RTCA Free Flight Select Committee
Safe Flight 21 Steering Committee

Eurocontrol ADS Programme

ADS-B Technical Link Assessment Team (TLAT)

Technical Link Assessment Report

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APPENDIX F

1090 MHz Extended Squitter System Description

System Proposed for Link Assessment

Revised 9 March 2001

Introduction

This appendix is provides a concise description of the Extended Squitter system for ADS-B, to support the evaluation of three candidate links for ADS-B, as a part of the Safe Flight 21 program in 1999-2001. In addition to the functions of ADS-B, the system described also includes capabilities for TIS-B (Traffic Information Service-Broadcast) and FIS-B (Flight Information Service-Broadcast).

The system description describes both the equipment tested in 1999-2000 and the future operational system. Any differences are highlighted.

F-1. **Basic System Characteristics**

F-1.1 Multiple Access

Provisions for multiple aircraft to transmit ADS-B information and for multiple aircraft and ground stations to receive the information are based on pseudo random timing of the transmissions. Whereas each type of message is transmitted in a pattern that is nominally periodic with a standard rate (rates given in Section F-1.3.1), the transmission times are deviated slightly using a pseudo random process. Specifically, a timing jitter uniformly distributed over a range of +/-100 ms is applied to each transmission. This jitter is much larger than the duration of each message, so that synchronous interference effects are avoided. The net effect is a random probability of losing each reception due to the presence of signals received from other aircraft. The tests in 1999 are identical in this respect to the proposed operational system.

F-1.2 Waveform

F-1.2.1 Radio Carrier Frequency and Modulation. The carrier frequency, modulation, and other characteristics of the Extended Squitter waveform are all identical to the standards for Mode S transponder replies [ref. 2]. The main parameter values are summarized in the following sections.

F-1.2.1.1 Carrier Frequency. 1090 MHz +/- 1 MHz.

F-1.2.1.2 Modulation. Pulse position modulation. For each bit period, a pulse is transmitted either in the first half of the period (indicating a 1) or the second half of the period (indicating a 0).

F-1.2.2 Data Rate. 1 M bit / second, within a message, as illustrated in Figure F-1.

F-1.2.3 Message Synchronization. A transmitted message includes a preamble so that a receiver can detect the beginning of the message and can synchronize on the data in the message. The preamble consists of 4 pulses as shown in Figure F-1.

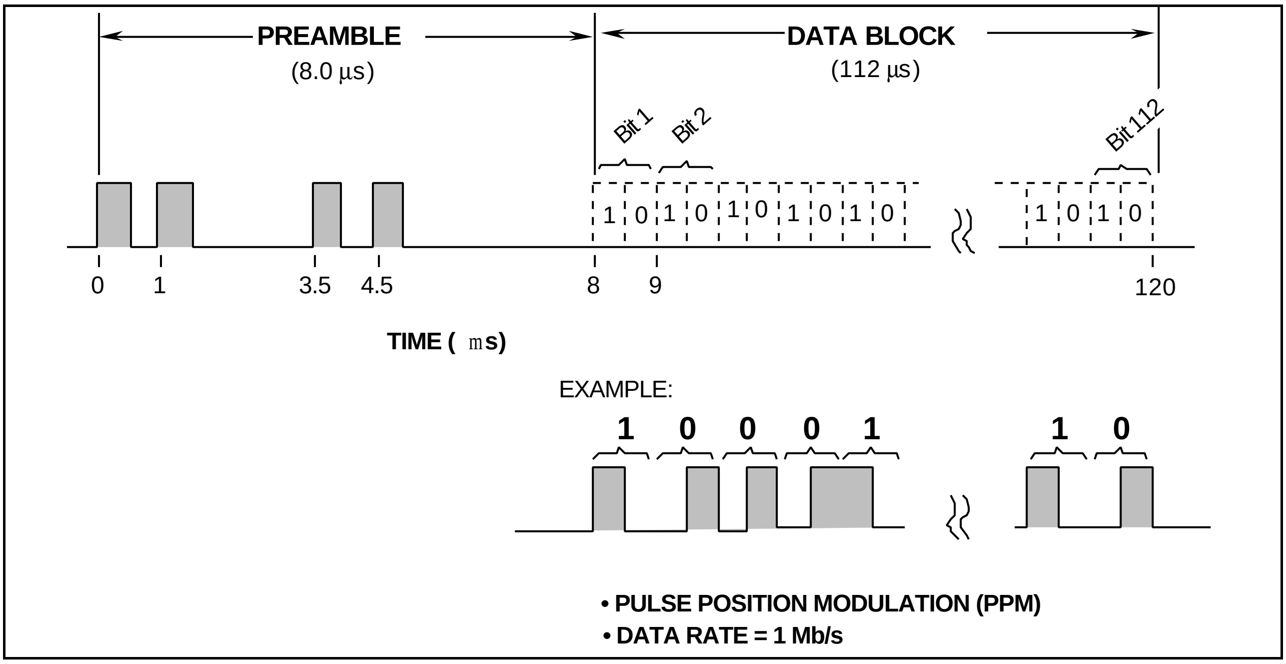


Figure F-1. Signal format, showing preamble and data block.

F-1.2.4 Message Size and Coding

F-1.2.4.1 Message Size. A message consists of 112 bits (Figure F-1).

F-1.2.4.2 Coding. Each message contains 24 parity bits, which can be used for error detection or correction. This is the standard Mode S code, which is currently used by transponders, SSRs, and TCAS [ref. 2].

F-1.3 Messages and Reports

F-1.3.1 Message Types and Broadcast Rates. The basic position-velocity-time information is broadcast as follows. Position is broadcast in a “position message” transmitted at a rate of 2 per second. Velocity is broadcast in a “velocity message” transmitted at a rate of 2 per second. For each of these, the time of applicability is given as the time of transmission. Additional messages are transmitted as follows. Aircraft identity (a message transmitted once per 2.5 seconds by Class A3 aircraft and once per 5 seconds by the others), Intent type A (a message transmitted once per 1.7 seconds), Intent type B (a message transmitted once per 1.7 seconds), and a status message which is transmitted once per 1.7 seconds. Intent and status messages are transmitted only by some aircraft, which are equipped for certain functions as described in the MASPS [ref. 1].

When an ADS-B aircraft is on the airport surface, the system includes a provision to change to surface message formats and rates. This change is to be triggered automatically by a squat switch. The surface formats include higher-accuracy position information, and they omit altitude information and include velocity together with position in the same message. The transmission rate is 2 per second while moving and 0.2 per second when stationary.

For small aircraft not equipped with a squat switch, it is not permissible for the system to depend on a manual switch. As a result, the airborne message formats have been designed to provide sufficiently high-accuracy position information so that they can be useful if transmitted by an aircraft on the surface.

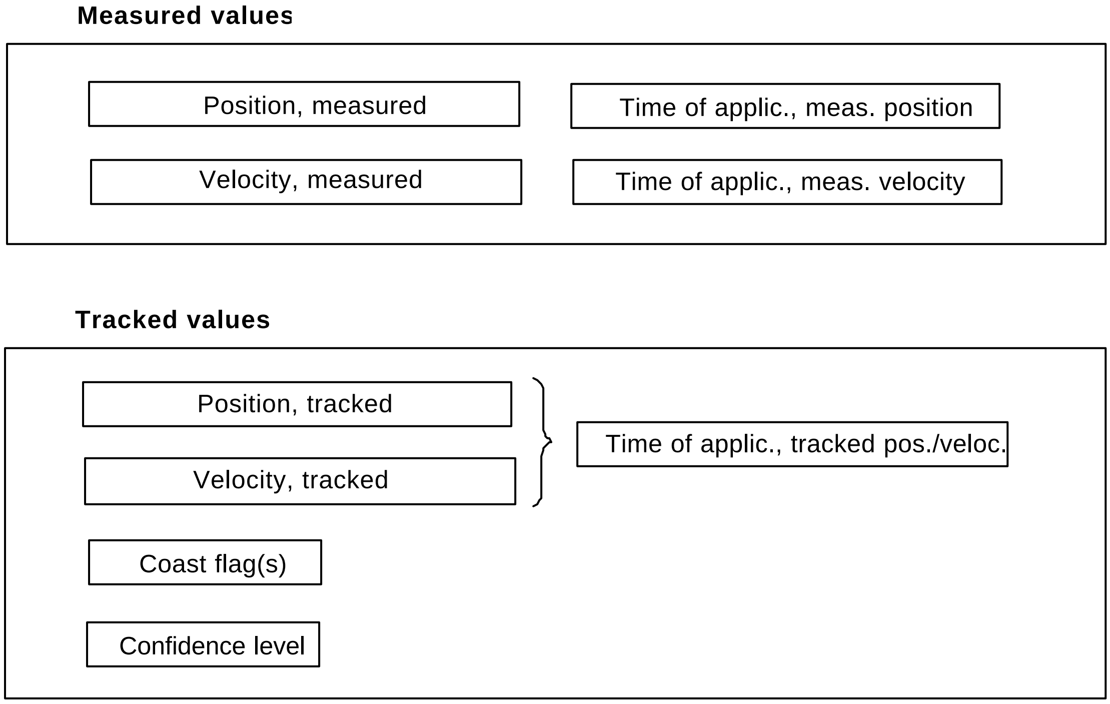
The tests in 1999 included surveillance (position, velocity, and time) and identity, but not intent. In one respect, the tests in 1999 differ from the proposed operational system: currently the transmission rate for aircraft identity is once per 5 seconds, whereas in the proposed operational system it is once per 2.5 seconds.

TIS-B information, to support see-and-avoid, can be transmitted from a ground station using data obtained from an SSR. In this case, TIS-B information is not transmitted for aircraft currently transmitting ADS-B information. Position and velocity are included in a single TIS-B message. Transmission rates for TIS-B and FIS-B are described in sections F-6.1 and 6.2.

F-1.3.2 Relationship Between Messages and Reports. Following the terminology defined in the MASPS [ref. 1], the term “message” is used to refer to one Extended Squitter of 112 bits, and the term “report” is used to refer to a block of information generated as an output by ADS-B for use as an input to “applications.” In many respects, the information in a received message is reproduced directly into a report. There are several exceptions. Parity checking and error correction are done before generating reports. Therefore parity bits in the messages are not included in the reports. Another exception is latitude and longitude. In a message longitude is compressed into 17 bits, whereas in a report this is decompressed into a 24-bit format. The same is true for latitude. The data compression technique, called Compact Position Reporting or CPR, is described in more detail in Section F-3.1.1.

Another special case is time-of-applicability. In each message, the time of applicability is not transmitted digitally, but is conveyed as the time of transmission. In a corresponding report, however, time-of-applicability is reported digitally as an element of the report. Because position and velocity are transmitted separately, when they are combined into a report, two different times of applicability are reported. This is illustrated in Figure F-2. Furthermore, as shown in this figure, both measured and tracked values of position and velocity are given in reports. The measured values have different times of applicability, whereas tracking is used to generate values of position and velocity for a common time of applicability. As shown, the tracked values are accompanied by additional elements giving the confidence of the track and coast information. It is possible in some cases for an application to provide control information to the ADS-B avionics indicating that only one of the two types will be used (either measured values or tracked values). In that case the other type is not provided by Extended Squitter ADS-B to that application.

In most other respects the information in messages is conveyed directly into reports. Figure F-3 illustrates the relationship between messages and reports for the major information elements. This figure applies to normal airborne ADS-B transmission. As described in Section F-1.3.1, when an aircraft is on the airport surface, message formats for surface conditions are used. Position information is still transmitted in 17 bits for each component, but altitude is not included and velocity and position are together in one message [reference 3]. In addition, Mode S messages and formats have been designed to allow for other fields for special circumstances, such as when data of a particular type is not available [reference 3, Tables 2-11 and 2-16].



Note. All of these elements are provided in each state-vector report, unless inhibited by an application (see text).

Figure F-2. ADS-B reports of position-velocity-time.

As described in Section F-6.1, TIS-B would use a message format including both position and velocity in the same message. More specifically, the message would contain latitude and longitude in 12 bits each (LSB = 120 m), velocity in 10 bits, altitude in 12 bits, and address in 24 bits, plus a 5 bit site ID.

F-1.4 Spectrum issues

F-1.4.1 Channel availability. Using Mode S Extended Squitter for ADS-B differs in this respect from the two alternatives. The two alternatives are being newly developed to meet the ADS-B standards in the MASPS, and as yet do not have specific channels designated for their operation. The concept for Mode S, however, is to use the existing Mode S signal format, including the RF channel, data rate, modulation, preamble, and all of the pulse shape and other standards that apply to the existing operational Mode S systems. Field measurements and simulation are used to assess the ability of this extension to existing Mode S formats to meet the MASPS standards for the various applications defined in the MASPS. Channel availability for Extended Squitter is dependent on the demonstrated compatibility with current approved systems operating in the 1090 MHz band. This issue has been addressed through work by the FAA Spectrum Office and the FAA TCAS development program beginning in 1994. This FAA work has two parts, (1) interference from the ADS-B transmissions to existing systems, and (2) interference effects on the performance of ADS-B, including self interference and interference from existing systems to ADS-B. The work is described in the following two sections.

REPORT ELEMENTS

MESSAGE TYPES	"State Vector"														"Mode Status"					"On-Condition"		
	ICAO address	Latitude	Longitude	Altitude (geo.)	NUC(p)	North velocity	East velocity	Vertical rate, geometric	NUC(R) velocity components	Altitude, baro	Baro. alt. rate	Air speed	Ground speed, ground track	Turn indication	Call Sign	TCP latitude	TCP longitude	TCP altitude	Emergency	TCP+1 latitude	TCP+1 longitude	TCP+1 altitude
Position squitter	24	17	17	12	5					12												
Velocity squitter	24			8		11*	11*	10	3		10	11*	22	2								
ID squitter	24														48							
Intent type A squitter	24															14	14	10				
Intent type B squitter	24																			14	14	10
Status squitter	24																		3			

Note 1. Entries indicate number of bits in a message.
Note 2. The 17 bits of latitude and 17 bits of longitude are compressed (Section F-3.1.1). The resulting reports are uncompressed to 24 bits each.
Note 3*. When airborne, normally velocity over the ground is transmitted. If velocity over the ground is not available, airspeed and heading are transmitted instead.
Note 4. Either barometric or geometric altitude is transmitted. The message indicates which form is being transmitted.

Figure F-3. Relationship between messages and reports.

F-1.4.2 <u>EMC Effects of ADS-B on Existing Systems</u>. The initial technical work on this issue was an interference analysis by Lincoln Laboratory, which is documented in reference [4]. . Much additional work has also been done using a comprehensive simulation that was developed by the Joint Spectrum Center (JSC) during the TCAS development program and the Mode S development program before that. Many results have been generated during the course of this work. Currently interference conditions have been found to be quite small and acceptable. In some respects additional work is ongoing, focusing mainly on the effects of squitters from aircraft on the airport surface as received by an SSR located at the same airport. Initial field results indicate that such interference is not significant.

Not included in these studies are TIS-B, FIS-B, and co-installation of an ATCRBS transponder with a separate Extended Squitter unit, which are now being considered in this link evaluation. Initial interference assessments are given below in sections F-6.1 and 6.2.

F-1.4.3. <u>EMC Effects on the performance of ADS-B</u>. The other part of the spectrum approval process is a determination of the effectiveness of ADS-B as limited by existing systems and self interference. The initial work on this issue was a technical analysis by Lincoln Laboratory, which is documented in reference [5]. Recently this analysis has been extended by use of a track-level simulation at Lincoln Laboratory, whose results are being documented in the Extended Squitter MOPS, Appendix E [ref. 3]. Airborne tests in Los Angeles are providing additional validation information, and are particularly useful in that they provide an opportunity to experience air-to-air Extended Squitter signaling in a high density environment, including high rates of signals from existing systems (ATCRBS, Mode S, and TCAS), as well as multipath conditions and signal fading conditions caused by aircraft antenna patterns.

F-1.5. Differences Between the 1999 System and the Operational System. As stated in the beginning of this document, differences between the 1999 tests and the proposed operational system are of interest for every aspect of the system. Any differences are described explicitly item by item. To summarize all of the above information, there is a difference in the rate of transmitting aircraft ID information, as stated in Section F-1.3.1. In all other respects, the 1999 tests are consistent with the proposed operational system.

F-1.6 Power Parameters

F-1.6.1 Transmitter Power. The transmitter power levels for transmitted Extended Squitter signals are the same as the existing standards for Mode S transponders. Specifically:

Equipment Class	Transmitter Power (at ant.)
Class A3	51 to 57 dBm
Class A2	51 to 57 dBm
Class A1	51 to 57 dBm
Class A0	48.5 to 57 dBm

These values are referred to the antenna end of a cable between the antenna and the ADS-B unit.

F-1.6.2 Receiver MTL. Receiver sensitivity is characterized by the Minimum Triggering Level (MTL). MTL is defined as the power level of a received signal for which correct reception is 90 percent reliable in the absence of interference. Standards for receiver MTL are divided into four classes, according to the classes defined in the ADS-B MASPS [1].

Equipment Class	MTL (at antenna)
A0	-72 dBm or lower
A1	-74 dBm or lower
A2	-79 dBm or lower
A3	-84 dBm or lower

These values are expressed with reference to the antenna end of a cable between the antenna and the ADS-B unit. The MTL values given here apply to ADS-B surveillance, intent communication, and TIS-B reception. For FIS-B reception, enhanced MTL values are specified for the two lower classes, as described in Section F-6.2.

F-1.6.3 Summary of Basic System Characteristics. For convenience the basic system characteristics are summarized as follows.

	Proposed operational system	1999-2000 tests
Frequency band	1090 MHz	same
Channels	one channel	same
Bit rate	1 Mb/s	same
Modulation	PPM	same
Synchronization	4 pulse preamble	same
Message length	112 bits	same
Parity	24 bits	same
Address	24 bits	same
Longitude	CPR, LSB ~ 5 meters 17 bits even, 17 bits odd	same
PVT segmentation	velocity in separate message	same
Transmitter power (at ant.)	51-57 dBm, normal 48.5-57 dBm, low end	
Rcvr. MTL (90%) (at ant.)	<= -84 dBm, high-end <= -72 dBm, low-end	same
Polarization	vertical	same
Transmission rate, PVT	2/sec. position 2/sec. velocity	same
Multiple access technique	random short messages	same

F-2. System Overview

F-2.1 Architecture Relating ADS-B with Navigation and Communications

F-2.1.1 Intended Surveillance Role. Extended Squitter does not differ from alternative ADS-B links in this respect.

F-2.1.2 Quality of Service

F-2.1.2.1 Availability and Continuity of Service. Extended Squitter does not differ from alternative ADS-B links in this respect.

F-2.1.2.2 Integrity

F-2.1.2.2.1 Report Validation. In the avionics configuration expected to be the most common, the ADS-B transmitting functions will be packaged together with Mode S transponder functions in a single unit. For air-to-air surveillance, a TCAS system can use direct interrogation-reply to measure the air-to-air range for comparison with ADS-B information, in order to validate ADS-B. This capability is viewed as important in TCAS, and has been developed as a standard mode of operation called Hybrid TCAS. Similarly, for surveillance of aircraft by a ground station, direct interrogation-reply can be used to measure the range of the aircraft for comparison with ADS-B information, in order to validate ADS-B. A system design may make use of validation by a ground station to support air-to-air surveillance. For example, an SSR at San Francisco airport could be used to check the validity of ADS-B data transmitted by landing aircraft, to support procedures based on air-to-air surveillance using ADS-B.

F-2.1.2.2.2 Probability of Undetected Message Error. This is controlled by the parity field included in each squitter, as described in Section F-1.2.4.2. Also, as described in Section F-2.2, when receiver sensitivity is enhanced to extend long-range performance, then a conservative form of error correction/detection should be used to keep undetected errors to a very low rate. Simulations indicate that this technique is effective is keeping the undetected error rate within the MASPS standards (1 x 10-6).

F-2.2 Transition From Current Systems to ADS-B. The concept of using the Mode S signal format for ADS-B was originally based on perceived advantages in transitioning from currently operating systems. Operational Mode S transponders currently transmit this waveform, so the avionics functions that generate the signal (including transmitter, modulator, etc.) could be used. Furthermore the proposed ADS-B power levels are also the same as the existing transponder power levels. Therefore a single unit can readily be used to implement both ADS-B transmission and Mode S transponder functions. Transitioning from a Mode S transponder to ADS-B transmission would be a small step. Manufacturers currently offer certified Mode S transponders that include this function.

Similarly, TCAS avionics currently receive the Mode S waveform. Therefore the experience gained through the design of avionics and operational use of TCAS would be expected to provide an extensive base from which to transition to ADS-B. A notable difference between TCAS reception and ADS-B reception is receiver sensitivity, which can be enhanced for ADS-B relative to TCAS to extend air-to-air range. The receiver MTL values given above (1.6.2) are enhanced in two of the four classes. An enhancement of receiver sensitivity should be accompanied by enhancements of Mode S reception techniques. This is because weaker signals are accompanied by higher rates of interference. At a minimum, a more conservative error correction technique must be used to prevent an excessive rate of undetected errors. Several other techniques for improved reception have been developed, as described in Section F-4.2.2.

A Useful Transition Path. It has been observed that a useful transition path can be followed using Mode S Extended Squitter. The concept is to use existing Mode S radars to elicit downlink messages containing the same information as in Extended Squitters. This can be done before ADS-B is operational, and can be used to build up experience with ADS data, originating in GPS, received onboard an aircraft, converted into Mode S messages, and conveyed to the ground in Mode S replies. Building up experience with this mode of operation will be useful in transitioning to future configurations in which confidence would ultimately be placed in ADS information.

F-3. Information Exchange

F-3.1 Broadcast Message Generation

F-3.1.1 Information Source Interface and Information Compression. In most respects, use of Extended Squitter for ADS-B would not differ from other possible links. For example, the normal source of position-velocity-time information would be a GPS receiver, but other sources are possible, and in any case the accuracy of the source is included in the messages.

As described above in Section F-1.4.1, the basic concept for Extended Squitter was to use an existing Mode S format, including message length of 112 bits. As a result it is necessary to encode position information efficiently to keep within the given message length. The form of data compression that has been developed for this purpose is called Compact Position Reporting, or CPR. The resulting messages are compact in the sense that several higher-order bits, which are normally constant for long periods of time, are not transmitted in every message. For example, in a direct binary representation of latitude, one bit would designate whether the aircraft is in the northern or southern hemisphere. This bit would remain constant for long periods of time. To repeatedly transmit this bit in every position message would be inefficient. Using CPR, a 23 bit latitude is compressed into a 17 bit message.

Because the higher-order bits are not transmitted, it follows that multiple locations on the earth will produce a particular encoded message. If only a single position message were received, the decoding would involve an ambiguity as to which of the multiple solutions is the correct location of the aircraft. The CPR technique includes a provision to enable a receiving system to unambiguously determine the location of the aircraft. This is done by encoding in two ways that differ slightly. The two formats, called even-format and odd-format, are each transmitted fifty percent of the time. Upon reception of both types within a short period of time (approximately 10 seconds), the receiving system can unambiguously determine the location of the aircraft. The multiple solutions from the even reception (which are spaced by at least 360 nmi) and the multiple solutions from the odd reception (similarly spaced) agree only at one point on the globe.

Once this process has been carried out and the receiving system has determined the location unambiguously, each subsequent single message reception from a moving aircraft is sufficient to unambiguously indicate the location of the aircraft. A simple track file is used to save the location of the aircraft for use in decoding subsequent receptions. When a target flies to long range and then disappears from coverage, its entry in the track file can be discarded. An appropriate time-out value is 200 seconds, which will be sufficient to retain the global solution for use after a temporary dropout.

Latitude-Longitude Quantization. Using Extended Squitter CPR the latitude-longitude quantization has a quantization accuracy of about 1.4 meters rms in the airborne format. The MASPS states that latitude-longitude accuracy can be as large as 20 meters rms [ref. 1, Table 3-4]. This applies to airborne aircraft. For aircraft on the surface, the inaccuracy should not exceed 2.5 meters rms [ibid.]. Therefore CPR in the airborne format provides sufficient accuracy for both airborne aircraft and aircraft on the surface. Extended Squitter was designed that way in order to allow for the fact that some low-end GA aircraft will not be equipped with a squat switch and will therefore always transmit the airborne format, even when on the surface.

TCP and TCP+1 latitude and longitude are each encoded in 14 bits in a message. CPR data compression encoding is used, having LSB of about 40 meters, and having an ambiguity separation of 360 nmi. A receiver is able to calculate the latitude and longitude unambiguously from a single reception using the location of the transmitting aircraft as a reference, and for that reason only even format messages are transmitted. Because the TCP Time-to-Go is always less than 15 minutes, the distance between the TCP and the current aircraft location is always well less than the ambiguity separation.

This description applies to four-dimensional TCP and TCP+1 intent messages. Three-dimensional TCP and TCP+1 messages are also possible, which include latitude, longitude, and altitude, but not time. The location can be anywhere on the earth, and message coding is defined to convey the location in a single message. Direct binary encoding is used, with 17 bits for latitude and 17 bits for longitude. The LSB is 303 meters or less.

F-3.2 Message Reception and Output Reports.

F-3.2.1 Message Reception and Information Decompression. This is described in Sections F-1.3.2 and 3.1.1.

F-3.2.2 Report Assembly. The relationship between messages and reports is described in Section F-1.3.2. Reports can be used by more than one application, and different applications can have different criteria for tracking, coasting, and dropping tracks. As described in Section F-3.1.1, within ADS-B a track file is used to decode latitude and longitude. The track file saves an initial even or odd position message in order to make the initial decoding of position when the other format is received. Similarly a decoded position is saved in the track file for use in decoding each new position message.

Reports are generated based on the following principles. No reports are issued until position has been determined using an even reception together with an odd reception. When an address is received for the first time, it is saved in the track file with the other information in the message plus a time stamp. A time-out is set up so that if no other messages are received to this address for 100 seconds it can be deleted from memory. As further messages are received having this address, they are checked to see if an even-position and an odd-position have been received within 10 seconds. When that happens, the location is computed and the first position report is issued, including all information available. Afterward, as each message is received, it is saved with a time stamp, and the previous message of that type is discarded.

F-3.3 Reports and Supported Applications

F-3.3.1 Output Report Format as Compared with the Format in the MASPS. ADS-B data in Extended Squitter messages are reported in the formats given in the MASPS [ref. 1], with one addition. As described in Section F-1.3.2, position and velocity are accompanied by the two different times of applicability.

F-3.3.2 Application Interface. Extended Squitter does not differ from alternative links in this respect.

F-3.3.3 User Adaptation Features. In some cases, an application may provide control signals back into the ADS-B system, to provide for special interface conditions. For example, as described in Section F-1.3.2, an application may provide a control signal to indicate that only one of the two report format, measured or tracked, will be used, and therefore the other need not be provided. Such configurations are optional.

F-4. Message Reception and Co-channel Interference

F-4.1 Interference Sources

F-4.1.1 TDMA Slot Overlap. Extended Squitter does not use slotting as a means of multiple access by a number of aircraft (ref., Section F-1.1.1).

F-4.1.2 Random Access Interference. Extended Squitter uses a random time multiple access technique for multiple access as described in Sections F-1.1.1, 1.4.2, and 1.4.3. Existing systems in the 1090 MHz band that constitute interference to ADS-B include SSR, military IFF, TCAS, and TACAN/DME. In recent years, live testing of Extended Squitter has been carried out at Logan Airport, Hanscom Field, in the Gulf of Mexico, in the Los Angeles Basin, and at Atlanta International Airport. These test programs have provided useful experience with the Extended Squitter concept in high density environments. Recently, additional detailed testing was carried out in the Los Angeles Basin to gain experience with Extended Squitter signals in the most challenging interference environment.

F-4.1.3. Multipath. For air-to-air transmissions, multipath caused by reflections from the ground or water over which the aircraft are flying are to be expected in many cases. These effects were a major factor during the development of TCAS. The live testing of Extended Squitter at Logan Airport and other locations has been quite useful in assessing the effects of multipath and other real-world phenomena. Field measurement results indicate that such interference is not expected to degrade the performance of 1090 Extended Squitter below that necessary to meet the ADS-B MASPS requirements.

F-4.1.4 Ownship Suppression Effects on Link Availability. In addition to the interference effects received from external sources, effects from ownship systems are to be considered. For an airborne Extended Squitter receiver, it may be appropriate to gate the receiver off when an Extended Squitter transmission is generated onboard, and also during SSR replies (in Mode A, Mode C, and Mode S). The receiver may also be gated off when an onboard TACAN or DME is transmitting. In these cases, it may be possible to leave the receiver on, relying on a limiter to protect the receiver front end from these strong signals. If the receiver is not gated off, the effect would normally be essentially the same, because a reception from another aircraft at a normal signal level would be overshadowed by the strength of a transmission from ownship. For an aircraft equipped with TCAS, similar conditions are to be expected. When TCAS transmits an interrogation of 1030 MHz, depending on the specifics of the installation, the effect in an Extended Squitter receiver at 1090 MHz may be so strong that no Extended Squitter receptions are possible at the same time. Similarly, in the reply period immediately after a TCAS Mode C interrogation, a large number of Mode C replies are normally received, and these would interfere with Extended Squitter receptions. After a TCAS Mode S interrogation, only one reply is expected, so Extended Squitter receptions may be received during this period, depending on the specifics of the avionics design. We note that the field measurements conducted recently in the Los Angeles Basin were performed with TCAS operational on several of the ADS-B receiving aircraft, and the operational effects of TCAS/ADS-B interaction are reflected in the results.

F-4.2 Reception Techniques.

F-4.2.1 Synchronization. The Extended Squitter signal format begins with a 4-pulse preamble as described in Section F-1.2.3. When an Extended Squitter is received, a basic receiver synchronizes on the reception from the 4 pulse preamble.

Several techniques for improved reception have been developed, one of which is improved preamble detection. This technique makes use of the first five message bits together with the 4-

pulse preamble. This "9-pulse preamble detection technique" is described in more detail in ref. [3], Appendix I.

F-4.2.2 <u>Probability of Correct Reception</u>. When an Extended Squitter is received in an environment including both interference and receiver noise, the probability of correct reception is a key performance measure. Much work has been done to evaluate performance under a variety of conditions. This is described above in Section F-1.4.3.

Several techniques have been developed for improving reception probability while keeping the undetected error rate very low. These techniques are particularly beneficial when receiving weak signals accompanied by high interference, which are the conditions of long-range air-to-air reception in a high density area. The techniques include (1) the "9-pulse preamble detection technique (ref., Section F-4.2.1), (2) use of amplitude information for demodulating message bits and assigning confidence levels, and (3) a more conservative and more capable error correction technique. These techniques are described in more detail in the Extended Squitter MOPS [ref., 3], Appendix I.

When ADS-B and TCAS are both on the same aircraft, the TCAS signals will diminish ADS-B reception probability by some amount. The amount of this degradation can be estimated as follows. TCAS transmits interrogations in both Mode C and Mode S. A Mode C interrogation prevents Extended Squitter reception during the interrogation (22 microsec.) and during the following Mode C replies. The Mode C replies will occupy a time period determined by the power of the interrogation, the result being approximately 30 nmi in range or approximately 360 microsec. in time. The total time period of reduced squitter reception is therefore about 22 + 360 microsec. The squitter duration (120 microsec.) should be added to this to account for the fact that reception loss can occur at any point in the squitter signal. The rate of Mode C interrogations is 83 top plus 4 bottom = 87 interrogations per second (the large number being associated with the whisper-shout sequence, which is transmitted on each of four antenna beams). Therefore the reduction in reception probability is

$$(83 + 4)/\text{sec.} * (22 + 360 + 120)\text{microsec.} = 0.044 \text{ for Mode C}$$

TCAS Mode S interrogations are transmitted at a rate determined by the number of Mode S aircraft under surveillance, as affected by the built-in Interference Limiting function. In a high density area, the rate can be as high as about 20 interrogations per sec. The interrogation duration is 18 microsec. The interrogation will elicit one reply, at some time during a period of about 360 microsec. Extended Squitter reception can continue during this reply period, with a reduction in reception probability of about 60/(360 + 60) = 0.18. Therefore the reduction in Extended Squitter reception probability caused by TCAS Mode S interrogations and replies is

$$(20/\text{sec}) * 420 \text{ microsec} * 0.18 = 0.002 \text{ for Mode S}$$

Adding these two effects, the total reduction is

Reduction due to Mode C	0.044
Reduction due to Mode S	0.002
Total reduction	0.046

Note that this loss of receiver availability occurs regardless of whether a deliberate blanking function is implemented.

The value calculated above applies to a design in which the Extended Squitter receiver is unavailable during each TCAS interrogation and the following 30 nmi range band. In some of the original TCAS implementations, short squitter reception was further reduced by keeping the receiver gated off during the entire Mode C interrogation whisper-shout period. Typically the whisper-shout interrogations are spaced by 2 ms, in which case the short squitter blanking is

$$(83 + 4)/\text{sec} * 2 \text{ ms} = 0.17 \text{ for Mode C whisper-shout}$$

For Extended Squitter reception, the MOPS standards include a requirement that receiver availability be 90% or higher (ref. 3). Consequently the simplistic form of receiver blanking (between whisper-shout interrogations) is not allowed for Extended Squitter reception.

F-4.2.3 Multipath Susceptibility. As described in Section F-4.1.3, this is a major subject. Although a presentation of multipath measurements, and estimates of the effects on performance would consist of a large amount of material, the system design in this respect is relatively simple. Extended Squitter messages are transmitted at a rate higher that the minimum rate at which ADS-B information is needed. Also, Extended Squitter transmissions alternate between top and bottom aircraft antennas, and Extended Squitter receivers use at least a top mounted antenna and preferably both top and bottom antennas.

F-5. Subsystem Block Diagrams

F-5.1 Avionics Configurations in the Proposed Operational System. Given that the Extended Squitter signal is identical except for message content with Mode S replies, it might be anticipated that Extended Squitter transmission would normally be combined with a Mode S transponder in one box. This is certainly reasonable, but it’s also possible for ADS-B avionics to be separate from a Mode S transponder. Similarly, given that TCAS avionics includes functions for reception and demodulation of Mode S replies, it might be anticipated that Extended Squitter reception would normally be combined with TCAS functions in one box. This is certainly reasonable but it’s also possible for ADS-B avionics to be separate from TCAS. Integration of ADS-B receive and transmit functions will be vendor-dependent; such integration is not expected to affect the performance of ADS-B via Extended Squitter, although various packaging configurations may have certain economic advantages to the users.

Considering other possible avionics configuration, we find that a large number of different combinations are possible, beginning with the fact that some ADS-B aircraft will have TCAS while others may not. In some cases the aircraft will be equipped with an SSR transponder, which is consistent with operation in most high-to-moderate density airspace today, although

ADS-B does not require an SSR transponder. In some cases ADS-B may use two antennas, top and bottom, but a single-antenna configuration is also possible. If the configuration includes two ADS-B antennas, it is possible for the ADS-B to have one receiver that is switched between the two antennas, and alternatively it is possible to employ two receivers so that both antennas are continually monitored. When a transponder is included, this may be normal power transponder, or it might be a low-end transponder (Section F-1.6.1). Also the transponder may employ antenna diversity or not. If the configuration does not combine ADS-B reception and TCAS into a single unit, then ADS-B reception has its own antennas, and these can be implemented with preamplifiers, as was done in the 1999 test avionics. Antenna-mounted preamplifiers are intended to help achieve good receiver sensitivity, since they essentially eliminate the effects of antenna-to-receiver cable loss on system sensitivity. Altogether more than 20 different avionics configurations are possible.

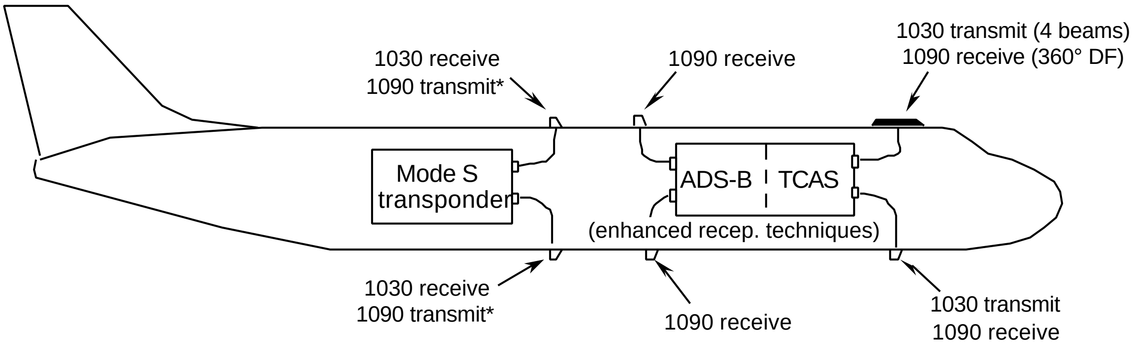
When ADS-B and TCAS are combined into a single avionics unit, there is a significant difference between the two that must be observed. When receiver sensitivity is enhanced for ADS-B, it must not also be enhanced for TCAS (because of interference control effects that are important in TCAS). Therefore it is necessary in such configurations to have a dual-sensitivity receiver for 1090 receptions.

To focus on a smaller number of likely configurations, the Link Evaluation Team has identified a set of four primary cases, which are illustrated in Figure F-4.

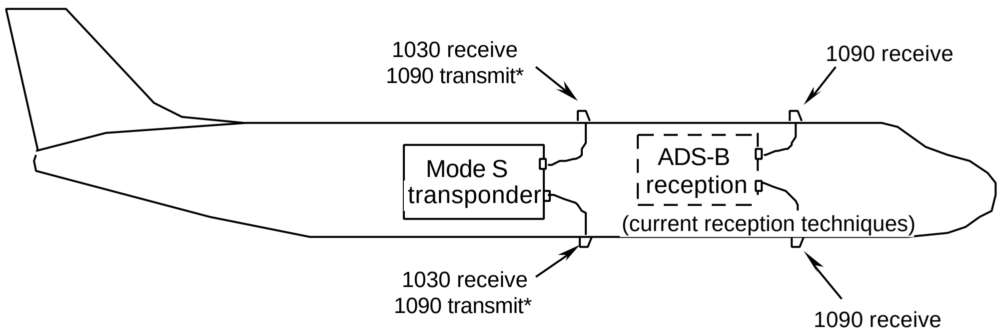
> Low-End GA Configuration (A0). The lowest level of these four includes an ADS-B and a separate ATCRBS transponder. The ADS-B transmissions are made by the ADS-B unit, using the low-end power standards (Section F-1.6.1). This configuration corresponds to MASPS Class A0. As noted in F-1.4.2, possible interference between the ADS-B unit and the transponder has yet to be studied in detail.
>
> A similar configuration not shown here is that in which the aircraft has ADS-B without any transponder. While this is an allowed configuration, it is judged by the LET to be unlikely to have widespread deployment. This configuration, because it lacks equipage with an SSR transponder and therefore will restrict operation to airspace where SSR transponder equipage is not mandatory, is considered to be one that is unlikely to see widespread deployment.
>
> GA Configuration (A0). As illustrated, the next level has a Mode S transponder. In this case, the ADS-B transmissions are made by the transponder. The Mode S transponder power conforms to the low-end power standards (Section F-1.6.1).
>
> Basic IFR Configuration (A1). The next higher level applies to MASPS Class A1, for basic IFR capability. It includes a diversity Mode S transponder, using the normal power level, and top-bottom transponder diversity. ADS-B reception also employs top-bottom antenna diversity. ADS-B employs the current reception techniques.
>
> ADS-B and TCAS Configuration (A2 or A3). The most capable configuration shown in Figure F-4 applies to Classes A2 and A3. It includes TCAS on the aircraft which can be

either separate or combined with ADS-B in one unit. ADS-B employs the enhanced receptions techniques (Section F-4.2.2).

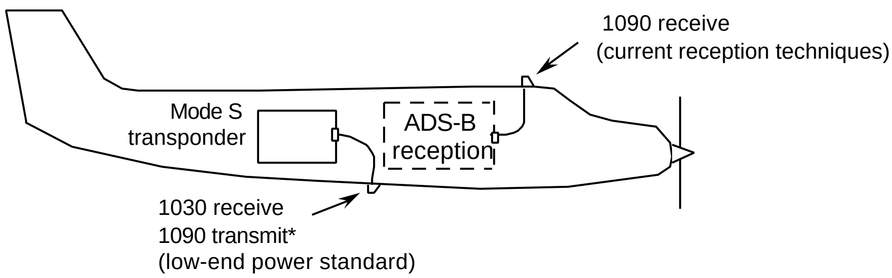
(a) ADS-B and TCAS (Class A2 or A3)



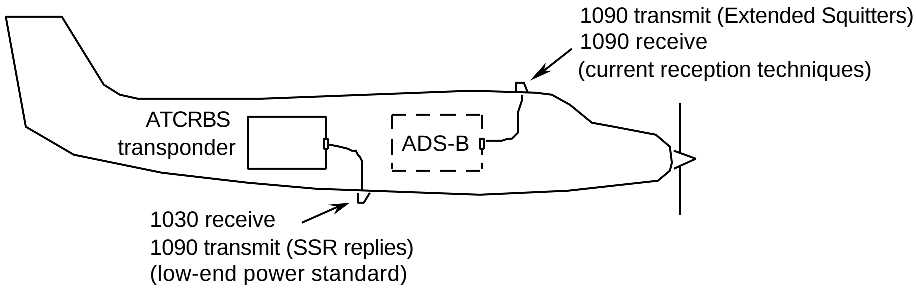
(b) Basic IFR Configuration (Class A1)



(c) GA Configuration (Class A0)



(d) Low-end GA Configuration (Class A0)



* These 1090 transmissions include SSR replies and squitters.

Figure F-4. Basic avionics configurations for Extended Squitter.

The above configuations apply to the evaluation for airspace in the United States. For European airspace, TCAS was assumed to be includes for all four classes, A3, A2, A1, and A0. Therefore all aircraft were assumed to be equipped with Mode S transponders.

F-5.2 Avionics in 1999-2000 Tests. The avionics developed for testing in 1999-2000 include Extended Squitter transmission and reception. This equipment is consistent with the proposed operational system design in all respects with one exception: the transmission rate for aircraft ID is once per 5 seconds whereas in the proposed operational system the rate is once per 2.5 seconds.

Several avionics configurations are available for testing, the main one being different from all the four cases shown in Figure F-4. This avionics configuration was developed by UPS Aviation Technologies. Antenna-mounted preamplifiers are included. A dual-channel receiver is also included, for continuous reception from both top and bottom antennas. The receiver is very sensitive, and conforms to the Class A3 sensitivity standards (Section F-1.6.2).

Other avionics that is available for testing include a Honeywell TCAS 2000, in which normal TCAS functions are combined with ADS-B, a general-purpose data acquisition system developed by Lincoln Laboratory (the 1090 MHz Test Bed), and a similar general-purpose data acquisition system developed by the FAA Technical Center (called DATAS). Data recorded by the 1090 MHz Test Bed is processed to provide either a non-real-time implementations of normal TCAS reception techniques, or the enhanced reception techniques described above in Section F-4.2.2. The Test Bed data is also used to make measurements of the interference environment during the tests.

F-5.3 Ground Stations in the Proposed Operational System. ADS-B using Mode S Extended Squitters can operate to some extent without ground stations. Ground stations can be used in order to provide surveillance information to ground based ATC systems. Ground stations can also be an important part of a system, providing redundant information for validation purposes. The ADS-B MOPS [ref. 3] addresses the issues of ground stations by including an appendix (Appendix D), written by the FAA, that states assumptions about the way the ground environment will evolve as a part of the ADS-B system. This appendix defines several levels of possible ground stations, beginning with a minimum level that performs 1090 MHz reception without 1030 MHz transmission. At the other extreme, a ground configuration is defined that includes 1030 MHz transmissions (to interrogate Mode S transponders and make direct range measurement for cross checking with ADS-B information). The maximum station also includes a multi-sector antenna, feeding multiple receiver channels. The transmitter is a one-channel transmitter, connected through an RF combiner to form an omnidirectional transmit pattern. The maximum station also includes multilateration functions which use receptions from multiple ground stations to determine the locations of aircraft passively using multilateration. A multilateration solution is useful for validation of ADS-B information and also for performing surveillance for aircraft not equipped with ADS-B.

Figure F-5 shows a block diagram for a ground station, based on material in reference [3], except extended to include TIS-B and FIS-B for purposes of this study.

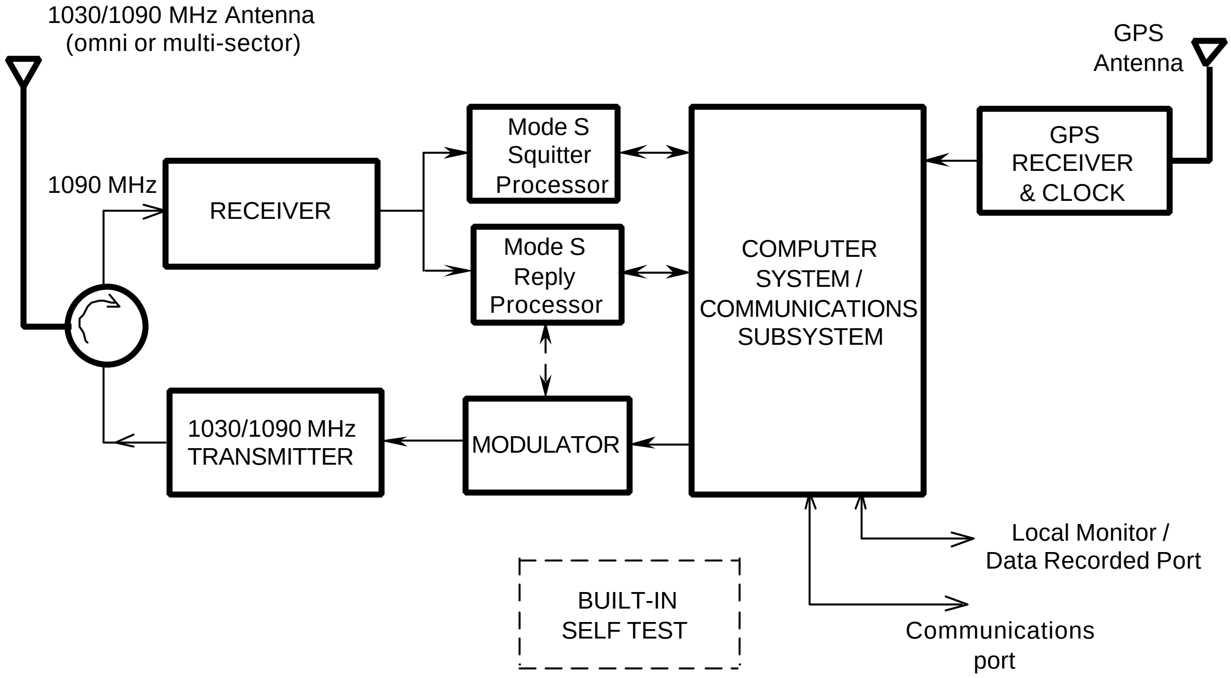


Figure F-5. Block diagram for an Extended Squitter ground station.

For surveillance of aircraft on the airport surface, an ADS-B receiving station will include a number of simple receivers. Because of the multipath environment at most airports, and obstructions by buildings, a single receiving antenna would not be sufficient to cover the full airport. It has been shown through testing at Logan Airport that approximately four receiving antennas are appropriate for an airport of that size. In the Logan tests, four receiving antennas provided effective coverage of the entire airport movements area. Coverage in the gate areas is more difficult, due to the congested structures of buildings and aircraft, and for that reason was not evaluated at Logan.

When a receiving system for airport surface surveillance is developed, it would be possible that a passive multilateration mode would also be included, for both validation of ADS-B information and for surveillance of aircraft not equipped with ADS-B. .

F-5.4 <u>Ground Based Equipment in the 1999 Tests</u>. The ground based equipment developed for the 1999 tests is consistent with the proposed operational system in regard to waveforms and reception processing. This was not a complete system including TIS-B and FIS-B and interrogation/reply, but it included many facilities and enabled the testing of a number of aspects of the system. For example, instead of TIS-B and FIS-B messages, the ground based equipment simply transmitted Extended Squitters in the position and identity formats. The test system was also limited in having just two receiver channels instead of six. Transmission of Extended Squitters from the ground made use of a Mode S transponder as the signal source.

For testing in the Los Angeles Basin, the ground equipment included both a six-sector antenna and an omnidirectional antenna. These were used in several different configurations. In some cases, reception was via the sector antenna, using just two of the sectors, while Extended Squitters were transmitted via the omnidirectional antenna. In other cases both transmissions and receptions were done in the same antenna sector. The underlying purpose of these tests involving ground equipment was to gain experience with air-to-ground and ground-to-air transmission and reception in a dense interference environment.

F-5.5. Proposed Equipage Classes. Defined equipage classes for Extended Squitter are given in the MASPS.

F-6. TIS and FIS.

F-6.1 TIS and TIS-B Description. For cases in which an ADS-B aircraft is equipped with a Mode S transponder, a basic form of Traffic Information Service (TIS) has been developed using the Mode S data link. Position messages are transmitted to the aircraft from a Mode S ground station, using the data block in Mode S interrogations. In addition to the interrogation(s) used for surveillance, up to three additional interrogations may be transmitted to supply the TIS information when necessary. This application has completed operational test and evaluation by the FAA Technical Center, RTCA has issued MOPS (DO-239) for avionics implementation, definition of TIS is included in the ICAO Manual of Mode S Specific Services, and terminal Mode S radars having the TIS function are deployed nationwide.

An extension of Extended Squitter to provide a broadcast form of TIS (called TIS-B) has been proposed for purposes of the Safe Flight 21 link comparison. In this concept, TIS information would be broadcast from the ground, using formats similar to Extended Squitter, based on surveillance information obtained from an SSR. This service is intended to support the application of enhanced see-and-avoid in the cockpit. TIS-B information is not transmitted for aircraft currently transmitting ADS-B information. Position and velocity are included in a single TIS-B message.

The rate and power of TIS-B transmissions can be estimated for purposes of the current study, whereas these are important system parameters whose final values would be determined in a more comprehensive development program. The TIS-B transmission rate is determined by the objective of providing reliable reception once per SSR scan (4.7 seconds). In considering interference, the TIS-B transmissions for a given non-ADS-B aircraft under surveillance can be compared with the corresponding ADS-B transmissions that would be transmitted by that same aircraft if it were ADS-B equipped, namely 4.2 squitters per second. This rate equals 19 squitters/scan. That rate is more than sufficient for reliable reception. Therefore a serviceable estimate of the TIS-B transmission rate is 2 per second (which equals 9 per radar scan) for each aircraft represented by TIS-B. This rate is approximately half the normal per aircraft ADS-B transmission rate. For transmitter power, a serviceable estimate for the current study is 500 watts referred to the antenna. This is somewhat higher than the normal power level for a transponder. This value is intended to keep interference effects very small, considering the overlapping of signals that would be expected if TIS-B were deployed in an area-wide configuration.

F-6.2 FIS and FIS-B Description. Similarly, Flight Information Services (FIS) can be transmitted to aircraft using Mode S signals. FIS information may include weather advisories, weather maps, ATIS, PIREPS, and SUA reports. A form of FIS included as a part of Mode S surveillance of aircraft from SSR ground stations has been developed by the FAA and tested extensively in recent years. In this service, the FIS information is transmitted to aircraft using Mode S interrogations in the 1030 MHz band with 1090 MHz replies for confirmation of reception.

An extension of Extended Squitter to provide a broadcast form of FIS (called FIS-B) has been proposed for purposes of the Safe Flight 21 link comparison. In this concept, FIS information would be broadcast from the ground. Data rate analysis by the Link Evaluation Team has concluded that an effective amount of FIS-B information can be conveyed with a data rate of 200 bits/sec. This rate refers to the information delivered, not including any parity transmitted for integrity reasons, nor any repeated transmissions intended to increase reliability.

For purposes of the TLAT link assessment, the following specifics of an FIS-B design using Extended Squitter are defined. This design is sized to deleiver a data rate of 200 bits/sec. Multiple stations transmitting FIS-B are spaced 60 nmi apart in a hexagonal pattern. FIS-B transmission rate is 10 Extended Squitters per second from each station. Transmitter power is 54 dBm effective radiated power. Therefore, if the transmitting station uses an omnidirectional antenna having 7 dB gain, transmitter power = 47 dBm at antenna input.

For airborne reception, the receiver sensitivity values are enhanced for FIS-B relative to ADS-B applications. In classes A0 and A1, receiver MTL is -79 dBm or lower, referred to the antenna.

F-7. Growth Potential. Beginning in 1992, Extended Squitter was developed based on a concept that it would be appropriate for equipage by all aircraft, and that the density of aircraft will likely increase in the future. As use of the system grows, it is to be expected that signal rates from existing systems will be reduced, partially as a result of Hybrid TCAS, partly as a result of an on-going transition from ATCRBS to Mode S, partly as a result of upgrading some SSRs from the older beam-splitting technology to monopulse technology, and also partly as a result of the success of ADS-B providing a basis for discontinuing operation of some SSRs.

The P4 Suppression Workaround is currently being used at operational Mode S radars, as a means of dealing with a class of transponders (some of which were manufactured by Terra Corp.) that do not reply to the ATCRBS/Mode S All-Call interrogation format. This is viewed as an undesirable condition, and steps are begin taken to replace or modify these transponders. Using the P4 Suppression Workaround, an SSR transmits ATCRBS interrogations in order to perform surveillance on these few aircraft. This fix has the undesirable consequence of eliciting ATCRBS replies from Mode S aircraft, which consequently are under dual surveillance at all times. The FAA is taking steps to eliminate the defective transponders from the airspace and phase out the P4 Suppression Workaround for several reasons. One is that it prevents Mode S SSRs from operating efficiently in the mode in which they were designed; they elicit more replies than needed, which contributes interference to the 1090 MHz band. Also, the defective transponders are invisible to TCAS, which could be a serious problem in some cases. Therefore these transponders should be upgraded as soon as possible. As the P4 Suppression Workaround is eventually phased out, this too will result in a reduction of interference in the 1090 MHz band.

There is also a significant trend in which SSR Mode A and C interrogation rates have been decreasing over many years. This has been observed in airborne measurements beginning in the 1070s and continuing in the 1980s and 1990s. The improvements is attributed mainly to a continuing FAA program of frequency management. This program includes identification of SSRs operating without Sidelobe Suppression, SSRs operating at excessively high power levels, and SSR testers operated omnidirectionally, at high power levels, and high interrogation rates.

Considering both the growth in number of aircraft and the trends of decreasing transmission rates per aircraft, it might be reasonable to expect that the conditions of maximum interference in the 1090 MHz band are currently being experienced. Airborne testing in 1999 is particularly valuable, especially for tests done in high density metropolitan areas such as New York and Los Angeles.

F-8. Pre-Existing Evaluation Information

Prior to the work of the Link Evaluation Team, an extensive amount of information about Extended Squitter design and performance had been developed. The FAA began the development of Extended Squitter in the early 1990s, and there followed a program that has included flight tests, bench tests, and simulations at the pulse level, and at the track level. Most of the resulting information has been documented in technical reports. This body of pre-existing information is summarized in the following.

System Concept. The initial work was focused in the documentation of the system concept in 1993 [ref. 6]. This technical report also identified key issues for development work, and presented a first-order analysis of each issue and its resolution.

The First Airborne Tests were in 1993, in eastern Massachusetts. These were followed by testing on the airport surface at Hanscom Field and Logan Airport. This work is summarized in a video tape that describes the system concept of Extended Squitter and summarizes the measured reliability of surveillance on the airport surface. Reliable surveillance over the full airport surface was achieved by using four receiving antennas.

Gulf of Mexico. A program of tests over the Gulf of Mexico was conducted in 1994. These tests focused on low altitude flights over water, and in surveillance of helicopters by reception on antennas mounted on oil rigs in the Gulf. Long range surveillance over water was also tested. This work is documented in ref. 7.

Six-Sector Antenna. For reception at a ground station, the system concept includes a multi-sector antenna as a means of achieving long-range surveillance and tolerating interference. The initial analysis was extended by designing and procuring a six-sector antenna. This antenna was tested, first at an antenna range, and then on a tower receiving Mode S signals from airborne aircraft. This work is documented in ref. 8. Specifications and antenna performance characteristics for a commercial unit are summarized in ref. 18.

Atlanta Tests. Tests were conducted at Atlanta airport focusing on multilateration using Mode S short squitters, ATCRBS replies, and Extended Squitters. The results are documented in ref. 9.

Interference. Tolerating interference from ATCRBS fruit was an issue identified in the original system concept report. A more detailed analysis of interference effects was conducted and documented in 1995 [ref.4].

A more detailed simulation of interference conditions has been conducted by the Joint Spectrum Center (JSC). This work was sponsored by the FAA to assess interference that would be caused by transmission of Extended Squitters to existing systems. Based on these results, which are documented in ref. 10, the FAA has accepted the airborne transmission of Extended Squitters.

Capacity. System capacity, in the form of the maximum number of aircraft that could participate in the Extended Squitter system was analyzed in more detail and documented in a technical report in 1994 [ref. 5].

Low-Noise Receiver. The original system concept document also identified receiver sensitivity as an issue. This issue was examined in more detail in 1996, through receiver bench tests and corresponding analysis. The results are documented in ref. 11.

Airborne Reception. Airborne tests focusing on long-range air-to-air reception using a low-noise receiver were conducted in 1996 in eastern Massachusetts. The results are documented in ref. 12.

Interrogation Rate Measurements. Airborne measurements of interrogation rates in the 1030 MHz band were conducted in 1994 including Boston, New York, Philadelphia, Baltimore, Washington DC, Atlanta, and Dallas-Fort Worth. These are follow-on to previous measurements made in the 1970s and in the 1980s, and are interesting in that a significant decrease in rates has become evident. The measured rates are documented in ref. 13.

Reply Rate Measurements. Similar measurements of reply rates received airborne with an omnidirectional antenna were also conducted in 1994 and 1995. The measurements were made in all of the same locations as above and also in the Los Angeles Basin. The measured rates are documented in ref. 14.

Reception Techniques. It was recognized during the Extended Squitter development program that the interference conditions are significantly more severe in long-range air-to-air Extended Squitter reception than in TCAS. This is a consequence of the improved receiver sensitivity and ability to receive weaker signals. Such signals are accompanied by higher rates of interference. Enhanced reception techniques were developed to improve reception performance under these conditions. The techniques include (a) improved preamble detection, making use of the first five information bits together with the 4 pulse preamble, (b) improved demodulation, making use of the pattern of received power levels within each bit time interval, and (c) improved error correction, that is both more conservative, to keep the undetected error rate very low, and also more aggressive in correcting receptions having multiple errors. The enhanced reception techniques are documented in the Extended Squitter MOPS, ref. 3, appendix I. Development of these techniques was done mainly with a pulse-level simulation, which is documented along with the major results in ref. 15. The simulation work was subsequently tested by air-to-ground testing in the Boston area, and then air-to-air testing in the Los Angeles Basin.

Long-Range Performance. After the ADS-B MASPS was completed in 1998, an assessment of air-to-air Extended Squitter performance was conducted for comparison with the MASPS standards. This assessment is in the form of a track-level simulation that includes even-odd position format alternation, top-bottom antenna alternation, correlation of signal power levels from message to message, deviations in received power caused by aircraft antenna gains, and similar phenomena to faithfully represent the actual air-to-air conditions. The formulation of the simulation is documented in ref. 16, along with simulation results showing system performance as compared with the MASPS standards.

Los Angeles Basin. The FAA conducted a major program of airborne testing in the Los Angeles Basin in June 1999, following a preliminary test mission a year before. These tests were mainly aimed at assessing air-to-air reliability of Extended Squitter in a maximum interference environment. Several different aircraft were involved and several different types of reception avionics were used. A ground station was also included, so that air-to-ground performance could also be tested as well as limited tests of ground-to-air transmissions. The results are documented in reference 17.

Frankfurt Tests. The tests in Los Angeles were followed by an expanded program of tests in Frankfurt, Germany, which were carried out in May 2000. Frankfurt was considered to be an area of very high interference, because of a number of military radars operating in the area. Three project aircraft participated, one from the United States, one from the Netherlands, and one from Germany. Also, it was realized during that tests that additional aircraft were transmitting Extended Squitters. These were identified as passenger carrying aircraft operated by British Airways. By receiving and recording these squitters, the paths of these aircraft were observed, and it became possible to measure reception reliability as a function of range. The testing also included two ground stations, involving receiving equipment of several different types. The Frankfurt tests were successful in gathering a large amount of data, both for measurements of the interference environment and measurements of reception performance in high density conditions. Initial results were presented to the SC-186 and TLAT, and an interim report was distributed to TLAT members in November 2000.

F-9. Additional Eurocontrol Evaluation Criteria

In October 2000, Eurocontrol proposed additional criterial for the TLAT assessment process. The new criteria are of three types:

(1) Additional functions. For example, whereas the RTCAS MASPS for ADS-B defines intent communications as being two Trajectory Change Points (TCPs), the Eurocontrol criteria include a total of four TCPs.

(2) Extended performance. For example, whereas the MASPS defines the air-to-air range for surveillance and intent communications as 90 nmi in oceanic and low density enroute airspace, the Eurocontrol criteria extend this air-to-air range to 150 nmi. Furthermore, the Eurocontrol criteria include this performance in all airspace, including high density areas.

(3) Quantitative performance criteria for existing functions. For example, whereas the MASPS describes air-to-ground applications but does not provide corresponding quantitative performance criteria, the new Eurocontrol criteria do include quantitative performance criteria for air-to-ground applications.

In responding to these new criteria, the TLAT is considering possible changes to the Extended Squitter system design for TLAT purposes. It has been decided to keep the system design unchanged in certain respects while making changes in certain other respects. The distinction is as follows.

(a) Basic System Parameters. A fundamental property of Extended Squitter is that it uses, without any changes, the 1090 MHz carrier frequency and the other existing standards for Mode S signals. This signal format was standardized in the 1979s, and is now in use operationally in both air-to-ground surveillance and in TCAS air-to-air signaling. In addition to the 1090 MHz carrier frequency, these basec standards include the data rate, message length, modulation, 4-pulse preamble, parity encoding, and airborne transmitter power levels. In all of these respects, the Extended Squitter system design is not being changed in response to the new criterial from Eurocontrol.

(b) MOPS System Parameters. The RTCA MOPS provides additional standards for a number of system parameters, such as airborne receiver sensitivity. These values were developed through a multi-year process, involving many contributors, which added considerable maturity and validity to the development level of the system. In these respects too the Extended Squitter system design is not being changed for TLAT purposes in response to the new criterial

(c) Ground System Parameters. Ground systems for Extended Squitter reception and transmissioin have been designed, but not to the same maturity level as avionics. Therefore it is reasonable to consider changes in receiver sensitivity and antenna characteristics. The number of ground stations and spacing between ground stations can also be adjusted to support the aditional functions.

(d) MOPS Exceptions. In certain limited respects, possible system design changes are considered which would require a MOPS change. Specifically these include the definition of two new TCP messages and TCP transmission rates.

An increase in the number of TCPs from two to four can be supported by defining two new TCP messages. These follow the existing TCP message formats, except for increasing the TCP index from two to four. This can be accomplished by using one of the unused type codes. Specifically type code = 25 can indicate that the message is TCP+2 or TCP+3. Following the existing format, within the message, bit 6 can indicate whether the message is TCP+2 or TCP+3.

The transmission rate for TCPs as defined in the MOPS is one transmission of each per 1.7 seconds (with pseudo random timing jitter). In supporting a change to four TCPs, there is a system design question of whether to retain the transmission rate for each TCP, or alternatively to retain the total transmission rate, and therefore reduce the per-TCP rate. During the time while this increase to four TCPs is begin considered for adoption, this tradeoff will likely be evaluated in detail. To retain the per-TCP rate will cause an increase in total transmission rate for some aircraft, which would require a change to both the MOPS and the SARPS. System-wide interference issues would be studied, and the need for an increase in number of TCPs would be investigated in depth to develop an understanding of whether the operational advantages would be enough to warrant this increase. If instead the total transmission rate were retained and shared among four TCPs, there would be a performance reduction for the MASPS functions.

It has been decided that for TLAT purposes the per-TCP transmission rate will be retained. As a result, the total transmission rate, for those aircraft that are transmitting all four TCPs, which is 6.2 per second in the current MOPS, would become 7.4 per second.

The interrelationship between Extended Squitter and SSR Mode S provides a convenient and flexible way to support new air-to-ground functions. It is to be expected that all air carriers and other high end aircraft will be equipped with a Mode S transponder, which will perform the Extended Squitter transmission function. This is the avionics configuration adopted for TLAT purposes for classes A3, A2, and A1, as shown in Figure F-4 above. Therefore, where an SSR Mode S ground station exists, it is possible to use the addressed Mode S data link to communicate the new TCP information to the ground. The two additional TCPs can be assigned to specific registers, of which there are many spares. The air-initiated Comm C protocol would be used, so that whenever a change occurs in TCPs, the change will trigger the air-to-ground communication process. The ground station receiving state vector and related information can also be a simple form of Mode S station called a “Small Terminal Sensor”. Instead of a rotating high-gain antenna, a Small Terminal Sensor is implemented using a TCAS-like antenna having no moving parts.

If the air-to-ground functions are to be implemented without using Mode S interrogation-reply, then the ground station is a simpler ADS-B station such as those described in section F-5.3. In any case, the four TCP messages will also be broadcast regularly to support air-to-air communication and air-to-ground communication to ADS-B ground stations.

The new Eurocontrol criteria also include “Selected Altitude” for air-to-ground communication. There is a similarity between Selected Altitude and TCPs, which include altitude. Eurocontrol has clarified the meaning of Selected Altitude by saying that it is different from the altitude information in TCPs, and is in fact a fifth altitude value to communicate from an aircraft to a ground station. To provide this communication to a ground station, there are the same three options: (1) a ground station that is an SSR Mode S, (2) a Small Terminal Sensor, and (3) a ground station that is a simpler ADS-B station. If the ground station is an SSR Mode S or Small Terminal Sensor, then the Mode S data link can be used for Selected Altitude. Accordingly the Selected Altitude value would be assigned to a Mode S register, making it available for communication to the ground, using the air-initiated Comm C protocol. If the ground station is a simpler ADS-B station, the Selected Altitude can be broadcast at a regular rate, similar to TCP messages. The Selected Altitude squitter can be assigned type code 26 to uniquely identify this type of message.

One other MOPS change has been considered, which is to allow a modest directionality in the airborne receiving antenna. Within the confines of an antenna that is physically small, consistent with existing transponder antennas and TCAS antennas, it is possible to enhance gain in the forward direction by about 3 to 4 dB. This boost is accompanied by a reduction in the aft direction by about the same amount. The added gain in the forward direction will increase air-to-air range by a factor approximately 1.5. Note that this range increase is only in the forward direction.

REFERENCES

[1] "Minimum Aviation System Performance Standards for Automatic Dependent Surveillance Broadcast (ADS-B)", RTCA/DO-242, Feb. 1998.

[2] "Minimum Operational Performance Standards for Air Traffic Control Radar Beacon System/Mode Select (ATCRBS/Mode S) Airborne Equipment," RTCA/DO-181B, 1999.

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