Understanding Mode S technology

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This article provides an introduction to some important SSR (Secondary Surveillance Radar) concepts that lie at the heart of Mode S.

Introduction

One of the primary purposes of the Mode S system is to resolve the operational problems associated with the legacy Mode A/C or ATCRBS (Air Traffic Control Radar Beacon System). Use of Monopulse interrogators allow the separation of closely spaced targets in azimuth, and reduce the number of transponder replies required, for determining the azimuth angle of the target. This in turn reduces transmission occupancy, allowing more targets to be tracked within a given airspace. However, several problems still remain, and these are now addressed in more details.

Mode S interrogation and reply formats

Refer to ***Figure 1***. The Mode S selective interrogation transmitted on a 1030 MHz carrier comprises a two pulse preamble, followed by a data lead in period. A sync phase reversal in the 1030 MHz carrier references the start of a 56-bit or 112-bit DPSK (Differential Phase Shift Keying) data block. The second preamble, pulse P2, will suppress Mode A/C transponders from replying.

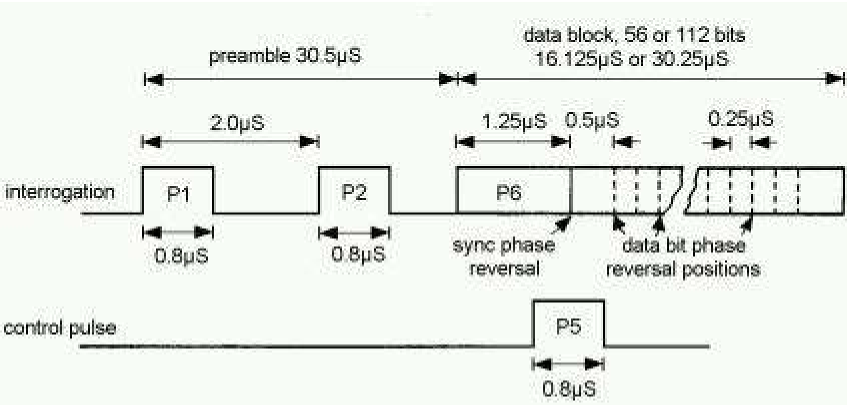

Figure 1: Mode S selective interrogation format

Refer to ***Figure 2***. The Mode S reply transmitted on a 1090 MHz carrier consists of a four pulse preamble, followed by a 56 bit (short) or 112 bit (long) PPM (Pulse Position Modulation) reply.

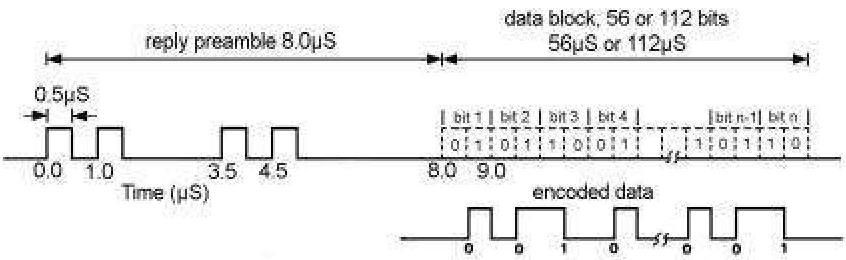

Figure 2: Mode S reply format

Refer to ***Figure 3***. The ATCRBS/Mode S All-Call format consists of two 0.8us pulse P1 and P3, that identify the Mode group A or C, with a 0.8us P2 ISLS (interrogation Side Lobe Suppression) or control pulse, followed by a P4 pulse that may be 0.8us (all-call short) or 1.6us (all-call long). Mode S transponders only reply to the all-call long, whereas Mode A/C (ATCRBS) transponders will ignore the P4 pulse and reply to both all-call short and all-call long.

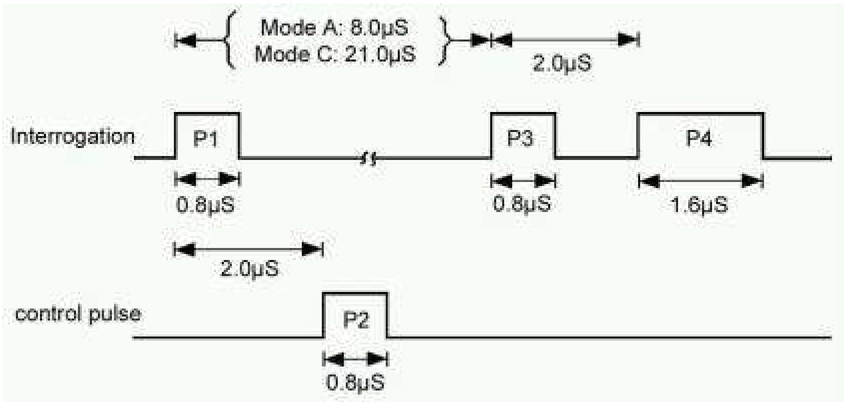

Figure 3: ATCRBS/Mode S All-Call format

All-Call and Selective (Roll-Call) periods

The Mode S ground interrogator provides surveillance of both Mode A/C and Mode S equipped aircraft, with minimal mutual interference. The 1030 MHz interrogation channel is divided into distinct and non-overlapping periods of Mode A/C and Mode S activity, known as the 'all-call' period and Mode S selective interrogation activity, known as the 'roll-call' period.

Interrogations during the all-call period elicit replies from Mode A/C aircraft and acquire Mode S aircraft via acquisition of the 24-bit ICAO aircraft address and the position of the aircraft. During the roll-call period (also known as the Mode S period), selective surveillance interrogations are sent to Mode S aircraft. Once an aircraft has been acquired during the all-call period, surveillance is then carried out discretely during the roll-call period.

Figure 3: All-Call/Roll-Call Periods

Refer to ***Figure 3***. The interrogations consists of a regular interleave of All-Call periods with Mode S (Roll-Call) periods, typically repeating with a frequency of anywhere between 40 Hz and 150 Hz. The repetition frequency and duration of the All-Call period is a local implementation issue, the duration of either period depending on the characteristics of the system such as the interrogator antenna revolution rate, the antenna beam-width and the maximum range. Normally there will be several all-call and roll-call periods available, to interrogate all targets in range, during one revolution.

The Mode S Only All-Call

During the all-call period, targets will normally be interrogated with Mode A/C Intermode (all-call short) interrogations, which inhibits Mode S aircraft from replying. Refer to ***Figure 4***. Targets will also be interrogated with 56 bit Mode S only, all-call (UF11) interrogations, with the ICAO aircraft address of 1111 1111 1111 1111 1111 1111, to which Mode S equipped aircraft reply with their own 24-bit ICAO Aircraft Address. The 3 bit CL field determines the content of the 4 bit IC field. For example, if the CL field is 000, then the IC field contains the II code; if the CL field is 001 through 100, then the IC field contains SI codes 1 to 63.

Figure 4: Mode S Only All-Call Interrogation

All Mode S aircraft in the beam, that receive this interrogation, would normally send a reply. However, this would cause many garbled and lost replies at the interrogator receiver and other problems for the RF environment. The issue of all-call FRUIT and garble is resolved through the use of the lockout principle, as well as stochastic acquisition and an ability to override lockout already set.

Refer to Figure 5. The 24 bit AA field contains the Aircraft Address. The first 20 bits of the 24 bit PI field have zero value. The last 4 bits are a replica of the II field contained in the UF11 and establish the Interrogator Identity. The 3 bit CA field provides information about transponder capability.

Figure 5: All-Call reply

All-call lockout

Lockout is one of the major SSR innovations employed to considerably reduce transponder reply rates, therefore, reducing interference. A number of safeguards have been built into the international standards for both interrogators and transponders to ensure that lockout is handled in a fail-safe manner, preventing undesirable, uncontrolled lockout of targets.

Refer to ***Figure 6***. A Mode S interrogator has two interrogation schemes: All-Call and Selective. All-Call interrogations are transmitted regularly at a steady rate in a similar way to conventional ATCRBS SSR. Any Mode S transponder that is not ‘locked out’ will reply to an all-call interrogation, transmitting its unique 24-bit aircraft address. In this way, the interrogator acquires targets not previously detected.

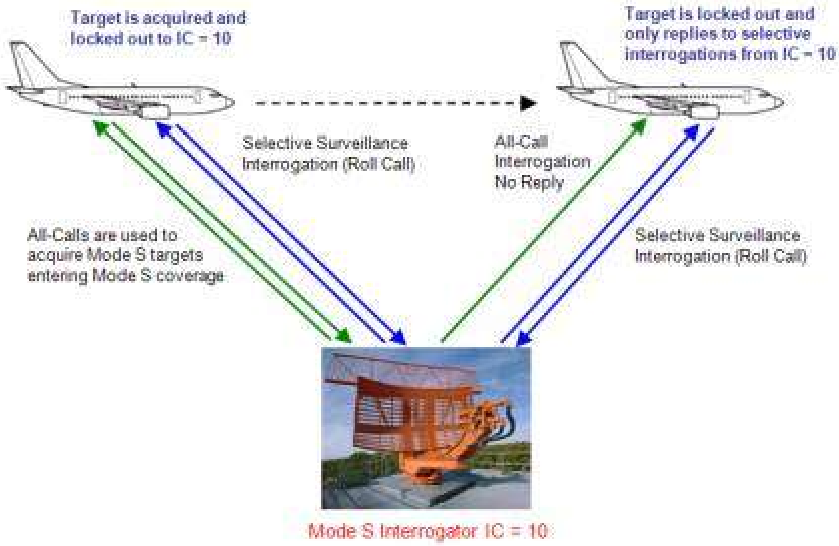

Figure 6: The lockout process

Once a transponder is known to the interrogator and its track has been established, it can be 'locked out'. This prevents the transponder from replying to any more All-Call interrogations from that or any other Mode S interrogator with the same identifier code. It will then only respond to Selective interrogations. However, it will continue to respond to interrogations from other Mode S interrogators with a different Identifier Code and also to Mode A/C interrogators.

The lockout period is controlled by an 18 second timer located in the transponder; however, during the roll-call period, lockout may be continually reset by the interrogator to its own IC by setting control information as part of selective surveillance interrogations. By this means, the all-call lockout is maintained as the target travels through the coverage of the interrogator.

To allow an interrogator to operate without co-ordination with adjacent Interrogators, a lockout override protocol is provided which allows the interrogator to force a transponder to reply to all-calls, regardless of the current lockout status to that interrogating IC. In order to avoid reply garbling, the lockout override is applied with a Probability of Reply value of less than 1.

The subject of reply garbling and stochastic (probabilistic) acquisition is covered later in the text.

FRUIT
(False Replies Unsynchronized to Interrogator) also known as (False Replies Unsynchronized In Time).
This occurs when the ground interrogator sees replies in response to interrogations from another interrogator. Defruiting replies using delay line and subtraction techniques can be effective. However, the probability of a reply is reduced, as FRUIT increases.

Adjacent Radars and FRUIT
Refer to ***Figure 7***. In order to allow effective operation of Mode S ground interrogators with overlapping coverage areas, a discrete identification code, known as an IC (or Interrogator Code), is allocated to each interrogator. The IC is included in selectively addressed interrogations and repeated back in the reply. This allows the interrogator to distinguish or defruit replies from individual targets.

The original ICAO provision was for 15 Interrogator Identifier (II) Codes. Amendment change 73 to ICAO Annex 10 resulted in an additional 63 codes being made available in the form of Surveillance Identifier (SI) Codes. SI codes may only be used when all aircraft in the coverage volume support SI operation. II or SI codes are contained in the UF11 4 bit IC field.

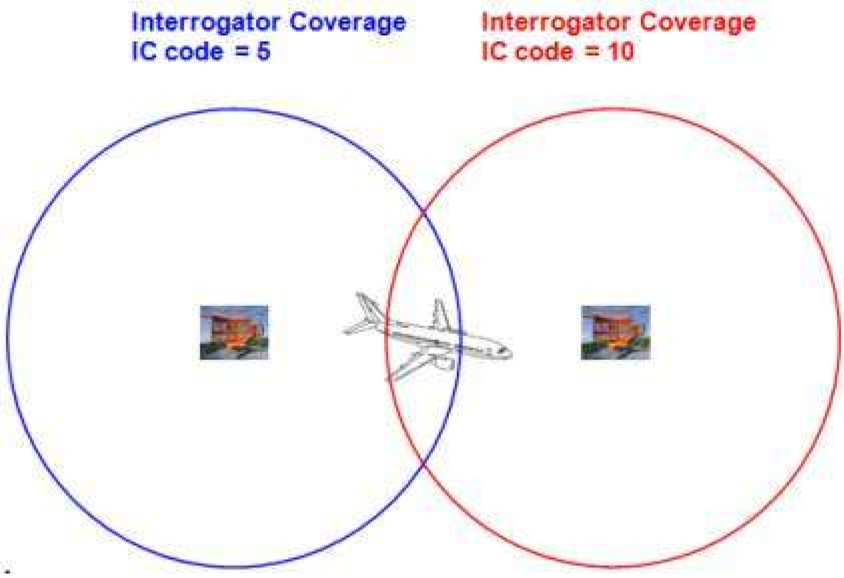

Figure 7: Use of IC Code

To ensure efficient surveillance, many factors need to be considered and often in coordination with adjacent radars, including:

* Pulse repetition frequency (PRF)
* Mode interlace pattern (A/C, All-Call A/C/S, All-Call Mode S only, Roll-calls)
* Interrogator Code (IC)
* Use of lockout (coverage and protocol)
* Use of datalink capability
* Types of transponders in the airspace

Selective interrogations

Selective interrogations make use of the unique 24-bit aircraft address, overlaid on parity (AP field) and can be transmitted close to the azimuth where the aircraft is expected to be. Other aircraft that happen to be in the interrogator beam at that time will not reply.

The type of Mode S reply is determined by the interrogator uplink format (UF), but in theory, only a single reply is required because there is no ambiguity as to which aircraft the reply belongs. Typically, additional interrogations are transmitted to ensure that at least one reply is received and that tracking performance is maintained.

Refer to ***Figure 8***. Typically, the selectively addressed aircraft will be interrogated with a UF4 Surveillance Altitude Request, the RR field being configured for a 56 bit short reply. The 16 bit SD field is comprised of 13 subfields.

The 4 bit IIS (Interrogator Identifier Subfield), within the SD field, contains the self-identification code of the interrogator and is numerically identical to the II code transmitted by the interrogator in Mode S Only All Calls (UF11).

The 1 bit LOS (Lockout Subfield), contained in the SD field, if set to One, initiates an All Call lockout to Mode S Only All Calls (UF11) from the Interrogator, indicated in IIS subfield of the interrogation.

Figure 8: Surveillance altitude request

Refer to ***Figure 9***. The aircraft will reply with a DF4 Surveillance Altitude Reply, with altitude reported in the AC field. The AC field supports 25 ft resolution compared with the 100 ft resolution of Mode C altitude replies.

The 6 bit UM (Utility Message) field, is comprised of two subfields. One of these is the 4 bit IIS (Interrogator Identifier Subfield), which reports the identity of the interrogator.

Figure 9: Surveillance Altitude Reply

Refer to ***Figure 10***. The aircraft will also be selectively interrogated with a UF5 Surveillance Identity Request, the RR field being configured for a 56 bit short reply.

The IIS and LOS subfields, contained within the SD field, operate the same as UF4.

Figure 10: Surveillance Identity Request

Refer to ***figure 11***. The aircraft will reply with a DF5 Surveillance Identity Reply, with aircraft identification and Mode A 4096 code (if assigned), reported in the ID field.

The IIS subfield operates the same as DF4.

Figure 11: Surveillance identity reply

Formats UF4 and UF5 may also be used by the interrogator to set the RR field to request a long reply, in which case, the reply will be a DF20 Comm B Altitude Reply or a Comm B Identity Reply, respectively. Refer to ***Figure 12***. Both of these replies will be 112 bits in length and contain the 56 bit MB message field. The use of the GICB (Ground Initiated Comm B) protocol allows the ground interrogator to extract DAP's (Downlinked Aircraft Parameters) contained in the MB message field of the reply, which may include additional aircraft information such as aircraft identity, flight number, airspeed, heading, roll angle and status.

Figure 12: Comm B altitude reply

Reply garbling

This occurs when overlapping replies, from two aircrafts that are closer than 2 Nm in slant range, are received.

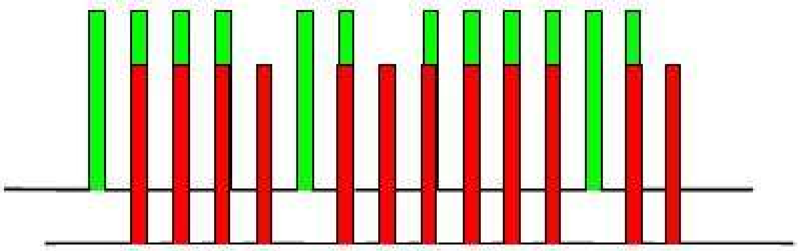

Figure 13: Synchronous garbling

Refer to ***Figure 13***. In the case of synchronous garbling, the reply pulses occupy legitimate positions that cause the reply to either be incorrectly decoded or dropped.

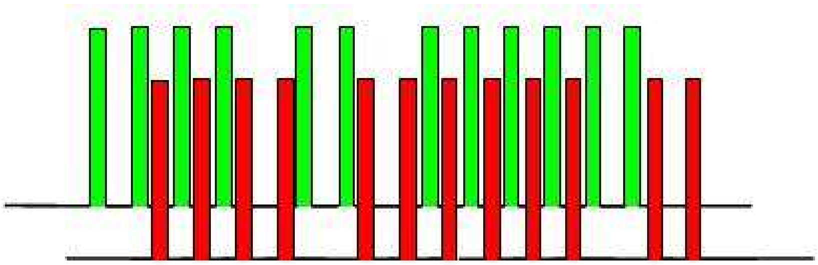

Figure 14: Non-synchronous garbling

Refer to ***Figure 14***. In the case of non-synchronous garbling, the reply pulses occupy inter pulse group positions. This typically may allow the first reply to be correctly decoded but not the second.

Using stochastic acquisition to minimize garbling

Stochastic (probabilistic) acquisition is a technique used during the all-call period to acquire closely spaced (in slant range) targets entering coverage. Refer to ***Figure 4***. Mode S only all-call interrogations (UF11) can be sent with a probability of reply weighting built into them. The 4 bit PR field contains the probability of reply of 100 percent, 50 percent, 25 percent, 12.5 percent or 6.25 percent.

For example, two aircraft designated X & Y, closely spaced in slant range but at different heights, receive an all-call interrogation with a PR of 50 percent. The possible outcomes are stated in Cases 1, 2, 3 and 4.

Case 1: All-Call interrogation with PR = 50 percent is transmitted. Aircraft X and Aircraft Y receive interrogation. Aircraft X and Aircraft Y both reply (both processed 50 percent probability and decided to reply). The replies overlap in time at the interrogator receiver and the de-garbling processes were unable to decode them, so both replies were lost.

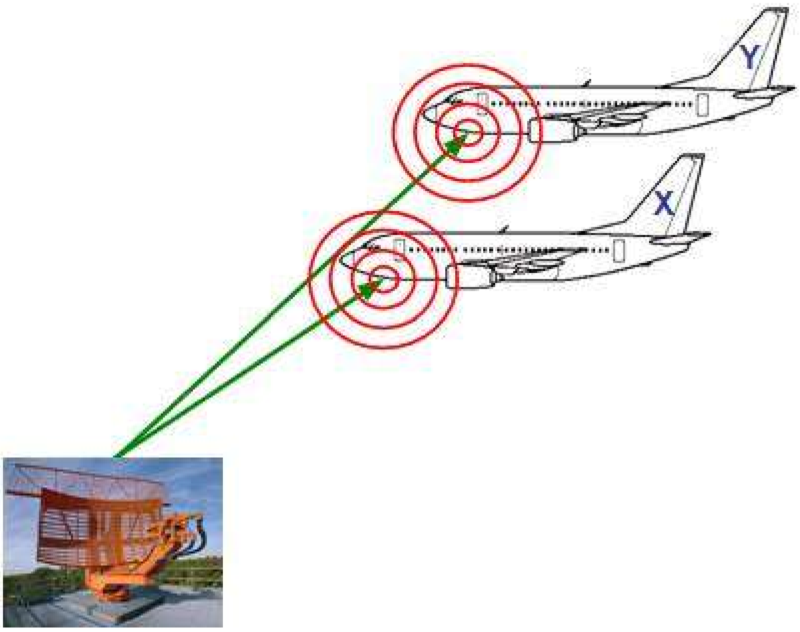

Figure 15: Case 1

Case 2: All-Call interrogation with PR = 50 percent is transmitted. Aircraft X and aircraft Y receive interrogation. Aircraft X decides on a ‘No Reply’ (50 percent) and aircraft Y Replies. Aircraft Y is then selectively interrogated and locked out.

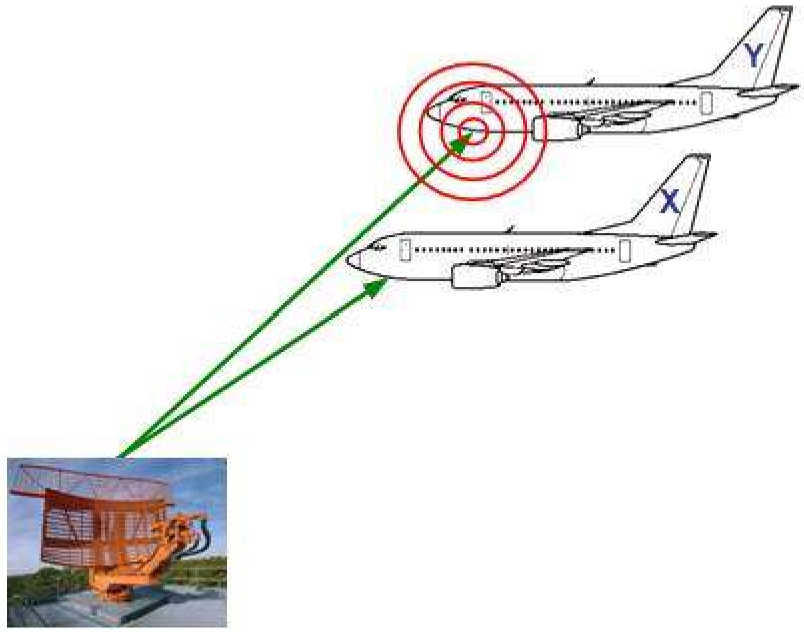

Figure 16: Case 2

Case 3: All-Call interrogation with PR = 50 percent is transmitted. Aircraft Y is locked out and ignores the interrogation. Aircraft X decides on a ‘No Reply’ (50 percent). No replies sent.

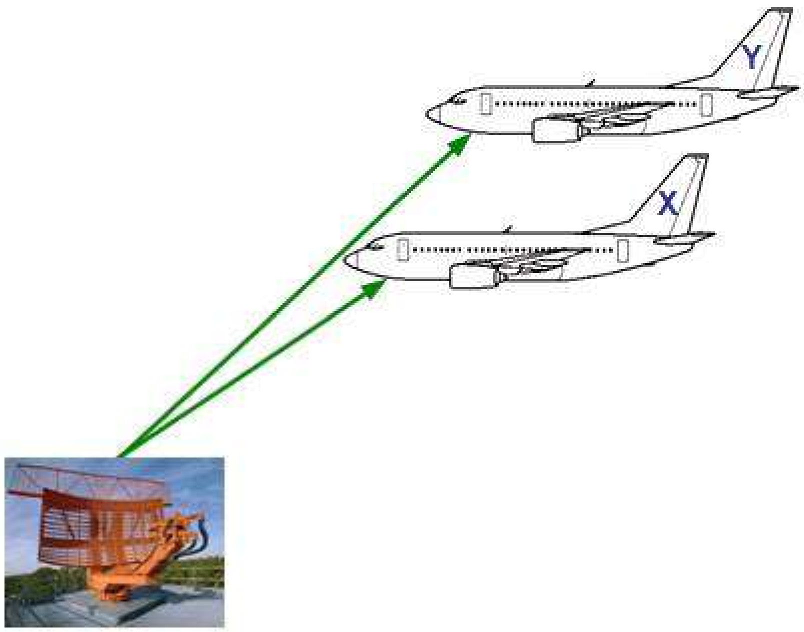

Figure 17: Case 3

Case 4: All-Call interrogation with PR = 50 percent is transmitted. Aircraft Y is locked out and ignores the interrogation. Aircraft X decides to Reply (50 percent). Aircraft X is then selectively interrogated and locked out. Both targets are now locked out to the ground interrogator.

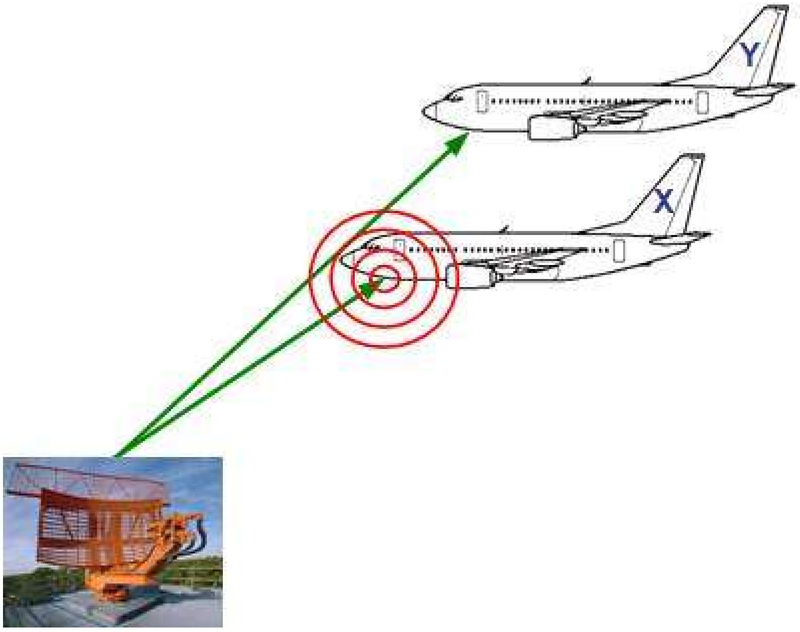

Figure 18: Case 4

As both targets X & Y could be closely spaced in slant range for several interrogator antenna revolutions, it is possible that neither target would be acquired without stochastic probabilities of reply, as the replies may have garbled, being overlapped in time.

Conclusion
The use of the Mode S lockout and stochastic acquisition techniques provide immunity to garbling and reduce RF pollution. Other advantages Mode S provides over Mode A/C are:

* Selective (addressed interrogations) based on 24-bit aircraft addresses
* Relief from Mode A code shortage (when Aircraft Identification is used)
* Additional information (i.e. identity and pressure altitude in 25 ft increments) plus DAP's.
* Data error detection
* 112 bit GICB data link

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Barry Beasley is the Assistant Director - Avionics Business Unit, Aeroflex Test Solutions.

He has been with Aeroflex for 16 years and has held positions in Product Development, Service Management & Sales Management. Prior to Aeroflex, he was with Hunting Aviation for 18 years in several positions, including Service Management, Avionics & GSE Sales. He can be reached at: **barry.beasley@aeroflex.com**

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