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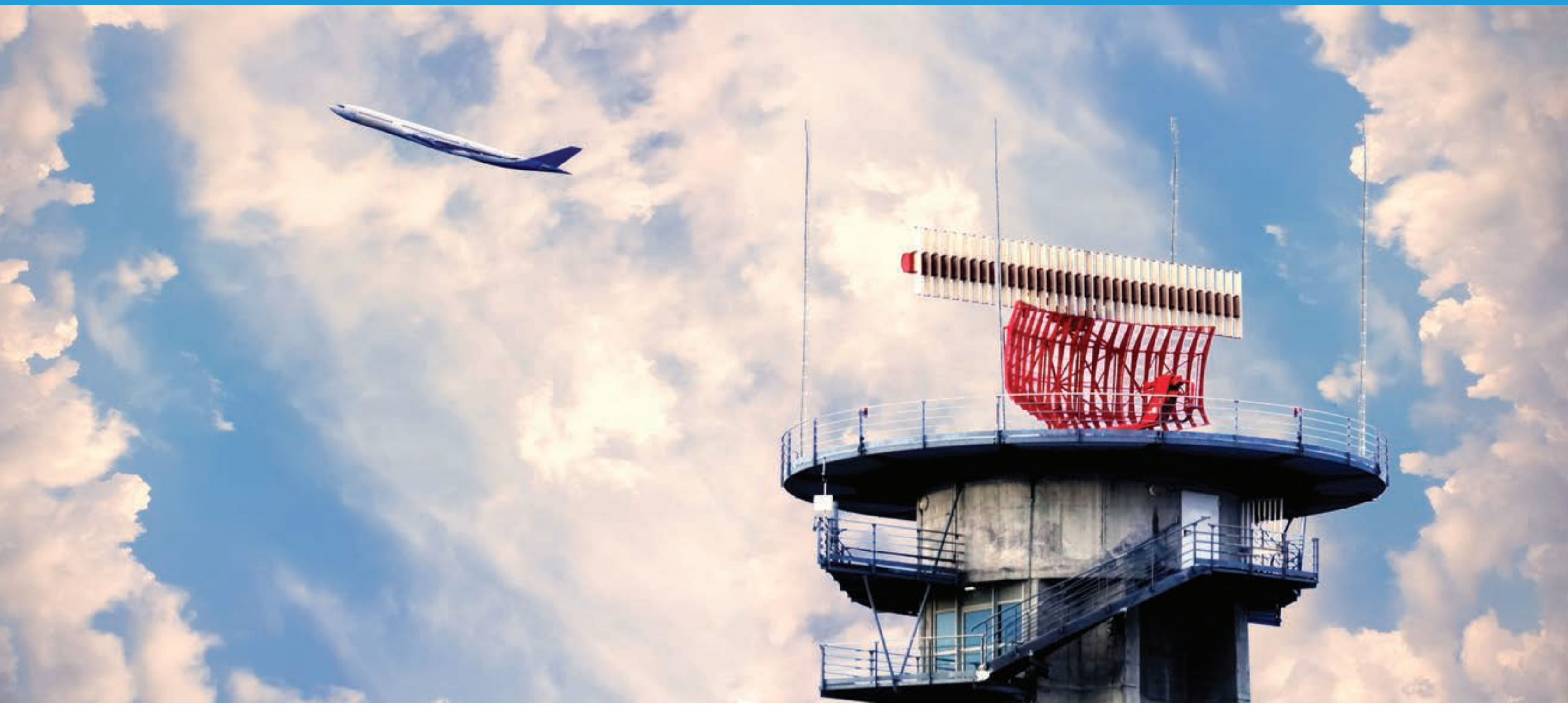
Doc 8071

Manual on Testing of Radio Navigation Aids

Volume III — Testing of Surveillance Radar Systems

Second Edition, 2020



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INTERNATIONAL CIVIL AVIATION ORGANIZATION

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AMENDMENTS

Amendments are announced in the supplements to the Products and Services Catalogue; the Catalogue and its supplements are available on the ICAO website at www.icao.int. The space below is provided to keep a record of such amendments.

RECORD OF AMENDMENTS AND CORRIGENDA

AMENDMENTS		
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FOREWORD

The Manual on Testing of Radio Navigation Aids (Doc 8071) comprises three Volumes, as follows:

Volume I — Testing of Ground-based Radio Navigation Systems;
Volume II — Testing of Satellite-based Radio Navigation Systems; and
Volume III — Testing of Surveillance Radar Systems

Volume III of ICAO Doc 8071 deals with the testing of surveillance radar systems (both primary and secondary radars) developed by the Secondary Surveillance Radar Improvements and Collision Avoidance Systems Panel (SICASP).

The purpose of this volume is to describe methods especially for the evaluation of the technical and operational performance of surveillance radar systems with primary radar signal processing (such as MTD Doppler processing, digital plot extraction and tracking) and SSR techniques (such as monopulse azimuth processing and selective (Mode S) interrogation).

Changes in equipment and progress made in developing modern surveillance systems require regular revisions of the document contents with the full cooperation of all interested parties.

Comments on this volume would be appreciated from States and other parties outside ICAO concerned with surveillance systems development and provision of services. Comments, if any, should be addressed to:

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Glossary

When the following terms are used in this manual, they have the following meanings:

Active reflector. A device used in primary radar systems for geographical alignment and system performance checking. It generates a signal from a stationary installation with an artificial Doppler shift to ensure that a stationary target will be presented on an ATC screen after moving target detection (MTD) or moving target indicator (MTI) processing.

Aircraft address. A unique combination of twenty-four 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.

All-call period. The time interval during which a Mode S interrogator issues all-calls (SSR only, Mode S only and intermode) to detect Mode A/C transponders and, for acquisition, Mode S transponders that have not been previously locked out.

All-call (stochastic). A Mode S-only all-call that elicits all-call replies from only a random subset of the 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.

Analogue. In radar terms, a signal which has not been converted into digital values. Analogue signals are to be found at antenna and receiver level in radar systems.

Analogue-to-digital converter. A device for the conversion of analogue signals into digital values. Usually operates by sampling the analogue signal at regular time intervals and converting the measured value of the analogue sample to a binary encoded number.

Antenna (electronically scanned, E-Scan). An SSR antenna consisting of a number of planar arrays or a circular array of radiating elements. The antenna beams are electronically steered to the desired azimuth angle by applying phase-shifting techniques, without rotating the antenna mechanically.

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 a different electronic tilt (typically +3°).

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 (omni-directional). An antenna with an approximately circular radiation pattern in the horizontal plane. In earlier SSR systems it was used to form the control pattern for ISLS by transmitting the P_2 pulse and also for transmission of the P_1 pulse for I^2SLS. Modern antennas for ground SSR form a control pattern that is omni-directional except for a null or "notch" in the direction of the antenna mainbeam (coinciding with the peak of the main beam sum pattern).

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 (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, S) and added in antiphase at a second output port (difference, D) 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.

Asynchronous surveillance processor (ASP). A type of video-plot processor.

Azimuth count (or change) pulses (ACPs). Output pulses of the incremental azimuth measuring device fitted to the radar antenna turning platform (turning gear). The encoding device may give its output in serial or parallel form, but typically provides 4 096 pulses (12 bit encoding), 16 384 pulses (14 bit encoding) or 65 536 pulses (16 bit encoding) in serial form per 360° in azimuth.

Azimuth extension (plot length, delta theta). An azimuth increment, often expressed as a number of ACPs, from detection of the leading edge of a radar plot to detection of the trailing edge of that plot, in a digital plot extractor system.

Back lobe. A lobe of radiated energy to the rear of an antenna (180° in azimuth with respect to the main lobe).

Beam sharpening. A technique applied to the monopulse antenna to decrease the plot runlength of SSR replies. The reduced runlength is required to improve the resolution capabilities of the extraction system.

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.

Blip. A presentation on an analogue radar display of the received signal from a target.

Blip-to-scan ratio. An approximation of detection probability (P_D) (i.e. for a given observation time, the number of blips actually detected for a selected aircraft divided by the number of radar scans).

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.

Built-in-test equipment (BITE). Internal self-check facilities in electronic equipment which allow the correct operation to be monitored on a continuous basis. Many checks may be GO-NOGO tests, with a failure causing a visual (or possibly audio) alarm to be given. The BITE is usually part of the remote control and monitoring system of a radar. Modern BITE can isolate faults down to a line-replaceable unit (e.g. a printed circuit board) in a majority (e.g. 80 per cent) of all fault conditions.

Chaining. A process of linking together radar target reports (plots and tracks) and other information relating to one particular object.

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”).

Clutter. A generic PSR term for unwanted, interfering reflections of radio energy from various sources. Types of clutter include ground clutter, sea clutter, precipitation clutter and “angels”.

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.

Combination criteria. Criteria in respect to azimuth and range coincidence with which a primary radar plot and an SSR plot must meet to be considered to have come from the same aircraft and therefore able to be combined.

Combined plot. A radar plot for which both PSR and SSR plots have been detected and found sufficiently adjacent to be combined to one plot message.

Cone of silence. A gap in coverage above a radar due to the limitations of the antenna performance at high elevation angles.

Constant false alarm rate (CFAR). A thresholding technique used to reduce false alarms (noise, clutter, etc.) to a quasi-constant level. Also known as constant false alarm regulation.

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 antenna 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_5 for Mode S) transmitted by the ground equipment (SSR interrogator) in order to ensure side-lobe suppression.

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).

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.

Cosecant squared antenna pattern. An antenna pattern for which the gain is proportional to the square of the cosecant of the elevation angle. This results in an approximately constant signal, as a function of range, from an aircraft at constant flight level.

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 trans-mission from an interrogator or from a primary radar system.

Dedicated flight check aircraft. An aircraft used occasionally in operational evaluations of radar systems. This aircraft will fly routes, etc., not normally covered by regular traffic and allow a complete operational evaluation through the specified coverage of the radar under test.

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

Defruiting. A process by which aircraft replies accepted by the interrogator-responsor 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 runlength.

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.

Digitized video. A binary encoded signal, the value of which is equivalent to the value of the originating analogue signal.

Display (analogue). A display in which the raw video (PSR or SSR) is normally presented on the radar screen in the form of a blip. The update of the display is synchronized with the radar antenna turning rate. The preceding processing is normally analogue (i.e. no digital messages).

Display (synthetic). A display in which information (radar, map, labels, etc.) is based on digital messages. The displayed radar data are not normally in “real time” due to digital processing delays.

Doppler speed. A radial velocity of a target (aircraft) or of a clutter source (false alarm) measured from its doppler frequency shift in a received radar reflection.

Double curvature. A PSR reflector design in which the upper and lower sections of the antenna have a different curvature. This technique is used to optimize the vertical radiation patterns for high beam (short range) and low beam (long range) performance.

En-route radar. A surveillance radar for the traffic passing through the area of control. Typically, the range of such a radar is between 240 km (150 NM) and 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.

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

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

Framing pulses. Pulses which “frame” the information pulses (code) of SSR Mode A and C replies (described as F_1 and F_2 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.

Gain (of antenna). A measure for the antenna of the relative transmitted power density radiated in a particular direction as compared with the power density that would have been radiated from an isotropic antenna with the same power input (usually expressed in dB) and at the same distance from the radiator.

Gain time control (GTC). A circuit which controls the gain of a radar receiver, allowing it to rise from an initial preset value to maximum at a predetermined rate to compensate for the decrease in received signal strength as range increases. Also known as sensitivity time control (STC).

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.

Hit. A reception and recognition by the aircraft (trans-ponder) of the SSR interrogation pulses P_1 and P_3, re-sulting in the return of a detectable reply code to the ground receiver.

I and Q channels. In-phase and quadrature channels of a primary radar receiver used for the extraction of phase and amplitude of the received signal. In older systems these channels were processed separately to avoid “blind phases”. See also 2.3.4 b).

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.

Improvement factor. Target to clutter ratio at the output of an MTI processor divided by the target to clutter ratio at the input of the processor, averaged uniformly over all target radial velocities of interest.

Integrated antenna. A PSR antenna in which the reflector of a PSR radar is used in conjunction with SSR radiating elements in order to obtain the required SSR horizontal and vertical radiation patterns.

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_3 and P_4) 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. A ground-based (normally) transmitter 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.

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

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

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

Line replaceable unit (LRU). A unit, part of a system, which can be exchanged as an entity for a spare of the same type and which may consist of a single printed circuit board, power supply or equipment module. The exchange of unit will take place at equipment (system) level.

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.

LogFTC. A signal processing technique comprising a logarithmic amplification stage followed by a differentiation (short time constant) stage used for the suppression of unwanted PSR signals.

Mode. SSR interrogation mode as specified in Annex 10, Volume IV, Chapter 2.

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 period. Refer to roll-call period.

Mode S transaction. The initiation, control and exchange of data between a Mode S interrogator and transponder over the air/ground link.

Monitor display. A device for the presentation of radar data, usually working in the plan-position indicator (PPI) mode of operation. This device is generally found as part of the maintenance equipment of a PSR and/or SSR station. Generally, radar data at various stages of processing may be observed on the monitor display.

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 target detector (MTD). A technique for achieving fixed and moving clutter rejection by a cascade of digital MTI and pulse Doppler filters.

Moving target indicator (MTI). Signal processing used in primary radar systems to reject signals from fixed or slow moving unwanted targets (buildings, trees, rain, etc.) and retain for detection or display of signals from moving targets (aircraft).

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.

Multi-radar trajectory reconstitution (MURATREC). A technique for the accurate a-posteriori determination of an object trajectory using simultaneous measured observations from a number of radars.

Noise factor. A figure defined for a receiver as the ratio of the noise at the output of the practical receiver and the noise output of an ideal receiver at standard temperature T_0 (290° K). The noise factor is, in practice, defined as the signal-to-noise ratio at the input divided by the signal-to-noise ratio at the output of a receiver.

North marker (NoM). A single pulse, typically produced by a digital encoder (shift encoder) attached to the radar antenna drive system, which indicates when the antenna passes through the direction to the North.

North message. Special messages generated by the extractor to indicate passage of the antenna rotation through an azimuth angle of zero degrees (true North).

Object. A combination of radar targets and related information which are correlated in time and space.

Off-boresight angle (OBA). In monopulse SSR, the angle within the beamwidth of the antenna (calculated by the OBA processor) by which a target is off (away from) the boresight.

Orbit. In the context of flight testing, a flight of circular pattern at a constant altitude and distance from the antenna of the ground equipment under test.

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. See remote field monitor in this glossary.

Plan position indicator (PPI). A monitor display with radar and other related information in plan position (as if projected on a horizontal plane).

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 radar video into an output data message suitable for transmission through a data transmission media, 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.

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). Separate uplink and downlink frequency polar diagrams, in each plane, are plotted for each of the main beam, control and difference (mon-opulse only) SSR antenna patterns, referenced to the mainbeam axis.

Polarization. Direction of the electrical field vector of radiated radar energy with respect to a plane tangential to the earth (horizontal, vertical, lefthand circular, righthand circular, elliptical, etc.).

Primary surveillance radar (PR or PSR). A radar which detects the presence of a target based on reflected radar energy from that target.

Probability of detection (P_D). Probability that a correct radar plot message is derived when a target is present.

Pulse compression. A transmitter frequency modulation technique (change in frequency within the pulse), coupled with a frequency sensitive receiver signal processing technique, which enables a radar to obtain the resolution and accuracy of a short pulse and the detection capability of a long pulse.

Pulse length. The time between the 50 per cent amplitude points on the leading and trailing edges of the pulse envelope. Also known as a pulse width.

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.

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 repetition interval (p.r.i.). An average interval between two successive pulses/interrogations transmitted by a radar.

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

Quantized video (QV). Generic term for a video signal generated by regularly sampling an analogue video signal and assigning it a binary value of one or zero depending on whether the analogue value exceeds or does not exceed a threshold. It is also known as hard bit quantized video.

Specific terms that occur in some manufacturers' documentation include:

a) for primary radar, the threshold may be referred to as a dynamic noise threshold or fast time constant threshold;

b) for secondary radar, quantized video may refer to a pulse generated within a plot extractor on detection of F_1, F_2 pulses, synchronized to the plot extractor timing; and

c) for monopulse SSR, quantized video may refer to an 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.

Real-time quality control (RTQC). A form of built-in test equipment and/or software in which system perform-ance parameters are monitored in real time (on-line).

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 field monitor. A system which monitors the uplink and/or downlink performance of an SSR or Mode S system from a site located at the specified distance from the radar (far field). The monitor is interrogated by the radar, and its replies can be evaluated on the radar site. In addition, the replies may contain data about certain interrogation parameters as seen by the monitor. Alternative terminology to "remote field monitor" in common usage includes "far field monitor", "Parrot" and "site monitor".

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).

Responsor. A ground-based receiver part of the SSR. The complete equipment is generally known as the interrogator/responsor.

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 mech-anism, at either the interrogator or the transponder side.

Roll-call. On the uplink, the roll-call is a regular scheduled selective Mode S interrogation that is addressed to a specific Mode S transponder and intended to elicit a reply to support the surveillance function.

Roll-call period (also known as Mode S period). The time interval during which a Mode S interrogator schedules the time windows allocated for Mode S transactions.

Round (trip) reliability. An SSR term used to state the probability of receiving a detectable reply at the interrogator, resulting from an SSR interrogation.

Run length. See “Delta theta”.

Screening. When the shape of the terrain or certain objects prevent the detection of targets in certain parts of the airspace, one speaks about screening of the parts of the airspace concerned.

Sea clutter. Unwanted primary radar reflections from sea. Varies with sea state.

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.

Sensitivity time control (STC). See “Gain time control”.

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 (par-ticularly 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_5) 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.

Split plots. Generation of two plots by a radar extraction system for the same target for one passage of the antenna main-beam through the target.

Spurious plots. An unwanted radar plot not corresponding directly with an aircraft position (generally applied to SSR).

Stagger. Deliberate, controlled variation of pulse repetition intervals of a PSR to overcome blind speeds and decorrelate second-time-around replies. Deliberate, controlled variation of the pulse repetition frequency of the SSR to prevent aircraft plots due to second-time-around replies.

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

Surveillance Coordination Network (SCN). The network used to connect Mode S radars that are operating as part of a cluster in order to share the same interrogator code (IC).

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 angel control.

Sync phase reversal. The 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.

Terminal approach radar (TAR). A surveillance radar for the approach area. Typically, the range of such a radar is limited to 110 km (60 NM) and the information renewal rate for mechanically rotating antennas is 4 to 5 seconds.

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”.

Validation (code). Process of correlation of the code information used in SSR Mode A/C systems. Generally 2 identical codes in 2 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 indication serves to indicate non-extrapolated code information.

Video display unit. Also known as a monitor screen and is generally used for the display of alphanumeric data, but may also have some graphic capabilities (more modern systems).

Zenithal gap. See “Cone of silence”.

LIST OF ACRONYMS

When the following acronyms appear in this volume, they have the following meanings:

ACP	Azimuth count pulses
ADS	Automatic dependent surveillance
ASP	Asynchronous surveillance processor
ATC	Air traffic control
ATCC	Air traffic control centre
ATS	Air traffic service
BITE	Built-in test equipment
CAP	Close approach probability
CFAR	Constant false alarm rate
CMB	Combined (PSR and SSR)
CMV	Coverage measurement volume
CW	Continuous wave
DAP	Downlink aircraft parameters
DATAS	Data test and analysis system
DPE	Digital plot extractor
DSS	Dependent surveillance sensor
FDPS	Flight data processing system
FFM	Far field monitor
FRUIT	False replies unsynchronized in time
GICB	Ground initiated Comm-B
GTC	Gain time control
HRP	Horizontal radiation pattern
IC	Interrogator code
IF	Intermediate frequency
II	Interrogator identifier
I/O	Input/output
I/R	Interrogator/responder
IRAS	Interactive radar analysis system
IRF	Interrogation repetition frequency
ISLS	Interrogator side-lobe suppression
I^2SLS	Improved interrogation side-lobe suppression
LAN	Local area network
LCS	Life cycle stage
LRU	Line replaceable unit
LVA	Large vertical aperture antenna
MA	Message, Comm-A
MAPt	Missed approach point
MB	Message, Comm-B
MDS	Minimum detectable signal
MOCA	Minimum obstacle clearance altitude
MSP	Mode S specific protocol
MSSR	Monopulse secondary surveillance radar
MTD	Moving target detection
MTI	Moving target indicator

MTL	Minimum triggering level
OBA	Off-boresight angle
ODS	Operational display system
PAR	Precision approach radar
Parrot	Position adjustable range reference orientation transponder
P_D	Probability of detection
PE	Permanent echo
P_{FA}	Probability of false alarm
PPI	Plan position indicator
PRF	Pulse repetition frequency
PSR	Primary surveillance radar (also “PR”)
RCS	Radar cross section
RDPS	Radar data processing system
RDQC	Radar data quality characteristic
RF	Radio frequency
RFM	Remote field monitor
RMCS	Remote monitoring and control system
RSLS	Receiver side lobe suppression
RTQC	Real-time quality control
SCF	Surveillance coordination function
SCN	Surveillance coordination network
SDD	Synthetic data display
SDPS	Surveillance data processing system
SLM	Standard length message
SLS	Side-lobe suppression
SRE	Surveillance radar element
SSR	Secondary surveillance radar
STC	Sensitivity time control
STCA	Short-term conflict alert
TLS	Target level of safety
UTC	Coordinated universal time
VDU	Visual display unit
VRP	Vertical radiation pattern
VSWR	Voltage standing wave ratio
ZVF	Zero velocity filter

Chapter 1

INTRODUCTION

1.1 GENERAL

This document provides guidance on methods for assessing the technical and operational performance of surveillance systems. This volume describes methods for the evaluation of the technical and operational performance of surveillance systems in general and especially, surveillance radar systems with primary radar signal processing (such as moving target detection (MTD) Doppler processing, digital plot extraction and tracking) and secondary surveillance radar (SSR) techniques (such as monopulse azimuth processing and selective (Mode S) interrogation).

Note.— This volume contains guidance material on radar testing; however, it does not include guidance for new surveillance systems such as automatic dependent surveillance broadcast (ADS-B) and multilateration (MLAT). For high-level guidance material on flight testing of new surveillance systems, refer to the Aeronautical Surveillance Manual *(Doc 9924).*

1.2 AIR TRAFFIC CONTROL (ATC) SURVEILLANCE SYSTEMS

A surveillance system may encompass a number of technologies using various ground-based and airborne sensors and emitters (e.g. primary surveillance radar (PSR), SSR, automatic dependent surveillance (ADS), multilateration technologies) together with the data fusion systems at the air traffic control centre (ATCC). The techniques used depend upon the air traffic service (ATS) provider requirement, the appropriateness of technologies and the environmental (e.g. oceanic, continental or high density) demands.

Each surveillance sensor system may consist of a PSR sensor or an SSR sensor, a dependent surveillance sensor (DSS) or a combined (PSR and SSR, PSR and DSS, SSR and DSS, or PSR, SSR and DSS) sensor installation. The sensors may be for en-route or terminal area surveillance purposes. The signals from various surveillance sensors may be used directly with simple plan position displays, or more commonly with a surveillance data processing system (SDPS), in an ATCC. Data processing can include mono-sensor track processing, or multi-sensor track processing in circumstances where a number of sensors are supplying data to the centre.

1.3 REFERENCE DOCUMENTS

Annex 10 to the Convention on International Civil Aviation, *Aeronautical Telecommunications*, provides the Standards and Recommended Practices (SARPs) for surveillance systems. Values and parameters used for testing and evaluation of radar systems shall be based on SARPs in Annex 10. Currently applicable ICAO documents are: Annex 10, Volume IV *(Surveillance Radar and Collision Avoidance Systems); Aeronautical Surveillance Manual,* (Doc 9924), providing additional information on radar systems; and Technical Provisions for Mode S Services and Extended Squitter (Doc 9871), providing information on coding and content of aircraft derived data for surveillance.

1.4 THE PURPOSE OF THE DOCUMENT

1.4.1 This document describes system performance testing (evaluation) methods for surveillance systems.

Organization of the document

1.4.2 This document is arranged into the following parts:

a) organization of surveillance sensor systems;

b) sensor system performance test methodology;

c) test application;

d) detailed radar test methods (testing of individual parameters);

e) impact of test results on the operational use of radar systems; and

f) impact of transponder characteristics on radar performance.

1.4.3 It also includes the following appendices:

— flight testing methods, Appendix A;

— secondary surveillance radar (SSR), Appendix B;

— overview of radar siting aspects, Appendix C; and

— examples of radar analysis systems, Appendix D.

Scope of the document

1.4.4 This document describes methods for the evaluation and testing of the technical and operational performance of surveillance sensor systems. Automatic monitoring and testing of modern equipment by means of built-in test equipment (BITE) has greatly reduced the need for extensive ground testing and allows economies to be made in this activity. The periodical check and maintenance actions necessary (and their frequency) for the good functioning of the radar system are very equipment and system specific. The schedule for such actions will not form part of this document and the surveillance system user is referred to the maintenance manuals and related recommendations provided by the surveillance system manufacturers.

Use of the document

1.4.5 It is intended that this document be used by the following ATC staff:

a) implementation engineers involved with new or modified surveillance systems, where the performance of the new equipment must be evaluated (commissioning and operational evaluations);

b) maintenance engineers, for assistance in the detection of system problems or anomalies (problem investigation, often resulting from operational complaints) using measurement, simulation and evaluation techniques;

c) maintenance engineers, following a major repair action and possibly some forms of system modification (repair/modification confirmation); and

d) maintenance engineers, in order to confirm on a periodic basis that no system degradation has occurred (routine maintenance).

For each of the above actions, the related technical staff shall, where applicable, cooperate with operational ATC staff in order to carry out a suitable performance evaluation and/or problem investigation using an appropriate combination of:

— opportunity traffic;

— dedicated aircraft;

— simulated or recorded data;

— the BITE of the system under test; and

— real-time quality control (RTQC) facilities of the equipment itself.

Each performance evaluation and/or problem investigation will involve actions at different system levels and/or the use of predefined actions. All such actions are described in the appropriate sections of this document.

1.5 PRINCIPLES FOR MONITORING AND EVALUATION OF SURVEILLANCE SYSTEMS

1.5.1 In order to maintain optimum performance, modern surveillance systems require sophisticated and permanent system performance monitoring. During the operational life of a system, periodic performance testing is also necessary to assure continued satisfactory operational performance.

1.5.2 Surveillance system performance monitoring is generally carried out by a number of methods:

a) *BITE.* These are internal functions that generally test the performance of a system, subsystem or unit by means of permanent monitoring of parameters. These checks are generally made on a short-term basis (pulse repetition interval to pulse repetition interval, or scan-to-scan);

Examples of internal functions tested are:

1) system parameters such as voltage standing wave ratio (VSWR), receiver noise level and transmitter output power;

2) status of power supplies.

The number of functions that can be tested by means of BITE are numerous and also radar manufacturer dependent. Thus, only a very short list is given above.

b) *RTQC.* RTQC is generally a function that carries out a set of dynamic tests of system performance (for example, probability of detection (P_D) or probability of false alarm (P_{FA}) measurements). RTQC is most often carried out using statistical analysis programmes which may run “in the back-ground” on an operational system or possibly using the processor of a “standby” system (if existing). For distributed systems, dedicated performance analyser systems may be used.

c) *Evaluation programmes.* These are generally statistical analysis programmes run in non-real-time (at least at present), which may give an in-depth analysis of the most important operational performance parameters of a system under test (evaluation).

1.5.3 In general, evaluation of system performance will be carried out at three basic system levels, namely:

— at video level (sensor (e.g. radar station) receiver output);

— at plot (or track) level at the output of the data processing system at the sensor; and

— at surveillance data processing level prior to display in the ATCC.

1.5.4 For instance, Figures 2-3 and 2-4 of Chapter 2 show the various input/output (I/O) interfaces at radar station and SDPS. A functional block diagram approach is used because of the diversity of PSR and SSR system architectures and data processing techniques or technologies applied by the numerous radar system manufacturers. Dependent upon the radar system architecture and operating philosophy, the system performance evaluations listed in 1.5.3 may be carried out at any of the numerous I/O interfaces listed. Some other I/O interfaces are also shown for guidance only (i.e. before video level) but are dealt with briefly in Chapter 4 where a life cycle stage (LCS) breakdown is given for tests and/or evaluations at each of the I/O interfaces.

1.5.5 Older radar systems in which analogue techniques only are applied require specialized measuring and analysis equipment for the application of the above-mentioned testing and evaluation. In the case that such equipment is not available, the radar is best evaluated using the techniques described in Appendices E and F.

Chapter 2

ORGANIZATION OF THE SURVEILLANCE SENSOR SYSTEM

2.1 GENERAL

This section will describe the most common surveillance sensor system configurations. In general, processing and display of data is similar for all surveillance systems. Differences are related to the type and age of the sensor. Modern systems use digital techniques, while older analogue systems are still in operation. It is not possible to cover all the possible combinations and variations in types of surveillance system elements (e.g. PSR, SSR and ADS sensors; ATCC display and data processing systems); therefore, a "functional block diagram approach" has been used where various elements can be assembled to represent a specific system type. Functional block diagrams are given for radar sensors and ATCCs in Figures 2-1 to 2-7[1] (analogue and digital versions).

Note.— *For high-level guidance material on application of air traffic surveillance and air-ground surveillance systems, refer to the* Aeronautical Surveillance Manual *(Doc 9924), Chapters 3 and 5.*

2.2 ANALOGUE RADAR SYSTEMS

Analogue PSR systems

2.2.1 Figures 2-1 a) and 2-1 b) show functional block diagrams of an analogue primary radar which comprises an antenna with associated turning gear, a transmitter receiver, an analogue intermediate video processing system, the required turning data, synchronization and range gateing signals, and either an analogue PPI or a scan converted television display system. (PPIs are only suitable for dark room viewing, whereas scan converted television displays may be viewed in near daylight conditions.)

2.2.2 The intermediate video processing system will typically comprise an analogue moving target indicator (MTI) together with the associated analogue thresholding circuits for constant false alarm regulation.

2.2.3 In older PSR systems, the MTI may not be present. It is to be noted that the analogue PSR systems may not easily lend themselves to modern testing and evaluation techniques.

Analogue SSR systems

2.2.4 Figures 2-2 a) and 2-2 b) show functional block diagrams of an analogue SSR which comprises an antenna with associated turning gear, a transmitter-receiver (known as an interrogator-responder), a decoder (which may be active or passive), the required turning data, synchronization and range gateing signals and either an analogue PPI or a scan converted television display system.

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1. All figures are located at the end of this chapter.

2.2.5 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.

Combined analogue PSR/SSR systems

2.2.6 It is quite common to find an analogue PSR and SSR co-mounted on the same turning gear (SSR antenna usually mounted on top of the PSR antenna). The respective transmitted RF signals (high power) and received RF signal returns (low power) for both PSR and SSR are passed through a multi-channel rotary joint to or from the antennas.

Transmission of analogue radar data

2.2.7 Analogue radar data (PSR and/or SSR) can be transmitted via "broadband" coaxial lines or radio links to PPI displays located at some distance from the PSR/SSR radar sensors.

Evaluation/testing of analogue radar systems

2.2.8 With the exception of SSR decoding equipment, signals and information used by this type of system remain in an analogue form. Equipment now exists that is capable of converting these data into a form suitable for analysis in modern data analysis equipment (see Chapter 4).

2.3 DIGITIZED RADAR SYSTEMS

2.3.1 In these systems the received analogue signals are converted into a digital form prior to intermediate video processing (e.g. in an MTI/MTD processor for PSR) and digital extraction in a digital plot extractor. In modern PSR systems the MTI/MTD processor and digital plot extractor, and sometimes also the receiver, may be found in a common equipment.

2.3.2 In older systems, the analogue signals typically undergo intermediate video processing in separate units to the receiver and this processed video is then output to the digital plot extractor (DPE). This is applicable for both the PSR and SSR cases.

2.3.3 The outputs of the PSR and SSR — DPEs may then be "combined" and possibly subjected to some form of "surveillance processing" prior to transmission to the ATCC. A generic functional diagram of a typical modern ATC system in functional block diagram form, clearly indicating the various I/O interfaces, is shown in Figure 23.

Digitized PSR systems

2.3.4 A modern primary radar system typically consists of the following elements:

a) a reflector antenna mounted upon a high-stability turning gear. The reflector antenna may be of the "double curvature" type and use switching or a combination of high and low beams for optimum precipitation and ground clutter rejection/coverage performance. Further precipitation rejection (i.e. rain clutter reduction) may be obtained by means of the use of circular polarization (which may be switched in and out depending on weather conditions);

b) a transmitter-receiver stage wherein a high-stability coherent or quasi-coherent transmitting stage develops the radio frequency pulses radiated by the antenna. The associated receiver stages are of precise linear or logarithmic behaviour and sensitivity, very low noise and wide dynamic range. Typical modern receivers will include linear intermediate frequency (IF) stages followed by phase detectors which will supply I and Q video for Doppler stationary echo cancellation processing, and logarithmic IF amplifiers and detectors to provide video for the “normal” channel. At the output of the log, I and Q receiver channels, the replies will be sampled at regular intervals and digitized. The values of each sample may be encoded as an 8, 10 or 12 bit binary number. The transmitter-receiver stages may possibly use pulse-compression techniques;

c) an intermediate video processing stage which will take the digitized I and Q channel outputs of the receiver and separately cancel clutter in each of these channels by means of MTI or MTD techniques. Typically the argument of the output of MTI/MTD-processed I and Q channels will then be taken and added to the normal video after logFTC thresholding to eliminate clutter residues and fluctuating noise. Further video processing such as constant false alarm rating is also carried out at this stage;

d) a PSR plot extractor which outputs, subject to various criteria, a plot message containing the range and bearing (azimuth) of the successfully detected PSR targets (aircraft within radar coverage). In some MTD designs the MTD incorporates the plot extraction process in its correlation and interpolation processing;

e) many modern primary radar systems also incorporate some form of “surveillance processing” which examines the positions of plots from antenna rotation to rotation and decides which plots show movement within the bounds of aircraft motion. In its simplest form, surveillance processing can be a “plot filter” which filters out primary radar clutter plots which do not move from antenna scan to scan. In its most complex form it can be a fully automatic primary radar tracker;

f) some designs may have independent PSR and SSR surveillance processing systems, and then combine the outputs of these systems to form a single message for each aircraft. Other designs combine the PSR and SSR plots to form a single plot (sometimes called a “reinforced” plot) which is then subjected to surveillance processing; and

g) in modern PSR systems, the PSR receivers, intermediate video processing and plot extraction may be found in a single unit. Further, a surveillance processing function may be integrated with the PSR plot extractor to form a complete PSR signal processor.

Digitized SSR systems

2.3.5 A modern SSR system typically consists of the following elements:

a) a mechanically rotating SSR antenna, which may be of the hog-trough or large vertical aperture (LVA) type, an LVA type antenna with active elements to allow for beam steering or even a static, fully electronically scanned type. The SSR antenna may provide a sum pattern for transmission and reception, or it may be electronically split in order to provide a sum pattern for transmission, and sum and difference radiation patterns for reception, permitting monopulse azimuth measurement techniques. In addition, it usually provides a control radiation pattern for transmitting the interrogator side-lobe suppression (ISLS) pulse. Some systems also receive on this pattern for receiver side-lobe suppression (RSLS) processing.

Older SSR systems normally use hog-trough SSR antennas in the conventional sum mode of operation and employ sliding window azimuth measurement techniques, while newer systems use LVA antennas in sum and difference mode of operation and employ monopulse azimuth measurement techniques. Mode S systems use monopulse azimuth determination techniques;

b) an SSR interrogator/responder (I/R) system. The interrogator transmits interrogation and ISLS pulses. The receiver may have one, two or three channels for sum (S), difference (D) and SLS (W) signals. Mode S interrogators also require a separate transmitter for transmission of the (I)SLS (P5) pulse;

Note.— From common usage, the term ISLS is abbreviated to SLS for Mode S.

c) an intermediate video processing stage which may, according to the system design, contain:

1) an off-boresight angle (OBA) processor;

2) an RSLS processor; and

3) an improved interrogation side-lobe suppression (I^2SLS) processor;

d) an SSR plot extractor, which may be one of three general types:

1) a sliding window extractor;

2) a monopulse plot extractor; or

3) that which may be embedded in a Mode S system.

The SSR plot extractor outputs digital messages containing the range, azimuth, identity and pressure-altitude code of all SSR targets (aircraft) within radar coverage, together with validation information.

The SSR plot extractor will also limit to a great degree spurious SSR data resulting from such phenomena as:

— side-lobe responses;
— fruit (false replies unsynchronized in time); and
— reflections (uplink and/or downlink).

The SSR plot extractor will also apply various criteria in order to attempt the "degarbling" of SSR replies that overlap in range and azimuth.

A Mode S reply processor also outputs additional information for surveillance and datalink. The Mode S reply processor provides Mode S reply reports to the Mode S surveillance processing. A Mode S reply report is defined as a Mode S summary report with, typically as a minimum, aircraft address, sensor derived position, message data (e.g. aircraft identification, communication capability, flight status) and surveillance status (e.g. reservation) for all successful transactions with a given target in the beam-dwell.

e) Surveillance processing may also be applied as part of the sensor system. This processes SSR plots on an antenna rotation-to-rotation basis to perform functions such as the identification and rejection of false plots or reflections, assist with the resolution of plots which have suffered from garbling on track crossings, and/or tracking to obtain ground speed and heading and/or vertical rates of climb or descent.

Surveillance processing is an essential part of a Mode S system. Every aircraft must be tracked and its position predicted ahead into the next antenna rotation. The acquisition of new aircraft is either performed autonomously using all-call or via the use of position information from neighbouring Mode S radar systems. Roll-call transactions for each aircraft are prepared in advance so that:

1) interrogations are scheduled for when the aircraft is in the beam;

2) overlap of replies is avoided; and

3) re-interrogation could be performed within the beam dwell period.

SSR Mode S systems

2.3.6 In older PSR or SSR systems, each radar station operates autonomously, i.e. they operate as stand-alone sensors quite independent of nearby systems of the same type. For SSR Modes S systems, each sensor provides a site identifier, known as an interrogator code (IC), in uplink transmissions. This IC may be an interrogator identifier (II) code in the range 1 to 15 or a surveillance identity (SI) code in the range 1 to 63. The ground station transmits all-call interrogations to acquire the addresses of Mode S aircraft. The SSR Mode S transponder responds with its unique address and once acquired by the ground station, it will be interrogated by roll-calls thereafter. The roll-call interrogation will “lockout” the aircraft by instructing its transponder to ignore further all-call interrogations with the same IC. Provided all nearby interrogators have different ICs, each interrogator will independently acquire the aircraft in turn as it transits their coverage volumes using all-calls. This is known as multi-site operation where each station operates in a stand-alone mode. However, in areas where there is such overlapping coverage that it is not possible to allocate an IC to each Mode S radar, the ground stations may operate as a cluster of Mode S sensors, where all of the Mode S sensors in the cluster share the same IC.

2.3.7 When Mode S ground stations are configured in clusters, the surveillance functions (acquisition, track support, etc.) and lockout responsibilities are coordinated via a surveillance coordination network (SCN). Thus, each sensor in the cluster acquires aircraft already acquired by an adjacent sensor in the cluster via the SCN, rather than via all-calls. The implementation of the surveillance coordination function (SCF) may be either as a centralized function or as a distributed function. A cluster controller, typically situated at the ATCC, forms part of the system for a centralized SCF, whereas a distributed SCF does not use a cluster controller.

Note.— *For guidance material on interrogator coordination and clustering, refer to* Aeronautical Surveillance Manual *(Doc 9924), Appendix J.*

Combined digitized PSR/SSR systems

2.3.8 For both the older (analogue) and modern (digital) radar systems it is quite common for the PSR and SSR equipment to be collocated. Collocated may mean:

a) the SSR antenna “on-mounted” above the PSR antenna;

b) the SSR antenna “integrated” into the PSR antenna; and

c) the PSR and SSR on the same site, but physically separated, and having their own turning gear, etc. In this case, when plot combination takes place, a compensation is then made for the aforesaid physical displacement.

Plot combiner

2.3.9 In the case of the radar station comprising PSR and SSR (Mode A/C or Mode S) equipment, whether on-mounted or not, the primary and secondary plot positions may be combined in a “plot combiner”. The plot combiner will apply combination criteria in order to ascertain which PSR and SSR plots are derived from the same target. On the basis of position, identity and other correlating data, the two plots best meeting the criteria are declared as a “combined plot” or a “reinforced plot”. If the criteria for plot combination are not met, the plot combiner will output the plots according to their type (PSR, SSR or Mode S), as “uncombined” plots. All plots will be identified as PSR, SSR, Mode S target reports or combined/reinforced reports according to whether the relevant combination criteria are met or not.

2.3.10 Compensation will be made in the combination process for any physical displacement of the primary and secondary radar heads. If the two antennas are synchronized in rotation, this combination is relatively simple except at short ranges where significant azimuth differences (and, therefore, the times when detected) can occur. If the two antennas rotate asynchronously, and possibly at different rates, combination requires a tracking process in order to estimate the current position of a target detected by the first radar at the time of detection by the second radar.

2.3.11 Some primary and secondary radar installations may, however, send the PSR and SSR/Mode S data to an ATCC without a prior combination process. The combination may be achieved at the centre using multi-radar tracking processes.

Surveillance processing and plot/track combination

2.3.12 A surveillance processing function may be found at a number of system levels, namely:

a) at both PSR and SSR (Mode A/C or Mode S) levels before plot combination;

b) after plot combination; and

c) at ATCC level, if no surveillance processing is applied at sensor site level (with a penalty of increased data transmission load).

Surveillance processing may output either plots or tracks. In addition to the target reports, messages containing system information such as turning data, station identity, station equipment status and synchronizing data may be output with the plot or track reports.

Remote monitoring and control system (RMCS)

2.3.13 A modern radar installation will have an integrated RMCS. The RMCS will allow either remote or local monitoring and control of all major system elements, typically using visual display unit (VDU) and keyboard techniques. Older systems may use “mimic-panel” techniques. An RMCS terminal may be located locally (on the radar station) and/or at the ATC centre.

2.3.14 The monitoring function of the RMCS is often integrated into the BITE of each system element. Thus, a system fault can be directly indicated on an RMCS terminal or a similar visible/audible warning is given by the mimic panel. Since modern BITE is capable of successfully analysing a fault to line replaceable unit (LRU) level for typically up to 95 per cent of the cases, repertory actions can be simplified and speeded.

2.3.15 In the case of the electronics of a radar or a radar data processing system (RDPS) being duplicated, the RMCS can automatically reconfigure the system to an operational state. In addition, for Mode S, when the station is configured as part of a cluster, the RMCS is used to initiate the process that causes the sensor’s SCF to establish its connection to the appropriate network.

Surveillance-related data transmission
(distribution from sensor station)

2.3.16 Plot, track, enhanced surveillance, Mode S SCN, data link and RMCS messages are distributed between radar sites and the ATCC by data transmission equipment. These data can be multiplexed on the same physical data lines using dedicated time division multiplexers and network routers, or each data category may be carried by individual transmission lines.

Data transmission medium

2.3.17 In Figures 2-3 and 2-4, the data transmission medium is represented by a "functional block". The data transmission medium may be by means of:

a) telephone line (twisted pair);

b) coaxial line;

c) microwave link;

d) RF link;

e) optical cable; and

f) satellite link.

The medium used will depend upon the distance for data to be transmitted, the data transmission rate required and available communication facilities. Generally modem (modulator/demodulator) techniques are used for digital data transmission applications although digital optical links are becoming more common in new installations. In order to provide increased system availability, the data transmission medium (e.g. data lines) may need to be duplicated and strategies for separate routing implemented.

Monitor display

2.3.18 The radar station is normally equipped with a monitor display (possibly with roller ball and keyboard) for the visualization of radar data (targets). The monitor display should be capable of showing both analogue (raw video) and digitized data at the different levels of processing in the radar system. It should also be capable of showing alphanumeric characters related to the targets.

Antenna turning gear

2.3.19 The antenna system (which may be PSR only, SSR only or collocated PSR/SSR) is mounted upon a long life/high reliability turning gear and drive system. The turning gear will most probably contain a 12- or 14-bit digital encoder for accurate determination of the pointing direction of the antennas.

Field monitoring devices

2.3.20 The SSR and PSR systems may be equipped with devices to check:

a) the correct geographical alignment of the system; and

b) the correct functioning of the system.

SSR remote field monitor (RFM)[2]

2.3.21 Associated with the site, at a distance and elevation suitable for far field measurement, there should be at least one RFM for the SSR system. This may be an adapted aircraft transponder or it may be to a special build. The RFM has preset identity and height codes (Mode A/C) and/or a Mode S address. It is permanently on-line being used to align the radar azimuth reference and provides an end-to-end integrity check of the operational SSR system. The RFM shall be either dual channel or duplicated equipment providing high integrity and the ability to distinguish failure of the SSR system from failure of the RFM. If the SSR system's internal BITE does not include a means to detect antenna diagram distortion, the RFM may be used to indicate such failures. In this case, it is preferable to use two RFMs at sites with a different azimuth to distinguish real failures from azimuth-dependent site effects. The RFM shall have a selectable range offset capability so that it may be adjusted to appear at a place acceptable for operational and technical purposes.

2.3.22 The RFM BITE should provide additional capabilities to confirm the correct operation of the Mode S radar, such as "remote setting" of parameters and tellback facilities. These could employ the Mode S specific protocols (MSPs) or ground initiated Comm-B (GICB) protocols.

2.3.23 Mode S RFM. The Mode S site monitor has many characteristics in common with a Mode S transponder. However, there are a number of important differences as indicated in the following paragraphs.

a) *Reply conditions.* The site monitor is intended to provide loop tests for all surveillance modes used by the interrogator. This includes SSR Mode A/C (civil and military), Mode S surveillance and Mode S acquisition (all-call replies).

b) *Mode A/C surveillance.* 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. Provision should be made to obtain Mode A/C interrogations from the site monitor in order to check P1/P3 spacing and the shape of the pulses.

c) *Lockout transition.* 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.

d) *Reply delay.* 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.

e) *Squitter suppression.* The site monitor shall not generate acquisition squitters in order to eliminate the possibility of a site monitor being acquired by an ACAS unit.

f) *Transmitter power.* 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 it to get nominal received power from a site monitor wherever its location from the sensor.

g) *Variable minimum triggering level (MTL).* 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.

h) *Continuous wave (CW) inhibitor.* The site monitor should sense for any failure that causes a continuous

2. Alternative terminology in common usage includes far field monitor (FFM), Parrot and site monitor. Also, refer to the Glossary.

transmission of the 1090 MHz carrier. If 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.

Active primary radar "reflectors"

2.3.24 In the case of primary radars, it may be necessary to have active "reflectors" in order to check the geographical alignment of the PSR video (as shown on a PPI) with the touchdown points, runway crossing points, etc., on an airfield. In a modern radar, MTI and MTD techniques are used for the suppression of stationary targets. The "active reflector" (also a stationary target) must then produce, by electronic means, a "Doppler shift" such that the so-generated stationary target may pass through the MTI/MTD processor and be presented on the radar screen in the ATCC and/or used in the BITE/RTQC for automatic detection of misalignment.

2.4 DSS SYSTEMS

Currently DSS systems are not in common operational use for ATC and the provision of material for this document will depend on publication of SARPs.

2.5 THE ATCC

General

2.5.1 For the simpler ATCC systems, the surveillance data for presentation as single target reports on ATC displays will originate from a single or mono-sensor. In larger ATCC systems, the same surveillance data may be derived and combined into a single report from a number of different sensors. Testing of a single sensor system can be regarded as a subset of multi-sensor testing.

2.5.2 Figure 2-4 shows a functional block diagram of an ATCC with radar input data. Again, no attempt is made to represent every type of ATCC philosophy, and simply a functional representation has been used.

Data reception

2.5.3 The surveillance data transmitted via the data transmission medium is received at the ATCC and demodulated. Further separation of multiplexed data such as RMCS messages and voice lines is also carried out in the ATCC. The demodulated output of the data transmission system provides an input to the at the ATCC. For Mode S sensors, the radar data delivered may also include "downlink aircraft parameter (DAP)" information to facilitate the concept known as "enhanced surveillance". In the case of multi-sensor tracking, there will be several data transmission links inputting to the SDPS.

The SDPS

2.5.4 The function of the SDPS is to process the incoming sensor data in order to provide a suitable output to the display subsystem, which is the machine interface with the air traffic controllers. The main SDPS functions are:

a) tracking, correlation of target reports, i.e. on a scan-to-scan basis;

b) estimation of track-state vector elements, e.g. position, ground speed, course and vertical speed (rate of climb/descent);

c) suppression of false plots; and

d) provision of track data to the operational display system (ODS) and automatic functions such as:

1) track to flight plan correlation;

2) conflict alert; and

3) flight-path monitoring.

Note.— Processes such as short-term conflict alert (STCA) could also be users of the DAP data provided by the Mode S targets (particularly aircraft intention data, which can be used to reduce false alerts).

2.5.5 In the mono-sensor SDPS configuration, only one source is available. In the case of the multisensor SDPS, data is available from a number of different sources, allowing surveillance coverage over a much greater area and providing dual or even multiple coverage in over-lapping sensor coverage areas. In the case of dual or multiple coverage, various options are open for the presentation of data, e.g. “mosaic” selection of data sources or a combination of data sources using predefined algorithms to obtain one single plot per target.

2.5.6 Multiple coverage can also be used for the RTQC of the data from one single data source. Abnormalities in the performance of a data source can thus be detected and corrective actions taken.

2.5.7 If code-call sign correlation facilities are incorporated in the processing, the aircraft’s call sign will be associated with the relevant code and included in the output as part of the displayed label. However, in the case of Mode S targets, the flight identity (or call sign) may be provided automatically as a DAP.

Flight data processing system (FDPS)

2.5.8 FDPS, if provided, may be used in conjunction with the SDPS to monitor the progress of the controlled flights. Once the track and the flight plan have been correlated, a flight plan label can then be displayed at the actual track position and the flight plan can be updated by the controller either manually or in cooperation with an automatic function. It is to be noted that an FDPS is shown with the SDPS in Figure 24. The incorporation of an FDPS into an ATCC is becoming increasingly common in order to assist the expedition of ATC functions.

The operational display subsystem

2.5.9 The SDPS output in the form of tracks is fed to the display subsystem which drives the displays. Each operational display will be fed with processed tracks and will have a control interface with message input devices, e.g. keyboard and target-identifying device (such as a rolling ball) to allow operator selection of the appropriate display data. Related alphanumeric data will most likely be shown on a synthetic data display (SDD). The following list of items may be displayed (not exhaustive):

a) display of target positions;

b) presentation of a label for each target containing at least the target identity (code and/or call sign and altitude for SSR or DSS. Note that Mode S may provide a call sign automatically via DAPs.);

c) presentation of special purpose codes (i.e. SSR codes 7500, 7600, 7700);

d) presentation of special identification symbols (e.g. SPI); and

e) supplementary information such as:

1) arrows indicating a climbing or descending target;

2) history dots;

3) a vector indicating the predicted position of the target, e.g. 5 minutes ahead; and

4) DAP information derived from the data delivered (such as “start of a turn”).

Other surveillance sensor data users

2.5.10 A modern ATCC is rarely a single entity for ATC and may send and receive surveillance data from other users or functions. Examples are:

a) conflict alert function;

b) sectors with military personnel;

c) flow control; and

d) other ATCCs.

2.6 RADAR ANALYSIS AND SIMULATION POINTS

2.6.1 In the progression from the radar head to the radar display in the ATCC, the radar data are subject to a number of transformation processes which can be used to identify interface points where analysis data can be extracted or test/simulation data can be injected.

2.6.2 Figures 2-3 and 2-4 show simplified functional diagrams (applicable for both the PSR and/or SSR cases) indicating the data I/O interface points in a radar system and the connection possibilities to an analysis tool, which may be in either the radar station or the ATCC. It is to be noted that many of the I/O interfaces shown in the diagrams allow both output of data for analysis and the input of simulated data (from some type of generator or recording device) such that special situations can be simulated. The input interfaces further allow the injection of signals/data for test purposes.

2.6.3 Figure 2-3 is a generic functional diagram which covers most different system designs. Figures 2-5, 2-6 and 2-7 show particular examples of sliding window, monopulse and Mode S SSR sensor functional block diagrams.

2.6.4 Modern integrated systems may present practical problems for making measurements at certain interfaces.

2.6.5 For example, a recent trend in surveillance systems is to integrate on-site tracking which gives rise to the surveillance processing plot combination and data trans-mission functions being combined into one system element. That makes it difficult or impossible to access the interfaces PI06, SI06, CI01 and CI02 without highly specialized interface equipment.

2.6.6 In order to avoid this kind of situation, manufacturers of equipment should be urged to provide, as much as possible, easily accessible interfaces.

Input/output (I/O) interfaces

2.6.7 Reference is made primarily to Figures 2-3 and 24 and in particular to the I/O interfaces designated:

PIO for I/O interfaces related to the primary radar element
SIO for I/O interfaces related to the SSR element
CIO for common I/O interfaces at radar sensor site level
RIO for RDPS I/O interfaces at ATCC level.

In Figures 2-3 and 2-4, the I/O interfaces are shown by a common designation. Although the input and output inter-faces may well be common points (i.e. a connector, a data bus), they may be physically separated. For the sake of convenience and simplicity, an input or output interface at a certain point within a system (e.g. receiver output) has been given a common designation (e.g. PIO2 and SIO3).

Output interfaces

2.6.8 The output interfaces are points in the radar system and/or RDPS where data can be output, either in analogue or digital form for:

a) analysis in a radar analysis tool;

b) standard measurements using normal test equipment (oscilloscope, etc.); and

c) recording.

Input interfaces

2.6.9 The input interfaces are points in the radar system or RDPS where data can be injected either in analogue or digital form in order to test the system particularly for special cases including performance anomalies. The injected signal/data may be either analogue or digitally synthesized (simulated) or in the form of a recorded message.

Location of the I/O interfaces

2.6.10 The I/O interfaces are located as follows:

PIO1: Primary radar radiated RF I/O interface
PIO2: Primary radar receiver (RF) I/O interface
PIO3: Primary radar receivers I/O interface (inter-mediate frequency)
PIO4: Primary radar processed video I/O interface
PIO5: Primary radar plot extractor output interface
PIO6: Primary radar surveillance processor plots (tracks) I/O interface
PIO7: Primary radar transmitter I/O interface
PIO8: Primary radar timing unit I/O interface

SIO1: Secondary radar radiated RF I/O interface
SIO2: Secondary radar receiver input (RF) I/O inter-face

SIO3: Secondary radar receivers I/O interface (video)
SIO4: Secondary radar processed video I/O interface
SIO5: Secondary radar plot extractor output interface
SIO6: Secondary radar surveillance processor plots (tracks) I/O interface
SIO7: Secondary radar transmitter I/O interface
SIO8: Secondary radar timing unit I/O interface
SIO9: Mode S radar interrogation handler I/O inter-face

CIO1: Plot combiner I/O interface
CIO2: Combined surveillance processor plots (tracks) I/O interface
CIO3: Transmitted data (sensor station) I/O interface
CIO4: Received data (ATCC) I/O interface

RIO1: Modulated received data I/O interface
RIO2: Demodulated received data I/O interface
RIO3: Processed data (tracks) I/O interface.

FIGURES FOR CHAPTER 2

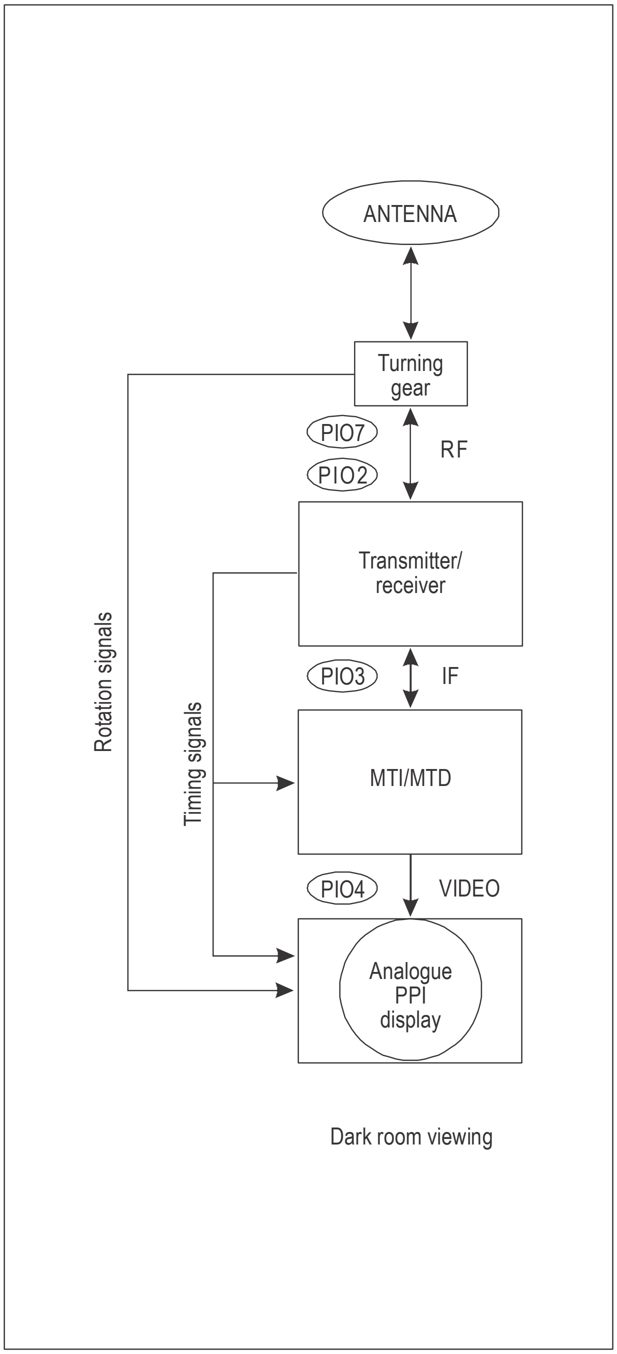

Figure 2-1 a) PSR
(analogue video and PPI display)

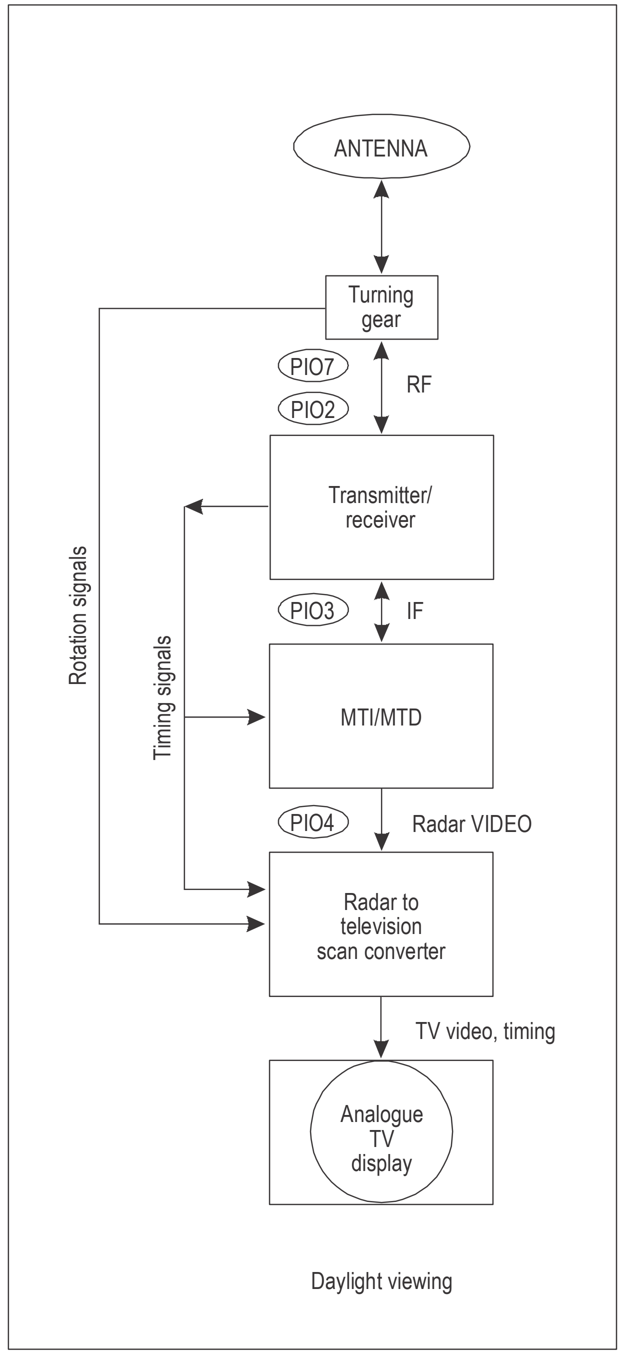

Figure 2-1 b) PSR
(analogue video and TV display)

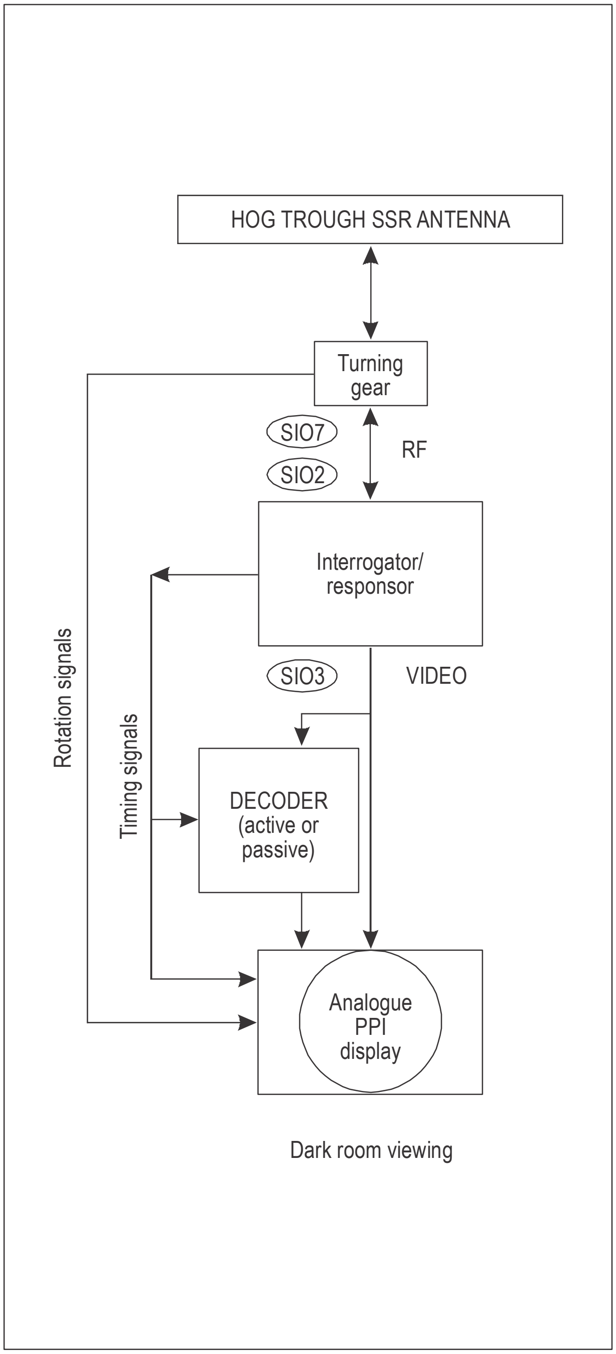

Figure 2-2 a) SSR
(analogue video and PPI display)

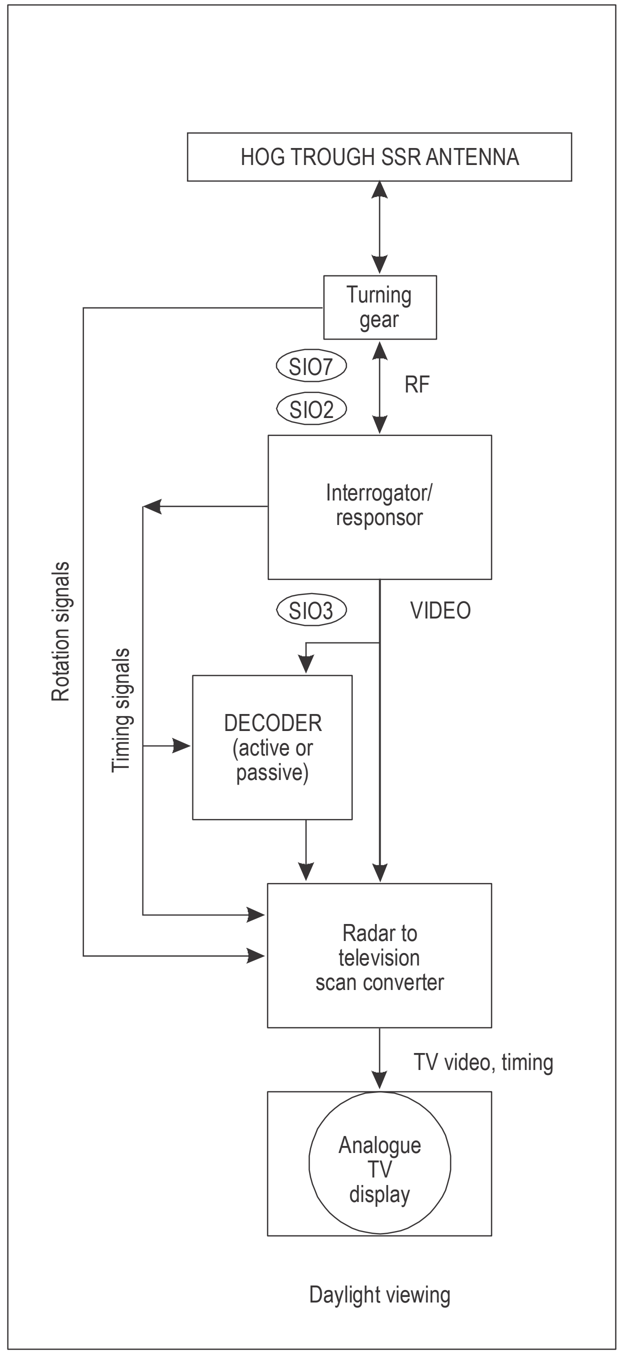

Figure 2-2 b) SSR
(analogue video and TV display)

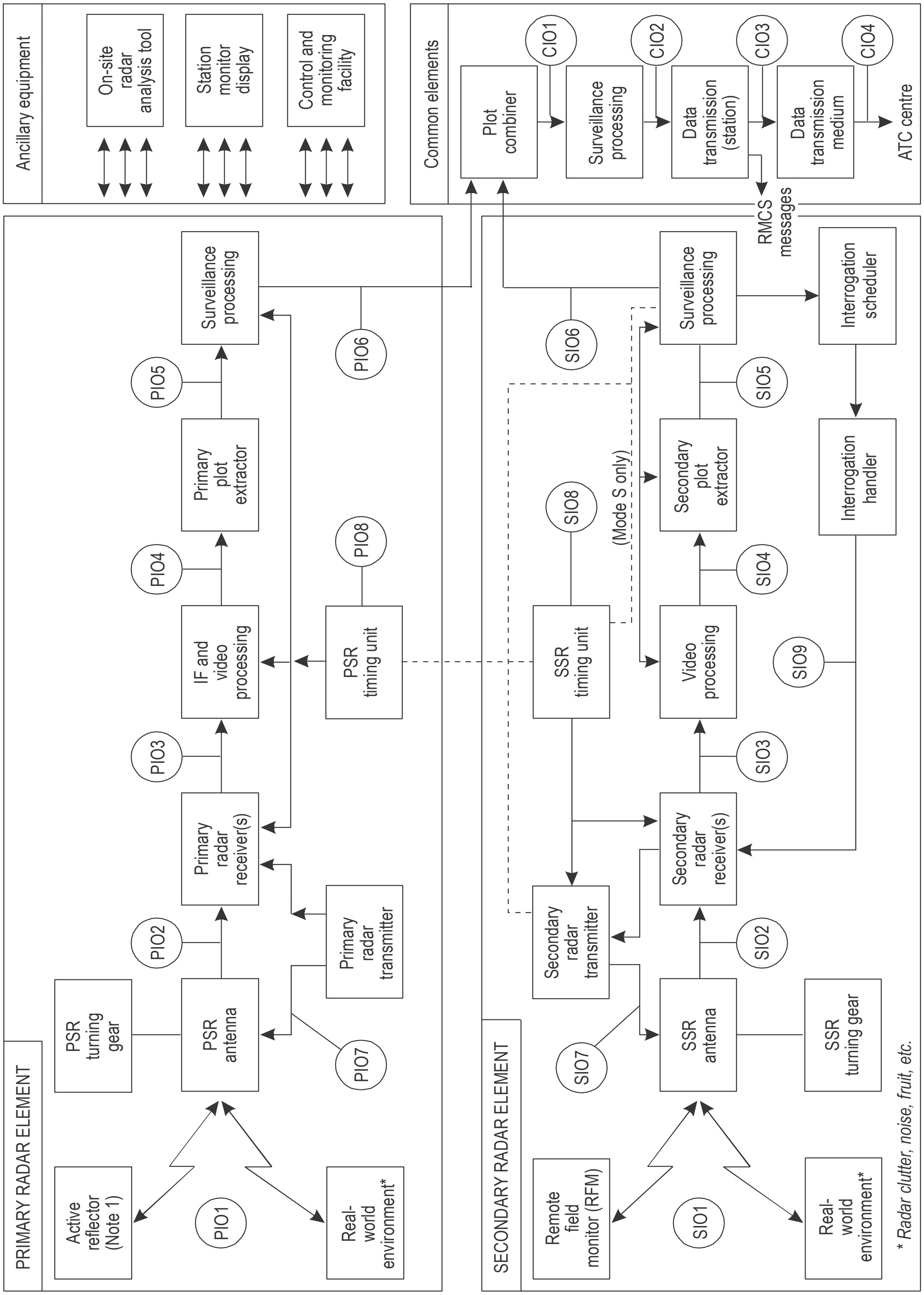

Figure 2-3. Functional block diagram of a radar station including PSR, SSR and common elements (certain configurations may consist of parts of these elements)

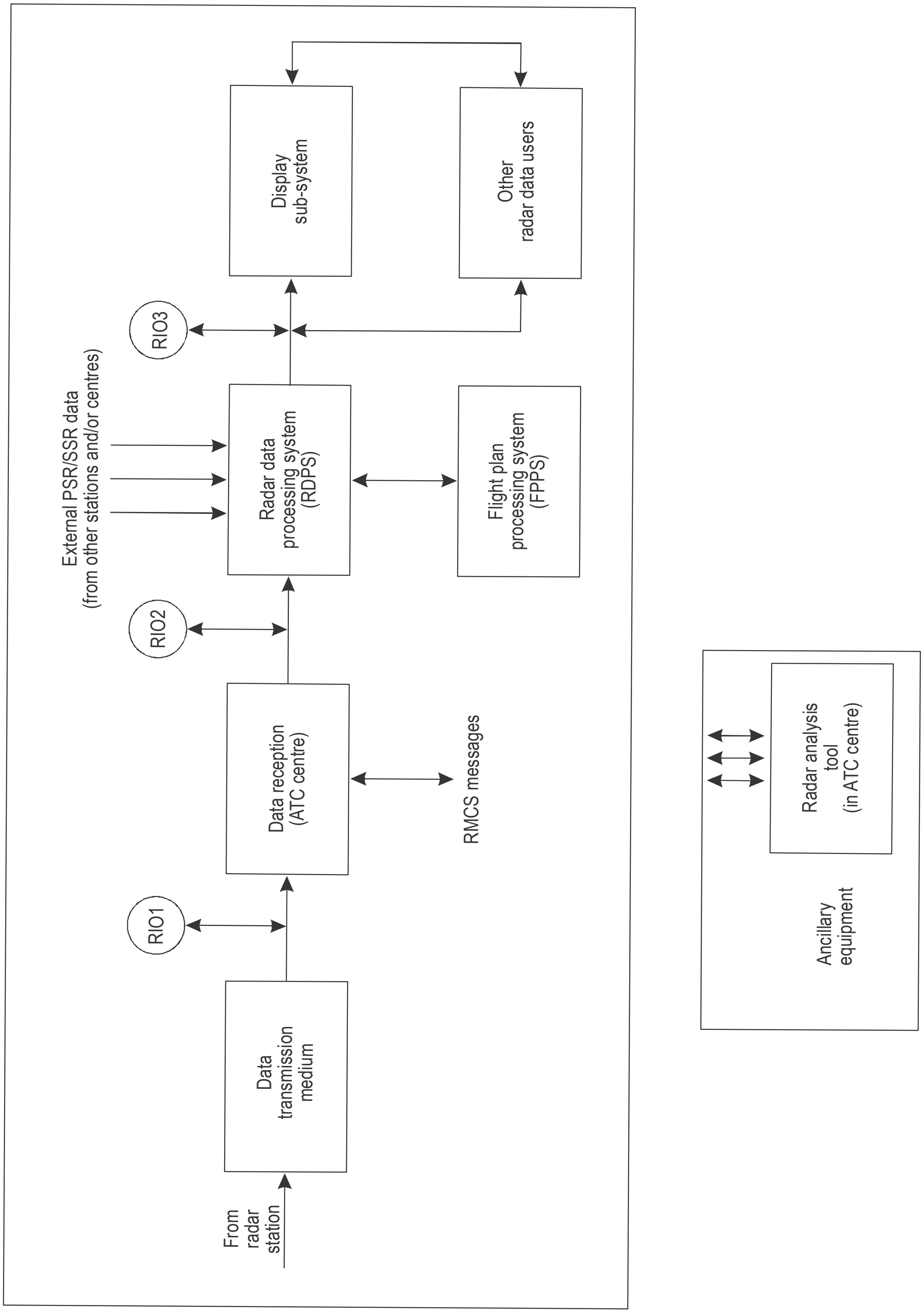

Figure 2-4. Functional block diagram of an ATCC

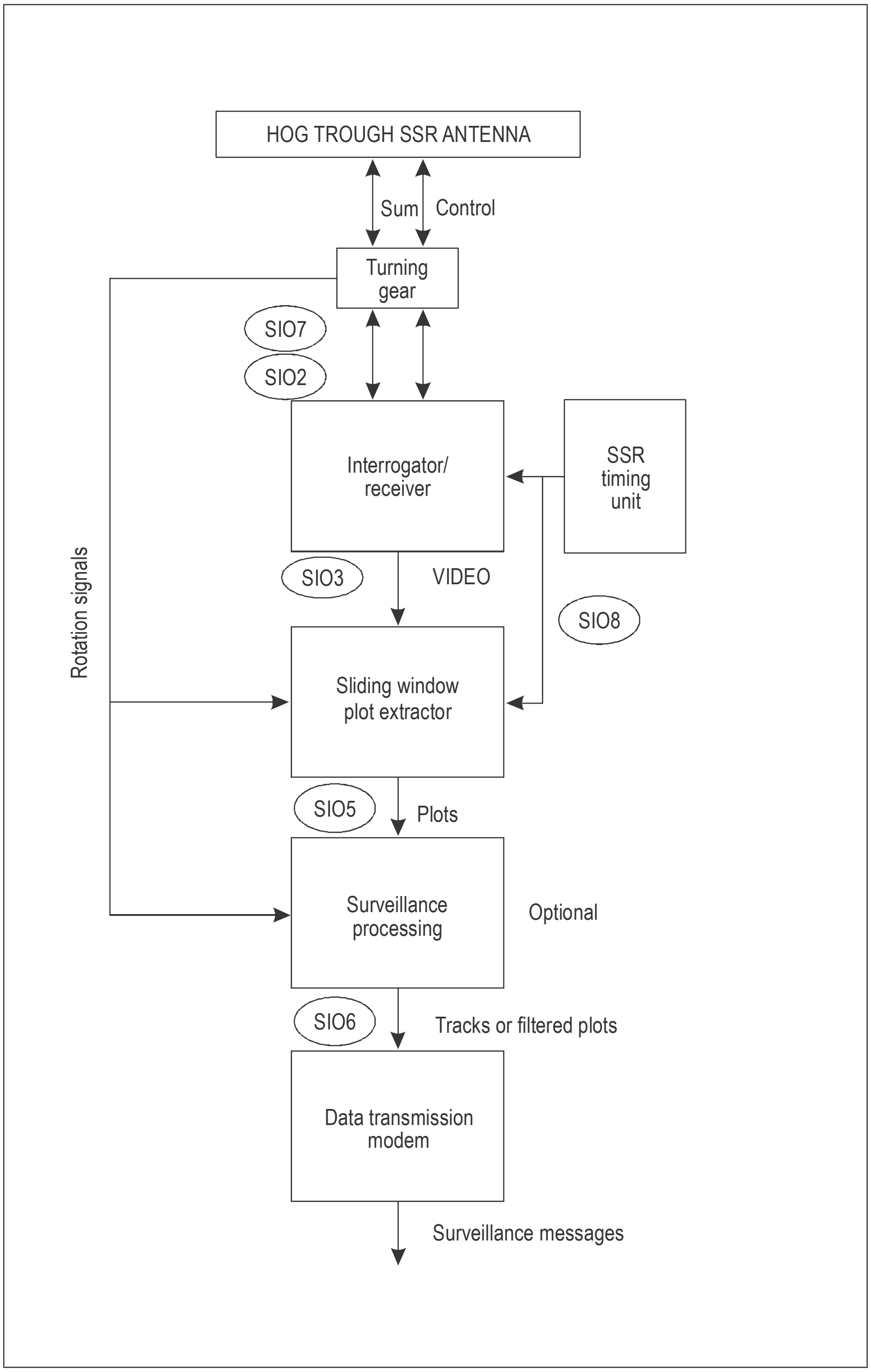

Figure 2-5. Sliding window SSR sensor

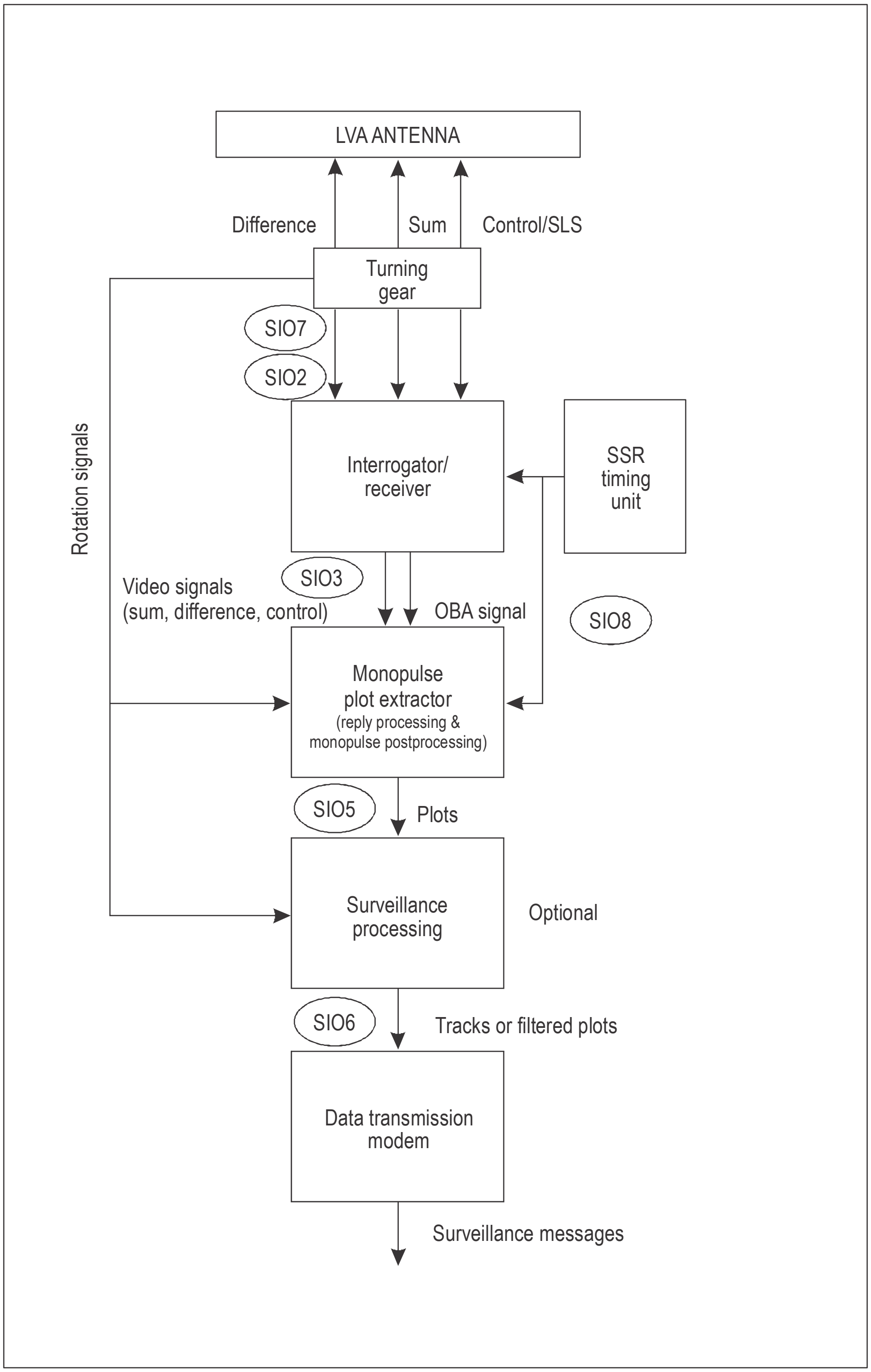

Figure 2-6. Monopulse SSR sensor

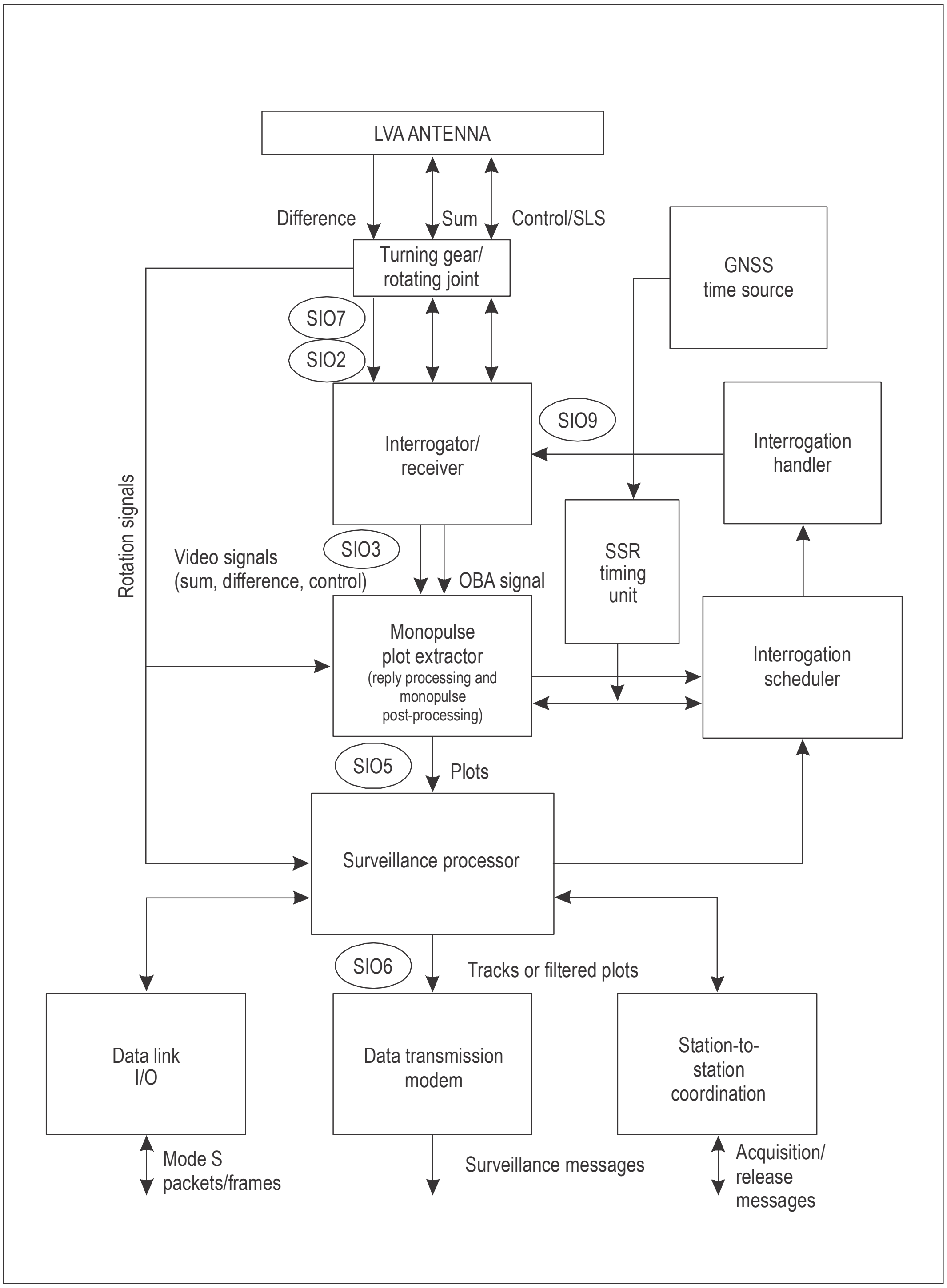

Figure 2-7. SSR Mode S sensor

Chapter 3

RADAR SYSTEM PERFORMANCE TEST METHODOLOGY

3.1 GENERAL

3.1.1 Radar stations have the function of being surveillance sensors providing radar data to assist in the process of ATC.

3.1.2 While there may be an “optimum” radar site for a given operational requirement, restraints such as finance, access, and site availability may result in a compromise where sub-optimum radar site(s) must be accepted for the location of the radar sensor(s). This may result in less-than-optimum radar sensor performance and thus increases the necessity for an in-depth evaluation of sensor performance.

3.1.3 Operational requirements dictate the volume of airspace through which radar information is required and may give a need for differing volumetric coverage for different azimuth sectors if the system has to include upper airspace, en-route and approach functions. The performance testing has to establish the system performances and its ability to meet all operational requirements effectively. Periodic performance testing can also be used to ensure the system is performing at the optimum level.

3.1.4 The use of a discrete dedicated aircraft for the complete investigation of system performance can be prohibitive in both time and cost. To overcome this, dedicated flights can be mixed with samples of opportunity traffic as the basis for testing. Recent changes in system design, recording techniques and data processing present a situation where the majority of performance testing can utilize opportunity traffic and reduce the need for dedicated flying to that required for the investigation of particular problems only.

3.1.5 The recommended methodology consists of making recordings at the various I/O interfaces in the system and their subsequent processing by the analysis tools which will be used to examine the data and provide information related to the performance characteristics.

3.1.6 In practice, a variety of measurement methods are used which all may provide useful outputs, but when interpreting these results the following considerations shall be kept in mind:

a) the reliability of a measurement depends on the reliability of the reference that is used;

b) the following levels of reference reliability shall be distinguished:

1) *subjective reference*, e.g. the expectation of the user (a mental model built from experience);

2) *relative reference*, e.g. comparison of performance before and after modification or comparison of the outputs of two (slightly different) parallel processing chains; and

3) *objective reference*, e.g. I/O comparison either by reconstructing the input, by input simulation, or by external references.

3.1.7 In the case of an *objective reference*, the quality of the input reconstruction shall be an order of magnitude better than the quality to be measured. This can be achieved by systems using the same information, but applying superior techniques or by using additional information, e.g. from other sensors.

3.1.8 In the case that only a *subjective reference* is available, the observer's experience is vital, e.g. in case of visual analysis of the data. An experienced analyst will quickly identify irregularities although occasional irregularities, which might happen to occur during the observation period, can easily mislead both human analyst and an automated system.

3.1.9 In the case of a *relative reference* a statistical approach is feasible, especially if the two systems to be compared use exactly the same input data. In the sections below a number of statistical performance parameters are defined which are all based on the availability of an objective reference. For detection measurements the reference system shall provide the expected number of plots; for accuracy measurements the reference system shall provide a very accurate trajectory.

3.1.10 In some cases the performance testing may be carried out at intermediate levels in the system using not only opportunity traffic or dedicated aircraft, but using video and/or radar data simulators connected to the relevant I/O interface. These devices may be particularly useful in investigating a problem at some specific level in the ATC system, especially when suitable real-time data is not available.

3.1.11 Replay of previously recorded information can be used to create a database of different parameters.

3.2 DEFINITION OF RADAR SYSTEM PERFORMANCE PARAMETERS

General

3.2.1 From an over-all system point of view the parameters which require evaluation to determine the performance of the system are categorized as follows:

a) *coverage*;

b) *detection performance*, including code detection and false target rate;

c) *accuracy*, comprising the following:

— systematic errors in time and position for each radar in a multi-radar system;

— residual errors in time and position for each radar; and

d) *resolution*.

3.2.2 Stability of the above parameters within the life cycle of the system shall be obtained by the frequency of the evaluation of the parameters as defined in Chapter 5. Further details are provided in 3.2.42 and 3.2.43.

3.2.3 The characteristics are analysed at various discrete points in the system as indicated in Figures 2-3 and 2-4.

Coverage

3.2.4 The coverage of a radar system is the three dimensional volume of airspace within which the system can meet the specified detection performance, accuracy and resolution values depending on geography and chosen variable parameters.

3.2.5 In order to measure the coverage in terms of the detection performance, accuracy and resolution parameters, a number of supplementary evaluation terms are introduced:

a) required coverage;

b) measured coverage;

c) actual coverage;

d) coverage measurement volume; and

e) fringe envelope.

These terms are described further in Chapter 5.

Detection performance

Probability of detection (P_D)

Note.— The probability of detection (P_D) is here defined as the probability that at each scan, for a given wanted target within the coverage measurement volume, a radar target report with position data will be produced. For editorial reasons, this section also includes a description of the SSR code detection measurements. Although determined analogous to the P_D figures, code detection is referred to as a rate rather than a probability throughout this document.

3.2.6 Probability of position detection is divided into the following aspects:

a) probability of SSR position detection; and

b) probability of PSR position detection.

SSR code detection rates are divided as follows:

— valid Mode A detection rate;
— valid Mode C detection rate;
— correct Mode A detection rate;
— correct Mode C detection rate; and
— correct Mode A and Mode C detection rate.

3.2.7 The following definitions are for over-all figures. It is recommended that input data categorization is used so that the analysis results can be produced for the predefined categories of data. Input categorization will give better control over the measurements and the results. To apply categorized input, data requires categorization constraints to be taken into account in each case.

3.2.8 *PSR position detection*. The probability of detection of the primary radar is defined as the ratio of the number of detected PSR target reports to the expected number of PSR target reports. A PSR target report in this context shall mean either a PSR or a combined target report message.

3.2.9 False plots (clutter, “angels”, etc.) have to be excluded from the detected PSR target report count before establishing this ratio. This is usually performed by a “surveillance processing” or “plot chaining” function which also establishes the number of expected plots as reference.

3.2.10 *SSR position detection*. The probability of detection of the SSR is defined as the ratio of the number of detected SSR target reports to the expected number of SSR target reports. An SSR target report in this context shall mean either an SSR or a combined target report message.

3.2.11 As for PSR, false plots have to be excluded before establishing this ratio. SSR false plots can be reflections, second-time-around plots, split plots, etc.

3.2.12 *Missing data*. The analysis of missing data is considered an important part of the probability of detection analysis. The analysis program has to reconstruct the trajectories. When expected plots are not present in the radar data, it identifies and regenerates the missing plots in position and time. The analysis of missed data can then be considered under two headings, missed plots and gaps.

3.2.13 *Missed plots*. Isolated losses of surveillance plots are categorized as missed plots and are typically expressed as the ratio of the number of missed plots to the total number of plots (usually expressed as a percentage). Possible reasons are loss of detection or aircraft-related faults such as antenna shielding.

3.2.14 *Gaps*. A gap is a sequence of consecutive missed plots from one radar and associated with one trajectory. A number of results may be determined for gaps:

a) percentage of missed plots in gaps of more than two misses;

b) percentage of gaps with more than two misses; and

c) average gap size.

3.2.15 Misses and gaps can be analyzed for both PSR and SSR at interfaces PIO/SIO 3, 5 and 6. Observations at interfaces PIO/SIO 1 and 4 can often assist in finding reasons for missing plots.

SSR code detection

3.2.16 These ratios are calculated in respect to the number of received SSR target reports which could be allocated to an object and which has been selected for use in the detection calculation defined above.

Valid Mode A detection rate (secondary radar): The ratio of the number of received SSR target reports with a valid Mode A code to the received number of SSR target reports in the trajectories used in the detection analysis.

Correct Mode A detection rate (secondary radar): The ratio of the number of received SSR target reports with correct Mode A code to the received number of SSR target reports.

Valid Mode C detection rate (secondary radar): The ratio of the received number of Mode C replies to the received number of SSR target reports.

Correct Mode C detection rate (secondary radar): The ratio of the number of received SSR target reports with correct Mode C code to the received number of SSR target reports.

Correct Mode A and Mode C detection rate (secondary radar): The ratio of the number of received SSR target reports with both correct Mode A and correct Mode C code to the received number of SSR target reports.

Note 1.— The results may be plotted on diagrams to give global or selective P_D figures. If Mode C information is available in the plot data, the diagrams can be plotted for selected height (altitude) bands. To achieve this the scanned area is divided into cells having predetermined height, azimuth width and range elements. These cells are analysed and their P_D values are obtained. In order to assist the presentation and reduce complication the P_D values are often placed in selected bands for display, e.g. zero, <50 per cent, >50 per cent, >75 per cent, etc., up to say >95 per cent, thereby giving a limited number of categories. Cells where no or not enough data for statistical assessments are available are considered a separate, empty category.

Note 2.— If interfaces PIO/SIO 3, 5 and 6 are used, the result will be objective; if interfaces PIO/SIO 1 and 4 are used, the result will be more subjective.

False target rate

3.2.17 There are two possible parameters for expressing the number of false targets produced by a radar system. One parameter is the number of false targets per scan, sometimes referred to as maximum rate. The other parameter is the number of false target reports expressed as a percentage of the total number of target reports.

3.2.18 The term "false target" is defined as any target report (plot, blip, track position) presented on the user's radar display which does not represent the position of a wanted target (aircraft).

3.2.19 False PSR target reports are generated from thermal noise and by reflections from objects other than aircraft, including clutter producing reflectors, i.e., near the ground, the sea, precipitation, and "angels"), cars (on a motorway), trains, ships, balloons, etc. "Angels" include migrating birds, insects or other natural phenomena such as clear air turbulence. Under anomalous propagation conditions (ducting effects) clutter plots (mainly ground clutter) from beyond the horizon or line of sight may be detected as second, or even multiple, time around clutter.

3.2.20 False SSR target reports are generated from fruit (synchronous and asynchronous), second-time around replies, shipborne transponders, reflected interrogations or replies and by interrogator side-lobe replies.

3.2.21 Reflected replies are replies arriving at the radar station via an indirect route either in the interrogation path to the aircraft or the returned reply path from the aircraft. Two principal kinds of reflections occur: reflections with a small (in-beam) deflection from the real target position, caused by reflecting surfaces oriented to the horizontal plane, and reflections with a large azimuth offset from the real target position, caused by reflecting surfaces oriented to the vertical plane.

3.2.22 Another category of false targets, applicable to both PSR and SSR, are split plots. The split plot can be identified in the SSR case as each report will often have the same identity and height information. It is normally considered that split targets will be separated by less than approximately twice the –3dB antenna beamwidth.

3.2.23 In the case of SSR reflections, the separated plots also often contain the same identity and height information but in general are separated by more than twice the –3dB beamwidth. This false target information would be examined at interfaces 3, 5 and 6 before and after filtering. Interfaces 1, 2, 4 and 10 can be used to obtain supporting information.

3.2.24 For analysis purposes, the false targets can also be categorized as false target reports and multiple target reports.

Relationship between false target rate and probability of detection

3.2.25 In a perfect system there would be 100 per cent detection throughout the whole system coverage and no false target reports. This ideal is not likely to exist in a real system. If there are no false targets, it is very likely that the system suffers from poor coverage and probability of detection. Conversely, if the number of false targets is high, the system coverage could be good with good detection of wanted targets but discrimination between false and real targets would be poor, with the radar display cluttered with false targets. Therefore the specification of a radar system normally allows for a certain number of false targets per antenna scan under specified operating conditions and the radar system is set up to achieve this. Refer to 3.3.1.

3.2.26 The specification of a radar system would normally allow for a certain number of false targets per antenna scan under specified operating conditions. In practice few systems achieve this requirement while maintaining the required probability of detection, and the people responsible for the radar must set up the system to achieve a compromise between good detection and low false target rate acceptable by the ATC controller.

Accuracy

3.2.27 As aircraft are normally moving when a radar position measurement is taken, accurate reporting of the aircraft position requires reporting of measured range, measured azimuth, measured pressure-altitude (for SSR) and time of measurement, often referred to as a four-dimensional report. The plot position variables (usually azimuth and range) will have a certain accuracy with respect to a stated position reference. The errors of these variables can, in most cases, be separated into a systematic as well as a residual part.

a) Systematic errors are bias errors for each radar in position and time with respect to an absolute reference system caused by, e.g. a bad north alignment of the radar.

b) Residual errors are the deviations in position which exist between the measured target report position and the trajectory at the time of the target report, after correcting the respective systematic errors. Residual errors are caused by such phenomena as occasional beam distortion, small timing errors, quantization noise, etc.

3.2.28 The plot position variables and applicable errors are described below. All errors are assessed using data at plot level (interface PIO/SIO 3, 5 and 6) where the target reports contain the measured position.

Accuracy in position

3.2.29 The position accuracy is the accuracy with which the radar system provides the true position of the aircraft at a given time. It is expressed in terms of maximum positional errors, which are categorized as systematic errors, residual random errors and jumps. The accuracy of the reference system has to be five to ten times higher than the accuracy of the radar system.

3.2.30 Accuracy performance parameters can be obtained by comparing radar-measured positions with an independent position reference from precision navigation systems, such as differential GPS, or precision lock and follow tracking radar. Alternatively, an independent position reference can be provided by reconstituting a trajectory from a multi-radar system in which the trajectory is covered by at least three radars at any time. However, comparison with a reference trajectory only computed from data obtained from the radar under test is not preferred because, although the residual random errors can be calculated this way, the systematic errors cannot.

3.2.31 *Measured azimuth*. The accuracy of this variable is determined by the deviations between the measured azimuth of each plot and the associated reference trajectory azimuth. The deviations in azimuth comprise two error components, systematic error, i.e. azimuth bias, and residual error, i.e. standard deviation of azimuth error.

3.2.32 *Measured range*. The accuracy of this variable is determined by the deviations between the measured range of each plot and the associated reference trajectory range. The deviations in range comprise three component errors:

a) systematic error — i.e. range bias at zero range;

b) systematic error — i.e. range-gain error (variation of range bias proportional to range); and

c) residual error — i.e. standard deviation of range error.

Note.— The range-gain error may be due to incorrect setting of the range clock.

3.2.33 *Calculated X/Y radar coordinates*. In a radar data processing system that uses target reports from a number of different radar stations, all measured plot positions have to be transformed into one common coordinate system. Sometimes the latitude-longitude coordinates of a radar are not accurate, causing systematic offsets in the calculated X and Y plot variables. Additional errors may be caused by inaccuracy of the coordinate conversion algorithm. Because all such errors are mixed with the errors in the measured range and azimuth variables, they can only be properly estimated by a tool that uses a very accurate coordinate conversion algorithm and a reliable earth model (e.g. WGS-84).

Accuracy in time

3.2.34 *Plot time stamping*. Surveillance reports (plots) should be time stamped at the radar site, either by absolute time stamp, or by time-in-storage. The accuracy of this time stamping is determined by the difference between the reported time of measurement and the actual time of measurement of the target position (mainly a systematic error). As aircraft are normally moving when a radar position measurement is taken, accurate reporting of the aircraft position requires reporting of measured range, measured azimuth, measured pressure-altitude (for SSR) and time of measurement — actually a so-called four-dimensional report.

Note 1.— The time of measurement of the above target parameters is considered to be identical with the absolute time when the antenna beam is pointing to the target.

Note 2.— As reference for time stamping a standard time source such as GPS derived UTC, British Rugby Time (GB), France Inter (F), DCF-77 (D), etc., should be used.

3.2.35 *Scan time*. It is the mean time between successive measurements of the same target. For mechanically rotating antennas, the accuracy of this parameter is determined by the stability of the drive (systematical error) and environmental effects (e.g. wind).

Note.— For rotating antennas the scan time is to be constant.

3.2.36 *Plot processing time*. It is the relative time difference from the time of detection to the end of plot processing in the radar sensor. Corresponding error is mainly systematic.

Note.— In this definition the plot processing time includes the time-in-storage. Therefore the plot processing time can be a parameter which depends on processing algorithms, target bunching, etc.

3.2.37 *Plot transmission time*. It is the relative time from the end of plot processing to the presentation of the plot on the display site.

Note.— This performance parameter is only relevant when using store and forward data transmission or a radar data network, eventually even with several hops. It is hence a variable which depends, amongst others, on the data block size, number of hops, etc.

3.2.38 *Plot end-to-end delay time*. It is the relative time difference from the target detection time to the time of plot presentation on the display.

Note 1.— This time span includes plot processing, plot transmission, tracking and all other delays. Hence, this performance parameter is also a variable which should be expressed as a probability for defined conditions, e.g. target bunching scenarios.

Note 2.— The plot end-to-end delay time is to be significantly lower than the scan time.

Resolution

3.2.39 The resolution of a radar system is defined as the capability to discriminate between two targets in close proximity and to produce a target report for both. The resolution performance is defined by the probability of target position detection, position accuracy and, for SSR targets, by the rate of code detection and code validation.

Note.— Due to the technique of selective interrogations and separate periods for Mode A/C and Mode S interrogations, resolution of nearby targets is generally not a problem for a Mode S radar if at least one target is equipped with a Mode S transponder.

Stability with time

3.2.40 It is acknowledged that stability with time is not a characteristic which can be divided into measurable parameters. The term is used here as a reminder that the other characteristics mentioned above must remain stable and compliant with the system operational requirements throughout the system's whole operational life.

3.2.41 Systematic errors and other performance parameters will, due to a number of reasons, change with time. It is, therefore, recommended that the general performance parameters which are considered to be critical are monitored on a permanent basis.

Air/ground message integrity

3.2.42 The Mode S system provides sufficient protection to ensure that no more than one undetected error occurs in 10E7 112 bit messages.

3.3 PERFORMANCE CHARACTERISTICS TO BE TESTED

Interdependence of radar data quality characteristics (RDQCs)

3.3.1 Careful consideration has to be given to the fact that RDQCs are strongly interdependent (see introduction to 3.2 and Figure 3-1*). Therefore, no general conclusions on the usability of the radar data in specific areas can be drawn even if some of the characteristics are far better than the typical performance figures. On the other hand, experience shows that generally a radar sensor or processing system problem might exist if the RDQCs are below the typical performance figures. Figure 3-1 explains the interdependence between the individual radar system performance parameters.

* Figure 3-1 is located at the end of this chapter.

Typical performance figures for RDQCs

3.3.2 Typical performance figures for RDQC are based on many years of experience with different radars, RDPSs and, last but not least, different evaluation tools. Radar data quality characteristics are by definition (see 3.2) of a statistical nature. Therefore, typical figures should always be expressed with an upper and a lower value. It is, furthermore, strongly recommended that “overall” figures refer to well-defined classes of objects such as geographical filter, aircraft type or operational sector of interest. Overall results which are derived from unclassified objects are only of use for trend analysis by a comparison between measurements of the same system under similar measurement conditions.

3.3.3 RDQC performance figures depend on the available evaluation tools and especially on the reference. Any RDQC performance figure is worthless if the measurement conditions, evaluation procedures and references are not clearly defined. Thus, Tables 3-1[*] and 3-2, with some typical performance figures on radar data characteristics, can only serve for general guidance and never as being fully representative.

Note.— Tables 3-1 and 3-2 refer to PSR and conventional SSR and monopulse SSR systems. It is expected that with the introduction of Mode S (e.g. transponder antenna diversity or selective addressing) certain performance figures are superior to those listed.

3.3.4 Tests to be performed with a Mode S site monitor:

a) *Standard message test.* A communications loop test using the standard length messages (SLMs) (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 A code) upon reception of a request from the Mode S station. 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. 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 the request for the transponder register accessed by 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. 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 the request for the transponder register accessed by 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. This request could consist of a Comm-A interrogation with a specific MA field value or

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* All tables are located at the end of this chapter.

of an interrogation with a particular RR value. This is to change the request for the transponder register accessed by BDS 3,0 to a test value and to check that the Mode S sensor correctly processes this event.

g) *II 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 BDS codes E,1 or E,2) as described in Annex 10, Volume III, Part II, Appendix 1 to Chapter 5. The GICB protocol would be used to extract this register.

TABLES FOR CHAPTER 3

Table 3-1. Typical over-all performance figures for primary and sliding window SSR systems

Parameter group	*Radar data quality characteristics*		*Typical performance figure*	*Remark(s)*
Target statistics	Target detection	PSR	85 – 90%	Absolute reference
	Probability (P_D)	SSR	90 – 95%	Absolute reference
	Combination probability	PSR/SSR	80 – 90%	Relative to SSR
	Code validation	Mode 3/A	85 – 95%	Absolute reference
	Probability	Mode C	83 – 92%	Absolute reference
	False code validation	Mode 3/A	0 – 1%	
	Probability	Mode C	0 – 1%	
	Number of false plots per scan	PSR	<20	Normal weather conditions
		SSR: –Reflections	1 – 3	
		– Split plots	0 – 1	
		– Others	0 – 1	
	Gap size between SSR plots	Mean value	1.5 – 2 plots	
		P(>2 gaps)	10 – 15%	
Systematic errors	Azimuth bias		0.1 – 0.15°	Mean value
	Range bias		50 – 100 m	Mean value
	Range error at maximum range		300 – 400 m	Maximum value
	Collimation error PSR/SSR		0.1 – 0.15°	Uncorrected
Time	Distribution plot processing time	Mean value	0.8 – 1 s	
		Maximum value	<2 s	
	Plot message transmission time (radar to display)	Maximum value	<0.25 s	One transit node considered
Accuracy/resolution	Azimuth error	PSR (s_Q)	0.15 – 0.2°	Standard deviation
		SSR (s_Q)	0.2 – 0.3°	Standard deviation
		P(DQ>1.5°)	0.1 – 0.3%	
	Range error	(s_R)	70 – 130 m	Standard deviation
	Resolution PSR	Distance	500 – 1 000 m	
		Azimuth	3.4 – 4.2° (Note 1)	
	Resolution SSR	Distance	750 – 6 740 m	
		Azimuth	3.6 – 7.5° (Note 1)	
	Radar site position error		100 – 200 m	Satellite reference

Note 1.— This figure strongly depends on the interrogation rate, antenna scan time and, for SSR, mode interlace.

Note 2.— The typical performance figures in this table are based on experience with different radars, different radar data processing and different evaluation tools. They are typical over-all performance figures as they cover unspecified target populations and conditions.

Note 3.— Refer to Chapter 5 for details about parameter characteristics.

Table 3-2. Typical over-all performance figures for monopulse SSR systems

Parameter group	*Radar data quality characteristics*		*Typical performance figure*	*Remark(s)*
Target statistics	Target detection probability (P_D)	SSR	>97%	Absolute reference
	Code validation	Mode 3/A	>98%	Absolute reference
	Probability	Mode C	>96%	Absolute reference
	False code validation	Mode 3/A	<0.1%	
	Probability	Mode C	<0.1%	
	False target report probability		<0.1%	
	Multiple target report probability	– Reflections	<0.2%	
		– Split plots	<0.1%	
		– Side lobes	<0.1%	
Systematic errors	Azimuth bias		<0.1°	Mean value
	Range bias		<50 m	Mean value
	Range error at maximum range		150 m	Maximum value
Accuracy/resolution	Azimuth error	(s_Q)	<0.08°	Standard deviation
	Range error	(s_R)	<70 m	Standard deviation
	Resolution SSR for P_D > 98%	Distance	$\geq$100 m	
		Azimuth	$\geq$1.5° (Note 1)	

Note 1.— This figure depends strongly on the interrogation rate, antenna scan time and mode interlace.

Note 2.— The typical performance figures in this table are based on experience with different radars, different radar data processing and different evaluation tools. They are typical over-all performance figures as they cover unspecified target populations and conditions.

Note 3.— Refer to Chapter 5 for details about parameter characteristics.

FIGURE FOR CHAPTER 3

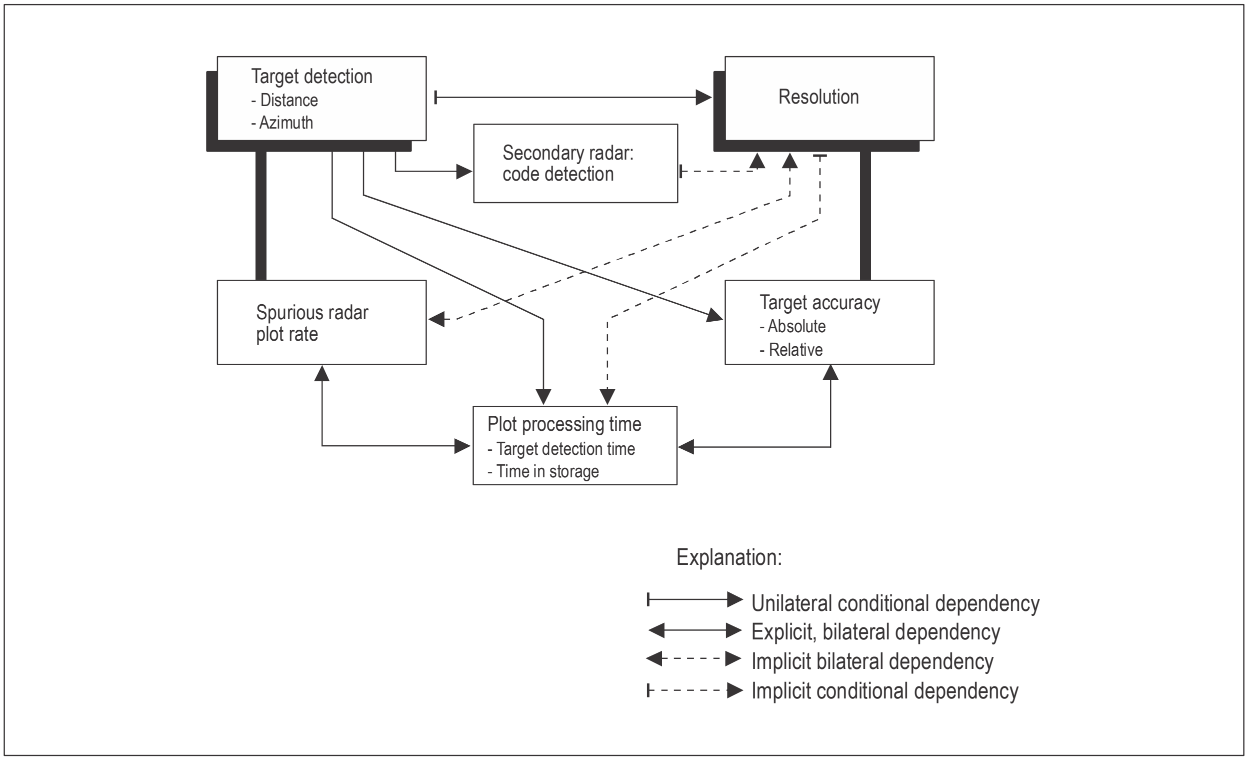

Figure 3-1. Interdependency of radar data quality characteristics

Chapter 4

TEST APPLICATION

4.1 GENERAL

4.1.1 The purpose of this chapter is to list, by means of cross-reference tables, all I/O interfaces defined in Chapter 2 and 4.4 below, the various parameters which can be tested, and the level at which the test shall be applied. In addition, the appropriate LCS is indicated during which the specific parameter should be checked. Finally, some remarks with respect to the method of testing the parameter are given.

4.1.2 Factory tests and part of the site acceptance tests are strongly dependent on the technique used by the different manufacturers. Therefore, no generally applicable test methods can be given; rather, the tests should be performed on the basis of manufacturer-provided information.

Note.— In addition to the manufacturer-related test procedures, flight checks should be performed as part of the site acceptance tests. The results of the evaluation of opportunity traffic and the special test flights may be taken into account for the provisional acceptance of the system.

4.1.3 As preparation for any radar evaluation, flight check, or operational usage, the actual performance of the equipment has to be assessed, i.e. the characteristic parameters have to be determined and documented.

4.2 DEFINITION OF RADAR PARAMETER CATEGORIES

Introduction

4.2.1 This section describes and defines the different categories for test levels (i.e. at which level an evaluation can be performed) and for LCSs (i.e. when can checks be performed).

4.2.2 While many of the parameters are of a low-level nature, it is essential to gain confidence that the various elements of the system under test are functioning correctly *before* evaluating the system as a whole.

Test levels

4.2.3 The parameters are categorized into so-called “test levels” as follows:

a) *system level*. Either a multi-radar system with tracking, such as the system illustrated in Figure 24, or a monoradar system, such as an approach radar or one of the radars in a multi-radar system, such as the system illustrated in Figure 2-3;

b) *sub-system level*. A part of a system which may be tested *in situ* involving the use of other parts of the system as test equipment. This implies that the parts of the system to be used as test equipment must be operating correctly; and

c) *unit level*. A part of a system which may be tested on a stand-alone or bench test basis.

Life cycle stages (LCSs)

4.2.4 The LCSs during which a test is performed are categorized into factory tests and on-site tests, as described in the following sections.

Factory tests

4.2.5 These may be of several types concerning individual units of a system, sub-system or occasionally a complete system. This document is not concerned with sub-unit tests, e.g. component testing, verification of amplifier performance, etc.

4.2.6 The tests specified may form part of a customer acceptance test for each piece of equipment or may be of the batch or type test variety. When and how often such tests are performed is dependent on the system requirements, and costs. For example, some manufacturers may not perform overload reaction tests as part of the acceptance of the radar system; as a result, the customer would have to be content with a set of bench test results.

Site tests (pre-operational)

4.2.7 These cover the installation and site acceptance phases of the system's life and any tests prior to the system becoming operational. Tests at this stage are divided into two areas:

a) *site commissioning*. This typically includes tests of units to verify results obtained in the factory, subsystem acceptance tests, technical acceptance of the system, and parameter optimization, e.g. antenna tilt, GTC, on system or sub-system level.

Note.— In principle, the site commissioning shall include the verification of the performance of the PSR system for all the environment conditions. Therefore the performance has to be checked under all seasonal conditions and, if applicable, also under anomalous propagation conditions. It is common practice of the radar manufacturer to initially tune the system to meet the contractual specifications which, in most cases, does not necessarily mean that the PSR/SSR system has been tuned for optimal performance.

b) *operational evaluation*. Should comprise system operational acceptance tests, e.g. on the basis of flight trials.

Site tests (operational)

4.2.8 Tests during the operational lifetime of a radar system comprise the following:

a) *BITE/RTQC.* On-line monitoring of various system parameters, and may include periodic checks of system performance while the system is operational using BITE, equipment/procedures for RTQC, or external test facilities;

b) *preventive maintenance.* Tests made during or after preventive maintenance activities and in accordance with manufacturer recommendations;

c) *corrective maintenance.* Tests made during or after corrective maintenance activities and in accordance with manufacturer recommendations;

d) *post modification.* Tests on a unit or sub-system following a modification which would affect the system's operational performance. Depending on the modification, part or all of the tests indicated above should be carried out before returning the system to operational service; and

e) *problem investigation.* Tests of system, sub-system or unit to investigate a particular problem, e.g. loss of coverage in a certain area or an increase in false plots.

Note.— The last two categories are not shown in the tables as they are applicable to all the parameters listed depending on the nature of the work being carried out. It is the responsibility of the system engineer to decide which parameters will require testing following either a modification or the investigation of a particular problem.

4.3 DEFINITION OF INPUT DATA

General

4.3.1 The performance of a radar system can be checked (evaluated) by means of the injection of data, either in analogue or digital form, at a number of levels within the system. This "input data" may be injected at any of the I/O interfaces shown in Figures 2-3 and 2-4 of Chapter 2.

4.3.2 The "input data" can be broken down into a number of different categories:

a) live opportunity traffic;

b) simulated flights;

c) special test flights (with or without onboard systems for precision position determination);

d) combinations of the three categories above; and

e) replay of recorded information from any of the above.

4.3.3 The input data can be entered at any of the levels of the radar system (radio frequency, video, plots, tracks, etc).

Opportunity traffic

4.3.4 This is a "live" data input which is obtained from the "real world" environment, i.e. from aircraft within the volumetric coverage of the system under test, be it radar sensor (PSR and/or SSR), or an RDPS, with one or several radar data inputs.

4.3.5 The opportunity traffic will therefore consist of the received RF replies from aircraft detected within the volumetric coverage of the system under test, "injected" at the antenna input(s) of the system interfaces PIO1 and SIO1.

4.3.6 The aircraft within the radar coverage may be considered as a statistical random selection of the total aircraft population. There will be a variety of reflecting surface areas for the primary radar and a variety of SSR transponders and aircraft SSR antenna radiation patterns. Opportunity traffic can give a large amount of data in a short time for assessing radar system performance. A sufficiently large sample of opportunity traffic will provide the data required to establish (i.e. measure) the system performance parameters. Opportunity traffic can provide the majority of the data needed for evaluation purposes.

Simulated traffic

4.3.7 Simulated traffic or simulated flights can be produced by analogue or digital methods in order to simulate an aircraft or a "population" of aircraft flying closely defined profiles. As this input is accurately known, the processed output of the system can be closely observed for determining system performance.

4.3.8 A precise control of the simulated traffic allows changes in operational parameters of the system under test to be checked for variation in system performance. In particular, a system may be optimized or investigated (particularly in the case of an operational anomaly) by the repeated use of the same simulated traffic population for a number of different system parameter settings or modifications.

4.3.9 Examples of the use of simulated traffic are:

a) the variation of target radial velocity in order to check "blind" and "dim" speeds of primary radar processing systems;

b) the variation of mode of flight to check the reaction of tracker systems;

c) the simulation of close approach situations (primary or secondary radar) in order to check the range and azimuth resolution of a radar system; and

d) the checking of the degarbling performance of SSR systems.

Special test flights (calibration aircraft)

4.3.10 These flights (also known as calibration flights) are made with a dedicated aircraft. The "calibration" aircraft performs an agreed flight profile or a number of flight profiles, in order to:

a) obtain the radar (PSR or SSR) performance characteristics in areas where few or no traffic at all occurs (low aircraft population), e.g. for resolution flights; and

b) investigate in detail areas of the radar coverage in which problems have been observed (lobing, loss of coverage, etc.). Typically, the calibration aircraft will carry additional electronic equipment for high accuracy navigational, positioning and recording purposes.

4.3.11 An aircraft used for PSR performance evaluation purposes will typically have a radar cross section (RCS) of a known value, preferably similar to that defined by the radar manufacturer for a given detection performance (e.g. RCS = 2 m^2 or 10 m^2) and which use has been agreed upon by the radar manufacturer.

4.3.12 In the case of an aircraft being used for SSR performance evaluation, it is essential that the aircraft carries a "calibrated" SSR transponder and antenna. The calibrated transponder must in all respects conform to SARPs in ICAO Annex 10, Volume IV. Checks should also be made of the transponder-antenna cable and the antenna itself. It is common practice, where transponder receiver sensitivity, power output levels, etc., are adjustable, to set these to the "worst case" values allowed within the tolerances of SARPs.

4.4 DEFINITION OF INPUT/OUTPUT (I/O) INTERFACES

General

4.4.1 The I/O interfaces are points in a radar system or RDPS where data flows should be easily accessed. The physical implementation of the interface depends on the system design and may require specific equipment. In this document, the input levels are defined at suitable interfaces, generally described as I/O interfaces. At these points data can be either injected (tests, simulations, etc.) or extracted (for recording or further data processing).

4.4.2 The data may be in the form of RF, video (analogue, quantized or digitized), plots or tracks. Figures 2-3 and 2-4 show functional block diagrams for:

a) a radar station including both primary, secondary and common elements; and

b) an ATCC.

An explanation of the functional block diagrams is given in Chapter 2.

Key to the I/O interfaces

4.4.3 Reference is made to Figures 2-3 and 2-4 where I/O interfaces are designated as follows:

PIO designates a primary input/output (I/O) interface
SIO designates a secondary input/output (I/O) interface
CIO designates a common input/output (I/O) interface
RIO designates an RDPS input/output (I/O) interface.

The functions of the I/O interfaces may be broken down as follows.

Primary radar I/O interfaces

4.4.4 The following is a list of the primary radar I/O interfaces:

a) *PIO1: Radiated RF input.* This is the radiated RF input to the PSR system and a test input will typically be from an active reflector (see 2.3.24). This is an input-only interface.

b) *PIO2: Primary radar RF input interface.* At this point, RF test signals can be injected into the input ports of the PSR receivers. This is also an input-only interface.

c) *PIO3: PSR video (analogue or digital) input/output interface.* This point represents the output of the PSR receivers where detected video can be output for recording purposes. Similarly, this point acts as an input interface for the injection of synthetic (simulated or recorded) video. According to PSR system philosophy, the video at this level may be in either analogue or digital form.

d) *PIO4: Primary radar processed video I/O interface.* This I/O interface represents the output of the PSR intermediate video processing of the primary radar system. The video at this point will have been subjected to processes such as MTI, MTD, constant false alarm rate (CFAR), LogFTC in order to obtain usable data (analogue or digital) for input to the primary plot extractor. At this point, data can be either injected (tests, simulations, etc.) or extracted (recordings, etc.).

e) *PIO5: Primary radar extractor video (plots) I/O interface.* This I/O interface represents the output of the primary plot extractor and the data is entirely in digitized form. As in the other cases, data can either be injected or extracted according to the task to be carried out.

f) *PIO6: Primary radar track/filtered plot I/O interface.* At this point, the extracted PSR plots have been subjected to a further rotation scan to scan processing in order to eliminate false plots, and possibly to form monoradar tracks. Reference is made to 2.3.12 with regard to the possibility of surveillance processing/tracking/plot filtering actions being carried out at other system levels. As in the other cases, data can either be injected or extracted at this point according to the task to be carried out.

g) *PIO7: Primary radar transmitter output.* This is an output-only interface.

h) *PIO8: Primary timing unit.* In most cases, this is an output-only interface.

Note.— In modern architecture systems several interfaces operate together, e.g. PIO5, PIO6, SIO5, SIO6 and CIO2, on a local area network (LAN).

Secondary radar I/O interfaces

4.4.5 The following is a list of secondary radar I/O interfaces:

a) *SIO1: Radiated RF input.* This is the radiated RF input to the SSR system and a test input will typically be from a remote field (or site) monitor. This is an input-only interface.

b) *SIO2: Secondary radar RF input interface*. At this point, RF test signals can be injected into the input ports of the SSR receivers. This is also an input-only interface.

c) *SIO3: SSR video (analogue or digital) I/O interface.* This point represents the output of the SSR receivers where detected video can be output for recording purposes. Similarly, the point acts as an input interface for the injection of synthetic (simulated or recorded) video.

According to SSR system philosophy, the video at this level may be in either analogue or digital form.

d) *SIO4: Secondary radar processed video I/O interface.* This I/O interface represents the output of the SSR intermediate video processing of the secondary radar system. At this level, the videos may have been subjected to such processes as:

1) RSLS processing;

2) OBA processing; and

3) video reconstitution.

The data at this point may be either in analogue or digital form and provides the necessary input to the secondary plot extractor. It should be noted, however, that in modern SSR equipment (particularly for monopulse SSR applications), the receiver, intermediate video processing and plot extractor may be one common unit, making it more difficult for accessing data (video/plots) at this level. At this point, data can be either injected (tests, simulations, etc.) or extracted (recordings, etc.).

e) *SIO5: Secondary radar extracted video (plots) I/O interface.* This I/O interface represents the output of the secondary plot extractor and the data is entirely in digitized form. As in the other cases, data can either be injected or extracted according to the task to be carried out.

f) *SIO6: Secondary radar surveillance processor plot/track I/O interface.* At this point, the extracted SSR plots have been subjected to further processing in order to eliminate false plots, and in some instances form monoradar tracks. Reference is made to 2.3.12 as regards surveillance processing actions being carried out at other system levels. As in the other cases, data can either be injected or extracted at this point according to the task to be carried out.

g) *SIO7: Secondary radar transmitter output.* This is an output-only interface.

h) *SIO8: Secondary timing unit.* In many cases, this unit may have an additional input for external (e.g. primary radar) synchronization.

Note.— In modern architecture systems several interfaces operate together, e.g. PIO5, PIO6, SIO5, SIO6 and CIO2, on LAN.

i) *SIO9: Mode S interrogation handler output interface.* At this point, pre-determined calculated Mode S interrogation segments are passed to the transmitter. This transmission time is controlled by the interrogation scheduler, and the data is deter-mined by the surveillance processor (and the data link I/O, if applicable).

Common radar I/O interfaces

4.4.6 The following is a list of common radar I/O interfaces:

a) *CIO1: Plot combiner I/O interface*. At this point, the extracted PSR and SSR (Mode 3/A or Mode S) data have been subjected to certain combination criteria and the output at CIO1 will consist of:

1) combined plots/tracks;

2) SSR-(Mode 3/A or Mode S) only plots/tracks; and

3) PSR-only plots/tracks.

In the case that the radar station is PSR- or SSR-(Mode 3/A or Mode S) only, no plot combiner will be required.

b) *CIO2: Combined surveillance processor I/O interface.* This is a special case of the PIO6 and SIO6 I/O interfaces and corresponds to a system where no separate PSR and/or SSR surveillance processing is carried out before plot combination.

As in the other cases, data can either be injected or extracted at this point according to the task to be carried out.

c) *CIO3: Modulated transmitter data.* This interface is suited for analogue data recording.

d) *CIO4: Output of transmission medium*. (Analogue base-band data before demodulation into digital data). At this point, however, the modulated data at the output from the link's receiver, containing possible errors due to additional noise from the transmission line and other distortions, can be analysed.

In some systems, demodulated digital information may be provided directly by a link provider. Error analysis can be applied at this point to determine the quality of the data transmission medium, pro-vided the appropriate error detection protocols are applied to the transmitted data.

ATCC radar interfaces

4.4.7 The following is a list of ATCC radar interfaces:

a) *RIO1: Input of transmission medium at ATCC.* This interface is generally identical to the output of the transmission medium (CIO4).

b) *RIO2: Output of data reception process.* See CIO2. At this interface the demodulated data from the radar sites are available.

c) *RIO3: RDPS output.* This interface is of special importance for the overall radar/RDPS performance evaluation.

4.5 TEST APPLICATION CROSS-REFERENCE TABLES

4.5.1 Tables 4-1 to 4-20* contain a series of cross-reference tables listing, for all input/output interfaces de-scribed in Chapter 2 and 4.4 above, the appropriate tests to be carried out and the corresponding LCS applicable.

4.5.2 Details of radar parameter test methods are given in Chapter 5.

4.5.3 Where applicable, remarks indicate the use of special test equipment. Examples of tools typically used within various administrations for radar evaluations and current development work are described in Appendix B.

* All tables are located at the end of this chapter.

TABLES FOR CHAPTER 4

Table 4-1. Input/output (I/O) interface: PIO1 — Antenna input, PIO2 — Receiver input

Input/ output reference	*Test level*	*Parameters to be tested or measured*	*Test to be carried out*	*Life cycle stage*							*Remarks*
				Factory		*Pre-operational*		*Operational*			
				Type test	*Acceptance test*	*Site commissioning*	*Operational evaluation*	*BITE RTQC*	*Preventive maintenance*	*Corrective maintenance*	
PIO1	System	Geographic alignment	Alignment of PSR with runways and reference points			X	X	X	X	X	Especially important for approach radars, e.g. sun run.
PIO2	Sub-system	Antenna performance	Polar diagrams — vertical — horizontal Gain Azimuth squint and skew	 X X X X	 X X	 X X					 Special test equipment. Evaluation at test range. Special test equipment. Special test equipment.
	Unit	Losses	Waveguide and rotating joint losses			X				X	

Table 4-2. Input/output (I/O) interface: PIO3 — Receiver outputs

Input/ output reference	*Test level*	*Parameters to be tested or measured*	*Test to be carried out*	*Life cycle stage*							*Remarks*
				Factory		*Pre-operational*		*Operational*			
				Type test	*Acceptance test*	*Site commissioning*	*Operational evaluation*	*BITE RTQC*	*Preventive maintenance*	*Corrective maintenance*	
PIO3	Sub-system	Clutter level	Test set or BITE		X	X	X	X			Video simulator.
		False alarm rate	Test set or BITE			X	X	X	X		
		System noise figure				X		X		X	
	Unit	Minimum detectable signal (MDS)	Test set or BITE		X	X		X		X	BITE checks in new equipment.
		Bandwidth		X	X						
		Noise figure		X	X	X				X	No BITE at unit level.
		I and Q phase linearity of A/D converters			X	X		X		X	
		Gain time control (GTC)				X					Optimization during site commissioning.
		Time side lobes (capture effect)	Calibration A/C or plot simulator		X	X				X	Pulse compression radars only.
		Range/azimuth gateing of system parameters				X					Confirm settings in operational evaluation.

Table 4-3. Input/output (I/O) interface: PIO4 — Intermediate video processor

Input/ output reference	*Test level*	*Parameters to be tested or measured*	*Test to be carried out*	*Life cycle stage*							*Remarks*
				Factory		*Pre-operational*		*Operational*			
				Type test	*Acceptance test*	*Site commissioning*	*Operational evaluation*	*BITE RTQC*	*Preventive maintenance*	*Corrective maintenance*	
PIO4	Sub-system	Filter response	MTI response with stagger on and off	X							With various clutter types.
			CFAR response			X					Short and longtime constant filters.
			Improvement factor	X							
			Zero velocity filter operation	X							
	Sub-system	Resolution	Range and azimuth resolution	X							Special test equipment required.

Table 4-4. Input/output (I/O) interface: PIO5 — Primary plot extractor output

Input/ output reference	*Test level*	*Parameters to be tested or measured*	*Test to be carried out*	*Life cycle stage*							*Remarks*
				Factory		*Pre-operational*		*Operational*			
				Type test	*Acceptance test*	*Site commissioning*	*Operational evaluation*	*BITE RTQC*	*Preventive maintenance*	*Corrective maintenance*	
PIO5	System	Detection	Plot detection (coverage)			X	X				
		False targets	Number of false plots per scan			X	X	X	X	X	May use RTQC.
		Alignment PSR/SSR	Align PSR with SSR in range and azimuth			X	X				Only for combined PSR/SSR radars.
	Sub-system	Correlation, interpolation				X					
		Extraction criteria	Leading-trailing edge performance			X					Dependent on techniques and technology.
		Accuracy	Range and azimuth accuracy			X	X	X			RTQC test may be made if active reflector available.
		Resolution	Range and azimuth plot resolution		X	X		X			May require simulated data for testing.
		Plot load			X	X		X			May require simulated data for commissioning.

Table 4-5. Input/output (I/O) interface: PIO6 — Plot filter (primary radar extraction)

Input/ output reference	*Test level*	*Parameters to be tested or measured*	*Test to be carried out*	*Life cycle stage*							*Remarks*
				Factory		*Pre-operational*		*Operational*			
				Type test	*Acceptance test*	*Site commissioning*	*Operational evaluation*	*BITE RTQC*	*Preventive maintenance*	*Corrective maintenance*	
PIO6	System	Coverage	Vertical and horizontal range limits			X	X		X	X	
		Detection, false targets, accuracy, plot resolution				X	X	X	X	X	Tests made at this level for PSRonly systems.
	System and/or sub-system	Filter functions	Correct functioning of all filter parameters	X	X	X					May require plot simulator for certain tests.
		Loss factor		X	X	X					Check for no degradation of data quality.

Table 4-6. Input/output (I/O) interface: PIO7 — Primary transmitter output

Input/ output reference	*Test level*	*Parameters to be tested or measured*	*Test to be carried out*	*Life cycle stage*							*Remarks*
				Factory		*Pre-operational*		*Operational*			
				Type test	*Acceptance test*	*Site commissioning*	*Operational evaluation*	*BITE RTQC*	*Preventive maintenance*	*Corrective maintenance*	
PIO7	Sub-system	Output power	Mean/peak power		X	X		X	X	X	
		Output pulse characteristics	Pulse width		X	X		X	X	X	
			Pulse spacing		X	X		X	X	X	
			Pulse stability		X	X		X	X	X	
		Spectrum analysis	Bandwidth		X	X					–3 dB plus other levels as per specification.
			Side-lobe levels		X	X					
			Harmonic levels		X	X				X	

Table 4-7. Input/output (I/O) interface: PIO8 — Primary timing unit

Input/ output reference	*Test level*	*Parameters to be tested or measured*	*Test to be carried out*	*Life cycle stage*							*Remarks*
				Factory		*Pre-operational*		*Operational*			
				Type test	*Acceptance test*	*Site commissioning*	*Operational evaluation*	*BITE RTQC*	*Preventive maintenance*	*Corrective maintenance*	
PIO8	Sub-system	Pulse timing	Range clock		X	X		X	X	X	These tests may be made using BITE for most equipment.
			Range sync (zero range)		X	X		X	X	X	
			PRF sync		X	X		X	X	X	Including staggering.

Table 4-8. Input/output (I/O) interface: SIO1 — Antenna input, SIO2 — Receiver input

Input/ output reference	*Test level*	*Parameters to be tested or measured*	*Test to be carried out*	*Life cycle stage*							*Remarks*
				Factory		*Pre-operational*		*Operational*			
				Type test	*Acceptance test*	*Site commissioning*	*Operational evaluation*	*BITE RTQC*	*Preventive maintenance*	*Corrective maintenance*	
SIO1	System	Geographic alignment	1. Active reflector 2. BITE tests also possible via 1 above or by injection at antenna level			X	X	X	X	X	RTQC tests.
SIO2	Sub-system	Antenna performance	Polar diagrams — vertical — horizontal Gain Azimuth squint and skew	 X X X X	 X X	 X X					If no integrated system, special test equipment. Evaluation at test range. Special test equipment. Special test equipment.
	Unit	Losses	Cable losses			X				X	Between antenna and transmitter/receiver.

Table 4-9. Input/output (I/O) interface: SIO3 — Receiver outputs

Input/ output reference	*Test level*	*Parameters to be tested or measured*	*Test to be carried out*	*Life cycle stage*							*Remarks*
				Factory		*Pre-operational*		*Operational*			
				Type test	*Acceptance test*	*Site commissioning*	*Operational evaluation*	*BITE RTQC*	*Preventive maintenance*	*Corrective maintenance*	
SIO3	Sub-system	False alarm rate	Test set or BITE	X	X	X	X	X			
		Fruit rate	Test set or BITE		X	X					
		Off-boresight angle	Test set or BITE		X	X				X	Monopulse systems only.
	Unit	Minimum detectable signal (MDS)	Test set or BITE		X	X		X		X	BITE checks in new equipment.
		Bandwidth		X	X						
		Noise figure		X	X	X				X	No BITE at unit level.
		Gain time control (GTC)	Test set or BITE			X			X		Optimization during site commissioning. If checked by BITE, preventive maintenance checks are not required.

Table 4-10. Input/output (I/O) interface: SIO4 — Intermediate video processor

Input/ output reference	*Test level*	*Parameters to be tested or measured*	*Test to be carried out*	*Life cycle stage*							*Remarks*
				Factory		*Pre-operational*		*Operational*			
				Type test	*Acceptance test*	*Site commissioning*	*Operational evaluation*	*BITE RTQC*	*Preventive maintenance*	*Corrective maintenance*	
SIO4	Sub-system	Resolution	Range and azimuth resolution	X							Special test equipment required.
	Unit	Range/Azimuth dependent thresholds				X			X		Optimization during site commissioning. If checked by BITE, preventive maintenance checks are not required.

Table 4-11. Input/output (I/O) interface: SIO5 — Secondary plot extractor output

Input/ output reference	*Test level*	*Parameters to be tested or measured*	*Test to be carried out*	*Life cycle stage*							*Remarks*
				Factory		*Pre-operational*		*Operational*			
				Type test	*Acceptance test*	*Site commissioning*	*Operational evaluation*	*BITE RTQC*	*Preventive maintenance*	*Corrective maintenance*	
SIO5	System	Detection	Plot and code detection			X	X				
		False target rate	Number of false plots per scan			X	X	X	X	X	May use BITE or RTQC.
		Alignment PSR/SSR	Align PSR with SSR in range and azimuth			X	X			X	Only for combined PSR/SSR radars.
	Sub-system	Correlation, interpolation				X					
		Extraction criteria	Leading-trailing edge performance			X					Dependent on techniques and technology.
		Accuracy	Range and azimuth accuracy			X	X	X			RTQC test may be made if active reflector available.
		Resolution	Range and azimuth plot resolution		X	X		X			May require simulated data for testing.
		Plot load			X	X		X			May require simulated data for commissioning.

Table 4-12. Input/output (I/O) interface: SIO6 — Plot filter (secondary radar extraction)

Input/ output reference	*Test level*	*Parameters to be tested or measured*	*Test to be carried out*	*Life cycle stage*							*Remarks*
				Factory		*Pre-operational*		*Operational*			
				Type test	*Acceptance test*	*Site commissioning*	*Operational evaluation*	*BITE RTQC*	*Preventive maintenance*	*Corrective maintenance*	
SIO6	System	Coverage	Vertical and horizontal range limits			X	X		X	X	
		Detection, false targets, accuracy, plot resolution				X	X	X	X	X	
	System and/or sub-system	Filter functions	Correct functioning of all filter parameters	X	X	X					May require plot simulator for certain tests.
		Loss factor		X	X	X					Check for no degradation of data quality.

Table 4-13. Input/output (I/O) interface: SIO7 — SSR transmitter output

Input/ output reference	*Test level*	*Parameters to be tested or measured*	*Test to be carried out*	*Life cycle stage*							*Remarks*
				Factory		*Pre-operational*		*Operational*			
				Type test	*Acceptance test*	*Site commissioning*	*Operational evaluation*	*BITE RTQC*	*Preventive maintenance*	*Corrective maintenance*	
SIO7	Sub-system	Output power	Mean/peak power		X	X		X	X	X	
		Pulse timing and pulse characteristics	Pulse width		X	X		X	X	X	
			Pulse spacing		X	X		X	X	X	
			Pulse stability		X	X		X	X	X	

Table 4-14. Input/output (I/O) interface: SIO8 — SSR timing unit

Input/ output reference	*Test level*	*Parameters to be tested or measured*	*Test to be carried out*	*Life cycle stage*							*Remarks*
				Factory		*Pre-operational*		*Operational*			
				Type test	*Acceptance test*	*Site commissioning*	*Operational evaluation*	*BITE RTQC*	*Preventive maintenance*	*Corrective maintenance*	
SIO8	Sub-system	Pulse timing	Range clock		X	X		X	X	X	These tests may be made using BITE for most equipment.
			Range sync (zero range)		X	X		X	X	X	
			PRF sync		X	X		X	X	X	Including staggering.

Table 4-15. Input/output (I/O) interface: SIO9 — Mode S interrogation instructions

				Life cycle stage							
				Factory		*Pre-operational*		*Operational*			
Input/ output reference	*Test level*	*Parameters to be tested or measured*	*Tests to be carried out*	*Type test*	*Acceptance test*	*Site commissioning*	*Operational evaluation*	*BITE RTQC*	*Preventive maintenance*	*Corrective maintenance*	*Remarks*
SIO9	Sub-system	Predicted range window	Plot detection		X						Re-interrogation rate may increase if poor predictions.
		Predicted azimuth window	Plot detection		X						Re-interrogation rate may increase if poor predictions.
		Interrogation substitution	Over interrogation		X		X				Efficiency improved if transactions combined.
		Transaction priority	Priority preser-vation		X						Delivered from highest priority queue first.
		Lockout	Acquisition delay		X		X				Requires correlation with all-call reply reports.

Table 4-16. Input/output (I/O) interface: CIO1 — Plot combiner (PSR/SSR (Mode A/C or Mode S) systems)

Input/ output reference	*Test level*	*Parameters to be tested or measured*	*Test to be carried out*	*Life cycle stage*							*Remarks*
				Factory		*Pre-operational*		*Operational*			
				Type test	*Acceptance test*	*Site commissioning*	*Operational evaluation*	*BITE RTQC*	*Preventive maintenance*	*Corrective maintenance*	
CIO1	System	Data transmission inventory	Plot counts of combined, primary, and SSR plots			X	X	X		X	Suitable recording point for evaluation purposes.
		Plot detection: – Combined plots – PSR plots – SSR plots				X	X	X			RTQC.
		False target rate				X	X	X			RTQC.
		Combination rate	Ratio of SSR-only plots to combined PSR-SSR plots			X	X	X		X	
		Accuracy of combined plots	Check of SSR/CMB weighting function			X	X	X			Site monitor used as reference in systems with SSR.
		Processing delay time		X	X	X	X	X			RTQC — test of time in storage. Type tests use simulated data.
		Overload reaction		X		X					
		Plot load		X		X		X			
		Alignment PSR/SSR				X	X	X		X	Field monitor, BITE/RTQC.

Table 4-17. Input/output (I/O) interface: CIO2 — Plot filter output (after plot combiner)

Input/ output reference	*Test level*	*Parameters to be tested or measured*	*Test to be carried out*	*Life cycle stage*							*Remarks*
				Factory		*Pre-operational*		*Operational*			
				Type test	*Acceptance test*	*Site commissioning*	*Operational evaluation*	*BITE RTQC*	*Preventive maintenance*	*Corrective maintenance*	
CIO2	System	Coverage	Vertical and horizontal range limits			X	X		X	X	Plot filter and combiner tests may be inseparable due to common unit in some systems.
		Detection, false targets, accuracy, plot resolution				X	X	X	X	X	Tests made at this level for PSR-only systems.
		Data transmission inventory	Message count of output to transmission system			X	X				Suitable recording point for evaluation purposes.
	System and/or sub-system	Filter functions	Correct functioning of all filter parameters	X	X	X					May require plot simulator for certain tests.
		Loss factor		X	X	X					Check for no degradation of data quality.

Table 4-18. Input/output (I/O) interface: CIO3 — Modulated transmitter data

Input/ output reference	*Test level*	*Parameters to be tested or measured*	*Test to be carried out*	*Life cycle stage*							*Remarks*
				Factory		*Pre-operational*		*Operational*			
				Type test	*Acceptance test*	*Site commissioning*	*Operational evaluation*	*BITE RTQC*	*Preventive maintenance*	*Corrective maintenance*	
CIO3	System	Data transmission inventory	Data loss or corruption			X		X		X	Similar to CIO2 and CIO4. Suitable injection point for evaluation of RDPS.
			Plot time sequence	X		X					Test to ensure no messages are lost nor out of sequence under normal conditions.
		Overload reaction	Modem data rejection and data rate control	X							
		Line failure recovery	Recovery time and reaction to line break	X					X		

Table 4-19. Input/output (I/O) interface: CIO4 — Output of transmission medium (input to ATCC)

Input/ output reference	*Test level*	*Parameters to be tested or measured*	*Test to be carried out*	*Life cycle stage*							*Remarks*
				Factory		*Pre-operational*		*Operational*			
				Type test	*Acceptance test*	*Site commissioning*	*Operational evaluation*	*BITE RTQC*	*Preventive maintenance*	*Corrective maintenance*	
CIO4 = RIO1	System	Data transmission inventory	Data loss or corruption			X		X	X	X	Similar to CIO2. Suitable injection point for evaluation of RDPS.
	Unit	Data transmission line performance	Frequency or phase and amplitude response/delay			X		X		X	Line test set required.
			Demultiplexer operation; separation of messages			X		X		X	RMCS messages can be sent by separate lines.
		Modem (or equivalent transmission device)	Correct performance			X		X	X	X	Internal BITE of modem shall give continuous selfcheck.

Table 4-20. Input/output (I/O) interface: RIO3 — RDPS output

Input/ output reference	*Test level*	*Parameters to be tested or measured*	*Test to be carried out*	*Life cycle stage*							*Remarks*
				Factory		*Pre-operational*		*Operational*			
				Type test	*Acceptance test*	*Site commissioning*	*Operational evaluation*	*BITE RTQC*	*Preventive maintenance*	*Corrective maintenance*	
RIO3	System	Inventory	Track message counts		X	X	X	X	X	X	Time sequence processing, time delay.
		Track reliability	Initialization, termination, continuity, stability		X	X	X			X	
		Residual random errors	Track accuracy with position, X/Y			X	X		X		Residual random errors.
		Time in storage	System delay		X	X	X	X		X	RTQC.

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Chapter 5

DETAILED RADAR TEST METHODS

5.1 GENERAL

5.1.1 The following information provides a detailed description of each parameter referenced in Chapter 4 and information about pre-requirements, methods, procedures, etc., recommended to be applied.

Documentation

5.1.2 The scope of radar performance measurements is to document the radar and radar system performance. The radar performance document must be complete, and all measurements, recordings and presentation of results are to be time stamped. Actions based on the evaluation and interpretation of results must be logged together with the necessary re-evaluations.

References

5.1.3 Several of the described test methods need accurate references and/or plot classification (“chaining”) procedures which in many cases might not be available. An “ideal” multi-radar-based chaining and trajectory reconstitution method is useless for the cases of monoradar coverage, pre-operational site commissioning, etc.

5.1.4 Therefore alternative and simpler methods are described for the above-mentioned cases which might need higher evaluation effort.

Standards

5.1.5 Standard equipment is to be used wherever possible. When checking SSR systems, calibrated transponders must be used. Special emphasis must be placed on measurements of power level, receiver sensitivity, pulse spacing, pulse width, and SLS function. It is recommended that coverage checks be performed with transponders having minimum permissible level of performance with respect to output power and receiver sensitivity.

5.2 HOW TO USE THIS CHAPTER

Categories of parameters

5.2.1 The following description of testing the individual parameters has been broken down into two categories:

a) general performance parameters, which are basic and fundamental but are typically dependent on more than one technical parameter, yet these performance parameters are strongly related to the operational use of radar systems. One typical example is the detection probability; and

b) detailed technical performance parameters, which are assessed primarily during commissioning, and for which the procedures, pre-requirements, methods, intervals, etc., can be expected to be specified in the manufacturer's documents. Within the framework of this document, only limited information is therefore given for this type of parameter.

Two charts showing the parameters listed in Chapter 4 and their allocation to these categories are given in Tables 5-1 and 5-2*.

Test description for each parameter

5.2.2 Within these two categories, descriptions of relevant radar system parameters together with further information concerning the test environment are given. In each category, the information given is in alphabetical order and basically organized as follows:

a) *description*, i.e. what does the parameter tell us about the system performance, units of measurement if applicable;

b) *pre-requirements*, i.e. any requirements which must be fulfilled before the parameter may be tested or evaluated;

c) *test points*, i.e. a cross-reference to the data I/O points given in the parameter tables of Chapter 4;

d) *test methods*, i.e. a description of the test procedures required to measure the parameter at the respective test points, including:

   1) data collection techniques;

   2) observations to make during data collection;

   3) data analysis techniques and procedures to follow for analysing the data; and

   4) definition of any specific terms used in the analysis.

e) *presentation of results*, i.e. description of any special methods of presentation which may be employed; and

f) *evaluation of results*, i.e. description of any special techniques for the evaluation and interpretation of results which may be required.

5.3 TESTING OF GENERAL PERFORMANCE PARAMETERS

5.3.1 General performance parameters discussed below are basic and fundamental but they are typically dependent on more than one technical parameter, yet these performance parameters are strongly related to the operational use of radar systems.

Accuracy

Description

5.3.2 The position accuracy is the accuracy with which the radar system provides the true position of the aircraft at a given time, and is expressed in terms of maximum acceptable positional errors, which are categorized as systematic errors, residual random errors and jumps.

5.3.3 Height accuracy performance is provided with the Mode C code detection analysis. The reliable method of measuring these errors to use the true position of the aircraft as a reference, against which the target report positions are compared. The traditional method of obtaining the reference position is to use a laboratory aircraft equipped with very sophisticated position finding instruments. The high costs and poor time resolution of the recorded position data make such flights prohibitive for radar evaluation accuracy performance assessment. For the purposes of radar evaluation, it is more feasible to use trajectory reconstruction.

5.3.4 Such sophisticated trajectory reconstitution based on multi-radar sources allows the radar systematic errors to be estimated and the aircraft reference trajectory to be reconstructed a posteriori from the recorded radar target data. The accuracy analyses would be divided into the following stages:

a) estimation of the systematic errors (also known as correlated or bias errors) for each radar in time stamping error, range bias, slant range gain, azimuth bias and *site position*. Using this method these errors can only be estimated in a multi-radar environment and must be taken into account before the individual radar accuracies can be estimated. In an optimized system, the systematic error should be approximately half the residual error standard deviation values for a modern approach radar;

b) reconstruction of the true aircraft trajectory from the recorded radar target data using curve fitting techniques;

c) analysis of the residual errors in position, range and azimuth for each category of plot data after correction of systematic errors. The errors are expressed in terms of the slant range standard deviation and azimuth error standard deviation; and

d) jump analysis. Jumps are target reports with positional errors larger than 1° in azimuth or 700 metres in slant range. The errors are expressed as the over-all rate of jumps determined as the ratio of the number of jumps in relation to the number of detected target reports.

Pre-requirements

5.3.5 Stable operating state of the system. Also refer to the sections on systematic errors and residual errors.

Test points

5.3.6 The following table lists the relevant test points.

Test point	*Test level*	*Life cycle stage*
CIO2, RIO2, RIO3	System	Preoperational: site commissioning Operational: RTQC, preventive and corrective maintenance

Test methods

5.3.7 Refer to sections on systematic errors and residual errors for detailed explanation. Figure 5-1* indicates the general event flow for accuracy analysis using a computer-based evaluation tool.

Alignment PSR-SSR

Description

5.3.8 Radar systems with collocated PSR and SSR systems normally provide combined target reports. It is essential for the SSR and PSR elements in the system to be aligned otherwise combination would not be possible. The collocated system may be on- or off-mounted. The alignment parameter is a measure of how accurately the constituent SSR and PSR parts of a combined plot are aligned in range and azimuth.

5.3.9 Depending on the system, either the PSR or SSR plot position may be chosen as the reference. An approach radar with SSR must use the primary radar as reference. An en-route system would normally use the SSR as a reference.

Pre-requirements

5.3.10 Stable operating state of both PSR and SSR systems. Optical and electrical alignment of the PSR and SSR antenna(s) to true North have been satisfactorily completed.

Test points

5.3.11 The following table lists the relevant test points.

Test point	*Test level*	*Life cycle stage*
PIO5, SIO5	System	Preoperational: site commissioning
CIO2	System	Operational: RTQC
	Subsystem	Preoperational: site commissioning
		Operational: RTQC

Note.— Tests at points PIO5 and SIO5 are intended for radars with operational analogue display systems.

Test methods

Test equipment

5.3.12 Computer-based plot analysis system, operated on the basis of opportunity traffic or (for an assessment in a limited area of coverage only) site monitors. The latter have to consist of a combination of PSR reflector and SSR test transponder. In addition, RTQC testing may be possible through BITE, or if plot messages contain suitable alignment quality values.

Test procedures

5.3.13 For successful measurement of this parameter, a sufficiently large data sample must be collected which has an even as possible distribution of data over the coverage volume of the system under test. Consequently, the recommended data source is opportunity traffic.

* All figures are located at the end of this chapter.

5.3.14 *Alignment reference.* It is recommended to choose as a reference whichever system the user has confidence in (PSR/SSR) being correctly geographically aligned. By default, the SSR position will be chosen as the reference since this is the system most likely to have been aligned to a test transponder (or parrot).

5.3.15 *Procedure.* The exact procedure depends on the system architecture and the system life cycle as to which I/O points the measurement can be made. The following methods are suggested:

a) it is recommended that the system allow the output of the separate plot extractors and the output of the plot combination process to be recorded simultaneously. Record and chain the data and analyse using a multi-radar alignment tool to generate the position reference and compare the PSR to the SSR alignment for those trajectories which have a reference position; and

b) during system commissioning or when the system is out of service, the plot combination process must be disabled. Visual inspection of the radar monitor screen may reveal any large alignment errors. In addition, it is recommended to make a data collection, to chain the data and to analyse as in a) above.

Presentation of results

5.3.16 Figure 5-2 is an example of the presentation of a result from an alignment evaluation. Displayed is the distribution of the differences in PSR position with respect to SSR position.

Evaluation of results

5.3.17 The mean alignment error must be less than or equal to one ACP in azimuth and one range increment. If this is not the case, the system must be re-aligned. After this re-alignment the measurement must be repeated. If the variance of the distributions of either the range and/or the azimuth is greater than ±3° in azimuth or 230 m (0.125 NM) in range, then it is recommended to check the PSR/SSR combination criteria.

Combination rate

Description

5.3.18 The majority of radar systems with collocated PSR and SSR systems normally provide combined plot or track outputs. The combination rate is expressed as the following ratio for targets within the common maximum range for the PSR and SSR systems:

$$\text{combination rate} = \frac{\text{total number of combined targets}}{\text{total number of combined + SSR targets}}$$

The combination rate will be more accurate if steps are taken to ensure that false targets (SSR only or combined) are not included in the calculation. This can be accomplished by applying a chaining function.

5.3.19 The expression may be used to indicate the relative coverage and detection between the PSR and SSR concerned.

5.3.20 The calculation is based on the principle that all aircraft targets within the shared coverage volume and within the common maximum ranges of a collocated PSR/SSR system will be detected as a combined target. Therefore the calculation is only valid if all aircraft are equipped with SSR transponders and it may not be valid for aircraft populations which include military aircraft or for coverage which includes VFR airspace, etc.

Pre-requirements

5.3.21 Stable operating state of both PSR and SSR systems. Geographical alignment of the system has been successfully completed.

Test points

5.3.22 The following table lists the relevant test points.

Test point	*Test level*	*Life cycle stage*
CIO1	System	Pre-operational: site commissioning, operational evaluation Operational: RTQC, corrective maintenance

Test methods

5.3.23 A sufficiently large data sample of opportunity traffic has to be recorded for some hours to provide as even a distribution of target data as possible. The data used for the calculation must be within the common range of both primary and SSR elements. A computer programme classifies the plots in combined targets and SSR-only targets and calculates the combination rate. It is recommended that graphical visualization tools are used to display the target data in polar and vertical display formats which will allow any deterioration of the combination rate to be seen.

5.3.24 Areas where insufficient data are available for a reliable statistical measurement should be marked. To distinguish between non false SSR targets and those SSR targets which were a result of a loss of primary detection, it is recommended that the combination ratio be calculated using chained data.

Presentation of results

5.3.25 It is very useful to produce combination rate diagrams for different geographic sectors and flight levels. Figure 5-3 is an example of the presentation of a result from combination rate analysis. Shown is the combination rate in the vertical plane.

Evaluation of results

5.3.26 The over-all combination rate must be better than 95 per cent.

5.3.27 Inspection of graphical diagrams will identify any areas of poor overlapping coverage between the PSR and SSR systems. When the combination rate results do not cover the whole volume of expected common coverage then the reasons for the missing detection must be analysed (see probability of detection).

5.3.28 If the combination rate is low only for certain elevation angles or certain flight levels, then the tilt of the PSR and SSR antennas must be checked, otherwise the detection might be degraded also by a wrong STC/GTC setting.

Coverage

Description

5.3.29 The coverage of a radar system is a three-dimensional volume of airspace within which the system satisfies the detection performance, accuracy and resolution specifications. The coverage may be expressed in terms of range, azimuth and altitude, flight level or screening angle with respect to the radar site. It may also be expressed in any other convenient coordinates such as Cartesian coordinates or air route structure.

5.3.30 It is important to understand that the term coverage does not only concern the detection capabilities of the radar. It also embraces all the performance parameters. Even if it is found that the radar has perfect detection in a certain area, the accuracy of the displayed data may be so degraded that the system cannot be relied on. A number of supplementary evaluation terms are introduced for the purpose of the analyses which are used to allow the measurements to be made in a controlled manner as follows:

a) required coverage;

b) actual coverage;

c) measured coverage;

d) coverage measurement volume; and

e) fringe envelope.

Required coverage. The required coverage is the reference volume of airspace within which the radar is required to meet the specified performance. The required coverage is normally derived from specified operational requirements and theoretical coverage volume.

Actual coverage. The volume of airspace within which the system can achieve the defined probabilities of detection and accuracy. The actual coverage may be better or worse than the required or expected coverage and would normally be contained within the established fringe envelope. The actual coverage is determined by making a series of performance measurements which yield the measured coverage and must be at least as good as the required coverage if the system is to be operationally acceptable. The actual coverage should normally not be greater than the established fringe envelope.

Measured coverage. The measured coverage is the volume of airspace within which the radar was able to meet the specified detection and accuracy requirements during a particular measurement campaign or evaluation of a radar data sample. The measured coverage is assessed within a defined coverage measurement volume (CMV). It should be the aim of the radar evaluation to make a sufficiently thorough study so that the measured coverage for a particular CMV is given a high confidence factor and is said to be a good estimate of the actual coverage.

Coverage measurement volume (CMV). The CMV is defined as the three-dimensional volume of airspace within which various performance parameters will be measured for a particular measurement campaign.

5.3.31 The CMV is used in the radar evaluation to allow the user more flexibility to control the geographical extent of the data to be used for the performance analyses as a function of the evaluation requirements. For example, if it is required to determine the actual coverage, this may be achieved by defining the CMV to be equal to the fringe envelope.

5.3.32 Use of a CMV can be defined and may be stored so that it can be re-used on successive occasions. By such, the actual coverage may be determined empirically over a period of time as can the comparison of the measured coverage between different data samples.

5.3.33 The boundaries of the CMV for any one evaluation are dependent on what has to be measured. Normally the CMV will be set to include the required coverage volume or volumes for the evaluation and determined empirically from the fringe envelope.

5.3.34 If the purpose is to measure the over-all probability of detection inside a well-defined (theoretical) coverage volume, the CMV must at least include the required coverage volume. If a thorough analysis of the actual coverage is desired, this implies that the CMV should be defined to include the system processing limits so that with each set of measured coverage results, a reliable estimate of the actual coverage may be gained.

5.3.35 Alternatively, it is expected that a CMV may be defined to cover a particular portion of airspace, e.g. a TMA, or may be derived from a combination of the following:

a) manufacturers' glossy brochure coverage (do not consider any STC/GTC influence);

b) theoretical coverage model;

c) line-of-sight coverage predictions;

d) operational requirements; and

e) contractual constraints.

5.3.36 In the absence of a required coverage volume or a defined fringe envelope, the default CMV for a radar would be 0 to maximum processing range, 0 to 360° azimuth and FL 12 to FL 500. This would be used as a starting point for an unknown system.

5.3.37 In the case of measurement in a multi-radar environment, the CMV may be defined either by a separate CMV for each of the available radars or by a polygon in X-Y system co-ordinates and minimum and maximum flight levels. Use of such an X-Y cell system would normally yield results which were X-Y based and not range-azimuth based.

Coordinate systems used for radar analysis

5.3.38 Once the CMV is defined it can be subdivided in an appropriate number of 3D cells. The cell boundaries may be adjusted by the user. Four grid-types are envisaged:

a) range-azimuth-flight level grid (monoradar analysis only);

b) range-azimuth-elevation grid (monoradar analysis only);

c) X-Y-flight level grid with the possibility to define non-equidistant cell boundaries in all dimensions; and

d) so-called prismatic volumes or irregular polygons covering particular parts of airspace, e.g. a set of air routes.

5.3.39 A special "layer" in range-azimuth will be required for objects with no altitude information (PSR-only flights, aircraft not reporting Mode C information, etc.). In an evaluation system these would normally be assigned a default flight level. This special layer is intended to trap such events and not allow them to influence the results for flights with Mode C information present.

5.3.40 *Fringe envelope.* The fringe envelope of a radar system is the detection performance limits in a vertical plane passing from the radar sensor, within which the system may detect targets. The parameters which describe the fringe envelope of the radar are as follows:

a) minimum and maximum detection range;

b) antenna cone of silence and horizon angles, throughout 360° of azimuth;

c) antenna vertical lobing patterns; and

d) location of the radar and surrounding topography.

5.3.41 *Theoretical coverage model.* This is the theoretical visibility limit of the radar defined in terms of:

a) maximum range;

b) screening angle (constant or as a function of azimuth);

c) cone of silence; and

d) maximum flight level.

Note.— More details could be added by using minimum flight level as a function of range and azimuth instead of screening angles.

Pre-requirements

5.3.42 None.

Test points

5.3.43 The following table lists the relevant test points.

Test point	*Test level*	*Life cycle stage*
SIO5/PIO5	System	Pre-operational: site commissioning, operational evaluation
SIO6/PIO6	System	Pre-operational: site commissioning, operational evaluation Operational: RTQC, preventive and corrective maintenance
CIO1	System	Pre-operational: site commissioning Operational: RTQC
CIO2	System	Pre-operational: site commissioning Operational: RTQC, preventive and corrective maintenance
RIO2	System	Pre-operational: site commissioning, operational evaluation Operational: RTQC

Note.— Measurements made at the test points 5 and 6 may allow objective evaluation of the detection performance. Measurements made via a PPI at point RIO2 would be subjective.

Test methods

Note.— Also refer to Appendix A, Flight testing methods.

General

5.3.44 SIO3/PIO3/SIO5/PIO5. Since analogue signals are available at these points, the traditional averaging method in conjunction with Appendix A is to be applied.

5.3.45 PIO4,5,6/SIO4,5,6/CIO1,2/RIO2,3. The recommended method requires a series of comparative measurements to determine the limits of coverage of the system under test.

5.3.46 The measurements may be made using:

a) traffic of opportunity;

b) special test flight;

c) combination of a) and b); and

d) synthetically generated data from plot or video simulator.

5.3.47 Special test flights are the recommended method if a radial flight in an azimuth sector with little clutter can be used. However, a test flight will not provide a complete picture of the coverage limits in all areas. Test flights are mandatory during a system commissioning technical acceptance test.

5.3.48 The test method comprises the following stages:

— data collection and observations;
— data analysis; and
— comparison of results to assess performance.

Data collection

5.3.49 For the traffic of opportunity method, the duration of the data collection is dependent upon LCS. The following durations are recommended for radars with high to medium traffic densities to provide good confidence interval results:

new monoradar	10 to 12 hours
new multi-radar system	8 to 10 hours
post modification — 1 radar	3 to 4 hours
RTQC	1 hour

The above times would normally be divided up between various equipment configurations.

5.3.50 For a multi-radar system each new radar in the system must be evaluated separately before testing it in the multi-radar environment.

Observations

5.3.51 In the case of a monoradar installation where the data collection is made on site, it is recommended to visually observe the output of the radar of the system under test using the technical monitor display at the same time as data recordings are taking place. This enables any anomalies which may have been noted to be given special attention during the data analysis phase. In the multi-radar environment, the visual observation is not always feasible unless the measured position solely of one individual radar can be displayed.

5.3.52 The equipment configuration must be noted for reference, i.e. which equipment was in service during data collection and the settings of parameters which can be easily changed by maintenance and/or operational staff, for example STC/GTC. If any changes to the system configuration are made during the recording, it is recommended to make separate analyses of the periods with stable configuration. Meteorological conditions, QNH, temperature, wind speed and wind direction should be observed and noted.

Data analysis

5.3.53 The coverage limits must be determined in order to define the *coverage measurement volume* (CMV). During a traffic of opportunity analysis, the CMV may be determined by the received data and may subsequently be modified for certain user requirements such as operational requirements or theoretical coverage volumes. Multi-radar analysis may take advantage of the coverage of adjacent radars to modify the CMV.

5.3.54 No matter which type of cells are used, it is essential to maintain a normalized data sample distribution when comparing results from different data collections.

5.3.55 The sizes of the cells may be chosen according to the evaluation requirements, but it must be kept in mind that the detection calculation requires a minimum number of target reports within each detection cell to give a reliable detection value for each cell.

Presentation of results

5.3.56 The results would be typically presented as polar and vertical graphs showing the detection performance. (See Figure 5-4 as an example.)

Evaluation of results

5.3.57 Reference to the technical and operational requirements of the system must be made when measuring the SSR and PSR coverage performance of the system.

Data transmission inventory

Description

5.3.58 Tests to measure the relationship between the time order of messages being sent over the transmission system and the order of arrival in the final stages of the on-site processing. In addition, time-in-storage measurements may be performed. Systems which are subject to heavy plot load are optimal candidates for this test. Such tests also attempt to quantify the data loss and corruption rate, including possible network protocols on top of the user data.

Pre-requirements

5.3.59 Stable operating conditions of the system.

Test points

5.3.60 The following table lists the relevant test points.

Test point	*Test level*	*Life cycle stage*
CIO2	System	Pre-operational: site commissioning Operational: evaluation
CIO3	System	Pre-operational: site commissioning 5.3.63Operational: RTQC, corrective maintenance
CIO4/RIO1	System	Pre-operational: site commissioning Operational: RTQC, preventive and corrective maintenance

Test methods

5.3.61 The test methods are equipment and technique dependent. The messages are to be classified in priority order such as control, combined, SSR, primary and map messages. A protocol analyser will be required if measurements are made in the data transmission environment.

Presentation of results

5.3.62 Tables showing the input and output message inventories for each message category, and/or graphs showing the number of targets of the different categories as a function of time.

Evaluation of results

5.3.63 Typically, less than 0.1 per cent of all messages may be corrupted. If a higher figure is measured, the sources have to be identified and units have to be maintained.

False target rate

Description

5.3.64 The analysis of unwanted plots, or false targets, is mainly an empirical activity which relies on the intuitive interpretation of the system performance by the person(s) carrying out the analysis. The analyst must assess the false plot performance of the system based on a knowledge of the system characteristics and its performance requirements in terms of coverage, probability of detection, false plot rate and accuracy.

5.3.65 It must also be recognized that it is often necessary to compromise between probability of detection/coverage and false plot rates. In other words, it is usually desirable to reduce the number of false plots to a minimum while maintaining sufficient coverage and probability of detection. The analysis of false plots must attempt to identify the cause of the false plot and to quantify the number of occurrences of each category in relation to the total number of plots present.

5.3.66 The analysis of false plots for analogue systems and digital systems are treated separately.

5.3.67 The false target rate is the ratio of false plots to the total number of plots detected.

5.3.68 *Analogue system.* Analysis must be made either by oscilloscope monitoring of receiver outputs and video processing stages or use of a PPI display, either at the radar site or operational display position. The analyst must assess the number of false plots and attempt to categorize them as far as possible into the following types:

a) split plot (range and/or azimuth);

b) multiple plots including garbling and code changes;

c) reflection;

d) ring around (azimuth side lobes);

e) second-time around plots;

f) multiple-time around plots; and

g) clutter residue.

5.3.69 *Digital systems.* Analysis of false plots for digital systems may take advantage of both a visual assessment, using an oscilloscope or PPI, and/or computer-aided analysis of recordings of plot data (or track) made over a period of time. Computer-based analysis of false plots should attempt to classify and count the number of false plots in relation to the total number of plots present. The computer-based method is preferred since it should provide repeatable quantitative results whereas a visual analysis is subjective. Methods of visual analysis are system dependent.

Pre-requirements

5.3.70 Stable operational conditions of the system.

Test points

5.3.71 The following table lists the relevant test points.

Test point	*Test level*	*Life cycle stage*
PIO3/SIO3	Sub-system	Pre-operational: site commissioning Operational: all stages
PIO5/SIO5	System	Pre-operational: all stages
PIO6/SIO6	Factory	All stages
	System	Pre-operational
	Sub-system	Operational: BITE
CIO1/CIO2	System	Pre-operational Operational: all stages except preventive maintenance
RIO2/RIO3	System	Pre-operational Operational: BITE

Test methods

Data collection

5.3.72 For digital systems the analysis would normally be made off-line from recorded data. It is advisable to use the same data set as for the other inventory, reliability and accuracy analyses. The length of data recording depends on the type of false plot analysis.

General assessment: 1 to 2 hours per radar, depending on traffic density.

Specific analyses: Unlimited. The duration depends on the analysis criteria and may be anything from a few minutes to several days.

Observations

5.3.73 User reports together with visual observations during data collection greatly help the analyst during false target assessment.

Analysis methods

5.3.74 Two generic groups exist:

Group 1 — False targets related to aircraft — splits, reflections, side-lobe responses;

Group 2 — False targets not related to (targets) aircraft — clutter, “angels”, thermal noise.

5.3.75 Analysis of group 1 false targets is usually made with respect to the target associated with each false target. Group 2 provides *inter alia* the false alarm rate, which is due to noise (either atmospheric, receiver or video processing) which can be assessed by turning the transmitter into stand-by and recording any targets which appear on the technical monitor.

5.3.76 The association for group 1 may be made on one or more of the following parameters in order of priority:

— time;
— range;

— azimuth;
— Mode A code and Mode C code; and
— run length.

5.3.77 For SSR-related false targets the order is usually the following:

— Mode A code;
— Mode C code;
— time; and
— range or azimuth.

5.3.78 For calculating reflections and similar phenomena a reference plot or the position of the associated aircraft trajectory is required. In order of preference the following reference positions should be used:

a) actual aircraft position at time of false target;

b) radar plot(s) adjacent in time to the false target from the associated trajectory; and

c) smoothed aircraft position derived from a multi-radar trajectory reconstitution technique.

Primary radar false targets

5.3.79 The primary radar false targets are divided into two groups as follows:

Group 1 — False targets may be associated with aircraft trajectories by a reliable chaining process and in clutter free areas.

The false target assessment will categorize and count any false targets in group 1.

Group 2 — Plots in this group may only be counted to provide frequency distributions in time and space.

5.3.80 Further analysis may be made to categorize the plots in this group if information such as run length, radial speed and target amplitude are available to the analysis system.

Presentation of results

5.3.81 Provide the following:

a) summary tables showing the global ratio of each category of false target to the total number of plots present;

b) frequency distributions in time and space;

c) graphics showing distributions in time/space between the false targets and reference points; and

d) graphical presentation of positions in space of false targets and reference points.

Figure 5-5 is an example of the presentation of a false plot analysis.

Evaluation of results

5.3.82 It was stated above that it is the responsibility of the person carrying out the analysis to determine what level of false target activity will be tolerable to the system users. This document provides some of the symptoms and solutions to common categories of false targets.

5.3.83 *Second-time around targets.* Careful use of PRF stagger will normally get rid of second- and multiple-time around targets. However, the amount of stagger which may be implemented will depend very much on the system architecture as regards clutter cancellation techniques.

5.3.84 *Split plots.* Separation of the real and false plots will be less than the predetermined thresholds in range and azimuth, e.g. range threshold –925 m (–0.5 NM), azimuth threshold –3 dB antenna beamwidth. SSR split plots due to antenna related problems (side lobes) will normally have the same identity and height values as the real plot.

5.3.85 *Multiple plots.* This category of false targets is similar to split plots except that the azimuth separation between the false and real target will be greater than the split plot azimuth threshold (one beamwidth).

Geographic alignment

Description

5.3.86 Before the radar may be used operationally it must be aligned in azimuth with respect to a reference point. The alignment is normally made in several stages — mechanical and electrical. The geographic alignment concerns the mechanical alignment of the antenna with respect to an arbitrary reference point or points. Reference points may be as follows:

Primary en-route. A building(s) or other topographical feature with known coordinates with respect to the radar.

Primary approach. Known permanent echoes and approach routes to all runways at the airport.

SSR. Remote field monitor with known coordinates with respect to the radar.

5.3.87 Normally the system would be aligned with respect to true North (note that some States align approach radars to magnetic North). For any operational requirement for magnetic or compass azimuth values to be displayed, the measured azimuth would be corrected at the display processing stage. For co-mounted SSR and PSR systems the two antennas must be electrically aligned in azimuth with respect to one another (see also alignment PSR/SSR).

Pre-requirements

5.3.88 Stable operating conditions of the system.

Test points

5.3.89 The following table lists the relevant test points.

Test point	*Test level*	*Life cycle stage*
PIO1	Sub-system	Pre-operational: site commissioning Operational: RTQC, preventive and corrective maintenance

Test methods

5.3.90 One of the following alignment methods may be used:

a) *Optical alignment.* This would be made with a theodolite attached to a suitable reference point on the antenna. The ambient conditions should be calm with sufficient visibility to enable the reference point to be seen;

b) *Solar alignment.* This may be used at lower latitudes and in favourable meteorological conditions (no clouds and light winds), where the sun reaches sufficient elevation to measure the major parts of the antenna's beam(s). The sun's rate of azimuth change with elevation should not be so large as to cause tracking problems for the antenna control (whether this be automatic or manual). In order for the sun run alignment to be successful, the site position must be accurately known. Accurate nautical almanac information must be to hand so that the sun's declination and azimuth may be determined with respect to the radar antenna at any point in time; and

c) *SSR alignment.* A common practice with SSR and co-mounted PSR/SSR systems is to first align the SSR using the remote field monitor as a reference and then, in the case of co-mounted systems, use the SSR plot data as a reference for aligning the primary system. Obviously the SSR must be in a stable operating state for this to be practicable. More details are given in the sections on "alignment PSR/SSR". Computer-based alignment is achievable with known reference points (buildings, test transponders, etc.).

Presentation of results

5.3.91 The presentation of transponder azimuth or position distribution with respect to the known reference and the calculation of mean and sigma values are reasonable methods for the analysis. Reference is made also to the sections on alignment PSR/SSR, which describe a similar assessment.

Evaluation of results

5.3.92 Geographic alignment is a prerequisite for accurate radar data. It is recommended to monitor the alignment as part of the RTQC function.

5.3.93 Azimuth alignment should be within 5 azimuth change pulses (ACP) if polar measurement is used for the evaluation.

Inventory

Description

5.3.94 While not strictly a parameter in the same sense as accuracy or detection, inventory is nevertheless an important aspect of a computer-assisted radar evaluation. The data inventory will provide counts of the different types of message recorded during the data collection and means of visualizing the recorded data on a graphical display. The following list of items gives an indication of the components covered by the data inventory:

a) tables of target report counts (SSR plots, PSR plots, combined plots, North messages, out of maximum range, mean number of plots per scan);

b) tables showing the SSR Mode A and Mode C code validation rates;

c) graphs of plots per scan against time, for each radar, plot source, line, etc.;

d) graphical display tools for viewing recorded data in horizontal (polar or cartesian) or vertical (slant range/flight level) diagrams. These tools should preferably be interactive to allow the user to query data items and arrange the views of the data to suit the analysis requirements (zoom, pan, scaling, rotation, etc.). The vertical display graphical tool is useful for visual analysis of the radar vertical coverage, especially if the tool allows the displayed data to be selected on azimuth; and

e) other graphical tools for viewing any of the data fields in the recorded data either as frequency distributions or as graphs of the parameter against time or space (range, azimuth, X, Y, time in storage, run length, etc.);

This list is not exhaustive. Special purpose tools, methods of display, etc., may be required.

Pre-requirements

5.3.95 None.

Test points

5.3.96 The following table lists the relevant test points.

Test point	*Test level*	*Life cycle stage*
CIO1, SIO6, PIO6, RIO1	System	Pre-operational: site commissioning, operational evaluation Operational: RTQC, corrective maintenance

Test methods

5.3.97 Interactive analysis as part of a computer-assisted analysis.

Presentation of results

5.3.98 Interactive graphical and tabular outputs. Figure 5-6 is an example for a data inventory.

Evaluation of results

5.3.99 The interpretation of the data displayed at the inventory level of an evaluation can, with a little experience, give a very good indication as to whether a system has any major problems. Some explanations are given below:

a) *plots-per-scan graph.* A good tool to give indication if there were any interruptions or system configuration changes during a recording; and

b) *vertical plot graph.* A good tool to visualize the vertical coverage limits of the recorded data.

Probability of detection (P_D)

Description

5.3.100 The probability of detection (P_D) is the probability that at each scan, for a given wanted target within the CMV (see 5.3.29), a radar target report with position data will be produced. For editorial reasons, this section also includes a description of the SSR Code detection rates. For a radar system, this parameter is defined by the following ratio:

$$PD = \frac{\text{number of times a target was detected}}{\text{expected number of target reports}}$$

The denominator in the definition (expected number of target reports) is based on the assumption that a radar should detect all wanted targets that are within the CMV of the radar. For computer-based analysis the expected number would be established by the plot chaining function. For a visual analysis the expected number would refer to the period between the first and last detected target report of a specific flight.

5.3.101 In certain cases (notably flight trials with dedicated aircraft) it is possible to determine, by communication with the pilot, the altitude of the aircraft and by reference to theoretical coverage charts, whether the target should be within coverage of the radar and thus should be detected. Obviously this method is not practical for more than a few trajectories. This task is much easier if the pilot has been asked to compute and fly true altitudes as opposed to flight level.

5.3.102 Special test flights do not provide a complete picture of the detection in all areas but are required for investigation of those areas where special traffic movements are required or little normal traffic occurs. Test flights are mandatory during technical acceptance tests associated with system commissioning.

5.3.103 Sophisticated evaluation systems may have access to theoretical radio and line-of-sight coverage volumes for a radar which can be used to determine the theoretical limits of the “expected number” value. However, the atmospheric influence on radar coverage is such that there is a risk that probability of detection values at or near the coverage limits may be unrealistic unless measured continuously (RTQC).

5.3.104 In a monoradar evaluation the “expected number of target reports” is taken to be the number of antenna scans between the first and last detection of the object. For a multi-radar evaluation, the number of expected target reports can be estimated by using information from adjacent radars whose coverage overlaps the radar concerned.

Note.— Multiple target reports (splits, reflections, etc.) and non-combination cases must be handled correctly in the P_D calculations. Normally, only one target report per scan per wanted target will be expected from a radar.

5.3.105 Depending on the measurement method used, the results obtained from each measurement should normally be compared to results of several measurements of the system under similar operating conditions to increase confidence. The analysis system should also allow results obtained under similar measurement conditions to be merged into a radar database.

5.3.106 Probability of position detection is divided into the following aspects:

a) probability of SSR position detection; and

b) probability of PSR position detection.

SSR code detection rates, divided as follows:

— valid Mode A and valid Mode C detection rate;
— correct Mode A detection rate;
— correct Mode C detection rate; and
— correct Mode A and Mode C detection rate.

Pre-requirements

5.3.107 Measurement of P_D is to be made when all the selected systems in addition to the one under test are in stable operating state and geographical and PSR/SSR alignment shall have been completed.

5.3.108 Particular regard must be given to the prevailing atmospheric conditions to ensure that no abnormal conditions, such as anomalous propagation, exist unless of course it is the objective of the analysis to study the system under such conditions.

Test points

5.3.109 The following table lists the relevant test points.

Test point	*Test level*	*Life cycle stage*
SIO5/PIO5	System	Pre-operational: site commissioning, operational evaluation
SIO6/PIO6	System	Pre-operational: site commissioning, operational evaluation Operational: RTQC, preventive and corrective maintenance
CIO1	System	Pre-operational: site commissioning Operational: RTQC
CIO2	System	Pre-operational: site commissioning Operational: RTQC, preventive and corrective maintenance
RIO2	System	Pre-operational: site commissioning, operational evaluation Operational: RTQC

Note.— Measurements made at the test points PIO/SIO 5 and 6 may allow objective evaluation of the detection performance. Measurements made via a PPI at point RIO2 would be subjective.

Test methods

5.3.110 For tests at interfaces SIO3/PIO3/SIO5/PIO5, analogue signals are available and a traditional averaging method is applicable.

5.3.111 For tests at interfaces PIO4, 5, 6/SIO4, 5, 6/CIO1, 2/RIO2, 3, the recommended method requires a series of comparative measurements within the coverage volume of the system under test. The measurements may be made using:

a) traffic of opportunity;

b) special test flight;

c) combination of a) and b); and

d) synthetically-generated data from plot or video simulator.

5.3.112 Special test flights do not provide a complete picture of the detection in all areas but are required for investigation of those areas where special traffic movements are required or little normal traffic occurs. Test flights are mandatory during system commissioning technical acceptance tests.

5.3.113 The test method comprises the following stages:

— data collection and observations;
— data analysis; and
— comparison of results to assess performance.

Data collection and observations

5.3.114 Duration of the data collection is dependent upon LCS. The following durations are recommended for radars with adequate traffic densities to provide good confidence interval results:

new monoradar	10 to 12 hours
new multi-radar system	8 to 10 hours
post modification — 1 radar	3 to 4 hours
RTQC	1 hour

5.3.115 The above times would normally be divided up between various equipment configurations. For a multi-radar system each new radar in the system must be evaluated separately before testing it in the multi-radar environment.

5.3.116 During the site commissioning phase or during any data collection "on site" it is recommended to visually observe the output of the radar under test (for multi-radar systems this generally implies having one observer per radar). This enables any anomalies which may have been noted to be given special attention during the data analysis phase.

5.3.117 The equipment configuration should be noted for reference, i.e. which equipment was in service during data collection and the settings of parameters which can be easily changed by maintenance and/or operational staff, for example STC/GTC. If any changes to the system configuration are made during the recording it is recommended to make separate analyses of the periods with stable configuration. Meteorological conditions, QNH, temperature, wind speed and direction are to be noted.

Data analysis

5.3.118 The data are sorted into objects, that is, all the target report messages relating to each target are chained (associated) together. Detection analysis is then made using the target reports associated with selected trajectories within predefined three dimensional cells within the system coverage. This technique implies that any identified false target reports are not used in the calculations. The object selection criteria would normally be set to reduce the effects of noise and inclusion of unwanted objects (e.g. correlated clutter) in the calculations.

5.3.119 The three dimensional cells are referred to as the CMV and may be defined in range/azimuth/height or prismatic sections covering portions of an airway structure or TMA. The P_D measurement volume defines the volume of airspace within which the radar system should be expected to detect targets. During a traffic of opportunity analysis, the CMV will be determined by the received data and may subsequently be modified for certain user requirements such as operational requirements or theoretical coverage volumes. Multi-radar analysis will take advantage of the coverage of adjacent radars to modify the measurement volume.

5.3.120 No matter which type of cells are used it is essential to maintain a normalized data sample distribution when comparing results from different data collections. It is recommended that some form of input categorization is used to give better control over the measurements and results.

5.3.121 The sizes of the cells may be chosen according to requirements, but it must be kept in mind that the detection calculation requires a minimum number of target reports within each detection cell to give a reliable detection value for each cell.

5.3.122 Within each defined cell the programme calculates the probability of detection for each trajectory within the cell. Separate calculations are made for the following:

PSR position detection. The ratio of the received number of PSR target reports to the expected number of PSR target reports. A PSR target report in this context shall mean either a PSR or a combined target report message.

SSR position detection. The ratio of the received number of SSR target reports to the expected number of SSR target reports. An SSR target report in this context shall mean either an SSR or a combined target report message with Mode A and/or C fields present.

Valid Mode A detection rate (secondary radar). The ratio of the received number of SSR target reports with a valid Mode A code to the received number of SSR target reports in the trajectories used in the detection analysis.

Correct Mode A detection rate (secondary radar). The ratio of the number of received SSR target reports with correct Mode A code to the received number of SSR target reports in the trajectories used in the detection analysis.

Valid Mode C detection rate (secondary radar). The ratio of the received number of Mode C replies to the received number of SSR target reports in the trajectories used in the detection analysis.

Correct Mode C detection rate (secondary radar). The ratio of the number of received SSR target reports with correct Mode C code to the received number of SSR target reports in the trajectories used in the detection analysis.

Correct Mode A and Mode C detection rate (secondary radar). The ratio of the number of received SSR target reports with both, correct Mode A *and* correct Mode C code to the received number of SSR target reports in the trajectories used in the detection analysis.

Basic terms used

5.3.123 The following are basic terms used in the analysis:

Received target report. A target report which has been chained to an object and which has been used in the detection calculations.

Valid. VALID is defined by the validation process of the radar sensor. It may be interpreted as meaning the SSR code was present and was validated (high quality) by the radar system.

Note.— The existence and interpretation of the term "validated" varies from system to system.

Correct. CORRECT means the SSR code value corresponded to the current "correct" value for the associated trajectory. The correct value is determined and maintained by the chaining process in the evaluation system.

Missing data

5.3.124 The analysis of missing data is considered as part of the probability of detection analysis. The chaining process will generate a missed plot for each scan where a plot was expected and none was found, i.e. between the start and end times of a trajectory. The missed plot is generated in position and time where the expected plot would have been. Allocation of missed plots is a function of the probability of detection measurement volume currently in use for the radar. Further analysis is divided into two sections.

a) *Missed plots.* The position in time and space of the missed plots generated for each radar may be displayed using graphical means. The user may then determine if any correlation in position has occurred. Any correlation in position must be further analysed to determine the cause of these missed plots.

Possible reasons are:

1) loss of coverage; and

2) missed plots correlated to specific trajectories, possibly aircraft related faults such as transponder failure or shielding.

Separate analyses are to be made for PSR and SSR misses for systems with collocated SSR and PSR. In this case, a chained primary plot is considered as an SSR miss if the primary plot lies within the SSR CMV. Conversely, a chained SSR plot is considered as a PSR miss if it lies within the PSR measurement volume.

b) *Gaps.* A gap is a *sequence* of consecutive missed plots from one radar and associated with one trajectory.

The analysis of gaps normally comprises a comparative study between different data samples for the frequency distribution of the size of gaps.

The following results are determined:

1) percentage of missed plots in gaps of more than two misses;

2) percentage of gaps with more than two misses;

3) average gap size; and

4) average gap size for gaps of more than two misses.

Presentation of results

5.3.125 Histograms graduated in discrete detection bands such as, e.g. <50 per cent, 50-80 per cent, 80-90 per cent, 90-95 per cent, 95-98 per cent, 98-100 per cent; and over-all figures derived from the mean detection values for each detection cell in the calculation.

5.3.126 Results of P_D analyses may only be reliably interpreted and compared between data samples if the analysis data are classified in some way, for example, by traffic type and geographical area.

5.3.127 Figure 5-7 is an example of the presentation of investigation results concerning P_D.

Evaluation of results

5.3.128 It is probably impossible to make absolute measurements of the probability of detection of a system, consequently it is usual to make comparative analyses between different sets of results. However, in the situation where traffic of opportunity results are required for an acceptance test the P_D analyses must be based on a strictly controlled set of traffic.

5.3.129 Comparison between results from different data samples must allow for a certain percentage spread in the detection results. The indication of the quality of the results dictates how much allowance should be allowed. Over-all percentage results are useful giving a general indication of the detection rate, assuming a high confidence in the results.

Random errors

Description

5.3.130 Residual random errors in the measured position of a target report will exist in any radar system. Technical and operational acceptance of the system will be conditional on the system providing positional information within the required accuracy limits. The analysis of residual errors is also an important parameter when determining the radar separation standards which may be applied with the radar concerned. Consequently, it is mandatory that the residual error characteristics are determined for a radar system as part of the system commissioning and regularly during the operational lifetime.

5.3.131 It has been shown that distribution of residual position errors in range and azimuth exhibit two separate distributions; one distribution (Gaussian) covering the central part of the population distribution and another covering the tails of the distributions.

5.3.132 The mean value of the residual errors should correspond to the mean systematic error. In a multi-radar system it is normal to correct for systematic errors before calculating residual errors.

5.3.133 The measurement of residual errors requires a reference position for each target report used in the error calculations. This reference may be obtained from external sources such as a test flight or obtained using multi-radar trajectory reconstruction from the recorded data. Computer-assisted analysis techniques allow reliable estimation of the residual errors using representative samples of traffic of opportunity.

Pre-requirements

5.3.134 Stable operating state of the system. For a multi-radar system, systematic errors have stabilized.

Test points

5.3.135 The following table lists the relevant test points.

Test point	*Test level*	*Life cycle stage*
CIO2, RIO2, RIO3	System	Pre-operational: site commissioning Operational: RTQC, preventive and corrective maintenance

Test methods

5.3.136 An established computer-assisted method for calculating residual random errors is to reconstruct the target trajectory using a multi-radar trajectory reconstruction tool and compare each target report against the reference for errors in range, azimuth, position, X and Y after having corrected any systematic errors which may exist.

5.3.137 After a sufficient number of trajectories have been processed, the bias errors should converge to steady state values at which point the analysis may be halted. The resulting bias errors may then be applied to each radar in the system to correct the time and position of each plot before estimating any residual random errors which may exist.

Data collection

5.3.138 The same data set used for reliability analysis would normally be used. It is essential to ensure that a sufficiently large data sample is available for the analysis; normally between 500 and 1 000 trajectories of at least 5 minutes each will be required.

5.3.139 It is preferable to use the plot/track legal recording if possible and if it contains the required data.

Analysis

5.3.140 The residual errors would be calculated in Cartesian coordinates with respect to the system origin and transformed into radar coordinates for the presentation of results. The errors should settle to steady state values well before the total number of trajectories have been processed.

5.3.141 The evaluation tool may provide regression analysis to help the user determine when the steady state of the various bias errors has been reached.

5.3.142 Settling of the standard deviation values for each error does not usually indicate steady state conditions of the main error values.

Presentation of results

5.3.143 The systematic errors of each radar may be presented as a summary of the final results of the calculations or a more detailed graphical presentation may be required of the magnitude of each error against trajectory or accumulated (sum time) trajectory time during the calculations. Figure 5-8 is an example of a residual random error distribution.

Evaluation of results

5.3.144 It is important to verify that the error values have stabilized before proceeding with any further accuracy analyses in multi-radar evaluation.

Resolution

Description

5.3.145 This parameter includes the resolution of intermediate sub-system units as well as the whole system. The resolution of the system is the ability to correctly resolve the positions of two or more real targets in close proximity.

5.3.146 The resolution of the radar is its ability to discriminate between two aircraft in close proximity, producing separate radar target reports for each aircraft. Two aircraft are considered to be in close proximity when their slant ranges and azimuths are sufficiently close for there to be a potential for degradation of resolution through mutual interference or interaction between the aircraft radar returns. The resolution performance for each aircraft is defined in terms of the probabilities of position detection of each of the aircraft in close proximity and, for SSR, the additional probabilities of correct code on both Modes A and C. Within the close proximity area there is a slant range separation limit and an azimuth separation limit. At target separations less than these lower limits, the performance is sufficiently degraded for the radar information to be operationally unacceptable. These lower limits are dependent upon the radar system design and operating parameters. In particular, the azimuth separation lower limit is dependent upon the radar operating parameters of PRF, antenna turning rate and, for SSR, the mode interlace pattern used. The range and azimuth resolution figures in Tables 3-1 and 3-2 relate to these limits.

5.3.147 Two aircraft may be considered to be in close proximity when the distance between them is within the following typical close proximity area for a radar system with monopulse SSR:

SSR (monopulse): slant range <3.7 km (2 NM) and azimuth < (3 x nominal 3 dB horizontal beamwidth)

PSR: slant range < (2 x nominal transmission pulse width) and azimuth < (3 x nominal 3 dB horizontal beamwidth).

5.3.148 Aircraft which are not in close proximity are treated as “isolated targets” by the resolution performance analysis.

Pre-requirements

5.3.149 Geographical and PSR/SSR alignment has been completed for tests at CIO2.

Test points

5.3.150 The following table lists the relevant test points.

Test point	*Test level*	*Life cycle stage*
PIO4/SIO4	Sub-system	Factory: type test
PIO5/SIO5	Sub-system	Factory: acceptance test Pre-operational: site commissioning Operational: RTQC
CIO2	System	Pre-operational: site commissioning, operational evaluation Operational: RTQC, preventive and corrective maintenance

Test methods

5.3.151 *Simulated targets.* A plot simulator may be used to give repeatable measurements of the processing system using two targets, one fixed in position while the other is moved in range and azimuth with respect to the fixed target.

5.3.152 *Live traffic.* To check performance for specific aircraft separations, for example during site commissioning, flight trials of test aircraft fitted with calibrated position-determining devices and facilities to record the aircraft positions at regular time intervals can be used, as shown in Figures 5-11 a) and b). The update rate of the aircraft positions must be equal to or greater than the radar update rate. Recordings made on board the aircraft are used in conjunction with the radar-measured position data to check that the radar performance is adequate at the specified aircraft separation.

5.3.153 However, to evaluate the resolution capability of the radar system, traffic of opportunity recordings is used. Chaining and trajectory reconstruction algorithms establish a reference trajectory for each aircraft. All pairs of trajectories that approach each other to within the close proximity area are identified. From these trajectories, those pairs that approach each other with separations of less than the lower slant range and azimuth limits are also identified.

5.3.154 The performance in close proximity is calculated in each of the areas bounded by above and below the lower slant range and azimuth separation limits and within the close proximity area by associating the target reports and trajectories with chaining algorithms.

5.3.155 The probability of position detection is obtained from the ratio of the total number of targets detected that associate with trajectories in the close proximity area to the total number of target report detections expected in the close proximity area.

5.3.156 Similarly the valid and correct Mode A and C code rates are obtained from the ratio of the total number of reports with valid and correct Mode A or C codes that associate with trajectories in the close proximity area to the total number of targets detected that associate with trajectories in the close proximity area.

Presentation of results

5.3.157 Figure 5-9 is an example of a range resolution investigation.

Systematic errors

Description

5.3.158 Otherwise known as bias or correlated errors in position and time of the radar reported position of a target. Systematic errors are most relevant to multi-radar systems of which most of this description is concerned. Range and azimuth systematic errors may occur for a single autonomous radar system and methods of assessing these are described.

5.3.159 The correction of systematic errors is essential in a multi-radar system if the data from the respective radars are to correlate in time and position. Systematic errors can be categorized as follows:

a) time stamping errors (relevant to multi-radar systems);

b) range bias;

c) azimuth bias;

d) range gain and range bias at maximum range; and

e) site position errors (bias errors in the latitude and longitude of the radar).

Pre-requirements

5.3.160 The positions of two radars in the system is accurately known. The positions would normally be surveyed using satellite surveillance techniques. The system under test is in a stable operating state.

Test points

5.3.161 The following table lists the relevant test points.

Test point	*Test level*	*Life cycle stage*
RIO2 and RIO3	System	Pre-operational: site commissioning Operational: RTQC, preventive and corrective maintenance

Test methods

5.3.162 The established method for calculating systematic errors is to reiteratively calculate the bias errors for a large number of aircraft trajectories covering the radars in the system. After a sufficient number of trajectories have been processed, the bias errors should converge to steady state values at which point the analysis may be halted. The resulting bias errors may then be applied to each radar in the system to correct the time and position of each plot before estimating any residual random errors which may exist.

5.3.163 Care should be taken to use, for the calculations, radars which are spaced relatively far apart from one another. As the calculations rely on having overlapping coverage and detection between adjacent radars in a multi-radar system, it will be difficult for the user to achieve reliable results.

Data collection

5.3.164 The same data set used for reliability analysis would normally be used. It is essential to ensure that a sufficiently large data sample is available for the analysis; normally between 500 and 1 000 trajectories of at least 5 minutes each will be required.

5.3.165 It is preferable to use the plot/track legal recording if possible and this contains the required data.

Analysis

5.3.166 The reiterative calculations to establish the systematic errors would normally require the positions of two of the radars present on the data collection to be fixed and one of the radars to be fixed in time.

5.3.167 The errors would be calculated in Cartesian coordinates with respect to the system origin and transformed into radar coordinates for the presentation of results. The errors should settle to steady state values well before the total number of trajectories have been processed.

5.3.168 The evaluation tool may provide regression analysis to help the user determine when the steady state of the various bias errors has been reached.

Note.— Settling of the standard deviation values for each error does not usually indicate steady state conditions of the main error values.

Presentation of results

5.3.169 The systematic errors of each radar may be presented as a summary of the final results of the calculations or a more detailed graphical presentation may be required of the magnitude of each error against trajectory or accumulated (sum time) trajectory time during the calculations. The example given in Figures 5-10 a) and b) illustrates the effect of systematic errors.

Evaluation of results

5.3.170 It is important to verify that the error values have stabilized before proceeding with any further accuracy analyses in multi-radar evaluation. In an optimized radar system, the estimated systematic error values are to be approximately half of the residual error standard deviation values for a modern approach/TMA radar.

5.4 TESTING DETAILED TECHNICAL PERFORMANCE PARAMETERS

5.4.1 The following sections discuss detailed technical performance parameters, which are assessed primarily during commissioning, and for which the procedures, pre-requirements, methods, intervals, etc., can be expected to be specified in the manufacturer's documents. Within the framework of this document, in most cases only limited information is therefore given for this type of parameter.

Antenna performance

Description

5.4.2 Several characteristics are covered by this parameter, including:

a) horizontal polar diagram;

b) vertical polar diagram;

c) antenna gain, i.e. the gain at the peak of each beam of the antenna; and

d) azimuth squint and skew, i.e. distortion of beam shape (squint) and/or skew (direction) as function of frequency within the operating bandwidth of the antenna.

Pre-requirements

5.4.3 Prior to tests carried out as part of planned maintenance, all the parameters listed above must have been measured by the manufacturer and the results of those measurements made available to the user.

Test points

5.4.4 The following table lists the relevant test points.

Test point	*Test level*	*Life cycle stage*
PIO2	Sub-system	Factory: type test Pre-operational: site commissioning Operational: RTQC, preventive and corrective maintenance

Test methods

5.4.5 *Test equipment.* Special test equipment and test sites are required to enable the above tests to be made. The preventative maintenance measurement of a horizontal polar diagram requires special test equipment that can be transported to a site enabling the measurement to be made while the radar system is operational.

5.4.6 *Horizontal radiation pattern (HRP).* The measurement of the HRP for SSR antennas is recommended as part of the planned maintenance of the system. The HRP may be measured while the system is operational using a special test set or at the manufacturer's test site.

5.4.7 *Vertical radiation pattern (VRP).* These would normally be made at the manufacturer's antenna test site. If the VRP cannot be made in the normal way (i.e. by measurements during a vertical test flight profile), an alternative method is to make several horizontal polar diagrams at various antenna elevations so as to make an estimation of the vertical pattern. Using special test flights, the vertical coverage, and by deduction, the antenna vertical pattern may be measured. The pilot of the test aircraft will be required to calculate and fly true altitude radial trajectories with respect to the radar so that the recorded target data may be associated with the antenna vertical diagram.

5.4.8 *Gain.* The gain of each beam of the antenna would normally be calculated at the peak of the beam and used to calibrate the horizontal and vertical polar diagrams. The measurements of interest are:

a) the gain at zero degree mechanical antenna elevation;

b) elevation of beam peak with respect to the antenna zero degree mechanical elevation.

The gain measurements require a special calibrated gain horn and receiver.

5.4.9 Azimuth squint and skew. As for the gain these measurements require a special calibrated gain horn. The variation in azimuth and elevation of the peak gain with respect to the mechanical elevation of the antenna must be measured over the specified operating frequency band of the antenna.

5.4.10 *RTQC test methods.* It is an advantage to have integrated built-in test equipment (BITE) which allows the HRP signature of the antenna to be analysed and reported to RMCS if any deviations from the normal tolerances are measured.

Presentation of results

5.4.11 Graphs of relative response of the antenna beam with respect to azimuth and elevation.

Evaluation of results

5.4.12 The results must be compared against agreed antenna results obtained during the commissioning or type tests. Diagrams presented in Figures 5-11 a) and b) are examples of HRP and VRP evaluation results.

Bandwidth

Description

5.4.13 The bandwidth of the receiver must be verified against the manufacturer's setting-up and maintenance specifications.

Pre-requirements

5.4.14 As prescribed in the manufacturer's setting-up procedures.

Test points

5.4.15 The following table lists the relevant test points.

Test point	*Test level*	*Life cycle stage*
PIO3, SIO3	Unit	Factory: type test, acceptance test

Test methods

5.4.16 As prescribed in the manufacturer's setting-up procedures.

Presentation of results

5.4.17 As prescribed in the manufacturer's setting-up procedures.

Evaluation of results

5.4.18 As prescribed in the manufacturer's setting-up procedures.

Correlation interpolation

Description

5.4.19 This parameter is a test of the performance of the plot extractor to interpolate the position of the target in the presence of noise/clutter and broken (intermittent) replies, i.e. how well the system will "fill in the gaps" given a set of non-homogeneous radar replies.

Pre-requirements

5.4.20 As prescribed in the manufacturer's setting-up procedures.

Test points

5.4.21 The following table lists the relevant test points.

Test point	*Test level*	*Life cycle stage*
PIO5/SIO5	System	Pre-operational: type test, corrective maintenance

Test methods

5.4.22 For this test a "hit pattern" generator is necessary to produce all kinds of different hit/miss patterns. The plots at the system output are recorded and checked against the expected plot position. It is to be determined which patterns lead to the generation of split plots.

Presentation of results

5.4.23 Determination of the number of split plots, and deviations of the plot position as given by the plot extractor from the expected one.

Evaluation of results

5.4.24 As prescribed in the manufacturer's setting-up procedures.

Constant false alarm rate (CFAR) performance

Description

5.4.25 To check the processing loss due to any CFAR techniques employed in the system.

Pre-requirements

5.4.26 As prescribed in the manufacturer's setting-up procedures.

Test points

5.4.27 The following table lists the relevant test points.

Test point	*Test level*	*Life cycle stage*
PIO4	Sub-system	Pre-operational: site commissioning

Test methods

5.4.28 As prescribed in the manufacturer's testing procedures. On system level: comparative over-all performance with CFAR.

Presentation of results

5.4.29 As prescribed in the manufacturer's setting-up procedures.

Evaluation of results

5.4.30 As prescribed in the manufacturer's setting-up procedures.

Data transmission line performance

Description

5.4.31 The transmission medium error rate must be below a specified value since it is imperative to the reliability of the system that no data are lost or corrupted due to the transmission system. The line performance is normally expressed as the probability of receiving a corrupt bit for a given number of bits transmitted.

Pre-requirements

5.4.32 As prescribed in the manufacturer's setting-up procedures.

Test points

5.4.33 The following table lists the relevant test points.

Test point	*Test level*	*Life cycle stage*
RIO1	System	Pre-operational: site commissioning
	Unit	Operational: RTQC Factory tests: type tests

Test methods

5.4.34 A data analyser with test data generator will be used to check the transmission line in both directions. Modems generally provide a loop-back capability allowing re-transmission of received data. A comparison of sent and received data on the opposite end of the transmission medium allows for the assessment of the line performance.

Presentation of results

5.4.35 Tables listing the amount of bits sent and the duration of the test, as well as the number of bit and byte errors. Figure 5-12 is an example of a bit error check result.

Criteria for plot extractors employing sliding window processing

Description

5.4.36 Tests of the leading and trailing edge detection criteria in the extractor.

Pre-requirements

5.4.37 As prescribed in the manufacturer's setting-up procedures.

Test points

5.4.38 The following table lists the relevant test points.

Test point	*Test level*	*Life cycle stage*
PIO5/SIO5	Sub-system	Pre-operational: site commissioning

Test methods

5.4.39 PSR: no details are given here as the tests are extractor dependant; and SSR: the tests will require an SSR video simulator.

Note.— These test methods are not applicable to MSSR extractors.

Presentation of results

5.4.40 As prescribed in the manufacturer's setting-up procedures.

Evaluation of results

5.4.41 As prescribed in the manufacturer's setting-up procedures.

False alarm rate

Description

5.4.42 This parameter is included in the false target rate parameter definition. It is a measure of the sensitivity of a radar system to generate false target reports from thermal noise, in the case of PSR, and from fruit replies for SSR. False alarm rate is obtained from the probability of false alarm, which is defined as the number of false detections, due to noise or fruit, divided by the theoretical maximum number of detections possible.

5.4.43 Measurement of false alarm rate at the detected video level will give good indication of a PSR receiver sensitivity. At this point in the system, the false alarm rate is obtained from the ratio of the total number of receiver noise detection threshold crossings to the maximum number of radar range resolution cells.

5.4.44 False alarm rate is more usually specified after the plot processing stages of a system. It is therefore convenient to estimate it from the ratio of the average number of false reports per antenna scan to the total number of range/azimuth resolution cells available in one antenna scan. It can also be expressed as the average number of false plots per scan. At the plot extractor output an average number of one false plot per scan due to noise or fruit is often considered a pragmatic measurement, acceptable for en-route surveillance.

Pre-requirements

5.4.45 The receiver must be aligned prior to the test and the video processing equipment must be set up according to the manufacturer’s instructions.

Test points

5.4.46 The following table lists the relevant test points.

Test point	*Test level*	*Life cycle stage*
PIO3	Sub-system	Factory: acceptance test Pre-operational: site commissioning, operational evaluation Operational: RTQC

Test methods

5.4.47 The parameter is normally tested with the respective transmitter in the standby state, i.e. not radiating, and a recording is made of any targets which appear on the technical monitor display. Sufficient time must be allowed for any automatic thresholds to stabilize after switching off the transmitter.

Presentation of results

5.4.48 Polar (range, azimuth) graphs.

Evaluation of results

5.4.49 Graphic tools make it easy for the user to determine if and where any false alarms occur. Any excess over the specified limit for the system must be investigated after analysis of the probability of detection and false plot rates.

Filter response

Description

5.4.50 The MTI or MTD techniques employed in the system should be fully investigated for their response over the radial speed range specified for the system. The techniques used may be classical MTI or MTD techniques and include a zero velocity filter (ZVF).

Pre-requirements

5.4.51 The system should be in a stable operating state. Further conditions as given in the manufacturer’s documentation.

Test points

5.4.52 The following table lists the relevant test points.

Test point	*Test level*	*Life cycle stage*
PIO4	Sub-system	Factory: type test

Test methods

5.4.53 The test would require a video simulator to generate targets at various amplitudes and phases with respect to the transmitted pulse.

5.4.54 The ZVF may also be checked during site commissioning with use of a test aircraft flying a circular pattern around the radar at constant height.

Presentation of results

5.4.55 As given in the manufacturer's documents.

Evaluation of results

5.4.56 As given in the manufacturer's documents.

Losses

Description

5.4.57 This parameter covers the insertion losses in the wave- guide or cable system between the antenna and the transmitter/receiver. Units of measurement: normally dB and as a VSWR.

Pre-requirements

5.4.58 The antenna and waveguide/cable system must be fully installed. Further conditions as given in the manufacturer's documents.

Test points

5.4.59 The following table lists the relevant test points.

Test point	*Test level*	*Life cycle stage*
PIO2/SIO2	Unit	Pre-operational: site commissioning, corrective maintenance

Test methods

5.4.60 A standard VSWR "bench" should be used. The insertion losses may be measured by short circuiting the waveguide at the top of the run, as near as possible to the antenna feed horn(s) and measure the VSWR at the bottom of the run, usually at the antenna side of the duplexer, i.e. the common part of the run between transmit and receive paths.

Presentation of results

5.4.61 As given in the manufacturer's documents.

Evaluation of results

5.4.62 As given in the manufacturer's documents.

Minimum detectable signal (MDS)

Description

5.4.63 The minimum detectable signal of the receiver must be verified against the manufacturer's setting-up and maintenance specifications.

Pre-requirements

5.4.64 As prescribed in the manufacturer's setting-up procedures.

Test points

5.4.65 The following table lists the relevant test points.

Test point	*Test level*	*Life cycle stage*
PIO3, SIO3	Unit	Factory: acceptance test Site commissioning, RTQC, corrective maintenance

Test methods

5.4.66 As prescribed in the manufacturer's setting-up procedures.

Presentation of results

5.4.67 As prescribed in the manufacturer's setting-up procedures.

Evaluation of results

5.4.68 As prescribed in the manufacturer's setting-up procedures.

OBA

Description

5.4.69 This parameter is applicable only to SSR monopulse antennas/receiver subsystems. The difference pattern null point must be accurately aligned with the boresight pointing angle of the antenna pedestal subsystem. The alignment of the electrical null point of the antenna relative to the mechanical pointing angle must be considered when operating a monopulse system. A surveyed 1 090 MHz fixed position signal source, preferably a Mode S aircraft transponder type device, is the most effective approach to determine the electrical boresight of the antenna. Correction for any noted bias in the boresight pointing angle will need to be accommodated by the adjustment of the azimuth sensing device portion of the antenna pedestal. No azimuth bias is permitted since the OBA estimates generated by the receiver subsystem are referenced to the electrical boresight.

5.4.70 The ability of the MSSR to produce accurate OBA values in the determination of target azimuth is dependent on the combined integration of the antenna and receiver subsystems. Each of these two subsystems can be coarsely aligned by implementing the respective manufacturer’s set-up procedures. Complete integration of all elements necessary in developing the OBA values is required before accurate results can be expected. Both phase and amplitude type monopulse receivers are sensitive to very slight changes in phase or amplitude characteristics of the antenna signals at their input ports. Differences in the antenna, rotary joint and cable characteristics at each installation are best compensated for when fully integrated with the monopulse receiver. Strict adherence to phase and signal strength relation between the sum and delta signal from the antenna to the receiver must be accomplished and maintained. Checks on the characteristics of the rotary joint as it rotates through its 360° travel should also be conducted to assure consistent phase and amplitude signals.

5.4.71 A calibration process using received target data from a rotating antenna to build a monopulse translation table is needed to generate the OBA information utilized by the surveillance functions of the MSSR. The calibration must provide the translation of the antenna pattern delta to sum ratio signal (the monopulse value) to the angular displacement from boresight (the OBA value). A fully integrated antenna and receiver subsystem is critical in the generation of an accurate OBA function since any component tolerance issues can be compensated for during this type of OBA calibration.

5.4.72 The OBA function also includes a check on the phase shift from left to right of the boresight. A 180-degree relative phase shift of the sum antenna signal to the delta antenna signal is experienced at boresight. This is required to allow the monopulse output of the receiver subsystem to be monotonic since the sum/delta antenna pattern is symmetrical about boresight. The absolute phase of the sum to delta signals will be dependent upon the particular antenna design being used. Typical phase transitions for current MSSR antennas are 180°/0°, 0°/180°, +90°/–90° or –90°/+90° degrees shift. The most critical aspect of the boresight phase transition is the sharpness of the transition. An ideal situation is to have no interim phase values detected. As a system deviates from this ideal situation and the phase transition spans some discernible angular displacement, a portion of the OBA data at boresight becomes ambiguous. This transition region should be evaluated with respect to system accuracy requirements since that portion of the antenna beam may not be suitable for accurate target azimuth determination.

5.4.73 The beam dwell error pattern, a check on actual position of the target in the antenna beam relative to detected position, is also checked. Utilization of a fixed aircraft transponder is appropriate for this type of process. Target reply data collected across the operational beamwidth is used to compare the detected azimuth to the known azimuth of the subject target. There are various approaches used in establishing the reference target’s position, such as a survey position or an empirically derived position. The resultant error pattern data will characterize the accuracy of the system azimuth data as a function relative to location within the antenna beamwidth. Collection of multiple data samples at each discrete OBA unit used by the MSSR is beneficial in developing good statistical analysis of the mean and standard deviation calculations of the error pattern.

Pre-requirements

5.4.74 As prescribed in the manufacturer’s setting-up procedures.

Test points

5.4.75 The following table lists the relevant test points.

Test point	*Test level*	*Life cycle stage*
SIO3	Subsystem	Factory: acceptance test Pre-operational: site commissioning Operational: preventive maintenance

Test methods

5.4.76 For amplitude systems, the error pattern is measured as the ratio of the log of the sum pattern to the difference pattern at specified azimuth points. Typically BITE and/or test sets will be used to verify the OBA. In some systems, direct output of the OBA signal itself is provided.

Presentation of results

5.4.77 As prescribed in the manufacturer's setting-up procedures. Typically, using error diagrams and/or "look-up" tables. Figure 5-13 is an example of an OBA evaluation.

Evaluation of results

5.4.78 As prescribed in the manufacturer's setting-up procedures.

Output power

Description

5.4.79 This parameter covers the transmitter power measured as mean and peak values and the associated spectrum in the waveguide or cable system between the antenna and the transmitter/receiver. Units of measure ment: normally dBW.

Pre-requirements

5.4.80 The antenna and waveguide/cable system must be fully installed. Further conditions as given in the manu facturer's documents.

Test points

5.4.81 The following table lists the relevant test points.

Test point	*Test level*	*Life cycle stage*
PIO7/SIO	Subsystem	Pre-operational: site commissioning, Operational: RTQC, preventive and corrective maintenance

Test methods

5.4.82 As prescribed in the manufacturer's documentation.

Presentation of results

5.4.83 As prescribed in the manufacturer's documentation.

Evaluation of results

5.4.84 As prescribed in the manufacturer's documentation.

Overload reaction

Description

5.4.85 To study the capability of the system to handle, in a controlled and predictable manner, the effects of plot overload. The transmission system employed to transport data from the radar site to the control centre or point of use will have an upper limit to the number of messages which may be transmitted. The reaction of the system to maximum above maximum plot load must be determined.

Pre-requirements

5.4.86 As given in the manufacturer's setting-up procedures.

Test points

5.4.87 The following table lists the relevant test points.

Test point	*Test level*	*Life cycle stage*
CIO1	System	Factory: type test
CIO3	System	Pre-operational: site commissioning, operational evaluation Post-operational: post mod, problem investigation

Test methods

5.4.88 Depending on the distribution of the traffic within the system coverage it may not be necessary to test this parameter throughout 360° of azimuth, in which case a sector of 90 to 180° would probably be sufficient. Objectives of an operational evaluation are to demonstrate and confirm the overload performance and to demonstrate to operational staff the correct load handling properties of the system.

Presentation of results

5.4.89 Graphical presentation, e.g. of the time in storage parameter as function of the number of targets (in the different sectors).

Evaluation of results

5.4.90 As given in the manufacturer's setting-up procedures.

Plot filter functions

Description

5.4.91 The various plot filter functions identified as surveillance processing boxes in Figure 2-3 are purely logical functions as opposed to physical pieces of equipment packaged separately from the surrounding equipment. Indeed the function may well be a software routine within the equipment.

5.4.92 The filter functions performed vary with the processing stage, however, they can be classified into the following generic groups: data reduction and data correction functions.

5.4.93 Data reduction filters may be of the type, e.g. high, low or band pass or stop such as:

a) dynamic “angel” limiter;

b) reflection suppression; and

c) data rate control.

5.4.94 Data correction filters perform a transformation on the input data such as tracking. Evaluation of the radar system must establish the correct functioning of any such filters incorporated into the system.

Pre-requirements

5.4.95 Hardware or software access to the filter function under test must be available. The rest of the system should be in a stable operating state.

Test points

5.4.96 The following table lists the relevant test points.

Test point	*Test level*	*Life cycle stage*
PIO6	System and/or sub-system	Factory: type tests, factory acceptance Pre-operational: site commissioning, operational evaluation Operational: RTQC
SIO6	System and/or sub-system	Factory: type tests, factory acceptance Pre-operational: site commissioning, operational evaluation Operational: RTQC
CIO6	System and/or sub-system	Factory: type tests, factory acceptance

Test methods

5.4.97 It is difficult to make specific recommendations here as the procedures employed are completely dependent on system architecture. However, this document can give general guidance in methods of testing the generic filter functions mentioned above.

5.4.98 These filters make counts in separate categories of the plots and/or track messages entering and leaving the filter so as to establish the filter characteristics.

5.4.99 The type of plot must be known and other relevant parameters such as range/azimuth/flight level/Mode A code/time, etc., may be required. It is essential that notes are kept of the filter criteria during data collections.

5.4.100 The duration of the data collection is generally dependent upon LCS. During data collection it is recom mended to visually observe the output of the system under test (for multi-radar system this implies having one observer per radar). This should enable any anomalies which may have been noted to be given special attention during the data analysis phase.

Presentation of results

5.4.101 As prescribed in the manufacturer's setting-up procedures.

Evaluation of results

5.4.102 As prescribed in the manufacturer's setting-up procedures.

Plot load

Description

5.4.103 A system will normally be specified as being able to process a certain data load in relation to a certain number of plots per scan, per second or per azimuth sector. Units are usually expressed as a mean number of plots per second or scan, together with sector peaks of a number of plots in a specified azimuth sector.

Pre-requirements

5.4.104 The subsystem and related system under test are in a stable operating configuration. Further conditions as given in the manufacturer's documents.

Test points

5.4.105 The following table lists the relevant test points.

Test point	*Test level*	*Life cycle stage*
PIO5/PIO6	Sub-system	Factory: acceptance test Pre-operational: site commissioning Operational: RTQC
SIO5 and SIO6	Sub-system	Pre-operational: site commissioning
CIO1 and CIO2	Sub-system	Pre-operational: site commissioning
RIO1 and RIO2	System	Pre-operational: site commissioning, Operational: RTQC

Test methods

5.4.106 *Test equipment.* A means of counting the plots at input and output of the system is required.

a) This may be a computer programme running in an off-line machine. If dual channel equipment is available it may be possible to programme the plot processing equipment in the channel not under test to count and display the number of plots.

b) From modem-based transmission mediums it may be possible to use a data analyser to count message types.

c) For testing sector peaks and high plot load specification it is advisable to use a "simulated plot" generator (plot simulator).

d) BITE may be used for the RTQC measurements of plot load by measuring the number of plots per scan for various plot types and channels; and

5.4.107 *Test procedure.* The procedures to apply are really equipment dependent; it is recommended that the manufacturer's maintenance documentation be consulted for the appropriate test procedure. It is recommended that measurements made at the control centre (RIO2) should include any weak points in the system such as multiplexers/de-multiplexers.

Presentation of results

5.4.108 As given in the manufacturer's documents.

Evaluation of results

5.4.109 As given in the manufacturer's documents.

Pulse timing

Description

5.4.110 The measurement of this parameter covers the determination of the characteristics of the following clock timing:

a) range clock;

b) range sync or zero range trigger;

c) PRF sync (may be same as range sync);

d) azimuth clock — if an azimuth count pulse system is employed; and

e) range azimuth gateing.

In modern systems the gateing would normally be under programme control, either hardware or software, and used to control various system functions, such as STC/GTC, beam selection, blanking, CFAR parameters.

Pre-requirements

5.4.111 As given in the manufacturer's setting-up procedures.

Test points

5.4.112 The following table lists the relevant test points.

Test point	*Test level*	*Life cycle stage*
PIO8/SIO8	Unit	Factory: acceptance test Pre-operational: site commissioning Operational: RTQC, preventive and corrective maintenance

Test methods

5.4.113 An oscilloscope and frequency counter are essential items of test equipment. RTQC checks on the PRF and range clocks should check the pulse repetition intervals and the drift with time of the PRI. Range azimuth gateing function should be set up at the site commissioning stage according to the manufacturer's instructions.

Presentation of results

5.4.114 As given in the manufacturer's setting-up procedures.

Evaluation of results

5.4.115 As given in the manufacturer's setting-up procedures.

STC/GTC

Description

5.4.116 It is normal to apply gain control which varies with range sensitivity time control (STC) to the radar receiver, usually at the RF and/or IF stages. The parameter is a check that the required control laws are being applied at the required points in the receiver. The STC/GTC laws may require modification during the lifetime of the system to accommodate changes in the topography and radar environment near the radar. The STC/GTC laws to be applied depend on the system design and requirements. In modern radar systems, STC/GTC is often derived from ground clutter maps.

Pre-requirements

5.4.117 As given in the manufacturer's documentation.

Test points

5.4.118 The following table lists the relevant test points.

Test point	*Test level*	*Life cycle stage*
PIO3/SIO3	Unit	Pre-operational: site commissioning

Test methods

5.4.119 Using test aircraft with calibrated transponders, e.g. flying at FL 100 for TMA and FL 300 for en-route or as close to these altitudes as operationally possible. Recording and examination of the received signal strength during inbound and outbound radial passages.

5.4.120 In cases where the target run length parameter is available, the distribution as function of range (R) is to be used to support the STC/GTC setting.

a) For SSR, the STC/GTC setting is usually a function of R^{-2}; and

b) for PSR, the STC/GTC setting is usually a function of R^{-4} or might be adapted to the clutter distribution up to R^{-7}.

Presentation of results

5.4.121 The STC/GTC setting is usually expressed as resulting signal strength versus range. A correct STC/GTC setting will give a reasonably constant signal. Refer to manufacturer’s documentation for further information.

Evaluation of results

5.4.122 Note that the STC/GTC setting heavily influences both probability of detection and the false target rate. Consequently, this evaluation shall be repeated if a new STC/GTC setting has been made. Refer to manufacturer’s documentation for further information.

Spectrum analysis

Description

5.4.123 This testing covers the determination of the RF signal spectrum measured in the waveguide or cable system between the antenna and the transmitter/receiver. The RF signal shall be checked for bandwidth, side-lobe level, and level of harmonics and in the case of SSR, for its compliance with Annex 10.

Pre-requirements

5.4.124 The antenna and waveguide/cable system must be fully installed. Further conditions as given in the manufacturer’s documents.

Test points

5.4.125 The following table lists the relevant test points.

Test point	*Test level*	*Life cycle stage*
PIO7/SIO7	Subsystem	Pre-operational: site commissioning Operational: corrective maintenance

Test methods

5.4.126 As prescribed in the manufacturer’s documentation.

Presentation of results

5.4.127 As prescribed in the manufacturer's documentation.

Evaluation of results

5.4.128 As prescribed in the manufacturer's documentation.

TABLES FOR CHAPTER 5

Table 5-1. List of general performance parameters

General performance characteristic	*Paragraph*
Accuracy	5.3.2
Alignment PSR-SSR	5.3.8
Combination rate	5.3.18
Coverage	5.3.29
Data transmission inventory	5.3.58
False target rate	5.3.64
Geographic alignment	5.3.86
Inventory	5.3.94
Probability of detection (P_D)	5.3.100
Random errors	5.3.130
Resolution	5.3.145
Systematic errors	5.3.158

Table 5-2. List of detailed technical performance parameters

Detailed technical performance characteristic	*Paragraph*
Antenna performance	5.4.2
Bandwidth	5.4.13
Correlation interpolation	5.4.19
CFAR performance	5.4.25
Data transmission line performance	5.4.31
Extraction criteria	5.4.36
False alarm rate	5.4.42
Filter response	5.4.50
Losses	5.4.57
Minimum detectable signal (MDS)	5.4.63
Off-boresight angle (OBA)	5.4.69
Output power	5.4.79
Overload reaction	5.4.85
Plot filter functions	5.4.91
Plot load	5.4.103
Pulse timing	5.4.110
STC/GTC	5.4.116
Spectrum analysis	5.4.123

FIGURES FOR CHAPTER 5

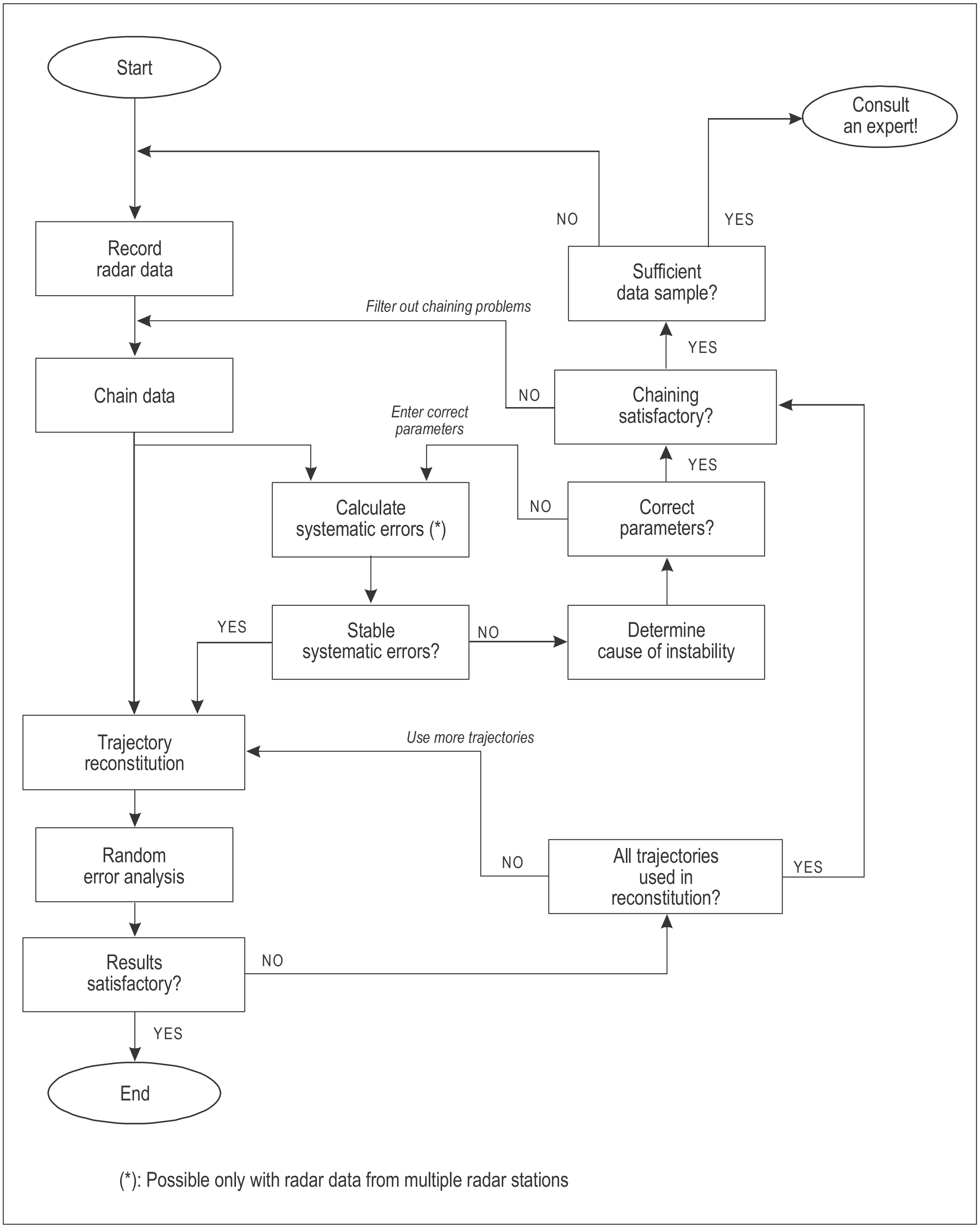

Figure 5-1. General accuracy analysis event flow

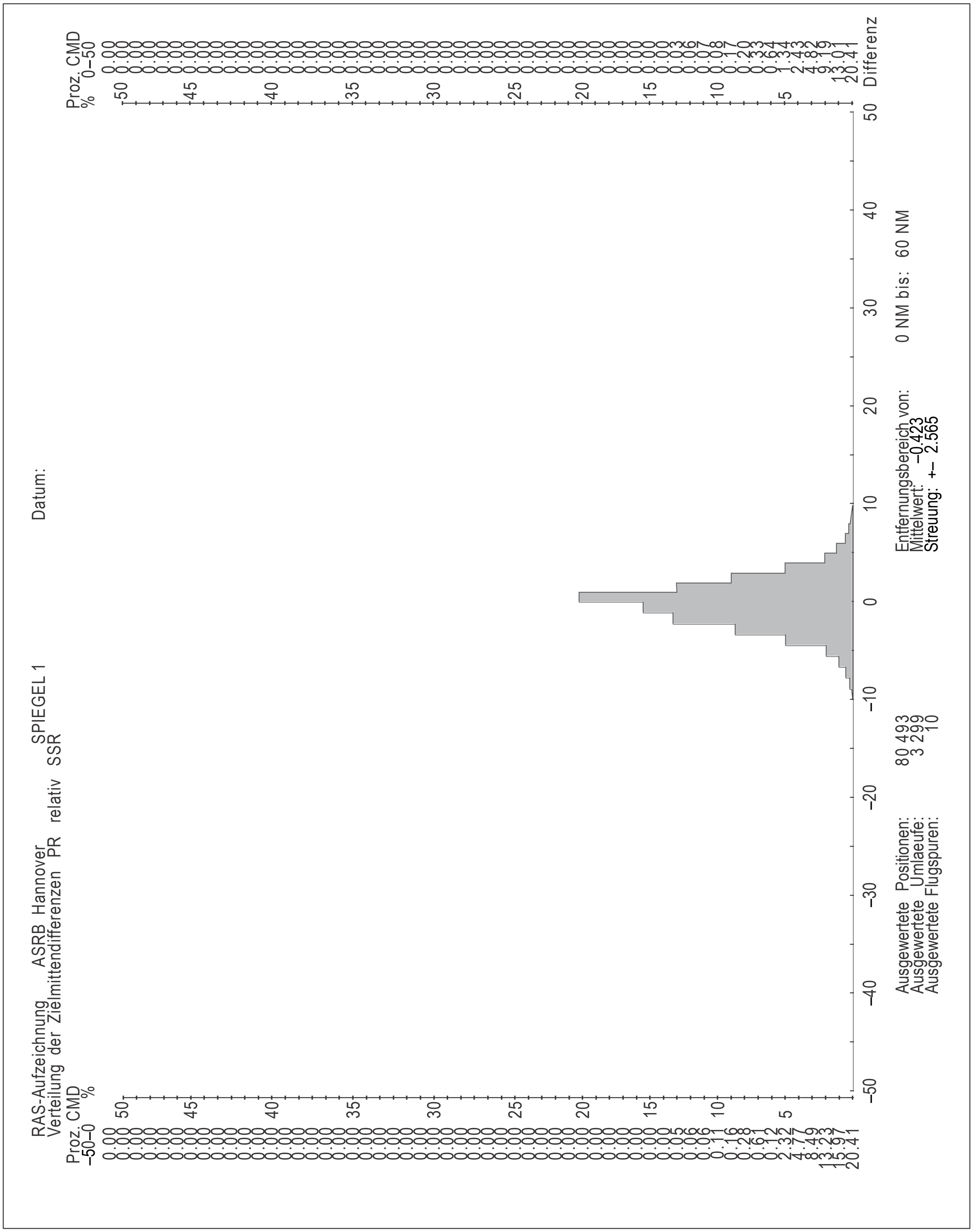

Figure 5-2. Example of an alignment check evaluation

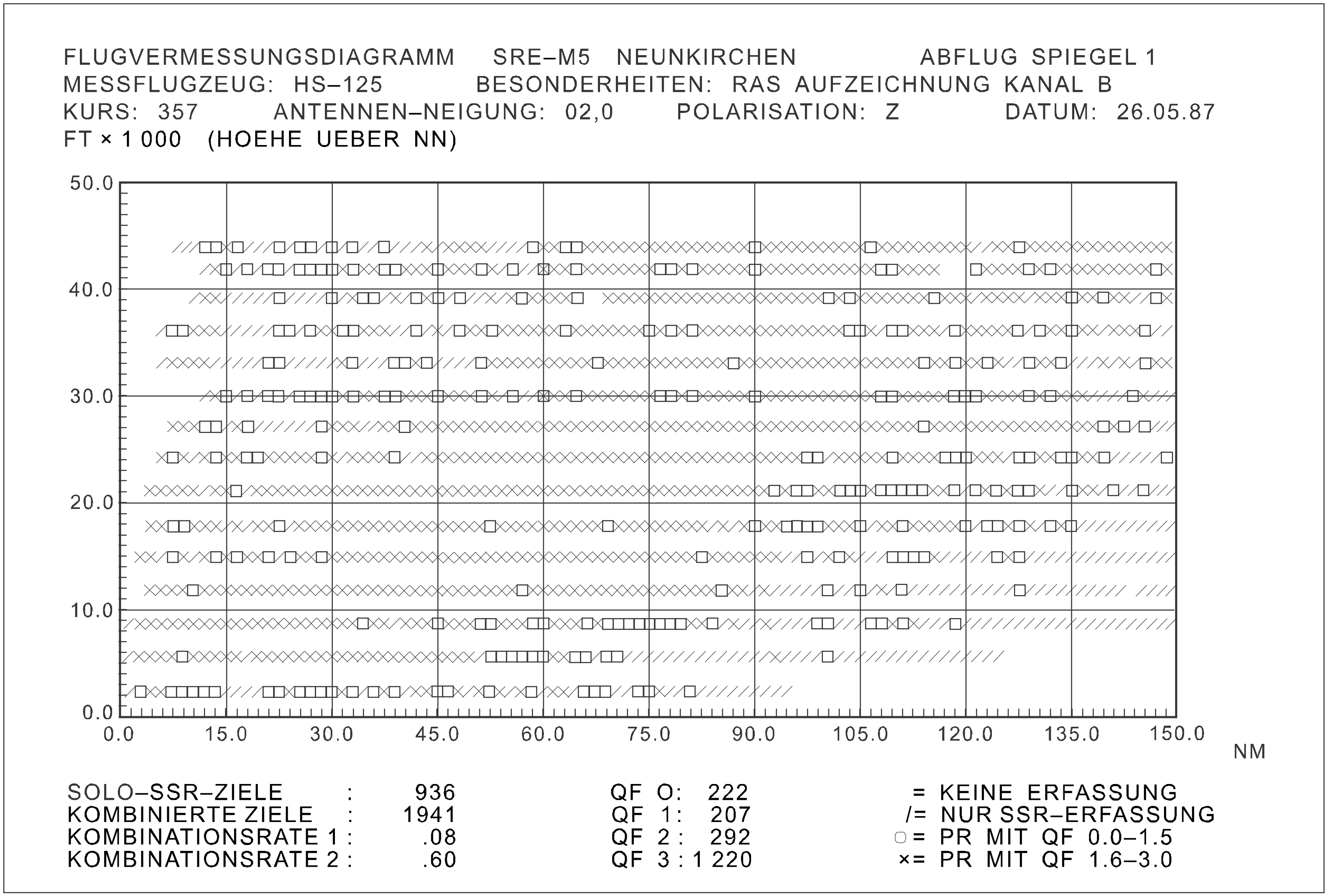

Figure 5-3. Example of a combination rate evaluation

Note.— The "/" sign denotes cases with SSR-only detection, "O" refers to cases where combination was possible, but with reduced quality.

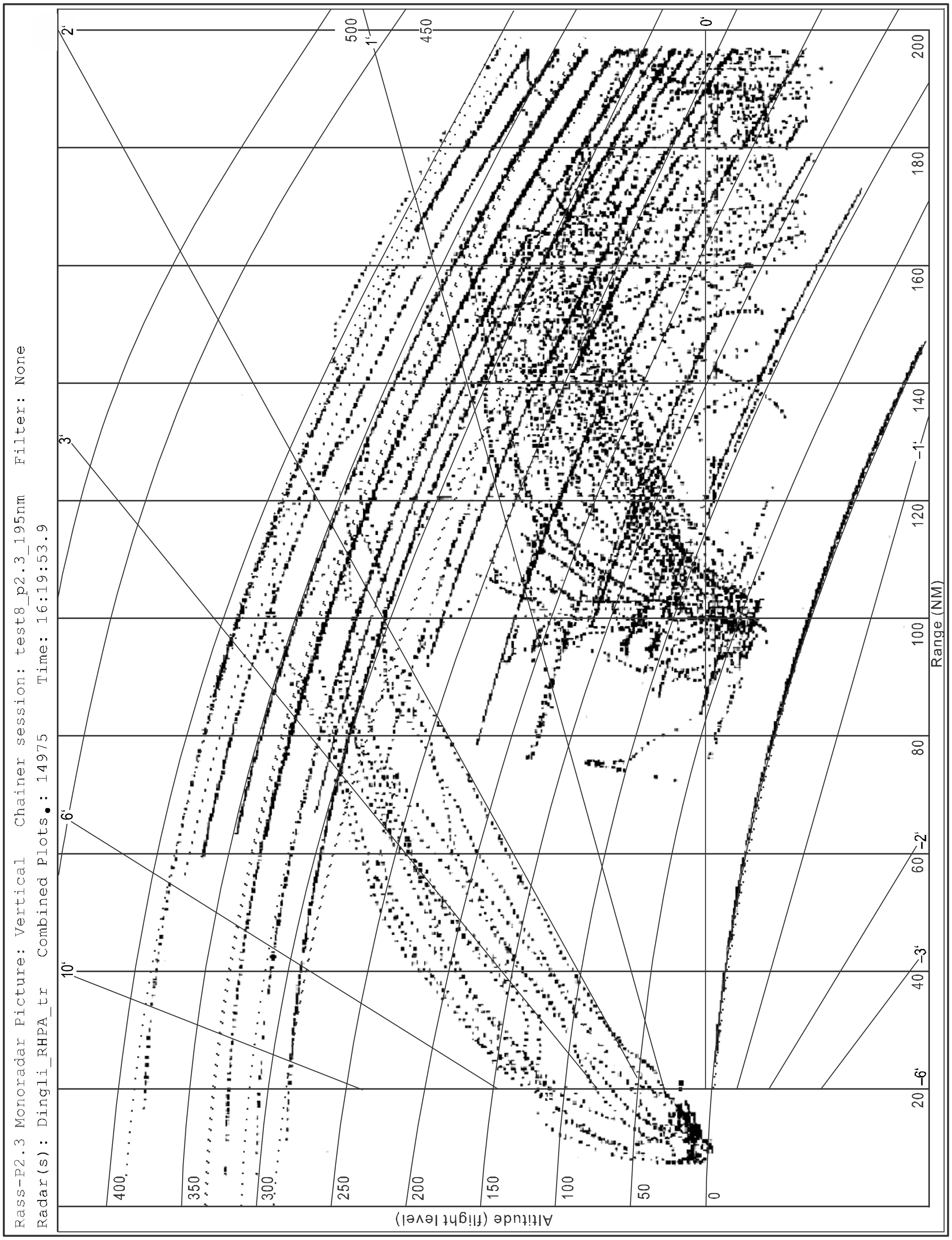

Figure 5-4. Example of a coverage limit evaluation

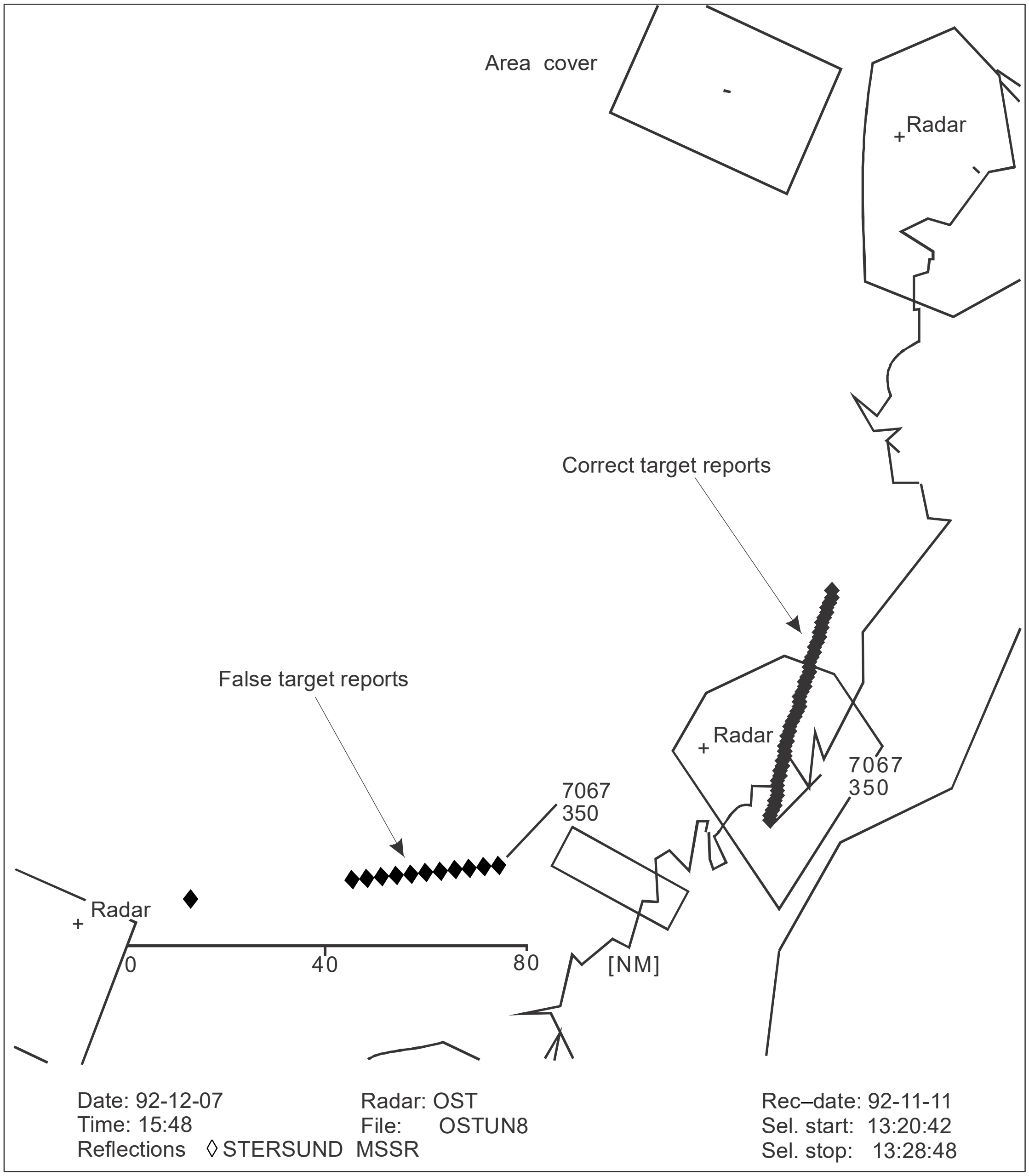

Figure 5-5. Example of a false target analysis evaluation

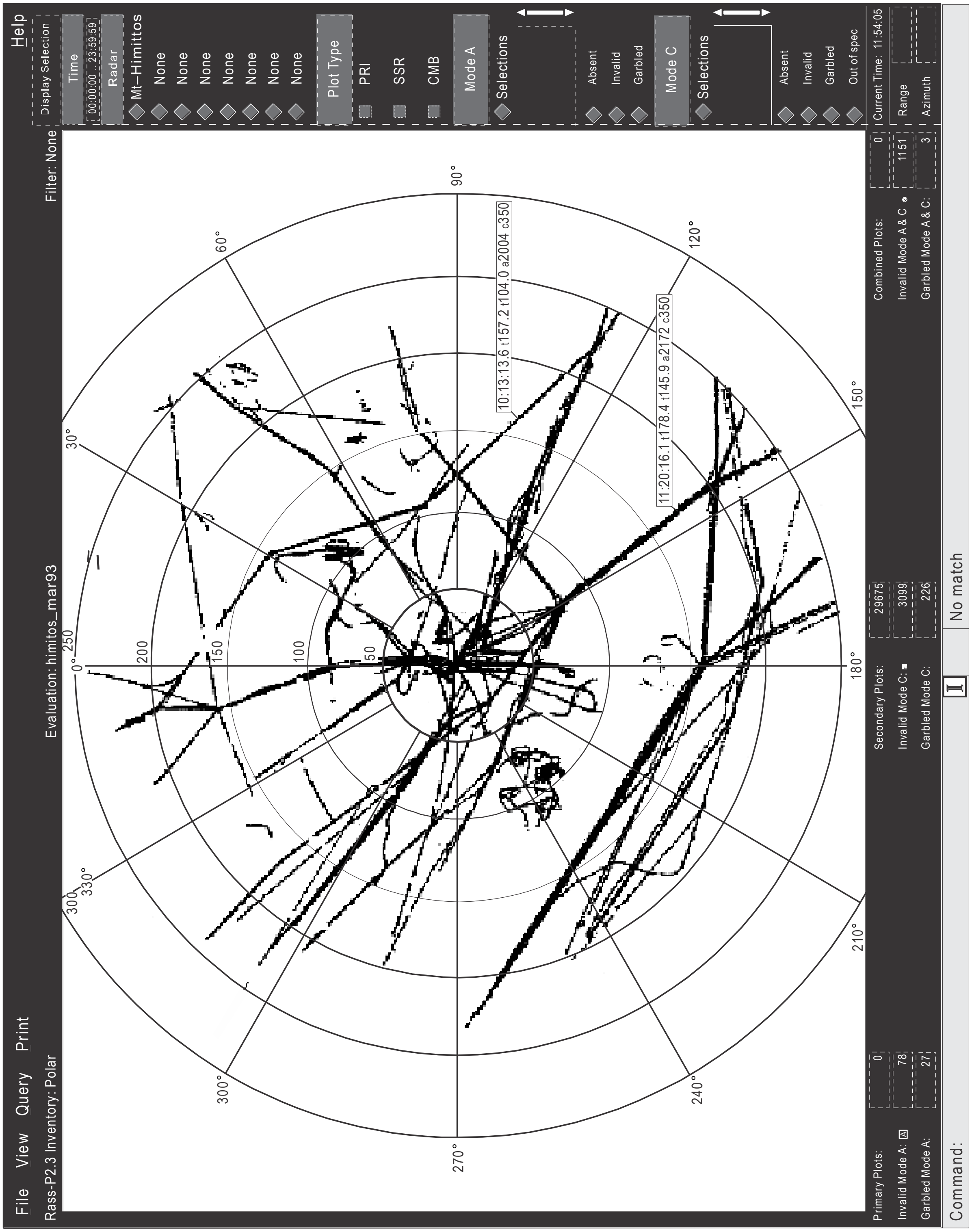

Figure 5-6. Example of a data inventory (polar diagram)

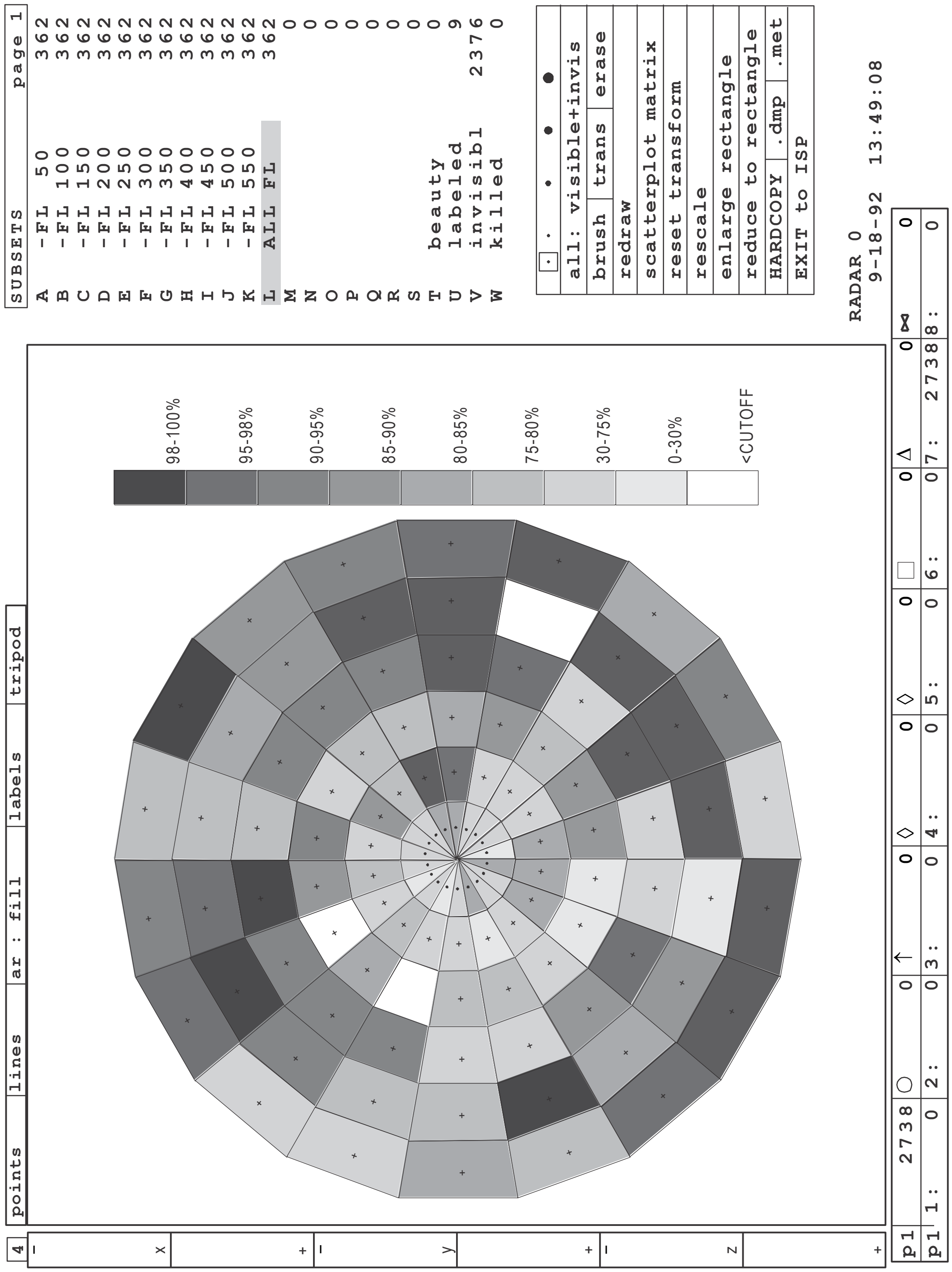

Figure 5-7. Example of an evaluation of the probability of detection

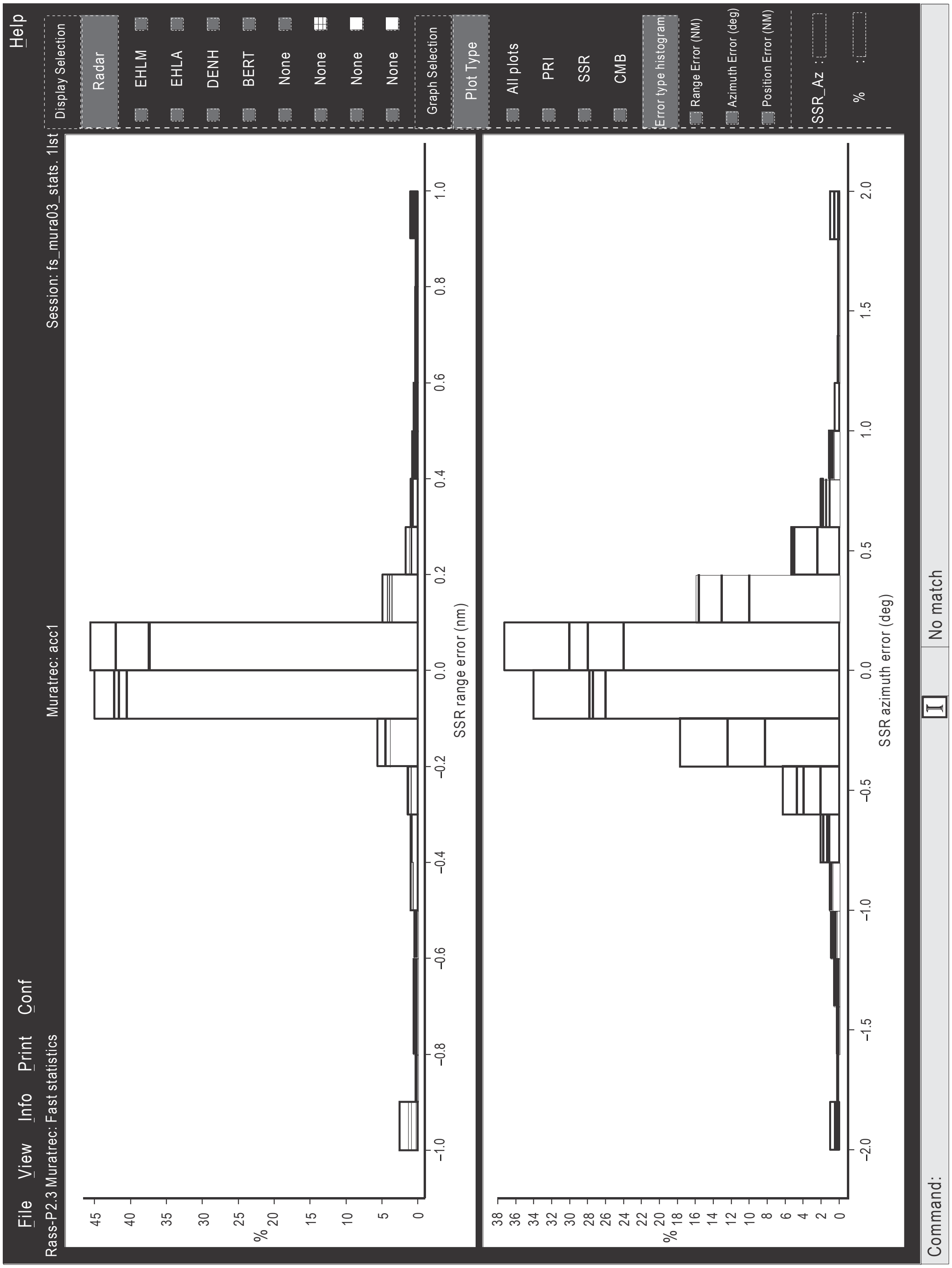

Figure 5-8. Example of a residual random error distribution

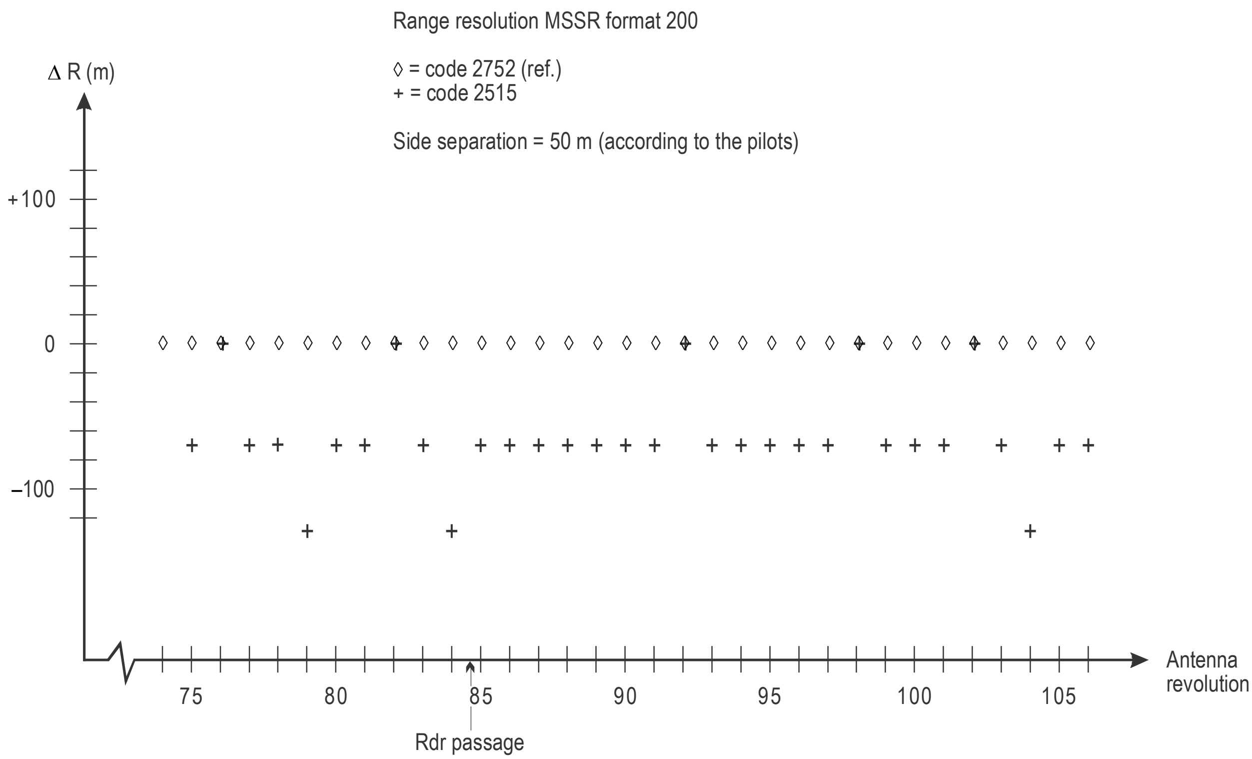

Figure 5-9. Example of a range resolution investigation

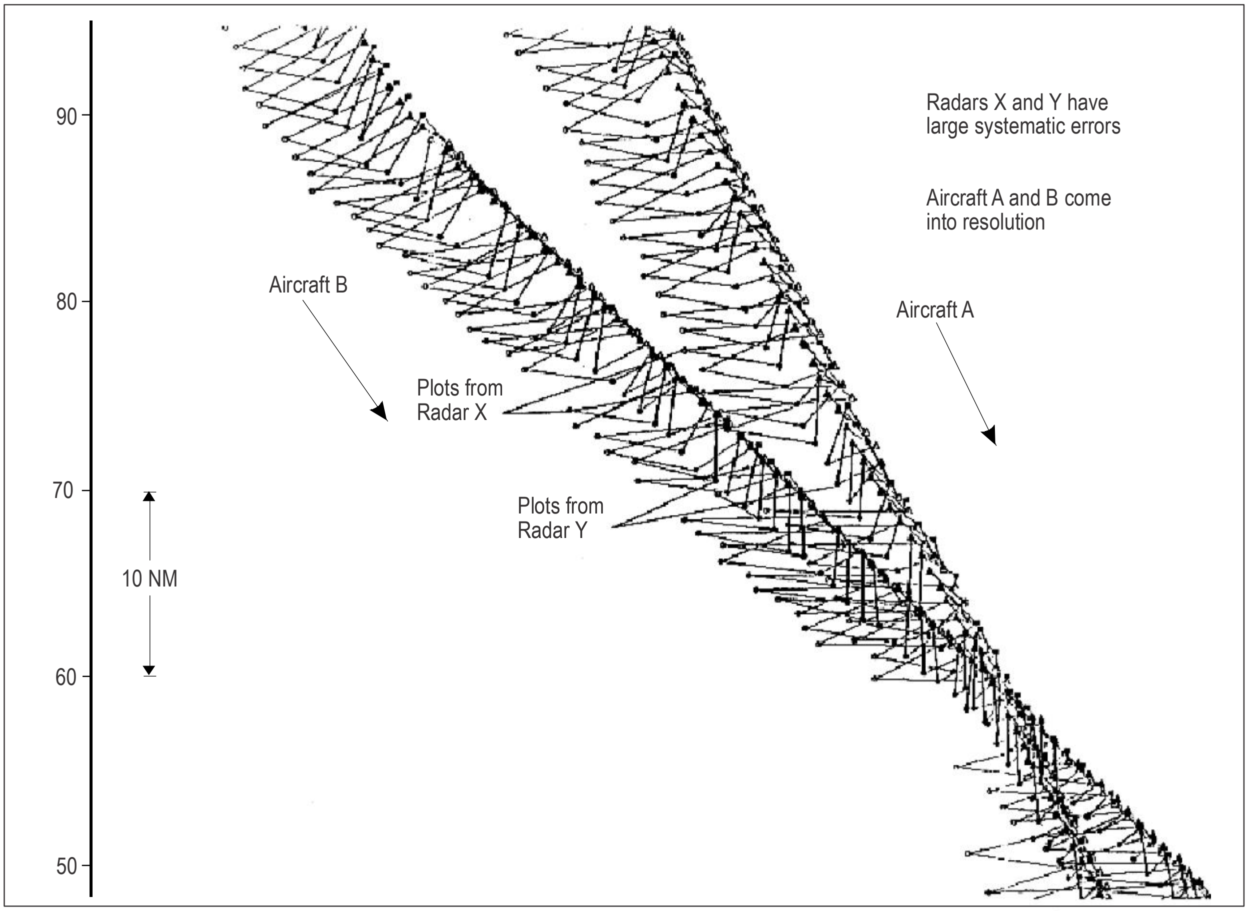

Figure 5-10 a). Multi-radar plot messages for two aircraft before correction of systematic errors

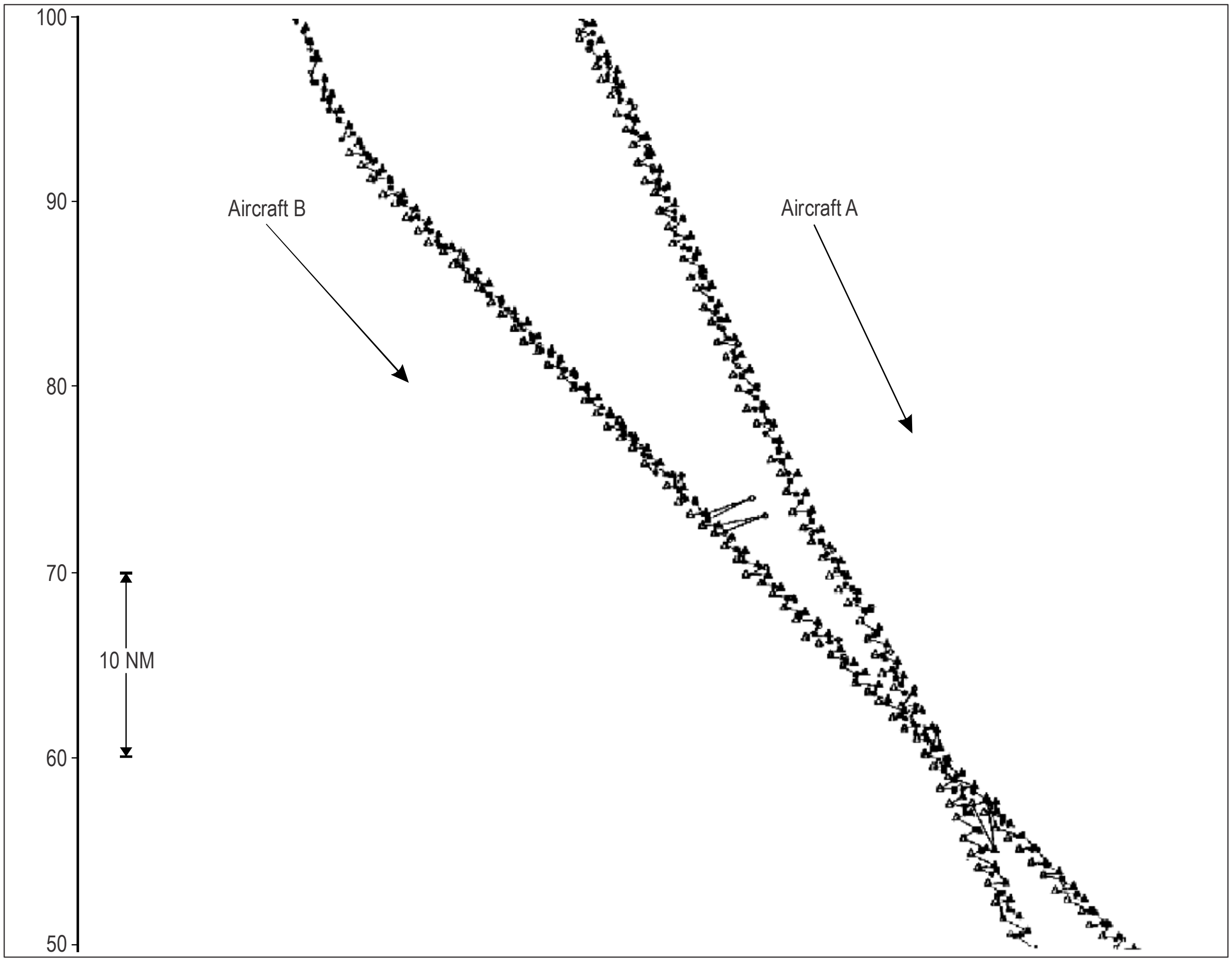

Figure 5-10 b). Multi-radar plot messages for two aircraft after correction of systematic errors

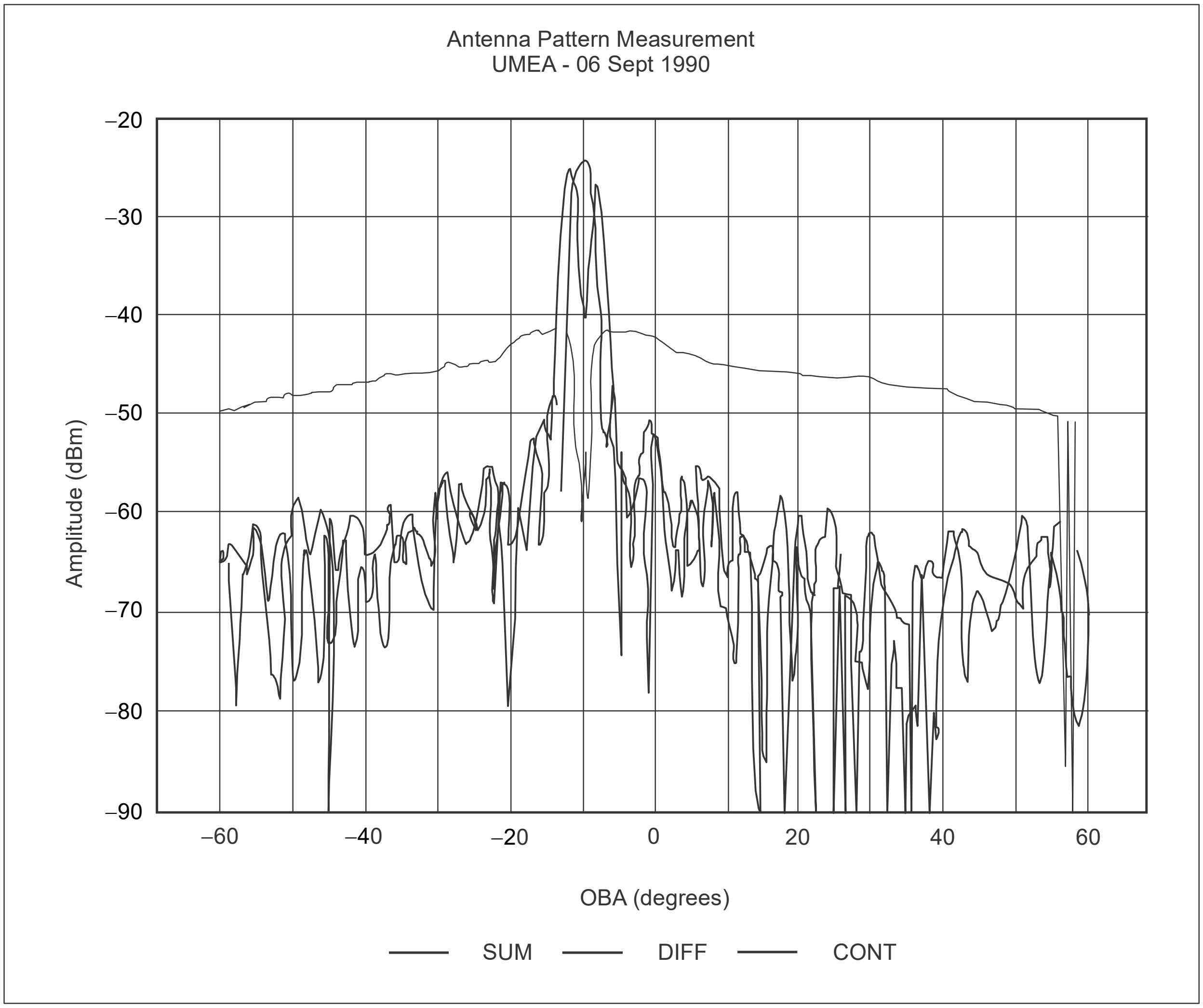

Figure 5-11 a). Example of an antenna pattern measurement

Note.— This figure illustrates an example of a semi-automated procedure to establish the approximate range resolution of a monopulse SSR system. The aircraft, with matched transponders, fly at a constant range separation (approximately 50 m) at the same height and at a tangential heading to the radar. The plots, with correct Modes A and C, were detected.

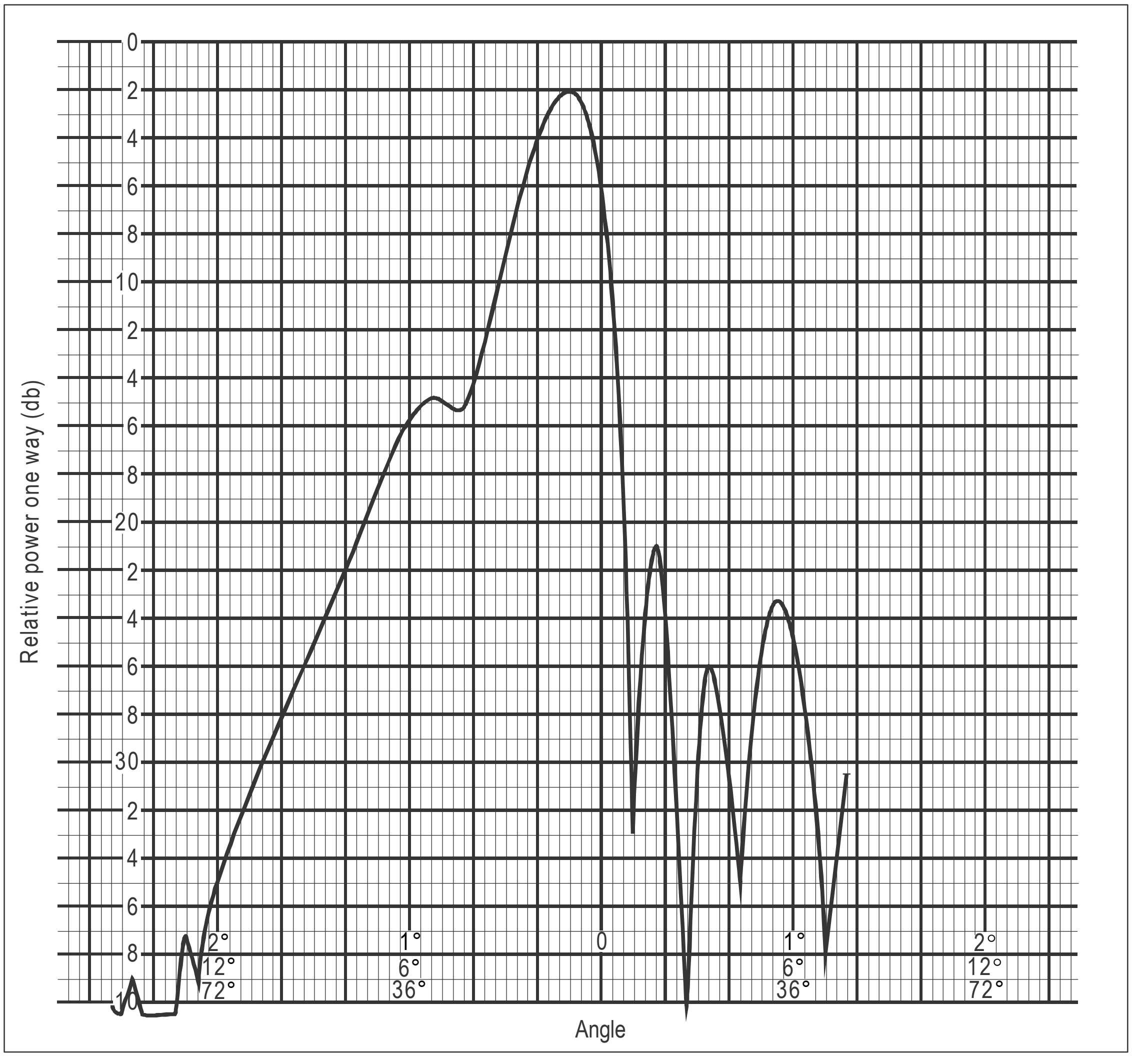

Figure 5-11 b). Example of a vertical polar diagram measurement

Note.— This figure illustrates an example of a semi-automated procedure to establish the approximate range resolution of a monopulse SSR system. The aircraft, with matched transponders, fly at a constant range separation (approximately 50 m) at the same height and at a tangential heading to the radar. The plots, with correct Modes A and C, were detected.

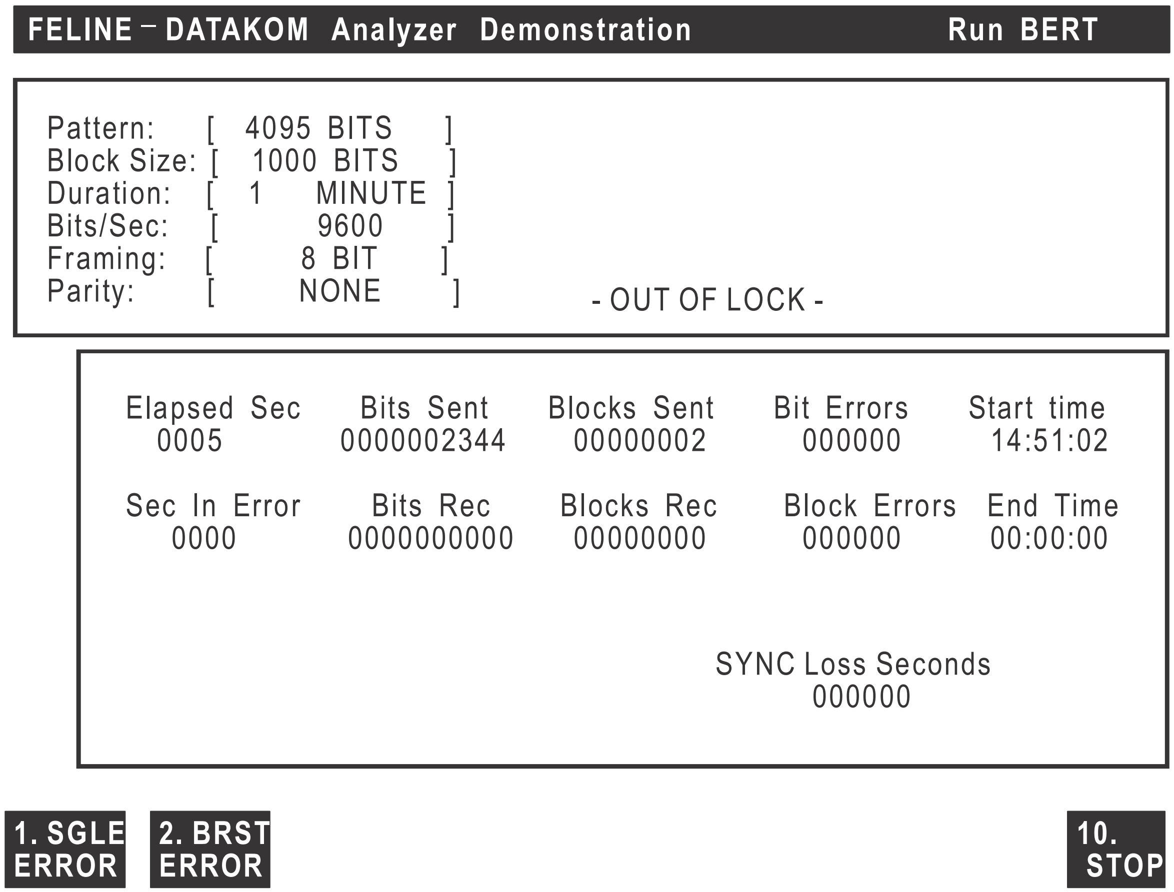

Figure 5-12. Example of a transmission line check result

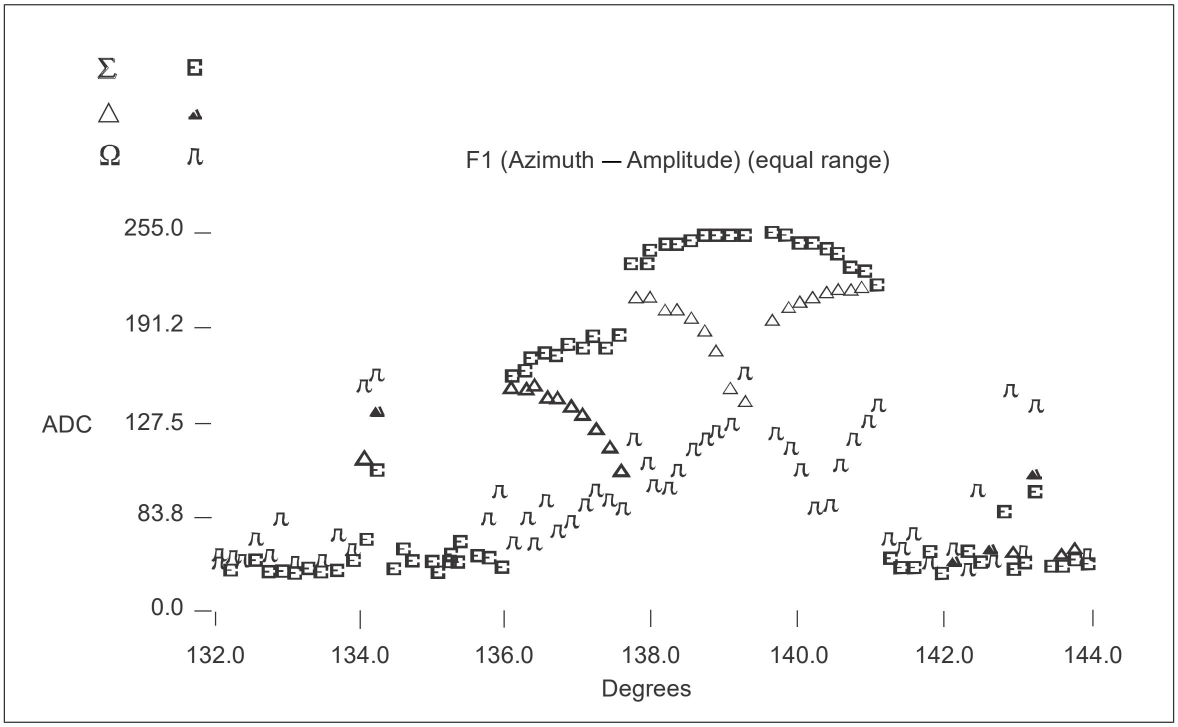

Figure 5-13. Example of a sum/difference pattern for a two-target situation

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Chapter 6

IMPACT OF RADAR PERFORMANCE ON THE OPERATIONAL USE OF RADARS

6.1 GENERAL

6.1.1 It is obvious that the performance of the various elements in the total so-called radar processing chain (antenna, receiver/ transmitter, extractor and subsequent processing, as well as centre data processing) have an important impact on the operational use of the displayed processed radar information. The radar separation minima that may be applied are directly related to the quality of the radar data. A lower quality of the processed radar data results in a lower confidence in the displayed present and possibly past radar derived aircraft positions.

6.1.2 This chapter discusses the relationship between the radar separation minimum and the various radar performance characteristics, with particular emphasis on accuracy.

6.2 OUTLINE OF THE IMPACT OF RADAR SYSTEM CHARACTERISTICS ON THE RADAR SEPARATION MINIMA

General considerations

6.2.1 Radar separation is hardly ever applied on the basis of the actually displayed radar positions alone. Four radar derived elements are also important in this context:

a) the size and direction of the two speed vectors (when provided);

b) recent history of potentially conflicting trajectories (e.g. history dots);

c) predicted future separation on the basis of the speed vectors; and

d) possible conflict warnings provided by a short-term conflict alert (STCA) facility.

6.2.2 For the *determination of the radar separation minimum* only the *accuracy of the displayed aircraft positions* is of importance; and for the *application of radar separation* by the controller other factors such as the *accuracy of the speed vector* are also of importance. Important in this context also are the amount of traffic (and traffic density) and the amount and rate of false tracks.

Requirements for radar coverage

6.2.3 For civil ATC, the following conditions apply:

a) separation control is applied only to transponder-equipped aircraft (including Mode C);

b) the transponder, once the aircraft is within the coverage of the SSR station, is able to provide sufficient replies to interrogations in order to allow the detection of a *plot* (i.e. the transponder shall not be blocked due to over-interrogation of, e.g. military IFF interrogations or various types of interference); and

c) the SSR performance is under all conditions such that certain minimum quality benchmarks are fulfilled.

6.2.4 In the case that separation has also to be assured between aircraft which have no transponder or do not always have their transponder switched on, the availability of PSR coverage also becomes mandatory.

6.2.5 An overlap of the coverage of at least two radars in the airspace carrying major streams of air traffic appears to be a minimum requirement. From a reliability point-of-view, one may consider that many radar stations consist of two autonomous radar systems (at least for the SSR), since the complete SSR chains are often duplicated (antenna, drives, transmitters, extractors, plot processors). A stand-by radar may, in this sense, be considered as the minimum requirement. Many recent radar stations, such as most monopulse SSR stations, have only one antenna, but have further fully duplicated electronics, including the extractors. Of course, this increases the availability but does not fulfil the necessary requirement for coverage redundancy.

6.2.6 With respect to the question of a possibly required double coverage in PSR, it should be noted that there are two specific requirements for the presence of PSR, i.e. to assure separation of non-SSR equipped aircraft and to provide back-up during SSR loss in manoeuvres. From a civil ATC point of view, these two points do not justify a double PSR coverage. Temporary loss of the PSR cover age can be coped with by giving special attention to problem areas and by imposing operational restrictions to non-SSR equipped aircraft. It should be stated in this context that antenna screening due to manoeuvring very rarely results in a loss of the SSR data for two different radar stations simultaneously.

6.2.7 A special problem exists with respect to the cone-of-silence of radar stations. Considering the limited size of the areas in question and their known positions, it appears sufficient to impose, as a supplementary requirement, that the cone-of-silence of radars is at least covered by single SSR.

6.2.8 Required performance characteristics of the displayed radar information in order to allow the use of the required separation minima are discussed in the next section. This discussion considers performance in relation to the type of radar data processing in use and the amount of available radar overlap.

The impact of the performance characteristics of the displayed radar information on the radar separation minimum

Basic considerations

6.2.9 The radar characteristic of dominating importance for the radar separation minimum is the accuracy of the displayed radar information. Although not specifically mentioned by the relevant ICAO documents, the accuracy is, for any given situation of two aircraft, directly related to the extent to which the displayed separation D(t), at a given time t, represents the real separation of the two air craft at the same time t, d(t).

6.2.10 The accuracy of a displayed aircraft position and therefore implicitly of D(t) is influenced by a number of factors such as:

a) the errors in the measured radar plot position;

b) the possible use of a tracking filter and, if this is the case, the type of tracking used;

c) the “age” of the displayed information, i.e. the time passed since the last update; and

d) possible errors in the display system.

6.2.11 With respect to point d), it has been demonstrated that, for modern display systems, the errors introduced in the displayed aircraft position may be neglected with respect to the errors introduced due to the three other reasons mentioned above.

The impact of the plot performance characteristics and plot accuracy

6.2.12 The errors in the measured plot positions can be categorized mainly in two different types:

a) systematic errors; and

b) residual (random) errors.

6.2.13 The impact on the separation minimum depends largely on the type of error in question.

a) *Systematic errors* have only an impact on D(t), when the two aircraft positions are derived from different radars (or different combinations of radars). All important systematic errors may be estimated with advanced radar evaluation programmes. Quite often also the multi-radar data processing system in use disposes of provisions to estimate and correct the systematic errors. It is, therefore, assumed that the necessary radar error corrections have been made; and

b) *Residual (random) errors* are generally of a pure gaussian nature and are practically completely de-correlated in size and direction from antenna scan to antenna scan. Their impact on the separation minimum is, in general, smaller than that of correlated errors.

6.2.14 In addition, correlated errors can be identified, which provide, in general, a scan-to-scan correlation in the direction and/ or size of the errors. Therefore, an aircraft flight path may be indicated which is in fact not correct. Correlated errors have two main causes, i.e. so-called multi-path and partial loss of radar resolution. It may be argued that aircraft which need to be separated are in close proximity and roughly at the same flight level. Correlated errors which are caused by multi-path will consequently have, in general, about the same size and the same direction. Their impact on the separation to be applied is, therefore, small.

6.2.15 Much more severe are errors caused by partial *loss of resolution*, i.e. cases where two targets are detected but not with their real separation. Certain types of extrac tor systems operate such that the displayed separation appears to be larger than the real separation. Such a situation may exist for several consecutive antenna scans. The duration of this situation will depend on the *relative* speed of the two targets.

6.2.16 The displayed separation of two aircraft may furthermore be dangerously affected in case a third air craft, possibly at a completely different height, is in resolution conflict with one or both of the two aircraft in question. Evidence exists about near misses caused by this situation.

6.2.17 Certain solutions have been found against resolution problems. However, even recent monopulse extractor systems suffer in certain conditions from dangerous resolution problems.

6.2.18 When using conventional SSR (including mono pulse SSR), the only almost complete countermeasure against resolution problems can be acquired with the use of multi-radar information. An “intelligent” use of multi-radar plot information allows the allocation of a low weighting to positions affected by resolution loss and appropriate weighting to the non-affected positions. The basis of this logic is the fact that resolution problems generally only occur for aircraft separated mainly in azimuth alone, with, at the same time, only a small difference in range. Such situations rarely exist for two radars at the same time and if they exist, they last only for a very limited period.

6.2.19 In summary, it appears that a generally reliable solution for the resolution problem can only be provided with Mode S, where selective addressing of targets, proper scheduling and separate periods for SSR and Mode S guarantee that replies of targets close to each other are not garbled.

The impact of plot-processing and tracking

6.2.20 There is a considerable number of different types of plot post-processing systems in use at the level of ATCC and radar sites.

6.2.21 RDPS serving only as a filter for certain categories of false plot information and as a chaining facility for successive plots belonging to a given aircraft trajectory have little impact on the considerations outlined in the previous section. Plots with large positional jumps are filtered out by this logic. However, plot position errors due to loss of resolution are generally not of such a size that they are eliminated by the filter logic and the related plots are, therefore, displayed.

6.2.22 Tracking filters providing smoothed positions have, in general, a four-fold effect on the displayed aircraft positions. These effects are:

a) filtering-out of large positional errors;

b) increase of the correlation in positional errors;

c) change of the nature of the distribution of the positional errors; and

d) delay in the detection of aircraft manoeuvres.

Furthermore, the tracking provides, in general, information about the speed vector of the aircraft and may, in certain cases, even provide information on their mode-of-flight.

6.2.23 Large positional jumps not falling within the tracking window are eliminated and therefore not visual ized as track positions. An extrapolated position may be created instead.

6.2.24 Large positional errors falling within a tracking window have an impact on the size and direction of the errors for a number of successive subsequent antenna scans and will therefore create more correlation in the positional errors. Correlated positional errors existing in the plot information, on the other hand, will be reduced in size by the same mechanism.

6.2.25 In general, it has been found that a well-tuned radar tracker has, at its output, positional track errors with maximally the same standard deviation as the errors of the incoming plot information. The distribution will, however, be more like a standard gaussian distribution (i.e. the tails have been cut off, the central part has become more pronounced).

6.2.26 Aircraft manoeuvres will, due to the filter, generally create track position off-sets (track positions are often "lagging behind"). The size of the off-set is a function of the plot-noise (credibility of the plot data), the radar update rate and the characteristics of the tracking filter itself. Certain tracking logics follow the aircraft manoeuvres better than others. Important in this context is also the use of multi-radar information in the tracker process. The proper use of multi-radar data provides two main advantages:

a) increase the radar update rate, therefore, better detection and following of manoeuvres; and

b) the possibility of de-correlating correlated errors.

6.2.27 A disadvantage of the use of multi-radar is the risk of an increase in track noise due to possible existing, not corrected or residual systematic radar errors (radar positions, range, azimuth and time).

6.2.28 In summary, one may state that the accuracy of the positions resulting from a tracking filter are determined by the accuracy of the incoming plot information, the type of aircraft manoeuvres and the level of sophistication of the radar data processing.

6.2.29 Aircraft manoeuvres may be categorized by transversal and longitudinal accelerations.

6.2.30 Meaningful tracking performance parameters have been defined which are also significant in the context of radar separation.

6.2.31 With respect to extrapolated track positions, special care must be exercised when applying radar separation. The next paragraph discusses somewhat further the issue of separation on normal and extrapolated track positions.

The impact of the "age" of the displayed radar information

6.2.32 In cases where monoradar plot information is dis played, it should be noted that this information is only updated once per antenna revolution. The displayed information may, therefore, represent aircraft positions which are up to one antenna revolution old. The age may be even larger in cases where plot misses occur. Successive plot misses occur generally with a higher probability than (1P_D). The availability of both PSR and SSR will improve this situation, since misses for SSR and PSR are quite often uncorrelated. During the time that the displayed information "ages", closely spaced aircraft may execute manoeuvres which decrease the separation.

6.2.33 In this context, it will be noted that a supplementary problem arises due to the fact that SSR plot misses for adjacent aircraft have a higher probability of being correlated.

6.2.34 In cases where tracking is applied, the impact of "aging" on the accuracy of the displayed position and separation will again depend on the type of tracking and the type of information being displayed.

6.2.35 The case of plot display after tracking shows important similarities to the case where plot information is displayed without tracking (with the exception that large positional jumps are eliminated). However, in the case where plot misses occur, these misses are, for certain systems, substituted by plots from fall-back radars. The use of extrapolated positions for radar separation is in general to be dissuaded in a pure monoradar (e.g. single SSR) situation, due to the risk of important unnoticed aircraft manoeuvres during plot misses. The situation is already different in the case where both PSR and SSR information is used. In general, uncorrelated misses in PSR and SSR make the risk of unnoticed, dangerous reductions in separation negligible. This situation improves even further when multi-radar data are used.

The notion of close-approach probability (CAP) and target level of safety (TLS)

6.2.36 The CAP is defined as the probability that two aircraft, which appear on the display to be separated by at least the separation minimum (>Ds), are in fact, so close together (<¯) that an accident is practically unavoidable. The CAP value can be assessed as a function of the Ds and ¯ values. Traffic studies for a given centre allow the transformation of the CAP into a TLS, which is defined as the number of close-approaches per unit of time (e.g. one close-approach per year). On the basis of traffic studies, this TLS may again be related to the number of close-approaches per hour of flight (similar to the ICAO review of general concept of separation's TLS value for the North Atlantic).

6.2.37 The CAP value may either be calculated from the error distributions of the displayed aircraft positions or be obtained directly from the error distribution of the reconstituted real distance between two aircraft.

6.2.38 The CAP is, therefore, a function of all elements contributing to the error in the displayed aircraft positions discussed above.

6.2.39 Within the European Organization for the Safety of Air Navigation (EUROCONTROL), studies have been made to assess which conditions, e.g. a 9 km (5 NM) separation minimum, may be safely applied considering all contributing error sources. These conditions are:

a) coverage requirements shall be at least those outlined in 6.2.3 above;

b) standard deviations of plot azimuth errors in a monoradar environment shall be equal to or less than 0.13 degrees for radars used up to a maximum range of 280 km (50 NM) and equal to or less than 0.11 degrees for radars used up to 370 km (200 NM);

c) in cases where monoradar information is used, the plot resolution capability shall be such that no situations are created where the displayed separation is considerably larger than the real separation. In cases where such resolution problems do occur, the radar separation minimum shall be increased to a value for which the particular resolution problem is either no longer possible or otherwise so un likely that this phenomenon cannot occur for several antenna revolutions successively;

d) the performance, other than the accuracy of the radar plot information, shall be at least as good as the benchmark values outlined in the EURO CONTROL Standard for surveillance systems;

e) for RDPS using plot displays, a fall-back radar is required to cover the cases of correlated plot misses; and

f) the resolution problems outlined in c) above may be compensated when a multi-radar data processing system is used, which makes appropriate use of a number of different radar sources. Resolution problems of a severe nature as described in c) generally occur for only one radar at a time.

Some considerations with respect to the impact of radar performance on the application of radar separation by the air traffic controller

6.2.40 Two further radar-related system characteristics are of importance for the application of radar separation by the controller. These are the past positions of the aircraft (afterglows) and the speed vector.

6.2.41 For the accuracy of the past radar positions, the same considerations apply as for the accuracy of the most recently displayed positions. Particularly important in this context are the possible correlated position errors, since these may provide a wrong impression about non-existing aircraft movements (e.g. apparent diverging tracks, when this is not the case).

6.2.42 The same effect applies here as has been described in 6.2.9, i.e. for systems suffering from correlated position errors, the minimum separation shall be increased. As discussed before, dangerous situations may only originate from particular resolution problems, which only occur when particular extractor systems are applied.

6.2.43 The accuracy of the speed vector is of importance for either the “mental” extrapolation by the controller predicting the likely occurrence of a conflict in the fore seeable future or for the accurate operation of an automatic short-term conflict alert facility. The speed accuracy depends, just like the positional accuracy, on three different elements:

a) the quality of the incoming plot information;

b) the behaviour of the aircraft to be tracked; and

c) the characteristics of the tracker.

Chapter 7

IMPACT OF TRANSPONDER CHARACTERISTICS ON RADAR PERFORMANCE

7.1 GENERAL

7.1.1 As SSR is a cooperative system, its over-all performance is determined by the transponder. Modern radars employing monopulse techniques will yield a much superior resolution of target clusters and more precise azimuth information. The success of this aspired improvement depends, however, upon the exact adherence to the tolerances for transponders stated in ICAO Annex 10, Volume IV.

7.1.2 Radars, slightly DATANET (or with wider tolerance bands) with respect to accepted reply pulse widths in order to detect non-complying transponders, will cause a reduced target resolution which is to be avoided. An excessive carrier frequency deviation of a transponder reply can also lead to an avoidable angular measuring error. Making such allowances to cater for a possible transponder non-compliance thus leads to a reduction in traffic capacity, as larger separations must be applied in the case of a reduced target resolution and/or positional accuracy.

7.1.3 In addition to these more surveillance-related aspects of transponder compliance, it is important to note the role of the SSR Mode S transponder in air-ground data link communications.

7.2. EFFECTS OF NON-COMPLIANT TRANSPONDERS

7.2.1 The effects of transponder characteristics on radar performance are widespread and, in the case of communication-related parameters, typically application-dependent. In order to highlight the potential effects of malfunction, Table 7-1* is provided.

7.2.2 It is pointed out that a strong interdependency for malfunctions of certain parameters exists; for example, one experience shows that an incorrect reply frequency often affects pulse width; furthermore, less advanced trans ponders with simple transmitter stages may suffer from an antenna mismatch as the result of a bad installation, often showing a significant reply frequency offset and thus reduced output power; but even for digital systems, a (rarely occurring) clock failure may equally affect all the timing parameters, like pulse width and pulse position.

Experience from transponder performance measurement campaigns

7.2.3 Mobile transponder performance testers were developed by some administrations. These test systems have been used in measuring campaigns at major airports in the past.

7.2.4 The experience gained from these campaigns may be summarized as follows:

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* Table 7-1 is located at the end of this chapter.

a) a non-negligible portion of transport aircraft were determined to have parameters out of tolerances. In total, figures in the order of 7 per cent were determined, and these figures increased further for air craft which were carrying non state-of-the-art equipment or were inadequately maintained;

b) for general aviation aircraft, the over-all performance figures obtained were generally lower than for commercial air transport aircraft reaching up to approximately 20 per cent of transponder faults; further experiments demonstrated the sensitivity of such transponders to incorrect external installation (e.g. antenna mismatch); and

c) more recent transponder installations (e.g. mostly digital Mode S transponders) showed typically better performance with respect to the "classical" areas of concern, like pulse timing values and frequency; however, what is becoming more vital with Mode S is the proper functioning of the logic of the transponder.

Nevertheless, the effect of such deficiencies on the operational use of the radar system is always hard to deter mine. In the light of the use of SSR Mode S not only for (enhanced) surveillance, but also for communication, the significance of ICAO concordant transponders is indisputable.

7.3. CONCLUSION

Due to the cooperative function of SSR, the performance figures determined for a radar system depend also on the proper functioning of the airborne equipment. This has to be taken into careful consideration when radar system parameters are assessed. Consequently, checks with flight check aircraft should be performed only after testing the appropriate operation of the transponder. When assessing performance parameters with opportunity traffic, reason able samples should be used to avoid individual installations to colour the statistics.

TABLE FOR CHAPTER 7

Table 7-1. Possible impact of transponder characteristics on SSR radar performance

Parameter	*Characteristic*	*Effect*
Conventional SSR and Mode S:		
Reply frequency	Offset	Depending on the monopole technique used, may lead to false OB. determination; in addition, if carrier frequency is out of ICAO tolerances (and hence outside the input band pass filter width), may lead to non-detection.
Pulse width	Enlarged	May lead to split plots or tracks; if tolerance window for pulse width is extended, the resolution capability is reduced.
Pulse spacing	Offset	Influences probability of detection (if the whole pulse train is affected), or to a reduced probability of code detection (if only the information pulses are affected).
SLS function	Incorrect	Increases ring-around targets and fruit and causes extractor over load.
Reply power	Too low Too high	Reduces probability of detection. Increases fruit and extractor overload.
Mode S only:		
Aircraft address	Non-unique	a) May lead to invisibility of two targets with same address and adversely affect operation of airborne collision avoidance systems (AAAS); b) Further tracker problems, if two targets with same address occur in a (multi-radar) system.
Aircraft identification (call sign)	Wrong or missing	No or false identification of target, disturbance of automatic services, etc.
Lockout timer	Wrong setting	Invisible, non-acquired targets; increase of all-call fruit → extra tor overload.
Comm-B timer	Wrong setting	Disturbance of communication handling.

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Appendix A

FLIGHT TESTING METHODS

1. GENERAL

The following sections outline the methods applied by one State for evaluation and flight testing of primary and secondary radar to commission a facility. The procedures for radar flight inspection differ from the procedures for navigation systems in that most of the data collection and analysis is conducted on the ground. The flight inspector's role in the radar environment consists largely of providing a known target in a required area. Presently, digital techniques allow for the evaluation of many radar parameters by the use of statistical sampling of target reports and SSR replies from the regular day-to-day site environment. The techniques provide the capability for reporting flight inspection results with greater accuracy than previously. Although certain requirements must be completed using a flight inspection aircraft, engineering personnel should use targets of opportunity, radar analysis tools, and other test equipment to the extent practicable for completing all checklist requirements. Engineering personnel shall normally evaluate and document all radar facility performance except for those parameters specifically evaluated by the flight inspector.

2. EXAMPLE OF FLIGHT TESTING METHODS

Preflight requirements

2.1 Engineering and operational personnel should prepare an outline of operational requirements, describing in detail all routes, fixes, holding patterns, approach and departure procedures including specified altitudes, distances and other information pertinent to the flight inspection. Air traffic personnel will coordinate with the engineering personnel responsible for the site assessment.

2.2 Prior to a flight inspection ensure that the radar equipment is tuned within facility operating specifications. Ensure that the participating engineering and operations personnel are experienced and that they are familiar with the objectives of the inspection and the requirements in this manual. Participation by the same personnel in each flight inspection results in a more consistent evaluation of facility performance.

2.3 Flight personnel are expected to obtain information from engineering personnel relative to operational requirements, expected facility performance, and performance evaluations obtained by use of targets of opportunity, and to define the extent of flight inspection necessary. The servicing flight inspection office should appoint a qualified flight inspection pilot as coordinator for all commissioning inspections. Flight inspection personnel should assist in determining which checklist requirements have been met at those facilities using targets of opportunity to partially fulfil flight inspection requirements.

2.4 Flight inspection will use small aircraft equipped with an approved transponder for all radar flight inspections. Small aircraft are considered to be the Beechcraft Bonanza, Cessna 182, and other aircraft of similar size which represent nearly the same reflecting surface. The Sabreliner, Jet Commander, Jetstar and other jets of similar size are also regarded as small aircraft for the purpose of radar flight checks.

2.5 Use a flight inspection aircraft with a calibrated transponder for SSR power optimization and GTC curve establishment. Flight inspection aircraft provide the pilot with a selection of any one of the following two combinations of power and sensitivity for the altitude at which the test is to be flown:

a) Transponder equipment for aircraft not permitted to fly higher than 15 000 feet

Measurements at the antenna end of the cable:

18.5 dB +1dB/–0dB above 1 W RF power output and –71 ± 1 dBm sensitivity (low/normal)

18.5 dB +1dB/–0dB above 1 W power output and –69 + 1 dBm/–0 dBm sensitivity (low/low); or

b) Transponder equipment for aircraft permitted to fly higher than 15 000 feet

Measurements at the antenna end of the cable:

21 dB +1dB/–0 dB above 1 W RF power output and –71 ± –1 dBm sensitivity (low/normal)

21 dB +1dB/–0 dB above 1 W power output and –69 + 1 dBm/–0 dBm sensitivity (low/low).

Normally the low power should be used.

Flight inspection procedure

Introduction

2.6 A radar flight inspection may be a single (special inspection) requirement to determine coverage over a new air traffic “fix” or may consist of a full radar commissioning inspection. The number of personnel, coordination, preparation, and reporting involved between the two extremes varies widely. A commissioning inspection (or a special inspection following significant modifications to existing equipment) consists of three distinct parts; planning, engineering and documentation. The engineering, or equipment, portion includes the tests necessary to ensure that the radar system performs according to design specification. Some tests in the engineering phase will require a flight inspection aircraft. The documentation or flight inspection portion determines to what extent the air traffic user requirements are met and establishes a radar coverage baseline. Air traffic user requirements should be outlined in the facility siting and inspection plan. The detailed procedures covered are devoted primarily to the flight inspection phase.

Commissioning inspections

2.7 The objective of the commissioning inspection is to evaluate system performance, determine and document the site coverage, and provide a baseline for the detection of future deterioration in equipment performance. Data obtained during this inspection will be used as a basis for periodic comparison of facility performance as well as subsequent inspections. Major events of commissioning inspection include:

a) pre-inspection planning (develop a technical plan);

b) measurement of equipment parameters as per specification;

c) equipment optimization;

d) site integration;

e) flight inspection (data collection and analysis);

f) documentation of results;

g) generation of a database (baseline);

h) record of all equipment measurements; and

i) preparation of final report.

Figure A-1* provides a flow chart of the sequence of events for a typical radar inspection.

Periodic inspection

2.8 Civil ATC PSR and SSR facilities, after being commissioned and set into operational service, do not require a periodic flight inspection. Instead, the radar performance parameters described in this manual shall be re-assessed at regular intervals by RTQC or by preventive/ corrective maintenance. Only in cases of specific problem investigation should it thus be necessary to perform measurement campaigns including flight checks.

Special inspections

2.9 Special inspections are conducted to fulfil a particular need and may be very limited in scope. The limited inspection may not require a formal written plan, but only a short report. Examples of testing events include: development of a starting baseline (as found), identification of problem areas (quantity, if possible), correction of the problem or recommendations for solutions, revision of performance, and generation of a new database.

2.10 If equipment changes/modifications to commissioned facilities change the coverage pattern, document the changes in the inspection report. The new coverage pattern will then become the basis for comparison during subsequent inspections. Special inspections include the following:

a) *engineering support.* Engineering support is performed to help engineers and air traffic personnel determine whether the radar meets equipment certification requirements. This data may be used for commissioning purposes, provided that no major equipment modifications are made prior to the commissioning inspection. Requirements for specific checks will be determined by engineering personnel and need not conform to a specific format;

b) *antenna change.* The checklist, Table A-1, indicates the requirements for installation of a new antenna, a new generation dual beam antenna, or an antenna with a different radiation pattern. A flight inspection is not required following an antenna pedestal or rotary joint replacement if the ground measurements of the reflector position, feedhorn alignment, and antenna tilt of the replacement pedestal are satisfactory;

c) *major modifications (other than antenna change).* This inspection should be confined to the parameters necessary to confirm facility performance. The radar engineer shall determine the extent of a special inspection during preparation and coordination of the plan. Depending upon the extent of the modification, an inspection using radar evaluation tools and targets of opportunity may satisfy the requirements;

* All figures and tables are located at the end of this appendix.

d) *near-miss inspections.* These inspections are conducted at the request of the air traffic manager of the facility involved, and are used to determine the radar coverage in the area in which the incident occurred. The flight inspection should be conducted as soon as possible following a near-miss, duplicating the manoeuvres, altitude, and direction of the aircraft incident. The flight inspector shall use an aircraft of the same type (or reflective surface) as the smaller aircraft involved. To the extent practicable, operate the radar in the same configuration as it was at the time of the incident. Accomplish flight inspection reports concerning near-miss collisions in the same manner as after-accident reports; and

e) *future requirements.* New PSR and SSR systems being developed may introduce features not common to existing radar, and may require techniques and procedures substantially different from those described below. Inspection procedures for future systems will be included as they become available.

Note 1.— For guidance materials on flight testing of ADS-B and WAM systems, refer to Aeronautical Surveillance Manual *(Doc 9924), Appendix P and Appendix O respectively.*

Note 2.— For information on Mode S specific testing (site monitor), refer to Aeronautical Surveillance Manual *(Doc 9924), Appendix D, section 2.7.3.*

Checklist

2.11 The inspection tests required to complete a full commissioning flight inspection are contained in Table A1. The procedures presented here are also those to be used singly when the requirements for a special inspection may be satisfied with one or more of the individual tests. Those items identified with an “x” are mandatory. The radar engineer shall perform the test by one or more of the methods listed, depending upon the radar type and resources available. Flight and engineering personnel shall evaluate the data obtained using targets of opportunity to determine if further evaluation by a dedicated flight inspection aircraft is needed. As the exact checks required may vary from one facility to another, the flight inspector must consult with the radar engineer prior to departing the area to ensure that all checklist requirements have been completed. The column labelled “transponder mode” denotes the proper aircraft transponder configuration for the specific test.

Vertical coverage/operational capability

Background

2.12 The purpose of this test is to determine and document the primary and secondary radar system vertical coverage.

a) *All radars.* Evaluate the inner and outer fringes on all primary and secondary radars using a flight inspection aircraft with a calibrated transponder;

b) *Radars without radar analysis tools.* Evaluate primary and secondary radar coverage within the fringe envelope using a flight inspection aircraft or rental aircraft;

c) *Radars with radar analysis tools.* Evaluate primary and secondary radar coverage within the fringe envelope using radar analysis tools, targets of opportunity, cooperating aircraft, or flight inspection aircraft. Radar analysis data recordings and analysis of the vertical coverage test are used as a continuing database for a permanent record, and as a legal document certifying facility performance.

Vertical coverage radial

2.13 A significant portion of the inspection is conducted on a reference bearing from the radar site. Conduct the commissioning inspection, and all subsequent inspections concerning facility performance on the same bearing for valid comparison. The radial should be free of clutter, dense traffic and populated areas, and influences created by line-of-site.

Commissioning procedure

2.14 Determine the outer fringe by evaluating tail-on targets and the inner fringe by nose-on targets. Aircraft reflective surface and transponder antenna characteristics vary between inbound and outbound flight; consequently, some difference in coverage can be expected. Using map checkpoints, a navigation system radial, or radar vectors to remain on vertical coverage radial, the flight inspector should complete the coverage check. Fly all pattern altitudes described herein as height above the radar antenna.

Note.— In order to produce a meaningful database, the flight inspector must compute and fly true altitudes (corrected for pressure and temperature).

Commissioning profile — terminal PSR/SSR radars without radar analysis

2.15 Refer to Figure A-2 and proceed as follows:

a) determine the inner fringe at 300 m (1 000 ft). Then fly outbound at 300 m (1 000 ft) and establish the outer fringe;

b) climb to 600 m (2 000 ft) and establish the outer fringe. Then proceed inbound at 600 m (2 000 ft) and establish the inner fringe;

c) climb to 900 m (3 000 ft) and establish the outer fringe;

d) climb to 1 500 m (5 000 ft) and establish the outer fringe;

e) repeat the outer fringe check at 1 500 m (5 000 ft) (or lower if necessary) as required in order to complete the overall quality test and to evaluate radar auxiliary functions (linear polarization, PIN diode, integrators, etc., for primary and GTC/STC for secondary). Most auxiliary functions produce a decrease in receiver sensitivity which is indicated by a decrease in cut-off range. Conduct the test by marking the outer fringe with the function on, then off, while noting the difference in range. Then proceed inbound at 1 500 m (5 000 ft) and establish the inner fringe;

f) climb to 2 100 m (7 000 ft) and establish the outer fringe;

g) climb to 3 000 m (10 000 ft) and establish the outer fringe. Then proceed inbound at 3 000 m (10 000 ft) to establish the inner fringe;

h) if the required operational altitude is greater than 3 000 m (10 000 ft), check the outer fringe in 1 500 m (5 000 ft) increments up to the operational altitude; e.g. if 5 100 m (17 000 ft), check the outer fringe at 4 500 m (15 000 ft) and 5 100 m (17 000 ft), then proceed inbound at the operational altitude and establish the inner fringes. If adequate radar coverage is not maintained during the inbound run, conduct flights through the coverage pattern to establish the maximum usable altitude;

i) check the inner fringe at the altitudes used to establish the outer fringe back down to 3 000 m (10 000 ft) level; and

j) unless specifically requested, do not inspect vertical coverage above the operational altitude, if the required operational altitude is lower than 3 000 m (10 000 ft).

Commissioning profile — en-route PSR/SSR without radar analysis tools

2.16 Refer to Figure A-3 and proceed as follows:

a) complete steps a) through g) of the terminal PSR/SSR commissioning profile procedures;

b) climb to 4 500 m (15 000 ft) and establish the outer fringe;

c) climb to 6 000 m (20 000 ft) and establish the outer fringe. Then proceed inbound at 6 000 m (20 000 ft) and establish the inner fringe;

d) climb to 7 500 m (25 000 ft) and establish the outer fringe;

e) climb to 9 000 m (30 000 ft) and establish the outer fringe;

f) repeat the outer fringe as required to complete the overall quality and auxiliary tests;

g) then proceed inbound at 9 000 m (30 000 ft) and establish the inner fringe; and

h) if operational or engineering requirements are greater than 9 000 m (30 000 ft), or if this level conflicts with air traffic, climb to a mutually agreeable altitude (to a maximum of 12 000 m (40 000 ft)) and establish the outer and inner fringes.

Commissioning profile — terminal/en-route PSR/SSR, radars with radar analysis tools

2.17 Refer to Figure A-4 and proceed as follows:

a) *Fringe envelope check.* The flight inspector shall fly outbound from the site at 300 m (1 000 ft) above the antenna to the outer fringe, up to the outer fringe to the required altitude, across the top inbound to the inner fringe, then down the inner fringe to the 300 m (1 000 ft) inner fringe. Probe and score the primary and secondary fringes at 300, 600, 900, 1 500, 2 100, 3 000, 4 500, 6 000, 7 500 and 9 000 m (as required) (1, 2, 3, 5, 7, 10, 15, 20, 25 and 30 (as required) thousand ft). Establish the ascending (outer) fringes by turning inbound and climbing to the next higher level, flying inbound at the higher level until solid primary and secondary reports are received, then turning outbound to establish the primary and secondary reports at that level. Evaluate the inner fringes in the same manner, with the directions reversed. Conduct the overall quality and auxiliary functions test at 1 500 m (5 000 ft) or 9 000 m (30 000 ft) as per the previous procedures.

b) *Coverage within the fringe envelope.* Engineering personnel shall use radar analysis tools and targets of opportunity to determine the coverage inside the fringe envelope, and identify the location and extent of holes and other lobing related anomalies. Coverage can be determined with analysis of plots on series of recording. Limit the tracks to a 20° wedge, centred on the vertical coverage azimuth and filtered for the altitudes of concern. The SSR delay should be active during the recordings to provide a better separation of primary and secondary tracks for independent analysis. Lobing will be evident as primary and secondary tracks, exhibiting decreasing run lengths as they enter a “hole”, disappear in the null, then reappear with progressively higher run lengths as they clear the fringe on the opposite side. Include the printout plots in the facility permanent database.

Note.— “SSR delay” refers to the technique of delaying the SSR signal beyond the merge window of the plot combiner.

En-route/terminal PSR antenna change

2.18 When the en-route/terminal PSR antenna is changed, fly the profile depicted in Figures A-5a and A15b, as applicable.

a) Repeat the outer fringe checks as necessary in order to complete an overall quality and auxiliary functions test as requested by engineering personnel. Conduct the remainder of the coverage check in the original configuration; and

b) checks of additional facility equipment configurations and additional altitudes may be conducted at the option of engineering personnel.

SSR antenna change

2.19 For the same type of antenna, all requirements may be completed using targets of opportunity. Comparison analysis is performed on the historic solar data, SSR parameters and performance measurements (targets of opportunity) to ensure that the same performance (commissioned) can be expected with new antennas. When the antenna is replaced with a different type, or targets of opportunity are not available, checklist requirements shall be completed using a flight inspection aircraft.

a) *Terminal SSR.* Fly the profile for a primary antenna change as illustrated in Figure A-5a.

b) *En-route SSR.* Fly the profile for a primary antenna change as illustrated in Figure A-5b.

Evaluation

2.20 Engineering personnel shall record target strength as defined in Table A-2 (Tolerance/limit), on each scan, aircraft position every five miles, and aircraft altitude for each fringe check and level run. Where available, engineering personnel shall document results of the vertical coverage check using radar analytical/diagnostic programmes for inclusion in their facility report and permanent records.

Horizontal screening

2.21 The purpose of this test is to verify the indicated coverage on the horizontal screening charts. The test is optional depending upon local requirements, and may be accomplished by one or more of the following methods:

a) using either flight inspection or rental aircraft, fly an orbit at an altitude and distance which corresponds to the lowest screening angle at which coverage is expected. Do not use an orbit radius of less than 18.5 km (10 NM). DME or headings provided by the controller may be used to maintain the orbit. Select “Normal” on the aircraft transponder. MTI, if used, should be gated to a range inside the orbit radius, except those locations where ground clutter will obscure the target unless MTI is used. If MTI must be gated outside the orbit, the radius of the orbit should be constantly changed to avoid target cancellation due to tangential blind speed. For example, vary the pattern on a 22.2 km (12 NM) orbit between 18.5 km (10 NM) and 25.9 km (14 NM) so as to average a 22.2 km (12 NM) orbit. Engineering personnel shall record target strength on each scan and target azimuth/distance position each 10°; and

b) horizontal screening can also be determined by running the radar analysis programmes on pre-recorded data. Limit the data input on successive runs to azimuth sectors with a constant screening angle for each run. Compute the screening angle for any given run (azimuth sector) from the lowest coverage returns at a given range. Then, coverage at any given range beyond the screen can be predicted and a comparison drawn between values on the horizontal screening chart of actual coverage. Limit tests to elevation angles near the expected horizon.

Airway/route coverage

2.22 The purpose of this check is to document coverage along all routes and airways required by air traffic, and may be accomplished by one or a combination of the following methods:

a) flight inspection or rental aircraft; and

b) radar analysis/targets of opportunity.

2.23 Approved procedures: select “normal” on the flight inspection/rental aircraft transponder. Configure the primary radar in circular polarization. Fly the minimum coverage altitude not lower than the minimum obstruction clearance altitude (MOCA), on airway centre line. Maintain course guidance by reference to ground checkpoints, navigation system signals, or radar vectors. Fly terminal arrival/departure routes and other areas of interest identified in the flight inspection, via radar vectors at the MOCA.

2.24 Radar analysis programmes and targets of opportunity: targets may consist of one cooperating aircraft or an assortment of aircraft reports on a particular airway. Targets included in the output data must be Mode C- or S-equipped for essential altitude information. Scoring may be accomplished either with radar analysis programmes or manually. Document the fix positional coverage by filtering a data run with the start/stop azimuth and high/low altitude that effectively “boxes” in the fix. Good coverage within the box constitutes adequate coverage at the position fix.

Way-point/map accuracy

2.25 The purpose of this test is to verify the accuracy of all airways, routes, fixes and centre lines displayed on the video map. This test may be accomplished by either of the following methods:

a) flight inspection or rental aircraft; and

b) targets of opportunity.

2.26 Approved procedures: since the object of the test is to compare the displayed video map feature against indicated target reports, radar configuration (MTI, antenna polarization, transponder settings, etc.) does not affect the test results. The procedure is the same whether using a flight inspection aircraft or targets of opportunity; compare reported aircraft position on or over an airway, route or fix, with video map presentation. Similarly, verify runway centre line-to-video map alignment by observing landing and departing aircraft. However, when using targets of opportunity, numerous target reports are required to verify the accuracy of any particular airway, route or fix. Verify accuracy with a flight inspection aircraft. Replacement map overlays, video maps or digitally generated maps do not require flight inspection if engineering personnel are satisfied through evaluation of targets of opportunity or by comparison to an existing map, that the new map is accurate.

Fixed target identification

2.27 The purpose of this test is to identify prominent primary broadband targets used for range and azimuth accuracy checks when solar and radar analysis programmes are not available. Identify the permanent echo (PE) by one of the following methods:

a) cooperating aircraft; and

b) flight inspection or rental aircraft.

2.28 Approved procedures: select identifiable features from comparison of the ground clutter reports and geo graphic maps (islands, mountain peaks, towers, etc.); and direct the pilot to the PE return. If the pilot can identify and describe the ground target, and the target is a permanent feature, record the PE in the inspection report.

Surveillance approaches

2.29 All terminal PSR approaches must be checked for accuracy and coverage by a flight inspection aircraft during commissioning inspections or any time a new approach procedure is developed. The flight inspector shall confirm with engineering personnel that the approach is conducted on a surveillance radar scope. Conducting a terminal PSR approach on a precision approach radar (PAR) scope is not acceptable for flight inspection purposes. Terminal PSR approaches are not authorized using SSR only; and the SSR should be offset for this check.

Approach to a runway

2.30 The approach course shall coincide with the runway centre line extended and shall meet accuracy and coverage tolerances.

Approach to an aircraft

2.31 The approach course shall be aligned to the missed approach point (MAPt) as determined by procedures and engineering personnel. Helicopter-only final approach courses may be established to a MAPt no further than 780 m (2 600 ft) from the centre of the landing area for a point-in-space approach to a MAPt from which flight to the landing area must be accomplished by visual reference to a prescribed route along the surface. In each instance, approach guidance shall be provided to the prescribed MAPt.

Approach procedure

2.32 Fly an 18.5 km (10 NM) terminal PSR final approach as directed by the controller. Fly at the lowest prescribed altitudes until reaching the final approach segment. Between the final approach fix (FAF) and the MAPt, fly 30 m (100 ft) below any stepdown fix altitudes, recommended altitudes and/or the minimum descent altitude (MDA). During the approach, the flight inspector shall evaluate the approach procedure, note the aircraft position relative to the runway centre line extended/airport, and determine at the MAPt whether a landing can be successfully performed without excessive manoeuvring.

Evaluation

2.33 Terminal PSR approach radars shall meet flight inspection tolerances or be cancelled; however, cancellation of a terminal PSR approach radar does not constitute a restriction on the radar facility. When the use of MTI is required for a terminal PSR approach, the flight inspection report should be so annotated. A requirement to use MTI does not constitute a facility restriction, however, terminal PSR approaches which require the use of MTI are not authorized when the MTI feature is inoperative.

Communication

2.34 The purpose of the optional check is to evaluate the VHF/UHF communications capability within the radar coverage area. All required checks can normally be completed by using participating aircraft. If additional requirements are identified by engineering personnel, conduct the inspection concurrent with the radar inspection.

Standby equipment

2.35 The purpose of this check is to evaluate the performance of standby equipment, and may be accomplished during pre-inspection testing using targets of opportunity. Some radars have been engineered to meet reliability requirements through the use of redundant parallel units. Structure the pre-inspection testing of these systems so as to thoroughly test all such redundant units. A standby antenna (duplicate) may be installed at selected locations to provide for continued radar service in the event of antenna failure. The commissioning requirements for a standby antenna may be completed using the antenna checklist.

Standby power

2.36 The purpose of this test is to evaluate radar performance on standby power (engine generator or uninterruptable power supply) and shall be conducted during pre-inspection testing. Results are satisfactory when the engine generator monitor equipment detects a power failure without manual intervention. Conduct this test with a simulated power failure by manually switching out the incoming commercial power.

Analysis

Testing precautions

2.37 Radar inspections should not be attempted during heavy precipitation, temperature inversion, or other atmospheric conditions which either increase or decrease radar coverage from the expected norm. Investigate any system deficiency or deterioration noted during inspection. When a system parameter does not meet the specified tolerances and cannot be adjusted within a reasonable length of time, discontinue the flight inspection until the discrepancy can be resolved. However, this does not preclude the continuation of testing in an effort to resolve the problem.

Evaluation

2.38 Continuous radar detection (one usable target report on every scan at every azimuth and all altitudes) is a difficult requirement to meet due to antenna lobing, physical limitations (line-of-sight), aircraft altitude, and antenna tilt. Therefore, expect isolated or non-recurring misses. After three or more consecutive misses in the radar pattern, investigate to determine whether a hole exists and, if so, its size. Reference is made to Figure A-6.

Lobing

2.39 Lobing is caused by the summation of radar energy at a point in space. The energy components at that point may consist of both direct and reflected energy. As the reflected and direct path lengths to that point differ, the two signals arrive with a different phase relationship. With an opposite phase from a strong reflection, the out-of-phase component may cancel the direct, resulting in a coverage hole. As reflected energy is the source of all lobing problems, preventing or altering the reflected energy component is the way to minimize the problem. Lobing in a critical area can occasionally be reduced, but usually at the expense of performance in other areas. Adjustments to the antenna tilt (primary and secondary) and secondary transmit power are the two most effective measures in combatting nulls. Use care in making tilt and power changes, since either can introduce additional problems. Optimizing antenna tilt and reducing the ground radiation may be all that is required to reduce a lobing problem.

Probing

2.40 Holes in radar detection are probed in a similar manner to VOR or TACAN. The following procedures may be used as a guide; refer to Figure A-7:

a) *Horizontal.* Fly through the area in question to determine the inner and outer limits of the hole. Vary aircraft position by 10° of radar azimuth until the lateral limits of the hole are determined; and

b) *Vertical.* Fly through the centre of the pattern (established in the horizontal probing procedure) at 300 m (1 000 ft) increments to determine the upper and lower limits of the pattern.

3. DOCUMENTATION

The responsible authorities shall compile and complete the facility inspection performance report. The report will consist of a detailed accounting of all coverage data obtained using participating and flight inspection aircraft, targets of opportunity, radar analysis tools, and all flight inspection reports. The report submitted by the flight inspector shall contain only that information evaluated by the flight inspection crew.

TABLES FOR APPENDIX A

Table A-1. Inspection test checklist

Note.— x = mandatory test; o = optional — at engineering/maintenance/controller request

		PSR/SSR antenna change				
	Commissioning	PSR		SSR		
Check		same type	different type	same type	different type	transponder mode
Orientation	x	x	x	x	x	normal
Tilt	x	x	x	x	x	normal
PSR optimization	x	x	x			normal
— STC/GTC	x		x			normal
— beam crossover	x		x			normal
— false target optimization	x		x			normal
SSR optimization	x				x	
— power	x			x	x	low
— SLS/ISLS	x			x	x	normal
— modes/codes	x			x	x	normal
— GTC/STC establishment	x			x	x	low/low*
PSR/SSR integrity	x			x	x	normal
Vertical coverage	x		x		x	normal
Horizontal screening	o			x	x	normal
Airways/route coverage	x			x	x	normal
FIX/MAPt accuracy	x					normal
Fixed target identification	x					normal
Surveillance approach	x	x	x		x	normal
Communications	o					
Standby equipment	x					normal
Standby power	x					normal

* For terminal SSR without radar analysis capability.

Table A-2. Tolerance for target strength

Parameter	*Tolerance/limit*
Target strengths	
(1) Broadband	
2—usable	Target shows each scan, remains on the scope for at least 1/3 of the scan.
1—unusable	Weak target, barely visible, possible miss.
0—unusable	No visible target.
(2) Narrowband	
1—usable	Visible target, satisfactory for ATC purposes.
2—unusable	No visible target.

FIGURES FOR APPENDIX A

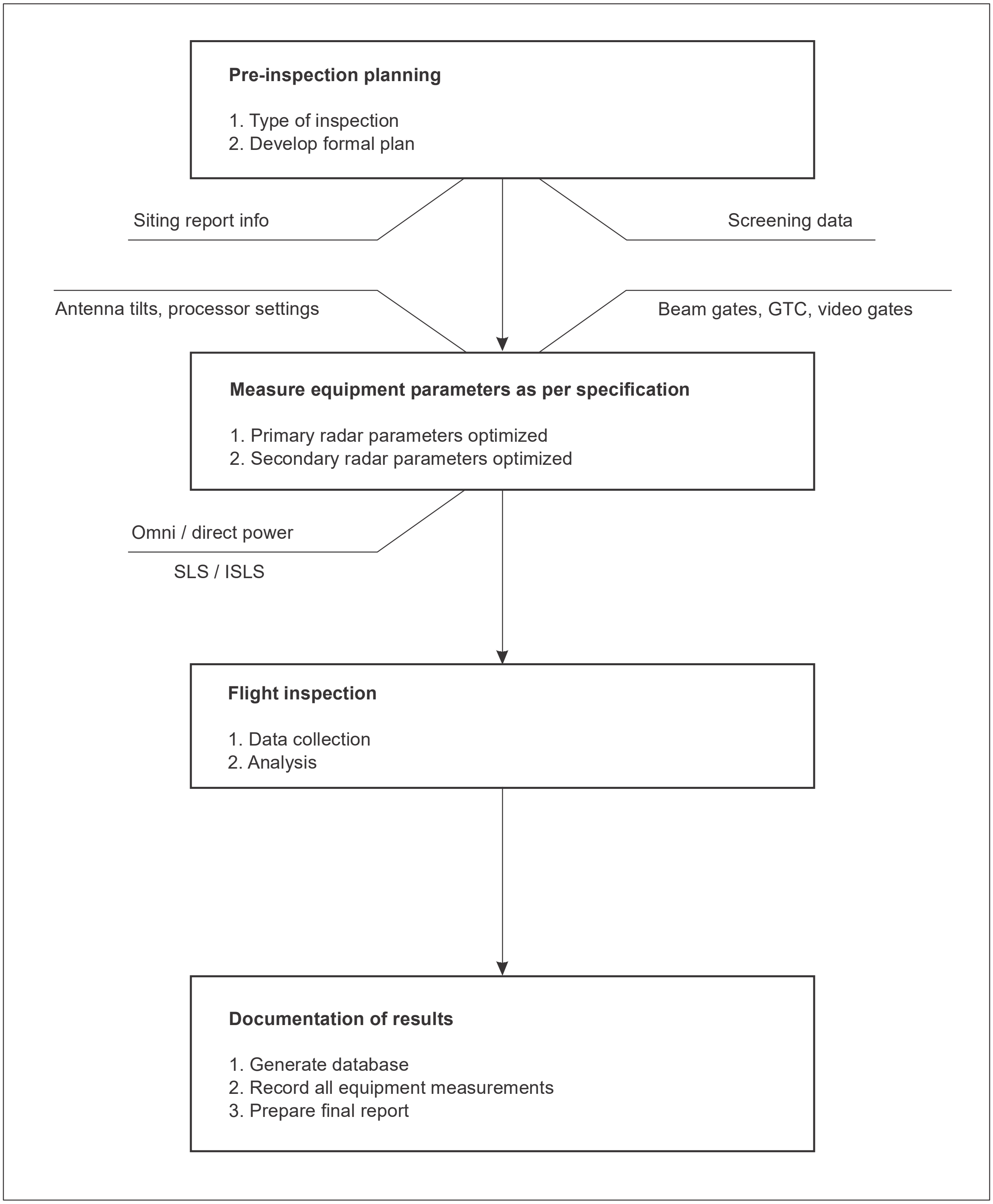

Figure A-1. Typical radar inspection events sequence

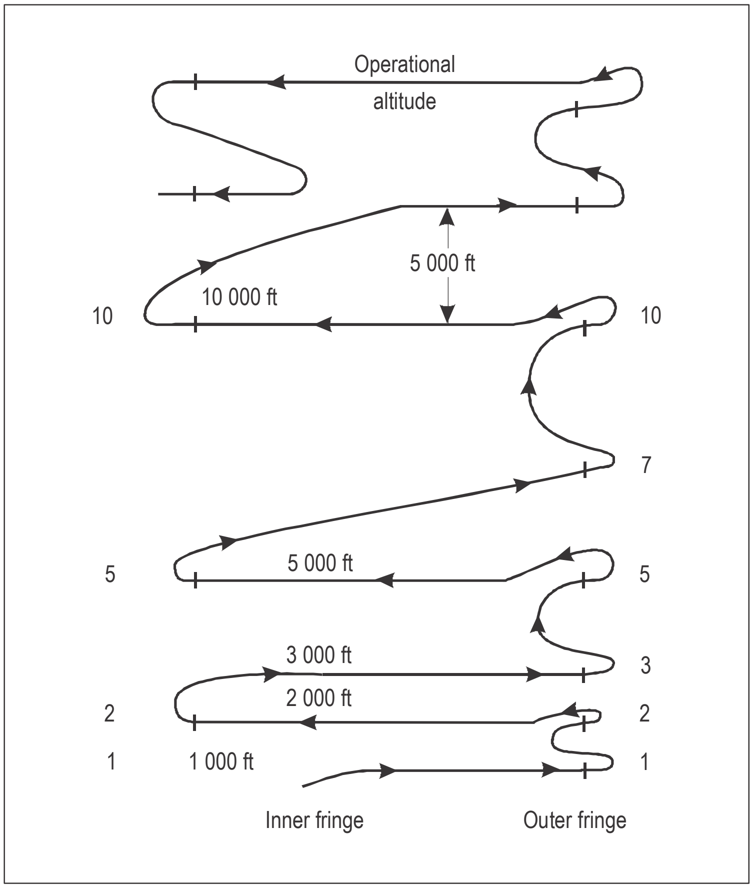

Figure A-2. Commissioning profile for terminal radars

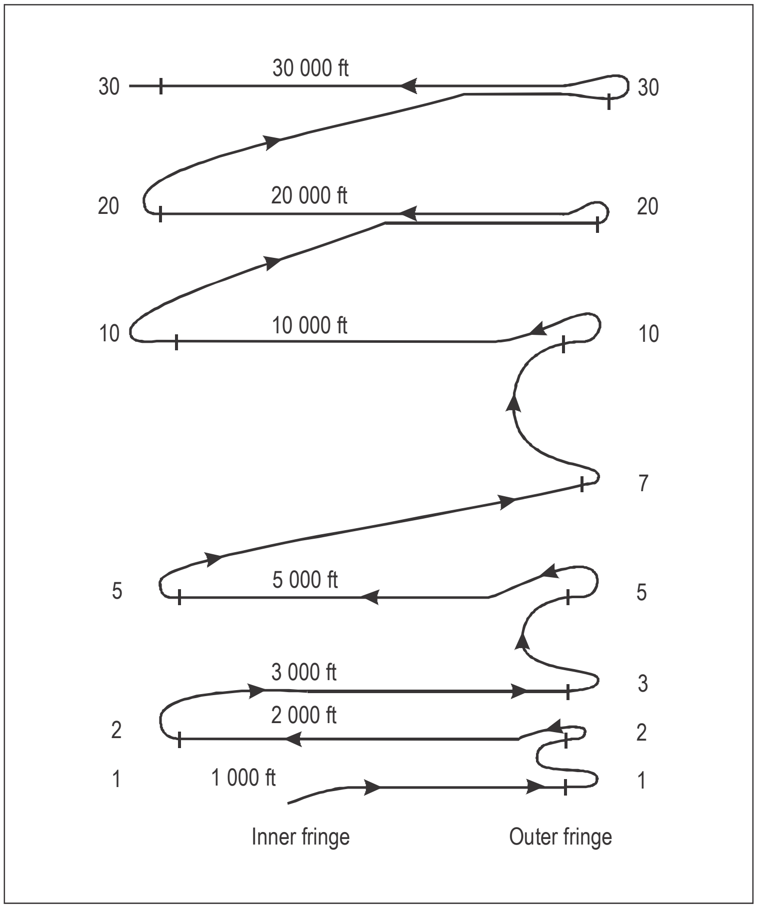

Figure A-3. Commissioning profile for en-route radars

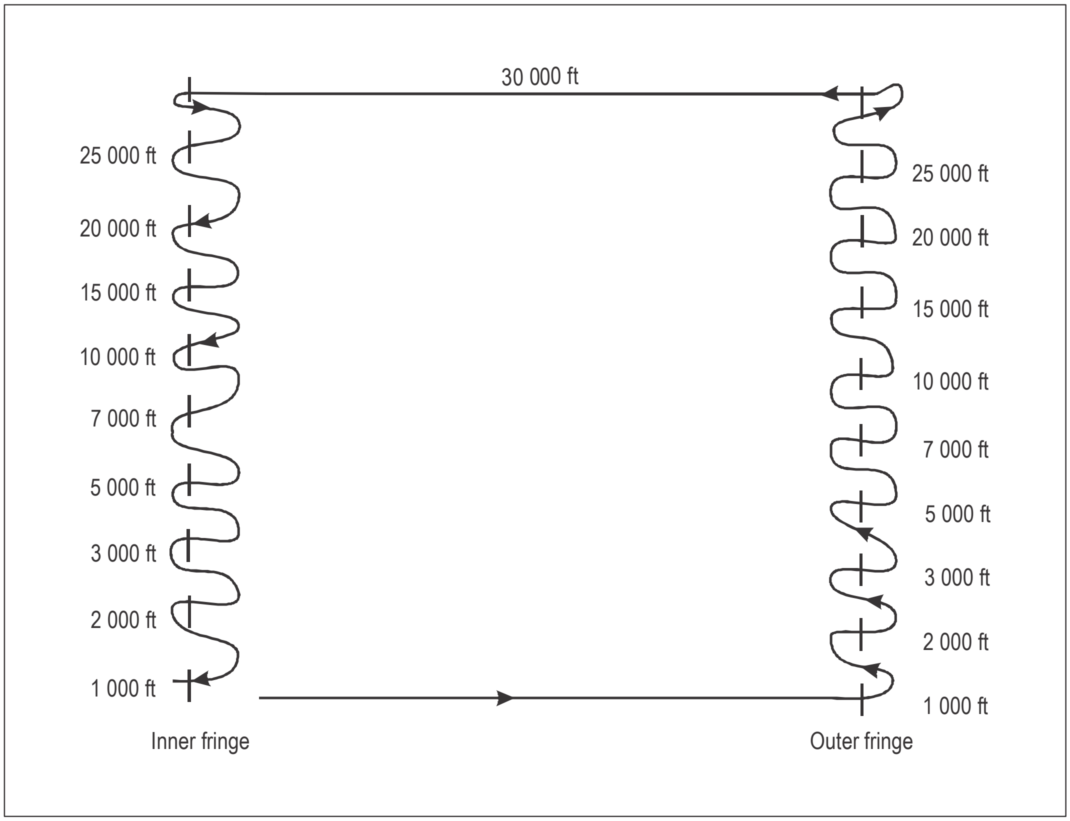

Figure A-4. Commissioning profile for terminal/en-route radars

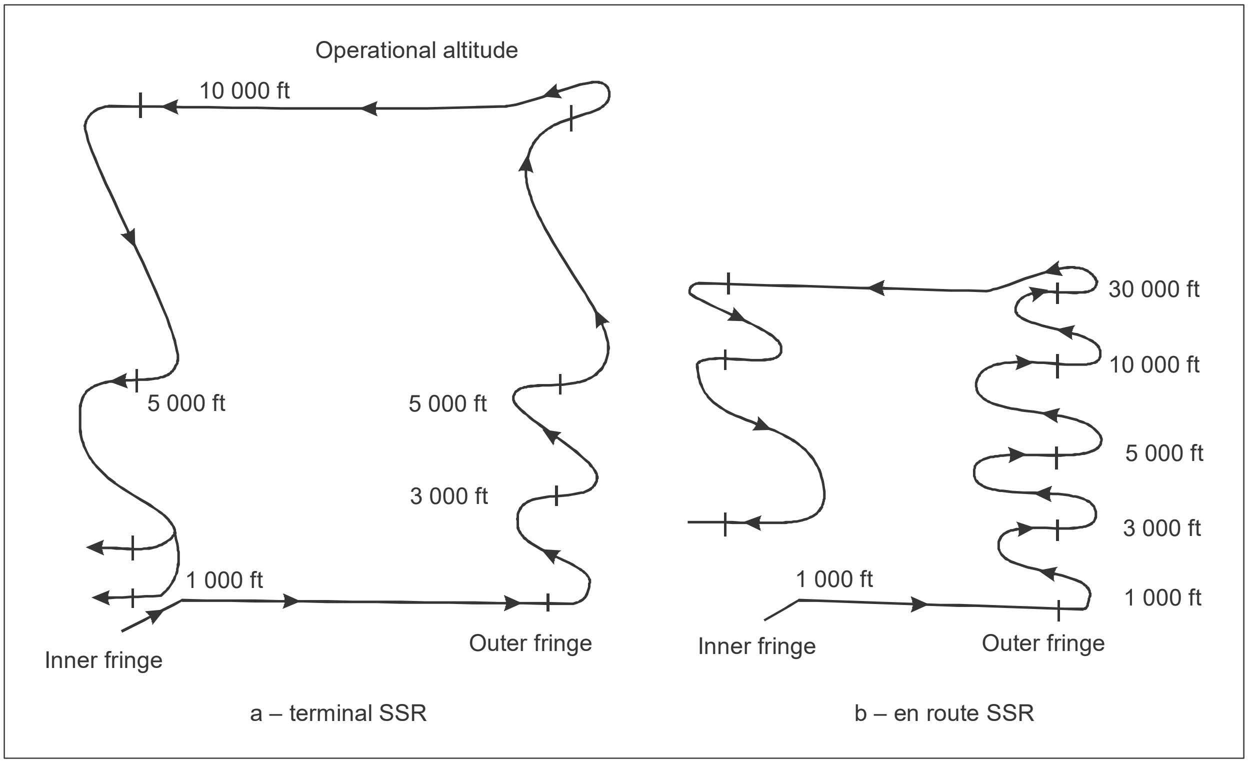

Figure A-5. Commissioning profile for terminal/en-route SSR

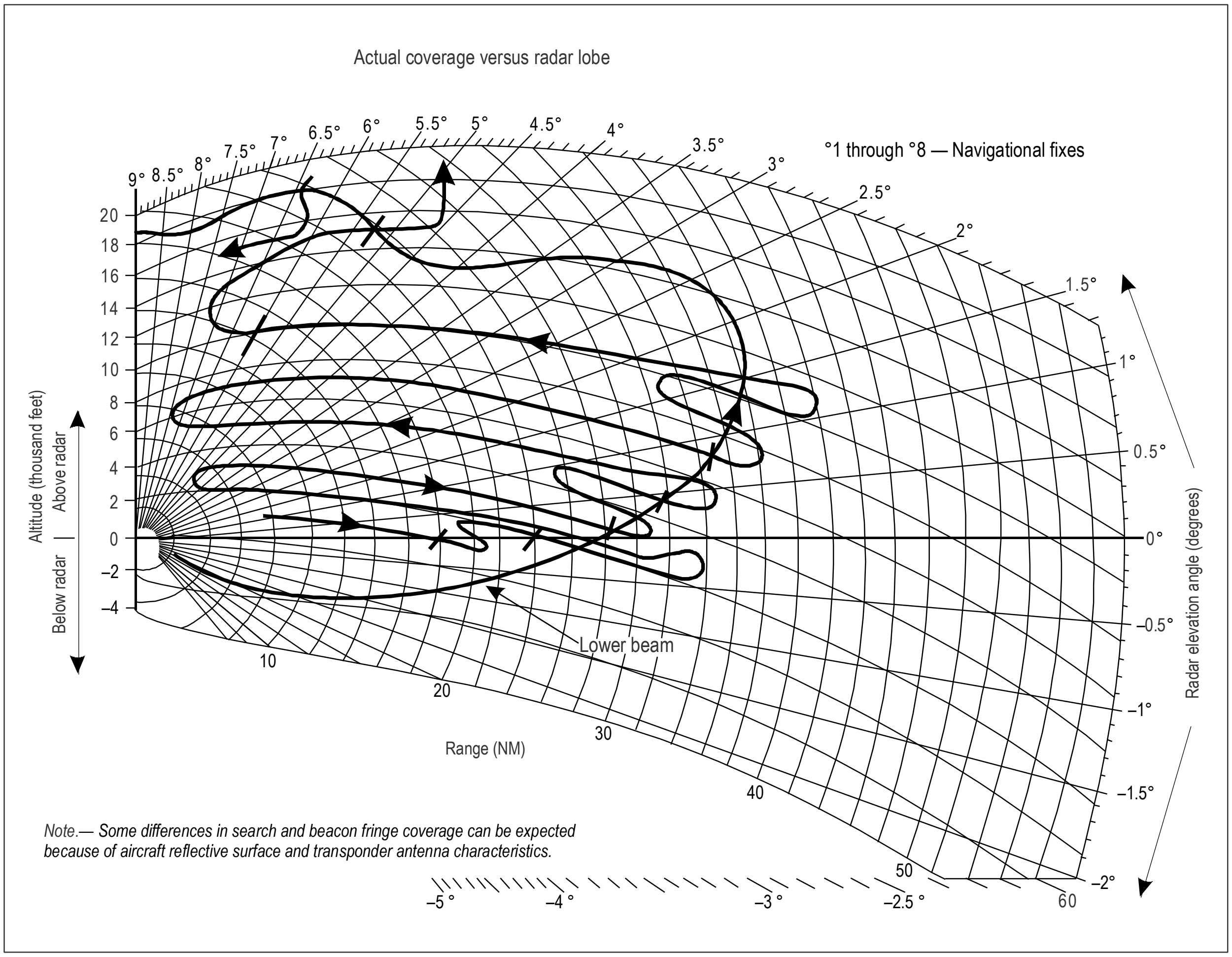

Figure A-6. Actual coverage versus radar lobe

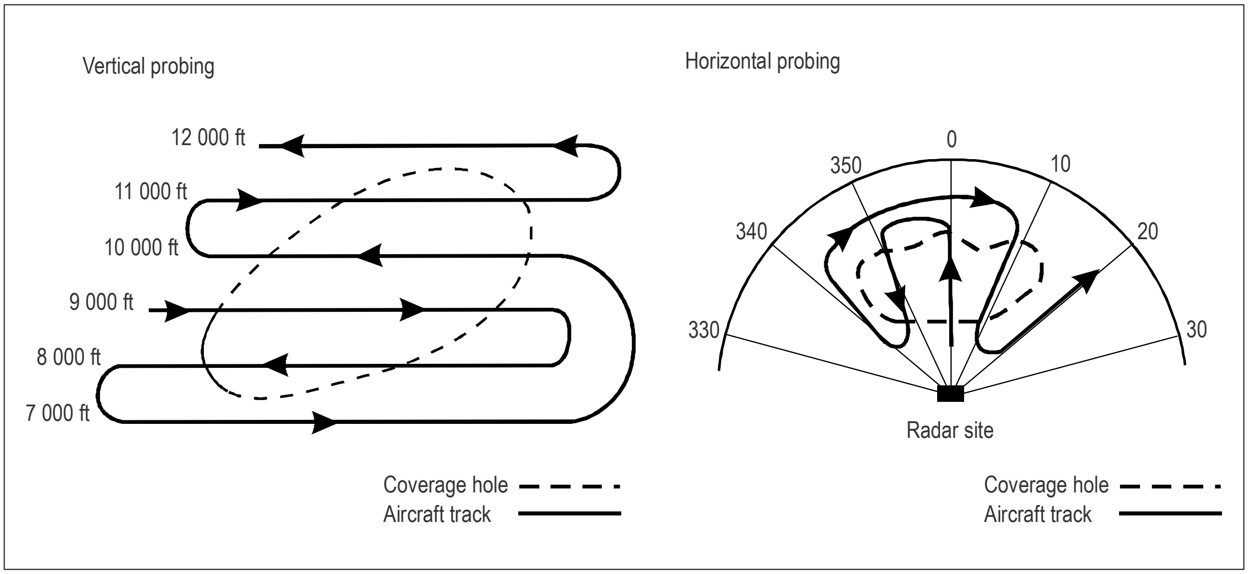

Figure A-7. Vertical and horizontal probing

Appendix B

SECONDARY SURVEILLANCE RADAR (SSR)

1. INTRODUCTION

1.1 This appendix describes:

a) the performance parameters of SSR requiring flight and/or ground inspection and the type of check to be used;

b) the applicable tolerances;

c) some of the recommended procedures for implementing the required checks.

1.2 The procedures described should not be construed as the only means of accomplishing the intended purpose; individual administrations might find modified or alternative methods more appropriate to the available local resources.

2. FLIGHT INSPECTION PROCEDURES FOR SSR

Summary of requirements

2.1 The object of the flight inspection is to determine the coverage characteristics and accuracy of the SSR system. Any deterioration from specifications established in Table F-1[1] noted during inspections must be reported to the appropriate authority. Normally the inspection should be discontinued if system performance falls below minimum operational standards.

2.2 SSR flight inspections should be performed in conjunction with primary radar inspections when possible. When primary and secondary radars are inspected simultaneously, discrimination on the display between the two replies can be obtained by introduction of a known time delay in the SSR signal, otherwise the SSR should be checked by turning it alternatively “off” and “on”, because SSR, if left “on” continuously, might blank out the primary radar returns.

2.3 Site trials are conducted to check the extent to which a proposed site will enable operational requirements to be achieved.

2.4 Commissioning flight inspections are conducted to supply engineering personnel with sufficient data to determine if the SSR meets operational requirements and/or equipment design specifications. These inspections will be extensive enough to provide required data and a basis for comparison of periodic data to detect future deterioration in the performance of the radar.

2.5 Routine flight inspections are conducted to determine that the facility performance continues to meet

1. All tables are located at the end of this appendix.

specifications and satisfies operational requirements. The recommended frequency for routine flight inspection is 120-day intervals, plus or minus 30 days, from the initial or annual inspection. In cases where there is a satisfactory record of performance of an equipment, an administration may extend the interval up to as much as 365 days. On the other hand, routine inspections at lesser intervals than 120 days may be needed if there are doubts about equipment performance at a given site.

2.6 Special flight inspections are conducted after major equipment modifications, for reported or suspected mal functions, after an aircraft accident to determine if facility performance could have been a contributing factor to the accident and for other reasons. Usually a routine flight inspection is sufficient to restore a facility to operation after modification; however, engineering personnel should request checks in excess of routine requirements if additional performance data is required.

2.7 Preflight requirements are as follows:

a) Engineering and operational personnel should pre pare an outline of operational requirements, describing in detail all fixes, holding patterns, approach and departure procedures, including specified altitudes, distances, and other special information pertinent to the flight inspection. This material may be depicted on an aeronautical chart to present a pictorial display of the operational requirements which can be used by ground and flight crews so that a well coordinated, orderly flight inspection, can be conducted.

b) Prior to the flight inspection, engineering personnel will conduct equipment checks as detailed in 2.21.

c) Flight personnel will assure that the transponder is properly calibrated according to the specifications given in Annex 10, Volume IV.

Details of flight inspection procedures

Coverage

2.8 *Vertical*. The radial selected for this evaluation should be one which is as free from ground clutter as possible, is in an area where negligible lobing exists, and is free of the effects of shielding or reflection. It should also be one on which the progress of flight inspection work is not likely to be unduly hindered by ATC difficulties. The same radial will always be used for vertical coverage checks. Level flights should be made inbound and outbound at the following heights above the site: 300 m (1 000 ft), 900 m (3 000 ft), 1 800 m (6 000 ft), 3 000 m (10 000 ft). Generally above 3 000 m (10 000 ft) level flight should be made in 1 500-metre (5 000-foot) increments to the maximum altitude required dependent on the specific type of equipment (but where adequate information is available on antenna performance, the increments may be at 3 000 m (10 000 ft) intervals). In the absence of an aircraft capable of flight at the greater heights, it is possible to extrapolate results by use of a calibrated attenuator in the aircraft antenna feeder while the aircraft is flying at lower heights. This method does not give the accuracy which might be expected (errors of the order of ±6 dB may be experienced) and this should be borne in mind when evaluating results obtained by this method.

2.9 Each flight will extend to just beyond the point where cover is lost on outbound flight along the established radial to determine the outer fringe; flight is then made inbound on the same radial over the ground antenna cone of silence and continuing to a point where cover is just re-established flying outbound on the reciprocal radial.

2.10 If adequate cover is not maintained at the maxi mum operational altitude, the maximum height at which adequate cover is obtainable must be established by additional flights below the specified maximum operational altitude.

2.11 Radar contact on routes, approaches, etc., is considered lost when the target is missed for any three consecutive scans.

2.12 *Route cover.* During commissioning inspections all airways and/or routes should be checked to the maxi mum distance for which coverage is required at the mini mum instrument altitude for the route. For routine inspections, only one route, in addition to the vertical coverage radial, need be flown. Target description should be recorded on every scan, and range in 5-mile increments should be recorded.

2.13 In addition to airways routes, all departure and arrival routes should be flown in the directions and lowest altitudes at which they are normally used to determine that adequate coverage exists. On routine inspections only one route need be checked.

2.14 *Fix coverage.* Fixes, or reporting points, should be checked at minimum instrument altitude. All fixes should be checked during routine inspection. This check can be combined with the route cover check.

2.15 *Azimuth cover.* This inspection should be made only on commissioning flights. The following orbital flights may be made as required for engineering purposes:

Orbit of 10 NM at 1 500 m (5 000 ft) above site;

Orbit of 20 NM at 3 000 m (10 000 ft);

Orbit of 30 NM at 10 700 m (35 000 ft).

This check is made to verify coverage in the horizontal plane as determined by panoramic photos, transits and computed measurements throughout 360°.

Height encoding

2.16 During the vertical coverage checks, Mode C will be used for a sufficient period of time at each height to compare the decoded height with that being noted in the aircraft. It is desirable that the pressure transducer used to operate the aircraft encoder also provides a display in the aircraft. The decoded height shall be within ±38 m (±125 ft) of the altitude displayed in the aircraft relative to standard sea level pressure (1013 hPa, or 29.92 in. Hg.).

Mode/code check

2.17 Satisfactory operation of all modes intended to be used by the installation will be checked during the course of the flights previously described. Representative codes may be validated during coverage checks. A limited test could be made by checking the following codes: 0557, 1557, 2557, 3557, 4557, 5557, 6557, 7557, and IDENT. This applies to the 4096 select code transponder. Caution must be exercised in checking codes 7600 and 7700 due to the probability of “alarming” adjacent radars.

Side lobe suppression

2.18 Side lobe suppression (SLS), installed to improve beacon performance, might possibly degrade facility performance. For example, flat terrain within 300 m (1 000 ft) of the antenna can cause lobing; and other circumstances can cause “ring around” or false targets.

2.19 Perform SLS inspection as follows:

a) Select an azimuth in an area considered by the controller to have been a side problem in the past. A radial should be flown at 300 m (1 000 ft) above the antenna elevation to coverage limits.

b) Select an azimuth which was a source of lobing from a siting standpoint, and perform check in same manner as above.

c) Fly radials in other areas as determined necessary by engineering and operational personnel.

d) Fly complete radar surveillance approaches to insure reliable beacon coverage.

e) Record target description, ghost targets, "ring around", etc., to determine all possible effects of the SLS installation.

2.20 With an antenna system which has been initially designed to the ICAO Standard for side lobe suppression, the mismatch between control and interrogate antenna which gives rise to the above difficulties, should not occur and therefore in such cases the above check is not necessary. However, during all checks it will be necessary to ensure that the side lobe suppression requirements are being met.

Details of ground tests procedures associated with flight testing of SSR

Introduction

2.21 This section deals with the testing and setting up of a ground based interrogator station prior to a flight check taking place. Many of the procedures can be used for subsequent in-service checks. (See Table F-2.)

2.22 The intention in this document is to describe procedures for checking a fairly sophisticated SSR system but in many instances, in areas in the world where facilities for testing systems are strictly limited, reduced checking procedures can still produce an acceptable air traffic control system.

2.23 It is emphasized, therefore, that after initial flight checking and acceptance of an SSR system, the service ability of such an aid is, by its very nature, under continuous test, and subsequent testing of any form should be minimal, especially if a full knowledge of the behaviour of the aid under a variety of conditions can be built up over the initial in-service period. This usually means that system checks may be carried out at frequent intervals to begin with, and as knowledge of system parameters and equipment serviceability grows, checks can be spaced at greater intervals of time.

System parameters to be tested

2.24 *Receiver sensitivity.* The precise method of measuring the receiver sensitivity will depend upon the type and design of equipment. The system designer is required to provide a sufficiently sensitive receiver to meet the system requirements. Measured tangentially[2] the ground receiver sensitivity should be between the limits –87 dBm to –92 dBm, excess sensitivity beyond this point being of no advantage. The received signal should increase in amplitude to about –76 dBm where a limit value of video output should be reached and no further increase in voltage output should then occur as the signal progresses up the dynamic range of the receiver i.e. the video output signal from the receiver should be constant in amplitude throughout the usable dynamic range of the receiver. Fringe signals below this limit level, i.e. below –76 dBm are not used in SSR.

2.25 *Receiver bandwidth.* The method of checking receiver bandwidth will be laid down by the manufacturer of the equipment in question but the overall bandwidth must be good enough to reproduce faithfully the shape of the pulses received from a transponder working at optimum efficiency. This means a rise time of the leading edge of each pulse must be preserved within the limits 0.05 to 0.1 microsecond and implies an overall bandwidth of 9 MHz or better.

2.26 *Receiver video output.* The design of the receiver output circuits may contain upper and lower limit level pre-set controls. The equipment manufacturer's literature should detail the setting of these controls but an initial check should be made to show that pulse-to-pulse timing for trains of pulses at signal levels throughout the usable dynamic range is

2. Technique of Microwave Measurements Vol. II. M.I.T. Radiation Lab. Series.

correct. This is particularly necessary at the upper part of the receiver dynamic range where limiting often produces an output consisting of most of the pulse below the original 50 per cent measurement point. Signal-to-noise ratio on the output should be 10:1 or better.

2.27 *Receiver swept gain* (sometimes called STC or GTC). In a perfect SSR system and one in which all transponders contain side lobe suppression circuitry, no swept gain should be necessary. However because SSR suffers from reflection problems and some transponders have no SLS, some degree of swept gain will always be needed. The provision of two swept gain characteristics which can be switched to appropriate modes is normal in most equipments. Mode A requires a larger amount of swept gain at the start of each pulse repetition frequency (PRF) than other Modes because of the existence of non-SLS transponders working in this mode. Since the dynamic range of the SSR system is 50 dB, a swept gain characteristic capable of providing at least that amount of gain reduction at a point 10 microseconds after T_o must be incorporated and, indeed, to encompass the upper and lower limits of dynamic range, should provide at least a 60 dB span (although the full range is not necessarily required at every site). The swept gain characteristics should then have a shape which causes an increase of gain from a minimum value of 60 dB at T_o + 10 micro seconds by 6 dB per octave of range until swept gain reaches maximum.[3] The second swept gain characteristic normally starts at –35 dB, is removed again at the rate of 6 dB per octave range and can be applied to Mode C. If the control of the start point, and rate of reduction for swept gain, are brought out to the front of the equipment, these controls should be calibrated and a graph of the results produced so that any known amount of swept gain can be applied at an instant's notice during flight trials. It should be noted that when antenna performance is to be measured no swept gain must be in use. The amount of swept gain to be used operationally should be determined experimentally to produce the best results for a given site and installation.

2.28 *Receiver range gate.* The range gate is adjusted to cover the required display range at normal PRF. If it is ever necessary to investigate the extremities of the system coverage, the normal display range will not be adequate and adjustments to equipment PRF and hence to range gate length must be made. Therefore during initial evaluation of the equipment the ability of the range gate to operate over the pulse repetition time (PRT) required should be investigated. (A typical operational requirement will not call for the maximum coverage of which the system is capable and interrogator output power can be reduced accordingly.)

2.29 *Spurious effects.* The output from the interrogator receiver to the processing equipment must consist of "clean" video signals. This output should be examined for the presence of spurious voltages such as breakthrough from other high power radar equipments. Presence of such voltages may cause unsatisfactory operation of SSR processing equipment.

2.30 *Transmitter Power.* The power output from the transmitter is measured at the base of the feeder leading to the antenna system. Hence antenna feeder losses and also antenna forward gain must be known or previously measured in order to calculate the effective radiated power (ERP) of the interrogator. This must not exceed the ICAO Annex 10 approved limit of 52.5 dBW. Power output is affected by pulse shape. (An SSR monitor can give indications of in-service change of power.)

2.31 *Transmitted pulse shape.* This aspect of the transmitted signal must also conform to ICAO Annex 10 requirements. The rise-time of each pulse should be between 0.05 and 0.1 microseconds, and the decay-time between 0.05 and 0.2 microseconds. This parameter must be adjusted in conjunction with transmitter power (2.30) to produce the correct power output from the system.

2.32 *Transmitted pulse spacing.* Again the limits must conform to ICAO Annex 10 requirements of P_1 to P_3 spacing of mode intervals ±0.2 microseconds and P_1 to P_2 spacing of 2 microseconds ±0.15 microseconds. Both requirements must be met but drift of P_1 and P_2 spacing outside the prescribed limits will have particularly serious effects on the

3. M.I.T. Principles of Radar, 2nd Edition, Chapter II, paragraph 3.

performance of SLS circuitry in trans ponders. Arrangements should be made during initial commissioning of equipment to monitor P_1 to P_2 spacing over considerable periods of time and throughout the range of local ambient temperature to ensure satisfactory compliance with Annex 10 requirements.

2.33 *SLS power ratio.* The ratio of power between interrogator and control transmitters measured at the equipment racks must be such that when radiated by the antenna, it conforms to ICAO Annex 10 requirements (Annex 10, Volume IV, 3.1.1.5). This can be achieved using a knowledge of antenna characteristics but a final check should be made at a remote monitor point using a logarithmic receiver (such as that found in an airborne transponder) to detect transmitted interrogation. The levels of each pulse can be measured and fine adjustments made to equipment rack power measurements so that the correct ratio of interrogate/control power is radiated.

2.34 *PRF of transmitted interrogations.* An initial check should be made to ascertain that the PRF to be used is below the ICAO Annex 10 recommended upper limit inclusive of all modes. Some interrogators contain circuitry to ensure that this rate of interrogation cannot be exceeded in order to protect the transmitter. The functioning of this circuitry should be checked during commissioning.

2.35 *Checking of duplicated or standby-equipment.* Checks detailed in 2.24 to 2.34 should be carried out on any duplicate set of equipment.

2.36 *Alignment of primary and secondary radar heads.* When secondary and primary radars work in synchron ism, it is desirable to bring the SSR head into azimuth alignment with its associated primary radar head to as high a degree of accuracy as possible. A procedure which can be used is to slacken off the body of the synchro fitted to the SSR data gear box, observe a display with primary and secondary video signals available, and rotate the synchro body until both sets of signals appear on the same radial. Since the heads are not co-mounted, a small divergence between primary and secondary signals will occur with rotation. This should be minimized by observing the position of the secondary signal against the primary and making minor, more delicate adjustment to the position of the synchro body. When the best accuracy has been obtained, the body of the synchro should be firmly clamped. Adjustment of the range error between the displayed primary and secondary video signals to a predetermined relationship can be done by varying the pre-pulse delay to the SSR interrogator

2.37 *Alignment of an autonomous SSR head.* For flight testing purposes it is preferable to align the antenna to a true North datum. A hand-held bearing compass can be used to align the interrogator antenna, longitudinally from a surveyed remote point (approximately 100 m (330 ft) from the SSR), using both East and West cardinal points adjusted by the appropriate amount for local magnetic variation. Two cardinal points are used to minimize the alignment error of the antenna. The North marker cam is then locked in the 0°(T) position, which is 90° away from the longitudinal E/W position.

2.38 If, however, very accurate alignment of the antenna head is required, fundamental surveying methods must be used followed by optical alignment of the antenna. The presence of a monitor (or transponder) capable of transmitting a unique signal also installed on the surveyed site enables alignment of the antenna to be swiftly completed and continually checked thereafter.

2.39 *Alignment of the interrogator antenna with the SSR monitor site.* The position of the SSR monitor site should be plotted on an accurate large-scale map and the bearing and range measured. Thus, when the servo control manual dial is aligned to the measured bearing, the interrogator should point exactly in the direction of the SSR monitor site. Apparatus set up at the site can then be used to assess the performance of the interrogator antenna system.

2.40 *Measurement methods at the SSR monitor site.* A transportable SSR monitor containing necessary test equipment, a transponder and associated power unit, and an antenna capable of being attached at a height of 5 m (16 ft) from the ground level, should be positioned at the SSR monitor site. VHF pack sets can be used to give instant communication between the monitor site and the interrogator antenna head. SSR signals, received by the antenna are fed to the transponder, amplified by its logarithmic intermediate frequency stages and detected by a linear detector before being extracted and fed as video signals to an oscilloscope. An attenuator must be incorporated in the feeder to the transponder to reduce received signals to a level equivalent to the middle point of the transponder receiver dynamic range.

2.41 *Balancing of "control" and "interrogator" pulses.* With the cooperation of personnel at the interrogator head, the SSR antenna is aligned on the monitor bearing and detected signals are observed. Small movements in azimuth to and from about this direction will ascertain that it is the correct bearing of the monitor from the SSR head and "control" and "interrogator" pulse levels can then be peaked and measured. Appropriate amendments to power readings shown can then be made. This will produce the optimum SLS pattern of radiated signals.

2.42 *Measurement of main lobe shape and first side lobe amplitudes.* Continuing the process of measurement using the SSR monitor site arrangement described previously, the SSR antenna should be placed on a bearing 10° to one side of the bearing found in 2.39 and the signal levels of "control" and "interrogate" measured in volts from the receiver detector. The antenna bearing is then progressively further increased by 0.5° intervals until a point 10° beyond the bearing of the SSR monitor site is reached, noting signal voltages at each new position after a short interval of time on each occasion to allow any servo systems to settle. It is important to pick up the backlash which may exist in such a system and to continue taking readings in the same direction of rotation all the time. The process should be repeated twice in the same direction. Inclement weather conditions should be avoided. The results of these measurements are shown on a graph indicating a first side lobe level relative to the main lobe level where width at the 3 dB "power points" (the sensing points of an accurately set up transponder) is equivalent to the displayed beamwidth.

2.43 *Investigation of SSR antenna backlobe.* SSR installations sometimes disclose the presence of a significant backlobe at the rear of the antenna. Therefore, the SSR antenna should be rotated on to a bearing of approximately the reciprocal of that found in 2.39 and an arc a few degrees on either side of this bearing explored to discover the presence of any spurious lobe which might be present. Adequate "control" power must be available to cover the backlobe area to assure proper operation of the SSR system.

2.44 *Plotting of horizontal polar diagram (HPD) results.* A substitution method can be used to calibrate the voltage range of an oscilloscope used for measurements in 2.40 so that signal input is related to video voltage observed. The graph so produced enables video voltage results obtained at the monitor site to be read off as signal levels and plotted as an HPD. The total process is a lengthy one unless a form of automatic plotting is used.

2.45 *Signal levels calculations (SSR monitor site).* An example of the method of calculation using typical practical figures is given below:

Measured interrogate power = +30.5 dBW
Interrogator antenna gain = +22.5 dB
Interrogator feeder loss = –2.7 dB
Effective radiated power = +50.3 dBW

Path loss over 4.7 NM (8.7 km), using the formula:

– (33 + 20 log f + 20 log d)
where f = frequency in MHz (1 030 MHz) and
d = distance in kilometres

= –112 dB assuming ideal transmission conditions, no obstructions and optimum VPD conditions.

Monitor antenna gain = 0 dB

Transponder sensitivity = –84 dBm for 2:1
signal/noise ratio at the detector output.

Monitor feeder loss = –1.6 dB

Therefore theoretical signal level arriving at monitor receiver input

= +50.3 dBW – 112 dB – 1.6 dB = –63.3 dBW or –**33.3 dBm**

Measured best main beam signal arriving at monitor receiver input = –35 dBm

Measured worst main beam signal arriving at monitor receiver input = –34 dBm

Measured first side lobe level at monitor receiver input = **21 dB down on mainlobe**

2.46 *Processing equipment.* Flight checking is usually done to establish the performance of an SSR interrogator on a particular site and the data processing equipment can be checked separately by artificial pulses injected at its input. The SSR monitor can be used for an all-through system check if sufficient capability is built into it. However, if no other means of checking the processing equipment exists, the aircraft equipment can be used for this purpose during normal flight trials. The procedure would then be to check the following features:

a) Each mode in use at the location.

b) Representative codes to test thoroughly the processing equipment.

c) Accurate detection of emergency codes and action of alarm indicators controlled by them.

d) Pressure altitude reporting read-out.

2.47 *Reflection problems.* SSR as a system may suffer from reflection problems, and some information on this subject is given in the Aeronautical Surveillance Manual (Doc 9924), section 2.1.

2.48 *Airborne Installation.* For information on the installation of airborne surveillance equipment and test considerations, refer to Doc 9924, Appendix D, chapter 3 and Appendix O.

TABLES FOR APPENDIX B

Flight inspection procedures for SSR

Summary of flight inspection requirements

Table B-1. Type of inspection

Requirements	*Commissioning*	*Routine*	*Purpose of flight check and tolerances*
Coverage (i) Vertical	x	x	This check is performed to determine the size, shape, and continuity of the vertical radiated pattern. It will establish the outer fringe of coverage at various altitudes, and should remain within 15 per cent of the coverage pattern obtained during the commissioning inspection.
(ii) Route	x	x	On commissioning checks, all ATC controlled routes (airways) will be checked for coverage to the maximum distances that radar contact can be maintained at minimum instrument altitude for the route. Coverage should remain within 15 per cent of that obtained on the commissioning check.
(iii) Fix coverage or cover at report ing points	x	x	This inspection is conducted to determine that adequate cover is provided at the minimum operational height required or to establish the minimum height at which adequate cover is obtainable. Accuracy should be such that an aircraft reported over the fix will be within 300 m (1 000 ft) of the fix or 3 per cent of the fix-to-station distance, whichever is greater.
(iv) Azimuth cover	x		This check is performed on commissioning inspections to establish relative coverage at all azimuths by orbital flights at various heights and ranges.
(v) Height encoding	x	x	Where Mode C is in use, checks will be made on its operation during vertical coverage checks. The decode height should be within ±38 m (±125 ft) of the flight level altitude information displayed in the cockpit (relative to 1 013 hPa or 29.92 in. Hg.) and must correspond exactly with the coded input to the transponder.
(vi) Mode and mode check	x	x	This check is performed to confirm correct functioning in required Modes (other than C). These checks may be conducted any time during the vertical coverage, fix or route checks.
(vii) Side lobe suppression	x		Side lobe suppression added to existing radars is checked to ascertain if expected improvement has been obtained and that no adverse effects have resulted. Flight check is a special **requirement** on commissioning checks.

Ground inspection procedures for SSR

Summary of ground inspection requirements

Table B-2. Type of inspection

Requirements	*Site*	*Commissioning or after major overhaul*	*Routine*	*Remarks*
1. Receiver sensitivity	x	x	x	
2. Receiver beamwidth	x	x	x	
3. Receiver video output	x	x	x	
4. Receiver swept gain	x	x	x	
5. Receiver range gate	x	x		
6. Spurious effects	x	x		
7. Transmitter power	x	x	x	
8. Transmitted pulse shape	x	x	x	
9. Transmitted pulse spacing	x	x	x	
10. SLS power ratio	x	x	x	
11. PRF of transmitted interrogation	x	x		
12. Duplicate or standby equipments	x	x	x	
13. Alignment of primary and secondary heads	x	x	x	
14. Alignment of autonomous secondary heads	x	x	x	
15. Alignment of interrogator or head with SSR monitor	x	x		
16. Measurement methods at the SSR monitor site	x			
17. Balancing of control and interrogate pulses	x	x		
18. Main lobe and side lobe amplitude measurement	x	x		
19. Investigation of antenna back lobe	x			
20. Plotting of HPD results	x	x		
21. Signal level calculations	x	x		
22. Processing equipment	x	x	x	

Appendix C

OVERVIEW OF RADAR SITING ASPECTS

1. GENERAL

The selection of an appropriate location for the installation of a radar system is a very complicated process which involves many compromises. The following is intended to provide an overview of such factors.

2. DEFINITION OF OPERATIONAL REQUIREMENTS

The first step in selecting a new radar site is to determine the operational requirements for aircraft detection in the area of interest. The principle factor is the desired coverage. Also, factors such as special requirements for overlapping coverage must be considered in the definition phase, as they could have an impact on the location of a new radar site. The first consideration made is based on the type of radar: approach control, terminal control area (TMA) or en-route. For example, with an approach control radar the desired minimum altitudes for important positional fixes and airports must be defined. The theoretical coverage can then be calculated and compared to the measured coverage upon system testing.

3. INVENTORY OF POSSIBLE RADAR SITES

3.1 The site selection procedure normally begins with a study of a topographical map for the possible radar sites, where the radar will be installed to meet the operational requirements previously defined. After initial study, some possible sites will be excluded from the list, while the remaining ones must be visited for a complete investigation. In addition to the operational requirements, many other aspects must be considered, such as:

a) site accessibility;

b) availability of power and water;

c) means of data transmission;

d) land ownership;

e) restricted area; and

f) environmental factors.

3.2 After all considerations and studies, it is advisable to produce panoramic photos from each potential radar antenna position for the sites still under consideration. It is preferable to do so for the entire 360° view of the radar. Another useful tool to produce screening angle charts is a theodolite, and these charts serve as an input for theoretical coverage analysis.

3.3 In the process to arrive at a final decision for radar site selection, an automated computer-based tool can be of valuable assistance in determining the “final” antenna coverage diagram. Computer-based tools also allow overlapping coverage to be analysed, of both existing radars and the new installation.

Note.— See Appendix D for more information on the tools.

4. POTENTIAL SITING PROBLEMS TO CONSIDER

Lobing

4.1 Vertical lobing of the antenna radiation pattern occurs when energy reflected from the surface of the earth combines with the directly radiated energy to form minimums (nulls) and maximums (lobes) in the vertical plane. This in turn results in a deterioration in aircraft detection within the null zones.

4.2 Factors which may impact lobing tendencies and which can be controlled at the time of site selection include: the height of the antenna above the terrain, the antenna tilt setting, the reflective characteristics of the surface in the vicinity of the radar, and equipment types. Antennas located at low elevations (especially with smooth surrounding terrain) frequently have lobing nulls which have a significant effect on low altitude secondary radar coverage, and antennas located at high elevations frequently have serious secondary radar nulls at higher (en-route) altitudes.

4.3 Antenna tilt directly affects the amount of energy radiated into the surrounding surface, and therefore affects the amount of lobing. However, the tilt setting also directly affects other important operational characteristics, such as coverage and the amount of clutter.

4.4 The type of surface surrounding the radar directly affects the amount of energy reflected, which in turn determines the amount of lobing. For instance, a smooth surface such as a calm sea or desert area produces more lobing than uneven land. Also, trees or other vegetation will absorb and scatter more of the energy, which will result in less lobing.

4.5 Certain equipment selections may also affect the amount of lobing. For example, large vertical aperture (LVA) type antennas radiate less energy towards the surrounding surfaces, which results in less lobing.

Screening

4.6 Screening occurs when target detection is impeded by an obstacle which produces a shadow effect in the coverage. This can affect the low altitude coverage significantly. Possible obstructions include natural objects (mountains, trees, etc.) as well as constructed objects (buildings, hangers, towers, etc.). In radar site selection, careful placement of the radar in relation to obstructions, as well as the elevation of the antenna, can be used to minimize the effects of screening. Special attention shall be paid to “thin” objects (poles, towers, etc.) when implementing MSSR systems, since errors may be introduced in the azimuth information of the targets in the azimuth sectors where obstructions have been erected.

4.7 Another type of screening that usually cannot be completely planned for during the radar siting process is that which is produced by the aircraft itself. This occurs when the aircraft position blocks the SSR interrogation from reaching the aircraft transponder antenna, due to a steep turn. Any special departure or arrival procedures which involve hard turns in the vicinity of the airport should be considered along with the other operational requirements when selecting a site, to attempt to minimize this possible effect. The implementation of Mode S transponders with antenna diversity will help to alleviate this problem.

Reflections

4.8 Although both PSR and SSR systems can experience reflections, and these reflections can be “up-link” or “down-link”, the most problematic type are the SSR “down-link” reflections. These down-link reflections of the SSR can be caused by natural terrain features of the radar site, but are usually caused by nearby buildings, fences, and other obstacles. This type of false target, which involves the reflection of both the interrogation and aircraft reply off the obstacle, results in a false plot at the azimuth of the reflecting surface, which is usually distinct from the azimuth of the actual aircraft position.

4.9 Depending on the location and size of the reflecting surface, the false target can be present during many consecutive antenna revolutions. This in turn may cause a false track to be presented to the controller, causing operational problems or even jeopardizing flight safety. These problems are normally most severe in the airport environment where structures with large reflecting surfaces are abundant.

4.10 Ground reflections may degrade the quality of the azimuth information, especially if the reflected energy is interfering on an asymmetrical (to the centre of the beam) manner with the direct energy. Diffraction or in-beam deflection may cause, by deviating part of the beam in an asymmetrical manner, azimuth errors or split plots which have a small azimuth offset from the genuine target position.

4.11 Modern SSR systems, such as monopulse SSRs usually have special features to reduce the possibility of reflected false targets, such as:

a) using LVA-type antennas, which greatly reduce the amount of energy radiated at lower angles, where the reflecting surfaces are usually located;

b) range azimuth gateing (RAG) of power, STC/ GTC, or receiver sensitivity; and

c) special processing within the SSR system to identify the location of reflectors, and then eliminating the suspected false targets from the data transmitted to the ATC facilities (this special processing may also be accomplished by the radar data processing system in the control centre).

4.12 Sometimes actions are taken to minimize the illumination of the reflecting surfaces by the radar, such as installation of absorbing material, placement of trees or bushes, or the bending of fences to reflect the energy towards the ground.

4.13 It can be seen that careful consideration must be given during radar siting to minimize possible reflected false targets from being generated.

Clutter

4.14 Clutter is a potential problem to be considered when siting a PSR. All of the surrounding surfaces will, when illuminated by the radar, produce clutter to a certain extent. Clutter echoes normally fall into two categories: volume clutter and surface clutter. Volume clutter results from scatterers that are distributed throughout a volume of space, such as rain, birds, insects, etc. Surface clutter is caused by echoes from irregular surfaces around the site. This will have a negative effect on the nearby coverage, and can originate from many different factors like surrounding mountains, large buildings at airports and nearby cities (city clutter) and rough seas/lakes close to the site.

4.15 It is important to select a site with as little clutter as possible. However, there are means in modern equipment to reduce clutter, such as:

a) antenna elevation;

b) antenna tilt;

c) selection of frequency band;

d) low/high beam switching;

e) GTC/STC-mapping (both on RF and IF); and

f) MTI/MTD-mapping.

Most of the above-mentioned means to reduce the clutter level will also affect the coverage.

Tangential approach

4.16 Another consideration when selecting a new radar site for a PSR with MTI is the possibility of not detecting aircraft when moving tangentially to the antenna. Therefore, care should be exercised not to place the radar in such a position as to result in the normal approach paths being tangential to the antenna. This must be considered during the specification of operational requirements and possible site selection.

Cone of silence

4.17 The cone of silence is yet another aspect to be considered, and refers to the cone-shaped area directly over the radar antenna which does not provide target detection due to the antenna radiation pattern. In a single coverage, environment the cone of silence will result in a complete loss of radar reports for aircraft within this area.

4.18 During radar siting, consideration of the cone of silence means that the radar should be sited such that airways and approaches are separated from the cone of silence as much as possible. With the implementation of Mode S, it will become even more important to ensure that these cones of silence are eliminated by overlapping coverage of adjacent radars.

5. SPECIFIC PROBLEMS IN RELATION TO MODE S IMPLEMENTATION

5.1 When siting Mode S radars (in the following text, referred to as Mode S interrogators), the anticipated traffic patterns must be considered. This applies not only to new facilities, but also to the upgrading of existing SSRs to Mode S SSRs.

Note.— For guidance materials on interrogator coordination and clustering, refer to Aeronautical Surveillance Manual *(Doc 9924), Appendix J.*

Traffic distribution with respect to the interrogator

5.2 The data-link capability of a Mode S interrogator is limited by the number of aircraft within the antenna beam and the distribution in azimuth of the aircraft within the radar coverage. Therefore, the interrogator should be located such that the traffic flow is evenly distributed as much as possible. For example, a radar location separated in distance from a busy airway would experience less traffic concentration than one which is located directly under a busy airway.

Coverage redundancy

5.3 It should be noted that when Mode S is implemented, the maximum effective range of some interrogators will be less than the actual maximum range. The determination of the maximum effective range should consider:

a) adequate overlapping coverage for both redundancy and optimum multi-radar processing;

b) not excessive overlapping coverage, as allocation of interrogator identifiers could become more complicated, and without significant improvements to the quality of radar information provided to the controller; and

c) link budget not calculated in excess because Mode S transponders triggered by a Mode S interrogator out of its responsibility zone are not locked out by this interrogator and, therefore, increase the all-call fruit.

Collocation of a Mode S interrogator with a PSR

5.4 When collocating a Mode S interrogator with a PSR, it should be kept in mind that the antenna rotation speed has a direct influence on the transfer delay of data-link messages. There is a trade-off involved in optimizing the antenna rotation speed. For instance, the Mode S data link transfer delay is reduced with a faster rotation rate. However, the PSR clutter cancellation requires a slower rotation rate. For Mode S, the disadvantage of a fast rotation rate would be a reduced access time (aircraft dwell time) for data link use. This must be taken into account when considering the collocation of a Mode S interrogator with an existing PSR.

APPENDIX D

EXAMPLES OF RADAR ANALYSIS SYSTEMS

The following sections explain some of the tools for the analysis of radar systems on various levels. This material serves as a guideline to users.

Note.— The information below was collected in 2017 and represents the most recent version of the tools, however, this may change in the course of further developments.

1. PHOENIX analysis working position (AWP)

The PHOENIX system is a Linux-based, multipurpose Surveillance Data Processing System (SDPS) used for many air traffic control (ATC) applications. It is used as the main air traffic services (ATS) fallback system for both the lower and upper airspace of Germany. It is designed, developed and maintained solely by the systems house of the German air navigation services provider (ANSP) DFS Deutsche Flugsicherung GmbH. PHOENIX comprises a large number of components to receive, process, analyse and display surveillance data. One of these components is the analysis working position (AWP).

Introduction and basic functions

Originally, the AWP was developed to evaluate tracking performance of the PHOENIX online Interacting Multiple Model Kalman Filter (IMMKF) tracker. Tracker developers had the need for a tool to display sensor measurements, tracked targets, tracking results and their corresponding statistics. Today new tracking features are implemented in the tracker and the AWP simultaneously in order to ensure tracking performance. At the DFS, the AWP is in operational use in the following fields:

- tracking performance evaluation of several trackers such as the PHOENIX tracker, ARTAS and the ATCAS RDPS;
- sensor performance evaluation with GPS reference tracks; and
- legal recording and airspace incident investigation (i.e. safety management).

The AWP provides quick online and offline methods to inspect the current sensor quality with respect to e.g. measurement standard deviations, bias estimation, clutter rate, delay of reports, rate of erroneous reports, or probability of detection. It is a scalable, distributed multi-process system, which consists of the online IMMKF tracker, the recording and replay processes, the statistics engine, the AWP display process, several interface agents, a second tracker used for reprocessing recorded surveillance reports, and a batch estimation process for trajectory reconstruction. All processes communicate via standard IP sockets using standard data formats such as ASTERIX.

A 3D display in the AWP serves as a tool for analytic purposes. It is not intended for controller work, but for technicians and engineers analysing or evaluating the sensor data situation, a minimum safe altitude warning (MSAW) algorithm, a specific air situation, or an incident. Input data can either be processed online (i.e. on-the-fly), or recorded and replayed. The latter facilitates incident evaluation tremendously, because a specific situation can be reproduced over and over again until it becomes clear.

The AWP offers a basic air situation display, as used in the controller working position (CWP), enriched with enhanced filtering and colouring mechanisms, next to a huge set of dialogues for statistics and auxiliary functions.

PHOENIX AWP – Supported formats

The AWP supports a variety of message standards, most of which are EUROCONTROL ASTERIX formats plus a set of proprietary formats coming from site-specific systems. Most commonly used formats supported by the AWP are:

- ASTERIX sensory data (CAT001, 002, 008, 009, 010, 019, 020, 021, 034, 048);
- ASTERIX track data (CAT062 in various versions);
- ASTERIX safety net data (CAT004);
- Flight plan data (ASTERIX CAT032, CAT062, ADEXP); and
- status data (ASTERIX CAT063, 065).

Proprietary message formats are supported through extensible and configurable import- and export dialogues.

PHOENIX AWP – Features

The AWP provides the following enhanced features:

- an online/offline collocated message display (e.g. plots, tracks and safety net alerts);
- sensor availability monitoring;
- an extensible and generic reporting framework including HTML and XML;
- an extensible and generic diagram framework;
- reference trajectory comparison and corresponding statistics;
- scene reconstruction and batch estimation;
- sensor quality control indicators such as:
    - standard deviation values and time series diagrams;
    - bias values and time series diagrams;
    - probability of detection (PD) values and time series diagrams; and
    - delay time values and time series diagrams;
- a complete set of both textual and graphical filtering mechanisms including around 200 selectable fields and attributes (e.g. SSR-code, track-ID, altitude);
- display of sensor rotations and sector/north mark arrival;
- display of contributing remote units in MLAT/WAM track updates;
- display of measurement covariance ellipses;
- display of track covariance ellipses;
- display of timely sequence of plot arrivals;
- display of trajectories;
- detailed plot message inspection;
- ADS-B quality indicator tables;
- full parallel recording and replay facilities including import- and export- functions;
- export to database tools;
- 3D sensor volume/airspace inspection features;
- vertical view displays for altitude inspection;
- collocated inspection of safety net alarms and events;
- inspection of third-party tracks and calibration flight GPS logs;
- synchronized redundant data logging/recording; and
- long-term key performance indicator (KPI) analysis and statistics.

PHOENIX AWP – Online tracking quality control – OTQC

The component used for generating online/offline statistics is the dedicated process online tracking quality control (OTQC), which extends the basic processing mechanisms of the AWP. This process acts as a statistics engine and communicates with the AWP, while it processes surveillance data.

The AWP OTQC uses a batch estimator, which collects all measurements of the recent past of the online tracker, performs a forward chaining with a third-order Kalman filter, plus a backward pass, and finally a B-spline processing for a continuous representation of the trajectories. Constructed trajectories can be compared with the online tracking results for each time step; this delivers the data for root mean square (RMS) based quality statistics.

The OTQC statistics comprise the numbers of track disruptions and split tracks over time, X/Y track and measurement covariance, deviations of track to trajectory, positional RMS (alternatively sigma) along and across trajectory, and RMS of various track state errors.

Illustrations

Figure D-1 depicts the basic air situation display of the AWP. Measurements (i.e. plots) and tracks (i.e. results of the tracker) for the target DLH5PL are displayed next to the message filtering dialogue, which currently filters by the attribute “ASTERIX category”.

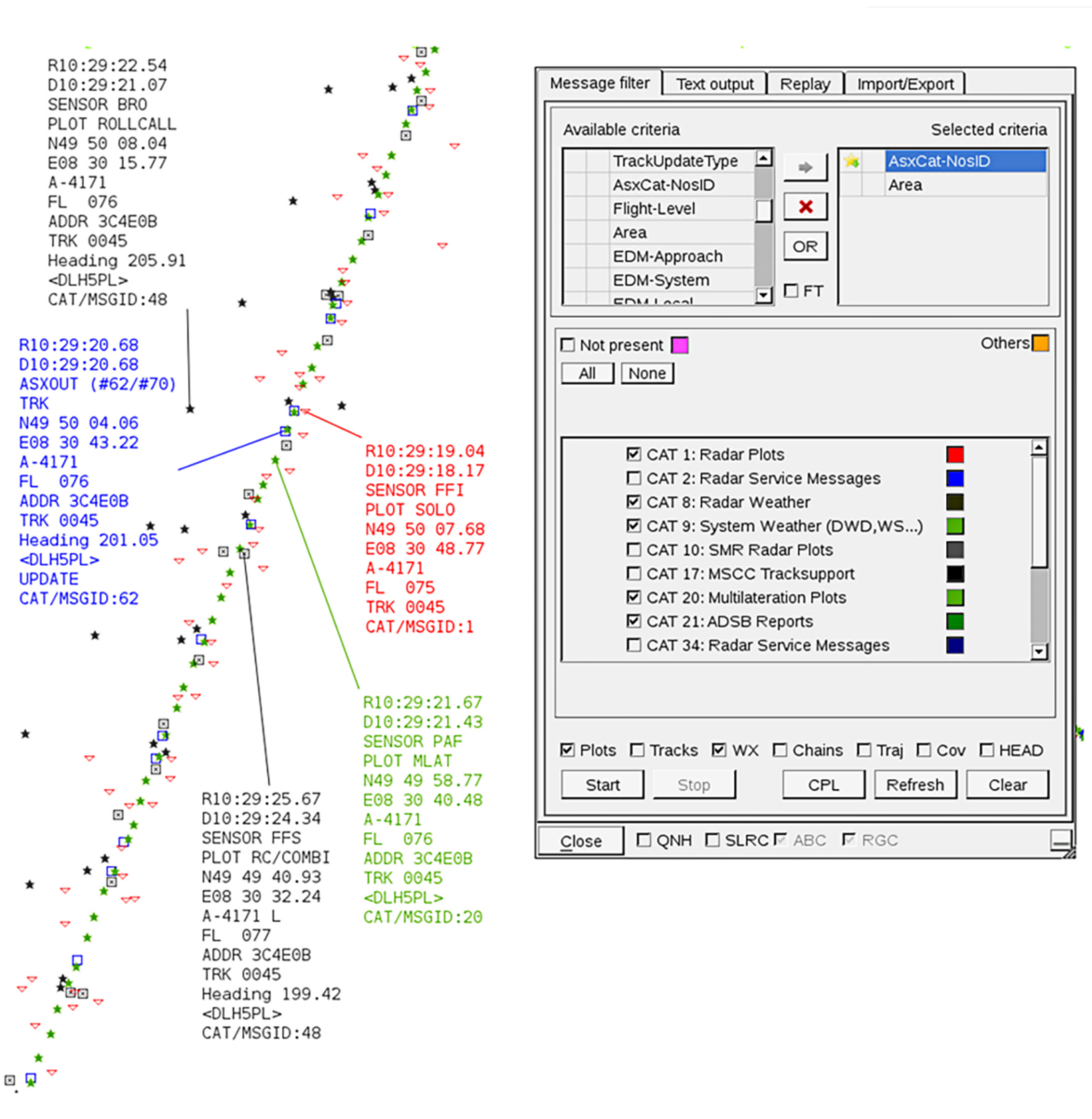

Figure D-1: AWP - Air situation display showing measurements and filtering

Figure D-2 depicts a PD evaluation of one of the sensors, Radar Frankfurt South (FFS) in Germany on the right side. On the left, the PD evaluation results are displayed as an overlay over the current air situation.

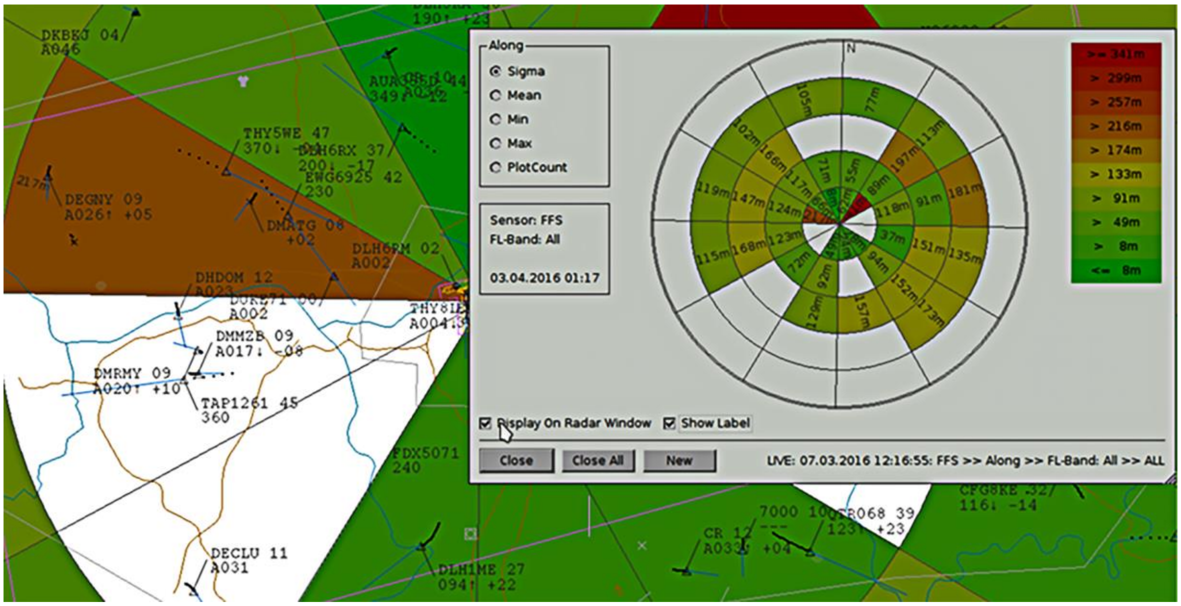

Figure D-2: Online PD evaluation of the sensor FFS with the results shown as an overlay over the air situation display

Figure D-3 shows the resulting statistics of a reference trajectory comparison, where plots measured by one of the sensors, – Radar Buechel (BUE) were compared against a reference trajectory given by GPS measurements. The minimum across-error [m] was 0.49 meters

	Number of measurements	DXY [m]	Across [m]	Along [m]	Latency [s]	Range [m]	Azimuth [deg]
Mean	102	55.63	31.02	-37.99	-0.2628	37.87	0.0140
Mean-PSR	41	50.99	41.75	-9.68	-0.0702	8.68	0.0989
Min	102	25.89	0.49	-59.89	-0.4177	25.84	-0.1050
Min-PSR	41	5.73	0.39	-51.56	-0.3798	na	na
Max	102	198.80	194.56	-25.84	-0.1734	59.47	0.2028
Max-PSR	41	113.26	113.21	20.36	0.1520	51.48	0.4961
Sigmas	102	64.94	52.16	38.68	0.2682	38.57	0.0616
Sigmas-PSR	41	60.16	56.98	19.30	0.1401	19.34	0.2124
RMS	102	32.88	41.61	6.20	0.0463	6.22	0.0597
RMS-PSR	41	30.51	37.75	16.41	0.1192	17.01	0.1850

Figure D-3: Statistics of a reference trajectory comparison

Figure D-4 depicts an example of the generic diagram framework. It shows the minimum, maximum, mean and standard deviation of the Deviation X-Y (DXY) error of the sensor FFS in meters over time. All the attributes can be added, removed or changed via drag-and-drop.

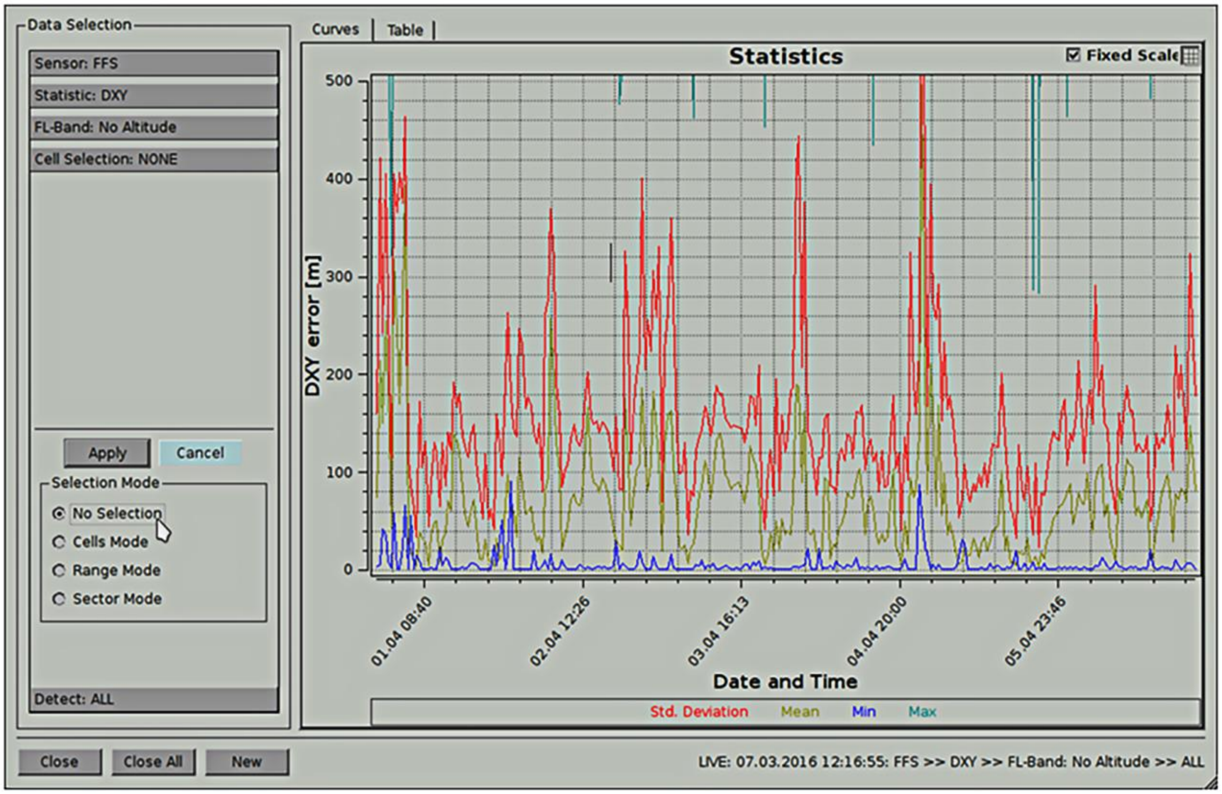

Figure D-4: Graphs for min, max, mean and std. deviation of the DXY error in [m]

Figure D-5 shows takeoff and approach on Cologne Bonn Airport (CGN), Germany. On the right side, the approach of a target is shown vertically (blue). On the left, the same target can be observed horizontally.

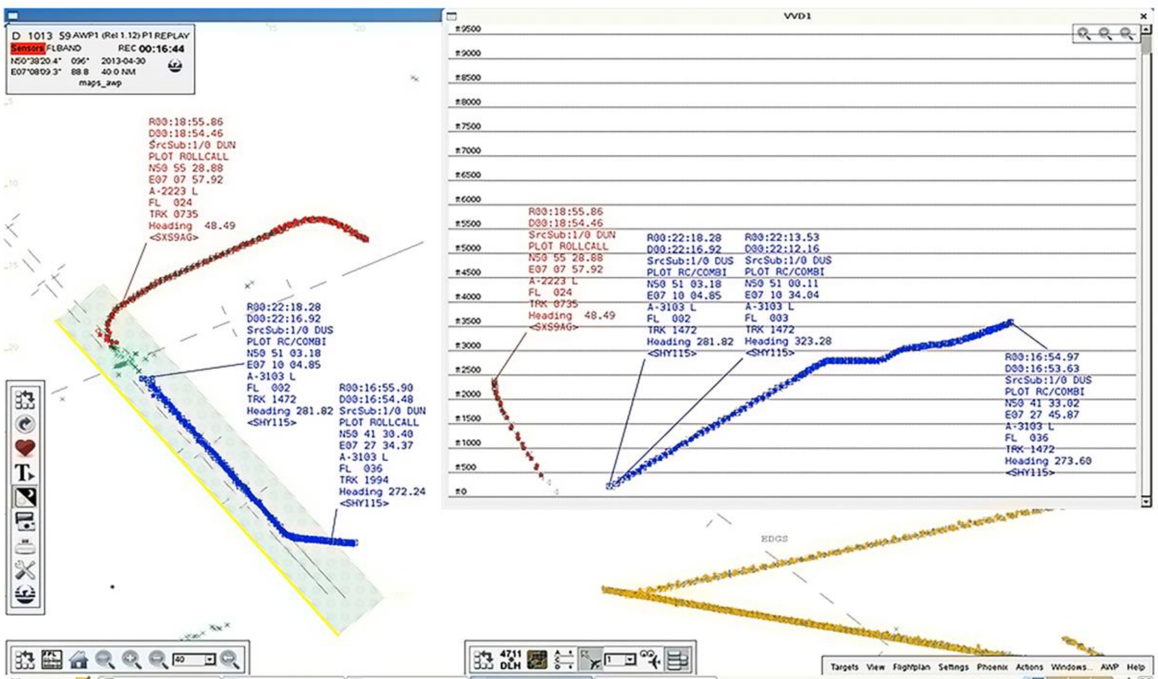

Figure D-5: Vertical view display showing an approach

2. Radar analysis support system (RASS)

The radar analysis support system (RASS) suite of analysis tools were designed and built by Intersoft Electronics, in collaboration with EUROCONTROL and FAA, in order to satisfy the requirements of ICAO for both periodic and real-time analysis of Radar surveillance systems. RASS is the known comprehensive radar manufacturer-independent system to provide a top-down assessment of the entire Radar chain and accurately determine the real-time performance state at the ATC center.

RASS-S primarily manages all aspects of measuring and analyzing the Radar chain at the Radar site, whereas the RASS-R and the real-time analysis tool, the surveillance monitoring system (SMS), manages the determination of overall detection and accuracy of the data at the ATC center.

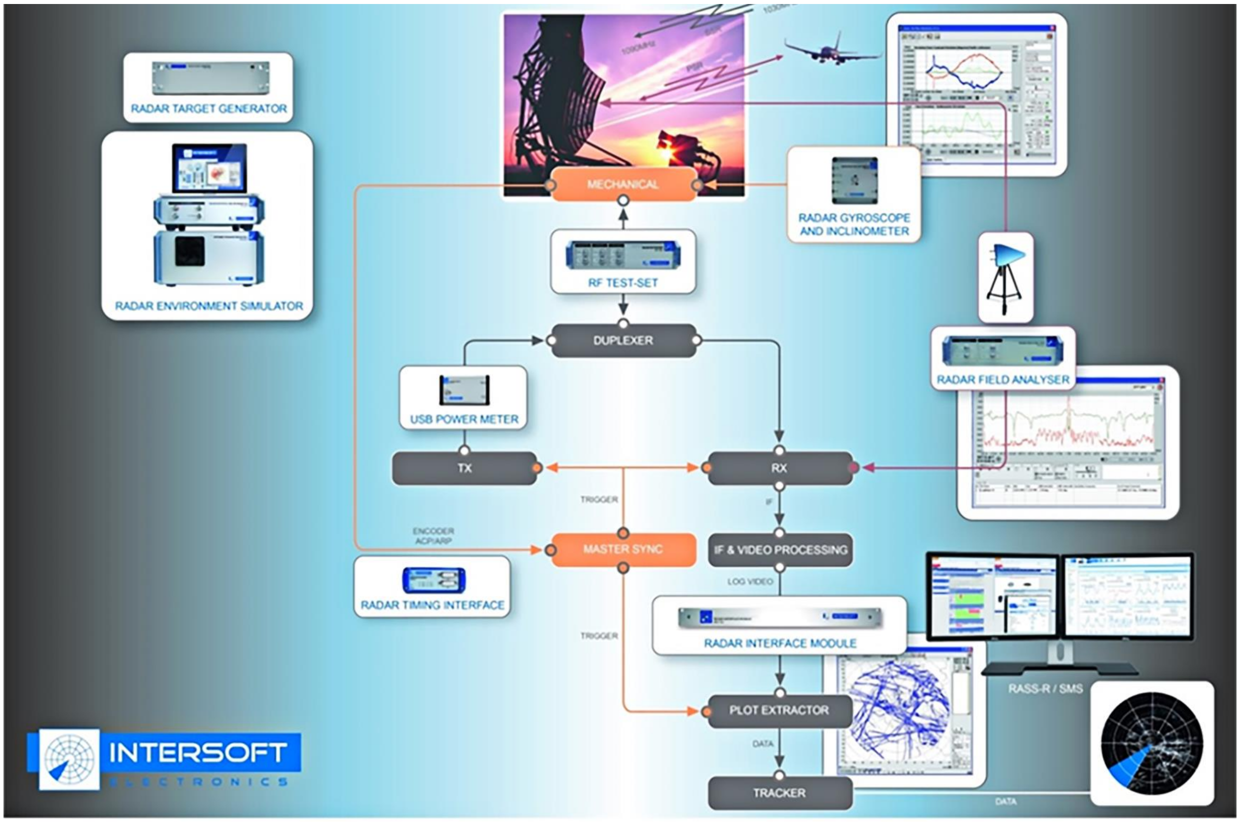

Figure D-6: Radar analysis support system (RASS)

RASS-S

The top-down methodology employed by the various RASS-S tools allows for critical analysis of all major subsystem components. These include, but are not limited to, such tools as:

- radar field analyser (RFA) for analysing (M)SSR and PSR antenna patterns;
- radar gyroscope and inclinometer (RGI) for analysing mechanical and encoder systems; and
- radar interface module (RIM) for analysing (M)SSR and PSR IF/Video level effectiveness as well as a local data assessment at the output of plot extractors and trackers.

Other RASS-S tools, such as the radsar environment imulator (RES) for SSR monopulse target generation and radar target generator (RTG) for PSR target generation, provide a deeper quantitative engineering qualification assessment at factory-level testing as well as supporting commissioning and post-maintenance rectification testing. Both target generators can significantly offset costs associated with flight test especially since they not only generate targets but also negative impact environments such as jammers, FRUIT or clutter.

RASS-R and surveillance monitoring system (SMS)

As outlined in this material, real time quality control (RTQC) is a fundamental principle in the evaluation of surveillance sensors with respect to detection and accuracy, which are key engineering inputs into management and application of aircraft separation.

RASS-R is an overall performance analysis tool of the quality of the surveillance sensor. The tool can analyse all facets of the radar message, however typical aspects include PD, azimuth/range accuracies, false target analysis and code validation.

The SMS is a scalable monitoring system that provides real-time analysis of the quality of the surveillance sensor data arriving at the ATC center. Like RASS-R, SMS can analyse all facets of the radar message, however typical aspects include PD, azimuth/range accuracies, false target analysis and code validation. The SMS receives data from any number of surveillance systems and types, including PSR/SSR/SSR Mode S radars, ADS-B stations, MLAT stations, A-SMGCS data, ASDE-X data or system track data (ARTAS multi radar tracker), prior to being fused in within the ATM system. This is a critical feature as a single sensor error can often impact a system track within the multi-sensor environment.

3. Surveillance analysis support system for ATC Centers (SASS-C)

SASS C is a standardized ATC center based toolbox, designed to analyse the performance of the surveillance infrastructure, including ATM surveillance sensors and surveillance data processing systems (SDPS). It is typically used for 24/7 verification of the compliance of operational sensors and trackers to nominal performance in the ATC centers.

SASS C is now widely distributed to national Civil Aviation Authorities, national Ministries of Defense, Civil and Military Air Navigation Services Providers (ANSPs), research and development organizations, and institutions in most of the EUROCONTROL Member States. Under the guidance of the EUROCONTROL Member States user community, EUROCONTROL is in charge of enhancing the SASS C service baseline and providing centralized maintenance and support service to EUROCONTROL Member States users.

SASS C Functional Overview

SASS C is a set of complementary software tools implementing three groups of top-level functions i.e. VERIFication and PREDICTion.

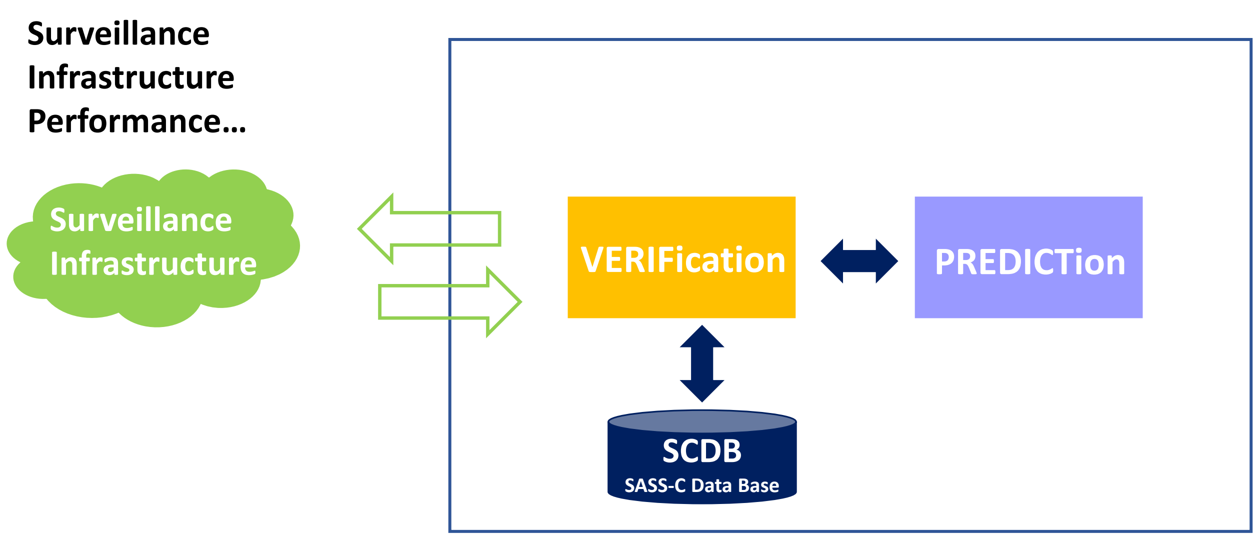

Figure D-7: SASS C Top Level Functional Architecture

VERIFication

The VERIFication function allows the performance assessment of a surveillance infrastructure and verification against internationally defined specifications (refer to Volume 1, EUROCONTROL Specification for ATM Surveillance System Performance (ESASSP). It also follows the new standard implementation and aims to support standards like ESASSP V2, ED 129B, and ED 142A. It is designed to work with opportunity surveillance data from multiple sensors, from mono-sensor data, as well as from simulated data.

VERIFication functions:

- collects the multi-sensor or SDPDS surveillance data;
- reconstructs “reference trajectories" for each flight, i.e. the most likely paths of the aircrafts, and all the other associated data e.g. SSR codes, optimally using the collected multi-sensor data provided by the infrastructure including by those under analysis; and
- analyses the collected input data by comparing it to the built reference.

The advantage of the approach is that it is a cost effective way to perform performance assessment (compared to test flights), but it also enables the implementation of a 24/7 performance monitoring function.

The first generation of SASS C, SASS-C V6, was developed in the early 1990s. Now functionally and technologically obsolete, this version is being phased out and replaced by VERIFication. Developed from scratch with new software concepts compared to SASS-C V6, VERIFication implements evolutions in both the surveillance domain and IT technologies.

The main functions implemented in VERIFication are summarized as follows:

1. Surveillance data acquisition, taking into account:

a. various input medium (files, Ethernet, serial lines);
b. various file formats/protocols (TCPdump, FINAL, UDPmulticast, UDPunicast, UDPbroadcast, HDLC, LAPB); and
c. various surveillance data formats (ASTERIX, SELEX, AIRCAT, MADREC, etc).

2. Multi-sensor data association, estimation of the position measurement biases and reconstruction reference trajectories;

3. Comparison of the sensor or SDPDS data to the reconstructed reference or an externally given reference for assessing their quality in terms of:

a. probability of detection/update (position report but also e.g. SSR codes);
b. accuracy of measurement (position but also velocity vector and height);
c. delay with regard to transmission of discreet data; and
d. probability of false report.

4. Aggregation of the basic measurements calculated by the comparison step and presentation of the figures in reports with a comparison against thresholds defined by standards, highlighting by colour whether the performance requirement was achieved or not.

5. Maintenance of a database containing those figures for trend analysis.

6. Generic DISPlay feature for graphically analysing or investigating the raw received data, the reconstructed data or the result of comparison. VERIFication implements features like filtering, styling, generating geographical analysis by generating mosaics, showing in scatter view, showing histograms, etc.

7. Generic filtering feature for input at any functionality, allowing filtering on surveillance data item or on basis of geographical/geometrical criteria

PREDICTion function

The PREDICTion function allows the theoretical prediction of the performance of surveillance infrastructures in terms of coverage (RADAR, WAM and ADS-B), of probability of message reception/transmission (ADS-B), as well as of position measurement accuracy (passive or active WAM).

PREDICTion calculates the coverage volumes and coverage multiplicity of radars at a given height/altitude. PREDICTion also calculates the coverage volume of a group of ADS-B or traffic information service – broadcast (TIS-B) sectored ground stations, WAM systems, and the probability of successful transmission of ADS-B or TIS-B, as well as the accuracy of passive or active WAM systems.

PREDICTion then offers a graphical/geographical navigation through a combination of the results.

Radar is a current and widely used surveillance technique. The range of an aircraft is determined by transmitting an RF signal from the radar antenna and determining the round trip time of the reply signal from the aircraft. The bearing of the aircraft is determined by the bearing of the antenna. Primary surveillance radar is a non-cooperative independent surveillance technology that requires no specific equipment on the aircraft. The RF signal from the radar is reflected from the aircraft hull. Secondary surveillance radar (SSR) is a cooperative independent surveillance technology that requires the aircraft to carry a transponder. However, SSR have greater operational ranges, are more accurate and provide more information on the aircraft (e.g. ID and altitude) than PSR. The SSR RF signal is decoded by the aircraft transponder, which then transmits a reply with the requested information.

ADS-B and TIS-B are two surveillance techniques that use data links to pass aircraft surveillance information. There are three data-links defined to support ADS-B and TIS-B:

a) 1090 MHz Extended Squitter;
b) VDL (VHF Digital Link) Mode 4; and
c) UAT (Universal Access Transceiver).

Wide area multilateration (WAM) is a new cooperative independent surveillance technology that can derive an aircraft's 3D position by passively receiving transmissions of opportunity from an aircraft. An advantage of WAM is that it can provide an independent position calculation using ADS-B transmissions. Ground stations are required to be implemented in order to:

a) transmit and receive radar pulses for traditional radar based surveillance;
b) receive ADS-B transmissions made by aircraft;
c) transmit TIS-B transmissions to aircraft; and
d) receive transmissions of opportunity for a WAM position calculation.

The location and configuration of the ground stations is important for ensuring that the required level of surveillance service is achieved.

The purpose of PREDICTion is, therefore, to allow users to specify ground stations associated with different surveillance technologies within a surveillance system, calculate the geographical coverage of the ground stations, and display the overall coverage achieved by a surveillance system including the multiplicity of coverage provided by either a single technology or a mixture of different surveillance technologies.

PREDICTion calculates and displays the following types of coverage:

a) line-of-sight (LoS) coverage maps based on an obstruction analysis of digital terrain data; and
b) performance restricted (PR) coverage maps (ADS-B\TIS-B\WAM only) based on comparing the calculated performance of the surveillance technology with user defined minimum performance requirements.

PREDICTion is designed as a geographical information system (GIS) based software application, running on a standalone PC, with a modern user friendly graphical user interface (GUI). A key aspect of PREDICTion design is to calculate, store and display coverage maps using a grid cell approach with a user selected grid resolution (based on Digital Terrain Elevation Data (DTED) resolutions). The user will, therefore, be able to select digital terrain data and coverage calculation resolutions to meet the needs of their specific analysis. PREDICTion is, therefore, also designed to be able to work with high-resolution digital terrain data and to calculate, store and display high-resolution coverage maps. In comparison to the VERIFication function, the PREDICTion function software is monolithic. The current version, V2, implements:

- polar LoS calculation for multi-sector radar and individual sectored antenna to be used for ADS-B, TIS-B or WAM systems ending in the old-fashioned SASS C V6/SALADT format with regard to EMG96 or WGS84 altitude referential;
- grid LoS calculation for polar for multi-sector radar, individual sectored antenna, ADS B, TIS-B and WAM systems ending in the new fashioned grid format with regard to WGS84 altitude referential;
- ADS-B/TIS-B probability of update performance calculation based on signal/noise ratio criteria; and
- passive/active WAM system positioning accuracy.

PREDICTion is however made of two main sides:

- the GIS oriented human machine interface (HMI) for defining the surveillance scenario (sensors, traffic) but also visualising the results; and
- the complex and heavy business calculations.

DISPlay

DISPlay is the module implementing generic graphical visualization features and enabling analysis of the surveillance data i.e. input or output of all VERIFication modules. Several types of view are available:

- geographical;
- scatter (A/B diagram plotting);
- histogram; and
- table.

All are multi-data sources (multi-sensor). The following figures show display examples of analyses results.

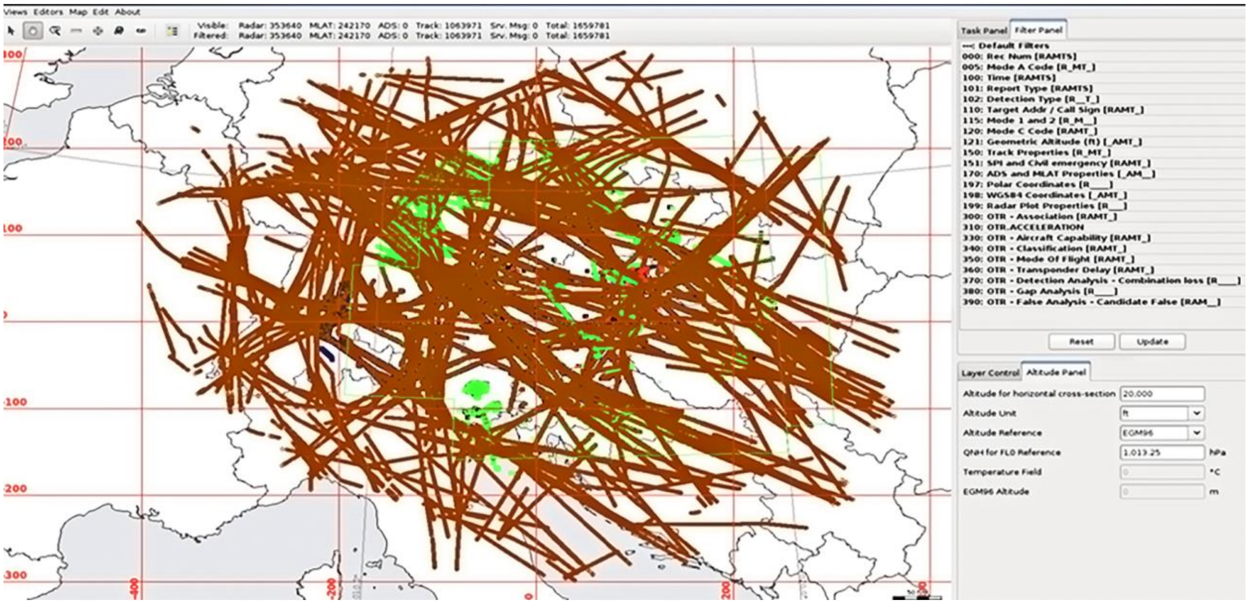

Figure D-8: VERIFication DISPlay Geographical View Illustration

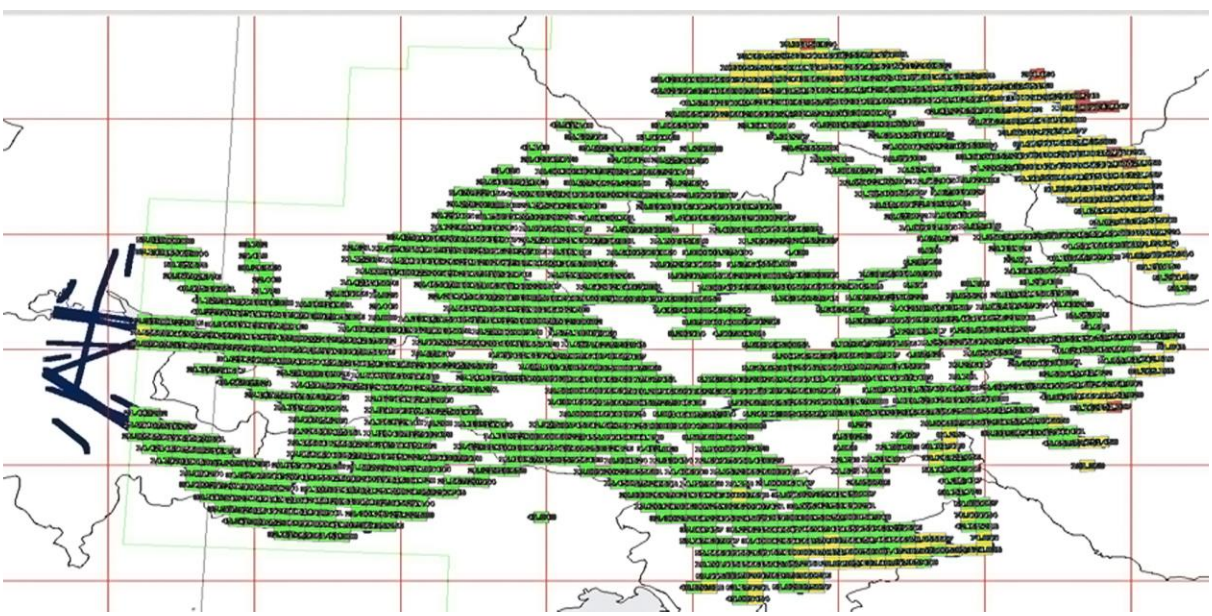

Figure D-9: VERIFication DISPlay Mosaic Illustration (WAM Accuracy per cell)

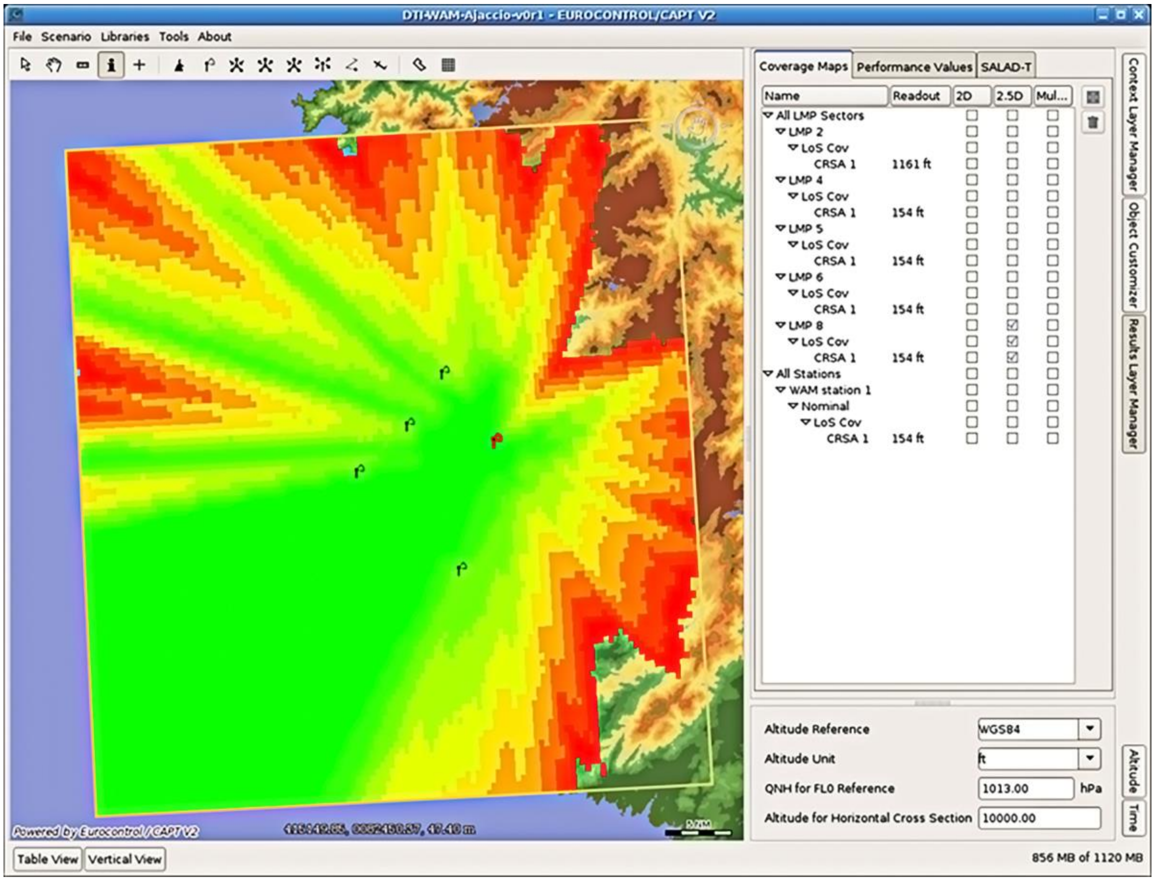

Figure D-10: PREDICTion – LoS Coverage 2,5D Diagram

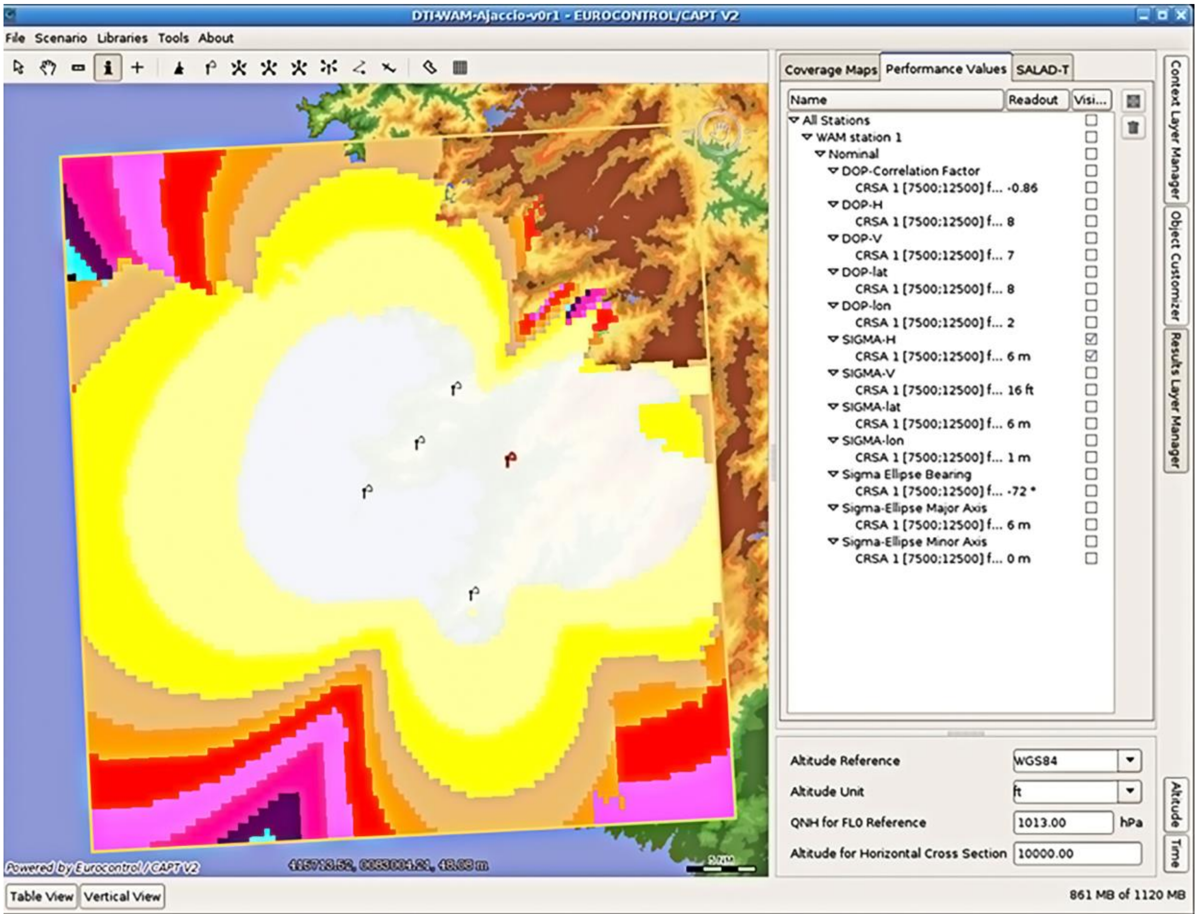

Figure 11: PREDICTion – 10.000ft WAM Horizontal Accuracy Diagram

— END —

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