IDENTIFICATION OF AN AIRCRAFT WITH THE MODE S

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The text is focused on analysis surveillance system employing modes A/C and mode S. Mode S slowly replacing conventional modes A/C, which have already reached their limit top at today's condensed traffic. Mode S offers new opportunities and a number of benefits that were previously impossible to reach, such as improved integrity of interrogations and replies, as well as an augmented capacity for transmitting information about the aircraft. It also eliminates errors that over time began to appear in the identification of aircraft and began to menace the safety of traffic at airports.

K e y w o r d s: Mode A, mode C, mode S, interrogator, transponder, SSR

1 INTRODUCTION

Nowadays it is necessary for aircraft in controlled airspace to be equipped with a transponder. Several years were used transponders mode A and C. However this identification, ceased to be sufficient and it was necessary to improve it. The first systems were developed ADSEL (Address selective) in the UK and DABS (Discrete Addressed Beacon System) in the USA. These two systems are not compatible and are quite varied, therefore, began to develop a new mode S. By now, most aircraft, nearly 90%, can work with Mode S and the remaining about 10% of the aircrafts can work only with mode A / C. This should be changed to 2020 and the communication of aircrafts should be provided only Mode S and transponders using modes A/C would no be supported for longer.

2 IDENTIFICAION WITH SECONDARY SURVEILLANCE RADAR

Interrogation for air traffic services shall be performed by the four modes. The uses of each mode shall be as follows:

- Mode A- to elicit transponder replies for identity and surveillance.

- Mode C- to elicit transponder replies for automatic pressure-altitude transmission and surveillance.

- Intermode-

- Mode A/C/S all-call: to elicit replies for surveillance of Mode A/C transponders and for the acquisition of Mode S transponders.
- Mode A/C-only all-call: to elicit replies for surveillance of Mode A/C transponders. Mode S transponders do not reply.

- Mode S-

- Mode S-only all-call: to elicit replies for acquisition of Mode S transponders.
- Broadcast: to transmit information to all Mode S transponders. No replies are elicited.
- Selective: for surveillance of, and communication with, individual Mode S transponders. For each interrogation, a reply is elicited only from the transponder uniquely addressed by the interrogation.

The transponders using modes A/C are suppressed by mode S interrogation and do not reply. There are 25 possible mode S interrogation (uplink) formats and 25 possible mode S reply (downlink) formats.

3 MODES A/C

Mode A transponders are old transponders, that send a reply to a interrogation on the flight number and do not send altitude of aircraft (Flight Level). On a mode A transponders can be set 4096 (2^{12}) different discrete codes (alpha codes), each responder code consists of four digits from 0 to 7. The responsible authority should determine the procedures for the allocation of SSR codes in accordance with regional air agreements and other users of the system. Principles for assignment of SSR codes are given in L 4444, Chapter 8. Using responder in this mode is very important because it serves to identify the aircraft on the radar screen of air traffic management. Pilot in plane must set the response code assigned to air traffic controllers, who then is able to clearly identify on the screen with this code. Some codes are reserved and they have particular importance.

The interrogation shall consist of two transmitted pulses designated P1 and P_3. A control pulse P_2 shall be transmitted following the first interrogation pulse P_1. Pulse P_2 is transmitted omni-directional and it is used to suppress side lobes. SSR mode S sends replies at a frequency of 1030 Mhz.

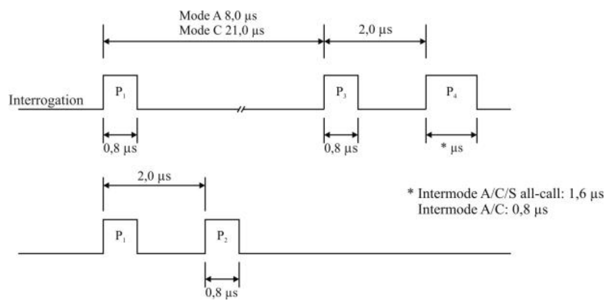

Figure 1. Modes A/C interrogation

On all interrogations replies are generated , to which must be used signals containing two framing pulses spaced 20,3 µs as the most elementary code. Information pulses shall be spaced in increments of 1.45 microseconds from the first framing pulse.

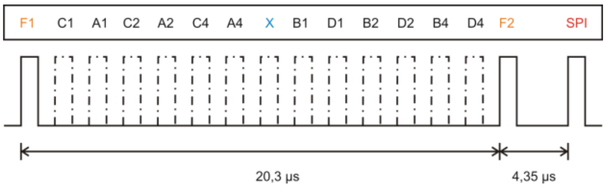

Figure 2. Modes A/C reply

Modes A/C have the same structure, whereas:
- F1 and F2 are framing pulses
- A1 to D4 are information pulses
- X pulse is a technical standard to safeguard possible future use
- SPI is a special position identification pulse

4 MODE S

The concept of mode S was mainly developed in the USA at the university MIT and this effort was coordinated with the FAA. In the Europe was the mode S adapted to the requests of European Organisation for the Safety of Air Navigation (EUROCONTROL), but the system still remained compatible with mode S used in USA and around the world. Mode S technology was developed first time in mid-1970, but has not been widely deployed to 1980. The idea was to develop a way of using the same SSR that was being used in mode A and C, but to make it addressable, more accurate and reliable, and operate with greater capacity. This technology is offer for abandoning and cost-free to use.

Mode S is compatible with existing modes A and C and can fully cooperate with them. “S” means a selective, so it is possible to limit the frequency congestion. Mode S makes it possible to send additional data. Any aircraft equipped with mode S transponder has at its installation set unique 24-bit ICAO address (therefore 16,777,216 possible codes) and will have been allocated by the registering authority of the State within which the aircraft is registered. Each ICAO Contracting State has been allocated a block of codes that it can allocate to aircraft within it and the number available depends on the relative size of that State and volume of air traffic. The way in which a State allocates codes between civil and military users is an issue for that State only. A block of codes may also be required for airport surface vehicles if they were to be required at airports to support multi-lateration - although this must also be managed by the State on a local basis. But in beginning it was suggested, that the 24-bit address will be unchanged and each aircraft has its own 24-bit address. But when States starts sell airplanes and change it, this requirement could not be met. Therefore address can be changed by the state, but could not became, that in the air will be two planes with the same 24-bit addresses. Sizeable unallocated blocks of codes have been reserved for different ICAO regions and over 3 million codes are as yet unallocated to any State or region. With careful management, there should be no shortage of codes, even in the longer term.

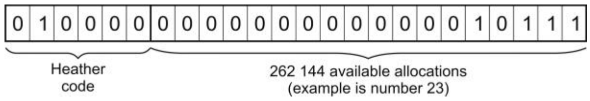

Figure 3. Unique 24-bit address

It contains 24 positions (bits), where it is either a binary 1 or 0. This code is further divided into the heather code, which size depends on the country, to which are this codes assigned. About the size of the heather code and number of combinations rules ICAO. The remaining positions of the code are determined by the State, that this 24-bit ICAO address allocate to the aircraft and their amount determines how many addresses can be allocated.

4.1 Implementation of mode S

The main reasons for the implementation of mode S are as follows:
Selective interrogation to reduce problems of convention SSR (All-call FRUIT and garbling.

1. selective interrogation to reduce problems of convention SSR (All-call FRUIT and garbling,
2. long term elimination of mode A code shortages,
3. integrated data link capability,
4. more precise altitude report (25 ft),
5. interrogation sequencing to eliminate synchronous garbling,
6. search (All-call) interrogations and selective (Roll-call) interrogations to reduce RF pollution,
7. code allocation and clustering,
8. Error detection (uplink) and error detection/correction (downlink).

These 8 points describe the main advantages of mode S in comparison with previously used modes A and C. First major error that occurs when classic mode is overlap replies (Garbling). Overlap occurs when two or more acquisition replies coming at the same time. This can cause on the radar receiver identification problems with this received replies. This error has succeeded to eliminate the use of a unique 24-bit address. This address is transmitted in each reply from aircraft. Upon accept with ground receiver is address detected, the aircraft is identified and then selective interrogated. This aircraft subsequently responds only to interrogations containing his address and other interrogations ignored. Thus request interrogator from the aircraft at the moment only one expected answer. The second major mistake is all-call "FRUIT". This error occurs because the replies from the aircraft are broadcasted omni-directional and they are received by the receivers of ground stations, which response from the aircraft did not request (asynchronous interference). This problem was solved by a IC code. This code is an identification code of ground station and it is contains in every interrogation sent to the aircraft and each reply from transponder to the interrogation of the interrogator. Thus, ground receiver receives only the replies to their own interrogations and replies from other aircrafts are ignored.

Sequencing excepted reply times so they don't overlap in time is fundamental to surveillance of mode S targets. The position of a target is known, so the time tie reach that target (at speed of light) is also known. A pre-defined processing time exists and the response time is the same as the send time. Therefore, it is possible to plan a sequence of interrogation replies that will not overlap in time. Deciding a suitable, non-overlapping ”schedule” is a complex issue and this “schedule” is planning with ground station (radar).

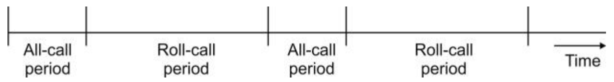

Figure 4. Sequencing of All-call and roll-call

The time period for a mode S interrogator is normally split into two distinct periods. One known as the All-call period which is used to acquire mode S targets and the other the mode S period (or roll-call period) which is used to selectively interrogate already acquired mode S targets. These are completely separated in time. Acquisition in mode S need happen only once. Subsequently, a protocol to reduce all-call FRUIT is used and the target is locket out to prevent him being continuously re-acquired. This is based on an 18 s timer in the transponder, one for every IC.

4.2 Acquisition and lockout

In order to allow for effective operation of Mode S ground sensors with overlapping coverage areas, a discrete identification code, known as an IC (or Interrogator Code), is allocated to each sensor. The IC field is included in all of its interrogations and in every reply that it sent to them. As part of selectively addressed interrogations, the IC is included and this is also included in the reply. Targets that have been acquired in the all-call period are subsequently selectively interrogated for surveillance information in the Mode S period. Control information within the interrogation allows the ground sensor to apply lockout which means that the target will not reply to an all-call with that IC for a period of 18 seconds. This will be applied by the sensor for all acquired Mode S targets in all areas for which it has responsibility for maintaining lockout.

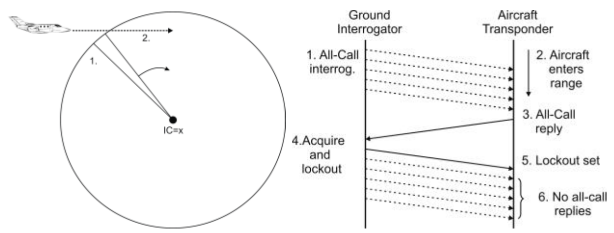

Figure 5. Stages of lockout

1. The Mode S interrogator (IC=x) rotates clockwise sending all-calls during the all-call periods. At point 1, the target shown has not yet entered coverage and no replies are received.
2. Aircraft enters sensor coverage and receives all-call interrogation (containing IC=x in a control field).
3. Aircraft transponder generates all-call replies containing sub-fields with the 24-bit ICAO aircraft address and the IC that was in the original received interrogation.
4. The ground sensor receives the all-call reply and decodes the aircraft address and position and has now “acquired” the target. It then sends selective interrogations during following roll-call periods.
5. The selective roll-call interrogations contain control information that instructs the transponder to disregard further all-calls from all sensors using that IC.
6. The transponder will then ignore all-call interrogations from all sensors using IC=x for a period of 18 seconds. The sensor will normally reset the lockout timer with all selective surveillance an interrogation, hence ensuring that all-call lockout is assured throughout as the target travels through the coverage of the sensor.

Of course, ground sensors continue to transmit Mode S only all-call interrogations during the all-call period in order to acquire new aircraft that enter the coverage of that sensor.

4.3 Interrogator code

Each interrogator is allocated a discrete interrogator code (IC) which it can use to uniquely identify itself. The IC is also included in the reply from a mode S transponder to indicate the interrogator being replied to.

Within the limits of ICAO Annex 10 specifications, there are a limited number of available ICs available. These are of two types:

- **II: Interrogator identifier.** This 4-bit value shall define an interrogator identifier (II) code. These II codes shall be assigned to interrogators in the range from 0 to 15. The II code value of 0 shall only be used for supplementary acquisition in conjunction with acquisition based on lockout override. When two II codes are assigned to one interrogator only, one II code shall be used for full data link purposes.
- **SI: Surveillance identifier.** This 6-bit value shall define a surveillance identifier (SI) code. These SI codes shall be assigned to interrogators in the range from 1 to 63. The SI code value of 0 shall not be used. The SI codes shall be used with the multisite lockout protocols. The SI codes shall not be used with the multisite communications protocols.

In terms of European mode S system implementation, the regulatory situation means that it is initially only possible to allocate and use II-codes. As mode S implementation continues, in areas where there are many radars covering the same area, 15allocatable II-codes is not enough to support allocation of a discrete code to every sensor and having no overlapping coverage areas with another sensor using the same II-code. This is in fact an original design flaw of mode S SSR.

4.4 Mode S categories

Elementary mode S (ELS) is the minimum surveillance function foreseen mode S in Europe, and they are:
- automatic report of aircraft identity (Call Sign from flight plan)
- report of aircraft identification (mode A discrete code)
- report unique 24-bit address
- report transponder capability
- altitude report (25 ft)
- flight status
- SI-code
- alert conditions and SPI (Special Position Identification Pulse)

Enhanced mode S (EHS) provides real-time aircraft derived data (in addition to that provided by ELS). However, to provide this additional data, the aircraft needs to have an interface between the transponder and its avionics systems. Many items of aircraft information may be available from the avionics. From a surveillance point of view these may be divided into two groups:
- firstly there is aircraft current state vector information, in particular that which indicates the current state of motion of the aircraft (e.g. ground speed, track angle, turn rate, roll angle, climb rate, magnetic heading, indicated air speed). This information may be used to improve the accuracy of the aircraft track in the ground system.
- secondary, aircraft (vertical) intention information may be available from the avionics to indicate the future path of the aircraft. This information should be of value to safety nets and future trajectory prediction tools.

4.5 Squitters

A definition of squitter is a reply format transmission without being interrogated.

Acquisition squitter (DF 11) is a short squitter and remains with 56 bits that contains 24-bit address. It is transmitted by all mode S transponders. It is used for ACAS acquisition when airborne or by multilateration systems. For a mode S rotating ground based surveillance interrogator, these replies is a nuisance simply causing all-call FRUIT. All mode S equipped targets will periodically emit the unsolicited ‘squitter’ transmission on 1090 MHz on a regular, semi-randomized basis (every 1 s ± 0,2 s unless other conditions apply which mean that the transmission must be delayed). These squitters support passive acquisition of targets. The squitter transmission is issued on the mode S downlink frequency using the format used for a mode S only all-call reply.

Extended squitter (DF 17) the concept of DF17 extended squitter is similar to elementary and enhanced surveillance with one exception: DF17 is a squitter and does not need an interrogation. Therefore, the DF17 will report its information regardless of any ground station or airframe asking. These squitter is very important part of ADS-B (Automatic Dependent Surveillance - Broadcast). Extended squitter must be also transmitted with partially randomness, however is known three types of extended squitters, and it is DO-260, DO-260A and DO-260B and any of them have different intervals of transmitting. Farther, this intervals of transmitting extended squitter are different accordingly, if the aircraft transmitting the squitter is on the ground or in the air. And if an aircraft is on the ground, than the difference between intervals is dependent, if the aircraft stay or move on the runway.

4.6 Stochastic acquisition

It is a technique used during the all-call period to acquire closely spaced (in slant range) targets entering coverage (Note: stochastic is a term meaning “probabilistic”). All-call interrogations can be sent with a probability of reply weighting built into them. The weighting can be a probability of reply of 1, ½, ¼, 1/8 or 1/16.

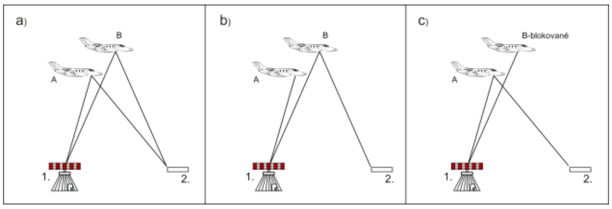

Figure 6. Stochastic acquisition

a) All-Call S/2 50% PR issued. Aircraft A and aircraft B receive it. Aircraft A and Aircraft B both reply (both examined 50% probability and decided to reply). The replies overlap in time at the ground receiver and the degarbling processes were unable to decode them so both replies were lost.
b) Aircraft A and aircraft B receive it. Aircraft A decides on a “No Reply” (50%) and aircraft B replies. Aircraft B is then selectively interrogated and locked out.
c) Aircraft B is locked out and ignores the interrogation. Aircraft A decides on a “No Reply” (50%). No replies sent.
d) Aircraft B is locked out and ignores the interrogation. Aircraft A decides to reply (50%). Aircraft A is then selectively interrogated and locked out. Both targets are now locked out to the ground sensor.

It is possible that both targets in the example could have been closely spaced in slant range for several antenna revolutions. Without stochastic probabilities of reply, it is possible that neither of them would be correctly acquired since the replies may have been overlapping in time and not effectively de-garbled. Clearly not a desirable situation. Although it is perfectly possible that targets are acquired and locked out during a single antenna revolution, It is likely to take more than one antenna revolution to complete this process. E.g. POEMS evaluation was over 3 antenna revolutions, with the first revolution receiving the all-call reply, the second revolution, starting selective roll-call interrogations and then in the third revolution, starting to reset lockout to the target.

4.7 Lockout override

In order to allow an interrogator to operate without co-ordination with its neighbours, the Mode S protocols allow the interrogator to force a transponder to reply to all-calls, regardless of the current lockout status to that interrogating IC (i.e. lockout is overridden). This method is known as "lockout override". In addition, in order to avoid garbling problem as explained in the section related to stochastic acquisition, it is recommended that lockout override is applied with a Probability of Reply value of less than 1. Possible stochastic values for the PR (Probability of Reply) field in an all-call interrogation are 1, ½, º, ⅛and 1/16 which is the same as for standard stochastic acquisition. If applied in an all-call interrogation, a target that is already acquired by IC=x and locked out by it as well could elicit an all-call interrogation from it.

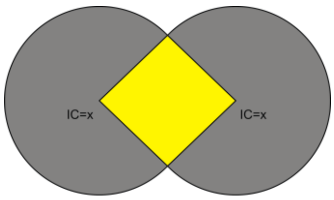

Figure 7. Overlapping coverage areas of two interrogators

Stochastic lockout override acquisition (SLA) might be used in coverage areas where there is some overlap with at least two sensors using the same IC and not communicating as a cluster.

4.8 Mode S characteristic signals

Mode A/C/S all-call interrogation.

This interrogation shall consist of three pulses: P_1 , P_3 , and the long P_4. One or two control pulses (P_2 alone, or P_1 and P_2) shall be transmitted using a separate antenna pattern to suppress responses from aircraft in the side lobes of the interrogator antenna. The mode A/C/S all-call interrogation elicits a mode A or mode C reply (depending on the P_1-P_3 pulse spacing) from a mode A/C transponder because it does not recognize the P_4 pulse. A mode S transponder recognizes the long P_4 pulse and responds with a Mode S reply.

Mode A/C-only all-call interrogation.

This interrogation shall be identical to that of the mode A/C/S all-call interrogation except that the short P4 pulse shall be used. The mode A/C-only all-call interrogation elicits a Mode A or Mode C reply from a Mode A/C transponder. A mode S transponder recognizes the short P_4 pulse and does not reply to this interrogation.

Mode S interrogation.

The mode S interrogation shall consist of three pulses: P_1, P_2 and P_6. Pulse P_6 is preceded by a P_1-P_2 pair which suppresses replies from mode A/C transponders to avoid synchronous garble due to random triggering by the mode S interrogation. The P_5 pulse shall be used with the Mode S-only all-call interrogation to prevent replies from aircraft in the side and back lobes of the antenna. When used, P_5 shall be transmitted using a separate antenna pattern.

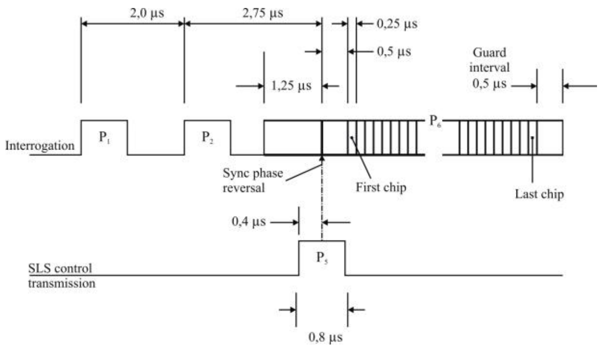

Figure 8. Mode S interrogation

Mode S reply. Reply shall consist of a preamble and a data block. The preamble shall consist of four pulses. The reply data block shall consist of 56 or 112 data bits formed by binary pulse position modulation encoding of the reply data. A pulse transmitted in the first half of the interval shall represent a binary one whereas a pulse transmitted in the second half shall represent a binary zero. This bit can be divided to two chips, which first have account of binary one and second of binary zero.

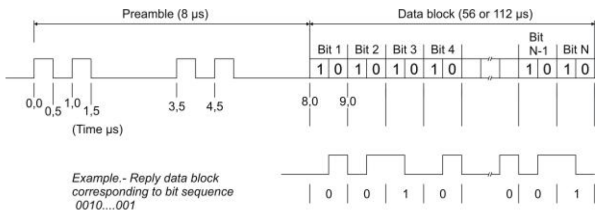

Figure 9. Mode S reply

5. MODE S DATA STRUCTURE

Every data transmitting with mode S have predefined structure. Information's are transmitted during uplink formats (interrogation) and downlink formats (reply or squitter). This formats is 25at all. But when is transmitted some format, this format must be used all the time in this communication. For example, if is the interrogation in downlink format DF 11, reply must be also in format UF 11.

Every Mode S transmission shall contain two essential fields. One is a descriptor which shall uniquely define the format of the transmission. This shall appear at the beginning of the transmission for all formats. The descriptors are designated by the UF (uplink format) or DF (downlink format) fields. The second essential field shall be a 24-bit field appearing at the end of each transmission and shall contain parity information. In all uplink and in currently defined downlink formats parity information shall be overlaid either on the aircraft address or on the interrogator identifier. The designators are AP (address/parity) or PI (parity/interrogator identifier).

The remaining coding space is used to transmit the mission fields. For specific functions, a specific set of mission fields is prescribed. Mode S mission fields have two-letter designators. Subfields may appear within mission fields. Mode S subfields are labelled with three-letter designators.

5 CONCLUSIONS

In this work I have dealt mainly with the analysis and comparison of surveillance systems using modes A/C and mode S. Most devote to Mode S, because in the near future should completely replace conventional modes. However, the mode S could be introduced into traffic gradually, had to be assured the compatibility with modes A/C, which was achieved, that interrogators are able to transmit interrogations in two modes, namely the intermode and mode S interrogations. In contrast to modes A and C provides a number of benefits and enhancements that with the growing density of air traffic have become essential to the safe operation of the airport. Among the biggest advantages are the possibility of mode S selective interrogating in aircraft and clarity of identification, elimination of errors resulting from the interrogated aircrafts and improved integrity of interrogations and responses.

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