Mode A/C-only aircraft requires the same active interrogation approach for airborne surveillance as it does for surface surveillance. The use of active interrogations (single or whisper/shout depending upon the Mode A/C traffic density) would be used to elicit Mode A or C replies at a regular rate. In effect, the ground station operates like an ACAS unit, but with a lower interrogation rate and at higher effective radiated power due to its increased operating range. Since the majority of the aircraft in high density environments will be Mode S-equipped (due to inter alia ACAS mandates), a limited whisper/shout sequence could be used, consistent with the density of Mode A/C aircraft. The central station could obtain range and a coarse bearing estimate from its multi-sector antenna. The position could be refined by use of multilateration data from the outriggers. The coarse position estimate would be very helpful in eliminating phantoms (position reports made up of replies from different aircraft). Sidelobe suppression will be required to limit replies in the antenna sidelobes.

Special considerations for precision runway monitoring (PRM)

10.10.35 One surveillance application is the monitoring of aircraft on precision approaches. This is referred to as precision runway monitoring (PRM). Using current technology, aircraft navigate on the approach using ILS or MLS and are monitored by SSR, sometimes operating at a higher scan rate than for normal ATC surveillance. Thus the navigation and monitoring techniques are completely independent.

10.10.36 Consideration is being given to use GNSS as the basis for future landing systems. If GNSS is used for this purpose, ADS-B (also based on GNSS) cannot be used for PRM. Such use of ADS-B for PRM would provide less safety than the current system since it would be unable to detect a blunder caused by a malfunction of the navigation equipment. Such a malfunction would result in both the air crew and the ground believing that the aircraft was on the correct approach, when in fact a deviation had occurred.

10.10.37 An alternative technique for PRM could be the use of multilateration on the extended squitter transmission, as described above. This technique provides the necessary independence of surveillance and navigation.
Table 10-1. Interference cases

<table>
<thead>
<tr>
<th>Case</th>
<th>Mode A/C</th>
<th>Mode S short</th>
<th>Mode S long</th>
</tr>
</thead>
<tbody>
<tr>
<td>1*</td>
<td>120</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>60</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>3**</td>
<td>0</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>4***</td>
<td>0</td>
<td>3</td>
<td>6</td>
</tr>
</tbody>
</table>

* Current high density  
** All Mode S with high data link activity  
*** Case 3 with passive ACAS

Table 10-2. Link budget for extended squitter reception

<table>
<thead>
<tr>
<th>Range</th>
<th>Air-air</th>
<th>Air-ground</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>14 NM</td>
<td>100 NM</td>
</tr>
<tr>
<td>Aircraft transmitter power (dBm)</td>
<td>57</td>
<td>57</td>
</tr>
<tr>
<td>Transmitter cable loss (dB)</td>
<td>-3</td>
<td>-3</td>
</tr>
<tr>
<td>Transmitter antenna gain (dBi)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Path loss for 1 090 MHz (dB)</td>
<td>-121</td>
<td>-138.5</td>
</tr>
<tr>
<td>Receive antenna GAIN (dBi)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Receive losses (dB)</td>
<td>-3</td>
<td>-2</td>
</tr>
<tr>
<td>Received power (dBm)</td>
<td>-70</td>
<td>-86.5</td>
</tr>
<tr>
<td>Receiver minimum trigger level MTL (dBm)</td>
<td>-77</td>
<td>-91</td>
</tr>
<tr>
<td>Link margin (dB)</td>
<td>7</td>
<td>4.5</td>
</tr>
</tbody>
</table>
### Table 10-3. Mode S reply sources

<table>
<thead>
<tr>
<th>Source</th>
<th>Short</th>
<th>Squitter</th>
<th>Long</th>
<th>Squitter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground surveillance and data link</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Current squitter</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All-call</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ACAS</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ground data link</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Position squitter</td>
<td></td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Identification squitter</td>
<td>0.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Supplementary squitter</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Event-driven squitter</td>
<td>0.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>4</td>
<td>0</td>
<td>2</td>
<td>4.5</td>
</tr>
</tbody>
</table>

**Notes.—**

1) Acquisition squitter will be phased out when ACAS converted to receive extended squitter.

2) Hybrid surveillance will lower ACAS interrogation rate by factor of 5.

3) Ground data link of 2 replies per second yields 10 replies per scan, equivalent to one downlink ELM every other scan per aircraft.

### Table 10-4. Extended-squitter air-ground operating capacity

5-second update, probability ≥ 99.5%

<table>
<thead>
<tr>
<th>Replies/aircraft(s)</th>
<th>Maximum aircraft</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SSR Mode A/C</td>
</tr>
<tr>
<td>90</td>
<td>10.5</td>
</tr>
<tr>
<td>60</td>
<td>10.5</td>
</tr>
<tr>
<td>0</td>
<td>10.5</td>
</tr>
</tbody>
</table>

* 90–180 km (50–100 NM) operational range

** Greater than 370 km (200 NM) operational range
Table 10-5. Extended squitter data link capacity summary (kilobits per second)

<table>
<thead>
<tr>
<th>Interference budget</th>
<th>Total</th>
<th>Number of stations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td><strong>Omni</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 per cent</td>
<td>22.5</td>
<td>22.5</td>
</tr>
<tr>
<td>2 per cent</td>
<td>45</td>
<td>45</td>
</tr>
<tr>
<td><strong>6 Sector</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 per cent</td>
<td>56</td>
<td>22.5</td>
</tr>
<tr>
<td>2 per cent</td>
<td>112</td>
<td>45</td>
</tr>
</tbody>
</table>
Figure 10-1. Extended-squitter concept
Figure 10-2. Mode S squitter for ACAS acquisition

Figure 10-3. Extended-squitter format
Figure 10-4. Extended-squitter air surveillance
Figure 10-5. Extended-squitter surface surveillance
Figure 10-6. Extended-squitter message structure
Figure 10-7. ATC ground receiver capacity vs. pseudo random squitter rate
Figure 10-8. Effect on capacity of one additional squitter per second
Figure 10-9. Extended-squitter air-air capacity for CDTI — Airborne only
Figure 10-10. Extended-squitter air-air capacity for CDTI —
Airborne plus 200 moving surface aircraft
Figure 10-11. CDTI report reception probability
Figure 10-12. Extended-squitter air-air capacity for ACAS hybrid surveillance — Airborne only
Figure 10-13. Extended-squitter air-air capacity for ACAS hybrid surveillance — Airborne plus 200 moving surface aircraft
Figure 10-14. ACAS hybrid surveillance report reception probability
Figure 10-15. Extended-squitter two-second scan air-air capacity for ACAS hybrid surveillance — Airborne only
Each ground station sees 20 airborne aircraft (60/4/2/4.5)
Multi-path factor = 0.95

Figure 10-16. Extended-squitter surface performance
Figure 10-17. Air-ground report reception probability
Appendix A
MODE S CYCLIC POLYNOMIAL ERROR DETECTION AND CORRECTION

1. OVERVIEW

1.1 The 24-bit address/parity field contains the aircraft’s 24-bit unique address code overlaid on 24 parity check bits generated from the preceding part of the transmission. This combined address/parity field requires fewer bits than would be needed if address and parity information were coded separately.

1.2 An error occurring anywhere in the reception of an interrogation or a reply will modify the decoded address. On the uplink, the transponder will not accept the message and will not reply, since the interrogation does not appear to be addressed to it. On the downlink, the ground station will recognize that an error has occurred, since the reply does not contain the expected address. Because the ground station knows the address of the transponder replying to a discrete interrogation, the ground station can perform a limited amount of error-correction to increase data throughput or link efficiency. The code parameters have been selected to permit the correction of many error patterns which span no more than 24 successive bits. In particular, most bursts of errors caused by interference from a simultaneously-received Mode A/C reply can be corrected.

1.3 The error detection features of Mode S provide an undetected error rate of 1 in $10^7$ messages. The use of error correction on the downlink will slightly reduce this undetected error performance.

2. PRINCIPLES

2.1 Cyclic polynomial methods are used to detect, and in some cases correct, errors occurring during transmission of Mode S messages.

2.2 Cyclic polynomial checking relies upon the transmitting station generating a parity sequence by a modulo-2 division of the content of the message by a predetermined “generator polynomial”. The remainder obtained from this division process is then added to the message and transmitted with it. Because of this, the transmitted messages are, in principle, divisible by the generator polynomial without a remainder.

2.3 At the receiver, the whole transmission — message content and parity sequence — is similarly divided by the generator polynomial. In the absence of errors, an all-zero remainder will result. In the presence of errors, a non-zero “syndrome remainder” will be obtained which can in some cases be used to identify and correct the errors.

2.4 In the Mode S system, an additional pattern, the aircraft address, is added modulo-2 to the parity check sequence before transmission. Hence, the receiver will not, in general, obtain an all-zero remainder. If a particular added pattern is expected, then the corresponding error-free remainder can be predicted. Error-correction, however, cannot normally be used in these cases unless the added pattern is invariant or at least known to the receiver.

2.5 In systems in which the message bits that could possibly be in error are known, and in which all actual errors are confined to within a short burst, the syndrome remainder can be used to identify and correct the errors. On the Mode S downlink, these conditions are met: the main sources of error are overlapping Mode A and Mode C replies, and the affected bits in the Mode S reply can be easily identified.

3. MATHEMATICAL EXPLANATION

3.1 Any sequence of m bits can be regarded as the sequence of coefficients of an (m-1) order modulo-2 polynomial:

$$C_{m-1}x^{m-1} + C_{m-2}x^{m-2} + ... + C_1x + C_0$$
where \( C_0, \ C_1, \ C_2, \) etc. are either 0 or 1, and “+” means modulo-2 addition. The coefficients \( C_i \) are given by the bits \( c_i \) in the sequence. Normally the first bit transmitted, \( c_1 \), is considered to be \( C_{m-1} \), the coefficient of the most significant term. Thus we have the following correspondence between bits and coefficients:

<table>
<thead>
<tr>
<th>( x^{m-1} )</th>
<th>( x^0 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( C_1 )</td>
<td>( C(x) )</td>
</tr>
<tr>
<td>( C_{m-1} )</td>
<td>( C_0 )</td>
</tr>
</tbody>
</table>

3.2 If the bits of the message are regarded as the polynomial sequence \( M(x) \), and the generator polynomial as \( G(x) \), then dividing \( M(x) \) by \( G(x) \) produces both a quotient \( Q(x) \) and a remainder \( R(x) \) according to:

\[
M(x) / G(x) = Q(x) + [R(x)/G(x)]
\]

If this remainder is then added to the message, then

\[
[M(x) + R(x)] / G(x) = Q(x) + [R(x) + R(x)] / G(x)
\]

3.3 One of the features of modulo-2 arithmetic is that anything added to itself gives a result of zero, so:

\[
[M(x) + R(x)] / G(x) = Q(x) + [0/G(x)] = Q(x) + 0
\]

i.e. the remainder after division of \([M(x) + R(x)]\) by \( G(x) \) will always be zero. Hence if any \([M(x) + R(x)]\) bit sequence is transmitted without errors, the division by \( G(x) \) at the receiver will always yield a zero remainder.

3.4 If an extra sequence, which will be denoted as \( B(x) \), is also added to the message then it will cause a remainder to appear, the same remainder that would result by division of \( B(x) \) by \( G(x) \), since if

\[
B(x) / G(x) = C(x) + [D(x)/G(x)]
\]

then:

\[
\frac{M(x) + R(x) + B(x)}{G(x)} = Q(x) + \frac{0}{G(x)} + C(x) + \frac{D(x)}{G(x)}
\]

Consequently, if the receiver knows \( B(x) \) then it can recognize an error-free message by the appearance of the remainder, \( D(x) \). Conversely if the expected \( D(x) \) is not found, then the receiver can deduce that either:

a) the received message had errors; or

b) the added sequence \( B(x) \) was not what was anticipated.

3.5 This latter feature can be used to ensure that messages transmitted to more than one receiver are accepted as error-free by only one. If each receiver is allocated its own unique \( B(x) \), then adding a particular \( B(x) \) sequence to a message will ensure that only the wanted receiver generates its expected \( D(x) \); all the rest fail to recognize the remainder as “theirs” and so reject the message as apparently corrupt.

3.6 If the message were received with no errors, then the received remainder \( R(x) \) would be equal to \( D(x) \). If \( D(x) \) is known by the receivers and is added to \( R(x) \) then the modulo-2 sum \( R(x) + D(x) \) would equal all zeros. In the case of errors the sum \( R(x) + D(x) \) will not be equal to all zeros. This sum is labelled \( S(x) \) and is referred to as the error syndrome.

3.7 In order to perform error correction, it is necessary to label message bits whose values are judged to be low confidence and hence subject to correction by the error correction process. Bit values judged to be high confidence are not allowed to be corrected. One technique for labelling the confidence of each message bit position is to generate a confidence bit sequence that is the same length as the message bit sequence. Each bit of the confidence bit sequence indicates the confidence of the corresponding bit of the message bit sequence. The confidence bits are obtained by monitoring the received signal quality (e.g. if both of the 0.5 microsecond positions of a bit interval contain a significant signal strength, this bit will be labelled as low confidence).

3.8 Once bit confidence is established, the following procedure will perform error correction:

a) compare the n-bit syndrome pattern to the n low order bits of the confidence pattern, where n is the order of the generator polynomial;

b) if all of the bit positions containing ones in the error syndrome correspond to low confidence bit positions in the low order message bits, then correct (i.e. change a binary one to a zero or vice versa) the message bits corresponding to the ones of the error syndrome;

c) alternatively, shift right by one bit the message and confidence sequences and compute the transformed syndrome that applies to these shifted message and confidence sequences;
d) repeat steps a) through c) until a match is found; and

e) if no match is found, the error is not correctable.

3.9 In step c), after shifting the message one bit, one in principle would have to calculate the syndrome again by a polynomial division. But, as the computation of the syndrome requires several shift operations, the computation time would increase sharply.

In fact, the syndrome of the shifted message sequence can be calculated from the current one by:

\[ S^r(x) = xS^s(x) + hG^r(x) \]

where \( h \) is the highest order bit of \( S^s(x) \), and the asterisk indicates the reciprocal (bit-reversed) polynomial. The bit reversals are required because cyclic transformations only apply to left-shifted operations and here right-shifted ones are being employed.

Note.— For convenience in practice it is usual to multiply \( M(x) \) by \( x^n \) before performing the division that generates \( R(x) \). The exponent “\( n \)” is the order of polynomial \( G(x) \). This is equivalent to appending \( n \) zero-bits to \( M(x) \). This is done so that the addition of \( R(x) \) to \( M(x) \) before transmission leaves all the information content of \( M(x) \) unchanged and eliminates the need to subtract \( R(x) \) from \( M(x) \) before interpreting the information in the received message.

4. REALIZATION

4.1 There are at least two common methods by which cyclic polynomial parity checks may be realized in hardware. (See Figures A-1 and A-2.) Both methods are equally effective and either may be readily assembled from medium-scale integrated (MSI) or large-scale integrated (LSI) components.

4.2 The circuit of Figure A-1 is essentially that of a multiplier. The shift register directly stores the quotient \( Q(x) \) and the modulo-2 array calculates the product of \( Q(x) \) and the generator polynomial \( G(x) \). The remainder, \( R(x) \), and the subsequent terms of \( Q(x) \) are formed by a bit-by-bit comparison of \( Q^s(x)G(x) \) and the input sequence \( M(x) \).

4.3 The circuit of Figure A-2 directly computes the remainder \( R(x) \) obtained after division of \( M^s(x)x^n \) by the polynomial \( G(x) \), where \( n \) is the number of stages in the shift register, i.e. the order of \( G(x) \).

4.4 Other circuits not shown here may be equally effective. In general, the only real test of a cyclic polynomial encoder is whether it generates the correct remainder data to append to the message.

5. EXAMPLE OF SSR MODE S

5.1 Parity check sequence generation

5.1.1 The SSR Mode S system employs a systematic code in which the 32- or 88-bit information field (of a 56- or 112-bit data block, respectively) is transmitted unmodified. Twenty-four parity check bits are generated by operating on the information fields as described in Annex 10, Volume IV, Chapter 3, 3.1.2.3.3. The generator polynomial \( G(x) \) is given by:

\[ G(x) = \sum_{j=0}^{24} G_j x^j \]

where

\[ G_j = \begin{cases} 1: & j = 0, 3, 10, 12, 13 \ldots 24 \\ 0: & \text{otherwise} \end{cases} \]

That is:

\[ G(x) = x^{24} + x^{23} + x^{22} + \ldots + x^{13} + x^{12} + x^{10} + x^3 + 1 \]

5.2 Address/parity combination

The parity check bits are combined with the 24-bit address and transmitted sequentially following the information field. Two different procedures are used for combining the address and parity check bits: one for interrogations and one for replies. The procedure used for interrogations was chosen to minimize transponder hardware complexity (i.e. the error-free remainder is directly the transponder address). The procedure used for replies was chosen to facilitate the use of error correction in reply decoding.

The interrogations contain the modulo-2 sum of the parity sequence and the most significant 24 bits of the 48-bit sequence generated by multiplying the reserved aircraft address polynomial by the reserved generator polynomial (see Figure A-3).
The replies contain the modulo-2 sum of the parity sequence and the (unmodified) aircraft address (see Figure A-4).

### 5.3 PI field generation

In downlink transmissions with format DF11, DF17 or DF18, another combination is used, which results in the generation of the PI field. In the format DF11, this field contains the modulo-2 sum of the parity sequence and the following sequence of 24 bits \((a_1,a_2,\ldots,a_{24}) = (17\text{ zeros, CL field (3 bits), IC field (4 bits)})\). In the format DF17 or DF18, this field contains the modulo-2 sum of the parity sequence and a sequence of 24 zeros (see Figure A-4 bis).

### 5.4 Realization using a multiplier circuit

5.4.1 Figure A-5 illustrates a realization of the ground station and transponder encoder using the multiplier circuit illustrated in Figure A-1. Other functionally equivalent encoder realizations are equally acceptable, provided that the address/parity field generated for all information and address fields is identical to that of the encoder in the figure. As illustrated, the encoder is a 24-stage shift register, where the outputs of certain stages, as defined by the generator polynomial, are summed modulo-2 with the input sequence and applied to the shift register input.

5.4.2 The encoder operates in two modes, the first during the transmission of the information field, the second during the transmission of the address/parity field. In the encoder shown, the mode is determined by the position of the switch; the position illustrated corresponds to the mode used during the transmission of the information field.

5.4.3 Encoding commences with all shift register stages initialized to zero. During transmission of the information field, the encoder output is connected directly to the input, i.e. the transmitted bits are identically the information bits. Simultaneously, the information bits are summed modulo-2 with selected shift register stages and applied to the shift register input. In this way, the message is divided by the generator polynomial.

5.4.4 During transmission of the address/parity field, the encoder output (i.e. the sequence of bits to be transmitted) is the output of the sum-modulo-2 network. In the ground station encoder, the address bits are applied sequentially to the shift register input as well as to the sum-modulo-2 network, thus achieving the desired multiplication by the generator polynomial. In the transponder encoder, the address bits are applied only to the sum-modulo-2 network; the shift register input is set to zero during Address/Parity field transmission.

### 5.5 Transponder error detection decoding

5.5.1 The transponder employs error detection logic matched to the transmitted parity sequence. The circuit shown in Figure A-5 also illustrates a realization of an error detection circuit for decoding the encoded sequence.

5.5.2 The entire received message is shifted into this circuit as well as into a storage buffer. After all 36 or 112 bits have been received, the shift register will contain a correct sequence only if no errors have occurred in transmission. If the sequence is received correctly, the data in the storage register can be accepted with high confidence. When using this circuit, the correct sequence is the unmodified address of the aircraft.

### 5.6 Ground station error correction

Note.— The coding used for Mode S transmissions has alternative possibilities for error correction compared to the algorithm described. An improved algorithm could take additional advantage of the bit confidence declarations together with a model of the mechanism by which an overlapping Mode A/C reply could cause errors in the receipt of a Mode S reply. Such an approach might be helpful in areas that have a high RF channel loading, particularly when the Mode S receiver is used in conjunction with a broad beam or omnidirectional antenna.

5.6.1 The ground station employs error correction logic to correct burst errors in the received message. The ground station error check/correction process is illustrated in Figure A-6.

5.6.2 During the reception of a message, the message bits are shifted into the message register. In parallel, the confidence bits are generated. After the received message is processed by the decoder circuit shown in Figure A-5, the remainder produced is added (compared) to the expected address to produce the error syndrome. If the syndrome is all zeros, an error-free message was received. In this case the message is directly available at the output. If the syndrome is non-zero, a single error or error burst is present.
5.6.3 After the receiver has calculated the error syndrome, error correction can be performed by the procedure described in 3.8 and 3.9. The 24-bit syndrome pattern corresponds to a 24-bit error burst somewhere in the received message. The confidence bits are used to obtain the location of the error burst. They indicate the section where interference has occurred. The error correction procedure uses the message bit sequence, the initial error syndrome and the confidence bit sequence.

5.6.4 The circuit shown in Figure A-7 illustrates a realization of the circuit that performs the error correction. The initial syndrome is extended into the E-register of Figure A-7 in the bit order shown, while the confidence word is placed in the L-register and the message in a parallel M-register. Note that the taps of the E-register implement \( G'(x) \), the reciprocal (bit-reversed) of the polynomial \( G(x) \). This permits a more efficient error correction process to be employed.

5.6.5 One shift at a time, the successively cycled syndrome is produced. In parallel, the message and confidence stream are cycled one bit at a time. When each one of the syndrome pattern matches a low confidence one in the low order 24-bits of the confidence bit pattern, the error has been trapped. The correction enable bit is then set by the error location function. No further attempts at correction are allowed.

5.6.6 At this time the feedback of the E-register is disabled, so the syndrome can be read out serially. In parallel, the M-register shifts out the message bits. Each bit corresponding to a one in the error syndrome is then corrected by adding the two streams bit-by-bit.

5.6.7 One further check is made during the detection phase of the correction process, namely the number of low confidence bits contained in each 24-bit segment of the message is determined. If their number ever exceeds a threshold, error correction is rejected. This is because the possibility of an erroneous correction goes up sharply with the number of low confidence bits. In fact, if any consecutive 24 bits were low confidence, the syndrome pattern would be matched no matter what it was and correction of those specific 24 bits would always occur.
After all but the last 24 bits of input data have been entered, the switch is moved to B, and the remainder after division can be read serially at the output as the remaining input bits are entered. Note that the remainder cannot be read in any other way: in particular, it cannot be read or tested in parallel.

N.B. Decoder version shown

Figure A-1. Multiplier realization of cyclic polynomial checker
Divison polynomial is $x^{24} + x^{23} + x^{22} + x^{21} + x^{20} + x^{19} + x^{18} + x^{17} + x^{16} + x^{15} + x^{14} + x^{13} + x^{12} + x^{10} + x^3 + 1$

represents a single element of a shift register

After division, the remainder is contained in the shift register, and can be read directly by switching to position B, and shifting out the data. The remainder can also be read in parallel.

N.B. Decoder version shown

Figure A-2. Alternative realization of cyclic polynomial checker
Figure A-3. Uplink encoding process

Figure A-4. Downlink encoding process for DF 0, 4, 5, 16, 20, 21 and 24 replies
Figure A-4 bis. Downlink encoding process for DF 11 and DF 17 or DF 18 downlink transmissions.
Figure A-5. Functional diagram of Mode S ground station and transponder encoders
Figure A-6. Ground station error check/correction process
Figure A-7. Error location logic
Appendix B

SSR DECODING AND DISPLAY FACILITIES

1. The SSR decoding and display facilities described in this section are based on utilization of SSR Modes A, C and S surveillance.

2. A wide range of decoding and display facilities are available to permit use of the information available from SSR Mode A and Mode C replies. In the choice of equipment for SSR decoding and display, account should be taken of the operational requirements of the ATS unit and of its workload characteristics and of the anticipated growth in workload over the design life of the equipment.

3. Automatic plot extractors process a number of individual Mode A and (if available) Mode C reply pulse trains, obtained as the interrogating beam sweeps across an aircraft, to generate a single plot report which contains the aircraft position (range and bearing), Mode A identity code and (if available) Mode C pressure-altitude code. Often an indicator of level of confidence or validation of code data is also provided, based on the quality and consistency of the code information received in the various reply pulse trains.

4. The range of decoding and display facilities that should be considered for new applications are:

   — display of the positions of SSR plot reports;

   — decoding of the Mode A identity data into a 4-digit numeric identity code and its presentation on the radar display, associated with the position report;

   — decoding of any Mode C pressure-altitude data into a numeric flight level, correcting if appropriate for actual barometric pressure, and its display as a numeric value on the radar display, associated with the position report and 4-digit Mode A identity code;

   — provision of a means of uniquely identifying on the radar display, plots that contain an SPI response (such as by a special symbol, or by flashing part or all of the display associated with that aircraft);

   — provision of automatic alerting devices and appropriate display, presentations for detection of emergency, radio failure and unlawful interference SSR Mode A code responses;

   — provision, if required, of controller input devices for such functions as selecting the identity codes to be displayed, selecting the altitude/flight level stratum to be displayed, or manual input of the current barometric pressure used for altimeter setting, to enable conversion of Mode C pressure-altitude data to altitude when such data indicates that the aircraft from which it is received is below the transition level;

   — in addition, where Mode S is available, the display of aircraft identification as specified in Item 7 of the ICAO Flight Plan may be obtained (as alphanumeric characters) in response to a ground-initiated Comm-B request.

5. There are a large number of possible variations and enhancements to the basic decoding and display system described in 4 above. All but the most basic decoding and display systems allow correlation between the individual Mode A identity codes and flight plan data, enabling alphanumeric call-sign labels to be presented on the radar display rather than the 4-digit numeric Mode A identity code. If desired, other information (e.g. assigned flight level) can be extracted from the flight plan and also presented on the radar screen. The information necessary to permit correlation between SSR Mode A identity code and flight plan data can be provided in a number of ways:

   — advanced systems employing computer-based flight data processing often manage the assignment of SSR Mode A codes to flight plans (aircraft) as part of FDPS and then pass this assignment automatically to RDPS which perform the code-to-flight-plan correlation automatically. This minimizes the input workload of the controller, but the controller will still need a means for incidental modification of displayed flight data;
— other systems require the data to be input at a central flight data section in the ATS unit; and

— in circumstances where controller workload permits, more simple systems can be employed in which the controller enters all data required for correlating SSR codes to flight plan data.

6. A similar range of options exist for entering the current altimeter setting for Mode C correction:

— automatically from digital pressure sensors;

— manually at a central flight data section; and

— manually by the controller at the display.

7. Controller input devices should be chosen with due regard to efficiency of operation and good ergonomic principles:

— often some form of alphanumeric keyboard will be required;

— functions that must be performed often or quickly should be selected by special function keys rather than by the entering of a string of alphanumeric characters;

— lightpens or touch input screens are sometimes used as alternatives to mechanical keyboards as input devices and offer advantages in some applications; and

— devices such as roll balls, track balls and joysticks are also used sometimes as controller input devices to designate particular aircraft on the controller’s radar screen for which SSR information display or other control actions are to be performed.

8. An automated system that can correlate aircraft position reports and flight plan data on the basis of correlation of SSR Mode A code offers the opportunity for a number of operationally useful functions to be performed automatically. Examples include the initiation of control jurisdiction transfer at defined boundaries, the updating of flight progress information by automatically logging actual time over waypoints, or providing a conflict alerting function based on trajectory predictions calculated from the radar tracks and flight plan data. The decision to implement functions of these types should be made by the State concerned, after an assessment of the benefits it would derive in the particular environment in which it operates.

9. SSR Mode S transponders categorized as level 2 and above are able to report aircraft radio call signs directly to Mode S ground stations. Decoding and display systems using this Mode S data are able to display these call signs on the radar display without the need to correlate Mode A code to flight plan data. Systems that need to correlate radar returns with flight plan data for other processes will find this association simpler and of higher integrity using the aircraft identification provided by SSR Mode S.
Appendix C

AUTOMATIC CONVERSION OF
PRESSURE-ALTITUDE DATA TO ALTITUDE

1. DISPLAY OF
ALTITUDE DATA

Automatically transmitted pressure-altitude data obtained via SSR may be displayed to air traffic controllers directly after being decoded, when such data indicates that the aircraft from which it is received is at or above the transition level. When the aircraft is below the transition level, such data could be misleading since it is based upon the standard atmospheric pressure reference datum of 1013.25 hectopascals while the pilot’s altimeter is adjusted to a different reference. In this case, therefore, the data must be converted by application of an appropriate correction factor, based upon the same reference datum as that to which the pilot’s altimeter is set.

2. ALTIMETRY SYSTEM REQUIREMENTS
FOR ALTITUDE DATA QUANTIZED
IN 25-FT INCREMENTS

2.1 Requirements for
25-ft quantization

2.1.1 Existing altimetry system standards are adequate to support finer quantization levels as regards basic position measurement accuracy, physical integrity, electrical connections and environmental standards. However, two new requirements must be met by altimetry systems in order to attain desired improvements in rate tracking performance with 25-ft quantization. The first new requirement concerns the spacing of the altimeter transition points (i.e. the points at which the encoded altimeter output changes from one discrete altitude to another). The variation in the pressure changes required to move from one transition point to another must be small compared to the nominal pressure difference between transition points. This requirement is discussed in 2.1.2. The second requirement is that the dynamic lag during periods of acceleration be small. This requirement is discussed in 2.1.3.

2.1.2 Test for spacing between transition points

2.1.2.1 Altitude rate estimates are derived from the observed rate of transitions in altimeter output. Thus the accuracy with which the altitude rate can be determined is dependent upon the precision in the spacings of altimeter transition points. Ideally, the spacing of successive transition points would correspond to an increase in the actual pressure-altitude by an amount equal to the quantization increment, q. For a given altimeter system, the spacings will differ from q due to fluctuations in the input static pressure and imperfections in the encoder. These spacing errors will contribute minimally to the rate tracking error only if their magnitudes are small in comparison to q. A simple test can be performed to verify this. The test is performed by subjecting the altimeter to a changing static pressure corresponding to a nearly constant rate of change of altitude.

2.1.2.2 Figure C-1 is an illustration of one possible test configuration. Since maintaining a pressure rate corresponding to constant altitude rate is difficult, a second qualified altimeter is used to provide the reference rate. The test unit samples the input encoded altitudes at intervals much smaller than the time between altimeter transitions. The reference velocity is obtained by smoothing the output of the reference altimeter using a simple linear tracking algorithm. As long as there is little acceleration in the pressure rate, the estimated reference rate should closely approximate the actual reference rate and the derived values of Dn and the error in transition-spacing values should be precise.
2.1.3 Dynamic lag

2.1.3.1 One of the principal benefits of 25-ft quantization is faster detection of vertical accelerations. These benefits can be realized only if the dynamic lag of the altimeter during periods of acceleration is less than the lag produced by quantization.

2.1.3.2 For the purpose of testing, the dynamic lag of a given system can be determined by introducing a sudden change in the input static pressure and measuring the time required for the altimeter input to respond. A step function change in pressure is probably the easiest to generate. This can be done by first increasing the static line pressure to a level corresponding to \( m \) quantization levels above the ambient pressure. After the altimeter has stabilized at the new pressure-altitude, the static line can be suddenly opened (at the static source end) to the ambient pressure. The time required for the altimeter output to converge to within \( q \) of the ambient pressure-altitude can be measured. The test would be passed if this time were less than a specified value. The settling time requirement would be:

\[ t \leq L_{\text{max}} \ln (m) \]

where \( L_{\text{max}} \) is the maximum allowable time constant for dynamic lag (approximately 1 second) and \( m \) equals the number of quantization levels.

2.2 Metric altitude coding

No provision exists in ICAO standards for the coding of pressure-altitude in metres. However in Mode S altitude replies, provision has been made to allow the coding of altitude in metres in the future. Until such time as this becomes a standard unit for the coding of altitude this feature should not be used.
Figure C-1. Possible test configuration for determining consistency of altimeter transition spacings

D_m is the error in transition spacing