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AMENDMENTS

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

RECORD OF AMENDMENTS AND CORRIGENDA

AMENDMENTS		
No.	Date	Entered by

CORRIGENDA		
No.	Date	Entered by

FOREWORD

The universal access transceiver (UAT) is a wideband broadcast data link operating on 978 MHz with a channel modulation rate of just over 1 Mbps. By design, UAT supports multiple broadcast services, including flight information services (FIS-B) and traffic information services (TIS-B), in addition to automatic dependent surveillance — broadcast (ADS-B). This is accomplished using a hybrid medium access approach that incorporates both time-slotted and random unslotted access. By virtue of its waveform, modulation rate, precise time reference and message-starting discipline, UAT can also support independent measurement of range to most other participants in the medium.

There are two basic types of broadcast transmissions — or messages — on the UAT channel: the UAT ADS-B message and the UAT ground uplink message. The UAT ADS-B message is broadcast by an aircraft to convey its state vector (SV) and other information. In addition, UAT ground stations can support TIS-B through transmission of individual UAT ADS-B messages. The UAT ground uplink message is used by UAT ground stations to uplink flight information, such as text and graphical weather data, advisories and other aeronautical information, to UAT-equipped aircraft that are in the service volume of the UAT ground station. Regardless of type, each message has two fundamental components: the message data block that contains user information, and message overhead, principally consisting of forward error correction code parity, that supports the transfer of the data.

This second edition of the manual reflects updates to the UAT technical specifications and implementation aspects to meet the requirements of RTCA DO-318/EUROCAE ED-161, *Safety, Performance and Interoperability Requirements for Enhanced Air Traffic Services in Radar Controlled Areas Using ADS-B Surveillance (ADS-B-RAD)*, September 9, 2009. Additionally, updates have been included to meet the requirements of ADS-B regulatory activities in several States. Backward compatibility with the first edition of this manual is described in RTCA DO-282B, *Minimum Operational Performance Standards for Universal Access Transceiver (UAT) Automatic Dependent Surveillance — Broadcast*, December 2, 2009, Appendix R. Updates reflected in this second edition of the manual have no impact on UAT system performance information presented in the first edition: additional system performance information for the new equipment class A1S is presented in the appropriate appendices of Part II of this manual. The updates in this second edition of the manual do not impact the UAT SARPs.

EXPLANATION OF TERMS

ADS-B rebroadcast. The ADS-B rebroadcast (ADS-R) service complements the operation of ADS-B by providing ground-to-air rebroadcast of ADS-B data about aircraft that are not equipped with UAT, but are equipped with an alternate form of ADS-B (e.g. 1090 MHz extended squitter). The basis for the ADS-R transmission is the ADS-B report received at the ground station using a receiver compatible with the alternate ADS-B data link.

High-performance receiver. A UAT receiver with enhanced selectivity to further improve the rejection of adjacent frequency DME interference (see Annex 10, Volume III, Chapter 12, 12.3.2.2, for further details).

Optimum sampling point. The optimum sampling point of a received UAT bit stream is at the nominal centre of each bit period, when the frequency offset is either plus or minus 312.5 kHz.

Power measurement point (PMP). A cable connects the antenna to the UAT equipment. The PMP is the end of that cable that attaches to the antenna. All power measurements are considered as being made at the PMP unless otherwise specified. The cable connecting the UAT equipment to the antenna is assumed to have 3 dB of loss.

Pseudorandom message data blocks. Several UAT requirements state that performance will be tested using pseudorandom message data blocks. Pseudorandom message data blocks should have statistical properties that are nearly indistinguishable from those of a true random selection of bits. For instance, each bit should have (nearly) equal probability of being a ONE or a ZERO, independent of its neighbouring bits. There should be a large number of such pseudorandom message data blocks for each message type (basic ADS-B, long ADS-B or ground uplink) to provide sufficient independent data for statistical performance measurements. See Part I, Chapter 2, 2.3, of this manual for an example of how to provide suitable pseudorandom message data blocks.

Service volume. A part of the facility coverage where the facility provides a particular service in accordance with relevant SARPs and within which the facility is afforded frequency protection.

Standard UAT receiver. A general purpose UAT receiver satisfying the minimum rejection requirements of interference from adjacent frequency distance measuring equipment (DME) (see Annex 10, Volume III, Chapter 12, 12.3.2.2, for further details).

Successful message reception (SMR). The function within the UAT receiver for declaring a received message as valid for passing to an application that uses received UAT messages. See Part I, Chapter 4, of this manual for a detailed description of the procedure to be used by the UAT receiver for declaring successful message reception.

UAT ADS-B message. A message broadcasted once per second by each aircraft to convey state vector and other information. UAT ADS-B messages can be in one of two forms depending on the amount of information to be transmitted in a given second: the basic UAT ADS-B message or the long UAT ADS-B message (see Annex 10, Volume III, Chapter 12, 12.4.4.1, for definition of each). UAT ground stations can support traffic information service — broadcast (TIS-B) through transmission of individual ADS-B messages in the ADS-B segment of the UAT frame.

UAT ground uplink message. A message broadcasted by ground stations, within the ground segment of the UAT frame, to convey flight information such as text and graphical weather data, advisories, and other aeronautical information, to aircraft that are in the service volume of the ground station (see Annex 10, Volume III, Chapter 12, 12.4.4.2, for further details).

Universal access transceiver (UAT). A broadcast data link operating on 978 MHz, with a modulation rate of 1.041667 Mbps.

ACRONYMS, ABBREVIATIONS AND SYMBOLS

ACAS	Airborne collision avoidance system
ACM	Airborne conflict management
ADS-B	Automatic dependent surveillance — broadcast
ADS-R	ADS-B rebroadcast
A/G	Air/ground
AGL	Above ground level
AMSL	Above mean sea level
AP	Address party
APDU	Application protocol data unit
ARNS	Aeronautical radio navigation service
AS	Airspeed
ASOP	Acquire stable operating point
ATC	Air traffic control
ATCS	Air traffic control services
ATIS	Automatic terminal information service
AUX SV	Auxiliary state vector
A/V	Aircraft/vehicle
AWG	Arbitrary waveform generator
BER	Bit error rate
BSOP	Break stable operating point
BW	Bandwidth
CC	Capability class
CDTI	Cockpit display of traffic information
CSID	Call sign identification
CW	Continuous wave
dB	Decibel
dBm	Decibel with respect to 1 milliwatt
DC	Direct current
DCB	Data channel block
DME	Distance measuring equipment
DPSK	Differential phase shift keying
D/U	Desired to undesired
EIRP	Equivalent isotropically radiated power
EPU	Estimated position uncertainty
ERP	Effective radiated power
ES	Extended squitter
EUROCONTROL	European Organization for the Safety of Air Navigation
E/W	East/west
FAA	Federal Aviation Administration (United States)
F/B	Front to back
FCU	Flight control unit

FDE	Fault detection and exclusion
FEC	Forward error correction
FIS-B	Flight information service — broadcast
FMS	Flight management system
f0	Nominal or centre frequency
GBAS	Ground-based augmentation system
GF	Galois Field
GNSS	Global navigation satellite system
GPS	Global positioning system
GS	Ground speed
GVA	Geometric vertical accuracy
HDR	Header
HFOM	Horizontal figure of merit
HIL	Horizontal integrity limit
HPL	Horizontal protection limit
ICAO	International Civil Aviation Organization
INR	Interference-to-noise ratio
INS	Inertial navigation system
ITU	International Telecommunication Union
JSC	Joint Spectrum Centre of the Defense Information Systems Agency
JTIDS	Joint tactical information distribution system (also known as Link 16 or MIDS)
LOS	Line-of-sight
LSB	Least significant bit
MASPS	Minimum aviation system performance standards
MAUS	Multi aircraft simulation
Mbps	Million bits per second
MCP	Mode control panel
MDB	Message data block
MDBS	Message data block selection
MIDS	Multifunctional information distribution systems (also known as Link 16 or JTIDS)
MOPS	Minimum operational performance standards
ms	Milliseconds
MS	Mode status
MSB	Most significant bit
MSL	Mean sea level
MSO	Message start opportunity
MSR	Message success rate
N/A	Not applicable
NAC_P	Navigation accuracy category — position
NACv	Navigation accuracy category — velocity
NIC	Navigation integrity category
NIC_{BARO}	Navigation integrity category — barometric
NIC_{SUPP}	Navigation integrity category supplement
NM	Nautical mile
NOTAM	Notices to airmen

ns	Nanoseconds
N/S	North/south
OM	Operational mode
PANS-ATM	Procedures for Air Navigation Services — Air Traffic Management
PMP	Power measurement point
POA	Position offset applied
PPM	Parts per million
PPS	Pulse per second
PVT	Position, velocity and time
QFE	Aviation “Q” code for “field elevation”
QNE	Aviation “Q” code for “nautical height” for en route
QNH	Aviation “Q” code for “nautical height”
RA	Resolution advisory
R_C	Radius of containment
RF	Radio frequency
RH	Radio height
RNAV	Area navigation
RNP	Required navigation performance
RS	Reed-Solomon
RTCA	Radio Technical Commission for Aeronautics
SA	Selective availability
SARPs	Standards and Recommended Practices
SBAS	Satellite-based augmentation system
SDA	System design assurance
SER	Symbol error rate
SIL	Source integrity level
SIL_{SUPP}	Source integrity level supplement
SINR	Signal to interference and noise ratio
SLS	Side lobe suppression
SMR	Successful message reception
SNR	Signal-to-noise ratio
SOI	Signal of interest
SSR	Secondary surveillance radar
SV	State vector
TA	Track angle
TACAN	UHF tactical air navigation aid
TA/H	Track angle/heading
TC	Trajectory change
TCR	Trajectory change report
TIS-B	Traffic information service — broadcast
TL	Threshold level
TLAT	Technical Link Assessment Team
TMA	Terminal control area or terminal manoeuvring area
TMSO	Transmit MSO
TOA	Time of applicability
TOMR	Time of message receipt

TOMT	Time of message transmission
TS	Target state
TSDF	Time slot duty factor
TSO	Technical Standard Order
TSR	Target state report
UAT	Universal access transceiver
UMER	Undetected error message rate
UTC	Coordinated Universal Time
VEPU	Vertical estimated position uncertainty
VFOM	Vertical figure of merit
VPL	Vertical protection limit
VSWR	Voltage standing wave ratio
VV	Vertical velocity
VV Src	Vertical velocity source
WGS-84	World Geodetic System —1984
WTC	Wake turbulence category

PART I

DETAILED TECHNICAL SPECIFICATIONS

TABLE OF CONTENTS

Chapter 1

INTRODUCTION

1.1 OBJECTIVE AND SCOPE

The objective of Part I of this manual (in conjunction with the UAT SARPs of Annex 10, Volume III) is to define internationally agreed detailed technical specifications for the UAT system that accomplish the following:

a) establish a basis for RF compatibility of UAT with other systems operating in the 960 MHz to 1 215 MHz frequency band (ACAS, DME, SSR, TACAN, JTIDS/MIDS and GNSS E5/L5);

b) establish a common basis for UAT inter-system interoperability across implementations manufactured and certified in different regions of the world.

This manual alone is not considered adequate for manufacture or certification of UAT equipment and is not a replacement for local certification guidance.

1.2 OUTLINE OF PART I

Part I of this manual contains detailed technical specifications related to the implementation of the Standards and Recommended Practices (SARPs) of Annex 10, Volume III, for the universal access transceiver (UAT).

Chapter 1 presents the objectives and scope of Part I of this manual as well as an outline of its structure.

Chapter 2 contains the specifications for the UAT ADS-B message data blocks and formats.

Chapter 3 contains the specifications for aircraft equipment and the ground transmitters including requirements for processing timing information.

Chapter 4 contains the criteria for successful message reception.

Chapter 5 contains the interface requirements for aircraft equipment.

1.3 RELATED DOCUMENTS

1. Annex 10 — *Aeronautical Telecommunications*, Volume III, — *Digital Data Communication Systems*, Chapter 12 (referenced in Part I, Chapter 1, 1.1 and 1.2 and Part II, Chapter 2, 2.4.2).

2. RTCA DO-178B (EUROCAE ED-12B), *Software Considerations in Airborne Systems and Equipment Certification*, December 1, 1992 (referenced in Part I, Chapter 2, 2.1.5).

3. RTCA DO-189 (EUROCAE ED-54), *Minimum Operational Performance Standards for Airborne Distance Measuring Equipment (DME) Operating within the Radio Frequency Range of 960–1215 MHz,* September 20, 1985 (referenced in Part II, Appendix G).

4. RTCA DO-242A, *Minimum Aviation System Performance Standards (MASPS) for Automatic Dependent Surveillance — Broadcast*, June 25, 2002 (referenced in Part I, Chapter 2, 2.1.5, and Part II, Chapter 1, 1.3 and Appendices H and K).

5. RTCA DO-254 (EUROCAE ED-80), *Design Assurance Guidance for Airborne Electronic Hardware*, April 19, 2000 (referenced in Part I, Chapter 2, 2.1.5).

6. RTCA DO-260B (EUROCAE ED-102A), *Minimum Operational Performance Standards for 1090 MHz Extended Squitter Automatic Dependent Surveillance — Broadcast (ADS-B) and Traffic Information Services — Broadcast (TIS-B)*, December 2, 2009 (referenced in Part II, Appendix K).

7. RTCA DO-282B, *Minimum Operational Performance Standards for Universal Access Transceiver (UAT) Automatic Dependent Surveillance — Broadcast*, December 2, 2009 (referenced throughout this manual).

8. RTCA DO-289, *Minimum Aviation System Performance Standards for Aircraft Surveillance Applications (ASA MASPS)*, December 9, 2003 (referenced in Part II, Appendix K).

9. RTCA DO-303 (EUROCAE ED-126), *Safety, Performance and Interoperability Requirements for the ADS-B Non-Radar Airspace (NRA) Application*, December 13, 2006 (referenced in Part II, Appendix K).

10. RTCA DO-312 (EUROCAE ED-159), *Safety, Performance and Interoperability Requirements for the In-Trail Procedure in Oceanic Airspace (ATSA-ITP) Application*, June 19, 2008 (referenced in Part II, Appendix K).

11. RTCA DO-314 (EUROCAE ED-160), *Safety, Performance and Interoperability Requirements for the Enhanced Visual Separation on Approach (ATSA-VSA) Application*, December 16, 2008 (referenced in Part II, Appendix K).

12. RTCA DO-317, *Minimum Operational Performance Standards for the Aircraft Surveillance Application System (ASAS)*, April 14, 2009 (referenced in Part II, Appendix K).

13. RTCA DO-318 (EUROCAE ED-161), *Safety, Performance and Interoperability Requirements for Enhanced Air Traffic Services in Radar Controlled Areas Using ADS-B Surveillance (ADS-B-RAD)*, September 9, 2009 (referenced in the Foreword and in Part II, Appendix K).

14. AC 23.1309-1D, AC 25.1309-1A, AC 27-1B and AC 29-2C (Referenced in Part I, Chapter 2, 2.1.5).

Chapter 2

UAT MESSAGE DATA BLOCKS

Note.— The term “message” specifically refers to an actual UAT transmission. UAT messages are one of two general types: a) UAT ADS-B messages; or b) UAT ground uplink messages. Additionally, UAT ADS-B messages can be in one of two fixed-length forms referred to as the “basic” or “long” format, depending on the amount of ADS-B information to be transmitted.

2.1 UAT ADS-B MESSAGE DATA BLOCK

Note.— ADS-B information transmitted in UAT ADS-B messages is referred to as the “message data block”. Message data blocks are composed of combinations of data elements that result in several message data block types available for UAT ADS-B messages as shown in Tables I-2-1 and I-2-2. Figure I-2-1 shows the relationship of the message data block within a UAT ADS-B message to the entire UAT ADS-B message.

	SYNC	Message data block	FEC PARITY
Bit intervals	36	144/272	96/112

Time →

Figure I-2-1. UAT ADS-B message components

2.1.1 Message data block elements

The UAT ADS-B message data block (MDB) shall be organized into message data block elements as shown in Table I-2-1.

Note.— These elements contain the individual message fields (e.g. latitude, altitude) that correspond to the various report elements issued by a UAT receiving subsystem to an ADS-B application.

2.1.2 Message data block type

The UAT ADS-B message shall contain a “message data block type code” encoded in the first 5 bits of the message data block.

Note.— The message data block type code allows the receiver to interpret the contents of the UAT ADS-B message data block as per the definitions contained in 2.1.1 through 2.1.5.7.

Table I-2-1. UAT ADS-B message data block elements

Message data block element	*# of bytes*	*Applicable ADS-B report*	*Reference*
HEADER (HDR)	4	All	2.1.5.1
STATE VECTOR (SV)	13	State vector (Note 1)	2.1.5.2 2.1.5.3
MODE STATUS (MS)	12	Mode status	2.1.5.4
AUXILIARY STATE VECTOR (AUX SV)	5	State vector, air reference velocity	2.1.5.5
TARGET STATE (TS)	5	Target state (Note 2)	2.1.5.6 2.1.5.6.3
TRAJECTORY CHANGE + 0 (TC+0)	12	Trajectory change	2.1.5.7
TRAJECTORY CHANGE + 1 (TC+1)	12	Trajectory change	2.1.5.7

Notes.—

1. *There are two variants of the STATE VECTOR element. Section 2.1.5.2 is specific to ADS-B and Section 2.1.5.3 relates to those specific differences particular to TIS-B.*

2. *There are two variants of the target state element. Section 2.1.5.6 is used with message data block type codes 3 and 4. Section 2.1.5.6.3 describes the target state element for message data block type code 6. They are different only in their position in the total message data block.*

2.1.3 ADS-B message data block composition by message data block type code

The assignment of message data block elements of Table I-2-1 to each message data block type code shall be as defined in Table I-2-2.

2.1.4 General message data block encoding rules

2.1.4.1 Message data block transmission order

The UAT ADS-B message data block shall be transmitted in byte order with byte #1 first. Within each byte, bits shall be transmitted in order with bit #1 transmitted first. Bit-level definitions of the message data block are provided in 2.1.5 through 2.1.5.7.

2.1.4.2 Truncation of data into message data block fields

When converting raw data with more resolution than that required by a message data block field, the accuracy of the data shall be maintained such that it is not worse than ±½ LSB where the LSB is that of the message data block field.

Table I-2-2. Composition of UAT ADS-B message data block

MDB type code (HDR byte 1, bits 1–5)	*UAT ADS-B message data block byte number*				
	1 4	5 17	18 24	25 29	30 34
0 (Note 1)	HDR	SV	Reserved Note 2	Byte 19–34 not present in type 0	
1	HDR	SV	MS		AUX SV
2	HDR	SV	Reserved (Note 2)		AUX SV
3	HDR	SV	MS		TS
4	HDR	SV	Reserved for TC+0 (Note 2)		TS
5	HDR	SV	Reserved for TC+1 (Note 2)		AUX SV
6	HDR	SV	Reserved (Note 2)	TS	AUX SV
7	HDR	SV	Reserved (Note 3)		
8	HDR	SV			
9	HDR	SV			
10	HDR	SV			
11 through 29	HDR	Reserved (Note 2)			
30, 31	HDR	Reserved for developmental use (Note 4)			

Notes.—

1. *Message data block type code 0 indicates a basic UAT ADS-B MESSAGE; byte 18 is reserved for future definition.*
2. *Not defined in this edition of the manual. Reserved for definition in future editions.*
3. *Future message data block type codes 7–10 are specified to contain both header and state vector information. Thus UAT equipment developed in conformance with this manual will be able to decode and use this portion of a type 7–10 message.*
4. *Message data block type codes 30 and 31 are intended for developmental use, such as to support on-air flight testing of new message data block types, prior to their adoption in future editions of this manual. These message data block type codes should be ignored by operational equipment.*
5. *UAT equipment will transmit messages containing different message data block type codes on a regularly scheduled basis. This message transmission schedule is essential to ensure that required UAT ADS-B message fields are transmitted at an appropriate rate. Part II, Chapter 3, 3.1.1, contains guidance on the scheduling of UAT transmissions.*

2.1.5 Message data block contents

2.1.5.1 HEADER element

Format for the HEADER element is defined in Table I-2-3. This encoding shall apply to UAT ADS-B messages with MESSAGE DATA BLOCK TYPE CODES of “0” through “31.” Each of the fields shown is defined in 2.1.5.1.1 through 2.1.5.1.3.6.

Table I-2-3. Encoding of the HEADER element into the UAT ADS-B message data block

MDB byte #	*Bit 1*	*Bit 2*	*Bit 3*	*Bit 4*	*Bit 5*	*Bit 6*	*Bit 7*	*Bit 8*
1	(MSB)		**MDB TYPE CODE**		(LSB)		**ADDRESS QUALIFIER**	
2	(MSB)A1	A2	A3	. . .				
3				**ADDRESS**				
4					. . .	A22	A23	A24(LSB)

.

.

2.1.5.1.1 *“MESSAGE DATA BLOCK TYPE CODE” field encoding*

Definition of the “MESSAGE DATA BLOCK TYPE CODE” field encoding that shall be used for all UAT ADS-B messages is provided in Table I-2-2.

Note.— The “MESSAGE DATA BLOCK TYPE CODE” field is a 5-bit (bit 1 of byte 1 through bit 5 of byte 1) field used to identify the message data block for decoding by the receiver.

2.1.5.1.2 *“ADDRESS QUALIFIER” field encoding*

Definition of the “ADDRESS QUALIFIER” field encoding that shall be used for all UAT ADS-B messages is provided in Table I-2-4.

Note.— The “ADDRESS QUALIFIER” field is a 3-bit (bit 6 of byte 1 through bit 8 of byte 1) field used to indicate what the 24-bit “ADDRESS” field represents.

2.1.5.1.3 *“ADDRESS” field encoding*

The meaning of the “ADDRESS” field shall depend on the “ADDRESS QUALIFIER” field as described in 2.1.5.1.3.1 through 2.1.5.1.3.6.

Note.— The “ADDRESS” field is a 24-bit (bit 1 of byte 2 through bit 8 of byte 4) field used in conjunction with the “ADDRESS QUALIFIER” field to identify the participant.

Table I-2-4. “ADDRESS QUALIFIER” encoding

Address qualifier (binary)			*Address qualifier (decimal)*	*Address type*	*Reference*
Bit 6	*Bit 7*	*Bit 8*			
0	0	0	0	ICAO 24-bit aircraft address of the aircraft broadcasting the UAT ADS-B message	2.1.5.1.3.1
0	0	1	1	Reserved for national use	2.1.5.1.3.2
0	1	0	2	ICAO 24-bit aircraft address being broadcast in a UAT ADS-B message by a ground station (TIS-B or ADS-R)	2.1.5.1.3.3
0	1	1	3	Address other than ICAO 24-bit aircraft address being broadcast in a UAT ADS-B message by a ground station (TIS-B)	2.1.5.1.3.4
1	0	0	4	Vehicle address	2.1.5.1.3.5
1	0	1	5	Fixed ADS-B beacon address	2.1.5.1.3.6
1	1	0	6	ADS-R target with non-ICAO address	2.1.5.1.3.7
1	1	1	7	Reserved	

Note.— Address qualifier value 7 is reserved for future definition.

2.1.5.1.3.1 ICAO 24-bit aircraft address of transmitting aircraft

An “ADDRESS QUALIFIER” value of ZERO (binary 000) shall indicate that the message is a UAT ADS-B message from an aircraft and that the “ADDRESS” field contains the ICAO 24-bit aircraft address that has been assigned to that particular aircraft. The ICAO aircraft address shall be stored (or “latched”) in the UAT transmitting subsystem upon power up. When using an “ADDRESS QUALIFIER” value of ZERO (binary 000), the UAT ADS-B transmitting subsystem shall not transmit UAT ADS-B messages and shall declare a device failure in the event that its own ICAO 24-bit aircraft address is unavailable or invalid, including addresses set to all “ZEROs” or all “ONEs.”

*Note.— The worldwide scheme for the allocation, assignment and application of the ICAO 24-bit aircraft addresses is contained in Annex 10 to the Convention on International Civil Aviation (*Aeronautical Telecommunications*), Volume III, Part I, Chapter 9.*

2.1.5.1.3.2 Reserved for national use

An “ADDRESS QUALIFIER” value of ONE (binary 001) is reserved for national use.

Note.— Caution should be exercised since the use of such a value could indicate that the “ADDRESS” field may hold a self-assigned temporary 24-bit address of the transmitting aircraft, rather than the ICAO 24-bit aircraft address.

2.1.5.1.3.3 ICAO 24-bit aircraft address of TIS-B target aircraft

An “ADDRESS QUALIFIER” value of TWO (binary 010) shall be used by a UAT ground station providing TIS-B or ADS-R uplinks in the UAT ADS-B message format to indicate that the message is for a TIS-B or ADS-R target and the “ADDRESS” field holds the ICAO 24-bit aircraft address that has been assigned to the target aircraft being described in the message.

Note.— The worldwide scheme for the allocation, assignment and application of the ICAO 24-bit aircraft addresses is contained in Annex 10, Volume III, Part I, Chapter 9.

2.1.5.1.3.4 TIS-B track file identifier

An “ADDRESS QUALIFIER” value THREE (binary 011) shall be used by a UAT ground station providing TIS-B in the UAT ADS-B message format to indicate that the message has been generated by a ground station for a TIS-B target and that the “ADDRESS” field holds a 24-bit TIS-B track file identifier by which the TIS-B data source identifies the target aircraft being described in the message.

Note.— Track file identifiers for those TIS-B targets for which the ICAO 24-bit aircraft address is unknown are assigned on a national basis.

2.1.5.1.3.5 Vehicle address

An “ADDRESS QUALIFIER” value of FOUR (binary 100) shall be used by the UAT transmitting subsystem of a vehicle to indicate that the “ADDRESS” field holds a 24-bit address of a vehicle authorized to transmit UAT ADS-B messages.

Note.— UAT ADS-B vehicle addresses are assigned on a national basis. It is recommended that a State assign 24-bit addresses to vehicles from its allocated address block.

2.1.5.1.3.6 Fixed ADS-B beacon address

An “ADDRESS QUALIFIER” value of FIVE (binary 101) shall be used to indicate that the “ADDRESS” field holds a 24-bit address assigned to a fixed UAT ADS-B beacon or “parrot.”

Note.— UAT ADS-B beacon addresses are assigned on a national basis. It is recommended that a State assign 24-bit addresses to UAT ADS-B beacons from its allocated address block.

2.1.5.1.3.7 ADS-R target with non-ICAO address

An “ADDRESS QUALIFIER” value of SIX (binary 110) shall be used to indicate that the “ADDRESS” field holds the address of an ADS-R target with a non-ICAO address (e.g. a ground vehicle transmitting on a different ADS-B data ink).

2.1.5.2 STATE VECTOR element for ADS-B
(Address qualifiers of 0, 1, 4 and 5)

The format for the STATE VECTOR element shall be as defined in Table I-2-5. This encoding shall apply to UAT ADS-B messages with MESSAGE DATA BLOCK TYPE CODES of “0” through “10,” when the ADDRESS QUALIFIER value is “0,” “1,” “4” or “5.”

Note.— Each of the fields shown is defined in 2.1.5.2.1 through 2.1.5.2.9.

Table I-2-5. Format of STATE VECTOR element

MDB byte #	*Bit 1*	*Bit 2*	*Bit 3*	*Bit 4*	*Bit 5*	*Bit 6*	*Bit 7*	*Bit 8*
5	(MSB)							
6					**LATITUDE** (WGS-84)			
7							(LSB)	(MSB)
8								
9					**LONGITUDE** (WGS-84)			
10							(LSB)	Altitude type
11	(MSB)				**ALTITUDE**			
12				(LSB)	(MSB)	**NIC**		(LSB)
13	(MSB)	**A/G STATE**	**Reserved**					
14					**HORIZONTAL VELOCITY**			
15								
16					**VERTICAL VELOCITY** or **A/V SIZE**			
17					**UTC**	**UPLINK FEEDBACK**		

.
.

When more than one position source is provided to the ADS-B transmitting subsystem, the transmitter shall select a single source to provide position, horizontal velocity, and their associated quality metrics. Heading used to populate the track angle/heading field on the surface may be supplied by a different source than that which supplies horizontal position and ground speed. When selecting among sources with equal source integrity level (SIL) values, the source with the smallest radius of containment shall be selected.

Note 1.— The source selection logic should be designed to prevent the selection from alternating between valid sources. One acceptable way to ensure this is to allow the source selection to switch sources only after an alternate source has consistently exceeded the performance of the currently selected source for several seconds.

Note 2.— Source selection logic may include criteria specific to the sources available on the aircraft.

2.1.5.2.1 *"LATITUDE" and "LONGITUDE" field encoding*

2.1.5.2.1.1 The "LATITUDE" field is a 23-bit (bit 1 of byte 5 through bit 7 of byte 7) field used to encode the latitude provided to the UAT ADS-B transmitting subsystem in conformance with WGS-84 and shall be encoded as indicated in Table I-2-6.

2.1.5.2.1.2 The "LONGITUDE" field is a 24-bit (bit 8 of byte 7 through bit 7 of byte 10) field used to encode the longitude provided to the UAT ADS-B transmitting subsystem in conformance with WGS-84 and shall be encoded as indicated in Table I-2-6.

Table I-2-6. Angular weighted binary encoding of latitude and longitude

Quadrant	*“LATITUDE” or “LONGITUDE” bits*		*Meaning* $LSB = \frac{360}{2^{24}} = 2.1457672 \times 10^{-5\circ}$	
	MSB	*LSB*	*Latitude*	*Longitude*
	0000 0000 0000 0000 0000 0000		ZERO degrees (equator)	ZERO degrees (prime meridian)
First	0000 0000 0000 0000 0000 0001		LSB degrees north	LSB degrees east
quadrant	**…**		**…**	**…**
	0011 1111 1111 1111 1111 1111		(90-LSB) degrees north	(90-LSB) degrees east
	0100 0000 0000 0000 0000 0000		90 degrees (North Pole)	90 degrees east
Second	0100 0000 0000 0000 0000 0001		<Illegal values>	(90+LSB) degrees east
quadrant	**…**		<Illegal values>	**…**
	0111 1111 1111 1111 1111 1111		<Illegal values>	(180-LSB) degrees east
	1000 0000 0000 0000 0000 0000		<Illegal values>	180 degrees east or west
Third	1000 0000 0000 0000 0000 0001		<Illegal values>	(180-LSB) degrees west
quadrant	**…**		<Illegal values>	**…**
	1011 1111 1111 1111 1111 1111		<Illegal values>	(90+LSB) degrees west
	1100 0000 0000 0000 0000 0000		90 degrees (South Pole)	90 degrees west
Fourth	1100 0000 0000 0000 0000 0001		(90-LSB) degrees south	(90-LSB) degrees west
quadrant	**…**		**…**	**…**
	1111 1111 1111 1111 1111 1111		LSB degrees south	LSB degrees west

Note.— The most significant bit (MSB) of the angular weighted binary “LATITUDE” is omitted from the transmitted message. This is because all valid latitudes, other than the latitude of the North Pole (exactly 90 degrees north), have the same value in their two most significant bits. The application using the ADS-B reports has the responsibility to differentiate the North and South Poles.

2.1.5.2.1.3 The encoding of ALL ZEROs in the “LATITUDE” and “LONGITUDE” and “NIC” (2.1.5.2.4) fields shall indicate that latitude/longitude information is “unavailable.”

Note 1.— Figure I-2-2 contains the angular weighted binary encoding of latitude and longitude.

Note 2.— Since the encoding of ALL ZEROs is a valid location on the Earth, UAT receiving subsystems will interpret this as latitude/longitude information “unavailable” only if the NIC field is also set to ZERO.

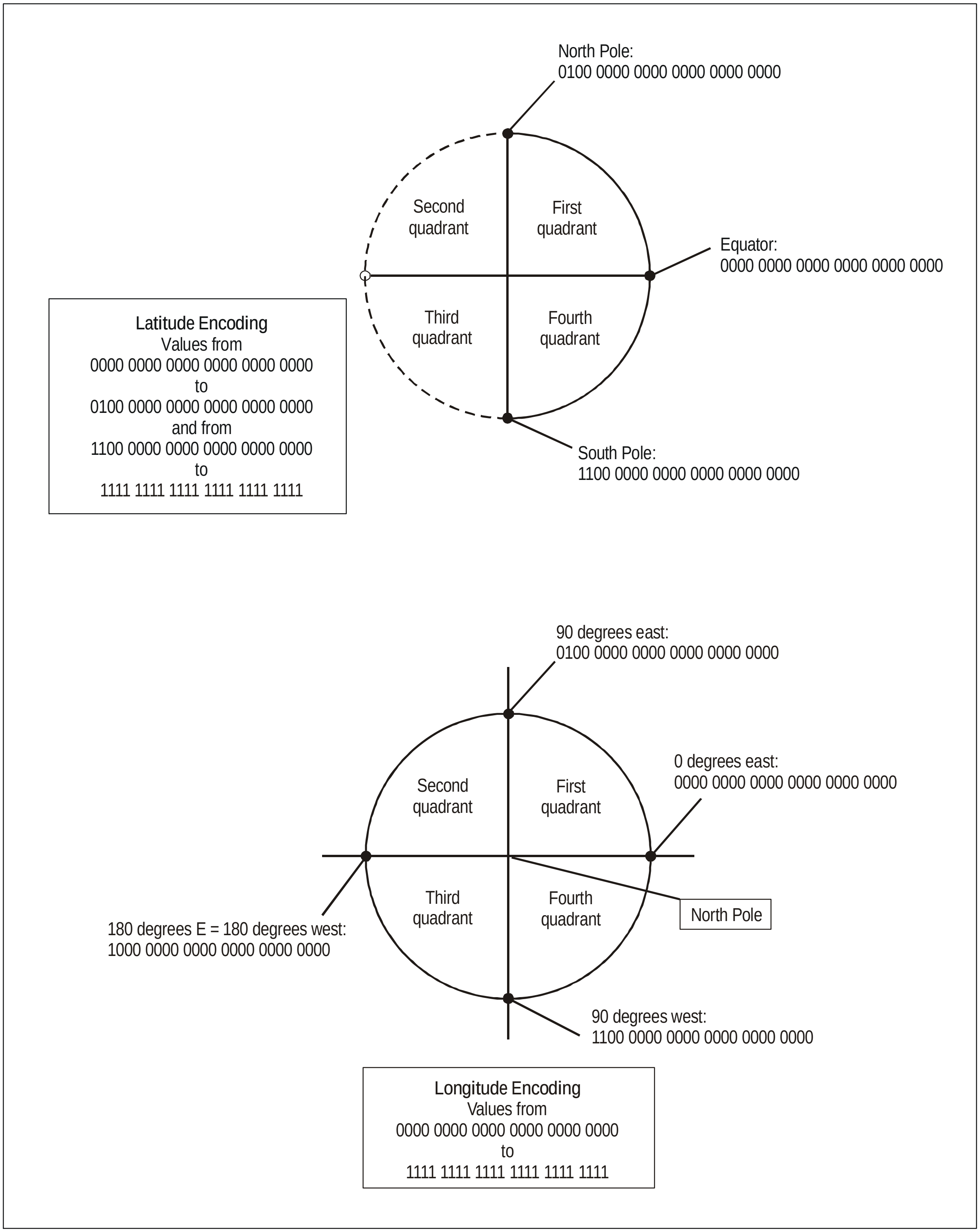

Figure I-2-2. Angular weighted binary encoding of latitude and longitude

2.1.5.2.2 *"ALTITUDE TYPE" field encoding*

2.1.5.2.2.1 The "ALTITUDE TYPE" field is a 1-bit (bit 8 of byte 10) field used to identify the source of information in the "ALTITUDE" field and shall be encoded as reflected in Table I-2-7.

Table I-2-7. "ALTITUDE TYPE" encoding

Altitude type	*"ALTITUDE" field (2.1.5.2.3)*	*"SECONDARY ALTITUDE" field (2.1.5.5.1)*
0	Pressure altitude	Geometric altitude
1	Geometric altitude	Pressure altitude

Note.— "Pressure altitude" refers to "barometric pressure altitude" relative to a standard atmosphere at a standard pressure of 1 013.25 hectopascals (29.92 inches of mercury) and specifically does not refer to "barometric corrected altitude".

2.1.5.2.2.2 A means shall be provided to operationally inhibit the broadcast of pressure-altitude information, making it unavailable for transmission.

2.1.5.2.2.3 A means shall be provided to operationally select the preferred ALTITUDE TYPE that is reported if more than one ALTITUDE TYPE is available. If only one ALTITUDE TYPE is available, then that altitude shall be indicated in the "ALTITUDE TYPE" field.

Note.— The means to operationally inhibit the broadcast of pressure-altitude information can be used at the request of ATC, or when altitude is determined to be invalid by the pilot.

2.1.5.2.3 *"ALTITUDE" field encoding*

The "ALTITUDE" field is a 12-bit (bit 1 of byte 11 through bit 4 of byte 12) field used to encode the altitude of the UAT ADS-B transmitting subsystem and shall be encoded as indicated in Table I-2-8.

Table I-2-8. "ALTITUDE" encoding

Coding $_{MSB}$(binary)$_{LSB}$	*Coding (decimal)*	*Meaning*
0000 0000 0000	0	Altitude information unavailable
0000 0000 0001	1	Altitude = –1 000 ft
0000 0000 0010	2	Altitude = –975 ft
...	...	...
0000 0010 1000	40	Altitude = –25 ft
0000 0010 1001	41	Altitude = ZERO ft
0000 0010 1010	42	Altitude = 25 ft
...	...	...
1111 1111 1110	4094	Altitude = 101 325 ft
1111 1111 1111	4095	Altitude > 101 337.5 ft

2.1.5.2.4 *“NIC” field encoding*

2.1.5.2.4.1 NIC” field encoding under nominal conditions (in the absence of a fault detection and exclusion condition)

The navigation integrity category (“NIC”) field is a 4-bit (bits 5 through 8 of byte 12) field used to allow surveillance applications to determine whether the reported position has an acceptable integrity containment region for the intended use and shall be encoded as indicated in Table I-2-9. The NIC integrity containment region is described horizontally using the R_C parameter. The value of the NIC parameter shall be the highest value in Table I-2-9 consistent with the NIC input with the exception that if the NIC input is consistent with a value of “9,” “10” or “11” and the ADS-B equipment is not UTC-coupled and therefore does not support the timing requirements for the precision condition (Chapter 3, 3.1.3.2), a NIC value of “8” shall be transmitted. The NIC supplement flag augments the existing NIC encoding to provide a higher degree of quantification of containment regions.

Table I-2-9. “NIC” encoding

NIC (binary)	*NIC (decimal)*	*NIC supplement flag*	*Horizontal containment bounds*
MSB … LSB			
0000	0		R_C unknown
0001	1		$R_C < 37.04$ km (20 NM)
0010	2		$R_C < 14.816$ km (8 NM)
0011	3		$R_C < 7.408$ km (4 NM)
0100	4		$R_C < 3.704$ km (2 NM)
0101	5		$R_C < 1852$ m (1 NM)
0110	6	0	$R_C < 1111.2$ m (0.6 NM)
		1	$R_C < 555.6$ m (0.3 NM)
0111	7		$R_C < 370.4$ m (0.2 NM)
1000	8		$R_C < 185.2$ m (0.1 NM)
1001	9		$R_C < 75$ m
1010	10		$R_C < 25$ m
1011	11		$R_C < 7.5$ m
1100	12		Reserved
1101	13		Reserved
1110	14		Reserved
1111	15		Reserved

Note.— The “NIC” field is closely associated with the “SIL” field (defined in 2.1.5.4.8).

2.1.5.2.4.2 “NIC” encoding during fault detection and exclusion condition

Under normal operating conditions, the radius of containment (R_C) can be directly determined from horizontal protection limit (HPL) or horizontal integrity limit (HIL) inputs to the ADS-B transmitting subsystem from the GPS/GNSS receiver. However, there are times when the fault detection and exclusion (FDE) function of the GPS/GNSS receiver has detected a satellite failure but has not excluded the satellite from the navigation data solution. For the purposes of this document, the condition just described will be referred to as an “FDE fault” which is typically annunciated by the GPS/GNSS receiver by an appropriate method. For example, ARINC 743A compliant GPS/GNSS receivers will set label “130” bit 11 to ONE (1) to indicate the “FDE fault.” If an “FDE fault” does not exist, then bit 11 is set to ZERO (0). Of import is the situation that even though an “FDE fault” indication has been set, the GPS/GNSS typically continues to provide HPL or HIL data as well as latitude, longitude and velocity data while continuing to declare them to be valid on the interface. As the “FDE fault” condition represents a condition where the position and accuracy data cannot be guaranteed by the GPS/GNSS receiver, the ADS-B transmitting subsystem shall apply the following process upon detection of the “FDE fault” annunciation:

a) The NIC field shall be set to ZERO.

b) Valid latitude and longitude position data shall continue to be processed and reported in the state vector element.

c) The NIC supplement field in the mode status element shall be set to ZERO (0).

d) The NAC_P subfield in the mode status element shall be set to ZERO (0).

e) The NAC_V subfield in the mode status element shall be set to ZERO (0).

Note 1.— Factors such as surface multipath have been observed to cause intermittent annunciation of “FDE faults” by the GPS/GNSS receiver. Such occurrences will result in the intermittent settings of the subfields addressed in subparagraphs a), c), d) and e) above. These intermittent conditions should be taken into account by ADS-B and air traffic services that are using the data provided by the ADS-B transmitting subsystems.

Note 2.— Although these requirements do not require HPL limiting, it is expected that some regulators will only accept installations that limit HPL. This may be standardized accordingly in future versions of this manual.

2.1.5.2.5 *“A/G STATE” field encoding*

The air/ground state (“A/G STATE”) field is a 2-bit (bits 1 and 2 of byte 13) field that indicates the format used for representing horizontal velocity. The value of this field determines the encoding of the “HORIZONTAL VELOCITY” field. The “A/G STATE” shall be composed of two (2) 1-bit fields used as follows (see also Table I-2-10):

a) The vertical status bit (bit 1 of byte 13) shall be used to reflect the airborne or on-ground condition as determined in 2.1.5.2.5.1.

b) The subsonic/supersonic bit (bit 2 of byte 13) shall be used to indicate the scale factor for the velocity information. The subsonic/supersonic bit (bit 2 of byte 13) shall only be set to ONE (1) if either the east–west velocity or the north–south velocity exceeds 1 022 knots. The subsonic/supersonic bit (bit 2 of byte 13) shall be reset to ZERO (0) if the east–west and the north–south velocities drop below 1 000 knots.

Table I-2-10. “A/G STATE” field encoding

Ownship conditions	*“A/G STATE” field encoding*			*Resulting “HORIZONTAL VELOCITY” subfield formats*	
	MSB	*LSB*			
	Vertical status (bit 1 of byte 13)	*Subsonic/ supersonic (bit 2 of byte 13)*	*(decimal)*	*“North velocity or ground speed” subfield meaning*	*“East velocity or track angle/heading” subfield meaning*
AIRBORNE condition Subsonic condition	0	0	0	North velocity (LSB = 1 kt)	East velocity (LSB = 1 kt)
AIRBORNE condition Supersonic condition	0	1	1	North velocity (LSB = 4 kt)	East velocity (LSB = 4 kt)
ON GROUND condition	1	0	2	Ground speed (LSB = 1 kt)	Track/heading
<Reserved>	1	1	3		

2.1.5.2.5.1 Determination of vertical status

The UAT ADS-B message contains information on the vertical status (i.e. AIRBORNE or ON-GROUND condition). The UAT ADS-B transmitting subsystem shall determine its vertical status using the following procedures:

a) If a UAT ADS-B equipped aircraft has means to determine whether it is airborne or on the ground, then such information shall be used to determine the vertical status.

Note.— The information concerning vertical status could, for example, come from a weight-on-wheels or strut switch, etc. Landing gear deployment is not considered a suitable automatic means.

b) If a UAT ADS-B equipped aircraft has no means to determine whether it is airborne or on the ground, and that participant’s emitter category is one of the following, then that participant shall set its vertical status to “AIRBORNE”:

- glider or sailplane
- lighter than air
- parachutist or skydiver
- ultralight, hang glider or paraglider
- unmanned aerial vehicle
- point obstacle (includes tethered balloons)
- cluster obstacle
- line obstacle.

Note 1.— Because of the unique operating capabilities of “lighter-than-air” aircraft, e.g. balloons, an operational “lighter-than-air” aircraft will always report the AIRBORNE condition unless the ON-GROUND condition is specifically declared in compliance with 2.1.5.2.5.1 a).

Note 2.— For the point, cluster and line obstacles, the vertical status reported should be appropriate to the situation. In any case, the altitude is always included in the UAT ADS-B message.

c) If a UAT ADS-B transmitting subsystem participant's emitter category is one of the following, then that participant shall set its vertical status to the "ON-GROUND" condition:

— vehicle — emergency vehicle;
– vehicle — service vehicle.

d) If a UAT ADS-B transmitting subsystem participant is not equipped with means to determine whether it is airborne or on the ground, and that participant's emitter category is "rotorcraft," then that participant shall set its vertical status to "AIRBORNE".

Note.— Because of the unique operating capabilities of rotorcraft, i.e. hover, an operational rotorcraft will always report the AIRBORNE condition unless the ON-GROUND condition is specifically declared in compliance with 2.1.5.2.5.1 a).

e) If a UAT ADS-B transmitting subsystem participant is not equipped with means to determine whether it is airborne or on the surface, and that participant's emitter category is "light aircraft," then that participant shall set its vertical status to "AIRBORNE," unless the participant can alternatively determine that it is on the surface using the following test: if the participant's ground speed (GS) is available and is less than an aircraft-specific threshold level (TL) value, the participant is allowed to set its vertical status to "ON-GROUND". The ground speed threshold level chosen for an aircraft type must reliably indicate "ON-GROUND" conditions.

Note.— The appropriate ground speed threshold level is chosen to provide, except under unusual operating conditions, a reasonable assurance that the participant will not set the AIRBORNE/ON-GROUND condition to "AIRBORNE" while taxiing on the airport and will not give false indications of being in the "ON-GROUND" condition while still "AIRBORNE".

f) If a UAT ADS-B transmitting subsystem participant is not equipped with a means to determine whether it is airborne or on the surface, and that participant's emitter category is not one of those listed in tests 2.1.5.2.5.1 b), c), d) or e) (i.e. the participant emitter category is either: small, large, high-vortex large, heavy, highly manoeuvrable or space/trans-atmospheric), then the following tests will be performed to determine the vertical status:

1) If the UAT ADS-B transmitting subsystem participant's radio height (RH) parameter is available, and RH is less than 50 feet, and at least ground speed (GS) or airspeed (AS) is available, and the available GS is less than 100 knots, or the available AS is less than 100 knots, then that participant shall set its vertical status to "ON-GROUND".

Note.— If all three parameters are available, the vertical status may be determined by the logical "AND" of all three parameters.

2) Otherwise, if radio height (RH) is not available, and if the participant's ground speed (GS) and airspeed (AS) are available, and GS is less than 50 knots and AS is less than 50 knots, then that participant shall set its vertical status to "ON-GROUND".

3) Otherwise, the participant shall set its vertical status to "AIRBORNE".

2.1.5.2.5.2 Validation of vertical status

When an automatic means of determining vertical status indicates the "ON-GROUND" condition, then the following additional tests shall be performed to validate the "ON-GROUND" condition:

a) If one or more of the following parameters is available to the UAT ADS-B transmitting subsystem participant:

– ground speed (GS); or
– airspeed (AS); or
— radio height (RH) from radio altimeter

and of the following parameters that are available:

– GS greater than 100 knots; or
– AS greater than 100 knots; or
– RH greater than 50 feet

then, the participant shall set its vertical status to the “AIRBORNE” condition.

b) Otherwise, the participant shall set its vertical status to the “ON-GROUND” condition.

Rotorcraft are exempted from this requirement because of their ability to hover.

Note 1.— The vertical status can be used by UAT ADS-B transmitting subsystems to select only the TOP antenna when in the ON-GROUND condition. A false indication of the automatic means could therefore impact signal availability. To minimize this possibility, the validation procedure in 2.1.5.2.5.2 a) and b) was established.

Note 2.— For more guidance on validation of on-the-ground status declared by an automatic means, reference Annex 10, Volume IV.

2.1.5.2.6 *“HORIZONTAL VELOCITY” subfields*

The “HORIZONTAL VELOCITY” field shall be composed of two components:

a) The “north velocity or ground speed” component shall be represented by an 11-bit subfield from bit 4 of byte 13 through bit 6 of byte 14.

b) The “east velocity or track/heading” component shall be represented by an 11-bit subfield from bit 7 of byte 14 through bit 1 of byte 16.

Note.— Each component can assume multiple formats depending on the “A/G STATE” field. Paragraphs 2.1.5.2.6.1 through 2.1.5.2.6.4 describe the encoding for each form of each component.

2.1.5.2.6.1 Encoding as “north velocity” form

When the “A/G STATE” field is set to “0,” or “1,” the “north velocity or ground speed” component shall assume the “north velocity” format indicated in Table I-2-11.

Table I-2-11. “North velocity” format

<table>
<tr><th colspan="5">Byte 13</th><th colspan="6">Byte 14</th></tr>
<tr><td>Bit 4</td><td>Bit 5</td><td>Bit 6</td><td>Bit 7</td><td>Bit 8</td><td>Bit 1</td><td>Bit 2</td><td>Bit 3</td><td>Bit 4</td><td>Bit 5</td><td>Bit 6</td></tr>
<tr><td>N/S sign</td><td colspan="10">(MSB) — North velocity magnitude — (LSB)</td></tr>
</table>

The “N/S sign” subfield (bit 4 of byte 13) shall be used to indicate the direction of the north/south velocity vector as shown in Table I-2-12.

Table I-2-12. “North/south sign” encoding

Coding	*Meaning*
0	NORTH
1	SOUTH

The “north velocity magnitude” subfield is a 10-bit (bit 5 of byte 13 through bit 6 of byte 14) subfield that shall be used to report the magnitude of the north/south velocity of the UAT ADS-B transmitting subsystem. The range, resolution and no data encoding of the “north velocity magnitude” subfield shall be as shown in Table I-2-13.

Table I-2-13. “North velocity magnitude” encoding

Coding $_{MSB}$*(binary)*$_{LSB}$	*Coding (decimal)*	*Meaning (subsonic scale) (A/G state = 0)*	*Meaning (supersonic scale) (A/G state = 1)*
00 0000 0000	0	N/S velocity not available	N/S velocity not available
00 0000 0001	1	N/S velocity is ZERO	N/S velocity is ZERO
00 0000 0010	2	N/S velocity = 1 kt	N/S velocity = 4 kt
00 0000 0011	3	N/S velocity = 2 kt	N/S velocity = 8 kt
...	**...**	**...**	**...**
11 1111 1110	1022	N/S velocity = 1 21 kt	N/S velocity = 4 084 kt
11 1111 1111	1023	N/S velocity > 1 021.5 kt	N/S velocity > 4 086 kt

Note.— The encoding represents positive magnitude data only. Direction is given completely by the N/S sign bit.

2.1.5.2.6.2 Encoding as “ground speed” form

When the “A/G STATE” field is set to “2,” the “north velocity or ground speed” component shall assume the “ground speed” format indicated in Table I-2-14.

Table I-2-14. “Ground speed” format

Byte 13					*Byte 14*					
Bit 4	Bit 5	Bit 6	Bit 7	Bit 8	Bit 1	Bit 2	Bit 3	Bit 4	Bit 5	Bit 6
Reserved	(MSB)				**— Ground speed —**					(LSB)

The 1-bit subfield (bit 4 of byte 13) shall be “reserved” and set to ZERO (0).

The “ground speed” subfield is a 10-bit (bit 5 of byte 13 through bit 6 of byte 14) subfield that shall be used to report the ground speed of the UAT ADS-B transmitting subsystem (in knots). The range, resolution and no data encoding of the “ground speed” subfield shall be as shown in Table I-2-15.

Table I-2-15. “Ground speed” encoding

Coding $_{MSB}$*(binary)*$_{LSB}$	*Coding (decimal)*	*Meaning (A/G state = 2)*
00 0000 0000	0	Ground speed information not available
00 0000 0001	1	Ground speed is ZERO
00 0000 0010	2	Ground speed = 1 kt
00 0000 0011	3	Ground speed = 2 kt
…	…	…
11 1111 1110	1022	Ground speed = 1 021 kt
11 1111 1111	1023	Ground speed > 1021.5 kt

2.1.5.2.6.3 Encoding as “east velocity” form

When the “A/G STATE” field is set to “0” or “1,” the “east velocity or track angle/heading” component shall assume the “east velocity” format indicated in Table I-2-16.

Table I-2-16: “East velocity” format

Byte 14		*Byte 15*								*Byte 16*
Bit 7	Bit 8	Bit 1	Bit 2	Bit 3	Bit 4	Bit 5	Bit 6	Bit 7	Bit 8	Bit 1
E/W sign	(MSB)				**— East velocity magnitude —**					(LSB)

The "E/W sign" subfield (bit 7 of byte 14) shall be used to indicate the direction of the east/west velocity vector as shown in Table I-2-17.

Table I-2-17. "East/west sign" encoding

Coding	*Meaning*
0	EAST
1	WEST

The "east velocity magnitude" subfield is a 10-bit (bit 8 of byte 14 through bit 1 of byte 16) subfield that shall be used to report the east/west velocity of the UAT ADS-B transmitting subsystem (in knots). The range, resolution and no data encoding of the "east velocity magnitude" subfield shall be as shown in Table I-2-18.

Table I-2-18. "East velocity magnitude" encoding

Coding $_{MSB}$*(binary)*$_{LSB}$	*Coding (decimal)*	*Meaning (subsonic scale) (A/G state = 0)*	*Meaning (supersonic scale) (A/G state = 1)*
00 0000 0000	0	E/W velocity not available	E/W velocity not available
00 0000 0001	1	E/W velocity is ZERO	E/W velocity is ZERO
00 0000 0010	2	E/W velocity = 1 kt	E/W velocity = 4 kt
00 0000 0011	3	E/W velocity = 2 kt	E/W velocity = 8 kt
...	**...**	**...**	**...**
11 1111 1110	1022	E/W velocity = 1 021 kt	E/W velocity = 4 084 kt
11 1111 1111	1023	E/W velocity > 1021.5 kt	E/W velocity > 4 086 kt

Note.— The encoding represents positive magnitude data only. Direction is given completely by the E/W sign bit.

2.1.5.2.6.4 Encoding as "track angle/heading" form

When the "A/G STATE" field is set to "2" the "east velocity or track angle/heading" component shall assume the "track angle/heading" format indicated in Table I-2-19. Heading shall be encoded if available; if not available track angle shall be encoded.

Table I-2-19. “Track angle/heading” format

Byte 14		*Byte 15*								*Byte 16*
Bit 7	Bit 8	Bit 1	Bit 2	Bit 3	Bit 4	Bit 5	Bit 6	Bit 7	Bit 8	Bit 1
TA/H type		(MSB)				**— Track angle/heading —**				(LSB)

The track angle/heading type (“TA/H type”) is a 2-bit subfield (bit 7 and 8 of byte 14) that shall be used to distinguish track angle from heading as shown in Table I-2-20.

Table I-2-20. “Track angle/heading type” encoding

Coding	*Meaning*
00	Data not available
01	True track angle
10	Magnetic heading
11	True heading

The “track angle/heading” subfield is a 9-bit (bit 1 of byte 15 through bit 1 of byte 16) subfield that shall be used to report the track angle or heading of the ADS-B transmitting subsystem as shown in Table I-2-21.

Table I-2-21. “Track angle/heading” encoding

Coding $_{MSB}$*(binary)*$_{LSB}$	*Coding (decimal)*	*Meaning*
0 0000 0000	0	Track angle/heading is ZERO
0 0000 0001	1	Track angle/heading = 0.703125 degrees
0 0000 0010	2	Track angle/heading = 1.406250 degrees
0 0000 0011	3	Track angle/heading = 2.109375 degrees
...	**...**	**...**
1 1111 1110	510	Track angle/heading = 358.593750 degrees
1 1111 1111	511	Track angle/heading = 359.296875 degrees

2.1.5.2.7 *“VERTICAL VELOCITY or A/V SIZE” field*

2.1.5.2.7.1 Encoding as “vertical velocity” format

When the UAT ADS-B transmitting subsystem is in the AIRBORNE condition, the format for the “VERTICAL VELOCITY or AIRCRAFT/VEHICLE (A/V) SIZE” field shall assume the “vertical velocity” format as shown in Table I-2-22.

Table I-2-22. “Vertical velocity” format

<table>
<tr><th colspan="7"><i>Byte 16</i></th><th colspan="4"><i>Byte 17</i></th></tr>
<tr><td>Bit 2</td><td>Bit 3</td><td>Bit 4</td><td>Bit 5</td><td>Bit 6</td><td>Bit 7</td><td>Bit 8</td><td>Bit 1</td><td>Bit 2</td><td>Bit 3</td><td>Bit 4</td></tr>
<tr><td>VV Src</td><td>VV sign</td><td colspan="9">(MSB) — Vertical rate — (LSB)</td></tr>
</table>

2.1.5.2.7.1.1 “Vertical velocity source” subfield encoding

The vertical velocity source (“VV Src”) subfield is a 1-bit (bit 2 of byte 16) field that shall be used to indicate the source of vertical rate information as defined in Table I-2-23.

Table I-2-23. “Vertical velocity source” encoding

Coding	*Meaning*
0	Vertical rate information from geometric source (GNSS or INS)
1	Vertical rate information from barometric source

Note.— Guidance on selecting the appropriate source of the vertical rate is expected to be provided in future installation guidance materials.

2.1.5.2.7.1.2 “VV sign” subfield encoding

The sign bit for vertical rate (“VV sign”) subfield is a 1-bit (bit 3 of byte 16) field used to indicate the direction of the “vertical rate” subfield and shall be encoded as indicated in Table I-2-24.

Table I-2-24. “Sign bit for vertical rate” encoding

Coding	*Meaning*
0	UP
1	DOWN

2.1.5.2.7.1.3 “Vertical rate” subfield encoding

The “vertical rate” subfield is a 9-bit (bit 4 of byte 16 through bit 4 of byte 17) field used to report the vertical rate (in feet per minute) of the UAT ADS-B transmitting subsystem where the “vertical rate” subfield shall be encoded as shown in Table I-2-25.

Table I-2-25. “Vertical rate” encoding

Coding *$_{MSB}$(binary)$_{LSB}$*	*Coding (decimal)*	*Meaning*
0 0000 0000	0	No vertical rate information available
0 0000 0001	1	Vertical rate is ZERO
0 0000 0010	2	Vertical rate = 64 ft/min
0 0000 0011	3	Vertical rate = 128 ft/min
...	**...**	**...**
1 1111 1110	510	Vertical rate = 32 576 ft/min
1 1111 1111	511	Vertical rate > 32 608 ft/min

Notes.—

1. *The encoding shown represents positive magnitude data only. Direction is given completely by the VV sign subfield.*

2. *For codes “0” and “1,” the VV sign subfield is encoded as ZERO.*

2.1.5.2.7.2 Encoding as “A/V size” format

2.1.5.2.7.2.1 When the UAT ADS-B transmitting subsystem is in the ON-GROUND condition, the “VERTICAL VELOCITY or A/V SIZE” field shall assume the “A/V SIZE” format as shown in Table I-2-26.

Table I-2-26. “Aircraft/vehicle size” format

Byte 16							*Byte 17*			
Bit 2	Bit 3	Bit 4	Bit 5	Bit 6	Bit 7	Bit 8	Bit 1	Bit 2	Bit 3	Bit 4
A/V size				**Res = 0**	**GPS antenna offset**					

2.1.5.2.7.2.2 Once the actual length and width of the A/V has been determined, each A/V shall be assigned the smallest A/V length and width code from Table I-2-27 for which the actual length is less than or equal to the upper bound length for that size code and for which the actual width is less than or equal to the upper bound width for that size code.

2.1.5.2.7.2.3 The “GPS antenna offset” field is a 6-bit field used to alternately define the lateral and longitudinal offset of the GPS antenna from the wing tip and nose of the aircraft respectively. Bit 7 of byte 16 is the “axis” subfield which shall be encoded as ZERO (0) to indicate that the remaining bits of the GPS antenna offset field represent the upper bound of the GPS antenna offset along the lateral (pitch) axis, and encoded as ONE (1) to indicate that the remaining bits of the GPS antenna offset field represent the upper bound of the GPS antenna offset along the longitudinal (roll) axis aft from aircraft nose.

Table I-2-27. “Aircraft/vehicle size” encoding

A/V–L/W code (decimal)	*Length code*			*Width code*	*Upper-bound length and width for each size code*	
	Bit 2	*Bit 3*	*Bit 4*	*Bit 5*	*Length (metres)*	*Width (metres)*
0	0	0	0	0	No data or unknown	
1	0	0	0	1	15	23
2	0	0	1	0	25	28.5
3				1		34
4	0	1	0	0	35	33
5				1		38
6	0	1	1	0	45	39.5
7				1		45
8	1	0	0	0	55	45
9				1		52
10	1	0	1	0	65	59.5
11				1		67
12	1	1	0	0	75	72.5
13				1		80
14	1	1	1	0	85	80
15				1		90

Note.— If the aircraft or vehicle is longer than 85 metres, or wider than 90 metres, use size code 15.

2.1.5.2.7.2.4 When in the ON GROUND condition, the UAT transmitting subsystem shall alternate the transmission of the lateral and longitudinal offsets each second.

2.1.5.2.7.2.4.1 Lateral axis GPS antenna offset. Bit 8 of byte 16 through bit 2 of byte 17 shall be used to encode the lateral distance of the GPS antenna from the longitudinal (roll) axis of the aircraft. Encoding shall be established in accordance with Table I-2-28A. Bits 3 and 4 of byte 17 are reserved in the lateral encoding case and shall be set to ALL ZEROs (0).

2.1.5.2.7.2.4.2 Longitudinal axis GPS antenna offset. Bit 8 of byte 16 through bit 4 of byte 17 shall be used to encode the longitudinal distance of the GPS antenna from the nose of the aircraft. Encoding shall be established in accordance with Table I-2-28B. If the antenna offset is compensated by the sensor to be the position of the ADS-B participant’s ADS-B position reference point (RTCA DO-242A, §3.4.4.9.7), then the encoding is set to binary “00001” in accordance with Table I-2-28B.

Table I-2-28A. Lateral axis GPS antenna offset encoding

Byte 16/Byte 17			*Upper bound of the GPS antenna offset along lateral (pitch) axis left or right of longitudinal (roll) axis*	
Bit 8	*Bit 1*	*Bit 2*		
0 = left *1 = right*	*Encoding*			
	Bit 1	*Bit 0*	*Direction*	*(metres)*
0	0	0	LEFT	NO DATA
	0	1		2
	1	0		4
	1	1		6
1	0	0	RIGHT	0
	0	1		2
	1	0		4
	1	1		6

Notes.—

1. *Left means toward the left wing tip moving from the longitudinal centre line of the aircraft.*

2. *Right means toward the right wing tip moving from the longitudinal centre line of the aircraft.*

3. *Maximum distance left or right of aircraft longitudinal (roll) axis is 6 metres or 19.685 feet. If the distance is greater than 6 metres, then the encoding should be set to 6 metres.*

4. *The "NO DATA" case is indicated by encoding of "000" as above, while the "ZERO" offset case is represented by encoding of "100" as above.*

Table I-2-28B. Longitudinal axis GPS antenna offset encoding

Byte 16/Byte 17					*Upper bound of the GPS antenna offset along longitudinal (roll) axis aft from aircraft nose*
Bit 8	*Bit 1*	*Bit 2*	*Bit 3*	*Bit 4*	
Encoding					
Bit 4	*Bit 3*	*Bit 2*	*Bit 1*	*Bit 0*	*(meters)*
0	0	0	0	0	NO DATA
0	0	0	0	1	Position offset Applied by Sensor
0	0	0	1	0	2
0	0	0	1	1	4
0	0	1	0	0	6
*	*	*	*	*	***
*	*	*	*	*	***
*	*	*	*	*	***
1	1	1	1	1	60

Notes.—

1. *Maximum distance aft from aircraft nose is 60 metres or 196.85 feet. If the distance is greater than 60 metres, then the encoding should be set to 60 metres.*
2. *The accuracy requirement is assumed to be better than 2 metres, consistent with the data resolution.*

2.1.5.2.8 *"UTC" field encoding*

The "UTC" field is a 1-bit field (bit 5 of byte 17) that indicates whether the UAT ADS-B transmitting subsystem is in the "UTC-coupled" condition or the "non-UTC-coupled" condition (3.1.1) and shall be encoded as indicated in Table I-2-29A.

Table I-2-29A. "UTC" encoding

Coding	*Meaning*
0	Non-UTC-coupled condition
1	UTC-coupled condition

2.1.5.2.9 *"Uplink feedback" encoding*

2.1.5.2.9.1 The "uplink feedback" field is a 3-bit field (bits 6 through 8 of byte 17) that shall be transmitted whenever the "ADDRESS QUALIFIER" field is set to "0" or "1." This field reports on the number of successful ground uplink messages that were successfully received on a particular data channel (see below) in the previous 32 seconds.

2.1.5.2.9.2 The identity of the data channel to be reported on in any given second and the method for determining the success rate shall be based on the prescribed "time slot rotation" as follows:

> The ground stations use the 32 uplink slots in the ground segment (see RTCA DO-282B, §1.3.2) on a rotating basis. A rotating set of time slots is called a data channel. A ground station that is assigned data channel "N" will transmit in time slot "N" in UTC second 0, time slot "N + 1" in second 1 and so on. After reaching time slot 32, it will "wrap around" and resume its rotation in time slot "1" in the following second. During any second in which data channel "N" is scheduled to be transmitted in time slot "1" the "uplink feedback" field contains information on the recent performance of data channel "N," so that the relationship between the UTC second (T) and the data channel (N) being reported on is given by the following:

$$(T + N)\text{mod}32 = 1.$$

In UTC second T, the UAT reports the code for *Score(T)*, which can be defined as follows:

$$Score\,(T) = \sum_{k=1}^{32} S(T - 33 + k, k).$$

The function *S(t,s)* is defined as:

> *S(t,s)* = 1 if there was a successful uplink decode in time slot = s in UTC second t; and
>
> *S(t,s)* = 0 if there was not a successful uplink decode in time slot = s in UTC second t.

For example, in UTC second 3217 the data channel being reported on is #16 and the definition of the score value is:

$$Score\,(3217) = \sum_{k=1}^{32} S(3184 + k, k).$$

Note.— This procedure obviates the need to use extra bits to identify explicitly the data channel to which the feedback pertains. It also ensures that each participant will report on each of the 32 possible data channels once each 32 seconds, thus providing timely feedback.

2.1.5.2.9.3 The format of this field shall be as shown in Table I-2-29B.

2.1.5.2.9.4 Transmit-only equipage classes (B0 through B3) shall set this field to ALL ZEROs.

2.1.5.2.10 *Reserved bits*

Byte 18 is reserved for future use and shall be set to ZERO when the "ADDRESS QUALIFIER" field is set to "0," "1," "4" or "5."

Table I-2-29B. “Uplink feedback” encoding

Feedback code	*Score*
111	32
110	31
101	29 to 30
100	26 to 28
011	22 to 25
010	14 to 21
001	1 to 13
000	0

Notes.—

1. *The score is the number of successful ground uplink messages received on a particular data channel out of a possible 32.*

2. *Uplink feedback code “000” indicates that the score is ZERO if the “UAT IN” capability code (RTCA DO-282B, §2.2.4.5.4.12.1) is set to ONE (UAT receive capable). If the “UAT IN” capability code is set to ZERO (no capability), then the feedback code “000” indicates “no information.”*

2.1.5.3 STATE VECTOR element for TIS-B for address qualifiers of 2 and 3

Format for the STATE VECTOR element used for a TIS-B shall be as defined in Table I-2-30. This encoding shall apply to UAT ADS-B messages with MESSAGE DATA BLOCK TYPE CODES of “0” through “10” only when a TIS-B target is being reported (ADDRESS QUALIFIER value is “2” or “3”).

2.1.5.3.1 *“TIS-B SITE ID” field encoding*

The “TIS-B SITE ID” field shall be a 4-bit (bits 5 through 8 of byte 17) field with the MSB as bit 5 and the LSB as bit 8 and shall be encoded as shown in Table I-2-49.

Notes.—

1. *The “UTC” field shown in Table I-2-5 for the STATE VECTOR element is not provided for TIS-B transmissions. The “UTC-coupled” status of the ground station transmitting TIS-B information is available in the UAT ground uplink message (2.2.1.4).*

2. *The application that uses TIS-B reports is assumed to make appropriate checks for a TIS-B site ID of value ZERO. If the address qualifier indicates that this is a TIS-B message, and the TIS-B site ID indicates a value of ZERO, the UAT receiving subsystem passes through the value of ZERO, and the application should detect an error condition.*

3. *The TIS-B site ID field is used to provide linkage for the latitude and longitude of a ground station, as identified in the ground uplink message. TIS-B messages uplinked by that ground station in the ADS-B segment also contain the same TIS-B site ID field in the UAT ADS-B message format. Providing this latitude and longitude supports a future ranging and TIS-B message validation capability with respect to the ground station.*

Table I-2-30. Format of STATE VECTOR element (for TIS-B)

<table>
<tr><th><i>MDB byte #</i></th><th><i>Bit 1</i></th><th><i>Bit 2</i></th><th><i>Bit 3</i></th><th><i>Bit 4</i></th><th><i>Bit 5</i></th><th><i>Bit 6</i></th><th><i>Bit 7</i></th><th><i>Bit 8</i></th></tr>
<tr><td></td><td colspan="8">.
.
.</td></tr>
<tr><td>5</td><td colspan="8" rowspan="2">LATITUDE (WGS-84)</td></tr>
<tr><td>6</td></tr>
<tr><td>7</td><td colspan="7"></td><td></td></tr>
<tr><td>8</td><td colspan="8" rowspan="2">LONGITUDE (WGS-84)</td></tr>
<tr><td>9</td></tr>
<tr><td>10</td><td colspan="7"></td><td>Altitude type</td></tr>
<tr><td>11</td><td colspan="8">ALTITUDE</td></tr>
<tr><td>12</td><td colspan="4"></td><td colspan="4">NIC</td></tr>
<tr><td>13</td><td colspan="2">A/G STATE</td><td>Reserved</td><td colspan="5"></td></tr>
<tr><td>14</td><td colspan="8" rowspan="2">HORIZONTAL VELOCITY</td></tr>
<tr><td>15</td></tr>
<tr><td>16</td><td></td><td colspan="7">VERTICAL VELOCITY or A/V SIZE</td></tr>
<tr><td>17</td><td colspan="4"></td><td colspan="4">TIS-B SITE ID</td></tr>
<tr><td></td><td colspan="8">.
.
.</td></tr>
</table>

Notes.—

1. *Each of the fields shown is defined in 2.1.5.3.1 and 2.1.5.3.2.*

2. *Design of the TIS-B ground subsystem is in a preliminary phase. The message structure in Table I-2-30 may be changed as this design matures.*

2.1.5.3.2 *Encoding of all other fields*

The encoding of all other fields in the STATE VECTOR element for TIS-B shown in Table I-2-30 shall be consistent with that of 2.1.5.2.1 through 2.1.5.2.7.2.

2.1.5.4 MODE STATUS element

Format for the MODE STATUS element shall be as defined in Table I-2-31. This encoding shall apply to UAT ADS-B messages with MESSAGE DATA BLOCK TYPE CODES of “1” and “3”.

Table I-2-31. Format of MODE STATUS element

MDB byte #	*Bit 1*	*Bit 2*	*Bit 3*	*Bit 4*	*Bit 5*	*Bit 6*	*Bit 7*	*Bit 8*
18	(MSB)	**EMITTER CATEGORY AND CALL SIGN CHARACTERS #1 AND #2** (Compressed encoding)						
19								(LSB)
20	(MSB)	**CALL SIGN CHARACTERS #3, #4 AND #5** (Compressed encoding)						
21								(LSB)
22	(MSB)	**CALL SIGN CHARACTERS #6, #7 AND #8** (Compressed encoding)						
23								(LSB)
24	**EMERGENCY/PRIORITY STATUS**			**UAT VERSION**			**SIL**	
25	(MSB)	**TRANSMIT MSO**				(LSB)	**SDA**	
26	**NAC_P**				**NAC_V**			**NIC_{BARO}**
27	**CAPABILITY CODES**			**OPERATIONAL MODES**			**CSID**	**SIL_{SUPP}**
28	**Geometric vertical accuracy**		**SA flag**	**NIC_{SUPP}**				
29	**Reserved**							

Notes.—

1. *Each of the fields shown is defined in the following paragraphs.*
2. *In Table I-2-31, were MSB and LSB are not specifically noted, the MSB is the leftmost bit and the LSB is the rightmost bit.*

2.1.5.4.1 *“EMITTER CATEGORY AND CALL SIGN CHARACTERS #1 AND #2” field*

The “EMITTER CATEGORY AND CALL SIGN CHARACTERS #1 AND #2” field shall be a 16-bit (bit 1 of byte 18 to bit 8 of byte 19) field encoded as the binary numeral generated as:

$40^2 B_2 + 40 B_1 + B_0$

where the values B_2, B_1 and B_0 are:

B_2 — EMITTER CATEGORY (encoded as in 2.1.5.4.4)

B_1 — character #1 of CALL SIGN (encoded as in 2.1.5.4.5)

B_0 — character #2 of CALL SIGN (encoded as in 2.1.5.4.5).

2.1.5.4.2 *“CALL SIGN CHARACTERS #3, #4 AND #5” field*

The “CALL SIGN CHARACTERS #3, #4 AND #5” field is a 16-bit (bit 1 of byte 20 to bit 8 of byte 21) field and shall be encoded as the binary numeral generated as:

$40^2 B_2 + 40 B_1 + B_0$

where the values B_2, B_1 and B_0 are:

B_2 — character #3 of CALL SIGN (encoded as in 2.1.5.4.5)

B_1 — character #4 of CALL SIGN (encoded as in 2.1.5.4.5)

B_0 — character #5 of CALL SIGN (encoded as in 2.1.5.4.5).

2.1.5.4.3 *“CALL SIGN CHARACTERS #6, #7 AND #8” field*

The “CALL SIGN CHARACTERS #6, #7 AND #8” field is a 16-bit (bit 1 of byte 22 to bit 8 of byte 23) field and shall be encoded as the binary numeral generated as:

$40^2 B_2 + 40 B_1 + B_0$

where the values B_2, B_1 and B_0 are:

B_2 — character #6 of CALL SIGN (encoded as in 2.1.5.4.5)

B_1 — character #7 of CALL SIGN (encoded as in 2.1.5.4.5)

B_0 — character #8 of CALL SIGN (encoded as in 2.1.5.4.5).

2.1.5.4.4 *EMITTER CATEGORY*

The EMITTER CATEGORY shall be encoded as shown in Table I-2-32.

Table I-2-32. “EMITTER CATEGORY” encoding

Coding (decimal)	*Meaning*	*Coding (decimal)*	*Meaning*
0	No aircraft type information	20	Cluster obstacle
1	Light < 7 000 kg (15 500 lb)	21	Line obstacle
2	Medium wake turbulence category (WTC) and 7 000 to 34 000 kg (15 500 to 75 000 lb)	22	Reserved
3	Medium WTC and 34 000 to 136 000 kg (75 000 to 300 000 lb)	23	Reserved
4	Medium WTC with a higher than normal vortex and 34 000 to 136 000 kg (75 000 to 300 000 lb) (e.g. aircraft such as B757)	24	Reserved
5	Heavy > 136 000 kg (300 000 lb)	25	Reserved
6	Highly manoeuvrable > 5 G acceleration and high speed	26	Reserved
7	Rotorcraft	27	Reserved
8	Reserved	28	Reserved
9	Glider/sailplane	29	Reserved
10	Lighter than air	30	Reserved
11	Parachutist/sky diver	31	Reserved
12	Ultralight/hang glider/paraglider	32	Reserved
13	Reserved	33	Reserved
14	Unmanned aerial vehicle	34	Reserved
15	Space/trans-atmospheric aircraft	35	Reserved
16	Reserved	36	Reserved
17	Vehicle — emergency vehicle	37	Reserved
18	Vehicle — service vehicle	38	Reserved
19	Point obstacle (includes tethered balloons)	39	Reserved

Note.— An aircraft that is of the type “amphibian” (Doc 8643 — Aircraft Type Designators*) will report its wake turbulence category as its emitter type.*

2.1.5.4.5 *“CALL SIGN/FLIGHT PLAN ID” field*

2.1.5.4.5.1 The “CALL SIGN/FLIGHT PLAN ID” field in a UAT ADS-B message shall consist of eight characters, which must contain only decimal digits 0–9, the capital letters A–Z and — as trailing pad characters only — the “space” character. Each character of the “CALL SIGN/FLIGHT PLAN ID” shall be encoded as shown in Table I-2-33. The leftmost character of the call sign corresponds to character #1; the rightmost corresponds to character #8. If the call sign is not available, then all eight characters of the CALL SIGN field shall be set to the base-40 digit code 37. The CSID field (see 2.1.5.4.16) identifies which type of data is contained in the “CALL SIGN/FLIGHT PLAN ID” field.

Table I-2-33. “CALL SIGN” character encoding

Coding (decimal)	*Character*		*Coding (decimal)*	*Character*
0	0		20	K
1	1		21	L
2	2		22	M
3	3		23	N
4	4		24	O
5	5		25	P
6	6		26	Q
7	7		27	R
8	8		28	S
9	9		29	T
10	A		30	U
11	B		31	V
12	C		32	W
13	D		33	X
14	E		34	Y
15	F		35	Z
16	G		36	SPACE
17	H		37	Not available
18	I		38	Reserved
19	J		39	Reserved

2.1.5.4.5.2 The “CALL SIGN/FLIGHT PLAN ID” field used for UAT ADS-B messages should be appropriate for the emitter category, operating rules and procedures under which the aircraft or vehicle is operating.

Notes.—

1. *For aircraft, the call sign should be either the full radiotelephony call sign as contained in Annex 10, Volume II, Chapter 5, 5.2.1.7.2.1, or abbreviated radiotelephony call sign for that aircraft as contained in Annex 10, Volume II, Chapter 5, 5.2.1.7.2.2, the aircraft registration marking or other authorized identifier for special operations.*

2. *A call sign of less than 8 characters should be padded with spaces in the rightmost (trailing) positions in the call sign field. The first character should not be a space.*

2.1.5.4.6 *“EMERGENCY/PRIORITY STATUS” field encoding*

The “EMERGENCY/PRIORITY STATUS” field is a 3-bit (bits 1 through 3 of byte 24) field and shall be encoded as indicated in Table I-2-34.

Table I-2-34. “EMERGENCY/PRIORITY STATUS” encoding

Status code bits $_{MSB}$(binary)$_{LSB}$	*Status code bits (decimal)*	*Meaning*
000	0	No emergency/not reported
001	1	General emergency
010	2	Lifeguard/medical emergency
011	3	Minimum fuel
100	4	No communications
101	5	Unlawful interference
110	6	Downed aircraft
111	7	Reserved

2.1.5.4.7 *“UAT VERSION” field encoding*

The “UAT VERSION” field is a 3-bit (bits 4 through 6 of byte 24) field and shall be internally hard-coded to TWO (binary 010) by all UAT ADS-B transmitting subsystems for equipment complying with this manual (see Table I-2-35).

2.1.5.4.8 *“SIL” field encoding*

2.1.5.4.8.1 The source integrity level (“SIL”) field is a 2-bit (bits 7 and 8 of byte 24) field used to define the probability of the reported horizontal position exceeding the radius of containment defined by the NIC, without alerting, assuming no avionics faults. Although the SIL assumes there are no unannunciated faults in the avionics system, the SIL must consider the effects of a faulted signal-in-space, if a signal-in-space is used by the position source. The probability of an avionics fault causing the reported horizontal position to exceed the radius of containment defined by the NIC, without alerting, is covered by the system design assurance (SDA) parameter. The SIL probability can be defined as either “per sample” or “per hour” as defined in the SIL supplement (SIL_{SUPP}).

Note.— In the first edition of this manual, the acronym “SIL” was used to refer to the “surveillance” integrity level. See RTCA DO-282B, Appendix R, for backward compatibility considerations.

Table I-2-35. UAT version number

UAT version # $_{MSB}$*(binary)*$_{LSB}$	*UAT version # (decimal)*	*Meaning*
000	0	Reserved
001	1	Complies with Annex 10 SARPs and the detailed technical specifications of Doc 9861, Part I, first edition.
010	2	Complies with Annex 10 SARPs and the detailed technical specifications of Doc 9861, Part I, second edition.
011	3	Reserved
100	4	Reserved
101	5	Reserved
110	6	Reserved
111	7	Reserved

2.1.5.4.8.2 The SIL field shall be encoded as indicated in Table I-2-36A.

Table I-2-36A. “SIL” encoding

SIL (binary)	*SIL (decimal)*	*Probability of exceeding the NIC containment radius* R_C
00	0	Unknown
01	1	1×10^{-3} per flight hour or per sample
10	2	1×10^{-5} per flight hour or per sample
11	3	1×10^{-7} per flight hour or per sample

Note.— The SIL and NIC should be set to unknown if the ADS-B position source does not supply an output certified to provide an indication of the integrity of the reported position (e.g. such as HPL from GNSS systems).

2.1.5.4.9 *"TRANSMIT MSO" field encoding*

The "TRANSMIT MSO" field is a 6-bit (bits 1 through 6 of byte 25) field that shall be used to encode the 6 LSBs of the message start opportunity (Chapter 3, 3.1.2.1) determined for the message transmission.

2.1.5.4.10 *"System design assurance (SDA)" field encoding*

The "system design assurance (SDA)" field is a 2-bit (bits 7 and 8 of byte 25) field that shall define the failure condition that the position transmission chain is designed to support as defined in Table I-2-36B.

The position transmission chain includes the ADS-B transmission equipment, ADS-B processing equipment, position source, and any other equipment that processes the position data and position quality metrics that will be transmitted. The supported failure condition will indicate the probability of a position transmission chain fault causing false or misleading information to be transmitted. The definitions and probabilities associated with the supported failure effect are defined in AC 23.1309-1D, AC 25.1309-1A, AC 27-1B and AC 29-2C. All relevant systems attributes should be considered including software and complex hardware in accordance with RTCA DO-178B (EUROCAE ED-12B) or RTCA DO-254 (EUROCAE ED-80).

Table I-2-36B. "System design assurance (SDA)" field encoding

SDA value		*Supported failure condition (Note 1)*	*Probability of undetected fault causing transmission of false or misleading information (Notes 2 and 3)*	*Software and hardware design assurance level (Notes 2 and 4)*
(decimal)	(binary)			
0	00	Unknown/ no safety effect	> 1 x 10^{-3} per flight hour or unknown	N/A
1	01	Minor	≤ 1 x 10^{-3} per flight hour	D
2	10	Major	≤ 1 x 10^{-5} per flight hour	C
3	11	Hazardous	≤ 1x10^{-7} per flight hour	B

Notes.—

1. *Supported failure classification defined in AC 23.1309-1D, AC 25.1309-1A, AC 27-1B and AC 29-2C.*
2. *Because the broadcast position can be used by any other ADS-B equipped aircraft or by ATC, the provisions in AC 23.1309-1D that allow reduction in failure probabilities and design assurance level for aircraft under 6 000 pounds do not apply.*
3. *Includes probability of transmitting false or misleading latitude, longitude, or associated accuracy and integrity metrics.*
4. *Software design assurance per RTCA DO-178B (EUROCAE ED-12B). Airborne electronic hardware design assurance per RTCA DO-254 (EUROCAE ED-80).*

2.1.5.4.11 *"NAC$_P$" field encoding*

The navigation accuracy category for position ("NAC$_P$") field is a 4-bit (bits 1 through 4 of byte 26) field used for applications to determine if the reported state vector has sufficient position accuracy for the intended use and shall be encoded as indicated in Table I-2-37. The value of the NAC_P parameter shall be the highest value in Table I-2-37 consistent with the NAC_P input with the exception that if the NAC_P input is consistent with a value of “10” or “11” and the ADS-B equipment does not support the timing requirements for the precision condition (Chapter 3, 3.1.3.2), then an NAC_P value of “9” shall be transmitted.

Table I-2-37. “NAC_P” encoding

NAC_P (binary) *MSB LSB*	*NAC_P (decimal)*	*Ninety-five per cent horizontal accuracy bounds (EPU)*	*Comment*	*Notes*
0000	0	EPU ≥ 18.52 km (10 NM)	Unknown accuracy	
0001	1	EPU < 18.52 km (10 NM)	RNP-10 and 5 accuracy	1
0010	2	EPU < 7.408 km (4 NM)	RNP-4 accuracy	1
0011	3	EPU < 3.704 km (2 NM)	RNP-2 accuracy	1
0100	4	EPU < 1 852 m (1NM)	RNP-1 accuracy	1
0101	5	EPU < 926 m (0.5 NM)	RNP-0.5 accuracy	1
0110	6	EPU < 555.6 m (0.3 NM)	RNP-0.3 accuracy	1
0111	7	EPU < 185.2 m (0.1 NM)	RNP-0.1 accuracy	1
1000	8	EPU < 92.6 m (0.05 NM)	e.g. GNSS (e.g. GPS with SA)	
1001	9	EPU < 30 m	e.g. GNSS high accuracy (e.g. GPS with SA off)	2
1010	10	EPU < 10 m	e.g. SBAS	2
1011	11	EPU < 3 m	e.g. GBAS	2
1100	12	Reserved		
1101	13	Reserved		
1110	14	Reserved		
1111	15	Reserved		

Notes.—

1. *RNP accuracy includes error sources other than sensor error, whereas horizontal error for NAC_P refers only to horizontal position error uncertainty.*

2. *The estimated position uncertainty (EPU) used in Table I-2-37 is a 95 per cent accuracy bound on horizontal position. EPU is defined as the radius of a circle, centred on the reported position, such that the probability of the actual position being outside the circle is 0.05. When reported by a GNSS system, EPU is commonly called HFOM (horizontal figure of merit).*

3. *A non-excluded satellite failure requires that the NAC_P and NAC_V parameters be set to ZERO along with the NIC parameter to indicate that the position cannot be confirmed to be valid.*

2.1.5.4.12 *“NAC$_V$” field encoding*

The navigation accuracy category for velocity (“NAC$_V$”) field is a 3-bit (bits 5 through 7 of byte 26) field used for applications to determine if the reported state vector has sufficient velocity accuracy for the intended use and shall be encoded as indicated in Table I-2-38.

RTCA DO-282B, Appendix Q, describes the manner in which GNSS position sources that do not output velocity accuracy can be characterized so that a velocity accuracy value associated with the position source can be input into ADS-B equipment as part of the installation process.

Note.— The “NAC$_V$” field reflects the least accurate velocity component being transmitted.

Table I-2-38. “NAC$_V$” encoding

NAC$_V$ (binary) MSB LSB	*NAC$_V$ (decimal)*	*Horizontal velocity error*
000	0	Unknown or ≥ 10 m/s
001	1	< 10 m/s
010	2	< 3 m/s
011	3	< 1 m/s
100	4	< 0.3 m/s
101	5	Reserved
110	6	Reserved
111	7	Reserved

Notes.—

1. *RTCA DO-282B, Appendix Q, contains information on how GNSS position sources that do not output a velocity accuracy can be certified to provide a NAC$_V$ of 1 or 2 so that the appropriate value of NAC$_V$ can be provided to the UAT equipment as an installation parameter. Additionally, RTCA DO-282B, Appendix Q, discusses the conservatism of GNSS velocity accuracy as characterized by this certification process compared to the expected GNSS velocity accuracy during stable flight — the latter accuracy should be expected to be better than 1 metre/second.*

2. *A non-excluded satellite failure requires that the R$_C$ be set to “Unknown” along with the NAC$_V$ and NAC$_P$ parameters being set to ZERO.*

2.1.5.4.13 *“NIC$_{BARO}$” field encoding*

The barometric altitude integrity code (“NIC$_{BARO}$”) field is a 1-bit (bit 8 of byte 26) field that indicates whether or not the barometric pressure altitude provided in the STATE VECTOR element of the message data block has been cross-checked against another source of pressure altitude and shall be encoded as indicated in Table I-2-39.

Table I-2-39. “NIC$_{BARO}$” encoding

Coding	*Meaning*
0	Barometric pressure altitude has NOT been cross-checked
1	Barometric pressure altitude has been cross-checked

2.1.5.4.14 *“CAPABILITY CODES” field encoding*

The “CAPABILITY CODES” field is a 3-bit (bits 1 to 3 of byte 27) field used to indicate the capability of a participant to support engagement in various operations and shall be encoded as indicated in Table I-2-40.

Note.— A capability code for VDL Mode 4 IN capability was considered for inclusion in this manual. VDL Mode 4 system experts have determined that a VDL Mode 4 IN capability code is not needed.

Table I-2-40. “CAPABILITY CODES” encoding

Byte #	*Bit #*	*Encoding*
Byte 27	Bit 1	UAT IN = Aircraft has UAT receive capability 0 = NO 1 = YES
	Bit 2	1090ES IN = Aircraft has 1090ES receive capability 0 = NO 1 = YES
	Bit 3	ACAS operational 0 = NO 1 = YES

2.1.5.4.14.1 “UAT IN capability” subfield

The capability code for “UAT IN capability” shall be set to ONE if the transmitting aircraft has the capability to receive ADS-B and ground uplink UAT messages. Otherwise, this code shall be ZERO.

2.1.5.4.14.2 “1090ES IN capability” subfield

The capability code for “1090ES IN capability” shall be set to ONE if the transmitting aircraft has the capability to receive ADS-B 1090 MHz extended squitter (1090ES) messages. Otherwise, this code shall be ZERO.

2.1.5.4.14.3 “ACAS operational” subfield

If the transmitting ADS-B equipment can determine that an ACAS computer is not installed, or that an installed ACAS computer is not operating in a mode that can generate resolution advisory (RA) alerts, the capability code for “ACAS operational” shall be set to ZERO. Otherwise, this capability code shall be set to ONE.

Note 1.— ADS-B does not consider ACAS operational equal to ONE (1) unless the ACAS is in a state which can issue an RA (e.g. RI = 3 or 4).

Note 2.— As a reference point, RTCA DO-181E (EUROCAE ED-73E) Mode S transponders consider that the ACAS system is operational when “MB” bit 16 of register 10_{16} is set to “ONE” (1). This occurs when the transponder/ACAS interface is operational and the transponder is receiving ACAS RI = 2, 3 or 4. (Refer to RTCA DO-181E (EUROCAE ED-73E), Appendix B, Table B-3-16. RI = 0 is STANDBY, RI = 2 is TA ONLY and RI = 3 is TA/RA.

2.1.5.4.15 *“OPERATIONALMODES” field encoding*

The “OPERATIONAL MODES” field is a 3-bit (bits 4 through 6 of byte 27) field used to indicate the capability of a participant to support engagement in various operations and shall be encoded as indicated in Table I-2-41A.

Table I-2-41A. “OPERATIONAL MODES” encoding

Byte #	*Bit #*	*Encoding*
Byte 27	Bit 4	ACAS resolution advisory active flag 0 = NO 1 = YES
	Bit 5	IDENT switch active flag 0 = NOT active (> 20 seconds since activated by pilot) 1 = Active (≤ 20 seconds since activated by pilot)
	Bit 6	“Reserved for receiving ATC services” flag 0 = NOT receiving ATC services 1 = Receiving ATC services

2.1.5.4.15.1 “ACAS resolution advisory active” flag

The “ACAS resolution advisory active” flag is set to ONE (1) in the messages that it transmits to support the MS report so long as an ACAS resolution advisory is in effect. At all other times, the transmitting ADS-B participant shall set the “ACAS resolution advisory active” flag to ZERO.

2.1.5.4.15.2 "IDENT switch active" flag

The "IDENT switch active" flag is activated by an IDENT switch, and upon activation of the IDENT switch, this flag shall be set to ONE in all scheduled UAT ADS-B messages containing the MODE STATUS element for an interval of 20 seconds ±4 seconds. After the time interval expires, the flag shall be set to ZERO.

Note.— This allows an ATC ground station 4 to 5 reception opportunities to receive the IDENT indication.

2.1.5.4.15.3 "Reserved for receiving ATC services" flag

The "reserved for receiving ATC services" flag (byte 27, bit 6) is reserved for future use. In this version of this manual, this field shall be set to ZERO (0).

Note.— This "reserved for receiving ATC services" flag provides for a future ground ATC system to identify an aircraft that is receiving ATC services, similar to an SSR transponder providing a squawk code of other than "1200," at such time in the future when Mode A code is no longer used.

2.1.5.4.16 "*Call sign identification (CSID)" flag*

2.1.5.4.16.1 The "call sign identification (CSID)" flag in the MODE STATUS element is a one-bit field (bit 7 of byte 27) that is used to identify the contents of the "CALL SIGN/FLIGHT PLAN ID" field. When the CSID flag is set to the value ONE (1), then the "CALL SIGN/FLIGHT PLAN ID" field shall contain the call sign. When the CSID flag is set to the value ZERO (0), then the "CALL SIGN/FLIGHT PLAN ID" field shall contain the flight plan ID.

2.1.5.4.16.2 When the "CSID logic configuration item" (2.1.5.4.17) is set to DISABLED, the CSID flag shall always be ONE (1), and the "CALL SIGN/FLIGHT PLAN ID" field shall contain the call sign.

2.1.5.4.16.3 When the "CSID logic configuration item" (2.1.5.4.17) is set to ENABLED, the CSID flag shall alternate between ONE (1) and ZERO (0), and the "CALL SIGN/FLIGHT PLAN ID" field shall alternate between the call sign and flight plan ID, respectively.

2.1.5.4.17 "*CSID logic configuration" item*

The UAT transmitting subsystem shall provide an installer configuration item that will place the UAT transmitting subsystem in one of two states:

a) CSID logic ENABLED. Causes the UAT transmitting subsystem to satisfy the requirements of 2.1.5.4.16, "call sign identification (CSID) flag."

b) CSID logic DISABLED. Causes the UAT transmitting subsystem to ignore the requirements of 2.1.5.4.16, "call sign identification (CSID) flag" with call sign ALWAYS encoded in the CALL SIGN field and with the CSID field ALWAYS encoded as ONE.

2.1.5.4.18 "*Source integrity level (SIL) supplement* (SIL_{SUPP})*" flag encoding*

The "SIL supplement" (SIL_{SUPP}) flag in the MODE STATUS element is a one-bit flag (bit 8 of byte 27) that shall define whether the reported SIL probability is based on a per hour probability or a per sample probability as defined in Table I-2-41B.

Table I-2-41B. “SIL supplement (SIL_{SUPP})” flag encoding

Coding	*Meaning*
0	Probability of exceeding NIC radius of containment is based on “per hour”
1	Probability of exceeding NIC radius of containment is based on “per sample”

Per hour. The probability of the reported geometric position laying outside the NIC containment radius in any given hour without an alert or an alert longer than the allowable time-to-alert.

Note.— The probability *of exceeding the integrity radius of containment for GNSS position sources is based on a per hour basis, as the NIC will be derived from the GNSS horizontal protection level (HPL) which is based on a probability of* 1×10^{-7} *per hour.*

Per sample. The probability of a reported geometric position laying outside the NIC containment radius for any given sample.

Note.— The probability *of exceeding the integrity radius of containment for IRU, DME/DME and DME/DME/LOC position sources may be based on a per sample basis.*

2.1.5.4.19 *“Geometric vertical accuracy (GVA)” field encoding*

The “geometric vertical accuracy (GVA)” field is a 2-bit field (bits 1 and 2 of byte 28) that shall be set by using the vertical field of merit (VFOM) (95 per cent) from the GNSS position source used to encode the geometric altitude field per Table I-2-41C.

Table I-2-41C. “Geometric vertical accuracy (GVA)” field encoding

GVA Encoding *(decimal)*	*Meaning* *(metres)*
0	Unknown or > 150 metres
1	≤ 150 metres
2	≤ 45 metres
3	Reserved

Note.— For the purposes of this document, values for 0, 1 and 2 are encoded. It is expected that ADS-B transmitting subsystems with ADS-B version numbers greater than 2 will define the GVA encoding of “3” as a value less than 45 metres at some point in the future. Therefore, ADS-B version 2 receiving subsystems should treat the GVA encoding of “3” as less than 45 metres for data received from ADS-B version number 2 or greater.

2.1.5.4.20 *"Single antenna (SA)" flag encoding*

The "single antenna (SA)" flag is a 1-bit (bit 3 of byte 28) field that shall be used to indicate that the ADS-B transmitting subsystem is operating with a single antenna.

a) Non-diversity, i.e. those transmitting subsystems that use only one antenna, shall set the single antenna subfield to "ONE" (1) at all times.

b) Diversity, i.e. those transmitting functions designed to use two antennas, shall set the single antenna subfield to ZERO (0) at all times that both antenna channels are functional.

At any time that the diversity configuration cannot guarantee that both antenna channels are functional, then the "single antenna" subfield shall be set to ONE (1).

Note.— Certain applications may require confirmation that each participant has functioning antenna diversity for providing adequate surveillance coverage.

2.1.5.4.21 *"Navigational integrity category (NIC) supplement (NIC$_{SUPP}$)" flag*

The "NIC supplement (NIC$_{SUPP}$)" flag in the MODE STATUS element is a one-bit flag (bit 4 of byte 28) that shall augment the encoding of the NIC reported in the STATE VECTOR element (2.1.5.2), as defined in Table I-2-9.

2.1.5.4.22 *Reserved bits*

This reserved bits field is a 12-bit (bit 5 of byte 28 through bit 8 of byte 29) field that may be used in the future to indicate the capability of a participant to support engagement in various operations and shall be set to ALL ZEROs.

2.1.5.5 AUXILIARY STATE VECTOR element

The format for the AUXILIARY STATE VECTOR shall apply to UAT ADS-B messages with "MESSAGE DATA BLOCK TYPE CODES" of "1," "2," "5" and "6" as defined in Table I-2-42.

Note.— Each of the fields shown is defined in the following paragraphs.

2.1.5.5.1 *"SECONDARY ALTITUDE" field encoding*

The "SECONDARY ALTITUDE" field is a 12-bit (bit 1 of byte 30 through bit 4 of byte 31) field that shall encode either the geometric altitude or barometric pressure altitude depending on the setting of the "ALTITUDE TYPE" field (2.1.5.2.2). The altitude encoded in the "SECONDARY ALTITUDE" field shall be the opposite type to that specified by the "ALTITUDE TYPE" field with encoding consistent with that used in Table I-2-8.

Table I-2-42. Format of AUXILIARY STATE VECTOR element

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MDB byte #	*Bit 1*	*Bit 2*	*Bit 3*	*Bit 4*	*Bit 5*	*Bit 6*	*Bit 7*	*Bit 8*
30	(MSB)			**SECONDARY ALTITUDE**				
31				(LSB)				
32								
33					Reserved			
34								

.
.
.

2.1.5.5.2 *Reserved bits*

Bit 5 of byte 31 through bit 8 of byte 34 are reserved for future use and shall be set to ALL ZEROs.

Note.— This field is reserved for future definition.

2.1.5.6 TARGET STATE element (message data block type codes “3” and “4”)

The TARGET STATE elements provide information on the intended horizontal and vertical positions toward which the ownship aircraft is manoeuvring for the active flight segment. Format for the TARGET STATE element shall apply to UAT ADS-B messages with “MESSAGE DATA BLOCK TYPE CODES” of “3” and “4” as defined in Table I-2-43.

Table I-2-43. Format of TARGET STATE element
(message data block type codes “3” and “4”)

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.

MDB byte #	*Bit 1*	*Bit 2*	*Bit 3*	*Bit 4*	*Bit 5*	*Bit 6*	*Bit 7*	*Bit 8*
30	**SAT**	**(MSB)**				**Selected altitude**		
31				**(LSB)**	**(MSB)**			
32	**Barometric pressure setting**				**(LSB)**	**Status**	**Sign**	**(MSB)**
33	**Selected heading**						**(LSB)**	**ST**
34	**AP**	**VNAV**	**ALT**	**APP**	**LNAV**	**(Reserved)**		

.
.

2.1.5.6.1 *"Selected altitude type (SAT)" field encoding*

The "selected altitude type (SAT)" subfield is a 1-bit (bit 1 of byte 30) field that shall be used to indicate the source of selected altitude data that is being used to encode bit 2 of payload byte 30, through bit 4 of payload byte 34. Encoding of the "selected altitude type" shall be in accordance with Table I-2-44A.

Table I-2-44A. "Selected altitude type (SAT)" field

Coding	*Meaning*
0	Data being used to encode bit 2 of payload byte 30, through bit 4 of payload byte 34, are derived from the mode control panel/flight control unit (MCP/FCU) or equivalent equipment.
1	Data being used to encode bit 2 of payload byte 30, through bit 4 of payload byte 34, are derived from the flight management system (FMS).

> *Note.— Users of these data are cautioned that the selected altitude value transmitted by the ADS-B transmitting subsystem does not necessarily reflect the true intention of the aeroplane during certain flight modes (e.g. during certain VNAV or approach modes) and does not necessarily correspond to the target altitude (the next altitude level at which the aircraft will level off). In addition, on many aeroplanes, the ADS-B transmitting subsystem does not receive selected altitude data from the FMS and will transmit only selected altitude data received from a mode control panel/flight control unit (MCP/FCU).*

2.1.5.6.2 *"Selected altitude" field encoding*

The "selected altitude" field (bit 2 of byte 30 through bit 4 of byte 31) shall contain the selected altitude of the ADS-B transmitting subsystem as defined in Table I-2-44B.

2.1.5.6.3 *"Barometric pressure setting (minus 800 millibars)" field encoding*

a) The "barometric pressure setting (minus 800 millibars)" subfield is a 9-bit (bit 5 of byte 31 through bit 5 of byte 32) field that shall contain barometric pressure setting data that have been adjusted by subtracting 800 millibars from the data received from the barometric pressure setting source.

b) After adjustment by subtracting 800 millibars, the barometric pressure setting shall be encoded in accordance with Table I-2-45.

Note.— These barometric pressure setting data can be used to represent QFE or QNH/QNE, depending on local procedures. They represent the current value being used to fly the aircraft.

2.1.5.6.4 *"Selected heading" field encoding*

a) The "selected heading" field (bit 6 of byte 32 through bit 7 of byte 33) contains the selected heading of the ADS-B transmitting subsystem. The selected heading status (bit 6 of byte 32) shall be set to ONE (1) if the contents of the selected heading sign and magnitude subfields are VALID, or set to ZERO (0) otherwise.

b) The selected heading sign (bit 7 of byte 32) shall be set to ZERO (0) if the selected heading is a positive angle, or to ONE (1) if the selected heading is a negative angle.

c) The magnitude of the selected heading subfield (bit 8 of byte 32 through bit 7 of byte 33) shall be encoded as defined in Table I-2-46.

2.1.5.6.5 *"Status of MCP/FCU mode bits (ST)" field encoding*

The "status of MCP/FCU mode bits (ST)" field (bit 8 of byte 33) shall be set to ONE (1) when any of the "mode" fields defined in 2.1.5.6.6 through 2.1.5.6.10 are valid, or set to ZERO (0) otherwise.

2.1.5.6.6 *"Mode indicators: autopilot engaged (AP)" field encoding*

The "mode Indicators: autopilot engaged (AP)" field (bit 1 of byte 34) shall be set to ONE (1) when the MCP/FCU source indicates that the autopilot function is engaged, or set to ZERO (0) otherwise.

Table I-2-44B. "Selected altitude" format

Coding		
(Binary)	*(Decimal)*	*Meaning*
000 0000 0000	0	NO data *or* INVALID data
000 0000 0001	1	0 feet
000 0000 0010	2	32 feet
000 0000 0011	3	64 feet
*** **** ****	***	*** **** ****
*** **** ****	***	*** **** ****
*** **** ****	***	*** **** ****
111 1111 1110	2046	65 440 feet
111 1111 1111	2047	65 472 feet

Notes.—

1. *When converting raw source data into the selected altitude field encoding, the accuracy of the data is maintained such that it is not worse than ±16 ft (±1/2 LSB).*

2. *On many aeroplanes, the ADS-B transmitting subsystem does not receive selected altitude data from the FMS and will transmit only selected altitude data received from a mode control panel/flight control unit (MCP/FCU). Users of these data are cautioned that the selected altitude value transmitted by the ADS-B transmitting subsystem does not necessarily reflect the true intention of the aeroplane during certain flight modes (e.g. during certain VNAV or approach modes) and does not necessarily correspond to the target altitude (the next altitude level at which the aircraft will level off).*

Table I-2-45. "Barometric pressure setting (minus 800 millibars)" field encoding

Coding		*Meaning*
(Binary)	*(Decimal)*	
0 0000 0000	0	NO data *or* INVALID data
0 0000 0001	1	0 millibars
0 0000 0010	2	0.8 millibars
0 0000 0011	3	1.6 millibars
* **** ****	***	*** **** ****
* **** ****	***	*** **** ****
* **** ****	***	*** **** ****
1 1111 1110	510	407.2 millibars
1 1111 1111	511	408.0 millibars

Note.— When converting raw source data into the barometric pressure setting (minus 800 millibars) field encoding, the accuracy of the data is maintained such that it is not worse than ±0.4 millibars (±1/2 LSB).

Table I-2-46. "Selected heading" magnitude subfield encoding

Coding $_{MSB}$*(binary)*$_{LSB}$	*Coding (decimal)*	*Meaning when status = ONE (valid)*
0000 0000	0	0.000 degrees
0000 0001	1	0.703 degrees (180/256)
0000 0010	2	1.406 degrees (2*180/256)
…	…	…
1111 1111	255	179.3 degrees (255*180/256)

Notes.—

1. *When converting raw source data into the selected altitude field encoding, the accuracy of the data is maintained such that it is not worse than (±180/512) degrees (±1/2 LSB).*

2. *On many aeroplanes, the ADS-B transmitting subsystem receives selected heading from a mode control panel/flight control unit (MCP/FCU). Users of these data are cautioned that the selected heading value transmitted by the ADS-B transmitting subsystem does not necessarily reflect the true intention of the aeroplane during certain flight modes (e.g. during LNAV mode).*

2.1.5.6.7 "*Mode indicators: VNAV mode engaged" (VNAV) field encoding*

The "mode indicators: VNAV mode engaged (VNAV)" field (bit 2 of byte 34) shall be set to ONE (1) when the MCP/FCU source indicates that the VNAV function is engaged, or set to ZERO (0) otherwise.

2.1.5.6.8 *"Mode indicators: altitude hold mode (ALT)" field encoding*

The "mode indicators: altitude hold mode (ALT)" field (bit 3 of byte 34) shall be set to ONE (1) when the MCP/FCU source indicates that the altitude hold function is engaged, or set to ZERO (0) otherwise.

2.1.5.6.9 *"Mode indicators: approach mode (APP)" field encoding*

The "mode indicators: approach mode (APP)" field (bit 4 of byte 34) shall be set to ONE (1) when the MCP/FCU source indicates that the approach mode function is engaged, or set to ZERO (0) otherwise.

2.1.5.6.10 "*Mode indicators: LNAV mode engaged" (LNAV) field encoding*

The "mode indicators: LNAV mode engaged" (LNAV) field (bit 5 of byte 34) shall be set to ONE (1) when the MCP/FCU source indicates that the lateral navigation function is engaged, or set to ZERO (0) otherwise.

2.1.5.6.11 *Reserved bits*

Bits 6 to 8 of byte 34 are reserved and shall be set to ALL ZEROs.

2.1.5.7 TARGET STATE element (message data block type code "6")

Format for the TARGET STATE element shall apply to UAT ADS-B messages with "MESSAGE DATA BLOCK TYPE CODES" of "6" consistent with Table I-2-47.

Note.— Each of the fields shown are defined in 2.1.5.6.1 through 2.1.5.6.10 with the exception of the byte offset that is indicated in Table I-2-47.

2.1.5.8 TRAJECTORY CHANGE element

Equipment conforming to this edition of the manual shall insert ALL ZEROs in bytes 18 through 29 whenever this element is present in a transmitted message.

Note.— This element contains 96 bits (bytes 18 through 29) that are reserved for future definition. See Part II, Appendix H.

Table I-2-47. Format of TARGET STATE element
(message data block type code 6)

<table>
<tr><th><i>MDB byte #</i></th><th><i>Bit 1</i></th><th><i>Bit 2</i></th><th><i>Bit 3</i></th><th><i>Bit 4</i></th><th><i>Bit 5</i></th><th><i>Bit 6</i></th><th><i>Bit 7</i></th><th><i>Bit 8</i></th></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td>.</td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td>.</td><td></td><td></td><td></td></tr>
<tr><td>25</td><td>SAT</td><td colspan="7">(MSB) Selected altitude</td></tr>
<tr><td>26</td><td colspan="4">(LSB)</td><td colspan="4">(MSB)</td></tr>
<tr><td>27</td><td colspan="5">Barometric pressure setting (LSB)</td><td>Status</td><td>Sign</td><td>(MSB)</td></tr>
<tr><td>28</td><td colspan="7">Selected heading (LSB)</td><td>ST</td></tr>
<tr><td>29</td><td>AP</td><td>VNAV</td><td>ALT</td><td>APP</td><td>LNAV</td><td colspan="3">(Reserved)</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td>.</td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td>.</td><td></td><td></td><td></td></tr>
</table>

2.2 UAT GROUND UPLINK MESSAGE DATA BLOCK

The UAT ground uplink message data block shall consist of two components: the first eight bytes that comprise the UAT-specific header and bytes 9 through 432 that comprise the application data as shown in Table I-2-48. Bytes and bits shall be fed to the interleaving process with the most significant byte, byte #1, transmitted first, and within each byte, the most significant bit, bit #1, transmitted first.

2.2.1 UAT-specific header

2.2.1.1 "GROUND STATION LATITUDE" field encoding

The "GROUND STATION LATITUDE" field is a 23-bit (bit 1 of byte 1 through bit 7 of byte 3) field used to identify the latitude of the ground station and shall be encoded by the ground station using the same format as defined for latitude information in the UAT ADS-B message (2.1.5.2.1).

Note.— The resolution of this field has been selected to support a potential passive ranging function.

2.2.1.2 "GROUND STATION LONGITUDE" field encoding

The "GROUND STATION LONGITUDE" field is a 24-bit (bit 8 of byte 3 through bit 7 of byte 6) field used to identify the longitude of the ground station and shall be encoded by the ground station using the same format as defined for longitude information in the UAT ADS-B message (2.1.5.2.1).

Note.— The resolution of this field has been selected to support a potential passive ranging function.

2.2.1.3 "POSITION VALID" field encoding

The "POSITION VALID" field is a 1-bit (bit 8 of byte 6) field used to indicate whether or not the position in the header is valid and shall be encoded such that a ONE represents a VALID position and a ZERO represents an INVALID position.

Table I-2-48. Format of the UAT ground uplink message data block

Byte #	*Bit 1*	*Bit 2*	*Bit 3*	*Bit 4*	*Bit 5*	*Bit 6*	*Bit 7*	*Bit 8*
1	(MSB)							
2	**GROUND STATION LATITUDE (WGS-84)**							
3							(LSB)	(MSB)
4								
5	**GROUND STATION LONGITUDE (WGS-84)**							
6							(LSB)	**POSITION VALID**
7	**UTC coupled**	**Reserved**	**Application data valid**	(MSB)		**SLOT ID**		(LSB)
8	(MSB)	**TIS-B SITE ID**		(LSB)	**Reserved**			
9	**APPLICATION DATA**							
432								

2.2.1.4 “UTC-COUPLED” field encoding

The “UTC-COUPLED” field is a 1-bit (bit 1 of byte 7) field used to indicate whether or not the ground station 1 pulse per second timing is valid and shall be encoded such that a ONE represents that the ground station is UTC-coupled and a ZERO represents that the ground station is not UTC-coupled.

Note.— See Chapter 3, 3.2.1.1 and 3.2.1.2.

2.2.1.5 Reserved bits

Bit 2 of byte 7 is reserved for future use and shall always be set to ZERO.

2.2.1.6 “APPLICATION DATA VALID” field encoding

The “APPLICATION DATA VALID” field is a 1-bit (bit 3 of byte 7) field used to indicate whether or not the application data is valid for operational use and shall be encoded such that a ONE represents VALID application data and a ZERO represents INVALID application data.

Note 1.— Aircraft applications should ignore the application data field when this bit is set to INVALID.

Note 2.— This field will allow testing and demonstration of new products without impact to operational aircraft systems.

2.2.1.7 "SLOT ID" field encoding

The "SLOT ID" field is a 5-bit (bit 4 through bit 8 of byte 7) field that shall be used to identify within which of the 32 time slots the UAT ground uplink message transmission took place.

Note.— The time slots used for ground uplink messages are continually shifted for maximum interference tolerance to other users sharing the band (see 3.2.2.2).

2.2.1.8 "TIS-B SITE ID" field encoding

The "TIS-B SITE ID" field is a 4-bit (bits 1 through 4 of byte 8) field used to convey the reusable TIS-B site ID that shall be encoded with each TIS-B transmission as shown in Table I-2-49.

2.2.1.9 Reserved bits

Bits 5 through 8 of byte 8 are reserved for future use and shall be set to ALL ZEROs.

Table I-2-49. Encoding of TIS-B site ID

Encoding	*Meaning*
0000	No TIS-B information transmitted from this site
0001 through 1111	Assigned to ground stations that provide TIS-B information

Notes.—

1. *This field supports TIS-B applications that verify TIS-B transmissions were transmitted from the site located at the latitude/longitude encoded in the UAT-specific header portion of the ground uplink message data block. The width of the field was selected based upon analysis of the needs of a potential passive ranging function.*
2. *The assignment of TIS-B site IDs requires coordination on a regional basis.*

2.2.2 Ground uplink application data

The APPLICATION DATA field is a 424 byte field (byte 9 through byte 432). The application data shall consist of information frames and shall always be an integral number of bytes. Any remaining unused portion of the field shall be filled with ZERO bytes.

2.2.2.1 Information frames

Each Information frame shall consist of ‘N’ bytes, comprising three subfields formatted as described in Table I-2-50.

Table I-2-50. Format for information frames

Byte #	*Bit 1*	*Bit 2*	*Bit 3*	*Bit 4*	*Bit 5*	*Bit 6*	*Bit 7*	*Bit 8*
1	MSB	**Length**						
2	LSB	**Reserved**			MSB	**Frame type**		LSB
3 – N	**Frame data**							

Note.— Byte numbers in this table are relative to the beginning of the current information frame.

2.2.2.1.1 *“Length” subfield encoding*

The “length” subfield (byte 1: bit 1 through byte 2: bit 1) is a 9-bit field that shall contain the length of the frame data field in bytes. Values shall range from 0 through 422 (decimal). The length value shall always equal to “N-2”.

2.2.2.1.2 *“Reserved” subfield encoding*

The “reserved” subfield (byte 2: bits 2 through 4) is a 3-bit field that is reserved for future use and shall be set to the ZERO value in equipment that complies with this document.

2.2.2.1.3 *“Frame type” subfield encoding*

The “frame type” subfield (byte 2: bits 5 through 8) is a 4-bit field that shall contain the indication for the format of the frame data field. The frame types are defined in Table I-2-51.

Table I-2-51. Frame type encoding

Coding $_{MSB}$*(binary)*$_{LSB}$	*Coding (decimal)*	*Frame data format*
0000	0	FIS-B APDU
0001	1	Reserved for developmental use
0010 through 1110	2 through 14	Reserved for future use
1111	15	TIS-B/ADS-R service status

Notes.—

1. *Frame type 1 is intended for developmental use, such as to support on-air flight testing of new ground uplink frame types, prior to their adoption.*

2. *A primary purpose of the TIS-B/ADS-R management messages is to convey the TIS-B/ADS-R service status. A detailed description of TIS-B/ADS-R service status and data contents of the TIS-B/ADS-R management messages are defined in RTCA DO-317.*

2.2.2.1.4 *"Frame data" subfield encoding*

The encoding of this field is beyond the scope of this manual.

2.3 AN EXAMPLE OF UAT PSEUDORANDOM MESSAGE DATA BLOCK GENERATION

2.3.1 Several UAT requirements specify that UAT performance will be tested using pseudorandom message data blocks. This section provides an example of how such data might be generated.

2.3.2 Suitable message data blocks can be provided using the sequence of bits generated by a 13-tap M-sequence generator defined (for $n \geq 13$) by the following recursion relation:

$$a(n) = [a(n-8) + a(n-11) + a(n-12) + a(n-13)]\mathrm{mod}2$$

with $a(0) = 1$ and $a(1)$ through $a(12) = 0$. This sequence has a length of 8 191 bits before repeating. For each message type, 8 191 different message data blocks can be generated without repetition if contiguous portions of the M-sequence are used for any given test requiring multiple message data blocks.

Chapter 3

SYSTEM TIMING AND MESSAGE TRANSMISSION PROCEDURES

3.1 UAT EQUIPMENT FOR AIRCRAFT AND SURFACE VEHICLES

3.1.1 Procedures for processing of time data

Note.— UAT equipment derives its timing for transmitter and receiver functions from GNSS (or equivalent) time sources. The time of applicability of the position, velocity and time (PVT) data is presumed to be within ±5 milliseconds of the leading edge of the time mark signal to which it applies.

Time mark information shall be utilized by the UAT equipment in the following ways:

a) Any extrapolation of position data shall comply with the requirements of 3.1.3.1 and 3.1.3.2.

b) The UAT transmit message timing shall comply with the requirements of 3.1.2.

c) The UAT receiver time processing shall comply with the requirements of 5.1.1.

Notes.—

1. *A possible implementation of the GPS/GNSS time mark pulse is illustrated in Part II, Chapter 5, 5.6.*

2. *Time sources equivalent to a GNSS time source must be within 1 millisecond of UTC (GNSS SARPs of Annex 10, Volume I, Appendix B, 3.1.4 and 3.2.4). Future developments, e.g. ranging using ADS-B messages on UAT, may require a time source equivalent of within 1 microsecond, as discussed in Part II, Appendix J.*

3.1.1.1 UTC-coupled condition

The “UTC-coupled” subfield shall be set to ONE, except under the conditions discussed in 3.1.1.2.

Notes.—

1. *Operation of the UAT system in normal mode presumes GNSS, or equivalent, equipage on system participants to, for example, prevent media access conflict with the UAT ground uplink transmissions. Short-term GNSS outages are mitigated by UAT ground infrastructure that provides timing information and/or by the ability of UAT avionics to prevent aircraft UAT ADS-B transmitting subsystems from transmitting in the ground uplink segment for a minimum of 20 minutes in the absence of GNSS (3.1.1.2.4). Long-term GNSS outages may lead to a degradation in the rate of successful message reception because of conflict with the transmission of UAT ground uplink messages. In areas without ground uplink transmissions, there is no media access conflict.*

2. *UAT timing is always relative to the 1.0 second UTC epoch. UAT avionics do not require time of day.*

3. *When synchronization is required, in addition to accepting the time tag information, the ADS-B transmitting subsystem needs to accept appropriate UTC time information in order to establish the UTC EPOCH. Typically, this information can be determined from the ARINC-743A label "140" and "150" words. If the UTC time words indicate that the beginning of the EPOCH is the same as the leading edge of the time mark, then the GPS/GNSS time mark can be used to establish the time of applicability.*

3.1.1.2 Non-UTC-coupled condition

3.1.1.2.1 This condition shall be entered when the ADS-B equipment has not been provided a GPS/GNSS, or equivalent, time mark.

Note.— This is not the normal condition; it is a degraded mode of operation.

3.1.1.2.2 Within 2 seconds of entering the non-UTC-coupled condition, the UAT equipment shall set the "UTC-coupled" subfield to ZERO in any transmitted messages.

3.1.1.2.3 While in the non-UTC-coupled condition, UAT aircraft equipment with operational receivers shall align to within ±6 milliseconds of UTC time based upon successful message reception of any UAT ground uplink message with the "UTC-coupled" bit set.

3.1.1.2.4 While in the non-UTC-coupled condition when UAT ground uplink messages cannot be received, the UAT transmitter shall estimate time through the outage period such that the drift rate of estimated time, relative to actual UTC-coupled time, is no greater than 12 milliseconds in 20 minutes.

3.1.1.2.5 While in the non-UTC-coupled condition, ADS-B transmissions shall continue.

3.1.1.2.6 The UAT equipment shall change state to the UTC-coupled condition within 2 seconds of availability of the UTC-coupled source.

Notes.—

1. *Paragraph 3.1.1.2.4 is consistent with an initial drift rate of 10 PPM in the baud clock over the 12 millisecond air-to-ground segment guard time. Clock drift can be compensated up to the time coasting begins.*

2. *In the non-UTC-coupled condition, the estimated 1 second UTC epoch signal does NOT indicate the time of validity of PVT information.*

3. *Any installations of equipment involving separated transmitters and receivers must provide a mechanism to fulfil the requirement stated in 3.1.1.2.3.*

4. *This reversionary timing exists for the following reasons:*

   a) *to support UAT ADS-B message transmission using an alternate source of position and velocity, if available;*

   b) *to support UAT ADS-B message transmission in the absence of position and velocity data in order that any available fields are conveyed (e.g. barometric altitude); and*

   c) *to ensure that a signal is provided in the event the ground network can perform an ADS-B-independent localization of the aircraft (e.g. multilateration).*

3.1.2 ADS-B media access timing

3.1.2.1 The message start opportunity (MSO)

3.1.2.1.1 UAT ADS-B messages shall be transmitted at discrete message start opportunities (MSOs) chosen by the pseudorandom process in 3.1.2.1.2 to 3.1.2.1.4.

Note.— Message start opportunities are further discussed in Part II, Chapter 2, 2.3. The specific pseudorandom number $R(m)$ chosen by an aircraft depends on the most recent valid position estimate available at the beginning of each second, and on the previously chosen random number $R(m-1)$ by first letting:

$N(0)$ = 12 LSBs of the most recent valid “LATITUDE”; and

$N(1)$ = 12 LSBs of the most recent valid “LONGITUDE”

where the “latitude” and “longitude” are as defined in Chapter 2, 2.1.5.2.1.

3.1.2.1.2 Using $N(0)$ and $N(1)$, the following procedure shall then establish the transmission timing (MSO) for the current UAT frame m.

When $m = 0$, $R(0) = N(0) \bmod 3200$

When $m \geq 1$, $R(m) = \{ 4001\, R(m-1) + N(m \bmod 2) \} \bmod 3200$.

3.1.2.1.3 When in the first frame after power up, and whenever the vertical status is determined to be in the AIRBORNE condition, the transmitter shall be in the full MSO range mode, where the MSO is determined as follows:

MSO = $752 + R(m)$.

3.1.2.1.4 Under all other conditions the transmitter shall be in the restricted MSO range mode, where the MSO is determined as follows:

MSO = $752 + R^* + R(m) \bmod 800$

With $R^* = R(k) - R(k) \bmod 800$, where “$k$” is the frame just prior to entering the restricted MSO range mode.

Notes.—

1. *Retention of N(0) and N(1) in non-volatile memory is required to prevent common MSO selections amongst A/Vs when no valid latitude and longitude are currently available.*

2. *The latitude and longitude alternate in providing a changing “seed” for the pseudorandom number generation. In most cases the most recent valid “LATITUDE” and “LONGITUDE” available at the very beginning of each second is the position from the previous second. (If the navigation source is temporarily unavailable, the available position data might be older.) Other acceptable definitions include:*

   a) *the position from the previous second extrapolated to the current second;*

   b) *the position estimate from the current second (if available at the time of MSO determination); or*

   c) *any equivalent.*

3. *The restricted range MSO mode makes the choice of MSO more nearly periodic in order to support certain applications in the airport surface environment.*

3.1.2.2 Relationship of the MSO to the modulated data

The optimum sample point of the first bit of the UAT synchronization sequence at the antenna terminal of the UAT equipment shall occur at T_{TX} microseconds after the 1-second UTC epoch according to the following formula:

$$T_{TX}\text{ (microseconds)} = 6\,000 + (250*\text{MSO})$$

where the value “6 000” accounts for the initial guard interval (see Part II, Chapter 2, Figure II-2-2), within the following tolerances:

a) ±500 nanoseconds for UAT equipment with an internal UTC-coupled time source;

b) ±500 nanoseconds for UAT equipment with an external UTC-coupled time source.

Notes.—

1. *This is required to support ADS-B range validation by a receiving application. This requirement sets the ultimate timing accuracy of the transmitted messages under the UTC-coupled condition. See Part II, Chapter 5, 5.3, for further information on UAT timing considerations.*

2. *Referencing this measurement to the optimum sampling point is convenient since this is the point in time identified during the synchronization process.*

3. *There is no requirement to demonstrate this relationship when in the non-UTC-coupled condition.*

3.1.3 Time registration and latency

Note.— This section contains requirements imposed on the UAT ADS-B transmitting subsystem relative to two parameters. The first relates to the obligation of the transmitter to ensure position data in each UAT ADS-B message relate to a standard time of applicability (TOA). The second relates to the obligation of the transmitter to reflect new UAT ADS-B message data available at the transmitter input into the transmitted UAT ADS-B message itself. This requirement is expressed as a cut-off time by which any updated data presented to the UAT transmitter should be reflected in the message output. Rules for TOA and cut-off time vary depending on the quality of SV data being transmitted and whether the transmitter is in the UTC-coupled state.

The UAT transmitter shall use the precision or non-precision condition for reporting SV data according to the criteria below:

a) The precision condition shall be in effect when UTC-coupled; and

   1) the “NAC_P” value is “10” or “11” (see Table I-2-37); or

   2) the “NIC” value is “9,” “10” or “11” (see Table I-2-9).

b) Otherwise, the non-precision condition shall be in effect.

3.1.3.1 Requirements when in the non-precision condition and UTC-coupled

When the UAT ADS-B transmitting subsystem is in the non-precision condition and is UTC-coupled:

a) At the time of the UAT ADS-B message transmission, position information that is encoded in the "LATITUDE" and "LONGITUDE" fields, and in the "ALTITUDE" field, when it conveys a geometric altitude, shall be applicable as of the start of the current 1-second UTC epoch.

b) All other updated UAT ADS-B message fields that are provided at the UAT equipment input interface at least 200 milliseconds prior to the time of a scheduled UAT ADS-B message transmission that involves those fields shall be reflected in the transmitted message.

Notes.—

1. *Specifically, any extrapolation of position performed should be to the start of the 1-second UTC epoch and not the time of transmission.*

2. *Velocity information cannot be extrapolated and may therefore have additional ADS-B imposed latency (generally no more than one extra second).*

3.1.3.2 Requirements when in the precision condition and UTC coupled

When the UAT ADS-B transmitting subsystem is in the precision condition and is UTC coupled:

a) At the time of the UAT ADS-B message transmission, the position information that is encoded in the "LATITUDE" and "LONGITUDE" fields, and in the "ALTITUDE" field, when it conveys a geometric altitude shall be applicable as of the start of the current 0.2-second UTC epoch.

b) All other updated UAT ADS-B message fields that are provided at the UAT equipment input interface at least 200 milliseconds prior to the time of a scheduled UAT ADS-B message transmission that involves those fields shall be reflected in the transmitted message.

Note.— Specifically, any extrapolation of position performed should be to the start of the 0.2-second UTC epoch and not the time of transmission.

3.1.3.3 Requirements when non-UTC-coupled

When the UAT ADS-B transmitting subsystem is in the non-UTC-coupled condition, any change in an ADS-B message field provided to the transmitter shall be reflected in any transmitted message containing that message field that is transmitted more than 1.0 seconds after the new value is received by the transmitter.

Note.— A UAT ADS-B transmitting subsystem that is capable of meeting the timing requirements of 3.1.3.2 makes no adjustment to the NIC or NAC_P *that it receives as inputs. It is not expected that a single transmitted message would ever indicate both the non-UTC-coupled condition and a NIC or* NAC_P *consistent with the precision condition.*

3.1.3.4 Data timeout

At the TOA for the ADS-B message transmission, any ADS-B message fields without an update provided to the transmitter within the data lifetime parameter (in seconds) of Table I-3-1 shall be encoded as “data unavailable” in the subsequent transmitted message containing that message field.

Note.— These input elements either provide data that map directly into the transmitted ADS-B message structure, or provide control signals that establish the message contents.

Table I-3-1. UAT ADS-B transmitting subsystem data timeout

Element #	*Input data element*	*Relevant paragraph*	*Data lifetime (seconds)*
1	ICAO 24-bit address	2.1.5.1.3.1	No limit
2	Latitude (Note 1)	2.1.5.2.1	1.5
3	Longitude (Note 1)	2.1.5.2.1	1.5
4	Altitude type selection (barometric versus geometric) (Note 2)	2.1.5.2.2	60
5	Barometric pressure altitude	2.1.5.2.3	2
6	Geometric altitude	2.1.5.2.3	1.5
7	NIC	2.1.5.2.4	2
8	Automatic AIRBORNE/ON-GROUND indication (Note 2)	2.1.5.2.5	2
9	North velocity (Note 1)	2.1.5.2.6.1	2
10	East velocity (Note 1)	2.1.5.2.6.3	2
11	Ground speed	2.1.5.2.6.2	2
12	Track angle	2.1.5.2.6.4	2
13	Heading	2.1.5.2.6.4	2
14	Barometric vertical rate	2.1.5.2.7.1.1	2
15	Geometric vertical rate (Note 1)	2.1.5.2.7.1.1	2
16	A/V size with GPS antenna offset and position offset applied by sensor indication	2.1.5.2.7.2	No limit
17	UTC 1 PPS timing (Note 1)	2.1.5.2.8	2
18	Emitter category	2.1.5.4.4	No limit
19	Call sign/flight plan ID	2.1.5.4.5	60
20	Emergency/priority status selection	2.1.5.4.6	60
21	Source integrity level (SIL)	2.1.5.4.8	60
22	System design assurance (SDA)	2.1.5.4.10	60
23	SIL supplement	2.1.5.4.18	60
24	NAC_P (Note 1)	2.1.5.4.11	2

Element #	*Input data element*	*Relevant paragraph*	*Data lifetime (seconds)*
25	NAC_V (Note 1)	2.1.5.4.12	2
26	NIC_{BARO}	2.1.5.4.13	2
27	ACAS operational	2.1.5.4.14.3	60
28	ACAS resolution advisory flag	2.1.5.4.15.1	18
29	IDENT selection	2.1.5.4.15.2	60
30	Call sign identification flag	2.1.5.4.16	2
31	Geometric vertical accuracy (GVA)	2.1.5.4.19	60
32	Single antenna flag	2.1.5.4.20	N/A
33	NIC supplement flag	2.1.5.4.21	2
34	Selected altitude type	2.1.5.6.1	60
35	Selected altitude setting	2.1.5.6.2	60
36	Barometric pressure setting	2.1.5.6.3	60
37	Selected heading	2.1.5.6.4	60
38	Status of MCP/FCU mode	2.1.5.6.5	60
39	Mode indicators: autopilot engaged	2.1.5.6.6	60
40	Mode indicators: VNAV engaged	2.1.5.6.7	60
41	Mode indicators: altitude hold mode	2.1.5.6.8	60
42	Mode indicators: approach mode	2.1.5.6.9	60
43	Mode indicators: LNAV engaged	2.1.5.6.10	60
44	Radio altitude (Note 2)	2.1.5.2.5.1	2
45	Pressure-altitude disabled (Note 2)	2.1.5.2.2	No limit
46	Airspeed (Note 2)	2.1.5.2.5.1	2

Notes.—

1. *If input is not directly accessible, a means to verify the encoding must be demonstrated.*
2. *These elements are control inputs and are not themselves directly contained in the transmitted ADS-B messages.*

3.1.3.5 Total latency of position measurements

All transmitted messages shall reflect position data with a total latency of no more than 1.5 seconds at the time of message transmission.

Note.— Total latency is defined as time of message transmission minus the time of applicability of the sensor measurement.

3.1.4 Special requirements for transceiver implementations

3.1.4.1 Transmit-receive turnaround time

A transceiver shall be capable of switching from transmission to reception within 2 milliseconds.

Note.— Transmit-to-receive switching time is defined as the time between the optimum sampling point of the last information bit of one transmit message and the optimum sampling point of the first bit of the synchronization sequence of the subsequent receive message.

3.1.4.2 Receive-transmit turnaround time

A transceiver shall be capable of switching from reception to transmission within 2 milliseconds.

Note.— Receive-to-transmit switching time is defined as the time between the optimum sampling point of the last information bit of one receive message and the optimum sampling point of the first bit of the synchronization sequence of the subsequent transmit message.

3.2 GROUND STATION

3.2.1 Procedures for processing of time data

UAT ground station equipment shall utilize time mark information in the following ways:

a) The UAT ground station transmitter message timing accuracy shall comply with the requirements of 3.1.2.2.

b) The UAT ground station receiver time processing shall comply with the requirements of Chapter 5, 5.1.1.

Notes.—

1. *UAT ground station equipment derives its timing for transmitter and receiver functions from GNSS (or equivalent) time sources.*
2. *A possible implementation of the GPS/GNSS time mark pulse is illustrated in Part II, Chapter 5, 5.6.*
3. *Determination of time sources equivalent to a GPS/GNSS time source will be made by the State responsible for providing air traffic services in the airspace concerned. Useful information concerning recommended accuracy of such a time source may be found in Part II, Appendix J.*

3.2.1.1 UTC-coupled condition

The “UTC-coupled” subfield shall be set to ONE, except under the conditions discussed in 3.2.1.2.

Note.— Operation of the UAT ground system in normal mode presumes GNSS, or equivalent, timing.

3.2.1.2 Non-UTC-coupled condition

This condition shall be entered when the UAT ground station equipment has not been provided a GNSS, or equivalent, time mark.

This is not the normal condition; it is a degraded mode of operations. Within 8 seconds of entering the non-UTC-coupled condition, the UAT ground station equipment shall set the “UTC-coupled” subfield to ZERO in any transmitted messages.

3.2.2 UAT ground station media access

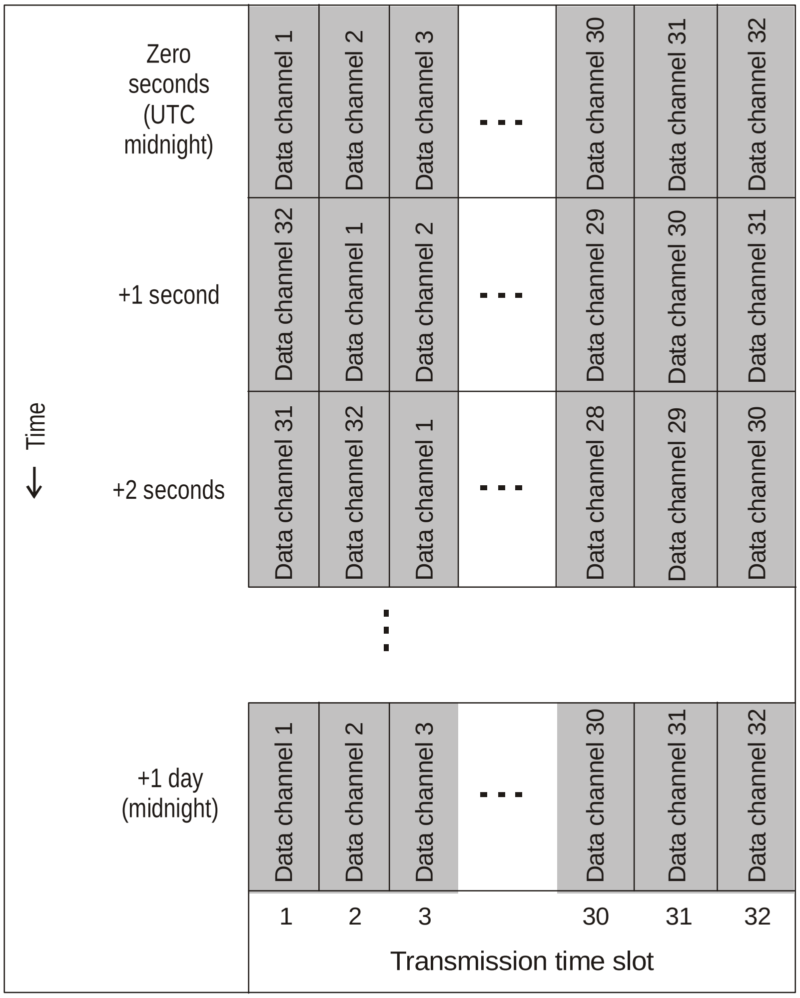
3.2.2.1 Transmission time slots

The UAT ground station shall establish 32 transmission time slots for transmission of ground uplink messages as defined in Table I-3-2.

Table I-3-2. Transmission time slot definition for the UAT ground segment

	Transmission time slot span			*Transmission time slot span*	
Slot ID #	*Starting MSO*	*Ending MSO*	*Slot ID #*	*Starting MSO*	*Ending MSO*
1	0	22	**17**	352	374
2	22	44	**18**	374	396
3	44	66	**19**	396	418
4	66	88	**20**	418	440
5	88	110	**21**	440	462
6	110	132	**22**	462	484
7	132	154	**23**	484	506
8	154	176	**24**	506	528
9	176	198	**25**	528	550
10	198	220	**26**	550	572
11	220	242	**27**	572	594
12	242	264	**28**	594	616
13	264	286	**29**	616	638
14	286	308	**30**	638	660
15	308	330	**31**	660	682
16	330	352	**32**	682	704

Note.— MSOs represent discrete points in time.



Time ↓	1	2	3		30	31	32
Zero seconds (UTC midnight)	Data channel 1	Data channel 2	Data channel 3	. . .	Data channel 30	Data channel 31	Data channel 32
+1 second	Data channel 32	Data channel 1	Data channel 2	. . .	Data channel 29	Data channel 30	Data channel 31
+2 seconds	Data channel 31	Data channel 32	Data channel 1	. . .	Data channel 28	Data channel 29	Data channel 30
	⋮						
+1 day (midnight)	Data channel 1	Data channel 2	Data channel 3	. . .	Data channel 30	Data channel 31	Data channel 32

Figure I-3-1. Relationship of "data channel numbers" to transmission time slot numbers

Notes.—

1. *The reason for the transmission time slot rotation is to make aircraft reception of ground uplink messages from a given ground station robust in the presence of time-synchronized sources of interference in the band.*

2. *With the addition of a leap second, the ground station does not shift slots from the previous second. With the subtraction of a leap second, a shift of slots is omitted.*

3. *Guidance material on the assignment of data channels to different UAT ground stations is contained in Part II, Appendix I.*

3.2.2.2 Transmission time slot rotation and "data channels"

3.2.2.2.1 Transmission time slot resources assignable to the ground station shall be made on a continually shifting basis.

Note.— This assignable resource will be subsequently referred to as a "data channel" to distinguish it from a transmission time slot.

3.2.2.2.2 The transmission time slot used for a given data channel shall increment by 1 time slot per second according to the following rule:

Transmission time slot = 1 + (data channel number + UTC second – 1) mod 32.

3.2.2.2.3 The data channel number and transmission time slot number shall be equal at midnight UTC time and every 32 seconds thereafter (see Figure I-3-1).

3.2.2.3 Transmission of ground uplink message

Ground uplink message transmissions shall begin at the start of the transmission time slot determined by the next available assigned data channel.

Note.— The duration of a ground uplink message is approximately 1.5 milliseconds less than the transmission time slot duration. This additional time provides a propagation guard time when adjacent data channels (transmission time slots) are assigned to ground station sites with common line-of-sight to the same aircraft.

Chapter 4

CRITERIA FOR SUCCESSFUL MESSAGE RECEPTION

Note.— In the UAT SARPs of Annex 10, Volume III, references are made in several places to the term "successful message reception" when describing receiver performance requirements. The specific criteria to which this term refers are provided in this section.

4.1 UAT ADS-B MESSAGES

Upon detection of the ADS-B synchronization sequence, the receiver shall determine successful message reception for a UAT ADS-B message according to the following procedure:

a) The receiver shall attempt to decode the message in the long format using hard decision decoding with no erasures allowed. The decoder shall correct no more than 7 errors. If the RS decoder determines that there are no residual errors after completing the decoding process, and any of the first 5 bits of the message data block (the "MESSAGE DATA BLOCK TYPE CODE" field) has a non-ZERO value, then a successful message reception shall be declared.

b) Otherwise, the receiver shall attempt to decode the message in the basic format using hard decision decoding with no erasures allowed. The decoder shall correct no more than 6 errors. If the RS decoder determines that there are no residual errors after completing the decoding process, and the first 5 bits of the message data block (the "MESSAGE DATA BLOCK TYPE CODE" field) are ALL ZEROS, and the long decoding process fails, then a successful message reception shall be declared.

c) Otherwise, no message reception shall be declared.

Notes.—

1. *This procedure discriminates the basic versus long message format by using the characteristics of the RS code without an explicit length indicator. This procedure prevents erroneous decoding of a long message as a basic message.*

2. *Part II, Appendix D, provides the analytic determination of the undetected message error rate (UMER) achieved through use of the RS coding.*

4.2 GROUND UPLINK MESSAGES

The receiver shall determine successful message reception for a ground uplink message according to the following procedure:

a) Each de-interleaved RS block of the UAT ground uplink message shall be individually examined for errors. Each RS block shall be declared as valid only if it contains no uncorrected error after RS decoding. The decoding process shall use hard decision decoding with no erasures allowed. The decoder shall correct no more than 10 errors per block.

b) Successful message reception shall be declared for a UAT ground uplink message when all six constituent RS blocks are declared valid from 4.2 a).

Note.— Part II, Appendix E, provides the analytic determination of the undetected message error rate (UMER) achieved through use of the RS coding.

Chapter 5

INTERFACE REQUIREMENTS FOR THE AIRCRAFT EQUIPMENT

5.1 UAT RECEIVING SUBSYSTEM OUTPUT REQUIREMENTS (REPORT GENERATION)

ADS-B reports are output from the receiving subsystem in response to UAT messages received. ADS-B reports shall be generated for received message data block types of ZERO (binary 0 0000) through TEN (binary 0 1010).

5.1.1 Receiver time of message receipt

The UAT receiving subsystem shall declare a time of message receipt (TOMR) and include this as part of the report issued to the on-board application systems. The TOMR value shall be reported to within the parameters listed below:

a) range of at least 25 seconds expressed as seconds since GPS midnight modulo the range;

b) resolution of 100 nanoseconds or less;

c) accuracy of ±500 nanoseconds of the actual time of receipt for UAT equipment using either an internal or external UTC-coupled time source.

The reported TOMR will be equal to the following quantity: seconds since the previous UTC midnight modulo the specified TOMR range.

Note.— TOMR is required to support ADS-B time of applicability (TOA) and range validation by a receiving application. See Part II, Appendix H, for a discussion of UAT timing considerations. ADS-B applications derive the TOA from the TOMR as follows:

1) If the report indicates UTC-coupled and is in the non-precision condition, the TOA is the TOMR truncated to the start of the UTC second.

2) If the report indicates UTC-coupled and is in the precision condition, the TOA is the TOMR truncated to the start of the 0.20-second UTC epoch containing the TOMR.

3) If the report indicates non-UTC-coupled, the TOA is the TOMR minus one (1) second.

5.1.2 Report assembly on receipt of ADS-B message

Reports shall contain the following information:

a) all elements of the received message data block applicable to the ADS-B report type with the range, resolution and units of each message data block field preserved;

Note.— Guidance for meeting this requirement when receiving an ADS-B message from a UAT transmitter with a UAT version of one (1) is provided in RTCA DO-282B, Appendix R.

b) the time of message receipt value (5.1.1) measured by the receiver.

Note.— The TOA may be derived by the receiving application from the time of message receipt.

5.1.3 Report assembly on receipt of ground uplink message

Reports may contain the following information:

a) the 432 bytes of unaltered received message data block;

b) the TOMR value (5.1.1) measured by the receiver.

Note.— The TOA may be derived by the receiving application from the time of message receipt.

5.1.4 Message reception to report completion time

5.1.4.1 All UAT ADS-B applicable messages shall be output from the report assembly function within 200 milliseconds of message input.

5.1.4.2 All UAT ground uplink applicable messages shall be output from the report assembly function within 500 milliseconds of message input.

5.2 MUTUAL SUPPRESSION

5.2.1 All UAT equipment classes shall provide an output suitable for sending suppression signals. The UAT equipment shall provide a mutual suppression signal whenever the transmitter output power exceeds –20 dBm. In addition, the suppression signal shall not become active prior to 5 microseconds before the start of the ADS-B message transmission interval (see Annex 10, Volume III, 12.1.2.6 and Figure 12-2). The suppression signal shall not remain active later than 5 microseconds after the end of the ADS-B message transmission interval.

Note.— The tolerance at the beginning and end of the suppression interval ensures that the suppression interval is minimized to prevent excessive receiver blanking of on-board equipment sharing the mutual suppression bus but adequately protects the SSR transponder from triggering on UAT transmissions. The UAT equipment must adhere to the electrical characteristics of the on-board mutual suppression bus and is recommended to provide protection circuitry to prevent against UAT equipment failure disabling the mutual suppression.

5.2.2 No UAT equipment of any equipment class shall respond to suppression signals.

Note.— UAT equipment is not to inhibit or delay its transmissions based on suppression signals. There is no need to desensitize the UAT receiver based on suppression signals.

5.3 VERSION NUMBER PROCESSING BY THE RECEIVING SUBSYSTEM

Irrespective of the value in the UAT version number field identified in Table I-2-35, UAT receiving subsystems that are compliant with this edition of the manual shall decode all of the fields that are identified in Table I-2-2 for all message data block type codes and ignore any fields that are identified as “reserved”.

PART II

IMPLEMENTATION ASPECTS

TABLE OF CONTENTS

APPENDICES

Chapter 1

INTRODUCTION

1.1 OBJECTIVE AND SCOPE

The objective of Part II of this manual is to provide information and guidance related to the implementation of the UAT system.

1.2 OUTLINE OF PART II

Part II of this manual contains guidance material relevant for the implementation of the universal access transceiver (UAT).

Chapter 1 presents the objectives and scope of this part of the manual as well as an outline of its structure. It also provides an explanation of key terms used in this part of the manual.

Chapter 2 describes the applications supported by UAT and the fundamentals of system operation and introduces an example set of aircraft equipage classes.

Chapter 3 provides guidance for scheduling of UAT ADS-B message transmissions by each of the example aircraft equipage classes described in Chapter 2.

Chapter 4 provides guidance on UAT ADS-B transmitter inputs by each of the example aircraft equipage classes described in Chapter 2.

Chapter 5 provides guidance on UAT aircraft installation aspects.

Chapter 6 provides guidance on the implementation of UAT ground infrastructure. Assumptions consistent with this guidance have been used to estimate UAT performance when supporting air-to-ground applications of ADS-B.

Chapter 7 describes UAT frequency planning criteria.

Chapter 8 describes guidance on UAT spurious emissions.

Chapter 9 describes potential future services that could be supported by UAT.

Appendix A summarizes the results of detailed UAT system performance simulations in the standard Interference environments contained in Appendix B. It also includes an estimation of the air-air, air-to-ground and ground-to-air system performances of UAT. All performance estimations reflect the broadcast of state vector (SV), mode status (MS), and intent information (which includes information for both target state (TS) and trajectory change (TC) reports), as appropriate to the UAT equipage class.

Appendix B describes the interference environments when operating UAT in the presence of distance measuring equipment (DME), tactical air navigation (TACAN), joint tactical information distribution system (JTIDS) and multifunctional information distribution system (MIDS) signals as well as the effects of UAT self-interference which were assumed for the performance simulations documented in Appendix A. These environments are based upon traffic scenarios for current and future high-density as well as low-density airspace and in particular contain near-worst-case estimates of interference caused by other systems transmitting on or near the UAT operational frequency of 978 MHz.

Appendix C describes measurement data that were collected on UAT equipment to characterize UAT receiver performance in various interference scenarios including nearby emissions from DME/TACAN, JTIDS/MIDS and the effect of self-interference from other UAT transmissions.

Appendix D describes the UAT error detection and correction performance.

Appendix E describes test results that substantiate compatibility of the operation of DME in the presence of RF UAT signals.

Appendix F contains a specific example of a UAT ADS-B message, formatted in a manner consistent with Chapter 12, 12.4.4, of Annex 10, Volume III, and Chapter 2, 2.1, of Part I of this manual.

Appendix G contains information and guidance regarding UAT aircraft antenna characteristics. A technique for sharing existing SSR transponder antennas with UAT equipment is described.

Appendix H contains an approach for UAT to convey trajectory change (TC) reports, a type of intent information. The appendix contains a description of how up to four (4) different TC reports from each appropriately equipped aircraft may be supported by UAT.

Appendix I contains guidance on UAT ground station data channel assignment.

Appendix J contains information on a future range validation capability for UAT ADS-B messages.

Appendix K contains UAT requirements and desirable features which served as the basis for the design of the UAT system. Performance requirements in Appendix K are based on ADS-B system requirements as understood when the UAT SARPs were developed. ADS-B applications to be supported by UAT have been updated in the Attachment to Appendix K.

1.3 EXPLANATION OF TERMS

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

Accuracy. A degree of conformance between the estimated or measured value and the true value.

Note.— For measured positional data the accuracy is normally expressed in terms of a distance from a stated position within which there is a defined confidence of the true position falling. With specific reference to UAT, accuracy is a measure of the difference between the A/V position reported in the UAT ADS-B message field as compared to the true position. Accuracy is usually defined in statistical terms of either: 1) a mean (bias) and a variation about the mean as defined by the standard deviation (sigma); or 2) a root mean square (rms) value from the mean. The values given in this document are in terms of the two-sigma variation from an assumed zero mean error.

ADS-B broadcast-and-receive equipment. Equipment that can transmit and receive ADS-B messages (defined as Class A equipment).

ADS-B broadcast-only equipment. Equipment that can transmit but not receive ADS-B messages (defined as Class B equipment).

ADS-B message. A modulated packet of formatted data which conveys information used in the development of ADS-B reports.

ADS-B report. Specific information provided by the ADS-B user participant subsystem to external applications. Reports contain identification, state vector and status/intent information. Elements of the ADS-B report that are used and the frequency with which they must be updated will vary by application. The portions of an ADS-B report that are provided will vary by the capabilities of the transmitting participant.

ADS-B subsystem. The set of avionics or equipment that performs ADS-B functionality in an aircraft or for ground-based, non-aircraft participants.

ADS-B system. A collection of ADS-B subsystems wherein ADS-B messages are broadcast and received by appropriately equipped participant subsystems. Capabilities of participant subsystems will vary based upon class of equipage.

Advisory. An annunciation that is generated when crew awareness is required and subsequent crew action may be required; the associated colour is unique but not red or amber/yellow (source: FAA Advisory Circular AC 25 11).

Aircraft address. A unique combination of twenty-four bits available for assignment to an aircraft for the purpose of air-ground communications, navigation and surveillance. In the context of UAT, the term “address” is used to indicate the information field in a UAT ADS-B message that identifies the ADS-B unit that issued the message. The address provides a convenient means by which ADS-B receiving units — or end applications — can sort messages received from multiple issuing units.

Aircraft/vehicle (A/V). Either: 1) a machine or service capable of atmospheric flight; or 2) a vehicle on the airport surface movement area. In addition to A/Vs, ADS-B equipage may be extended to temporarily uncharted obstacles (i.e. obstacles not identified by a current NOTAM).

Applications. The ultimate use of an information system, as distinguished from the system itself. For the case of ADS-B, applications are defined in terms of specific operational scenarios.

Barometric altitude. Geopotential altitude in the earth's atmosphere above mean standard sea level pressure datum surface, measured by a pressure (barometric) altimeter.

Barometric altitude error. For a given true barometric pressure, PO, the error is the difference between the transmitted pressure altitude and the altitude determined using a standard temperature and pressure model with PO.

Call sign. The term “aircraft call sign” means the radiotelephony call sign assigned to an aircraft for voice communications purposes. (This term is sometimes used interchangeably with “flight identification” or “flight ID”). For general aviation aircraft, the aircraft call sign is normally its national registration number; for airline and commuter aircraft, it is usually comprised of the company name and flight number (and therefore not linked to a particular airframe); and for the military, it usually consists of numbers and code words with special significance for the operation being conducted.

Cockpit display of traffic information (CDTI). A generic avionics device on the flight deck that is capable of displaying the position information of nearby aircraft. It may also include ground reference points and navigation information to increase the airborne situational awareness (AIRSAW). In the specific context of UAT, CDTI is a function which provides the pilot/flight-crew with surveillance information about other aircraft, including their position. The information may be presented on a dedicated multi-function display (MFD) or processed for presentation on existing cockpit flight displays. Traffic information for the CDTI function may be obtained from one or multiple sources (including ADS-B, ACAS and TIS) and it may be used for a variety of purposes. Requirements for CDTI information will be based on intended use of the data (i.e. application).

Collision avoidance. An unplanned manoeuvre to avoid a collision.

Conflict. Predicted covering of aircraft in space and time which constitutes a violation of a given separation minima. In the specific context of UAT, conflict is any situation involving two or more aircraft or an aircraft and an airspace or an aircraft and ground terrain, in which the applicable separation minima may be violated.

Conflict management. The process of detecting and resolving conflicts.

Coordinated time scales. A time scale synchronized within stated limits to a reference time scale. Coordinated Universal Time (UTC) is the time scale maintained by Bureau International des Poids et Mesures (BIPM), and the International Earth Rotation Service (IERS), which forms the basis of a coordinated dissemination of standard frequencies and time signals. It corresponds exactly in the rate with the International Atomic Time (TAI), but differs from it by an integer number of seconds.

Data channel. In the context of UAT ground stations, a "data channel" is a time-slot-sized resource assignable to a ground station for the transmission of ground uplink messages. The actual time slot used shifts on a continual basis per a defined time slot rotation scheme.

Data channel block (DCB). The "data channel block" of a UAT ground station is the fixed set of one or more data channels assigned to that UAT ground station.

Eye diagram. The eye diagram of the transmitted UAT waveform can be constructed from a graph of frequency deviation versus time by overlaying multiple versions of the graph shifted by integral numbers of symbol (bit) periods. An example can be seen in Figure II-1-1. The timing of the points where the lines converge defines the "optimum sampling point." Figure II-1-2 shows an eye pattern that has been partially closed.

Field. The elements of the UAT ADS-B message data block. Most of these elements are enumerated in the ADS-B Minimum Aviation System Performance Standards (MASPS) document, RTCA Document DO-242A (e.g. latitude, longitude, velocity).

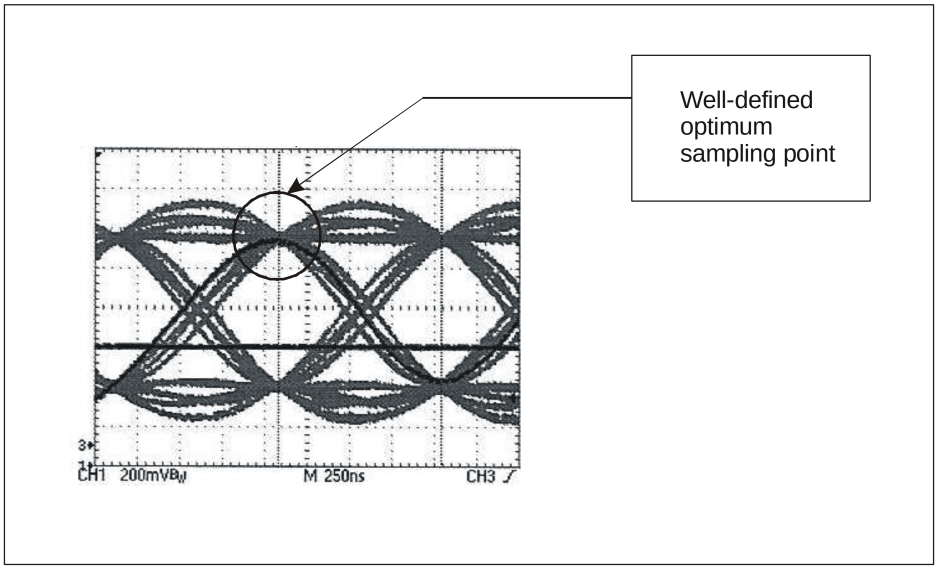
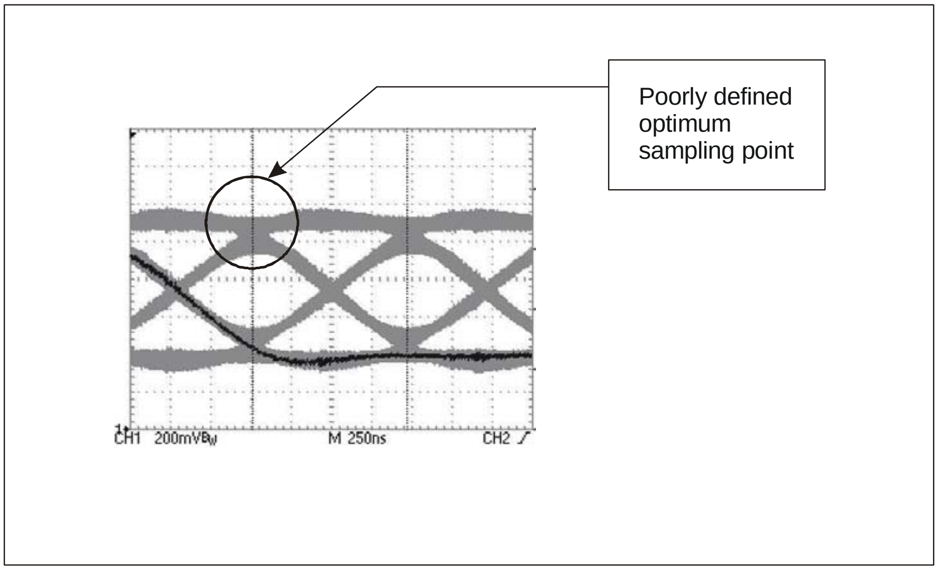


Figure II-1-1. Ideal eye diagram



Poorly defined optimum sampling point

Figure II-1-2. Distorted eye diagram

Global navigation satellite system (GNSS). A worldwide position and time determination system that includes one or more satellite constellations, aircraft receivers and system integrity monitoring, augmented as necessary to support the required navigation performance for the intended operation.

Global positioning system (GPS). The satellite navigation system operated by the United States.

Ground uplink message. A message containing 432 bytes of data transmitted only by UAT ground stations and only within the ground segment of the UAT frame.

Horizontal figure of merit (HFOM). A 95 per cent bound on the horizontal position error.

Joint Tactical Information Distribution System (JTIDS). A military command, control and communications system operated by several States, which is implemented on a frequency hopping basis on 51 frequencies between 969 MHz and 1 206 MHz. This system is also called “Link 16.” A further implementation of this system’s waveform is known as “MIDS” (Multifunction Information Distribution System). This system is operated on a non-interfering basis with aeronautical radio navigation systems.

Latency. The latency of an ADS-B transmission is the time period from the time of applicability of the aircraft/vehicle position ADS-B report until the transmission of that ADS-B report is completed.

Message. The actual RF transmission on the UAT frequency. There are fundamentally two message types: UAT ADS-B messages and UAT ground uplink messages. (See also ADS-B message.)

Message data block (MDB). The portion of the UAT ADS-B message that carries data (user information) that will be consumed by application systems outside the UAT system.

Message data block selection cycle. A 16-second time interval during which each of up to four UAT ADS-B message types is transmitted at least four times (in order to optimize the effect of antenna diversity).

Message overhead. The portion of the message which supports the physical layer transfer of the data.

Message reception and decoding. The primary function of the message reception and decoding function is to deliver all successful message receptions to the report assembly function.

Message start opportunity. Discrete times separated by 250 μs which define the moments when messages can be transmitted. The MSO selected for each transmission changes each second as a result of a pseudorandom process.

Message transmission cycle. A period of 16 seconds in which each MTO appears four times in a pattern that ensures a proper mix of message types are distributed to both top and bottom antennas when diversity transmission is used.

Mode A/C/S. As referred to in this document, Mode A/C transponders are those that conform to the characteristics prescribed in ICAO Annex 10, Volume IV, 3.1.1. Mode S transponders are those that conform to the characteristics prescribed in ICAO Annex 10, Volume IV, 3.1.2. The functional capabilities of Mode A/C transponders are an integral part of those of Mode S transponders.

Optimum sampling point. The point during the bit period at which the opening of the eye diagram (i.e. the minimum separation between positive and negative frequency offsets at very high signal-to-noise ratios) is maximized.

Power measurement point (PMP). A cable connects the antenna to the UAT equipment. The PMP is the end of that cable that attaches to the antenna. All power measurements are considered as being made at the PMP unless otherwise specified. The cable connecting the UAT equipment to the antenna is assumed to have 3 dB of loss.

Product coverage. The geographical area covered by the information contained in a UAT ground uplink message that conveys FIS-B information. This geographical area may be larger or smaller than the service volume of the ground station. It also includes the geographical area covered by the information contained in UAT ADS-B messages broadcast by a single ground station that convey TIS-B information.

Report. The encapsulated message data block elements of received UAT ADS-B messages that are forwarded to on-board application processors. (See ADS-B Report.)

Report assembly function. The report assembly function receives all successful message receptions from the message reception and decoding function and structures reports for delivery to the report output storage buffer.

Required navigation performance (RNP). A statement of the navigation performance necessary for operation within a defined airspace.

Note.— Navigation performance and requirements are defined for a particular RNP type and/or application.

Resolution. A number of units or digits to which a measured or calculated value is expressed and used. In the specific context of UAT, the smallest increment reported in an UAT ADS-B message field. The representation of the least significant bit (LSB) in a UAT ADS-B message field.

Seamless. A “chock-to-chock” continuous and common view of the surveillance situation from the perspective of all users.

State vector. An aircraft or vehicle’s current kinematic state.

Successful message reception. Detection of synchronization pattern and successful FEC decoding for either ADS-B or uplink (i.e. FIS-B) messages.

Target. An aircraft or vehicle from which an ADS-B message can be received, or which can be the subject of a TIS-B message uplinked by a UAT ground station.

Target state (TS) report. The target state (TS) report provides information on the intended horizontal and vertical positions toward which the aircraft is manoeuvring for the active flight segment.

Track angle. Instantaneous angle measured from either true or magnetic north to the aircraft's track.

Traffic information service — broadcast (TIS-B). A service that broadcasts traffic information derived from one or more ground surveillance sources to suitably equipped aircraft or surface vehicles.

Transition level (TRL). The lowest flight level available for use above the transition altitude.

Transponder diplexer channel. RF path of the (optional) diplexer which connects an SSR transponder to the antenna. This RF path provides a passband which includes the 1 030 MHz SSR interrogation frequency and the 1 090 MHz SSR reply frequency.

Trigger. Detection of ADS-B or ground uplink synchronization sequence.

UAT diplexer channel. RF path of the (optional) diplexer which connects the UAT equipment to the antenna. This RF path provides a passband centred at the UAT frequency of 978 MHz.

UAT frame. In the UAT system, the frame is the most fundamental time unit. Frames are one second long and begin at the start of each UTC (or GPS) second. Each frame is divided into two segments: one segment in which ground uplink messages occur and another segment in which ADS-B messages occur.

UTC (Coordinated Universal Time). See coordinated time scales.

UTC 1-second epoch signal. The reference timing used to establish message transmit and reception times with precision, as well as the time of applicability of position and velocity when the UAT transmitter is “UTC coupled” to a GPS/GNSS navigation source.

Vertical figure of merit (VFOM). A 95 per cent bound on the vertical position error.

World Geodetic System (WGS). A consistent set of parameters describing the size and shape of the earth, the positions of a network of points with respect to the centre of mass of the earth, transformations from major geodetic datums and the potential of the earth (usually in terms of harmonic coefficients).

World Geodetic System — 1984. A set of quantities, developed by the U.S. Department of Defense for determining geometric and physical geodetic relationships on a global scale, based on a geocentric origin and a reference ellipsoid with semi-major axis 6378137 and flattening 1/298.257223563.

Chapter 2

OPERATING CONCEPTS

2.1 APPLICATIONS SUPPORTED

2.1.1 Automatic dependent surveillance — broadcast (ADS-B)

2.1.1.1 Automatic dependent surveillance — broadcast (ADS-B) is a means by which aircraft, vehicles and other objects can automatically transmit and/or receive data such as identification, position (latitude, longitude and altitude), velocity, and additional data as appropriate, in a broadcast mode via a data link.

2.1.1.2 When such information is made available through ADS-B transmissions from other nearby aircraft, the relative position and movement of those aircraft with reference to one's own aircraft can be established. Further, ground-based facilities can monitor ADS-B broadcasts to provide surveillance capabilities or to supplement existing surveillance systems. Other data that can be included in an ADS-B message is intent information related to the aircraft's intended flight path, aircraft type and other information.

2.1.1.3 ADS-B is automatic in the sense that no pilot or controller action is required for the information to be transmitted (broadcast). The surveillance provided by ADS-B is dependent in the sense that the aircraft surveillance-type information is derived (dependent) from data provided by on-board navigation equipment.

2.1.1.4 ADS-B is considered to be a key enabling technology to enhance safety and efficiency in airspace operations. These include basic applications, such as the use of ADS-B to enhance the pilot's visual acquisition of other nearby aircraft,[1] as well as more advanced applications, such as enabling enhanced closely spaced parallel approach operations. Other applications involving airport surface operations, improved surveillance in non-radar airspace, and advanced conflict management are also described. Fleet management and search and rescue are also applications that can be supported by ADS-B.

2.1.1.5 Initial PANS-ATM procedures for the use of ADS-B, including ADS-B provided over the UAT data link, will likely use ADS-B in a traditional "radar-like" manner in order to provide separation in airspace that does not have radar coverage. The standardization of air-air use of ADS-B for applications other than those of a purely advisory nature will have a further consequential effect on PANS-ATM and other ICAO documents. Such standardization is likely to build upon efforts currently in progress in several regions to harmonize such applications.

2.1.2 Ground uplink services

2.1.2.1 Traffic information service — broadcast (TIS-B) is a ground-based service intended to provide aircraft with a more complete traffic picture in situations where not all aircraft are equipped with the same ADS-B system, or none at all.

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[1] Ground vehicles on the airport movement area, obstacles, etc., may also transmit UAT ADS-B messages where appropriate. The term "aircraft" may include such other transmitters.

2.1.2.2 When providing surveillance data for non-ADS-B-equipped aircraft, TIS-B involves three major steps. First, another source of surveillance information on non-ADS-B aircraft (such as secondary surveillance radar (SSR)) must be available. Second, this surveillance information must be converted and processed so as to be usable by ADS-B-equipped aircraft. Third, TIS-B conveys this information to aircraft with UAT or other data link systems capable of receiving and processing such information.

2.1.2.3 When providing surveillance data for ADS-B-equipped aircraft that are equipped with a data link other than UAT, the TIS-B service takes as input ADS-B reports from such aircraft and converts those reports to a format appropriate to UAT, for uplink broadcast to UAT-equipped aircraft.

2.1.2.4 UAT preferably supports TIS-B by having UAT ground uplink stations transmit TIS-B information for each aircraft in the format of UAT ADS-B messages in the ADS-B segment of the UAT frame. The discussion of TIS-B in this manual is based upon supporting TIS-B through uplink ADS-B messages. Alternatively, if necessary, TIS-B information could be broadcast in the ground segment of the UAT frame, but not in the format of a UAT ADS-B message.

2.1.2.5 FIS-B is the ground-to-air broadcast of advisory information needed by pilots to operate more safely and efficiently. For example, FIS-B may provide weather graphics and text (e.g. METAR and TAF), special use airspace information, notices to airmen (NOTAM) and other information. UAT has been designed to support the broadcast of FIS-B information in the ground segment of the UAT frame using the ground uplink message.

2.1.3 UAT broadcast connectivity

2.1.3.1 Figure II-2-1 shows the connectivity supported by UAT for ADS-B air-air, ADS-B air-to-ground and the uplink services of TIS-B and FIS-B.

2.1.3.2 Aircraft UAT equipment may support transmit-only or transmit and receive capability. When aircraft are in the service volume of a ground station, uplink services may be provided and the ground station can serve as a surveillance sensor for ground-based ADS-B applications. Regardless of whether aircraft users are in coverage of a ground station or not, air-air ADS-B connectivity is available. While networking of ground stations can offer certain advantages, each can also operate independently of others if desired. Requirements for coordination among ground stations are that they all operate on a common time standard (as do UAT avionics) and that the ground uplink data channels (see Chapter 6, 6.2.1) on which they transmit are assigned through appropriate coordination on a regional basis.

2.1.3.3 Appendix A presents performance estimates for the UAT system under a variety of different operational scenarios. The information in Appendix A is intended to provide guidance on the expected performance (compared with UAT requirements and desirable features in Appendix K) in different types of airspace regions for States that wish to implement a UAT capability. Detailed results of full-scale multi-aircraft simulations are shown for air-air, air-to-ground and ground-to-air performance for two high-density air traffic scenarios and one low-density scenario. In addition, performance results for several specific circumstances are presented, including track acquisition, surface-surface and reception of aircraft on approach.

2.1.3.4 The two high-density air traffic scenarios are intended to represent worst-case stressful conditions for an ADS-B link. One of these, the Los Angeles (LA) 2020 scenario, is a scenario that was developed to represent a single high-density central region with a large percentage of low-flying aircraft. The other, Core Europe (CE) 2015, has five high-density regions around TMAs and includes a large percentage of high-altitude aircraft. The low-density scenario is made up of a much smaller, uniform density of high-flying aircraft spread out over a large area. Each of these scenarios is meant to represent a different type of airspace that may resemble one where implementation is planned. A State wishing to implement UAT in an airspace region resembling one of these could expect to achieve performance results no worse than those presented in Appendix A.

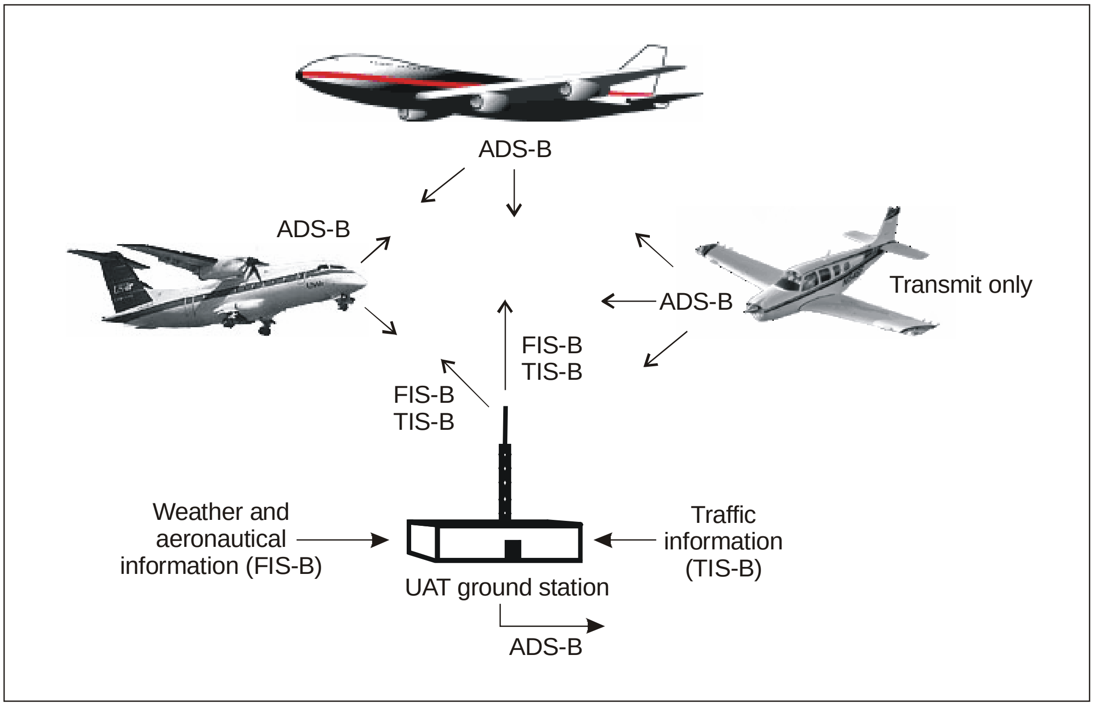

Figure II-2-1. UAT connectivity

2.1.3.5 The LA 2020 scenario performance results may be expected to be valid for a central region of high density, gradually tapering off outside that region, with a large percentage of general aviation aircraft. This scenario is also characterized by the absence of a DME/TACAN at 979 MHz, although one as close in frequency as 980 MHz could operate in this environment and not materially affect the performance results presented in Appendix A. A State wishing to implement UAT in a high-density air traffic region in the absence of DME/TACAN interference sources at 979 MHz could expect performance results no worse than those presented in Appendix A, 4.1, for LA 2020. For example, as illustrated in Appendix A, Figure II-A-20, in LA 2020 air-to-ground update rates are expected to meet or exceed those for typical radar scan rates for all aircraft equipage classes to well past 100 NM.

2.1.3.6 The CE 2015 scenario performance results may be used to predict expected performance in a high-density region in the presence of a number of high power DME/TACANs at 979 MHz. One of the performance evaluation points used in this scenario was chosen to be the worst-case DME/TACAN location. This location was selected to provide the highest interference from DME/TACANs. The worst-case DME/TACAN environment selection required moving a high-power mobile 979 MHz TACAN to a particular location near several other 979 MHz TACANs and placing the receive evaluation point in the midst of these interference sources. A State wishing to implement UAT in a high-density air traffic region in the presence of DME/TACAN interference sources could expect performance results no worse than those presented in Appendix A, 4.2, for CE 2015.

2.1.3.7 A further aspect of the CE 2015 scenario is the large proportion of aircraft flying at high altitudes. This characteristic of the scenario results in a UAT ground station receiving transmissions from a very large number of aircraft-in-view. In order to achieve satisfactory air-to-ground reception at all ranges to 150 NM for all UAT-equipped aircraft, UAT ground station design should include a higher performance receive antenna than the omnidirectional antenna discussed in Chapter 2, 2.5. For example, Appendix A, Figure II-A-30, illustrates expected air-to-ground performance for a UAT ground station using an omnidirectional antenna in the CE 2015 scenario at Brussels (BRU). As illustrated in Appendix A, Figure II-A-31, in order to achieve typical radar scan rates for air-to-ground reception out to 150 NM in the CE 2015 environment, a three-sector receive antenna would be required.

2.1.3.8 Another consideration for States wishing to implement UAT in the presence of a high-power 979 MHz DME/TACAN located near a potential UAT ground receiver is what siting restrictions would be necessary. While the UAT transmissions would not pose restrictive interference with the DME/TACAN performance, Chapter 7, 7.2, describes some of the restrictions on the range between the DME/TACAN and the UAT receiver that would be necessary to prevent the DME/TACAN transmissions from hindering UAT air-to-ground receive performance.

2.1.3.9 The low-density scenario is intended to represent a typical en-route airspace region. A State wishing to implement UAT in an environment such as this could expect performance that would be no worse than that shown in Appendix A for low density.

2.2 FREQUENCY CHANNEL AND WAVEFORM DESCRIPTION

2.2.1 The UAT employs the single common frequency channel at 978 MHz for both the aircraft and ground-based transmissions and has a signalling rate of just over 1 Mbps. The single-channel architecture ensures seamless air-air connectivity and obviates the need for multi-channel receivers or tuning procedures. The UAT frequency channel has been sized to ensure adequate ADS-B performance is maintained in future high-density traffic environments. Additionally, the UAT waveform has been designed specifically to provide tolerance to intra-system interference and other pulsed interference encountered on nearby frequencies (e.g. DME/TACAN). The UAT waveform is defined in the UAT SARPs of Annex 10, Volume III.

2.2.2 Detailed information on UAT ADS-B performance assessment in low-density and in current and future high-density traffic airspace is provided in Appendix A. This assessment also accounts for expected sources of interference from other systems in the 960 MHz to 1 215 MHz as described in Appendix B. Appendix C describes the bench test measurements used to develop receiver performance models that provide a basis for the simulations in Appendix A.

2.2.3 There are two types of broadcast transmissions — or messages — on the UAT frequency channel: the UAT ADS-B message (from aircraft, surface vehicles or ground stations (for TIS-B messages)) and the UAT ground uplink message. Regardless of type, each message has two fundamental components: the message data block that contains user information, and message overhead, primarily consisting of forward error correction (FEC) code parity that supports the error-free transfer of the data. The FEC was selected to ensure that UAT messages would be received with an undetected error rate, at the UAT link layer, of at most one in 10^{-8} per UAT message. Details on the format of these message types are provided in Annex 10, Volume III, Chapter 12, 12.4.4. Details on the contents and format of the message data blocks are provided in Part I, Chapter 2, 2.1.

2.2.4 Information on the error detection and correction performance of the UAT FEC scheme is provided in Appendix D, and test results assessing the impact of UAT signals on DME interrogator receivers are presented in Appendix E. Guidance on sharing antennas with SSR transponders is provided in Appendix G. The output of suppression pulses by UAT equipment and the impact of UAT on other on-board systems operating in the 960 MHz to 1 215 MHz frequency band are discussed in Chapter 5, 5.1 and 5.2.

2.3 TIMING STRUCTURE AND MEDIUM ACCESS

2.3.1 General

2.3.1.1 UAT support for multiple services is accomplished using a hybrid medium access approach that incorporates both time-slotted and pseudorandom access. By virtue of its waveform, modulation rate, precise time reference and message-starting discipline, UAT may in the future be used for independent validation of position information of received UAT ADS-B messages (see Chapter 9).

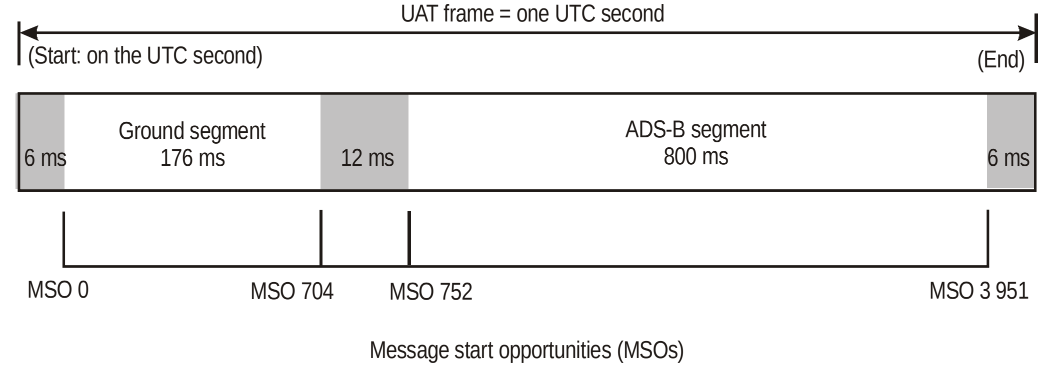

Figure II-2-2. UAT frame

Notes.—

1. *Shaded segments represent guard times for signal propagation and timing drift (not to scale).*

2. *When the last MSO is selected for the transmission of a UAT ADS-B message, part of a transmission (20 microseconds for a basic UAT message and 180 microseconds for a long UAT message) will occur within the final guard interval of 6 milliseconds.*

2.3.1.2 Figure II-2-2 illustrates the message timing structure called a UAT frame. A UAT frame is one second long and begins at the start of each Coordinated Universal Time (UTC) second. Each UAT frame is divided into two segments:

a) the ground segment in which UAT ground uplink messages are broadcast in one or more time slots; and

b) the ADS-B segment in which UAT ADS-B messages are broadcast.

2.3.1.3 Guard times are incorporated between the segments to allow for signal propagation and timing drift. The UAT frame contains 3 952 message start opportunities (MSOs) that are spaced at 250 µs intervals. This spacing represents the smallest time increment used by UAT for scheduling message transmissions, and each transmission must start only at a valid MSO.

Note.— The MSO concept was established primarily to govern the transmission protocol used by avionics UAT transmitters — as detailed in Part I, Chapter 3, 3.1.2. The MSO serves to constrain the pseudorandom transmit time to a finite number of time-synchronized possibilities spaced evenly throughout the allowed UAT ADS-B message transmission interval (i.e. ADS-B segment). Using a transmission protocol constrained to a set of synchronized MSOs, as opposed to a totally random approach, allows a receiver to infer the precise time of transmission, thus allowing a measurement of the propagation time of a UAT message.

2.3.1.4 For consistency, the same MSO framework is used to define the time slots used for transmission of UAT ground uplink messages by UAT ground stations as detailed in Part I, Chapter 3, 3.2.2. The ground segment contains 32 transmission time slots, each consisting of 22 MSOs.

2.3.1.5 As shown in Figure II-2-2, 176 milliseconds in each 1-second UAT frame are devoted to UAT ground uplink message transmissions, and 800 milliseconds are devoted to UAT ADS-B message transmissions. MSOs start at the end of the initial 6-milllisecond data block guard-time, are spaced at 250 µs intervals and are numbered sequentially from 0 through 3 951. In the 12-millisecond guard-time between the ground segment and the ADS-B segment no messages are transmitted, bringing the total of MSOs available to 3 904.

2.3.2 UAT ADS-B message transmission by aircraft

2.3.2.1 As shown in Figure II-2-2, the ADS-B segment of each UAT frame is 800 milliseconds long and spans 3 200 MSOs (i.e. from MSO 752 to MSO 3 951). All UAT ADS-B messages, including ADS-B messages containing TIS-B information that are generated by ground stations, are transmitted in this segment of the frame. Each UAT-equipped aircraft or vehicle generates only one UAT ADS-B message transmission per frame and makes a pseudorandom selection from among any of the 3 200 MSOs in the segment to start transmission of the message. Approximately 6 milliseconds of guard-time are appended after the ADS-B segment to fill out the UAT frame to the end of the UTC second.

2.3.2.2 The pseudorandom selection of an MSO within each UAT frame for the start of an aircraft's UAT ADS-B message is intended to prevent two aircraft from systematically interfering with each other's UAT ADS-B message transmissions.

2.3.2.3 Construction of an example UAT ADS-B message data block, including the FEC, is provided in Appendix F.

2.3.3 Ground uplink services

2.3.3.1 UAT ground uplink messages are used to support services such as FIS-B. UAT ground uplink messages will occur within one or more of the 32 time slots defined within the ground segment of the UAT frame. Detailed procedures for UAT ground uplink message transmission are provided in Part I, Chapter 3, 3.2.2.

2.3.3.2 UAT ground stations can support TIS-B through the transmission of individual messages in the UAT ADS-B format in the ADS-B segment of the UAT frame. This includes re-transmission from ADS-B messages available at the ground from other ADS-B systems or from primary or secondary radar. Using this approach, TIS-B transmissions will appear to be nearly identical to UAT ADS-B messages, both in terms of message format and media access. Each such TIS-B transmission must start only at a valid MSO as is the case with transmission of ADS-B messages from aircraft.

2.4 BASIC AVIONICS OPERATION AND EQUIPAGE LEVELS

2.4.1 Avionics operating concept

2.4.1.1 Implementations will consist of transmit-and-receive subsystems. Most implementations will include both subsystems; however, transmit-only configurations are also possible. Figure II-2-3 shows the high-level functions of an avionics implementation that supports both transmission and reception.

2.4.1.2 The UAT ADS-B transmitting subsystem performs the following basic functions:

a) determines the proper message format based on the predetermined (fixed) message transmit schedule;

b) acquires various inputs for elements of the UAT ADS-B message and formats those elements into the UAT ADS-B message structure;

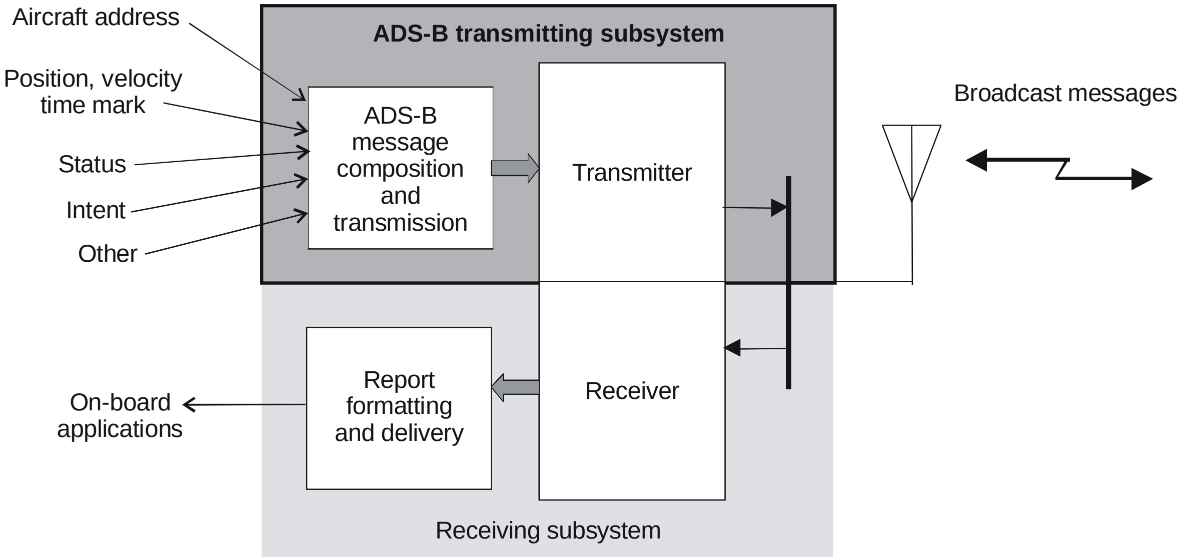

Figure II-2-3. High-level function of UAT avionics

c) determines the appropriate MSO for transmission (once per second) based on pseudorandom seed;

d) selects the antenna for transmission (for installations requiring transmit diversity, see 2.4.2);

e) transmits the UAT ADS-B message over the UAT frequency channel.

These functions result in one UAT ADS-B message being transmitted each second. Additionally, the UAT ADS-B transmitting subsystem may make use of information indicating whether the vertical status of the aircraft is “ON GROUND” or “AIRBORNE”. Where this information is available, the UAT ADS-B message format and MSO selection algorithm change in several respects depending on the vertical status declared. Further information may be found in Chapter 3, 3.1.2, as well as in Part I, Chapter 2, 2.1.5 and Part I, Chapter 3, 3.1.2.1.

2.4.1.3 The UAT receiving subsystem performs the following basic functions:

a) selects the antenna for reception (in installations that employ antenna switching but does not employ receiver diversity; see 2.4.2);

b) detects and decodes UAT messages (both ground uplink messages and UAT ADS-B messages) on the UAT frequency channel;

c) applies “successful message reception” criteria to each detected message to ensure integrity (see Part I, Chapter 4);

d) for each successful message reception, formats the resulting message data block for use by on-board applications.

2.4.1.4 Each UAT message successfully received will trigger the generation of a report, which includes the message data block information of that message and an indication of the time (time stamp) indicating when the message was received. Forward error correction coding is used to ensure that the received message is identical to that transmitted.

2.4.2 UAT equipage classes

2.4.2.1 Examples

2.4.2.1.1 RTCA has categorized ADS-B equipment (other than ground stations) into equipage classes as defined in RTCA/DO-242A, the ADS-B Minimum Aviation System Performance Standards (MASPS). This categorization is based on potential ADS-B applications and the needs of particular airspace users. This manual provides, for exemplary purposes, configurations of UAT avionics consistent with the RTCA equipage categories. Appendix A provides projected UAT performance for each of these equipage classes using both high- and low-density traffic scenarios. For UAT ADS-B equipment, the installed performance of these equipment classes is defined in Table II-2-1.

2.4.2.1.2 Aircraft systems supporting both transmission and reception of UAT messages, termed Class A UAT systems, are defined by equipage classification according to the provided user capability. All Class A UAT aircraft configurations support the provision of at least basic air-to-ground ATC surveillance services to an estimated range of 150 NM (see Appendix A for supporting analysis and UAT ground station receiver assumptions). The variations listed below are primarily distinguished by their support of air-air applications. The following types of Class A[2] systems are defined:

a) *Class A0.* Supports minimum message transmission and reception capability for UAT-equipped aircraft that always operate below 18 000 feet MSL. Air-air ADS-B applications for this class of equipage are intended to support a range of at least 10 NM between participants (an air-air range of at least 20 NM has been projected). UAT ADS-B messages are based upon source data available on the aircraft. UAT ADS-B messages received from other aircraft support generation of UAT ADS-B reports that are used by on-board applications.

b) *Class A1.* Supports all Class A0 functionality and supports ADS-B air-air applications to a range of at least 20 NM between participants. The Class A1 equipage class has been divided into three classes. Class A1 low (A1L) is to be used by aircraft that always operate below 18 000 feet MSL; Class A1 single antenna (A1S) and A1 high (A1H) are used by aircraft operating at all altitudes. The major equipment performance difference between classes A1L and A1H is the transmitter RF output power. An air-air range of at least 40 NM has been projected for Class A1H equipment.

c) *Class A2.* Supports all Class A1 functionality and supports ADS-B air-air applications to a range of at least 40 NM between participants. Additional data is supplied in ADS-B messages to support further ADS-B air-air applications for receiving aircraft. This service requires the broadcast and receipt of intent information contained in target state and trajectory change reports.

d) *Class A3.* Supports all Class A2 functionality and supports ADS-B air-air applications between A3-equipped users to a range of at least 120 NM. Class A3 has the ability to broadcast and receive multiple trajectory change reports. The analysis in Appendix A, which assumes a particular method of transmitting two trajectory change reports, indicates that the exchange of a second trajectory change report at distances of 120 NM is accomplished at approximately one-half of the update rate of the first trajectory change report. Alternative methods of transmitting up to four trajectory change reports for an ADS-B system participant are discussed in Appendix H.

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[2] There may be future recognition of receive-only configurations in which the requirements for an appropriate Class A receive capability are met. Such configurations would be intended for use only in aircraft that support an interactive capability on an alternate ADS-B data link.

Table II-2-1. Examples of UAT installed equipment classes

Equipage class	*Air-to-air application ranges supported*	*Transmit RF power delivered to antenna system*	*Intended antenna diversity (when airborne for Classes A and B0–B1)*	
			Transmit	*Receive*
A0	10 NM	Low power (Altitude always below 18 000 feet)	Single antenna (see Note 4)	Single antenna (see Note 4)
A1L	20 NM		Alternating every 2 seconds	Alternating every second
A1S		Medium power	Single antenna (see Note 4)	Single antenna (see Note 4)
A1H		Medium power	Alternating every 2 seconds	Alternating every second
A2	40 NM	Medium power	Alternating every 2 seconds	Dual receiver
A3	120 NM	High power	Alternating every 2 seconds	Dual receiver
B0	10 NM	Low power (Altitude always below 18 000 feet)	Single antenna (see Note 4)	N/A
B1	20 NM	Medium power	Alternating every 2 seconds	N/A
B1S	20 NM	Medium power	Single antenna (see Note 4)	N/A
B2	5 NM	+28 to +32 dBm	Single antenna	N/A
B3	5 NM	+30 dBm (minimum)	Single antenna	N /A
Ground station	Specified by the service provider to meet local requirements within the constraint of Annex 10, Volume III, Chapter 12, 12.1.2.3.2.			

Notes.—

1. *See 2.4.2.2 which defines the transmitter RF power levels.*

2. *Transmitter RF power requirement depends on the aircraft maximum altitude capability. Low-altitude aircraft (maximum certified altitude for aircraft <18 000 feet MSL) need not support the higher-power transmitter requirements due to line-of-sight limitations.*

3. *Top antenna is not required if the use of a single antenna does not degrade signal propagation. This allows for single-antenna installation on radio-transparent airframes.*

4. *For single-antenna A1S/B1S installation, antenna gain pattern performance will need to be shown at least equivalent to that of a quarter-wave resonant antenna mounted on the fuselage bottom surface. For single-antenna A0/B0 installations, such an analysis should be performed.*

5. *For further information on antenna diversity, see RTCA DO-282A, 2.2.8.1 and 2.2.6.1.3, or equivalent certification guidance.*

6. *Consistent with Annex 10, Volume III, Chapter 12, Table 12-1, projected performance is 20 NM for Class A0 and 40 NM for Class A1H. The intended ranges in Table 12-1 were taken from Appendix K to this manual and used as "design-to" numbers.*

2.4.2.1.3 The UAT SARPs in Annex 10, Volume III, refer to “standard” and “high-performance” receivers. Class A3 equipment employs the high-performance receiver and the remaining Class A equipment employs the standard receiver. The performance projections in Appendix A assume that receivers for UAT ground stations are standard receivers with a receiver sensitivity at the unit 2 dB better than the sensitivity of a standard receiver in an aircraft.

2.4.2.1.4 The high-performance receiver employs a narrower bandwidth filter to allow it to better reject adjacent frequency DME emissions. The use of high-performance receivers is recommended to support longer range air-air ADS-B applications in airspace which has a significant number of DME assignments on frequencies adjacent to the 978-MHz UAT transmission frequency. The narrow bandwidth introduces some distortion of the desired signal, which degrades the performance in the presence of self-interference. However the benefit of rejecting the DME energy offsets this effect in terms of overall performance. The full effect of the narrow bandwidth filter was accounted for in the performance assessments in Appendix A.

2.4.2.1.5 Table 12-4 of Annex 10, Volume III, Chapter 12, specifies a more stringent receiver rejection ratio for high-performance receivers at a 1 MHz offset from the UAT frequency of 978 MHz than at a –1 MHz offset. This higher rejection ratio requirement was adopted to provide additional performance margin for aircraft UAT equipment operating in a high-density 979-MHz DME environment, as is found in the European Region. Additionally, the rejection characteristics in Table 12-4 were found to be provided by readily available avionics components. Should DME operation at 977 MHz reach the level that presently exists at 979 MHz, a symmetric rejection ratio at ±1 MHz of 40 dB would be desirable.

2.4.2.1.6 Some UAT ADS-B system participants will not need to receive information from other participants but will only need to broadcast their state vector and associated data. Class B UAT ADS-B systems meet the needs of these participants. Class B UAT systems are defined as follows:

a) *Class B0: Aircraft broadcast-only system.* Class B0 UAT systems require an interface with own-platform navigation systems. Class B0 UAT systems require transmit powers and information capabilities equivalent to those of Class A0. Class B0 installations are on aircraft that always operate below 18 000 feet MSL.

b) *Class B1: Aircraft broadcast-only system.* Class B1 UAT systems require an interface with own-platform navigation systems. Class B1 UAT systems require transmit powers and information capabilities equivalent to those of Class A1H.

c) *Class B2: Vehicle broadcast-only UAT ADS-B system.* Class B2 UAT systems require a high-accuracy source of navigation data and a nominal 5 NM effective broadcast range. Vehicles qualifying for UAT ADS-B equipage may be limited to those that operate within the airport surface movement area.

d) *Class B3: Fixed obstacle broadcast-only UAT ADS-B system.* Class B3 UAT systems do not require a source of navigation data (their position can be determined through an appropriate pre-installation survey) and a nominal 5 NM effective broadcast range. Collocation of the transmitting antenna with the obstacle is not required as long as broadcast service volume requirements are met. Structures and obstructions identified by appropriate ATS authorities as safety hazards may have their positions communicated to aircraft using UAT.

UAT ground stations are discussed further in 2.5.

2.4.2.1.7 The complete set of ADS-B information transmitted will vary somewhat for each equipment class as determined by the schedule of UAT ADS-B message data blocks to be transmitted by each equipment class (see Chapter 3, 3.1.1). Receiving applications can infer the equipment class of a system participant by observing the set of UAT ADS-B message data blocks being received from each participant. Certain air-air applications may require the receiving application to determine the applications supported by ADS-B targets under surveillance. In the future this information will be explicitly encoded in the message data block of the MODE STATUS element (see Part I, Chapter 2, 2.1.5.4).

2.4.2.1.8 Important characteristics of the UAT ADS-B Class A and Class B equipage classes are summarized in Table II-2-1.

2.4.2.2 UAT ADS-B aircraft transmitting subsystem

A UAT ADS-B aircraft transmitting subsystem is classified according to the unit's range capability and the set of parameters it is capable of transmitting. Table II-2-2, adapted from Table 12-1 of Annex 10, Volume III, Chapter 12, defines the transmitter power levels.

Table II-2-2. Transmitter power levels

Transmitter type	*Minimum power at PMP*	*Maximum power at PMP*	*Intended minimum air-air ranges*
Aircraft (low)	7 watts (+38.5 dBm)	18 watts (+42.5 dBm)	20 NM
Aircraft (medium)	16 watts (+42 dBm)	40 watts (+46 dBm)	40 NM
Aircraft (high)	100 watts (+50 dBm)	250 watts (+54 dBm)	120 NM

2.4.2.3 UAT aircraft receiving subsystem

All UAT aircraft receivers have the same receiver sensitivity requirements. The receiver sensitivity at the PMP, for 90 per cent message success rate in the absence of interference, is –93 dBm for long UAT ADS-B messages, –94 dBm for basic UAT ADS-B messages and –91 dBm for ground uplink (ground-to-air) messages. Performance of UAT aircraft receivers in the presence of interference is discussed in Appendices B and D.

2.5 GROUND STATION OPERATION

2.5.1 The UAT ground station will operate as a UAT ADS-B sensor similar to that of aircraft units. The UAT system has been designed to support line-of-sight air-to-ground ADS-B service volume for a single ground station, even in future high-density airspace. The UAT ground station is also capable of transmitting UAT ground uplink messages in one or more of the 32 ground segment time slots assigned to the ground station. TIS-B transmissions from a UAT ground station can utilize the UAT ADS-B message format in the ADS-B segment of the UAT frame. In this event, the aircraft UAT receiving subsystem makes no distinction in its processing of UAT ADS-B messages from other aircraft or TIS-B data in the format of a UAT ADS-B message from a ground station (although the aircraft application can distinguish these via the address qualifier field). Alternatively, in particular traffic environments, a UAT ground station may transmit TIS-B information in one or more of the 32 assigned ground segment time slots.

2.5.2 The typical UAT ground station antenna has an antenna gain of 6 to 8 dBi, with an omnidirectional antenna pattern (the maximum EIRP of the UAT ground station is 58 dBm, as per Annex 10, Volume III, Chapter 12, 12.1.2.3.2). High-density traffic environments may require use of separate transmit-and-receive antennas and/or sectorized receive antennas (see Appendix G). The air-to-ground performance simulation results in Appendix A were based on a ground station receiver sensitivity of –98 dBm, measured at the PMP. Additionally, it was assumed that the maximum tolerable power level of continuous wave interference at 978 MHz was –106 dBm at the PMP. Figure II-2-4 gives an overview of the ground station.

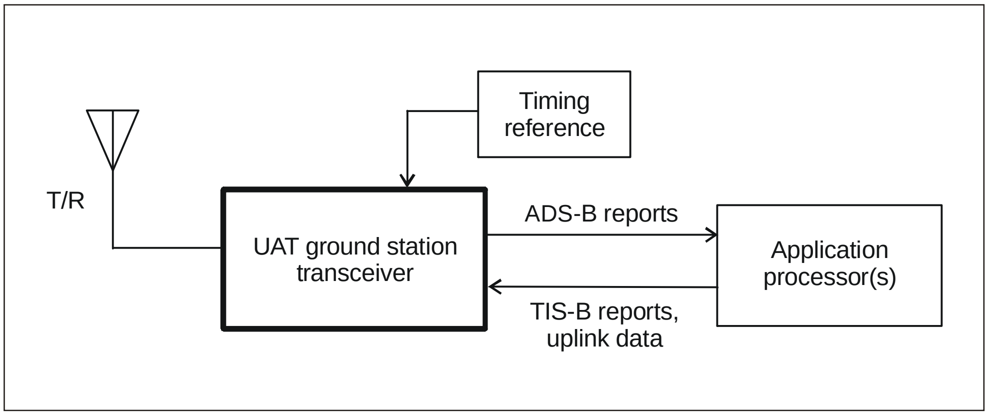

Figure II-2-4. UAT ground station simplified block diagram

2.5.3 A single UAT ground station is capable of supporting the following functions:

a) receiving air-to-ground UAT ADS-B messages and producing UAT ADS-B reports;

b) ground broadcast transmission (e.g. TIS-B, FIS-B);

c) providing backup timing for aircraft (see Part I, Chapter 3, 3.1.1.2.3). In order to implement this backup timing capability the ground station will need to provide ground uplink messages on a regular basis.

Additional guidance on the working concept for a UAT ground infrastructure is provided in Chapter 6 of this manual.

Chapter 3

SCHEDULING OF UAT ADS-B MESSAGES

3.1 MESSAGE DATA BLOCK SELECTION CYCLE

UAT ADS-B message data block types are to be transmitted according to a message data block selection cycle defined to ensure timely transmission of appropriate ADS-B information. For the exemplary equipment classes of Chapter 2, Table II-2-1, UAT ADS-B messages of seven different message data block types (out of 32 possible message data block types) have been defined. Each equipment class transmits up to four of these message data block types in a pre-determined sequence: message data block selection (MDBS)-A, MDBS-B, MDBS-C and MDBS-D.

3.1.1 ADS-B message data block type transmission sequence

For the equipment classes of Chapter 2, Table II-2-1, Table II-3-1 specifies the message data block selections, using UAT ADS-B message data block type codes defined in Part I, Chapter 2, Table I-2-2.

Table II-3-1. Message data block type code transmission sequence

Equipment class	*MDBS-A*	*MDBS-B*	*MDBS-C*	*MDBS-D*
A0, A1L, A1S, A1H, B0, B1S, B1	1	0	2	0
A1H, B1 (see Note 2)	3	6	0	6
A2	1	4	4	4
A3	1	4	5	4
B2, B3	1	0	0	0

Notes.—

1. *This schedule is to be followed regardless of the unavailability of any message data block fields.*
2. *Optional message data block type code assignment if the installation can support transmission of target state information.*

3.1.2 Event-driven ADS-B message data block allocation

3.1.2.1 Immediately following any modification of the fight plan ID (see Part I, Chapter 2, 2.1.5.4.5), the message data block selection sequences specified in 3.1.1 shall be modified for a period of 6 seconds. For 6 consecutive seconds all transmissions from all equipment classes shall be message data block type codes 1 or 3, as appropriate for the equipment class. During this interval, the flight plan ID shall be transmitted in every message and the CSID flag (see Part I, Chapter 2, 2.1.5.4.16) will be set to the value ZERO (0).

3.1.2.2 Immediately following any modification of the emergency/priority status selection input (see Part I, Chapter 2, 2.1.5.4.6), the message data block selection sequences specified in 3.1.1 shall be modified for a period of 6 seconds. For 6 consecutive seconds all transmissions from all equipment classes shall be message data block type code 1 or 3, as appropriate for the equipment class.

3.1.2.3 Immediately following any modification of the NIC supplement (NIC_{SUPP}) input (see Part I, Chapter 2, 2.1.5.4.21), the message data block selection sequences specified in 3.1.1 shall be modified for a period of 6 seconds. For 6 consecutive seconds all transmissions from all equipment classes shall be message data block type code 1 or 3, as appropriate for the equipment class.

3.1.2.4 Immediately following any modification of the IDENT switch active input (see Part I, Chapter 2, 2.1.5.4.15.2), the message data block selection sequences specified in 3.1.1 shall be modified for a period of 6 seconds. For 6 consecutive seconds all transmissions from all equipment classes shall be message data block type code 1 or 3, as appropriate for the equipment class.

3.1.2.5 After the transmission of 6 event-driven messages is completed, the transmission sequence specified in 3.1.1 shall be resumed unless one or more triggering events occurred during the 6 seconds. In that case, the transmission of only message data block type 1 or 3, as appropriate for the equipment class, shall continue until no triggering event has occurred within the most recent 6 seconds.

Note.— The revised sequence provides for the transmission of a MODE STATUS element containing the flight plan ID in every ADS-B message whenever the flight ID is changed. The MODE STATUS element also contains the EMERGENCY/PRIORITY STATUS field. Transmission of the MS element at a high rate allows recipients to rapidly update the flight plan ID and/or emergency/priority status in the event of a change.

3.1.3 Message transmission cycle

A message transmission cycle of 16 seconds is defined to ensure a proper mix of message data blocks for installations that support ADS-B message transmission from dual (diversity) antennas. When an aircraft is determined to be in the airborne condition, transmissions occur through top (T) (if so equipped) and bottom (B) antennas, each message transmission cycle as shown in Figure II-3-1.

Antenna	T	T	B	B	T	T	B	B	T	T	B	B	T	T	B	B
MDBS #	A	B	C	D	D	A	B	C	C	D	A	B	B	C	D	A
Seconds	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

Message transmission cycle

Time

Figure II-3-1. Transmitter antenna use for diversity installations

Notes.—

1. *There is no requirement that the message transmission sequence be aligned in time between different aircraft/vehicles (A/Vs); the sequence is defined for each A/V to ensure a proper mix of transmitted message types from the A/V.*

2. *For Class A1 receivers with antenna diversity provided by switching according to Chapter 2, 2.4.2, the transmission pattern in Table II-3-1 ensures that each message data block type transmitted by a UAT aircraft according to the transmission pattern is received by the Class A1 receiver using each possible transmit (by the UAT aircraft) /receive (by the A1 receiver) antenna combination once every 16 seconds.*

When an aircraft is determined to be in the on-ground condition, the top antenna (if so equipped) is selected for all transmissions. The transmission sequences are as shown in Figure II-3-1, second and third rows.

Chapter 4

UAT AIRCRAFT/VEHICLE ADS-B TRANSMITTING SUBSYSTEM INPUT REQUIREMENTS

4.1 The UAT aircraft/vehicle (A/V) ADS-B transmitting subsystem should accept the input data elements listed in Table II-4-1 via an appropriate data input interface and use such data to establish the corresponding UAT ADS-B message contents.

4.2 Data elements that are indicated as "optional" and that have no input interface on a particular aircraft should either indicate the "data unavailable" condition or be processed using the "data unavailable" procedures related to that element.

Table II-4-1. UAT ADS-B transmitting subsystem input requirements

Element #	*Input data element*	*Relevant paragraph of Part I, Chapter 2*	*Data lifetime (seconds)*	*Applicability to UAT equipment class*						
				A0, B0	*A1L A1S B1S*	*A1H, B1*	*A2*	*A3*	*B2*	*B3*
1	ICAO 24-bit aircraft address	2.1.5.1.3.1	No limit	M	M	M	M	M	M(1)	M(1)
2	Latitude(2)	2.1.5.2.1	1.5	M	M	M	M	M	M	M
3	Longitude(2)	2.1.5.2.1	1.5	M	M	M	M	M	M	M
4	Altitude type selection (barometric versus geometric)(3)	2.1.5.2.2	60	O	O	O	O	O	N/A	M
5	Barometric pressure altitude	2.1.5.2.3	2	M	M	M	M	M	N/A	N/A
6	Geometric altitude	2.1.5.2.3	1.5	M	M	M	M	M	N/A	M
7	NIC	2.1.5.2.4	2	M	M	M	M	M	M	M
8	Automatic airborne/on-ground indication(3)	2.1.5.2.5	2	O	O	M	M	M	N/A	N/A
9	North velocity(2)	2.1.5.2.6.1	2	M	M	M	M	M	M	M
10	Ground speed	2.1.5.2.6.2	2	O	O	M	M	M	O	N/A
11	East velocity(2)	2.1.5.2.6.3	2	M	M	M	M	M	M	M
12	Track angle	2.1.5.2.6.4	2	O	O	M	M	M	N/A	N/A
13	Heading	2.1.5.2.6.4	2	O	O	M	M	M	N/A	N/A
14	Barometric vertical rate	2.1.5.2.7.1.1 2.1.5.2.7.1.3	2	M	M	M	M	M	N/A	N/A
15	Geometric vertical rate(2)	2.1.5.2.7.1.1 2.1.5.2.7.1.3	2	O	O	O	O	O	N/A	N/A
16	A/V size, with GPS antenna offset and position offset applied by sensor indication	2.1.5.2.7.2	No limit	M	M	M	M	M	M	M
17	UTC 1 PPS timing(2)	2.1.5.2.8	2	M	M	M	M	M	M	M
18	Emitter category	2.1.5.4.4	No limit	M	M	M	M	M	M	M

Element #	*Input data element*	*Relevant paragraph of Part I, Chapter 2*	*Data lifetime (seconds)*	*Applicability to UAT equipment class*						
				A0, B0	*A1L A1S B1S*	*A1H, B1*	*A2*	*A3*	*B2*	*B3*
19	Call sign/flight plan ID	2.1.5.4.5	60	M	M	M	M	M	O	O
20	Emergency/priority status selection	2.1.5.4.6	60	M	M	M	M	M	O	N/A
21	Source integrity level (SIL)	2.1.5.4.8	60	M	M	M	M	M	M	M
22	System design assurance (SDA)	2.1.5.4.10	60	M	M	M	M	M	M	M
23	SIL supplement	2.1.5.4.18	60	M	M	M	M	M	M	M
24	NAC_P(2)	2.1.5.4.11	2	M	M	M	M	M	M	M
25	NAC_V(2)	2.1.5.4.12	2	M	M	M	M	M	N/A	N/A
26	NIC_BARO	2.1.5.4.13	2	Can be internally "hard-coded"		M	M	M	N/A	N/A
27	ACAS operational	2.1.5.4.14.3	60	M	M	M	M	M	N/A	N/A
28	ACAS resolution advisory flag	2.1.5.4.15.1	18	Required only if the UAT ADS-B transmitting subsystem is intended for installation with ACAS; otherwise can be "hard-coded"						
29	IDENT selection	2.1.5.4.15.2	60	M	M	M	M	M	M	N/A
30	Call sign identification flag	2.1.5.4.16	2	M	M	M	M	M	M	N/A
31	Geometric vertical accuracy (GVA)	2.1.5.4.19	60	N/A	N/A	O	M	M	M	N/A
32	Single antenna flag	2.1.5.4.20	N/A	N/A	N/A	O	M	M	N/A	N/A
33	NIC supplement flag	2.1.5.4.21	2	N/A	N/A	O	M	M	N/A	N/A
34	Selected altitude type	2.1.5.6.1	60	N/A	N/A	O	M	M	N/A	N/A
35	Selected altitude setting	2.1.5.6.2	60	N/A	N/A	O	M	M	N/A	N/A
36	Barometric pressure setting	2.1.5.6.3	60	N/A	N/A	O	M	M	N/A	N/A
37	Selected heading	2.1.5.6.4	60	N/A	N/A	O	M	M	N/A	N/A
38	Status of MCP/FCU mode	2.1.5.6.5	60	N/A	N/A	O	M	M	N/A	N/A
39	Mode indicators: autopilot engaged	2.1.5.6.6	60	N/A	N/A	O	M	M	N/A	N/A
40	Mode indicators: VNAV engaged	2.1.5.6.7	60	N/A	N/A	O	M	M	N/A	N/A
41	Mode indicators: altitude hold mode	2.1.5.6.8	60	N/A	N/A	O	M	M	N/A	N/A
42	Mode indicators: approach mode	2.1.5.6.9	60	N/A	N/A	O	M	M	N/A	N/A
43	Mode indicators: LNAV engaged	2.1.5.6.10	60	N/A	N/A	O	M	M	N/A	N/A
44	Radio altitude(3)	2.1.5.2.5.1	2	O	O	O	O	O	N/A	N/A
45	Pressure altitude disable(3)	2.1.5.2.2	No limit	M	M	M	M	M	N/A	N/A
46	Airspeed(3)	2.1.5.2.5.1	2	O	O	O	O	O	N/A	N/A

M = Mandatory (the equipment must have the ability to accept the data element).
O = Optional.
N/A = Not applicable to this equipage class.
(1) = Addresses for vehicles and obstacles may be assigned by the appropriate ATS authority.
(2) = If input is not directly accessible, a means to verify the encoding must be demonstrated.
(3) = These elements are control inputs and are not themselves directly contained in the transmitted ADS-B messages.

Chapter 5

UAT AIRCRAFT INSTALLATION GUIDANCE

5.1 AIRCRAFT MUTUAL SUPPRESSION BUS

Part I, Chapter 4, 4.2, requires UAT equipment to output suppression pulses during UAT transmission. In practice these pulses will be transmitted on the aircraft's mutual suppression bus. On aircraft without such a bus, the installation of UAT equipment effectively results in such a bus being implemented. The mutual suppression bus is used in aircraft for systems operating in the 960 MHz to 1 215 MHz band such as secondary surveillance radar (SSR) transponders, ACAS and DMEs (the use of the mutual suppression bus for future receipt of GNSS signals in the 1 151 MHz to 1 215 MHz band is not planned). The 960 MHz to 1 215 MHz frequency band systems on the aircraft physically connect to the common bus. The 960 MHz to 1 215 MHz frequency band systems that are connected to the bus may drive the bus to announce to other systems that a transmission is taking place during the interval that the bus is activated. They may also listen on the bus to react to other 960 MHz to 1 215 MHz frequency band transmissions on the aircraft. The 960 MHz to 1 215 MHz frequency band systems that listen on the bus may choose to delay their own transmissions so as not to simultaneously transmit while another 960 MHz to 1 215 MHz frequency band system is transmitting and/or desensitize its receiver to protect itself during high-powered transmissions which could damage or impair its receive capability.

5.2 UAT SUPPRESSION PULSE IMPACT ON AIRCRAFT CO-SITE SSR, ACAS AND DME PERFORMANCE

5.2.1 General

5.2.1.1 As indicated above, systems operating within the 960 MHz to 1 215 MHz frequency band may need interference protection from each other to ensure safe and proper operation. A major consideration of systems connecting to and driving the mutual suppression bus is to minimize the duration of the suppression pulse to minimize the impact on other connected systems. This section demonstrates that UAT operation does not operationally impact performance of co-site SSR, ACAS or DME systems. It should be noted that while UAT receivers are not required to respond to suppression pulses from co-site transmissions from these systems, the performance estimates of Appendix A assume that no UAT message reception will occur during periods of co-site transmissions in the 960 MHz to 1 215 MHz frequency band.

5.2.1.2 UAT is required to drive the mutual suppression bus during the UAT transmission. UAT does not monitor the mutual suppression bus so it does not inhibit or delay its transmissions as a result of mutual suppression bus pulses from other 960 MHz to 1 215 MHz frequency band systems connected to the bus. The impact on the UAT receiver during other 960 MHz to 1 215 MHz frequency band transmissions that drive the suppression bus was considered when assessing UAT receiver performance in high-density airspace, as the UAT receiver was considered completely blanked during on-board 960 MHz to 1 215 MHz frequency band transmissions from ACAS, SSR transponders and DME systems. The UAT system performance estimates in Appendix A reflect this conservative blanking assumption. UAT averages one transmission per second and transmits either a basic UAT ADS-B message, which is 280 microseconds in duration, or a long UAT ADS-B message, which is 420 microseconds (436 bit periods × 0.96 microseconds/bit period). The suppression interval is required as per Part I, Chapter 5, 5.2, to be active during the transmission interval when the power is –20 dBm or higher. The –20 dBm requirement was developed based on the maximum power tolerable without

SSR transponders generating unsolicited replies when signal levels from out-of-band emissions from UAT transmitters fall within the SSR transponder receiver band are above the transponder receiver threshold. The maximum length of a suppression pulse generated by UAT aircraft equipment is 430 microseconds (420 microseconds for a UAT ADS-B long message plus 10 microseconds as per Part I, Chapter 5, 5.2). The impact of this suppression interval on other 960 MHz to 1 215 MHz frequency band systems is documented below. The results of the compatibility analysis have been coordinated with the appropriate ICAO technical panels.

5.2.2 Analysis of the impact on DME

The impact on DME systems of the mutual suppression interval as a result of on-board UAT transmissions was assessed. The short duration of the UAT suppression is insignificant to the DME transmitter/interrogator. The DME operation can safely withstand interrogation delays of 430 microseconds each second that may result if worst-case delay were imposed on the DME. Looking at the receiver blanking of DME that would result from UAT suppression activity, the 0.043 per cent worst-case blanking is insignificant when considering that DME operation is acceptable at relatively low reply efficiencies. Appendix E contains data showing consistent DME operation on four different DME units when a reply efficiency of 30 per cent or more is achieved. The measurements were performed relative to two performance criteria used in DME operation:

a) acquire stable operating point (ASOP), the point that prohibits the DME to acquire a track;

b) break stable operating point (BSOP), the point that causes DME to lose a track that it has already acquired.

ASOP and BSOP were not operationally affected by UAT suppression pulses.

5.2.3 Analysis of the impact of UAT suppression bus pulses on ACAS

5.2.3.1 ACAS systems are connected to the mutual suppression bus and accept and respond to suppression pulses on the bus so that ACAS activity (at least for reception) is disabled when other 960 MHz to 1 215 MHz frequency band equipment transmit. The ACAS receiver, which decodes SSR Mode C/S signals, is required to recover to within 3 dB of normal receiver sensitivity within 15 microseconds of the end of the suppression pulse. UAT long message transmissions would result in a worst-case 445 microsecond desensitization of the ACAS receiver. ACAS activity can be divided into three major functions:

a) listening period for transponder acquisition squitters;

b) whisper-shout interrogation/reply processing; and

c) Mode S interrogation/reply processing.

5.2.3.2 The impact of UAT mutual suppression bus activity can be assessed for each of these functions. The potential blanking of a 445-microsecond interval during the listening period of squitters is considered not to be a significant performance issue. Acquisition squitters are broadcast randomly on average once per second. The probability of reception of an aircraft squitter is reduced by 0.045 per cent by the combination of UAT mutual suppression pulses and ACAS receiver recovery time and is considered as an insignificant factor in squitter acquisition. The probability of two squitters from the same aircraft being missed on subsequent seconds due to UAT is in the order of 2×10^{-7}. The impact of missing a single acquisition squitter at any point in time is not a performance issue for ACAS. The system design allows reception of acquisition squitters with enough margin from target aircraft prior to the target aircraft being within range of the listening aircraft for threat determination. The whisper-shout function is an interrogation sequence to acquire SSR Mode A/C transponder-equipped aircraft which varies interrogation power levels to reduce aircraft replies in a systematic way to reduce the overlap of replies, or garbling, that can occur in high-density airspace. Whisper-shout interrogations occur at defined power levels and typically one to six power levels are transmitted under normal operating conditions. The number of whisper-shout interrogations can exceed 120 per second in a high-density aircraft situation. The 445 microsecond UAT interval per second is not a significant impact on the whisper-shout sequence of ACAS. The 445 microseconds may blank the receiver and cause one or more missed replies in any one second. But since the UAT transmission is random and a low probability exists for losing more than one SSR reply from any individual aircraft from the whisper-shout interrogation sequence, this aspect of ACAS performance remains acceptable with UAT mutual suppression bus blanking. The impact of UAT mutual suppression bus pulses to the Mode S interrogation interval of ACAS is also seen as not a significant performance issue. The ability of ACAS to re-interrogate a particular aircraft if a reply is not received mitigates any risk of not receiving a reply from any individual interrogation. The main sources of interference are co-frequency SSR Mode A/C/S overlaps of desired replies. The limited UAT blanking of the ACAS receiver is not a significant factor.

5.2.4 Analysis of the impact of UAT suppression bus pulses on SSR transponders

When assessing the impact of UAT occupation of the mutual suppression bus on SSR transponders, the addition of UAT suppression pulses to SSR transponder availability is to be considered. With the exception of the acquisition and extended squitter transmissions of a Mode S transponder, the transponder transmits on a request basis from ground and aircraft interrogators, including ground SSR Mode A/C/S, both en-route and terminal, and ACAS. transponder availability is impacted by several mechanisms. Transponders have side lobe suppression (SLS) functionality to inhibit the transponder from responding to interrogations for a defined interval (typically 35 microseconds). Ground interrogators use SLS to prevent transponders from replying to interrogations that are not within the main beam of the rotating antenna. The transponder is additionally not available during the active interrogation acceptance/reply and recovery interval. In high-density airspace, where the number of ground interrogators and the number of aircraft are high, the transponder has a reduced availability due to the high number of interrogations. The transponder is also not available due to other on-board 960 MHz to 1 215 MHz frequency band systems such as ACAS and DME that blank the transponder receiver. Worst-case transponder availability relative to all of these factors can be determined for high-density airspace by using the number of SSR Mode A/C/S and ACAS interrogations in the Core Europe 2015 future high-density scenario contained in Appendix B, Table II-B-5, along with measured data from high-density areas. The worst-case transponder availability is calculated to be around 90 per cent, meaning that the transponder cannot respond to interrogations at most 10 per cent of the time. The addition of the UAT mutual suppression bus blanking of the SSR transponder receiver reduces the availability at most from 90 to 89.957 per cent. This reduction has not been considered to be of significant impact on the operational availability of SSR transponders.

5.3 SHARING ANTENNAS WITH SSR TRANSPONDERS

5.3.1 Passive frequency diplexer

5.3.1.1 A potential method of providing an antenna for the UAT is to use a passive frequency diplexer that is installed between an existing SSR transponder and the SSR antenna. The use of a diplexer to operate UAT equipment and the on-board SSR transponder must ensure proper operation of UAT equipment and SSR transponders. Certain characteristics were critical to enable the use of a diplexer. The power loss across the diplexer was an important consideration. The typical cable attenuation that installations allow between the SSR transponder and antenna is 3 dB. The diplexer cannot use up a significant portion of this allocation without eliminating most existing transponder installations as candidates for UAT antenna sharing. To ensure the proper operation of both UAT and SSR, a diplexer loss less than 0.5 dB is expected to enable most existing SSR installations to use a diplexer, permitting sharing of the

SSR transponder antenna with UAT. The goals of the diplexer design are to support a transponder port in a manner that would minimize the insertion loss in the 1 030/1 090 MHz band while providing adequate passband so that 1 030 MHz interrogation signals and 1 090 MHz reply signals are unaffected by the diplexer.

5.3.1.2 As shown in Figure II-5-1, the diplexer is a passive device and consists of three ports that provide connectivity from the UAT port to the antenna port (UAT diplexer channel) and connectivity from the Mode A/C/S port (transponder diplexer channel) to the antenna port. An optional direct current (DC) path in the transponder diplexer channel is allowed so that installations that require antenna sensing can maintain the capability to sense the presence of an antenna. The transponder diplexer channel will attenuate signals at 978 MHz, providing isolation from the UAT. In some cases, diplexer isolation actually exceeds the level of isolation obtained by using separate transponder and UAT antennas. The latter is a function of distance between antennas. The UAT’s diplexer port can provide minimal insertion loss to the antenna at 978 MHz while manifesting a high impedance at the 1 030/1 090 MHz band.

5.3.2 Optional diplexer requirements

An option to use a passive frequency diplexer to allow sharing of a single antenna between the SSR Mode A/C/S transponder and the UAT unit is provided herein. Sharing a common antenna between the two systems may be desirable in aircraft to minimize antenna installation cost and complexity. The UAT diplexer channel frequency response requirements ensure adequate passband bandwidth around the 978 MHz UAT frequency to ensure that UAT signal integrity is maintained through the UAT unit, diplexer and antenna path. Likewise, the transponder diplexer channel frequency response requirements ensure adequate passband bandwidth around the 1 030 MHz and 1 090 MHz frequencies to ensure that the required interrogation and reply signal integrity is maintained through the SSR transponder, diplexer and antenna path. The diplexer characteristics must ensure that performance of both the UAT and SSR transponder systems is equivalent to their performance without the diplexer. An attenuation of up to 0.5 dB through the diplexer is acceptable. A delay within the diplexer of up to 10 nanoseconds for the SSR signals and up to 30 nanoseconds for UAT signals through the diplexer is also acceptable. The insertion loss and delay characteristics of the diplexer must be taken into consideration when determining the overall cable loss and cable delay budgets between the UAT unit and antenna as well as between the SSR transponder and the antenna. The use of the diplexer does not preclude the UAT from driving the suppression bus during UAT transmissions. Diplexer installations must include connection to and use of the suppression bus driven by the UAT and received by the SSR transponder and any co-site DME equipment. Installations that incorporate the diplexer must ensure that the off-frequency power seen by the front end of the UAT equipment and the SSR Mode A/C/S transponders through the diplexer are within the design characteristics of each unit to ensure proper operation. The UAT installation needs to consider the power seen at the input of the UAT receiver from the SSR transponder, and it should be verified that the SSR transponder as installed can handle the UAT power through the isolation provided by the diplexer.

5.3.2.1 The UAT diplexer channel

The diplexer includes a UAT channel that conveys UAT signals without distortion of the waveform. The UAT diplexer channel conveys UAT basic, long and ground uplink messages while maintaining the modulation accuracy of the input UAT signals as specified in Annex 10, Volume III, Chapter 12, 12.4.3, and produce no more than 0.5 dB amplitude additional attenuation (to be included in the 3 dB assumed for cable losses) and no more than 30 nanoseconds in propagation delay within the diplexer. Additionally, the variation in delay is no more than 10 nanoseconds over the frequency band of 977 MHz to 979 MHz. The UAT diplexer channel provides a passband beginning at or below 977 MHz and ending at or above 979 MHz (2.0 MHz minimum) with a maximum attenuation of 0.5 dB. The minimum and maximum attenuation in the passband are different by no greater than 0.20 dB. The UAT port of the diplexer needs to be capable of peak-power transmissions according to the appropriate aircraft equipage class given by Chapter 2, Tables II-2-1 and II-2-2. The VSWR produced by the diplexer at the UAT port of the diplexer, when the other two ports are terminated in a 50-ohm load, does not exceed 1.3:1 for frequencies between 977 MHz and 979 MHz.

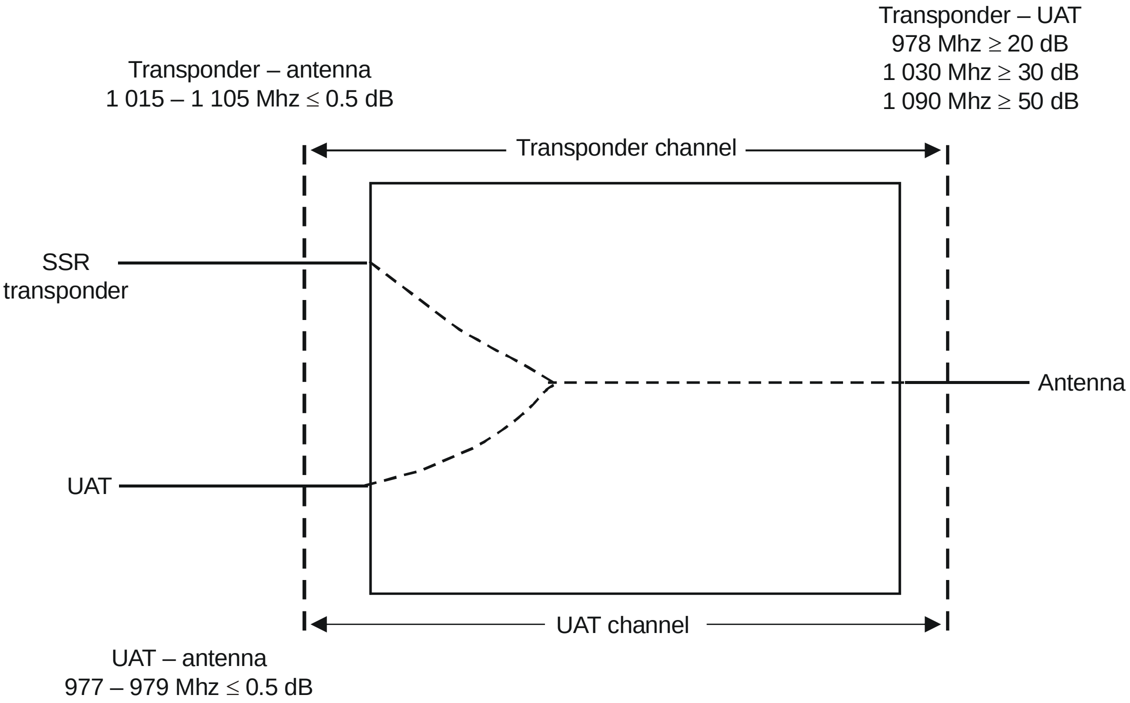

Figure II-5-1. Optional passive diplexer block diagram

5.3.2.2 The transponder diplexer channel

The diplexer includes a transponder diplexer channel that conveys 1 030 MHz and 1 090 MHz signals without distortion of the waveform. The transponder diplexer channel conveys pulses that are amplitude modulated on either 1 030 MHz or 1 090 MHz and have rise and fall times of 50 nanoseconds or more and produce no more than 0.5 dB additional amplitude attenuation and no more than 10 nanoseconds delay within the diplexer while retaining the pulse rise and fall times and pulse width of the input pulses. Additionally, the variation in delay over the frequency band of 1 015 MHz to 1 105 MHz is no more than 5 nanoseconds. The transponder diplexer channel provides a passband from no greater than 1 015 MHz to no less than 1 105 MHz (90 MHz minimum) and a maximum attenuation of 0.5 dB. The minimum and maximum attenuation in the passband are different by no greater than 0.20 dB (within the 0.5 dB maximum attenuation). The transponder port is capable of handling 1 000 watts instantaneous power. The VSWR produced by the diplexer at the transponder port, when the other two ports are terminated in a 50-ohm load, does not exceed 1.3:1 for frequencies within the passband. If required by the transponder installation, the diplexer supports DC coupling from the transponder port to the antenna port as required by the electrical characteristics of the installed equipment.

5.3.2.3 Isolation between the UAT diplexer channel and the transponder diplexer channel

The diplexer provides RF isolation between the UAT diplexer channel and the transponder diplexer channel. The diplexer provides a minimum of 50 dB of isolation between these ports at 1 090 MHz. Additionally, the diplexer provides a minimum isolation of 30 dB between the UAT and transponder ports of the diplexer at 1 030 MHz. The diplexer provides a minimum of 20 dB of isolation between the ports at 978 MHz.

Note.— Installations that incorporate the diplexer must ensure that the SSR reply power seen by the front end of the UAT receiver and the UAT transmission power seen by the front end of the SSR Mode A/C/S receiver through the diplexer are within the design tolerances of each unit to ensure proper operation. It has been determined that the isolations provided above should in general ensure safe operation for most transponders with respect to off-frequency effects. This determination should be verified for a specific aircraft installation.

5.4 COMPATIBILITY WITH SSR WHEN UAT AND SSR ARE USING SEPARATE ANTENNAS

This compatibility is assured by the UAT equipment providing suppression pulses as outlined in Part I, Chapter 5, 5.2, and the supporting analysis shown in section 5.3 above.

5.5 COMPATIBILITY WITH FUTURE GNSS OPERATING IN THE BAND 1 164 MHz TO 1 215 MHz

The band 1 164 MHz to 1 215 MHz is planned to be used for a future GNSS. An assessment of radio frequency interference relevant to the GNSS L5/E5A frequency band was undertaken in RTCA. This study assessed the combined pulsed interference impact from all on-board sources including UAT. The study noted the frequency separation and low duty factor of UAT relative to other on-board systems and concluded that the combined effects from all sources would not cause interference to L5/E5A. Information on the compatibility of UAT and L5/E5A GNSS operation is provided in RTCA/DO-292, *Assessment of Radio Frequency Interference Relevant to the GNSS L5/E5A Frequency Band*.

5.6 UAT INTERFACE TO GPS/GNSS RECEIVER

UAT aircraft equipment must be interfaced to a GPS/GNSS receiver in order to obtain position, velocity and time information. One component is a 1 pulse per second time mark. Position, velocity and timing information is provided over a data interface. Timing information provided over the data interface could include the offset of the time mark relative to the 1.0-second UTC epoch (if any) and time of day. Figure II-5-2 shows the interfaces and timing requirements related to these interfaces.

5.7 SOURCE INTEGRITY LEVEL ("SIL") FIELD VALUE

When the ADS-B position source is a GNSS receiver that is outputting a valid horizontal protection limit (HPL), the SIL field value should be set to 3. For alternate ADS-B position sources to report integrity, they will need to be certified for their fault detection characteristics. A non-zero SIL value should be reported only when the ADS-B equipment has a valid GNSS HPL input, or has an alternative input that has been certified to be representative of the integrity of the ADS-B position source being used.

5.8 "SYSTEM DESIGN ASSURANCE (SDA)" FIELD VALUE

5.8.1 The "system design assurance (SDA)" field defines the failure condition that the position transmission chain for ADS-B is designed to support. The position transmission chain includes the ADS-B transmission equipment, ADS-B processing equipment, position source, and any other equipment that processes the position data and position quality metrics that will be transmitted in ADS-B messages (e.g. data concentrator).

5.8.2 The value for the SDA field generally involves multiple pieces of equipment and will likely be established at the time of ADS-B equipment installation approval. Therefore, the certification level of the components of the position transmission chain should be evaluated to determine the appropriate level at which to set the SDA field value. It is recommended that when considering an installation which has multiple equipments in the position transmission chain, an SDA field value of 2 or higher be assigned if each of those equipments is certified to at least a design assurance level corresponding to a "major" failure condition.

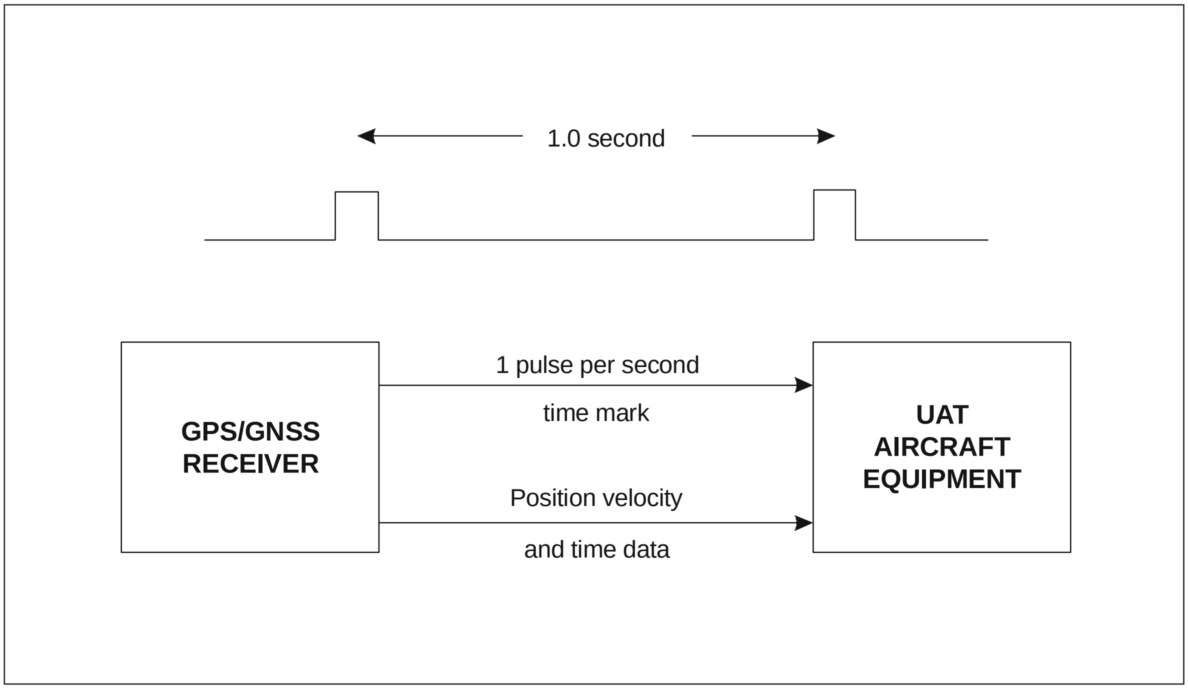

Figure II-5-2. UAT interface to GPS/GNSS receiver

Notes.—

1. *One pulse per second leading edge should be within ±1 millisecond of the 1.0 second UTC epoch.*
2. *Position and velocity data provided by the GPS/GNSS receiver should be applicable to within ±5 milliseconds of the 1 pulse per second time mark.*
3. *Position, velocity and time data should be available to the UAT aircraft equipment within 200 milliseconds of the leading edge of the 1 pulse per second time mark.*

Chapter 6

UAT GROUND INFRASTRUCTURE

6.1 GENERAL DESCRIPTION

This chapter describes the working concept for a UAT ground infrastructure and clarifies the provisions made to support the ground infrastructure. The role of the UAT ground infrastructure is threefold:

a) to receive UAT ADS-B messages from aircraft and generate a summary of the UAT-equipped air traffic in a given area, possibly fusing UAT ADS-B data with other surveillance data (e.g. radar or multilateration systems);

b) to transmit, in the UAT ground segment, flight service information (e.g. weather, NOTAM) to aircraft for use in the cockpit; and

c) to transmit, in the UAT ADS-B segment, TIS-B messages.

There is considerable flexibility for the deployment and functionality of the ground infrastructure. The receive and transmit functions may be physically separate and even have different providers, or they could be a single ground network of transceivers feeding an integrated system and providing all the above functions. This will probably be decided more by economics and regulations than by engineering design. This section describes the key elements of the UAT ground Infrastructure at a functional level.

6.1.1 Ground broadcast

6.1.1.1 Geometric service volumes

6.1.1.1.1 Because of the limited range and geometry of a single ground station, a network of ground broadcast transmitting stations will be required to provide service over a large area. The service volume of a ground station is the geographic scope of responsibility the ground station assumes for each product broadcast.

6.1.1.1.2 The UAT system uses time division multiplexing for ground uplink messages to allow multiple ground stations to operate on the same frequency. At the designer’s disposal are the 32 time slots within the ground segment of the UAT frame. Since time slots must be reused geographically, there is a potential for self-interference where radio coverage is greater than the designed minimum. The allocation of one or more time slot resources to a given ground station based on some reuse pattern will mitigate this self-interference.

6.1.1.1.3 As an example of assigning service volumes, a hexagonal “cellular” pattern of ground stations with a nominal intersite spacing of 100 NM would assure single coverage everywhere down to about 3 000 feet above ground level (AGL). (This is based on a 4/3 earth refraction model, a nominal antenna height of 50 feet, and ignores terrain effects.) This intersite spacing would require each ground station to have a service volume of radius of about 58 NM. A longer range may be specified if additional overlapping coverage is desired. A nominal coverage cell layout is shown in Figure II-6-1. In this example case, the service volume has a radius of 58 NM. As discussed below, different uplink products broadcast by a ground station may cover different geographical areas, called product coverages, than the service volume of that ground station.

FIS-B product coverage

6.1.1.1.4 The FIS-B product coverage and update rate can be tailored to suit the characteristics of the particular FIS-B information being broadcast. For example, information that is relatively small in terms of total data volume and that is updated infrequently, such as automated terminal information service (ATIS) messages, could have a relatively large product coverage (e.g. a circle of diameter 500 NM) and a relatively low update rate. The FIS-B product coverage of, for example, a weather map, could exceed the service volume of a single ground station.

6.1.1.1.5 If an aircraft receives FIS-B uplinks from multiple UAT ground stations, it may combine these data. This task can be minimized by having the ground infrastructure assure that product information from different ground stations for the same geographical location is identical. For example, adjacent uplink stations reporting precipitation strength for a given point or grid element should report exactly the same data. Then the application in the aircraft need only associate the reports and choose either for displaying or processing (rather than averaging, interpolating or inferring data integrity). Note that with autonomous, isolated ground stations this is not an issue.

6.1.1.1.6 In Figure II-6-1 a sample product coverage is shown along with the service volume for a single cell. For this product coverage, there is a consistent picture of the product as the aircraft flies through the lightly shaded region depicted.

TIS-B product coverage

6.1.1.1.7 A product such as traffic data (TIS-B) calls for a higher update rate than FIS-B, which results in a smaller product coverage area to keep UAT data link uplink requirements at a reasonable level. TIS-B product coverage overlap between adjacent ground stations should be just enough to assure service continuity across the boundary. This approach keeps the load on the data link as low as possible and minimizes the burden on the ADS-B receiving subsystems to eliminate redundant reports.

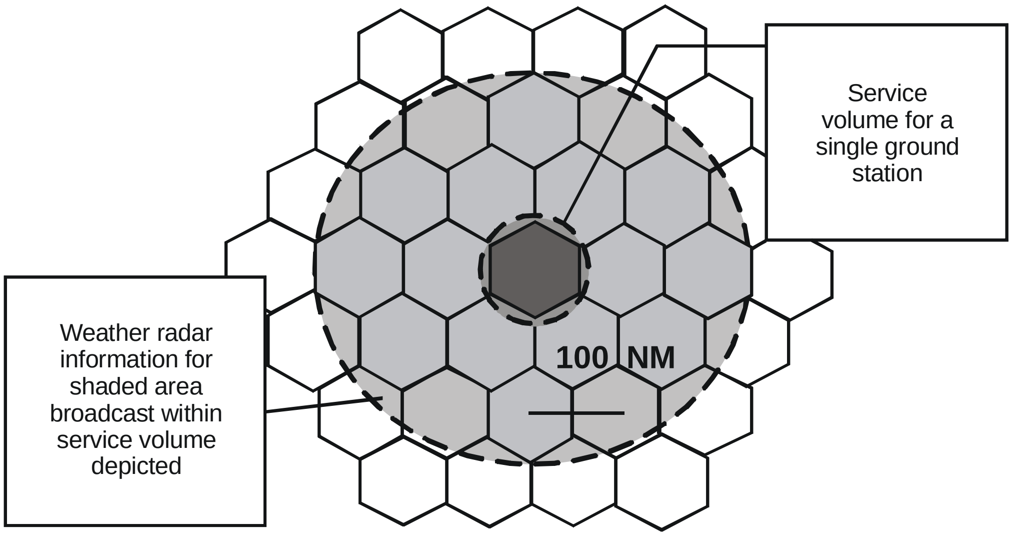

Figure II-6-1. Example coverage cell layout

6.1.1.2 Data source for ground broadcast

6.1.1.2.1 Contents of the ground broadcast messages can be put in the following categories:

a) flight information services-broadcast (FIS-B) — the broadcast distribution of weather and aeronautical information;

b) traffic information from other surveillance sources (radar, multilateration) — this augments the ADS-B data received directly from the air-air link;

c) ADS-B data collected from non-UAT ADS-B sources; and

d) other.

6.1.1.2.2 In the UAT data link, FIS-B and "other" information is sent during the ground segment of the UAT frame. TIS-B data can be broadcast during the UAT ADS-B segment of the UAT frame in an ADS-B message format.

6.1.1.2.3 There are many possible configurations for the flow of information for UAT ground stations. Not all stations need to be configured the same way. The configuration chosen will depend on the products being provided. In any case, a single UAT ground station is one part of the overall ground infrastructure, which will be primarily defined by the communication links between ground stations (land line (phone, fibre) or RF links such as satellite, microwave or other), by the data sources (radar, multilateration, weather observation and forecast) and by the applications that fuse these data and generate the UAT ground uplink messages (FIS-B) and TIS-B messages.

6.1.2 Ground surveillance of UAT-equipped aircraft and vehicles

UAT ADS-B messages being transmitted by aircraft and surface vehicles will be received (in general) at multiple UAT ground stations. This redundancy is readily fused since all stations are receiving the same message contents. Because of the required frame synchronization of all UAT transmitters and receivers, there is ample accuracy in the time-of-arrival stamp on each message to readily associate them and merge them. No averaging or weighting need be done on the contents as they are all the same.

6.1.3 Summary of infrastructure and implications

6.1.3.1 Figure II-6-2 shows a generalized diagram of the components and interconnnect of a ground infrastructure for the UAT data link. Many variations of this general structure are possible. Transmitters and receivers may or may not be collocated. Different sites may have different levels of service.

6.1.3.2 A considerable transition time period to full ADS-B equipage will need to be supported, and the UAT data link has the necessary flexibility to provide such support. Because of the generality of the data link, the system can be expanded as the ground infrastructure is developed and "filled in". The UAT ground station is adapted to each specific deployment by the application(s) driving it.

6.1.3.3 The characteristics of the UAT data link required to support this general structure are in the areas of time stamps and predicable latency, one-second frame synchronization, time-division coordination of adjacent ground cells, and a waveform tolerant of self-interference.

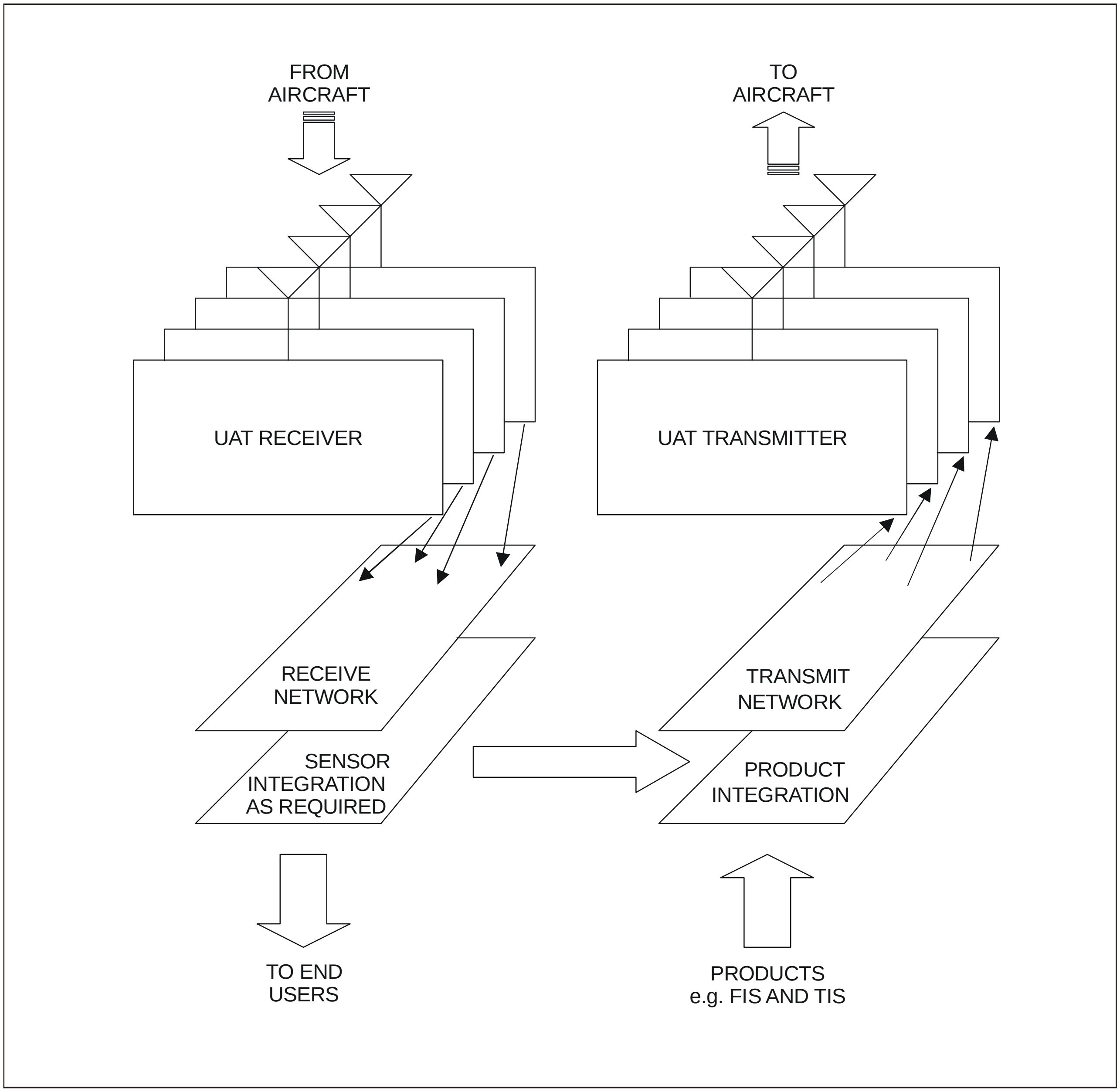

Figure II-6-2. General form of ground infrastructure

6.2 GROUND STATION DEPLOYMENT

6.2.1 Time slots and "data channels"

6.2.1.1 The UAT data link has 32 uplink time slots available within the ground segment of the UAT frame. As described in Part I, Chapter 3, 3.2.2, this results in 32 data channels, where each data channel represents the incremental resource that can be assigned to ground station transmitters so they can operate without mutual interference. That is, a "data channel" is a time-slot-sized resource assignable to a ground station where the actual time slot uses shifts on a continual basis per a defined time slot rotation scheme. One or more data channels may be assigned to any given UAT ground station.

6.2.1.2 One or more data channels assigned to a UAT ground station is the station's "data channel block" (DCB). A conservative approach to forming DCBs is to give one data channel to each ground station. In a hexagonal deployment using this conservative approach, the nearest station using the same data channel as a given station will on average be about 6 cell diameters away.

6.2.1.3 In practice, it will be desirable for each DCB to contain multiple data channels. This will allow the uplink bandwidth necessary for each ground station to deliver its entire product. An assignment of data channels to one of 7 distinct DCBs (A–G) will meet this objective by allowing cells that reuse a given DCB to be separated by about 2.5 cell diameters as shown in Figure II-6-3.

6.2.2 TIS-B site identifier (ID)

6.2.2.1 Each station is assigned a TIS-B site ID number (Part I, Chapter 2, 2.2.1.8). This number is not unique, having only a 4-bit value. The purpose of the ID is to give a short way (few bits) of identifying the source of a TIS-B uplink message. This source identification is useful for confidence measures of time synchronization and to counteract spoofing. In low-density areas, as well as in the approach to data channel block assignment given in Appendix I, with a unique TIS-B site ID assigned to each data channel block, only one station with a given TIS-B site ID will be within reception range. In the event that more than one ground station can be received (but not a large number) with the same TIS-B site ID, range checking can be performed, using uplinked UAT ground station locations to remove any ambiguity in TIS-B information. The remainder of this section discusses this latter event.

6.2.2.2 As an example, consider a 7-cell reuse pattern of data channels. Figure II-6-4 shows an assignment of 7 data channel blocks (labelled A through G) and of the 15 TIS-B site ID numbers (labelled 1 through 15). To see the repeat pattern in this example, look at a cell with data channel block label "G" as the centre of a 7-cell cluster. Data channel blocks A through F are clockwise around it. These clusters are then packed hexagonally. This is just an illustrative example to demonstrate the idea.

6.2.2.3 The approximate reception area of an aircraft is shaded in Figure II-6-4. The aircraft's trajectory is shown by the arrowed line, and the swath of the reception area is shown by the dotted lines. During the UAT ground segment, the aircraft is solidly receiving data from UAT ground stations using data channel blocks A, B, D and E (these ground stations are labelled A9, B14, D10 and E5 in Figure II-6-4). The aircraft can tell that these UAT ground stations are within a normal reception range based on the UAT ground station location broadcast in each UAT ground uplink message.

6.2.2.4 Table II-6-1 shows a list of these locations and TIS-B site IDs as they can be kept in the aircraft's ADS-B application. Entries can be dropped from the table when they are beyond range by some pre-determined amount. At the time shown, there are also two entries in the table with TIS-B site ID 4 as well as two entries with TIS-B site ID 8. Note that the data channel block indicator (labelled A–G) in the table is for clarity of the example only.

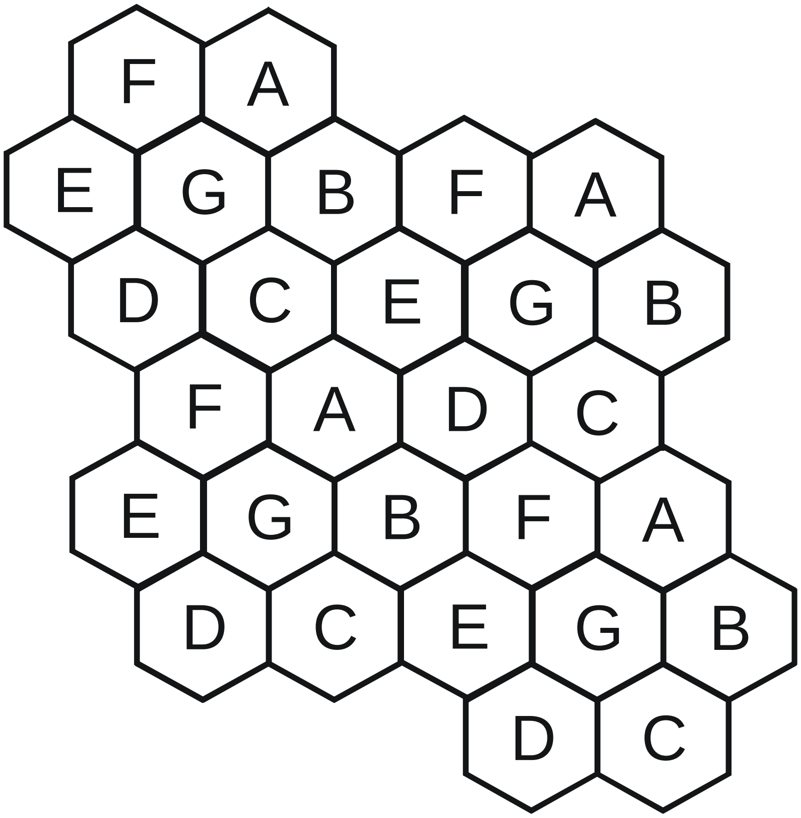

Figure II-6-3. Seven data channel block reuse pattern

Note.— The data channel block reuse pattern of Figure II-6-3 is provided for illustrative purposes and is suitable for providing services within a limited altitude range. A possible approach that covers a wide range of altitudes is discussed in Appendix I.

6.2.2.5 Each of these UAT ground stations also transmits TIS-B messages in the ADS-B segment of the UAT frame. Since UAT ground stations transmit TIS-B messages in random MSOs, the messages can all be received with high probability. Since each TIS-B message contains the TIS-B site ID (0–15) of the UAT ground station that transmitted the message, an ADS-B application in the UAT-equipped aircraft can validate the received TIS-B message using the aircraft's known position, the location of the UAT ground station that transmitted the message, and time-of-arrival techniques.

6.2.2.6 It is possible that a legitimate TIS-B message can be rejected from a distant station based on this method, if the station is not on the list. This is not a problem because if the target is important to the aircraft it will be included in the TIS-B messages transmitted by a nearer station, giving good range validation checks. This can be assured by the design of the product coverage for each cell.

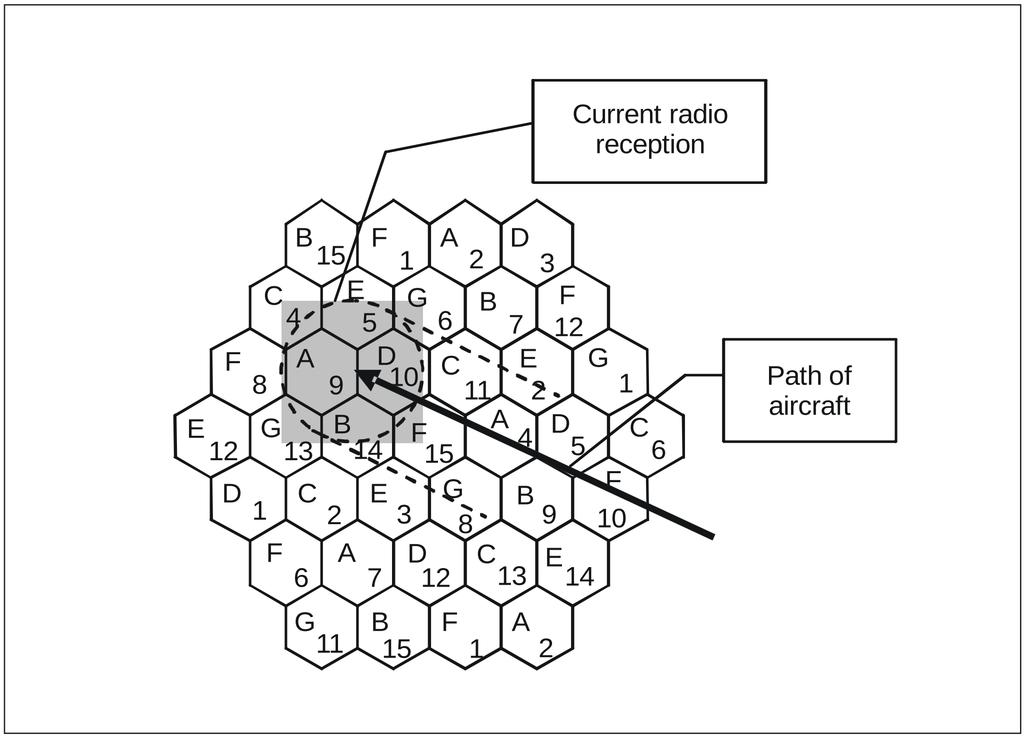

Figure II-6-4. Example of TIS-B site ID and data channel block

Table II-6-1. Example of TIS-B site ID table

TIS-B site ID	*Location*	*Data channel block*
9	lat long	A
14	lat long	B
4	lat long	C
10	lat long	D
5	lat long	E
13	lat long	G
6	lat long	G
8	lat long	F
15	lat long	F
11	lat long	C
2	lat long	E
4	lat long	A
8	lat long	G

6.2.3 Sectorized cells and co-site transmission isolation

6.2.3.1 In some areas of dense air traffic, a UAT ground station's range for reception of ADS-B messages from aircraft can be limited by UAT self-interference (see, for example, Figure II-A-30 in Appendix A which presumes that the UAT ground station has an omnidirectional receive antenna). In this event, satisfactory air-to-ground reception can be achieved by the installation of additional UAT ground stations. An alternative solution to this problem is to implement the UAT ground station with a sectorized antenna.

6.2.3.2 In cases where UAT ground equipment is collocated with other transmitting equipment at a nearby frequency (e.g. a DME/TACAN installation at 979 MHz), it is desirable to get as much rejection of that DME/TACAN interfering signal as possible. In these cases, the same sectorized antenna mentioned above can also help. Section 6.3 discusses the required signal rejection in cases of DME/TACAN interference.

6.2.3.3 Figure II-6-5 shows an antenna radiation pattern for a 3-sector UAT ground station antenna. The solid curve is one sector and the dashed curves are the other two sectors. This pattern is representative of a DME-type column antenna with a reflector behind it to shape the pattern and block the backlobe.

6.2.3.4 Figure II-6-6 shows two possible geometries that will produce isolation between co-sited DME equipment and UAT equipment. The required isolation will depend on the power of the DME equipment and the tolerable maximum signal level of the interference at the UAT equipment. Sections 4.1 and 4.2 of Appendix A discuss performance with various scenarios of DME/TACAN interference. In a future Core Europe high-density air traffic scenario, for example, the tolerable DME interference signal level (measured at 979 MHz) from a DME operating at 979 MHz is –30 dBm at the PMP corresponding to a sector of the antenna. This is discussed further in Chapter 7, 7.2.

6.3 RF INTERFERENCE

There are two primary sources of RF interference from other systems at the UAT operational frequency of 978 MHz: DME/TACAN and JTIDS/MIDS. There has been a considerable amount of analysis, simulation and laboratory measurement to determine the working limitations of UAT with these other two systems developed. Most of the limitations are as a result of DME usage and are discussed below.

6.3.1 DME/TACAN interference

6.3.1.1 An important potential interference factor to the UAT data link operating at 978 MHz is DME/TACAN transponders operating on adjacent frequencies. The DME channel (frequency) allotment table (Annex 10, Volume I, Chapter 3) identifies 977 MHz and 979 MHz as the closest assignable DME/TACAN transponder transmitting frequencies relative to the UAT frequency of 978 MHz.

6.3.1.2 Siting criteria for UAT ground stations in the presence of DME/TACAN transponders operating at 979 MHz and above are contained in Chapter 7, 7.2.

6.3.1.3 There are a number of techniques that may be used to mitigate the effect of high DME/TACAN signal levels on a collocated UAT ground station receiver. If the UAT ground station is using sectorized antennas (6.2.4) a 25-dB attenuation of the DME/TACAN signal may be achieved by locating the DME/TACAN antenna in the UAT antenna backlobe. Vertical stacking of the antennas may yield even more isolation. The UAT air-to-ground performance is ultimately a function of the DME/TACAN interfering signal level.

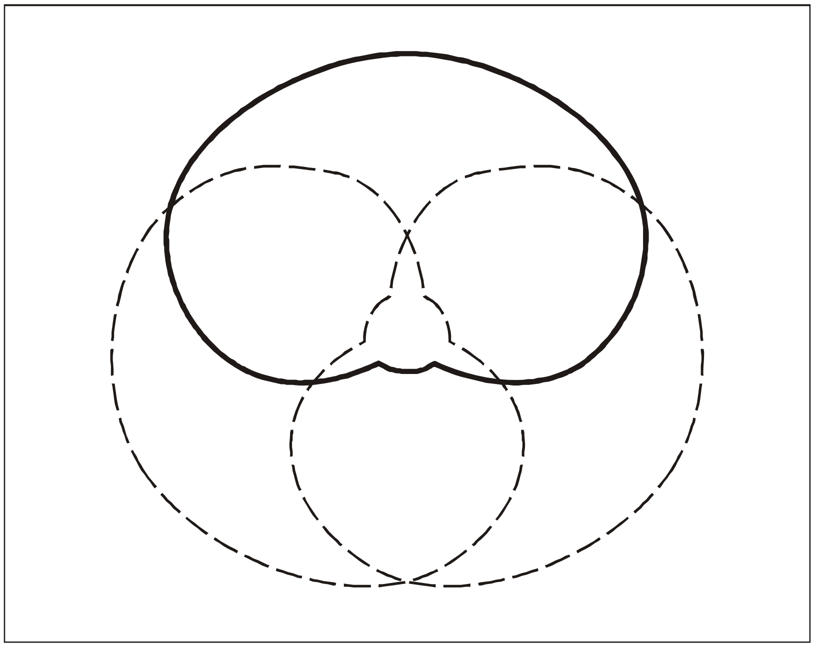

Figure II-6-5. Sectorized antenna pattern (3 sectors)

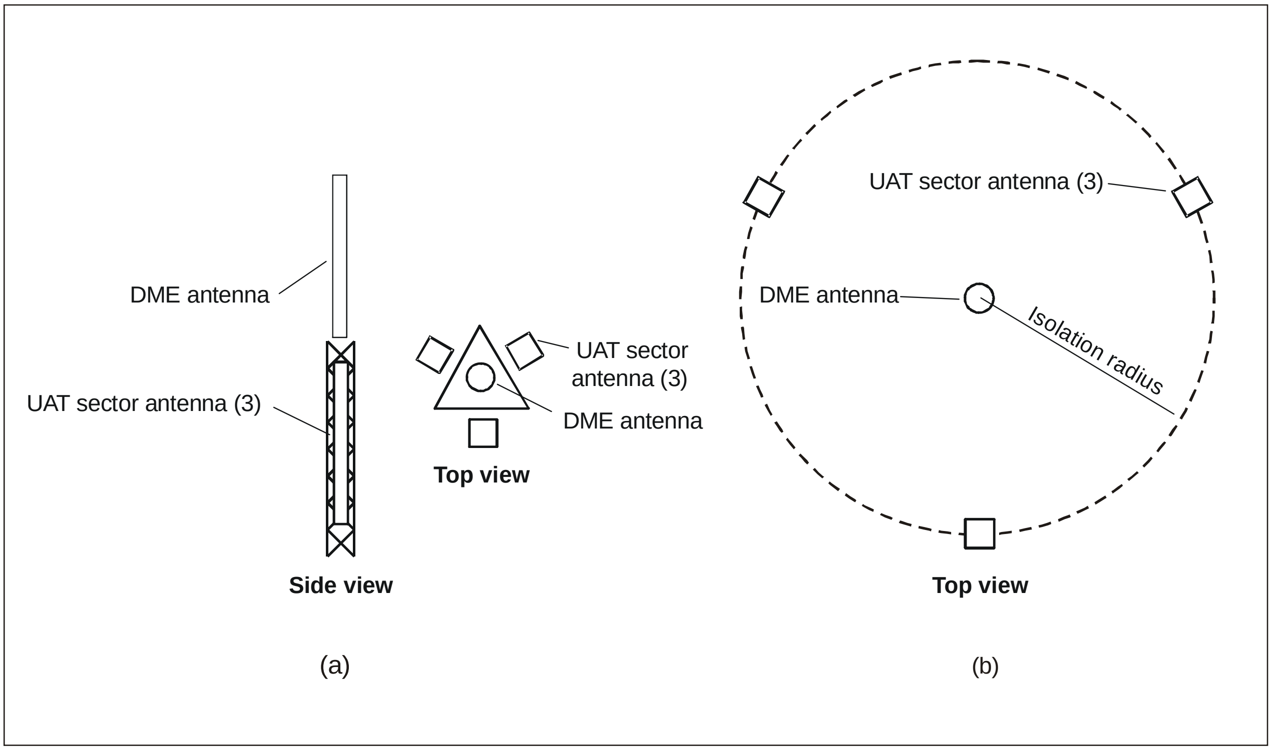

Figure II-6-6. Possible UAT ground station antenna geometries

6.3.1.4 An alternative technique to achieve the necessary isolation is the use of a very sharp (e.g. tuned cavity) filter on the UAT ground station. The approach would be to find a filter for the UAT receiver with acceptable in-band loss for the desired sensitivity to be achieved and then use the 979-MHz rejection of the filter to ease the burden on the antenna separation. A representative filter will give less than 5 dB of in-band (insertion) loss while rejecting the out-of-band (979 MHz) interference by 40 dB. This net benefit of 35 dB is available if the insertion loss will not reduce the intended service range of the UAT ground station.

6.3.1.5 In environments where the collocated DME/TACAN transponder is at 980 MHz (or higher frequencies) instead of 979 MHz, the above isolation techniques are not likely to be necessary, provided that the DME/TACAN transponder and UAT ground station are separated as recommended in Chapter 7, 7.2.

6.3.2 JTIDS/MIDS interference

The mutual effects of JTIDS/MIDS and UAT are discussed in Appendix C. In short, between the spread spectrum nature of JTIDS/MIDS and the interference rejection of the UAT modulation, the systems operate compatibly.

6.4 MULTIPLE ADS-B LINKS

ADS-B in high-density air traffic airspace may use multiple ADS-B data links. Through its support of ADS-B re-broadcast, the UAT data link is capable of supporting a multi-link deployment. This allows information on any non-UAT ADS-B traffic to be obtained by the ground infrastructure and supplied to UAT-equipped aircraft.

Chapter 7

UAT FREQUENCY PLANNING CRITERIA

As previously discussed, the UAT frequency is centred at 978 MHz with a necessary bandwidth of 1.3 MHz. UAT/DME frequency planning criteria to support future high-density air traffic environments will specify that the closest assignable DME ground station transmitting frequencies relative to the UAT frequency of 978 MHz are the first adjacent DME frequencies.

7.1 USE OF 978 MHZ FOR DME/TACAN

Co-frequency operation of UAT and DME/TACAN is not recommended. Test, simulation and analysis have shown that UAT and co-frequency DME could be operated on a compatible basis when both the number of DME stations in view to UAT aircraft receivers is limited and the density of UAT transmitters is low. Further analysis would be required to establish appropriate parameters for co-frequency operation. It should be noted however that the use of 978 MHz for DME ramp test equipment can still be supported, as the characteristics of the operational interaction scenario for UAT-to-ramp tester serves to preclude interference.

7.2 DME/TACAN TO UAT GROUND STATION SITING CRITERIA

7.2.1 Extensive testing has indicated no operationally significant impact on DME/TACAN in a high-density UAT environment when DME/TACANs are receiving on the first upper adjacent DME frequency (979 MHz) to the UAT frequency (978 MHz). A similar result can be inferred for DME reception at the lower first adjacent frequency of 977 MHz. Analysis of an example approach/landing scenario in Core Europe 2015 has shown that first adjacent frequency DME operation is also compatible with an environment that includes a nearby UAT ground station broadcasting at a high duty factor.

7.2.2 Any limitations on the siting of UAT ground stations vis-à-vis DME/TACANs are likely to result from the effects of DME/TACAN transmissions on UAT performance. This question has been studied by examining UAT performance with a first upper adjacent frequency DME/TACAN ground station collocated with a UAT ground station receiver at a high-density airport. Air-air, ground-air, air-to-ground and surface-surface performance were studied. The result of the combined analysis of these cases is a recommendation that a sufficient level of isolation be provided between a DME/TACAN transmit antenna and a UAT receiver on the surface. This could be supplied through either separation by distance or some other means, and the amount of isolation required depends on the parameters of the DME/TACAN and the design of the UAT receive system.

7.2.3 For example, to provide a performance level sufficient to allow for the air-to-ground reception requirement to be met to 150 NM for Class A0-equipped aircraft in high-density Core Europe 2015 in the presence of a collocated DME/TACAN, Tables II-7-1 and II-7-2 show the trade-off between distance from the UAT ground receiver and EIRP for a 979-MHz DME/TACAN. The analysis is based upon a maximum DME/TACAN signal level, measured at 979 MHz, of -0 dBm at the PMP of the UAT ground receiver, assuming an omnidirectional UAT receive antenna. For further assumptions used in this analysis, see Appendix A.

Table II-7-1. Maximum power of a 979 MHz DME/TACAN for a given separation distance to a UAT ground station receiver

DME/TACAN-UAT distance	*Maximum DME/TACAN EIRP (W)*
2 NM	10 000
1 NM	2 500
0.5 NM	625
0.25 NM	157

Table II-7-2. Minimum distance of a UAT ground station receiver to a 979 MHz DME/TACAN

DME/TACAN EIRP (W)	*Minimum distance*
10 000	2 NM
5 000	1.4 NM
1 000	0.63 NM
500	2 700 ft

7.2.4 For DME/TACAN transponders operating at frequencies between 980 MHz and 1 213 MHz, the distance between the UAT ground receiver and a DME/TACAN transponder should be such that the power of the DME/TACAN transmission received by the UAT ground receiver is less than –30 dBm at the PMP. This provides for air-to-ground reception which supports surveillance up to 150 NM for all aircraft transmit power levels.

Note.— This statement is based on analysis performed for a high-density Core Europe 2015 air traffic scenario (as described in Appendix A), with a UAT ground station receiving signals from 980 to 1 213 MHz DME/TACAN transponders.

Chapter 8

GUIDANCE ON UAT SPURIOUS EMISSIONS

8.1 ITU REGULATIONS

8.1.1 The ITU Radio Regulations require that the bandwidths of emissions be such as to ensure the most efficient utilization of the radio spectrum. In general this requires that bandwidths be kept at the lowest values which the state-of-the-art and the nature of the radio service permit. An emission outside the necessary bandwidth is called an unwanted emission and consists of out-of-band and spurious emissions. Out-of-band emissions are the main component of the unwanted emissions close to the fundamental emission, and the spurious emissions become dominant further from the fundamental emission. The out-of-band and spurious domains are characterized by the type of unwanted emissions which are predominant; the boundary between the domains is generally 2.5 times the necessary bandwidth, but with certain exceptions. Guidance on these exceptions is given in Recommendation ITU-R SM.1539.

8.1.2 ITU Radio Regulations contain the following definitions:

> 1.144 *Out-of-band emission.* Emission on a frequency or frequencies immediately outside the necessary bandwidth which results from the modulation process, but excluding spurious emissions.
>
> 1.145 *Spurious emission.* Emission on a frequency or frequencies which are outside the necessary bandwidth and the level of which may be reduced without affecting the corresponding transmission of information. Spurious emissions include harmonic emissions, parasitic emissions, intermodulation products and frequency conversion products but exclude out-of-band emissions.
>
> 1.146 *Unwanted emissions.* Consist of spurious emissions and out-of-band emissions. (Note: Both out-of-band and spurious emissions occur outside the necessary bandwidth of an emission.)
>
> 1.152 *Necessary bandwidth.* For a given class of emission, the width of the frequency band which is just sufficient to ensure the transmission of information at the rate and the quality required under specified conditions.

Figure II-8-1 provides a pictorial representation of the above terms.

8.1.3 Attenuation values used to calculate maximum permitted spurious domain emission power levels for use with radio services are defined in the ITU Radio Regulations, Appendix 3, Section II, as well as Recommendation ITU-R SM.329-9 for transmitters installed after 1 January 2003 and all transmitters after 1 January 2012.

8.1.4 The spurious emission levels are specified in the following reference bandwidths:

a) 1 kHz between 9 kHz and 150 kHz;

b) 10 kHz between 150 kHz and 30 MHz;

c) 100 kHz between 30 MHz and 1 GHz;

d) 1 MHz above 1 GHz.

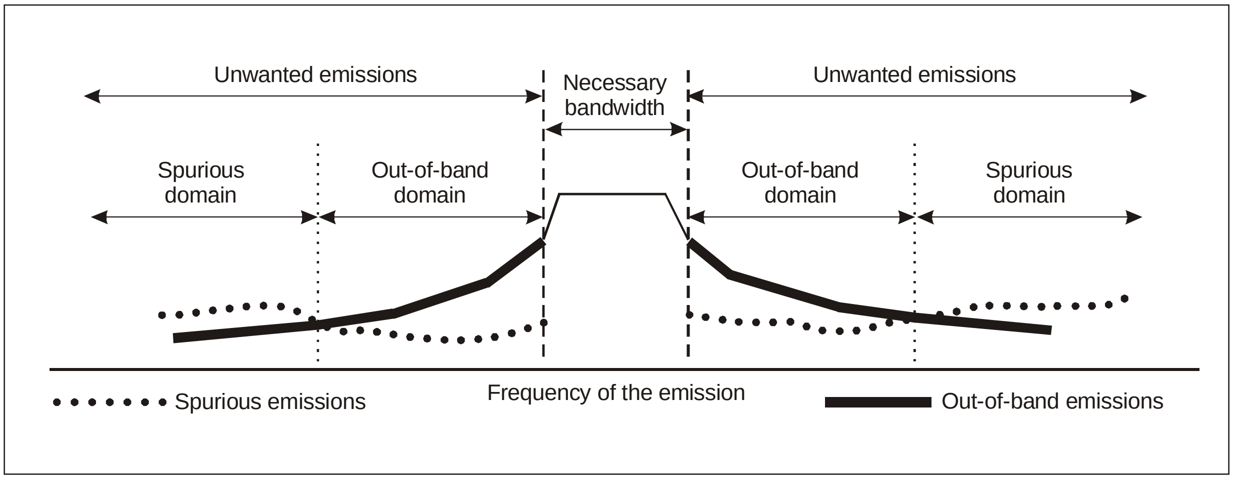

Figure II-8-1. Unwanted emissions and necessary bandwidth

8.1.5 A UAT transmitter installed after 1 January 2003 must meet a spurious domain emission attenuation of 43 + 10 log (P), or 70 dBc, whichever is less stringent (where P is the mean power in watts supplied to the antenna transmission line).

8.1.6 Recommendation ITU-R SM.329-9 also provides guidelines on the frequency range within which unwanted emissions need to be measured. For transmitted frequencies between 600 MHz and 5.2 GHz, the lower measurement limit should be 30 MHz and the upper limit is (including) the 5th harmonic.

8.2 EXAMPLE APPLICATION OF THE ITU REGULATION TO THE UAT CASE

8.2.1 Information received from the ITU indicates that the two main functions of the UAT system (ADS-B and ground uplink) belong to different radio services. The ADS-B part of UAT is considered as an aeronautical radio navigation service (ARNS) whereas the UAT ground uplink part needs to be treated as an aeronautical mobile (R) service.

8.2.2 With a maximum total mean power of 500 W[1] supplied by a UAT transmitter to the antenna transmission line, the attenuation relative to the total mean power equals 43 + 10 log (500) = 70 dBc. Therefore, the spurious emissions supplied by a UAT transmitter to the antenna transmission line of maximum power UAT transmitters must not exceed 57 dBm – 70 dBc = –13 dBm. That spurious emission level is to be measured with a 100 kHz reference bandwidth for spurious emissions in the frequency range 30 to 1 000 MHz and with a 1-MHz reference bandwidth for spurious emissions at frequencies above 1 000 MHz.

8.2.3 In the case of UAT, a necessary bandwidth of 1.3 MHz (equal to the measured occupied — i.e. 99 per cent power — bandwidth) has been determined. Therefore the boundary between spurious and out-of-band emissions is set to 2.5*1.3 MHz = 3.25 MHz. With a UAT carrier frequency of 978 MHz, the spurious emission domain is located at frequencies below 974.75 MHz and above 981.25 MHz.

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[1] The UAT SARPs of Annex 10, Volume III, specify a maximum power of 54 dBm at the PMP. Assuming a 3-dB feeder line loss, the maximum UAT transmitter output power will be 57 dBm (500 W).

8.2.4 The requirements for the spurious domain for UAT cover the frequency band 30 MHz to 5*978 = 4 890 MHz excluding the fundamental emission and the out-of band domain (974.75 MHz to 981.25 MHz).

8.2.5 Annex 10, Volume III, Chapter 12, 12.1.2.3.3, states:

> “12.1.2.3.3 *Transmit mask*
>
> The spectrum of a UAT message transmission modulated with pseudorandom message data blocks (MDB) shall fall within the limits specified in Table II-12-2 when measured in a 100 KHz bandwidth.”

At frequencies off-tuned by 3.25 MHz (where the spurious domain starts), UAT signal components should be attenuated by at least 60 dB compared to the UAT signal at 978 MHz (measured in a 100-KHz bandwidth). Therefore, Figure 12-1 of Annex 10, Volume III, has to be interpreted for a maximum power UAT transmitter as if that maximum power at 978 MHz (i.e. 57 dBm measured in a 1.3-MHz bandwidth) equals approximately 47 dBm per 100 KHz. At 3.25 MHz offset, the mask requires the emission to be 60 dB less (i.e. –13 dBm per 100 KHz). Hence, the transmit mask of the SARPs of Annex 10, Volume III, is consistent with the spurious emissions requirements of the ITU Radio Regulations even for the maximum UAT transmit power levels. It is important to note that the mask is more conservative than the ITU spurious emission requirements for lower UAT transmit power levels.[2]

8.3 CONCLUSION

The transmit mask in the SARPs of Annex 10, Volume III, will ensure that the ITU spurious emission requirements are met at the out-of-band/spurious emission boundary. Spurious emissions should be measured in a reference bandwidth of 100 KHz in the frequency band 30 MHz to 974.75 MHz and 981.25 to 1 GHz, and in a reference bandwidth of 1 MHz in the frequency band of 1 GHz to 4.890 GHz.

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[2] For example, in the case of a 50-watt UAT, the spurious emission limit is 43 + 10 log(50) = 60 dBc, or 47 dBm – 60 dB = –13 dBm. The mask however requires the emission at the out-of-band/spurious boundary to be 60 dB down from approximately 37 dBm (i.e. the portion of the 50-watt 1.3 MHz UAT emission that is measured in a 100-kHz measurement bandwidth) or –23 dBm.

Chapter 9

POTENTIAL FUTURE SERVICES FOR UAT

Some potential future services for UAT-equipped aircraft are described in this section and summarized in Table II-9-1. The services identified here support position determination of UAT-equipped aircraft based on time of message reception (TOMR) of UAT signals. The services are listed below:

a) *Range validation of ADS-B reported position data, based on the one-way propagation time of the ADS-B message.* This function can be performed by a single receiving station and relies on both the transmitter and receiver having access to precise timing information (referred to as being in the “UTC coupled” condition). This is useful mainly to attain some confidence the ADS-B transmission is from a bona fide user and is not a result of “spoofing”. Further information on this potential future service can be found in Appendix J.

b) *Localization of a mobile (aircraft or surface vehicle) ADS-B transmitter from a fixed ground receiver network.* This function requires reception of the ADS-B message by at least three UAT ground stations. Each UAT ground station requires precise knowledge of time in order to provide the TOMR with each reception. The TOMR allows a central processor to localize the transmitter via the time-difference-of-arrival technique. The mobile transmitter does not require knowledge of its own position nor does it require precise knowledge of time. This capability — coupled with the reported identification and barometric altitude — could provide backup air-to-ground surveillance in the event of widespread outage of GNSS, presuming that the ground station time source is independent of GNSS and accurate to within 500 nanoseconds of UTC.

c) *Localization of the mobile (ownship) ADS-B receiver.* This is based on reception of three or more UAT ground station transmissions within the same UTC second. Each UAT ground station transmission is based on precise knowledge of time. The ownship UAT receiver need not have precise knowledge of time, but determines position from the time-difference-of-arrival technique and knowledge of the UAT ground station locations encoded in the received messages. This capability could provide a crude form of backup navigation in the event of widespread outage of GNSS, presuming that the UAT ground station time source is independent of GNSS and accurate to within 500 nanoseconds of UTC.

Table II-9-1. Summary of potential future applications of UAT

Potential future UAT service	*UAT transmitting subsystem requirements*	*UAT receiving subsystem requirements*	*Primary application*	*Limitations*
Range validation	Navigation input, UTC-coupled	Navigation input, UTC-coupled	Integrity check of ADS-B	Total timing errors limit range accuracy to ~ 0.7 NM (see Appendix J)
Backup air-to-ground surveillance	None	UTC-coupled	Surveillance backup for GNSS	Service available only in areas of significant ground station infrastructure
Backup navigation	UTC-coupled (stable source can operate without GNSS for hours)	None	Navigation backup for GNSS	Service available only in areas of significant ground station infrastructure

Appendix A

UAT SYSTEM PERFORMANCE SIMULATION RESULTS

1. INTRODUCTION

1.1 Organization

1.1.1 This introductory section discusses the background and assumptions for the multi-aircraft UAT simulation (MAUS), which has been used as a tool for evaluating the performance of UAT as an ADS-B data link under a number of different possible system parameters and configurations.

1.1.2 Section 2 describes in detail the antenna gain model, which is used by MAUS in calculating the signal levels received from the transmitting aircraft in the simulation. This antenna gain model is identical to that used in simulations employed in the past to evaluate all three ADS-B link candidates (see, for example, Comparative Analysis of Potential ADS-B Links, AMCP/8 at http://legacy.icao.int/anb/panels/acp/index.cfm).

1.1.3 The UAT receiver performance model used by MAUS is described in Section 3. The model is based on measured data, and both the data and model characteristics are described in that section.

1.1.4 The results shown in Section 4 are compared to the requirements of Appendix K, as specified in Tables II-K-1 and II-K-3. Section 4 presents the results of the analysis of UAT performance. Section 4.1 describes the Los Angeles 2020 (LA 2020) scenario and the UAT system performance in that environment. Section 4.2 presents the Core Europe scenario and describes the performance of UAT in that environment. Section 4.3 describes and presents results for the low-density scenario. Acquisition performance is presented in Section 4.4, and aircraft-aircraft performance on the surface is discussed in Section 4.5. Section 4.6 presents the results for an A0 receiver on the surface receiving aircraft on approach. Section 4.7 describes the results of a study on the use of a geographical distribution of UAT ground stations for uplinking TIS-B information in the LA 2020 environment.

1.1.5 Finally, validation of the MAUS results is presented in Section 5. That section describes a comparison of MAUS predictions with measured data from specially devised test equipment designed to emulate a high-density UAT self-interference environment, and the MAUS was run for identical conditions.

1.2 Background

Analytical models and detailed simulations of data links operating in future scenarios are required to assess expected capabilities in stressed circumstances. Accurately modelling future capabilities for potential system designs in a fair way, however, is challenging. Since validation of simulation results in future environments is unrealistic, other means of verification such as the following are required. System characteristics represented in these simulations should agree with actual measurements on components of the proposed design, e.g. bench measurements on prototype equipment and calibrated flight test data should be used, when possible, for the receiver/decoder capabilities and as comparison with modelled link budgets. Similarly, suitable interference models help to support estimates of how these conditions may change in future scenarios. Credibility of any simulation results for future scenarios also requires that they be able to model current conditions and provide results that appropriately agree with measurements made under these conditions. Existing tools have been used as cross-checks where possible for the final detailed simulations and models.

1.3 General assumptions

In an effort to capture as many real-world effects important to the assessment of the performance of UAT as possible, an attempt was made to include, to the extent possible, representations of the effects of:

- propagation and cable losses;
- antenna gains;
- propagation delays;
- co-channel interference (specifically, DME/TACAN and JTIDS (Link 16));
- co-site interference (in and out of band);
- multiple self-interference sources;
- alternating transmissions between top and bottom antennas (where applicable);
- performance as a function of receiver configuration (e.g. diversity, switched, bottom only);
- transmit power variability and configuration;
- receiver re-triggering;
- receiver performance based on bench-testing;
- message transmission sequence and information content by aircraft equipage;
- ground receiver assumptions.

Section 4.7.1 contains additional assumptions that were required to analyse the TIS-B uplink performance of UAT.

1.4 UAT detailed simulation description and limitations

The UAT detailed simulation software is written in the "C" programming language and allows for horizontal, constant-velocity motion of the aircraft in the scenario, if the user so chooses. The simulation reads in the inputs specifying the particular case to be run, generates all of the ADS-B transmissions and interference, calculates signal levels and times of arrival for these transmissions, and determines the corresponding message error rates for each ADS-B transmission by all aircraft within line-of-sight of the victim receiver. MAUS is often run in a mode that regards all of the ADS-B transmissions by the air traffic scenario as interference and inserts a number of probe aircraft as desired transmitters to provide message error rate data. This permits the augmentation of the statistical sample used. This information is then written to an output file, one entry line for each ADS-B transmission, which is then analysed by post-simulation software. Each of the effects listed in Section 1.2 will now be discussed in turn.

- *Propagation and cable losses.* The UAT simulation calculates the free-space propagation loss for each transmission, using the range between transmitter and receiver at the time of transmission. There is also a nominal receiver cable loss of 3 dB incorporated into the calculation. An optional transmit cable loss is also included in the simulation, but since the transmit powers have been defined at the antenna, the transmit cable loss has been set to zero.

- *Antenna gains.* The antenna gain model included in the UAT simulation is described in Section 2.

— *Propagation delays.* Calculation of the propagation delay incurred by the signal in traversing the free space between transmitter and receiver has been included in the UAT simulation.

— *Co-channel interference.* In certain geographic areas, UAT may have to coexist with transmissions from DME/TACAN and Link 16 sources. Link 16 scenarios have been provided in cooperation with a military authority and have been applied to all of the performance analysis shown in this document. Various DME/TACAN scenarios provided by Eurocontrol have been applied to the Core Europe analysis. In all cases, every attempt has been made to provide conservative estimates of the co-channel interference environment. (See Appendix B for a more detailed explanation of the interference environment.)

— *Co-site interference.* Co-site transmissions of UAT messages, DME interrogations, Mode S interrogations and replies, whisper-shout interrogations and ATCRBS replies are all modelled as interference in the UAT simulation. All of these are treated as interference which completely blocks UAT reception; therefore, it is assumed that no UAT reception may occur during any of these co-site transmissions (including a 15 microsecond suppression period added to the end of each co-site transmission). (See Appendix B for a more detailed explanation of the interference environment.)

— *Multiple self-interference sources.* Although the UAT transmission protocol specifies that a transmission begins on one of a fixed number of message start opportunities, the propagation delay described above will cause the arrival of messages at the victim receiver to be quasi-random. There may be a number of messages overlapping one another, and these overlaps will be for variable amounts of time. This interference is accounted for in the multi-aircraft simulation. Multiple UAT interferers are treated in the receiver performance model by combining their interference levels in a way consistent with bench-test measurements. The simultaneous presence of UAT interference, co-channel interference and self-interference is treated in a detailed fashion by the model. Further discussion is presented in Section 3. Since the UAT system description specifies that the ground uplink transmissions occur in a separate, guarded time segment than the air-to-air transmissions, FIS-B should not interfere with the ADS-B transmissions of the aircraft. Therefore, the simulation does not model this data load for the ADS-B performance assessment.

— *Alternating transmissions.* The model simulates the alternating transmission sequence specified for aircraft Class A1, A2 and A3 equipage, TTBBTTBB, where T = top and B = bottom. For Class A0 equipage, the model simulates transmission from a bottom antenna.

— *Receiver diversity.* For Class A2 and A3 equipage, the model simulates receiver diversity by calculating the message error rate at both the top and bottom receive antennas and calculating the joint reception probability. For A1 equipage, the model simulates the single-receiver dual-antenna configuration by switching the receive antenna alternately between top and bottom each successive second. For Class A0-equipped aircraft, reception is permitted only from a bottom antenna.

— *Transmit power variability.* The transmit power for an aircraft is chosen from a uniform distribution given by the limits specified for the aircraft equipage. The transmit powers for different equipage levels are defined in Chapter 2, 2.4.2.1.

— *Receiver retriggering.* The UAT simulation checks each individual ADS-B message arriving at the victim receiver for its message error rate. This procedure amounts to allowing for retriggering in the receiver, i.e. the potential for the receiver to switch from receiving a message to a stronger message signal that arrives after the start of the reception of the first message.

— *Receiver performance model.* The receiver performance model used in the UAT simulation is based on experimental data collected on special UAT receivers that were provided for that purpose. Those receivers were modified to be compliant with the requirements specified in this document. Both the 0.8-MHz filter specified for A3 equipage and the 1.2-MHz filter used in A0–A2 equipage were tested. The results of the bench-testing and the receiver performance model are described in Section 3. The sensitivity of the receiver is assumed to be –93 dBm. This represents the signal level at which 10 per cent error rate is achieved in the absence of interfering signals. This parameter was validated in the simulation.

— *Message transmission sequence and content.* Part I, Chapter 2, and Part II, Chapter 3, 3.1.1, define the types of messages, their content and the sequence of messages transmitted for each category of aircraft equipage. See Table II-A-3 for a summary of all the types of information transmitted by each equipage class. The information content transmitted by each aircraft is explicitly modelled by the multi-aircraft simulation.

— *Ground receiver assumptions.* For the air-to-ground studies that follow, several assumptions were changed for the special case of the ground receiver. There is assumed to be no co-site interference, but the same Link 16 baseline interference used in airborne receptions is included. The receiver sensitivity used is –96 dBm. The antenna gain is slightly different in that it uses an omnidirectional TACAN antenna, with elevation gain based on measured data. The ground antenna uses a 1.2-MHz filter only. In certain cases, a 3-sector antenna is used.

2. ANTENNA MODEL

2.1 The antenna gain model contains two components to accommodate both the elevation pattern variation as well as non-uniformity in the azimuth pattern. A fixed component is based on the elevation angle between the two aircraft. An additional random component is used to characterize the real-world effects of fuselage blockages in the azimuth pattern. The distributions describing these two components are based on measurement data and are intended to provide sufficient statistical variability to capture a wide variety of antenna installations on aircraft. The two components in dB units are summed to create the total antenna gain pattern for each of a given pair of aircraft.

2.2 Figure II-A-1 shows the elevation gain for a top-mounted antenna. The same gain is used for a bottom-mounted antenna, with the pattern inverted vertically. The antenna has a peak gain of 4.1 dBi at an elevation angle of 26 degrees. For best resolution of display, this figure is limited to a minimum gain of –40 dB.

2.3 The variation in gain due to azimuth pattern effects is based on the probability distribution shown in Figure II-A-2. A uniform random variable on the x-axis is used to select a value that characterizes the azimuth variation in antenna gain. Note that approximately one-third of the time, the variation can be a loss of up to 8.6 dB. Approximately two-thirds of the time, the variation is an additional gain of up to 6 dB. Note that the median gain in the azimuthal direction is 1 dB.

2.4 The elevation and azimuth angles to other aircraft are constantly changing. To simulate this, the antenna model allows for a new random selection of the azimuth gain variation each time the relative azimuth between a pair of targets is altered by more than 5 degrees. This antenna gain model was used in the performance assessments of each of the three links treated in the Comparative Analysis of Potential ADS-B Links, AMCP/8.

3. RECEIVER PERFORMANCE MODEL

3.1 Measured data

3.1.1 Measurements of the bit error rate (BER) receive performance were made on two pre-production UAT transceivers: one with a nominal 1.2-MHz bandwidth and one with a nominal 0.8-MHz bandwidth. Simultaneous measurements were made while the same input signal was applied to both units. The input signal consisted of a signal of interest (SOI), from a nominal 1.5-MHz bandwidth UAT transceiver, summed with an interference signal. The SOI was a long UAT ADS-B message.

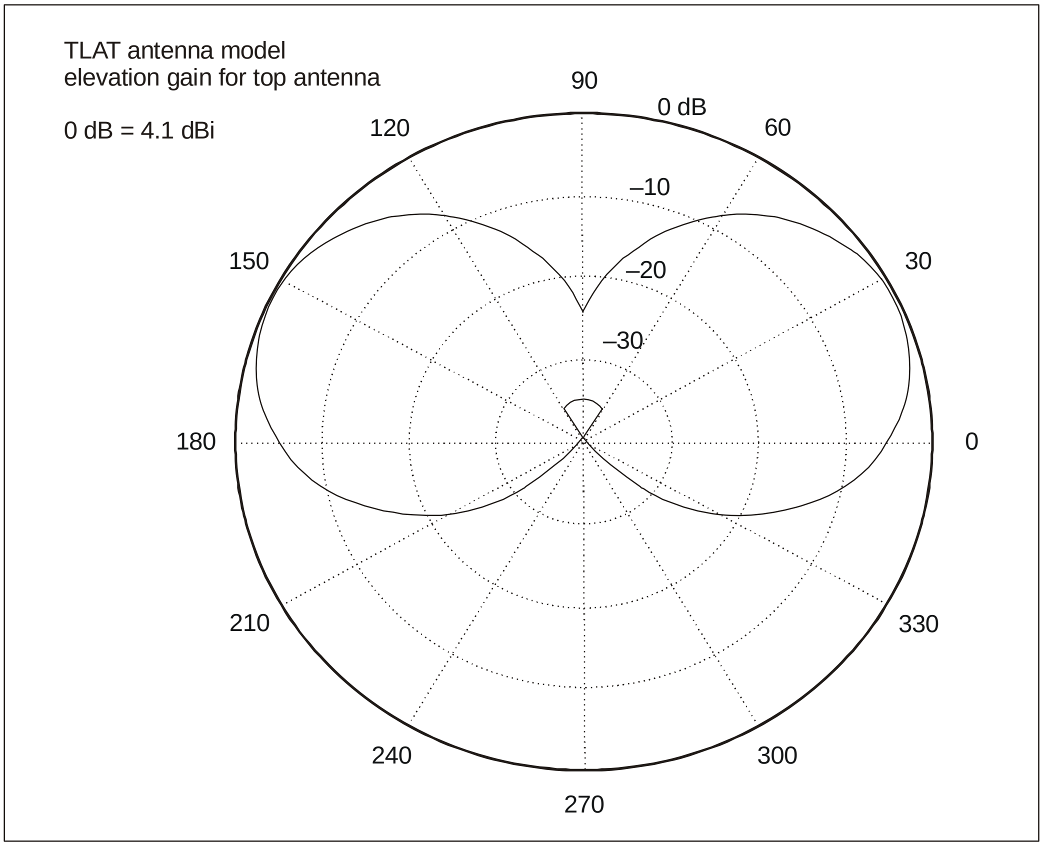


Figure II-A-1. TLAT antenna model elevation gain

3.1.2 A BER test fixture was created in order to allow measuring the BER impact of pulsed interference as a function of time relative to the start of the pulse. It included circuitry for gating the test interference signal off during the UAT message synchronization header and software for determining the position of every bit error in every received message data block or FEC. The test setup is shown in Figure II-A-3.

3.1.3 The interference signals used for the BER tests were the following:

a) *No external interference (internal receiver noise only).* The SOI level was varied to achieve various signal-to-noise ratios (SNRs). Note that SNR depends on the noise bandwidth used, which will be defined later in this section.

b) *White Gaussian interference.* The SOI level was varied to achieve various SNRs.

c) *A single UAT (1.5 MHz bandwidth) interferer.* The levels of both the SOI and the interferer were independently varied to achieve various SNRs and various interference-to-noise ratios (INRs).

d) *A simulated combination of multiple UAT (1.5-MHz bandwidth) interferers.* An arbitrary waveform generator (AWG) produced these combination signals by playing back a variety of input data files. The input data files were generated from a set of single UAT files recorded by a digital oscilloscope. These files were adjusted in level, offset in time and summed together to create the multi-UAT scenarios of interest, specifically:

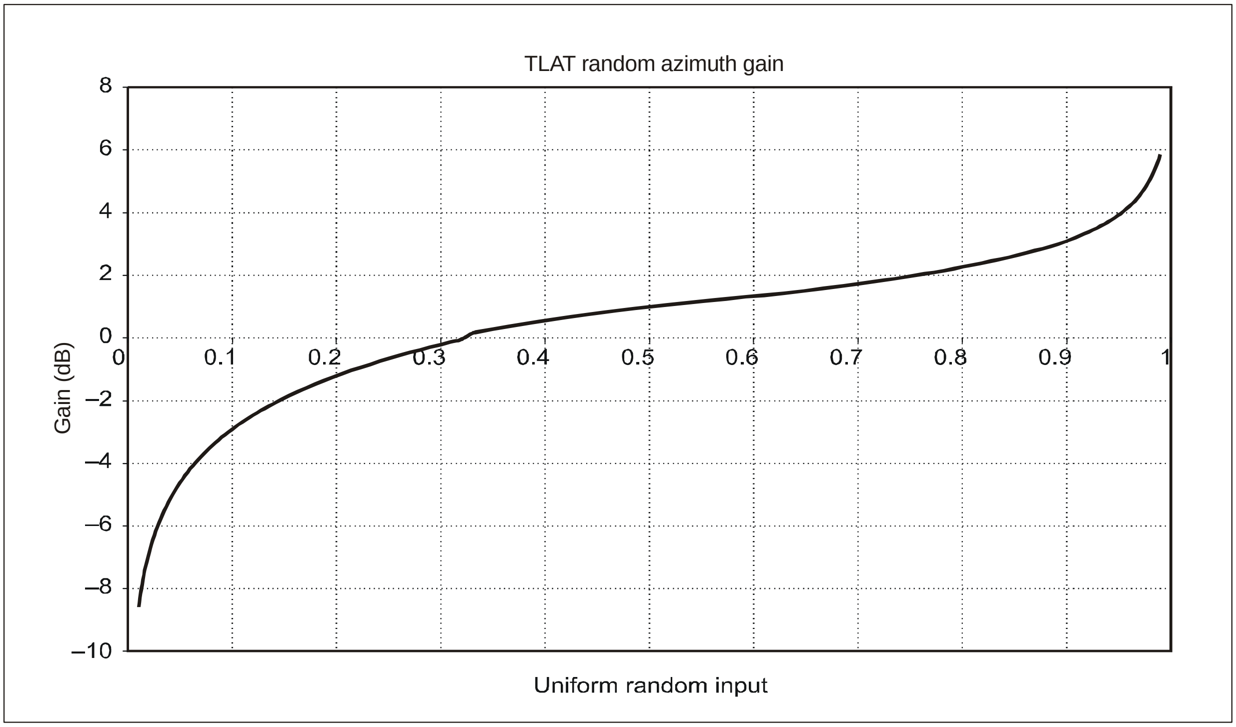


Figure II-A-2. TLAT random azimuth gain

1) Two UATs, both at the same level, and at various INRs.

2) Two UATs at high INR and at various relative levels.

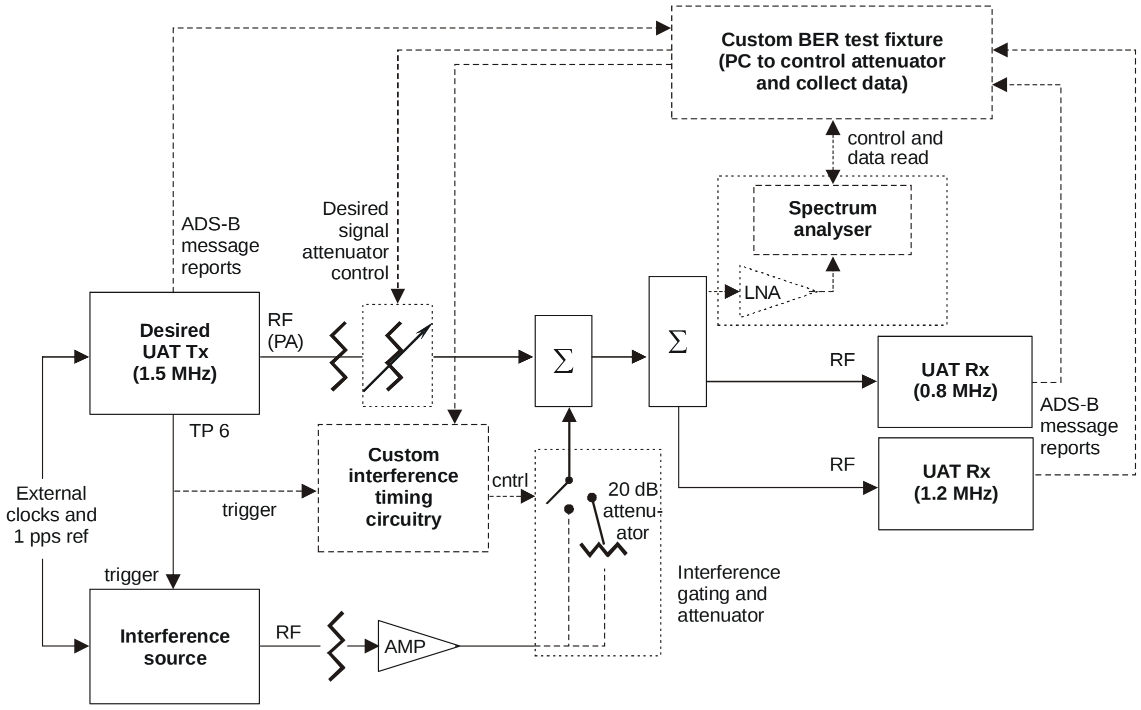
3) Three, five and ten UATs, all at the same level and at high INR.

4) As a check on the fidelity of the simulation, a single UAT at high INR was also simulated and measured, and the BER was compared with the corresponding BER measured using an actual UAT at high INR. The discrepancy between the two was found to be less than 0.7 dB.

e) *A DME interferer emitting pulse pairs with 12-μs separation.* DME signals at two frequencies were used, at the SOI centre frequency and one MHz above. The level of the SOI was varied to achieve a wide range of signal-to-interference ratios (SIRs). The variation of BER with time during and shortly after the DME pulse pair was measured.

f) *A Link 16 interferer, at various frequencies, at the SOI centre frequency, three MHz higher, 6 MHz higher and so on up to 21 MHz higher.* It was assumed that the corresponding lower frequency response would be similar. The level of the SOI was varied to achieve a wide range of signal-to-interference ratios (SIRs). The variation of BER with time during and shortly after the Link 16 pulse pair was measured.

3.1.4 For all of the above interference conditions, bit errors were measured at every position in the message data block and FEC. Results from multiple messages were averaged together. Enough messages were measured to permit determining BER values down to about 10^{-5}. For the continuous interference conditions (no external interference or Gaussian noise), bit errors from all received message data blocks and FEC bits were averaged together. For the UAT interferers, bit errors from all message data blocks and FEC bits during interference transmission were averaged together.



Fixed attenuators and amplifiers are adjusted to provide:

— a desired signal level at the UAT Rx inputs of –20 dBm when signal attenuator is set to 0 dB; and

— a peak interference level at the UAT Rx inputs of –20 dBm when interference is gated on and the 20-dB interference attenuator is bypassed.

Figure II-A-3. Test setup for measuring BER

3.1.5 For the pulsed interference conditions (DME and Link 16 signals), bit errors were averaged independently for each time offset after the start of the interference pulse (to a resolution of 0.5 UAT bit periods). This enabled determining BER values as a function of SIR, time and frequency offset. Sample plots of measured BER data for DME and Link 16 interferers are shown in Figures II-A-4 through II-A-6.

3.2 Receiver model

3.2.1 UAT BER model

3.2.1.1 Based on the above bit error rate (BER) measurements, a computer programme (the “UAT BER model”) was designed to estimate MOPS-compliant UAT BER performance under arbitrary combinations of UAT, DME and Link 16 interference. The UAT BER model is incorporated within the multi-aircraft UAT simulation (MAUS), which uses the BER estimates to evaluate the reception success of UAT messages.

3.2.1.2 The following simplifying assumptions were made in the UAT BER model:

a) The variation of BER with signal to interference and noise ratio (SINR) for any given interference scenario is specified by just three parameters, B0, B1 and B2. In terms of the variable $\log_{10}(-\log_{10}(2^*BER))$, called “llBER” in the following, every BER(SINR) relationship is specified by a three-segment piecewise linear llBER versus SINR curve (for SINR specified in dB). The parameters B1 and B2 are the SINR values at the llBER values of –0.5 for the first segment and +0.5 for the third segment. The first and third segments intersect at SINR = B0 with an llBER value of 0. The second segment simply rounds off the knee at B0 by connecting the points at llBER = –0.1 and +0.1.

b) For multiple UAT interferers, the BER is determined only by the SINR, the INR, and the difference in level, dI, between the two strongest UAT interferers. If INR<<0 (INR specified in dB), BER is unaffected by dI. If there are more than two simultaneous UAT interferers, the third strongest and all weaker ones have the same impact as noise sources of the same power levels (measured in a noise bandwidth yet to be specified), so their powers are understood to be included in the noise term for computing INR. The interference term in INR is the power sum of the two strongest interferers only.

c) For combined Gaussian noise and multiple UAT interference, the variation in each of the parameters B0, B1 and B2 with INR for any given value of dI follows a four-parameter sigmoid curve of the form:

$$B = a + b \cdot \frac{INR - d}{\sqrt{c^2 + (INR - d)^2}}$$

where the parameters a, b, c and d are given by:

a = {B(INR>>0) + B(INR<<0)}/2;
b = {B(INR>>0) – B(INR<<0)}/2;
d = INR at which B = a; and
c = b divided by the slope of the B(INR) curve at INR = d.

d) For combined Gaussian noise and multiple UAT interference, the variation in each of the parameters B0, B1 and B2 with dI follows a three-parameter sigmoid curve of the form:

$$B = a + b \cdot \frac{dI}{\sqrt{c^2 + dI^2}}$$

where the parameters a, b and c are given by:

a = B(dI=0);
b = {B(dI>>0) – B(dI=0)}; and
c = b divided by the slope of the B(INR) curve at dI = 0.

e) Assumptions 2, 3 and 4 together mean that any of the three B parameters for any combination of Gaussian noise and multiple UAT interference may be specified by eight parameters (a0, b0, c0, d0 to describe B(INR) when dI>>0; b1, c1, d1 to describe B(INR) when dI = 0; and c2 to describe B(dI) when INR>>0. The requirement of continuity of B(INR, dI) determines the remaining parameters:

a1 = (a0–b0) + b1,
a2 = B(INR) for dI = 0, and
b2 = {B(INR) for dI>>0} – a2.

f) The BER impact of combining DME with other UAT interference and with receiver noise is the same as if the DME interference on any bit were replaced by an additional UAT interferer with a level such that it alone would produce the same BER as the DME interference alone.

g) The BER impact of combining Link 16 with other UAT interference and with receiver noise is the same as if the Link 16 interference on any bit were replaced by an additional Gaussian noise interferer with a level such that it alone would produce the same BER as the Link 16 interference alone.

3.2.1.3 With the above assumptions, BER is determined for every combination of Gaussian noise, multiple UAT, DME and Link 16 interference, by SINR, INR and dI, as defined above, together with 24 parameters. These parameters are then determined for each of the two pre-production UAT receive bandwidths as the values that best fit the measured Gaussian noise plus UAT interference data.

3.2.1.4 One additional parameter, the appropriate noise bandwidth must also be specified. This is conveniently represented as dN, the increase in effective noise power over that computed for a 1 MHz bandwidth. Initially, dN was chosen to equalize the SNR required for a given BER when interference was pure Gaussian noise with the SIR required when interference was ten equal-power UAT interferers. Subsequently, it was found that a better overall fit could be obtained with dN about 2 dB higher (bandwidth 60% larger). The dN values used are +1.5 dB for the 1.2 MHz bandwidth UAT and 0 dB for the 0.8 MHz bandwidth UAT.

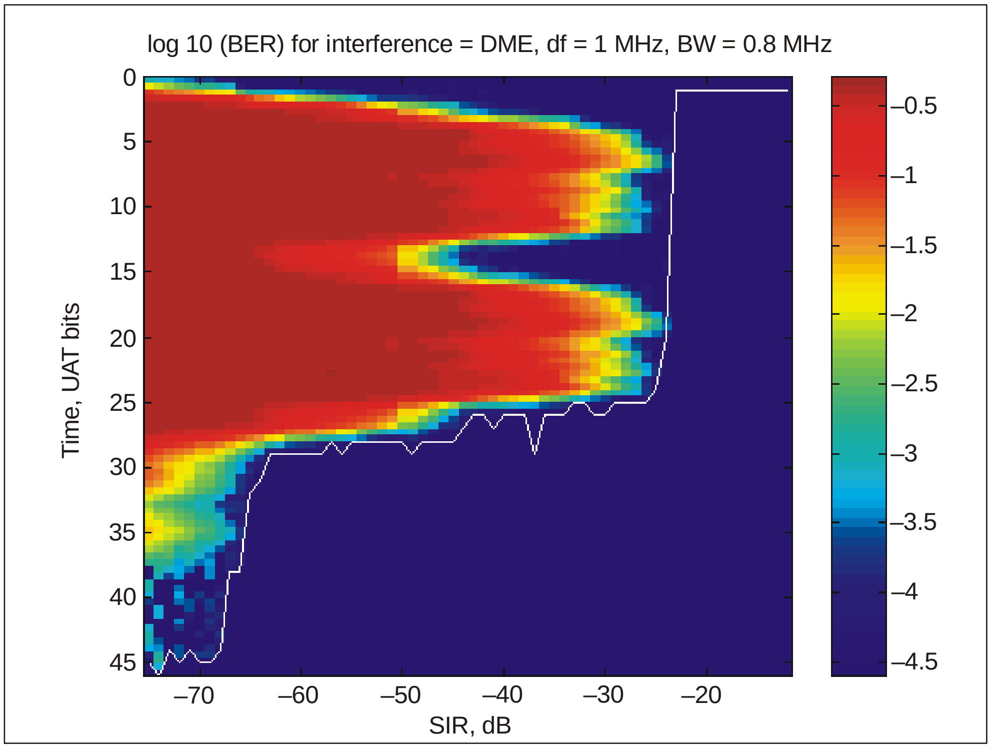


Figure II-A-4. BER due to DME interference
(Frequency offset = 1 MHz, receiver bandwidth = 0.8 MHz. log10 {BER} encoded as colour)

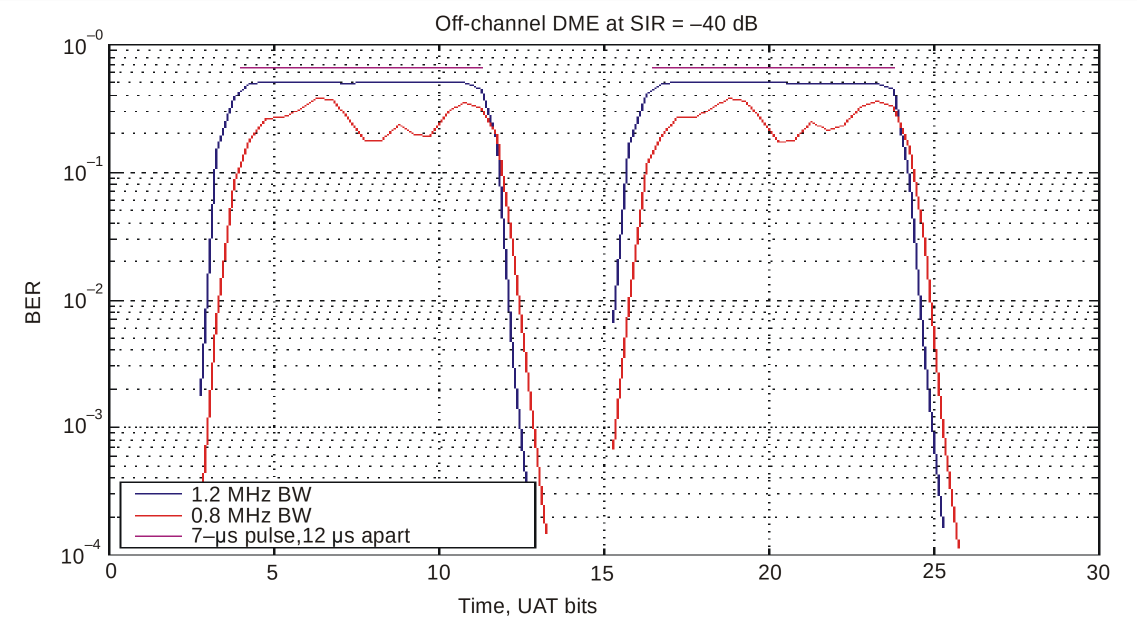


Figure II-A-5. BER due to DME interference
(Frequency offset = 1 MHz, vertical slice through colour plots like Figure II-A-4 at SIR = –40 dB)

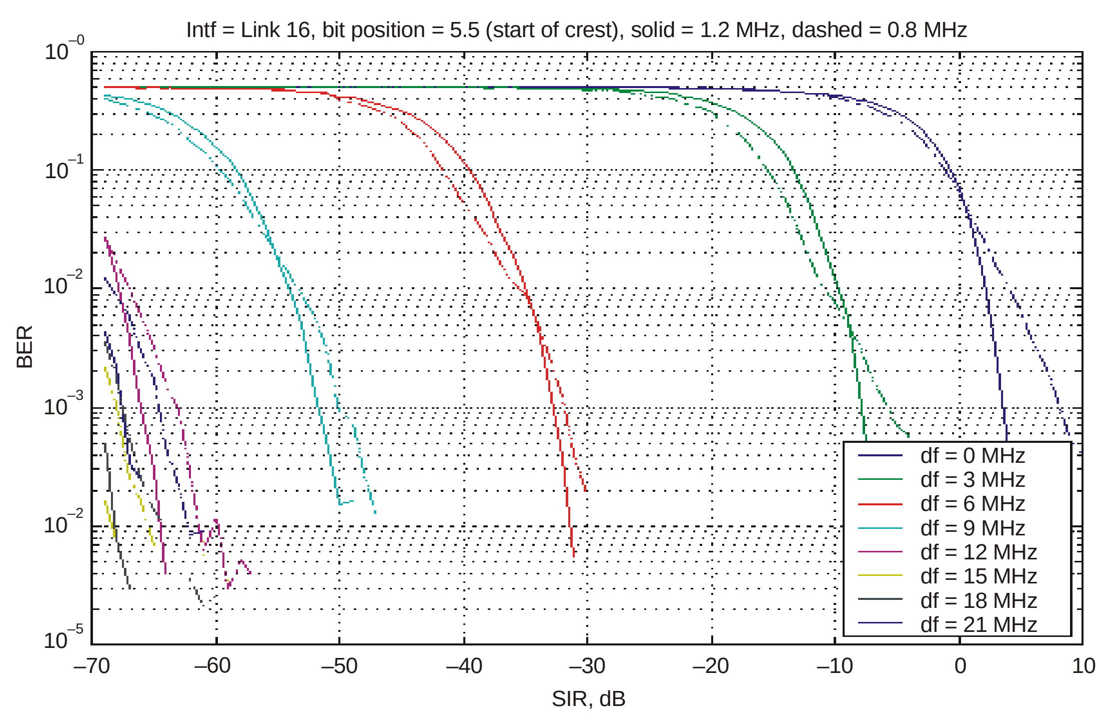


Figure II-A-6. Link 16 interference
(Horizontal slice through colour plots like Figure II-A-4 at Bit Position 5.5)

3.2.2 Receiver model accuracy

Figures II-A-7 through II-A-10 show the measured and modelled BER versus SINR curves for four sample subsets of the measured data. Figures II-A-9 and II-A-10 show the BER modelling error for all the Gaussian noise plus UAT interference data so as to indicate the equivalent power error in dB. The BER-to-power curve used for Figures II-A-11 and II-A-12 is the curve appropriate for pure Gaussian noise interference. With this measure, it can be seen that most of the data are modelled to ±1.5-dB accuracy.

4. MULTI-AIRCRAFT SIMULATION (MAUS) RESULTS

4.1 Los Angeles Basin 2020 (LA 2020)

4.1.1 This scenario is based on the LA Basin 1999 maximum estimate. It is assumed that air traffic in this area would increase by a few per cent each year until 2020, when it would be 50 per cent higher than in 1999. The distribution of aircraft in the scenario is based on approximations of measured altitude and range density distributions.

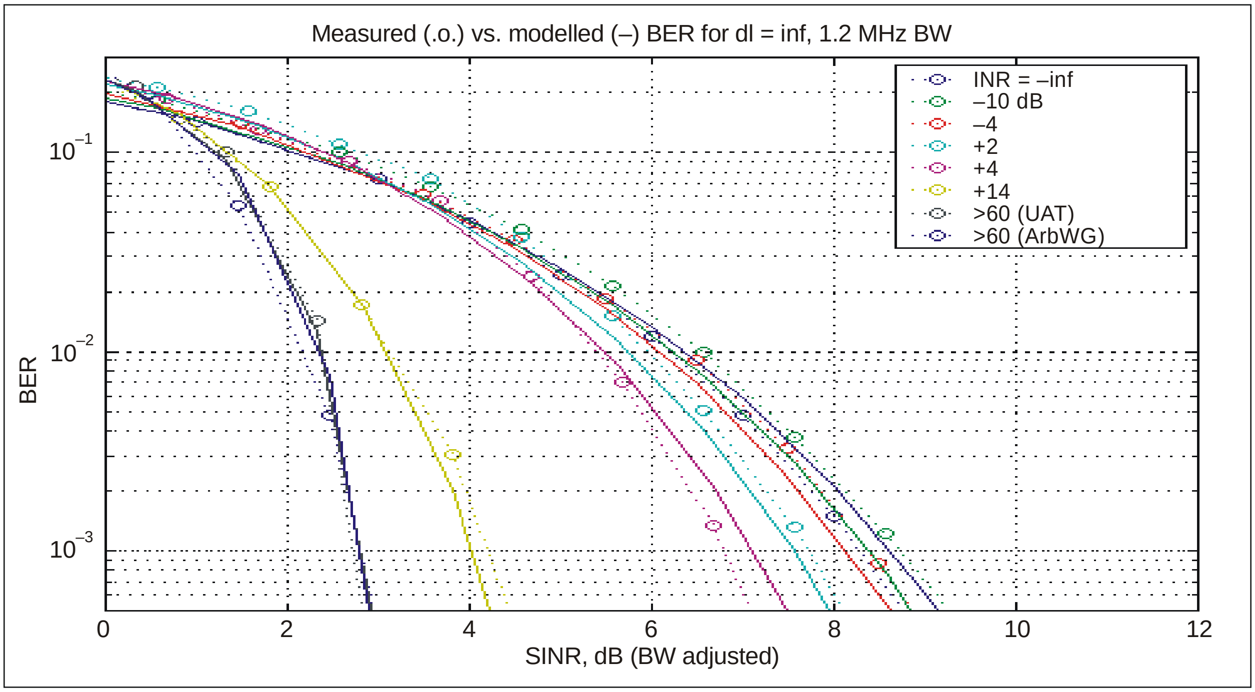


Figure II-A-7. Gaussian noise + single UAT, 1.2 MHz receiver

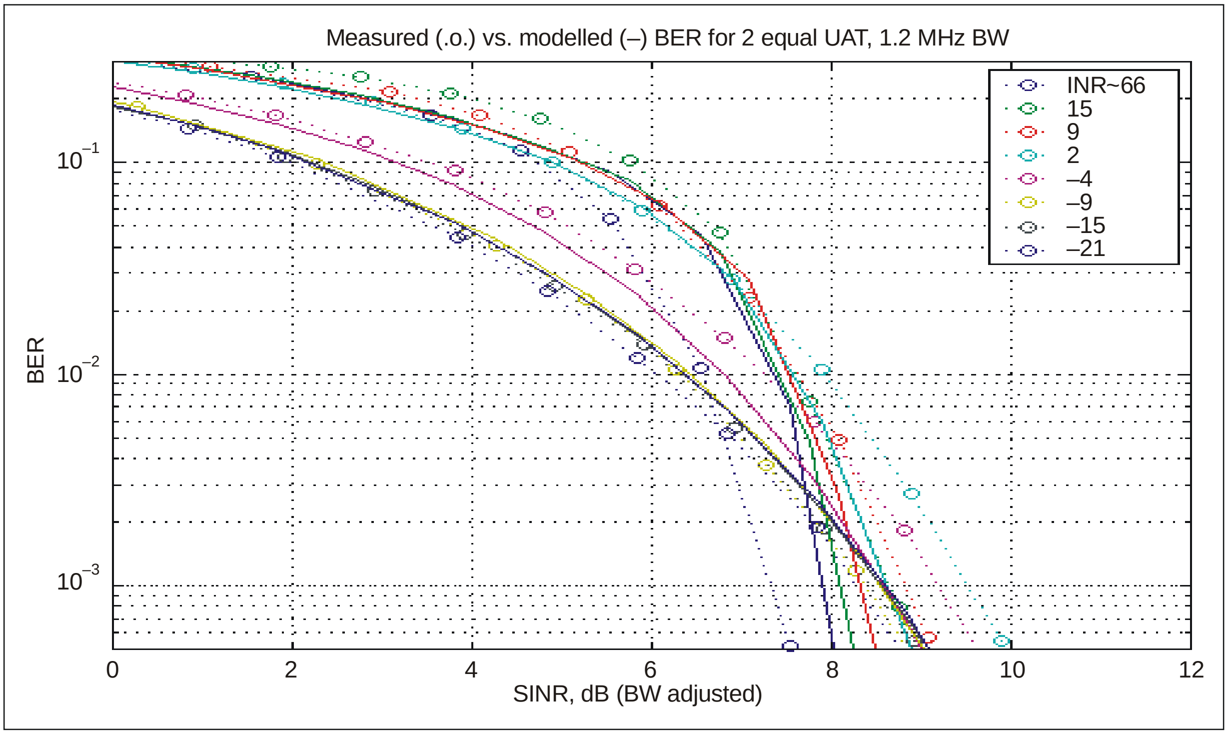


Figure II-A-8. Gaussian noise + two equal UATs, 1.2 MHz receiver

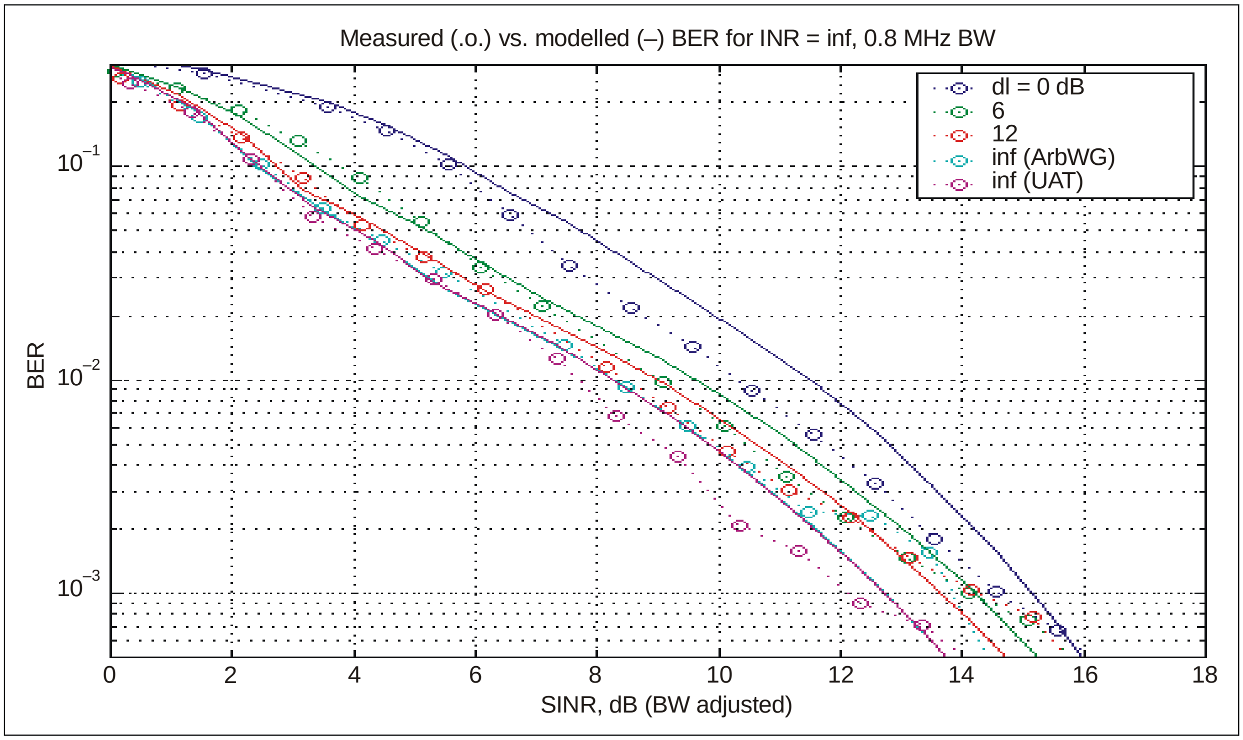


Figure II-A-9. Two unequal UATs, INR >> 0 dB, 0.8 MHz receiver

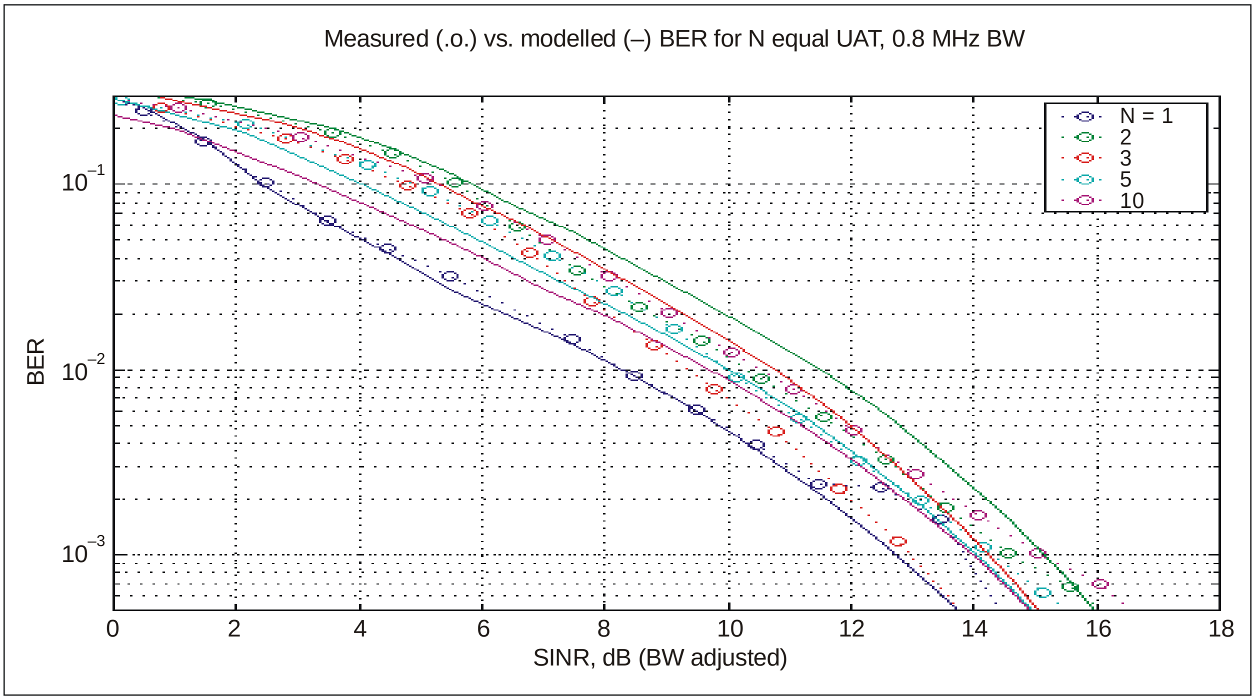


Figure II-A-10. N equal UATs, INR >> 0 dB, 0.8 MHz receiver

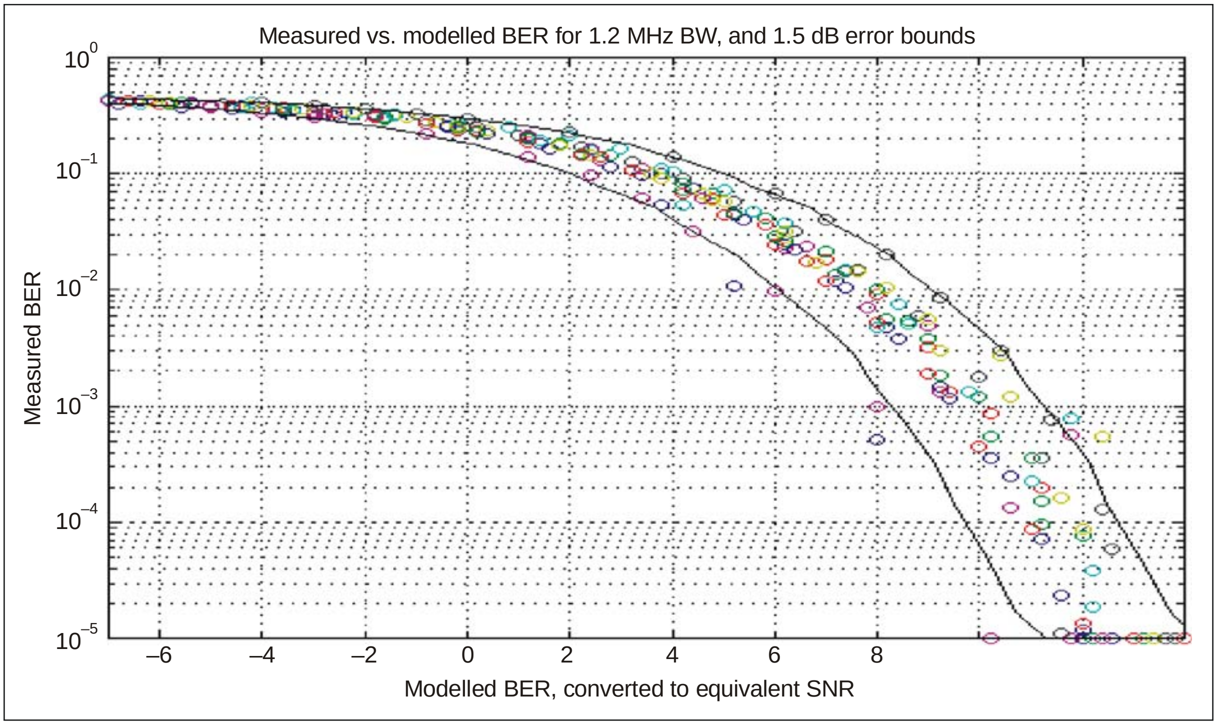


Figure II-A-11. Model errors for all data, 1.2 MHz receiver

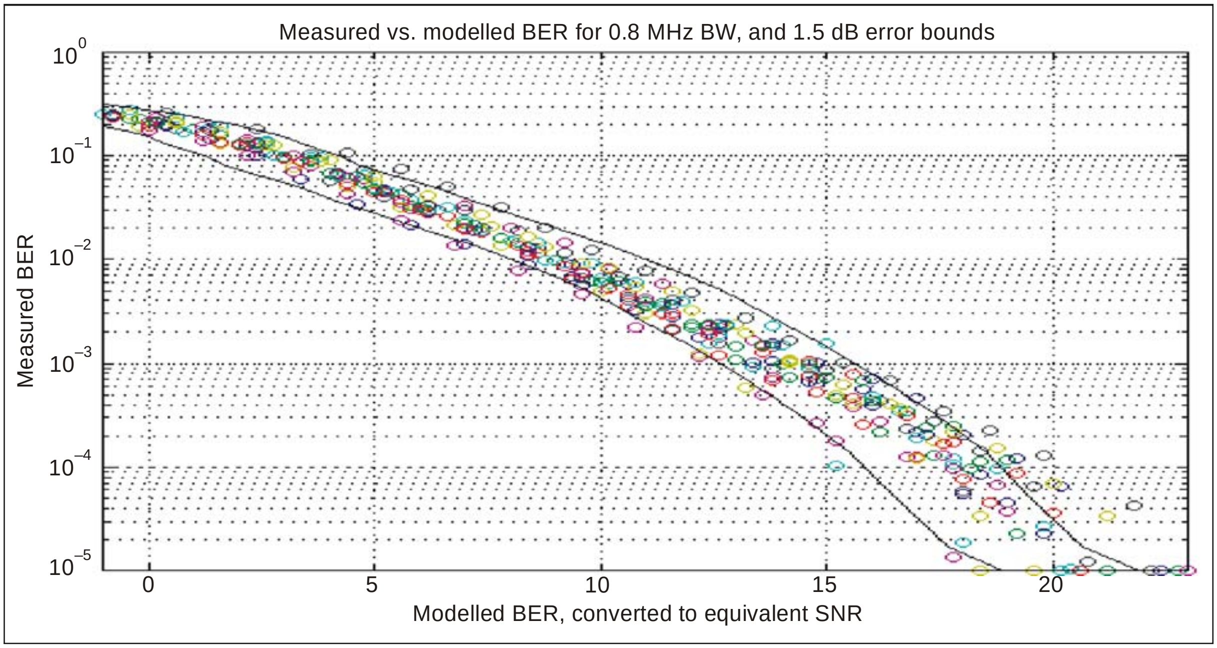


Figure II-A-12. Model errors for all data, 0.8 MHz receiver

4.1.2 The following assumptions are made for the airborne and ground aircraft and ground vehicles for the LA Basin 2020 scenario:

a) The density of airborne aircraft is taken to be:

   1) constant in range from the centre of the area out to 225 nautical miles (5.25 aircraft/NM) (i.e. the inner circle of radius one NM would contain approximately five aircraft, as would the ring from 224 to 225 NM); and

   2) constant in area from 225 NM to 400 NM (0.00375 aircraft/NM^2).

b) There are assumed to be a fixed number of aircraft on the ground (within a circle of radius 5 NM at each airport), divided among LAX, San Diego, Long Beach and five other small airports, totalling 225 aircraft. Half of the aircraft at each airport are assumed to be moving at 15 knots, while the other half are stationary. In addition, a total of 300 ground vehicles are distributed at these airports as well.

c) The altitude distribution of the airborne aircraft is assumed to be exponential, with a mean altitude of 5 500 feet. This distribution is assumed to apply over the entire area.

d) The airborne aircraft are assumed to have the following average velocities, determined by their altitude. The aircraft velocities for aircraft below 25 000 feet are uniformly distributed over a band of average velocity ±30 per cent.

   1) 0 to 3 000 feet altitude: 130 knots

2) 3 000 to 10 000 feet: 200 knots

3) 10 000 to 25 000 feet: 300 knots

4) 25 000 and up: 450 knots.

e) The aircraft are all assumed to be moving in random directions.

f) UAT equipage Class A0 (and A1L as defined in Chapter 2, 2.4.2) are restricted to fly below 18 000 feet. All other aircraft are assumed to be capable of flying at any altitude. The aircraft in the LA 2020 scenario are assumed to be in the following proportions:

1) A3: 30 per cent

2) A2: 10 per cent

3) A1: 40 per cent

4) A0: 20 per cent.

4.1.3 For the LA 2020 scenario, the A1 equipage is assumed to include two subclasses: A1H (high) and A1L (low). These subclasses are defined in Chapter 2, 2.4.2.

4.1.4 The scenario for the 2020 high-density LA Basin case contains a total of 2 694 aircraft: 1 180 within the core area of 225 NM, 1 289 between 225 and 400 NM, and 225 on the ground. This represents a scaling of the estimated maximum 1999 LA Basin levels upward by 50 per cent. Of these aircraft, 471 lie within 60 NM of the centre. (This includes aircraft on the ground.) Around ten per cent of the total number of aircraft are above 10 000 feet in altitude, and more than half of the aircraft are located in the outer (non-core) area of the scenario.

4.1.5 An attempt was made to at least partially account for the expected lower aircraft density over the ocean. In the third quadrant (between 180 degrees and 270 degrees), for distances greater than 100 NM from the centre of the scenario, the density of aircraft is reduced to 25 per cent of the nominal value used. The other 75 per cent of aircraft which would have been placed in this area are distributed uniformly among the other three quadrants at the same range from the centre. This results in relative densities of 1:5 between the third quadrant and the others.

4.1.6 As outlined in Section 3 of Appendix K, the ADS-B requirements for ADS-B air-to-air surveillance range and report update interval are used to assess how the candidate links perform in relation to suggested operational enhancements. These requirements specify the minimum range for acquisition of the state vector and the mode-status and TC and TS reports where applicable, as well as the maximum update periods allowed for this information.

4.1.7 Appendix K contains specific air/ground performance requirements. These air/ground criteria specify ranges and update times. Additionally, air-to-air requirements for long-range deconfliction are also specified. Results are presented as a series of plots of 95 per cent update times as a function of range for state vector updates and intent updates, where applicable. The 95 per cent time means that at the range specified, 95 per cent of aircraft will achieve a 95 per cent update rate at least equal to that shown. Each point on the plot represents the performance of aircraft/vehicles within a 10-NM bin centred on the point. The ADS-B requirements specified in Appendix K are also included on the plots for reference. Since the transmit power and receiver configuration are defined for each aircraft equipage class, performance is shown separately for each combination of transmit-receive pair types. In addition, performance of different transmit-receive pairs is shown at several different altitudes, where appropriate. The first altitude considered is “high altitude”, which is defined to be the aircraft near the centre of the scenario with the largest number of other aircraft in view. This is invariably an aircraft in the range of FL 350 to FL 400, and applies to Classes A3, A2 and A1H equipage. The other altitude used is FL 150 at the centre of the scenario and applies to all equipage classes.

4.1.8 Results for all of these cases are shown for state vector updates in Figures II-A-13 through II-A-21 and conclusions are presented below. The ADS-B requirements for state vector updates are shown as black lines on the plots. As specified in Appendix K, the maximum required ranges for air-to-air update rates are: for Class A0 to 10 NM, Class A1 to 20 NM, Class A2 to 40 NM and Class A3 to 90 NM (120 NM desired), while the criteria shown on the plots continue to 150 NM for Class A3. This may not include all potential requirements. Air-to-ground requirements are defined to 150 NM for all aircraft equipage classes. Performance in compliance with ADS-B requirements is indicated by results that are below the black line.

4.1.9 Recall that the LA 2020 scenario includes 2 694 aircraft and 300 ground vehicles transmitting on UAT. In addition, a baseline Link 16 scenario is also included as co-channel interference.

4.1.10 The results for LA 2020 UAT air-to-air system performance shown in Figures II-A-13 to II-A-19 are summarized in Table II-A-1. This summary indicates that the UAT system is projected to be fully compliant with the Appendix K air-to-air state vector report update requirements at both the required and desired ranges.

4.1.11 The results for the LA 2020 scenario, shown in Figures II-A-13 through II-A-21, may be summarized as follows:

a) ADS-B air-to-air requirements and desired criteria are met for all aircraft equipage transmit-receive pairs in the LA 2020 scenario for state vector update rates at all ranges specified by Appendix K. Performance for receivers located at FL 150 tends to be better in general than the corresponding receivers at high altitude, due primarily to the lower levels of self-interference encountered at lower altitudes.

b) The extension to 150 NM for Class A3 equipage air-to-air reception is only met for LA 2020 at the 95 per cent level out to 120 to 130 NM, but the 95th percentile update rate at 150 NM is 14 to 15 seconds, depending on the altitude of the receiving aircraft.

c) Air-to-ground update requirements are met to 150 NM for a standard ground receiver located at LAX in the LA 2020 scenario for Class A3, A2 and A1H equipages. Class A1L and A0 equipage met requirements out to 140 and 120 NM, respectively. A test case was run for the case of a 980-MHz DME/TACAN collocated with the ground receiver. The results of the test case show that, in the presence of a 5-kw TACAN at 980 MHz located 50 feet away from the ground receiver at LAX in the LA 2020 scenario, a three-sector antenna allows the update requirements to be met for all aircraft equipages to 150 NM. Another test case was run for the case of the collocated 980 MHz TACAN with a standard ground receiver to see what level of power at the UAT antenna could be supported without degradation in performance. The results show that –90 dBm TACAN power at the UAT antenna at 980 MHz does not significantly change the standard ground performance in LA 2020. Class A3, A2 and A1H performance meet the update rate requirements out to 150 NM, and Class A1L and A0 meet the requirements out to 120 and 110 NM, respectively. This means that, if the TACAN were located 1 000 feet from the ground receive antenna, an additional 30 dB of isolation would be required in order to assure compliance with reception update rate requirements. This could be achieved by increasing the separation distance, for example.

d) System performance results are presented for state vector updates of ground vehicles to an aircraft on approach to LAX in the LA 2020 scenario. There is no specific update rate requirement for this situation.

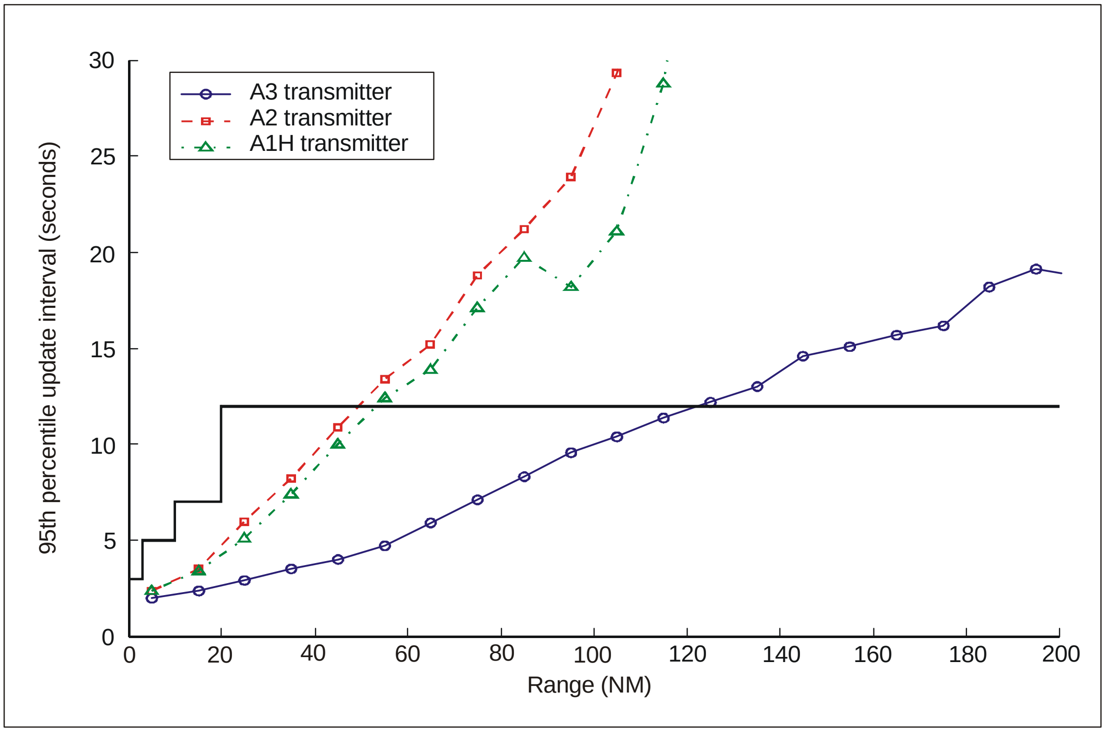


Figure II-A-13. Air-to-air reception by A3 receiver at high altitude over LA 2020

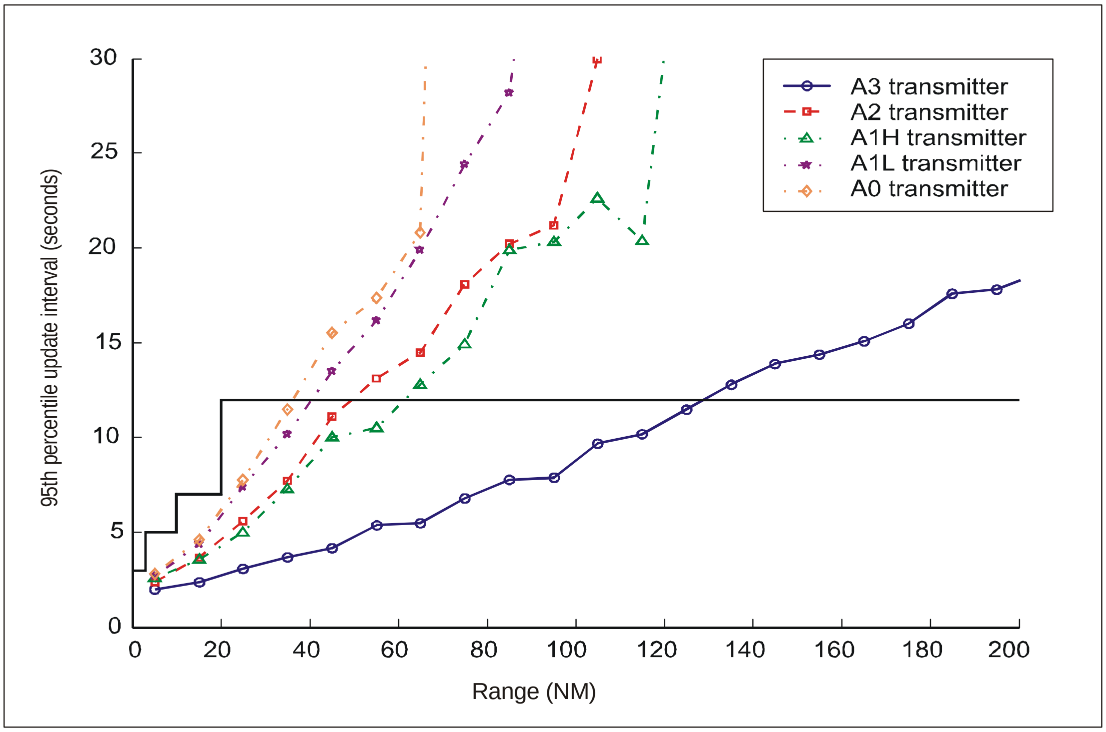


Figure II-A-14. Air-to-air reception by A3 receiver at FL 150 over LA 2020

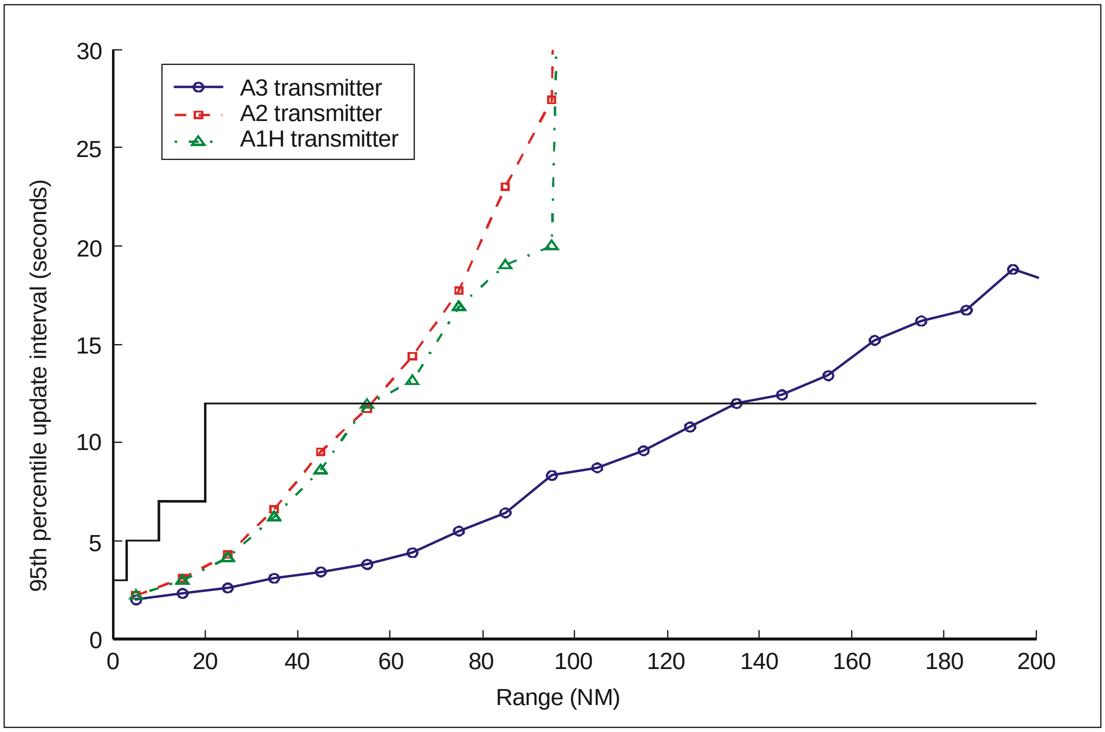


Figure II-A-15. Air-to-air reception by A2 receiver at high altitude over LA 2020

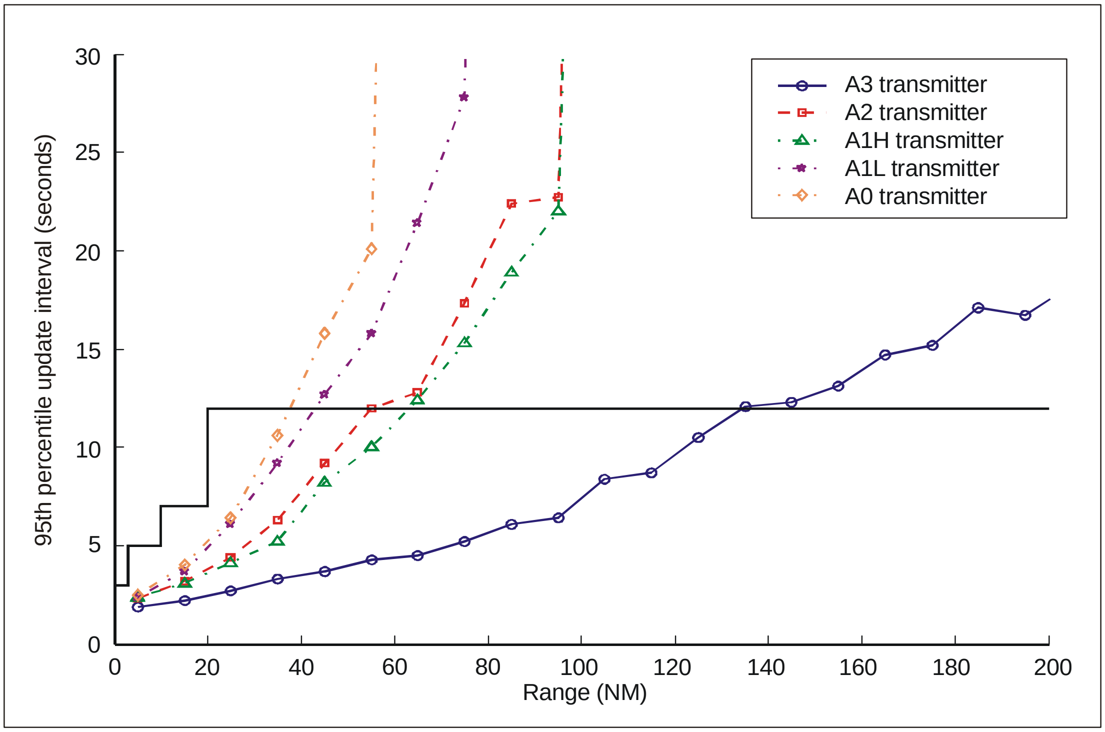


Figure II-A-16. Air-to-air reception by A2 receiver at FL 150 over LA 2020

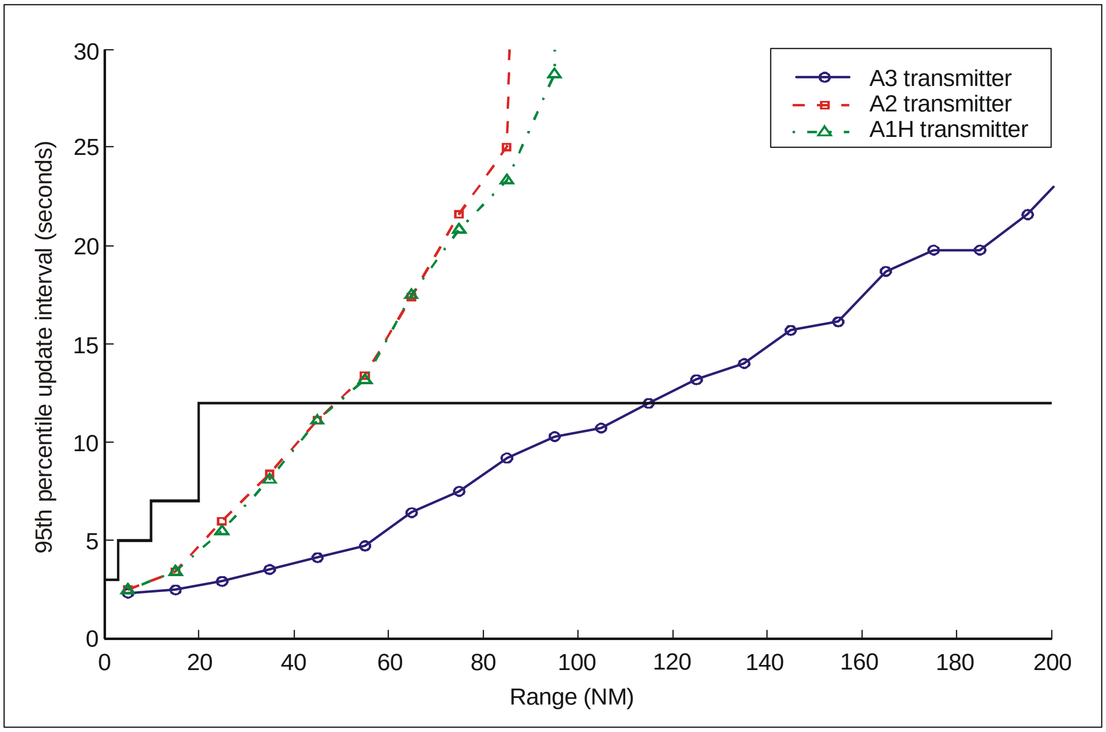


Figure II-A-17. Air-to-air reception by A1 receiver at high altitude over LA 2020

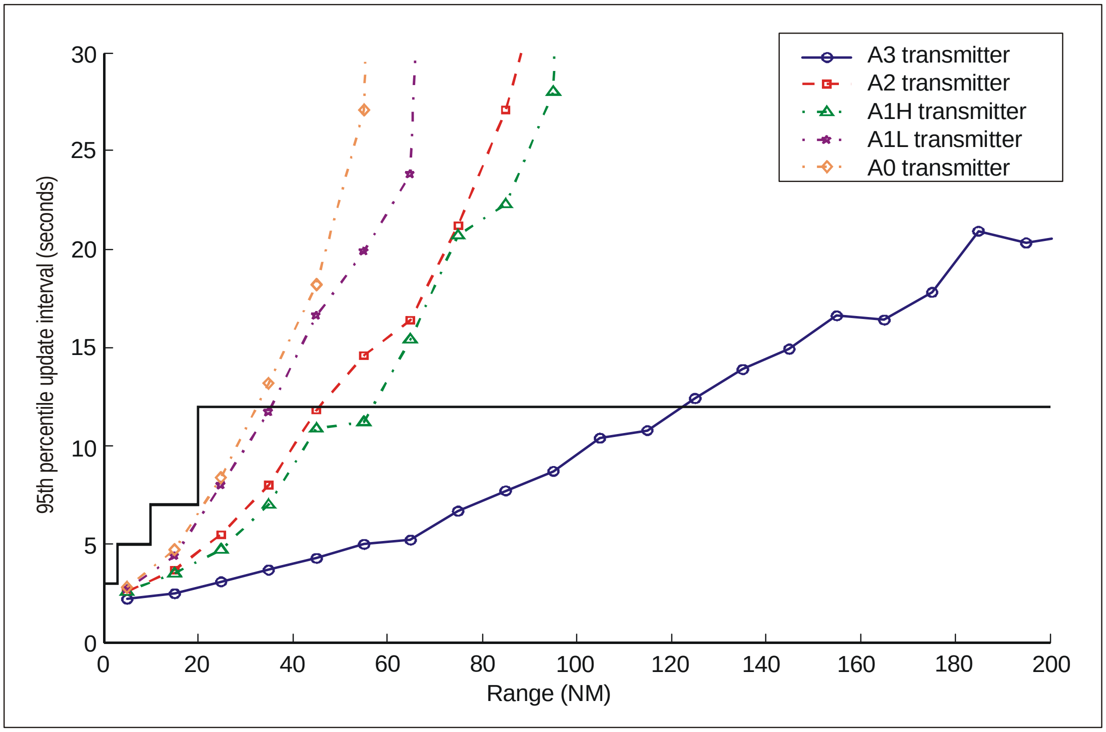


Figure II-A-18. Air-to-air reception by A1 receiver at FL 150 over LA 2020

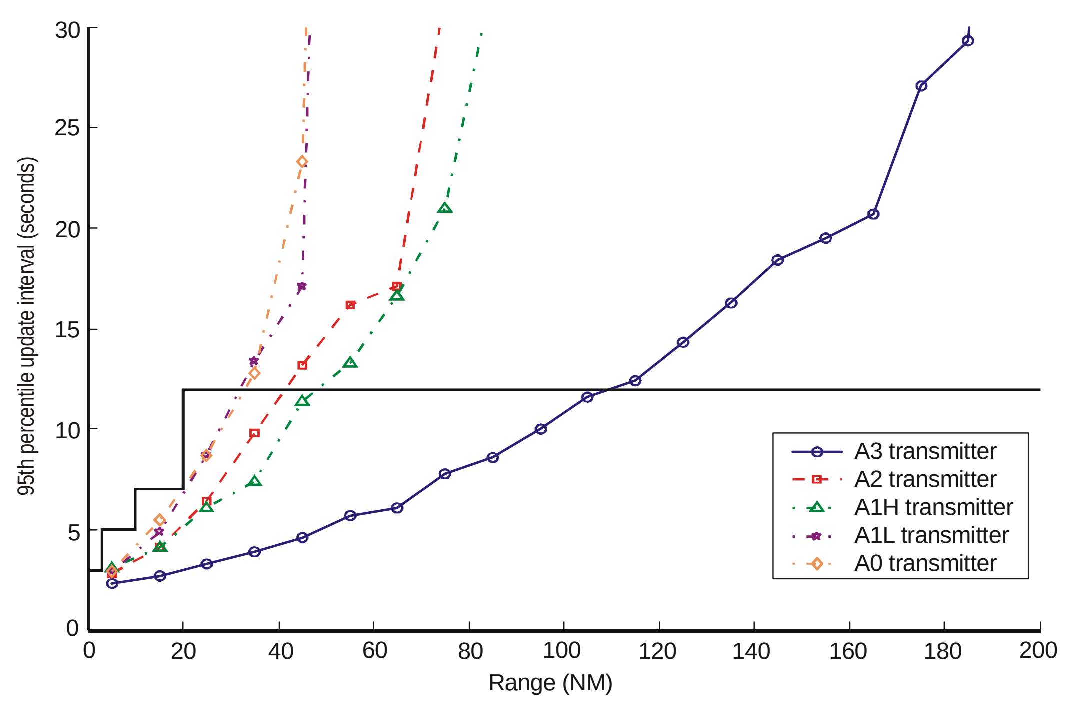


Figure II-A-19. Air-to-air reception by A0 receiver at FL 150 over LA 2020

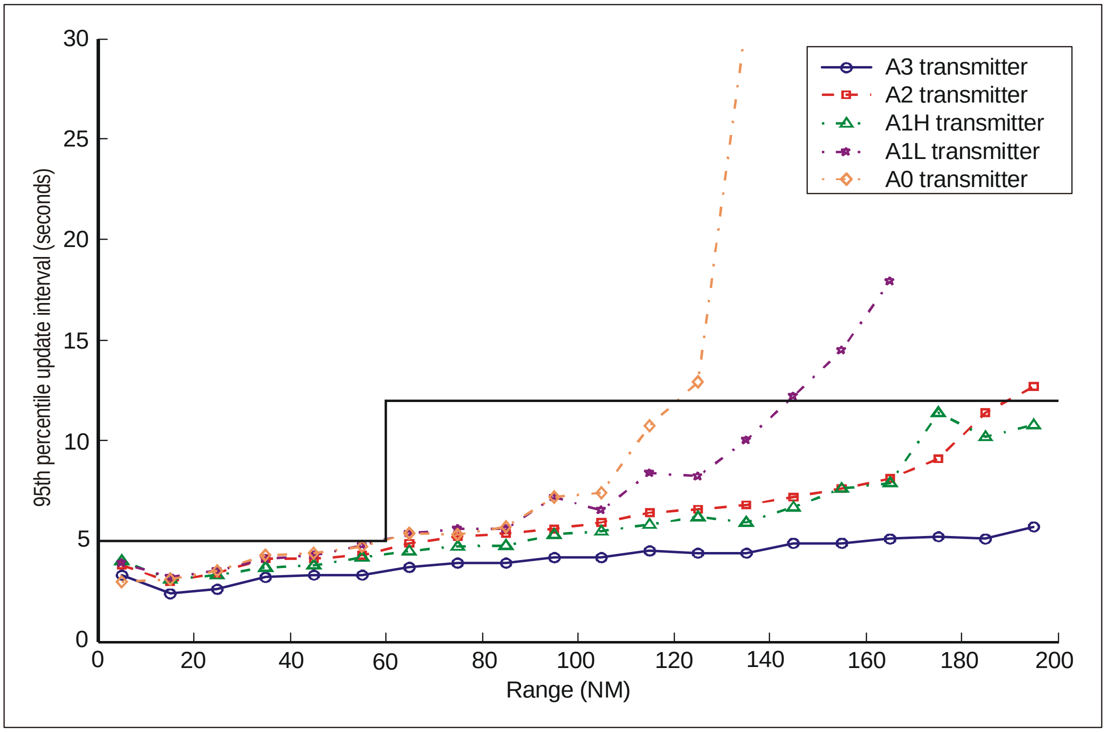


Figure II-A-20. Air-to-ground reception by a receiver at LAX in LA 2020

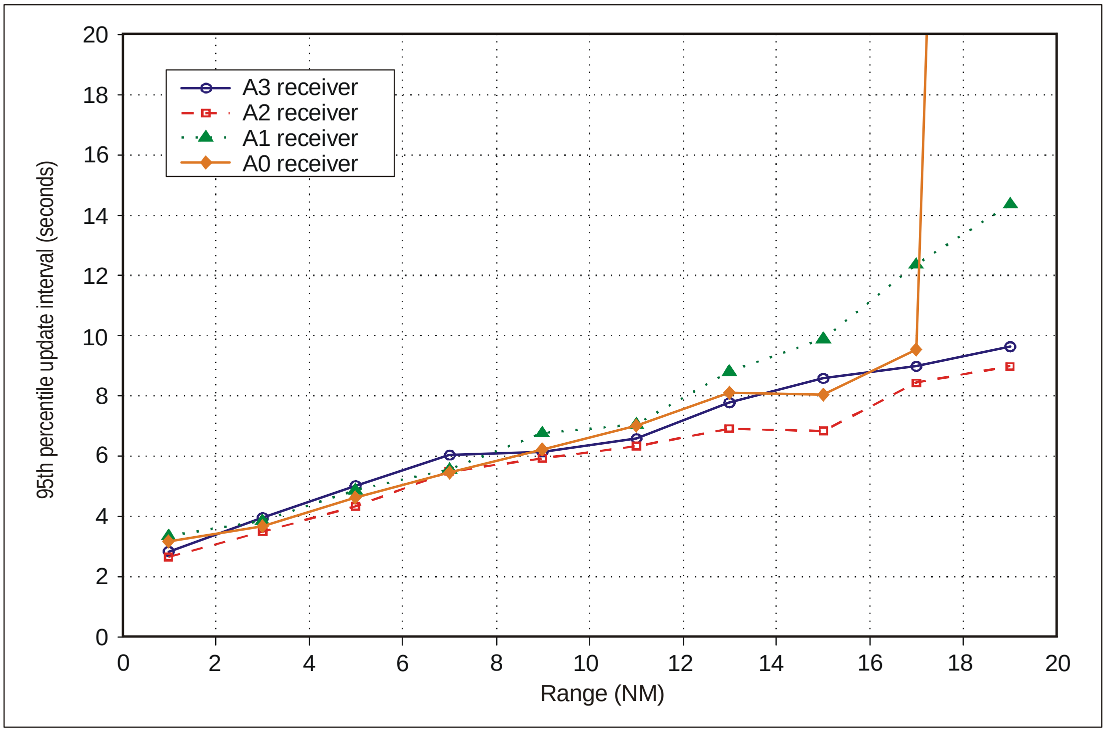


Figure II-A-21. Reception of ground vehicle transmissions by aircraft on approach at 2 000 feet into LAX in 2020

Table II-A-1. Ranges of compliance for UAT transmit-receive combinations in the LA 2020 scenario

Receiver	*Transmitter*			
	A3	*A2*	*A1*	*A0*
A3 (High Altitude)	120	40+	40+(A1H)	N/A
A3 (FL 150)	130	40+	50+(A1H)/30+(A1L)	30+
A2 (High Altitude)	130	50	50(A1H)	N/A
A2 (FL 150)	130	50	60(A1H)/40(A1L)	30
A1 (High Altitude)	110	40	40+(A1H)	N/A
A1 (Low Altitude)	120	40	40+(A1H)/30(A1L)	30
A0	100+	40	40+(A1H)/30(A1L)	30

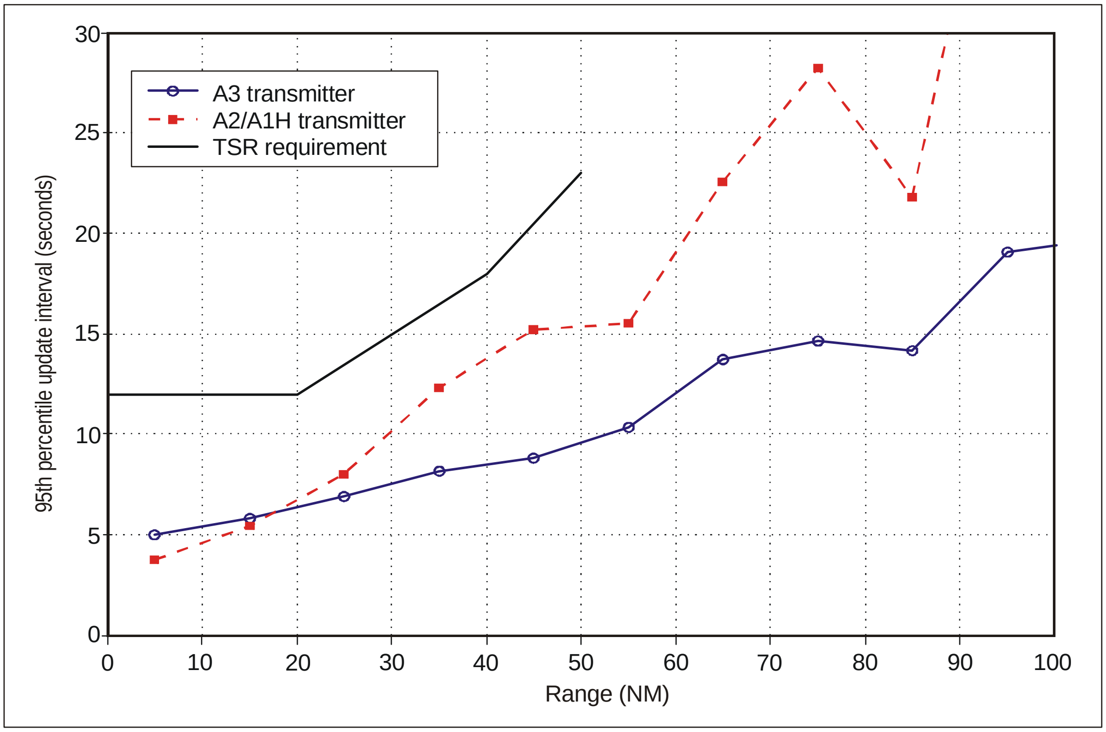


Figure II-A-22. 95th percentile update interval for target state reports as a function of range for A3 and A2/A1H transmitters

4.1.12 Figure II-A-22 shows the result for air-to-air ADS-B reception over UAT of target state report information in the LA 2020 scenario. This intent information is transmitted by high-altitude aircraft (Class A3, A2 and A1H equipage) and the receiver for this plot is a Class A3.

4.1.13 The results in Figure II-A-22 confirm that UAT in a high-density environment is expected to meet the air-to-air reception requirement for target state reports.

4.2 Core Europe 2015

4.2.1 A high-density air traffic scenario was developed by Eurocontrol to represent Core Europe in 2015 (CE 2015). The operation of UAT in Core Europe 2015 is based on the premise that the existing on-channel DME/TACANs will be moved from 978 MHz to other available frequencies. Therefore, the future scenario assumes that there will be no DME/TACANs on 978 MHz, but that all existing and planned DME/TACANs at 979 MHz will be operational and running at full allowed power levels, no matter how close they are to one another. This condition was chosen in order to provide a conservatively severe estimate of the DME/TACAN interference environment.

4.2.2 Two cases were analysed: worst-case traffic density (over the centre of the scenario at Brussels, selected to provide the highest UAT self-interference levels) and worst-case DME/TACAN environment (location selected to provide the highest interference from DME/TACANs). The worst-case DME/TACAN environment selection required moving a high-power mobile 979-MHz TACAN to a particular location near several other 979-MHz TACANs.

4.2.3 For the Core Europe 2015 scenario, the distributions and assumptions made were taken directly from the Eurocontrol document entitled *High-density 2015 European Traffic Distributions for Simulation*, dated August 17, 1999. This scenario is well-defined and straightforward to apply. The scenario used in this analysis includes a total of 2 091 aircraft (both airborne and ground) and 500 ground vehicles and is based on the following assumptions:

a) There are five major TMAs (Brussels, Amsterdam, London, Paris and Frankfurt), each of which is characterized by:

   1) The inner region (12 NM radius) contains 29 aircraft at lower altitudes.

   2) The outer region (50 NM radius) contains 103 aircraft at mid to higher altitudes.

   3) There are 25 aircraft on the ground within a 5-NM radius of each TMA. Additionally, there are 25 aircraft not associated with a TMA randomly distributed through the scenario.

   4) There are assumed to be 100 ground vehicles equipped with transmit-only UAT equipment.

b) These aircraft are assumed to be symmetrically distributed azimuthally, and the aircraft in an altitude band are assumed to be uniformly distributed throughout the band. However, all aircraft in the same band are assumed to be travelling at the same band-dependent velocity.

c) Superimposed over these aircraft is a set of airborne en-route aircraft, which are distributed over a circle of radius 300 NM. These aircraft are distributed over four altitude bands, ranging from low to upper altitudes. They also travel at velocities that are altitude-band dependent.

d) As in the LA Basin 2020 scenario, for the Core Europe 2015 scenario all aircraft are assumed to be ADS-B equipped. The equipage levels have been adjusted to be:

   1) 30 per cent: A3

   2) 30 per cent: A2

   3) 30 per cent: A1

   4) 10 per cent: A0.

4.2.4 Aircraft equipage is assigned according to altitude. The lower percentages of Class A0 and A1 aircraft than those found in the LA Basin scenarios reflect differences in operating conditions and rules in European airspace.

4.2.5 The two geographical areas that underlie the scenarios discussed above (LA Basin and Core Europe) correspond to very different types of situations for an aircraft to operate in, and thus should provide two diverse environments for evaluation. The LA Basin scenario contains only about 14 per cent of all airborne aircraft at altitudes above 10 000 feet, while the Core Europe scenario has around 60 per cent above 10 000 feet. Thus, there will be vastly different numbers of aircraft in view for the two scenarios. Additionally, the aircraft density distributions are also quite different, which will place different stresses on the data link systems.

4.2.6 The results of simulation runs which correspond to the assumptions stated above for the full complement of 2 091 aircraft and 500 ground vehicles are presented below. Recall that DME/TACANs on 978 MHz are assumed to have been moved and that all potential and planned DME/TACANs on 979 MHz are assumed to have been implemented and transmit at maximum allowed powers. Two locations are considered for CE 2015: one in the midst of worst-case UAT self-interference, in the centre of the scenario over Brussels; the other in a location that is thought to represent the worst-case DME environment, over Western Germany. In addition, the baseline B Link 16 scenario is also assumed to interfere with

UAT transmissions in the CE 2015 environment. Results are presented as a series of plots of 95 per cent update times as a function of range for state vector updates. The 95 per cent time means that at the range specified, 95 per cent of aircraft will achieve a 95 per cent update rate at least equal to that shown. The ADS-B requirements are also included on the plots for reference. Since the transmit power and receiver configuration are defined for each aircraft equipage class, performance is shown separately for each combination of transmit-receive pair types. In addition, performance of different transmit-receive pairs is shown at several different altitudes, where appropriate.

4.2.7 Results are presented in Figures II-A-23 to II-A-33 for 95 per cent update times as a function of range for state vector updates. Each point on the plot represents the performance of aircraft/vehicles within a 10-NM bin centred on the point. Appendix K requirements for state vector updates are shown as black lines on the plots. The maximum ranges specified for air-to-air update rates are: for Class A0 to 10 NM, Class A1 to 20 NM, Class A2 to 40 NM and Class A3 to 90 NM (120 NM desired), while the criteria continue to 150 NM for Class A3. Air-to-ground requirements are defined to 150 NM for all aircraft equipage classes. Performance in compliance with requirements is indicated by results that are below the black line.

4.2.8 Recall that the CE 2015 scenario includes 2 091 aircraft and 500 ground vehicles transmitting on UAT. The DME/TACAN interference environment is characterized by up to four adjacent-channel emitters, all at the maximum allowable powers. In addition, a baseline Link 16 scenario is also included as co-channel interference.

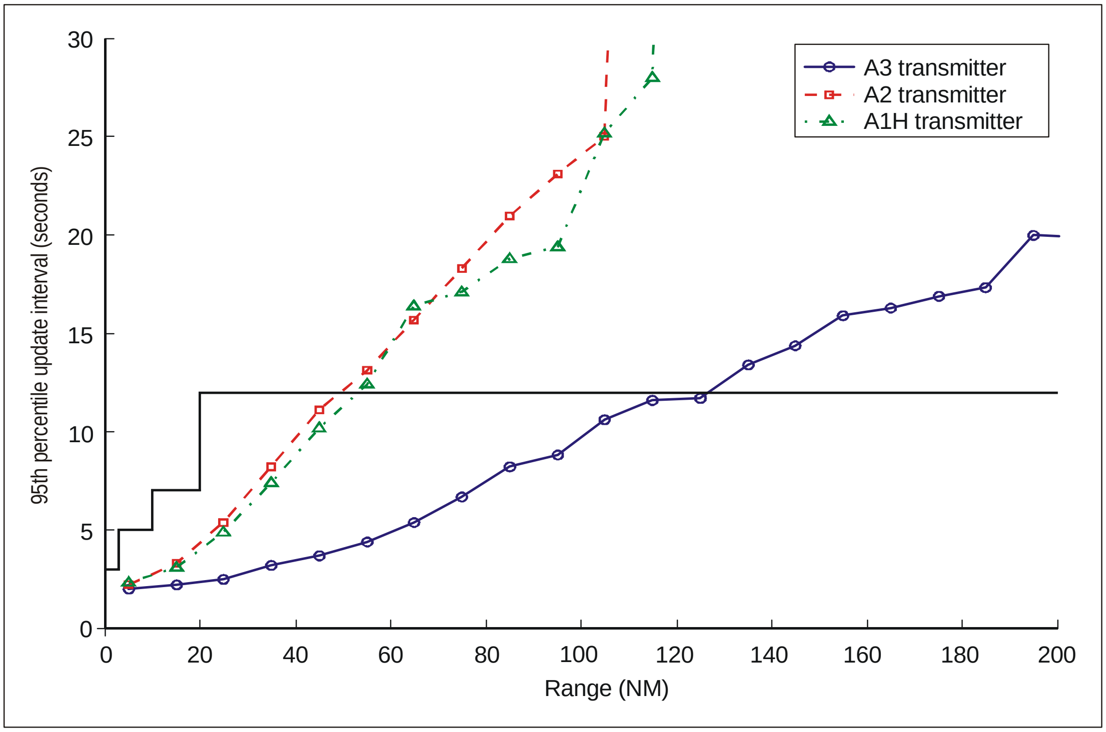


Figure II-A-23. Air-to-air reception by A3 receiver at high altitude over BRU in CE 2015

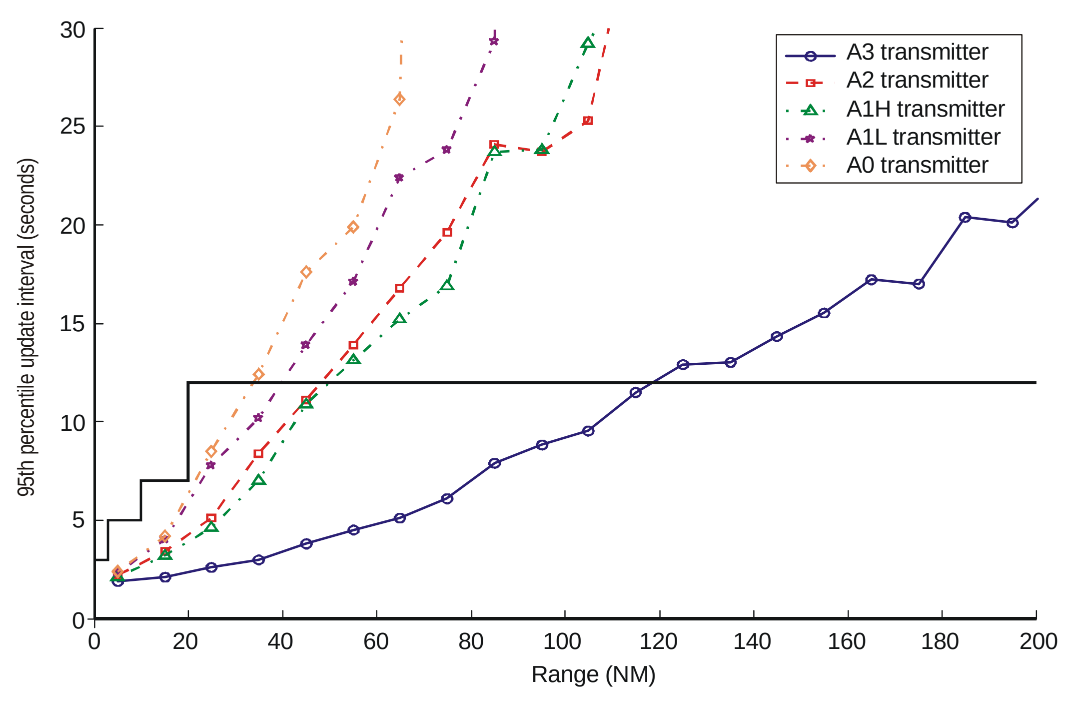


Figure II-A-24. Air-to-air reception by A3 receiver at FL 150 over BRU in CE 2015

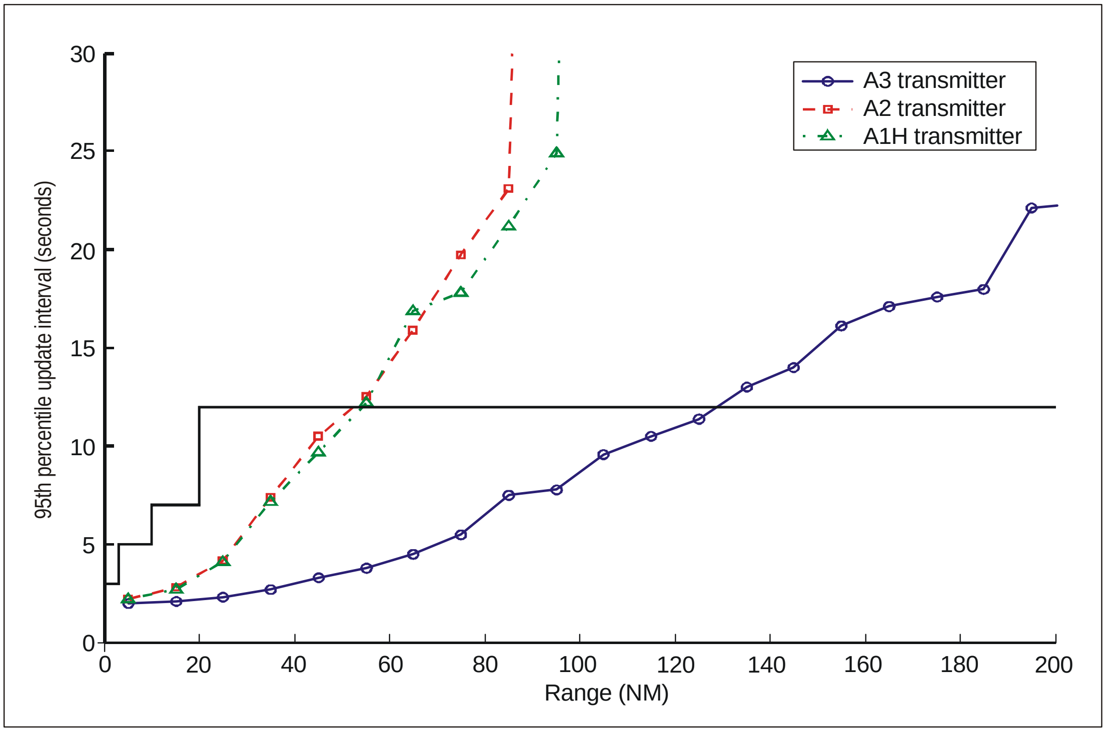


Figure II-A-25. Air-to-air reception by A2 receiver at high altitude over BRU in CE 2015

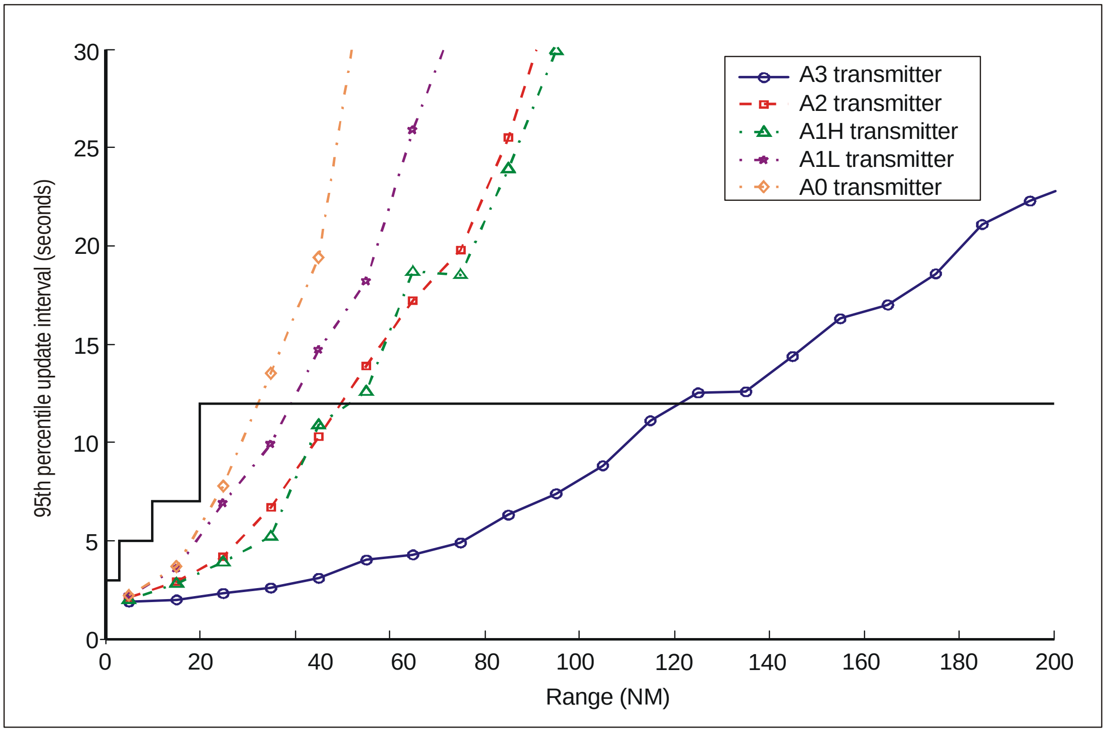


Figure II-A-26. Air-to-air reception by A2 receiver at FL 150 over BRU in CE 2015

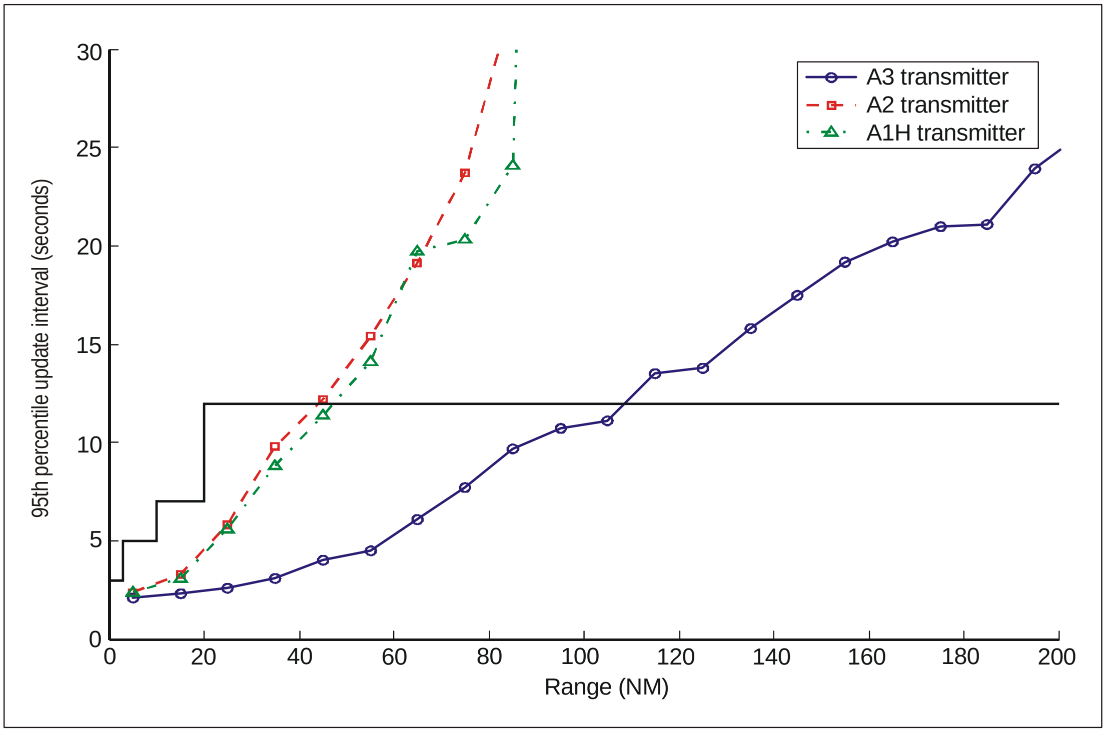


Figure II-A-27. Air-to-air reception by A1 receiver at high altitude over BRU in CE 2015

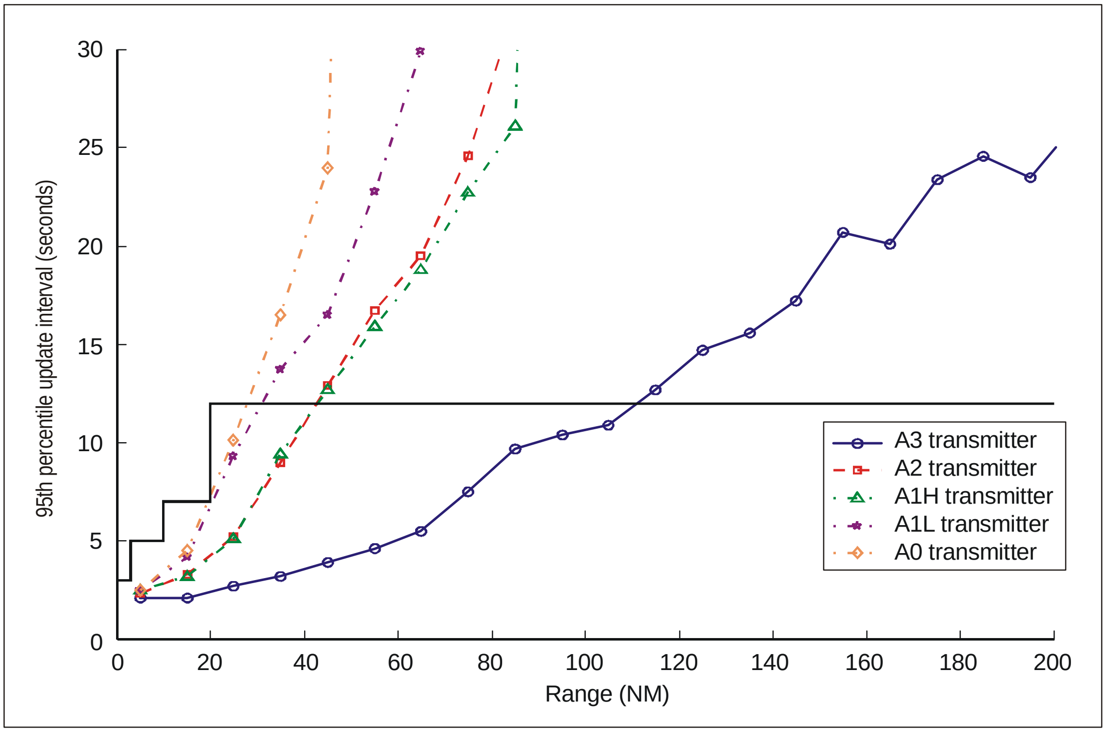


Figure II-A-28. Air-to-air reception by A1 receiver at FL 150 over BRU in CE 2015

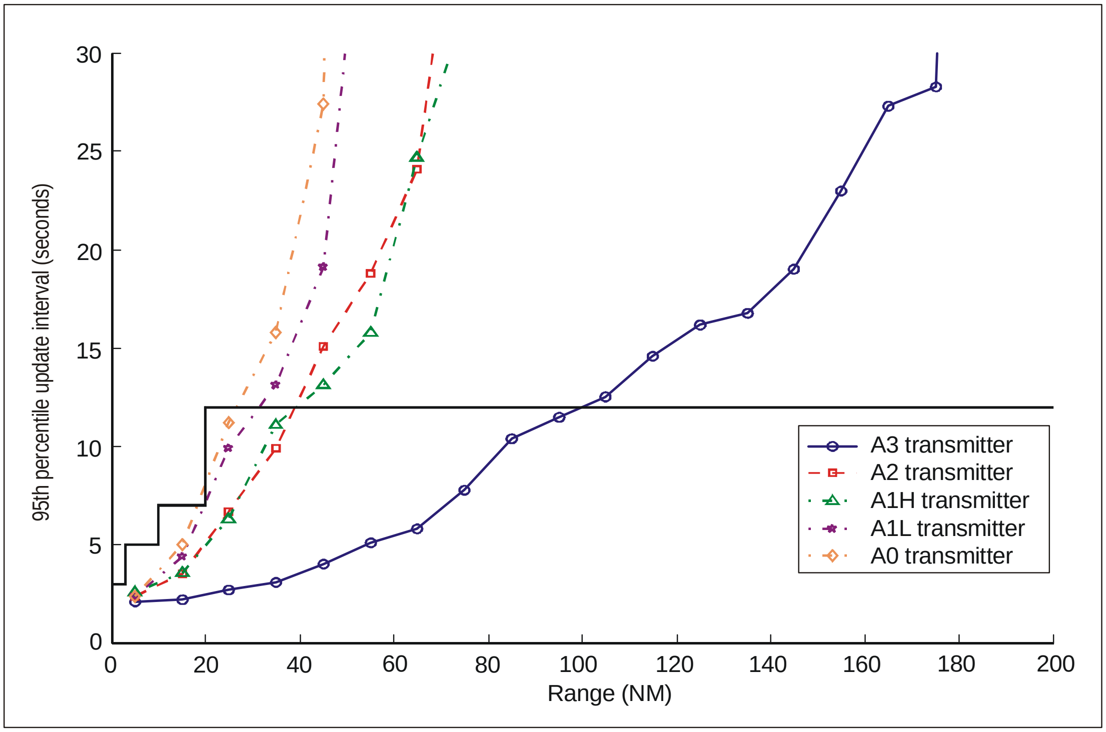


Figure II-A-29. Air-to-air reception by A0 receiver at FL 150 over BRU in CE 2015

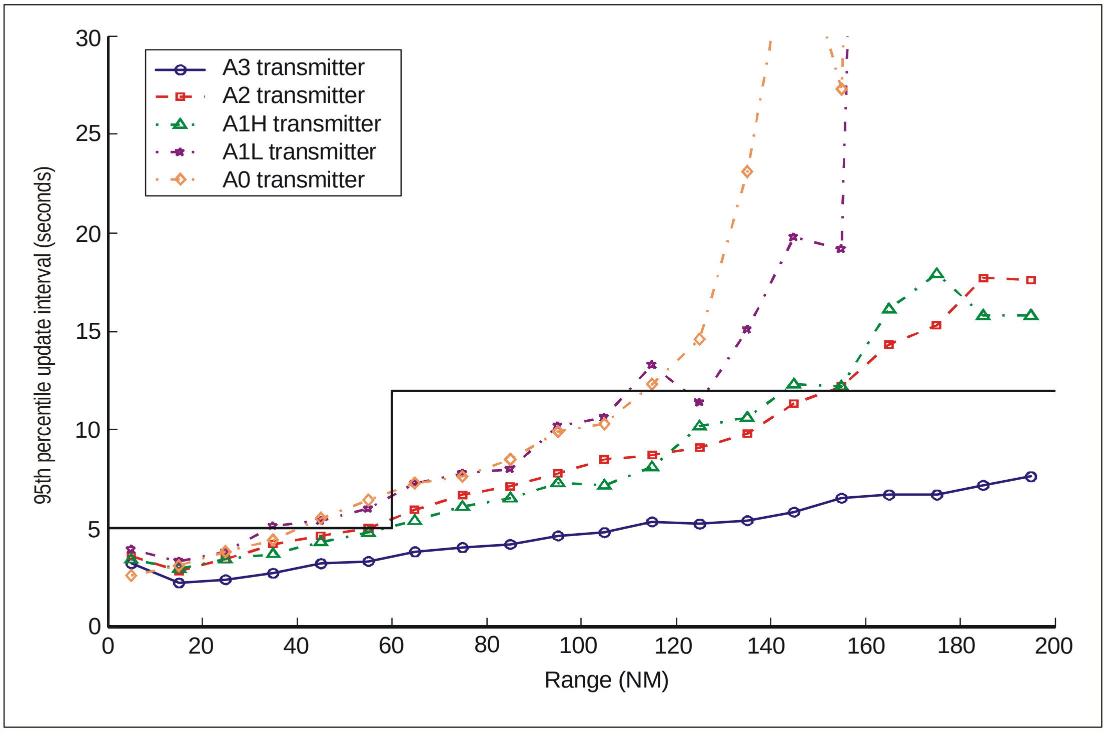


Figure II-A-30. Air-to-ground reception at BRU in CE 2015

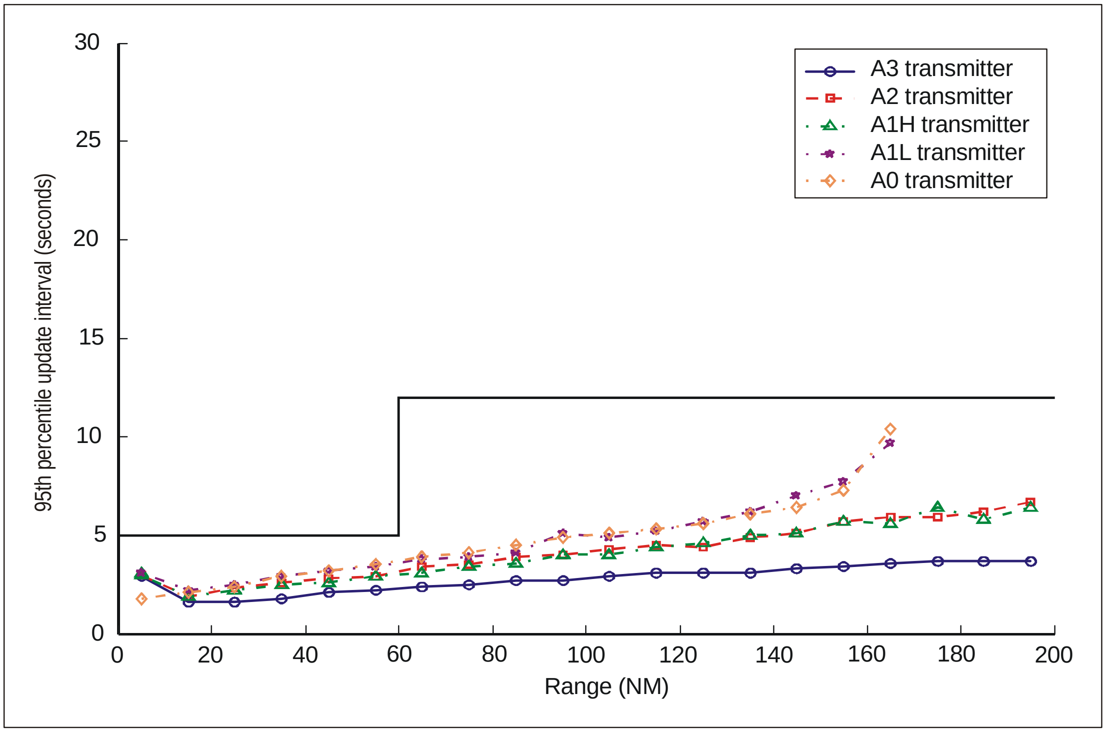


Figure II-A-31. Air-to-ground reception using a 3-sector antenna at BRU in CE 2015

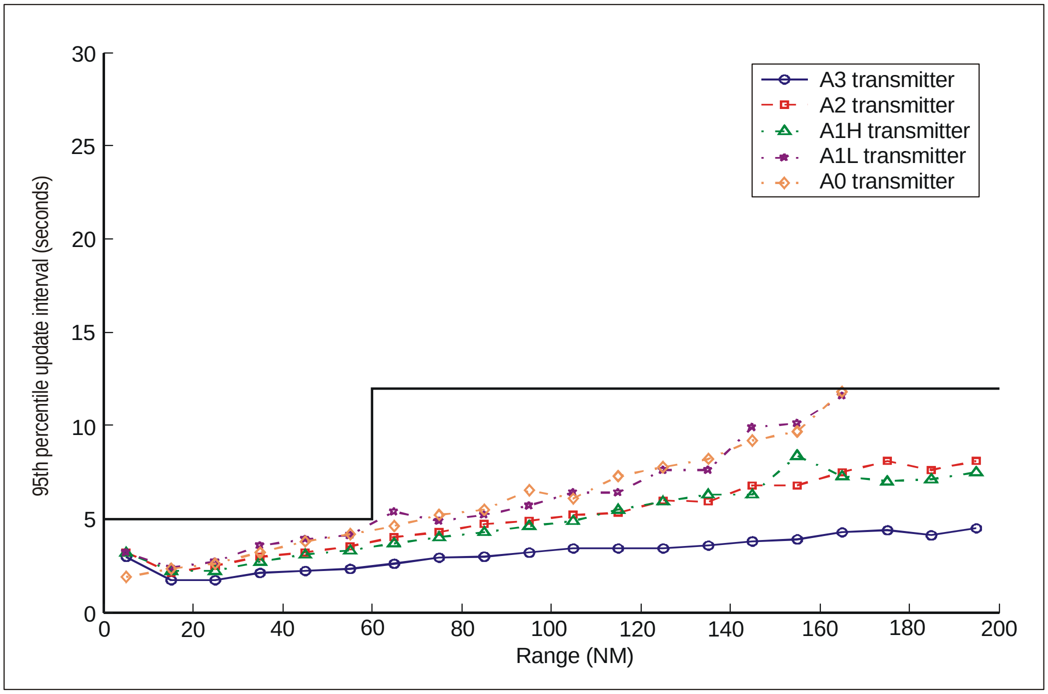


Figure II-A-32. Air-to-ground reception 2 NM from a 10-kW TACAN using a 3-sector antenna at BRU in CE 2015

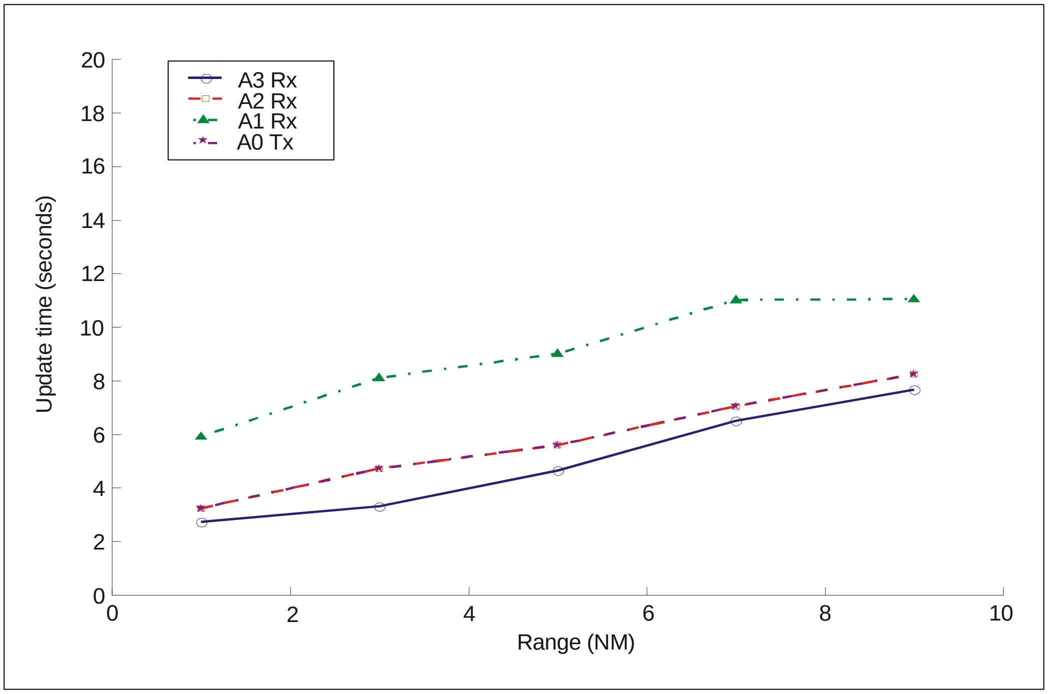


Figure II-A-33. Reception of ground vehicle transmissions by aircraft on approach at 2 000 feet into BRU in 2015 with 10-kW 979-MHz TACAN at airport

4.2.9 The UAT air-to-air performance in Core Europe shown in Figures II-A-23 through II-A-29 is summarized in Table II-A-2. This summary indicates that the UAT system is projected to be fully compliant with the ADS-B air-to-air report update requirements at both the required and desired ranges.

Table II-A-2. Ranges of ADS-B compliance for UAT transmit-receive combinations in CE 2015 scenario

Receiver	*Transmitter*			
	A3	*A2*	*A1*	*A0*
A3 (High altitude)	120	40+	40+(A1H)	N/A
A3 (FL 150)	120	40+	40+(A1H)/30+(A1L)	20+
A2 (High altitude)	130	50	50(A1H)	NA
A2 (FL 150)	120	40+	40+(A1H)/30(A1L)	20+
A1 (High altitude)	100+	40	40+(A1H)	N/A
A1 (FL 150)	110	40	40(A1H)/20+(A1L)	20+
A0	100	30+	30+(A1H)/20+(A1L)	20+

4.2.10 The results for Core Europe 2015 shown in Figures II-A-23 through II-A-33 may be summarized as follows:

a) ADS-B air-to-air requirements and desired criteria are met for all aircraft equipage transmit-receive pairs for both state vector update rates at all ranges specified by Appendix K.

b) The extension to 150 NM for A3 equipage is not met at the 95 per cent level, but the 95 per cent state vector update time at 150 NM is 15 to 16 seconds, depending on receiver altitude and location. The 95 per cent level is achieved to around 120 NM, depending on receiver altitude and location.

c) All known air-to-ground update rate requirements are substantially met for all classes of aircraft out to at least 150 NM, even in the presence of a collocated TACAN emitter, by using a three-sector antenna. A test case was run, which included a 10 kW collocated 979-MHz TACAN. It was determined that the TACAN signal at the receive antenna had to be received at a level that did not exceed –30 dB in order for all equipage classes to meet air-to-ground requirements. This corresponds to an isolation of 20 dB from the receive antenna, in addition to that provided by a 50-foot separation distance between the TACAN transmitter and ground receiver plus isolation provided by the receive antenna null. This could be achieved by increasing the separation distance, for example.

d) System performance results are presented for updates of ground vehicles to an aircraft on approach. No specific ADS-B requirements for this situation are known.

4.3 Low-density scenario

4.3.1 In addition to the two high-density scenarios described above, a scenario was also run to represent low-density traffic levels. This scenario was developed for 360 total aircraft. These aircraft are uniformly distributed in the horizontal plane within a circle of radius 400 nautical miles. In the vertical direction, they are distributed uniformly between 25 000 feet and 37 000 feet. The velocities are all set to 450 knots and are randomly distributed in azimuth. All of the aircraft are assumed to be A3-equipped. In order to evaluate the performance of a ground receiver in this environment, one was located at the centre of the scenario, along with a collocated TACAN transmitter at 979 MHz.

4.3.2 Results of the MAUS runs for the low-density scenario are shown in Figures II-A-34 and II-A-35, and conclusions are presented below. The ADS-B requirements for state vector updates are shown as black lines on the plots. The requirements specify that the maximum ranges for air-air update rates required for A3 to 90 NM (120 NM desired), while the criteria are extended on the plot to 150 NM. Performance in compliance with requirements is indicated by results that are below the black line.

4.3.3 The results for the low-density scenario may be summarized as follows:

a) ADS-B air-to-air requirements and desired criteria are met for all aircraft for both state vector and intent update rates at all ranges specified in Appendix K.

b) The extension to 150 NM for A3 equipage is met at the 95 per cent level, as required.

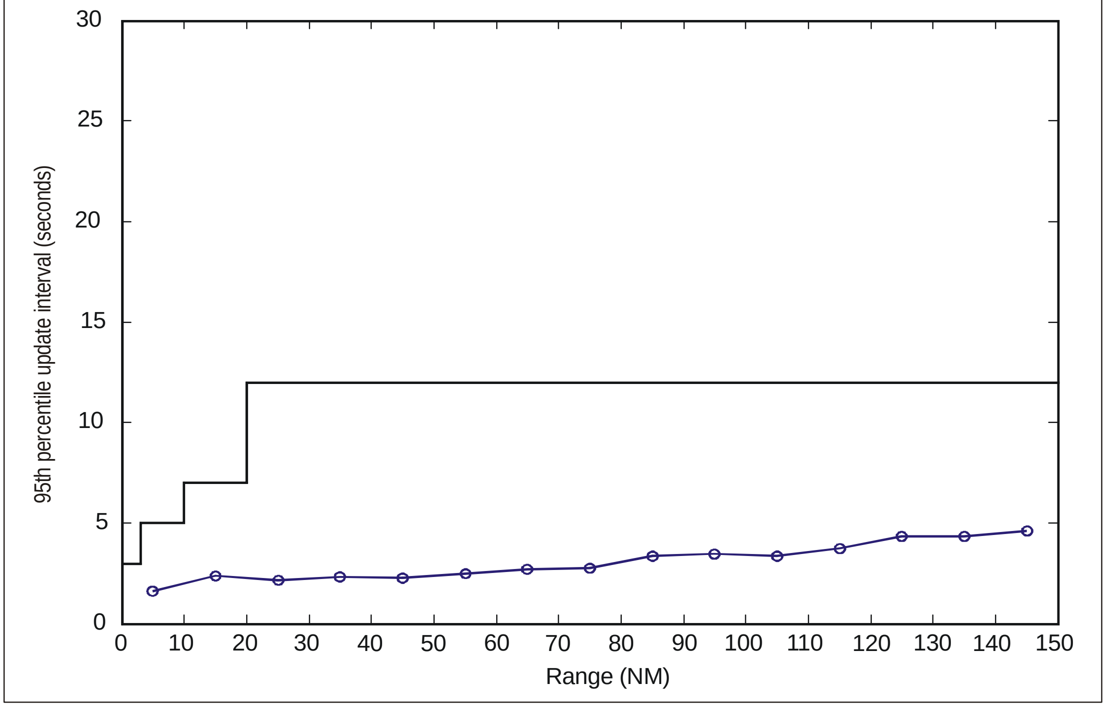


Figure II-A-34. A3 receiver in low-density scenario receiving A3 transmissions

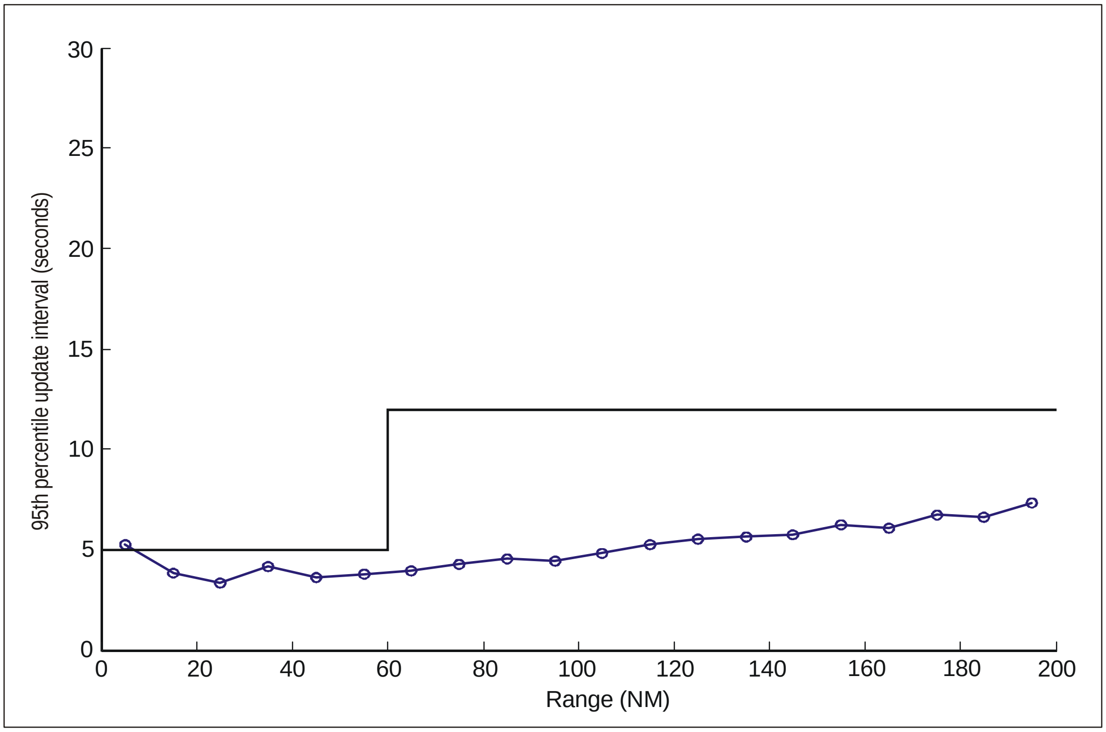


Figure II-A-35. Receptions of A3 transmissions by a UAT ground receiver in a low-density scenario collocated with a TACAN at 979 MHz with –30-dBm power at the UAT antenna

c) All known air-to-ground update rate requirements are met out to at least 150 NM, in the absence of the collocated TACAN emitter, with the use of a single antenna on the ground. A test case was run, which included a 10 kW collocated 979-MHz TACAN. It was determined that the TACAN signal at the receive antenna had to be received at a level that did not exceed –30 dBm in order to meet air-to-ground requirements. This corresponds to an isolation of 20 dB from the receive antenna, in addition to that provided by a 1 000 ft separation distance. Alternatively, a three-sector ground antenna configuration should also enable satisfaction of the air-to-ground requirements to 150 NM.

4.4 Acquisition performance

4.4.1 Performance of the UAT ADS-B system in the area of aircraft information acquisition was evaluated. In a head-on situation in the LA 2020 scenario, the 99th percentile range for acquisition by the victim receiver of all information transmitted on ADS-B by the desired aircraft was determined for each aircraft equipage type. This was done for a large sample of cases, and the 99th percentile case was chosen. In other words, 99 per cent of aircraft are expected to achieve a 99 per cent probability of acquiring all information about an aircraft flying on a head-on path by the range selected.

4.4.2 The information necessary to acquire varies by aircraft equipage, so the evaluation was done for various transmitter-receiver combinations of equipage. For each equipage type, the message-transmit sequence used was that defined in Chapter 3, 3.1.1. Table II-A-3 shows the assumptions made in this analysis for information required to achieve acquisition for each type of transmit equipage.

4.4.3 The methodology used in this analysis was to run a set of probe aircraft in a head-on scenario and determine, for each probe aircraft, the 99th percentile range at which all of the above information was received by the victim aircraft. The results are shown in Table II-A-4 for each transmit-receive combination. These results are for somewhat more restrictive acquisition criteria than are usually applied. From the results, it appears that UAT will be able to comply with all known ADS-B track acquisition requirements.

Table II-A-3. Acquisition requirements

Transmit equipage class	*Required information for acquisition*
A3	SV, MS, TSR, TCR0, TCR1
A2	SV, MS, TSR, TCR0
A1H	SV, MS, TSR
A1L	SV
A0	SV

SV = state vector
MS = mode status
TSR = target state report
TCR0 = trajectory change report 0
TCR1 = trajectory change report 1

Table II-A-4. 99th percentile range for information acquisition for various combinations of transmit-receive pairs (NM)

Receiver	*Transmitter*				
	A3	*A2*	*A1H*	*A1L*	*A0*
A3	137	53	53	49	18
A2	145	54	53	52	17
A1	122	50	48	37	11

4.5 Surface performance

4.5.1 An evaluation was performed of the performance of the UAT system on the surface, i.e. aircraft-to-aircraft state vector update rates were determined for transmit-receive pairs on the ground at LAX in the LA 2020 scenario. The aircraft separation was varied between one and five nautical miles, and cases were run with and without severe horizontal surface multipath included. The multipath model used is described in Appendix M.6 of the ADS-B Technical Link Assessment Team (TLAT) Technical Link Assessment Report, March, 2001. It was thought that these two cases would provide conservative bounds on expected performance, since it was assumed that the severe multipath effects would always interfere destructively with the received signal.

4.5.2 Recall that the LA 2020 scenario includes, in addition to a total of 2 694 aircraft (75 on the ground at LAX) transmitting UAT, 100 transmitting ground vehicles at LAX as well. The results for the analysis of aircraft-to-aircraft surface-to-surface performance may be summarized as follows:

a) For the bounding cases with no multipath and with worst-case elevation plane multipath, the 95th percentile surface update requirements in Appendix K (1.5 seconds out to 5 NM) are met for Class A3 transmitters up to 1 to 2 NM away.

b) The 95th percentile surface update requirement (1.5 seconds out to 5 NM) is not met for all other cases on the surface.

c) The 95th percentile update time on the surface for all aircraft classes to 5 NM for the bounding case of no multipath is approximately 2 seconds. Class A3 transmitters can be seen by Class A2 and A3 receivers out to 5 NM with, approximately, a 3-second 95th percentile update time. Class A2 transmitters can be seen by Class A2 and A3 receivers out to 5 NM with, approximately, a 5-second 95th percentile update time.

d) The 95th percentile update time on the surface for all aircraft classes for the bounding case of worst-case multipath is approximately 3 seconds at a range of 1 NM. The limiting factor at ranges greater than 1 NM is the transmit power and antenna placement for Class A0 and A1L class equipment, combined with the effect of 175 interferers at close range.

4.6 A Class A0 aircraft on the surface receiving an aircraft that is on approach

4.6.1 An evaluation was performed of the performance of the UAT system for an aircraft on the surface receiving state vector transmissions from aircraft on landing approach in both the LA 2020 and CE 2015 scenarios. The aircraft on approach were modelled at an altitude of 2 000 feet. The receiving aircraft on the ground was equipped as a Class A0 receiver. It was thought this would provide a worst-case performance for aircraft on the surface receiving airborne transmitters due to the Class A0 receiver potentially having only a single antenna on the bottom of the aircraft. No multipath was included.

4.6.2 The evaluation was performed using the same co-site interference environment as for the airborne scenarios. In practice, the actual interference environment would be more benign because of much lower instances of interrogations from ACAS and radar ground systems when operating on the surface, and potentially from a lack of DME equipment on some portion of the Class A0 and A1L fleet. In addition, the Core Europe scenario had a 10 kW 979-MHz TACAN located 1 000 feet away from the UAT receiving antenna.

4.6.3 Results of the MAUS runs for a Class A0 aircraft on the ground receiving UAT transmissions from aircraft on approach are shown in Figures II-A-36 and II-A-37 for the LA 2020 and CE 2015 scenarios, and conclusions are presented below. No specific ADS-B requirements for this situation are known.

4.6.4 Recall that the LA 2020 scenario also includes, in addition to a total of 2 694 aircraft (75 on the ground at LAX) transmitting UAT, 100 transmitting ground vehicles at LAX as well. Furthermore, the CE 2015 scenario has 2 091 aircraft transmitting UAT, including 25 aircraft and 100 ground vehicles on the surface in Brussels.

4.7 TIS-B performance of UAT in the LA 2020 environment

An analysis was performed to investigate UAT ground-to-air performance of TIS-B uplinks in the high-density air traffic environment of LA 2020 (see 4.1 for a description of the LA 2020 scenario). This section presents the results of that work. Section 4.7.1 reviews many of the additional assumptions necessary to describe the system under study, and Section 4.7.2 summarizes the results of the analysis.

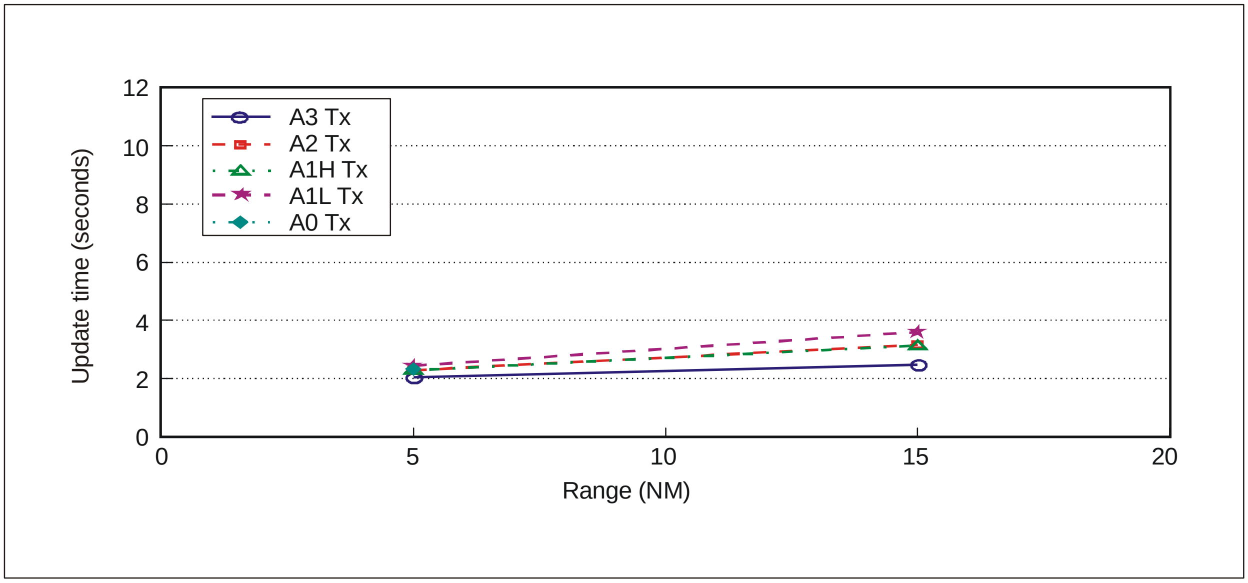


Figure II-A-36. A0 receivers on the ground in LA 2020 receiving all aircraft on approach at an altitude of 2 000 feet

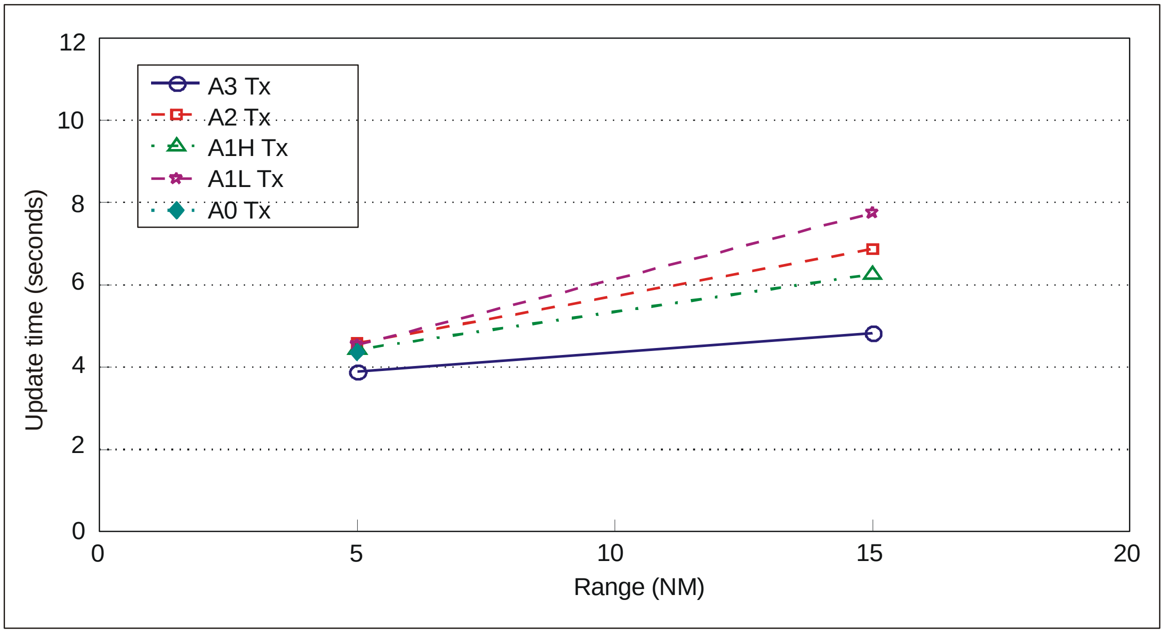


Figure II-A-37. A0 receivers on the ground in CE 2015 receiving all aircraft on approach at an altitude of 2 000 feet to Brussels collocated with a 10-kW 979-MHz TACAN

4.7.1 Additional TIS-B assumptions

4.7.1.1 This section describes additional assumptions (to those described in 4.1 for the LA 2020 scenario), which were necessary to describe a more complete ground infrastructure for the UAT system. It addresses the number and locations of UAT ground stations, their basic operation and the TIS-B transmissions from these ground stations.

4.7.1.2 A total of 21 locations for UAT ground stations were selected for the Los Angeles Basin region defined for the LA 2020 scenario. Most of these were selected to be located at various airports in the area. Each of these stations was responsible for the aircraft in a defined service volume, as shown in Figure II-A-38.

4.7.1.3 TIS-B transmissions were assumed to be made in the ADS-B segment of the UAT frame by the ground stations, using two possible scheduling algorithms. One was the so-called “Capstone” algorithm, because it reflects the technique implemented for the UAT ground stations acquired for the Alaska Capstone programme. The other algorithm studied was a simple random selection method.

4.7.1.4 Two operational time frames were investigated: near-term (2008) reflecting no ADS-B equipage, with TIS-B updates provided by radar reports; and 2020, assuming 100 per cent ADS-B equipage (40 per cent 1 090 ES and 60 per cent UAT), with TIS-B updates provided by ADS-B rebroadcast (ADS-R). The radar updates occurred once every 1.2 to 4.8 seconds, depending on the altitude of the aircraft, while ADS-R updates were assumed to be provided at a constant rate of once per second.

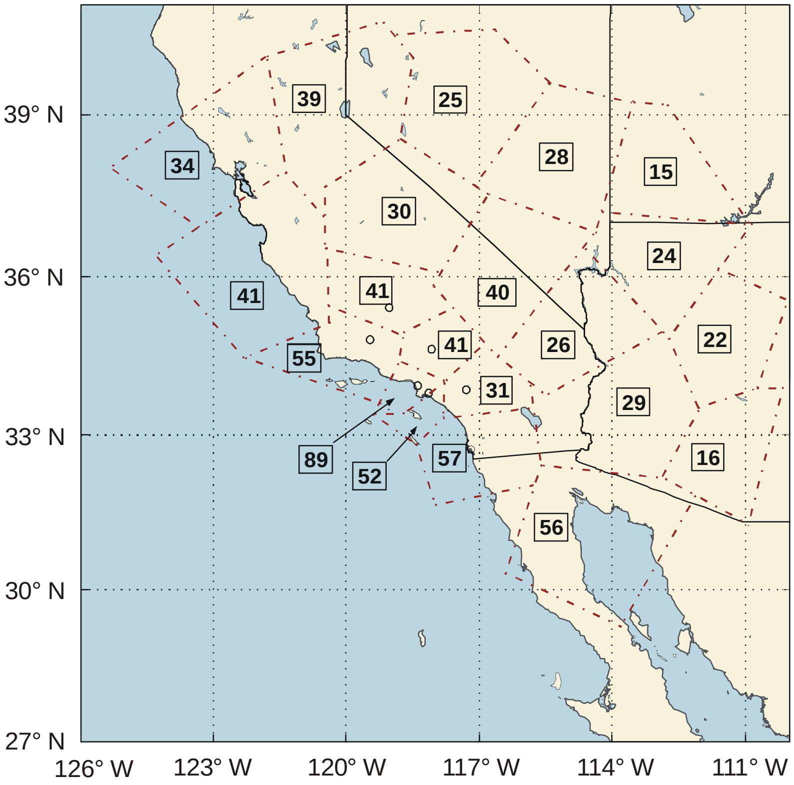


Figure II-A-38. Locations of UAT ground stations, including service volumes and number of uplinks per second (2008) in each service volume for LA 2020 scenario

4.7.1.5 TIS-B uplinks were assumed to begin at an MSO and were further assumed to consist of a long UAT ADS-B message. The ground station transmit power was assumed to be 45 dBm, with an antenna gain pattern that is omnidirectional in azimuth and TACAN in elevation. A number of airborne receivers were studied, but the results reported here are for the worst-case Class A1 receiver type.

4.7.2 TIS-B results

4.7.2.1 Figure II-A-39 shows the results for the 95 per cent TIS-B update interval for a receiver located at a worst-case position in the near-term (2008) scenario, receiving TIS-B messages from LAX. There are three sets of outcomes shown on the graph, representing the update intervals for the three different radar detection intervals: 1.2 seconds, 2.4 seconds and 4.8 seconds. For each detection interval, results are shown for both a single UAT transmission for each update and for two transmissions per update. For this scenario, there appears to be little difference in UAT TIS-B uplink performance between the two algorithms, although in this high-density air traffic environment with low ADS-B equipage, repeating the TIS-B uplink message does seem to provide an important advantage.

4.7.2.2 The ADS-B air-to-air UAT performance is affected by the large amount of TIS-B uplink traffic coming from the UAT ground stations in this near-term scenario. However, as shown in Figure II-A-40, the effect is not sufficiently large to cause the performance to exceed the required ADS-B 95 per cent update time.

4.7.2.3 For the LA 2020 scenario, all aircraft are assumed to be ADS-B-equipped with either 1 090-MHz extended squitter or UAT, so all ground uplinks are ADS-R and updates are assumed to occur every second for each 1 090 ES-equipped aircraft. Table II-A-5 shows the 95 per cent update time for the ADS-R transmissions as received at an airborne receiver located near a number of ground stations in the dense central area of the scenario. Note that the 95 per cent time for the Capstone slot selection algorithm is around two seconds for all of the ground stations.

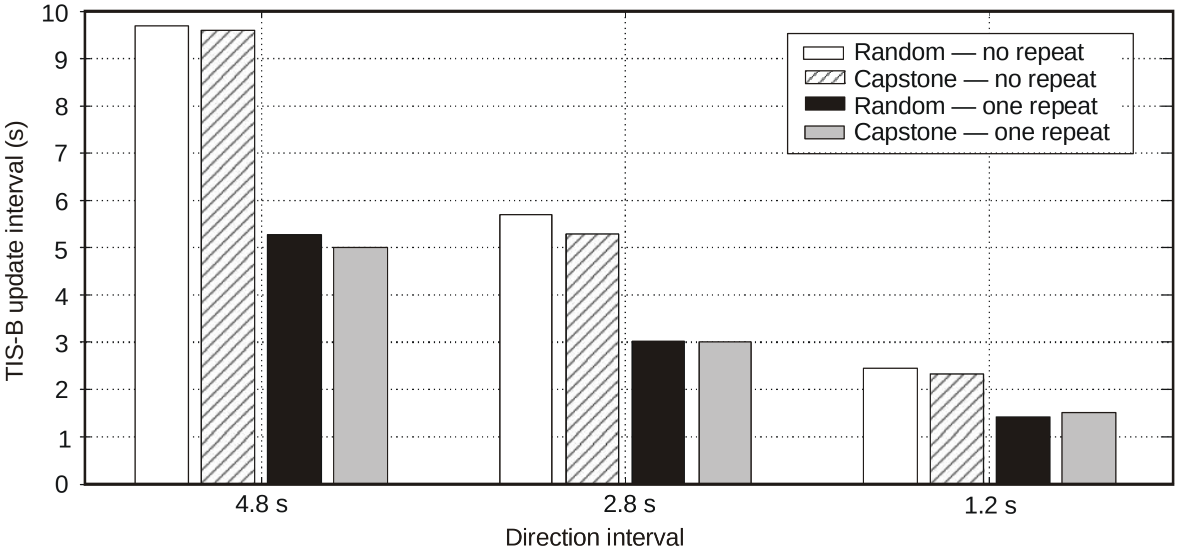


Figure II-A-39. TIS-B 95 per cent update intervals in LA 2008 (no ADS-B equipage)

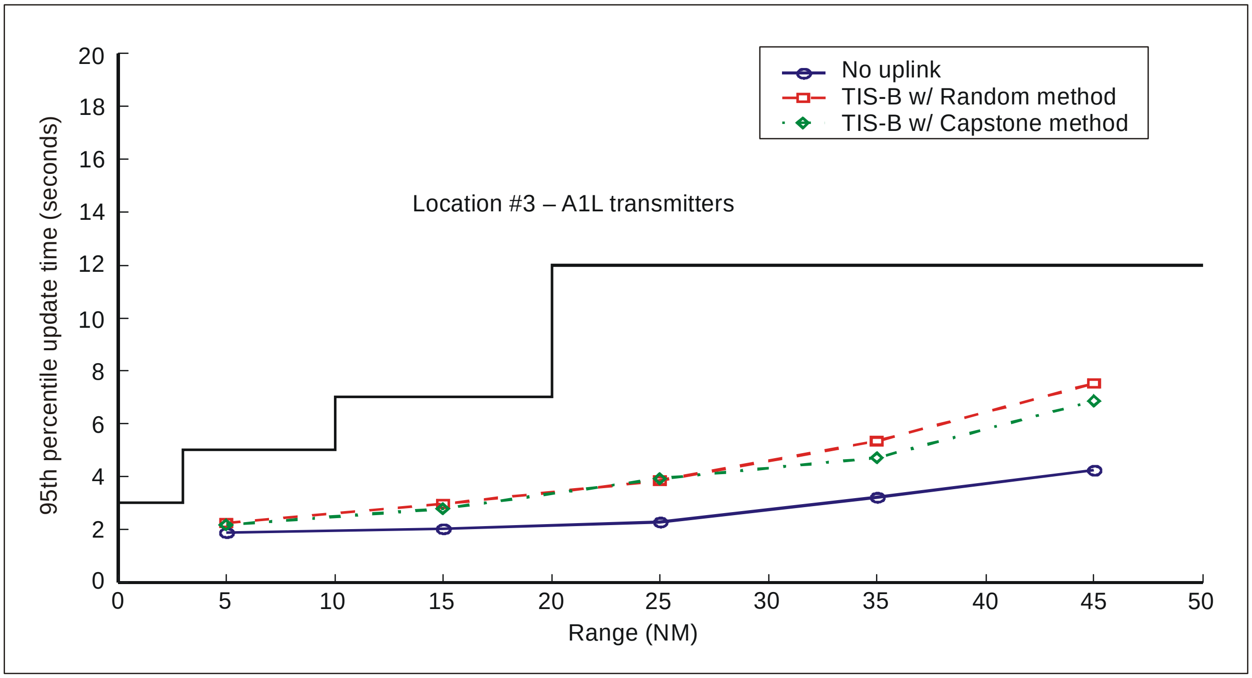


Figure II-A-40. ADS-B 95 per cent update interval in near-term scenario

Table II-A-5. 95% update times for ADS-R transmissions from UAT ground stations in LA2020

Ground station	*Uplinks per second*	*Range (NM)*	*Random*	*Capstone*
1 (LAX)	89	36.6	2.3	2.0
5	55	38.2	2.5	2.0
6	41	33.6	2.3	2.0
7	41	51.2	3.0	2.1

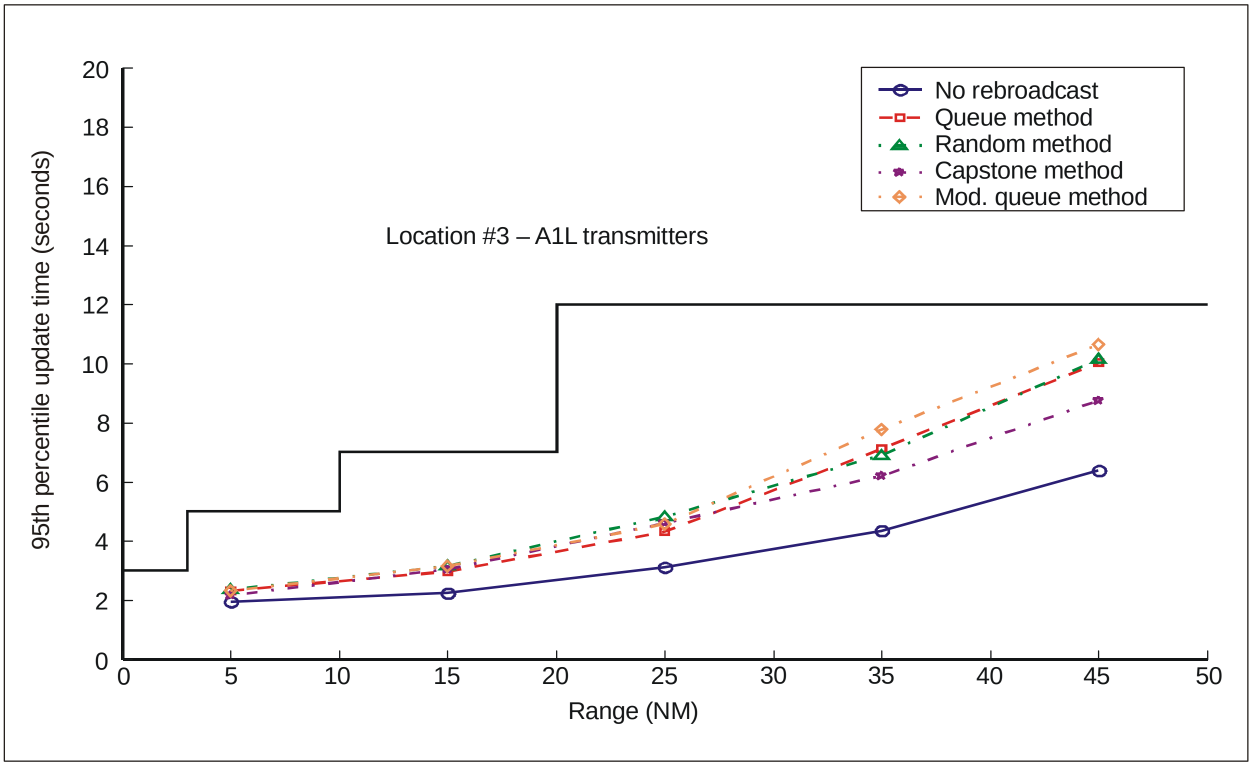


Figure II-A-41. ADS-B air-to-air performance in the presence of ADS-R ground transmissions in LA 2020

4.7.2.4 Figure II-A-41 shows the effect of the ADS-R transmissions from the ground stations on the ADS-B air-to-air performance of Class A1L transmitters to the Class A1 airborne receiver. Note that there were four algorithms tested for this case, and all made the ADS-B air-to-air performance worse than with no ground transmissions, but none caused the ADS-B performance to exceed the required 95 per cent update time.

TIS-B hotspot analysis

4.7.2.5 This section discusses the performance of a Class A3 receiver in the Core Europe 2015 traffic scenario attempting to receive ADS-B messages from one other airborne UAT transmitter in an extreme TIS-B interference environment. This is intended to be a worst-case analysis of the early transition to ADS-B in which most aircraft are not equipped with UAT transmitters. The term “hotspot” has been used to describe the effect to be simulated here, where one ground-based transmitter generates all TIS-B message traffic (in the ADS-B segment of the one-second frame) rather than the distributed nature of the airborne transmitters in the standard CE 2015 scenario. It is the intention of this section to estimate the effect that this hotspot has on airborne ADS-B performance in CE 2015.

4.7.2.6 To estimate the worst case of TIS-B uplinks providing interference, it is assumed that only two aircraft are equipped with ADS-B in the CE 2015 scenario. In the CE 2015 scenario, there are approximately 1 000 aircraft within line of sight of a ground station at Brussels. Therefore, for the worst case the ground station is assumed to transmit 1 000 TIS-B messages per second in the ADS-B segment of the UAT frame. Other cases, where the ground station transmits fewer than 1 000 messages per second, are also reported. In addition to the TIS-B interference, Link 16 Baseline B, co-site and the appropriate DME interference are all assumed to be present.

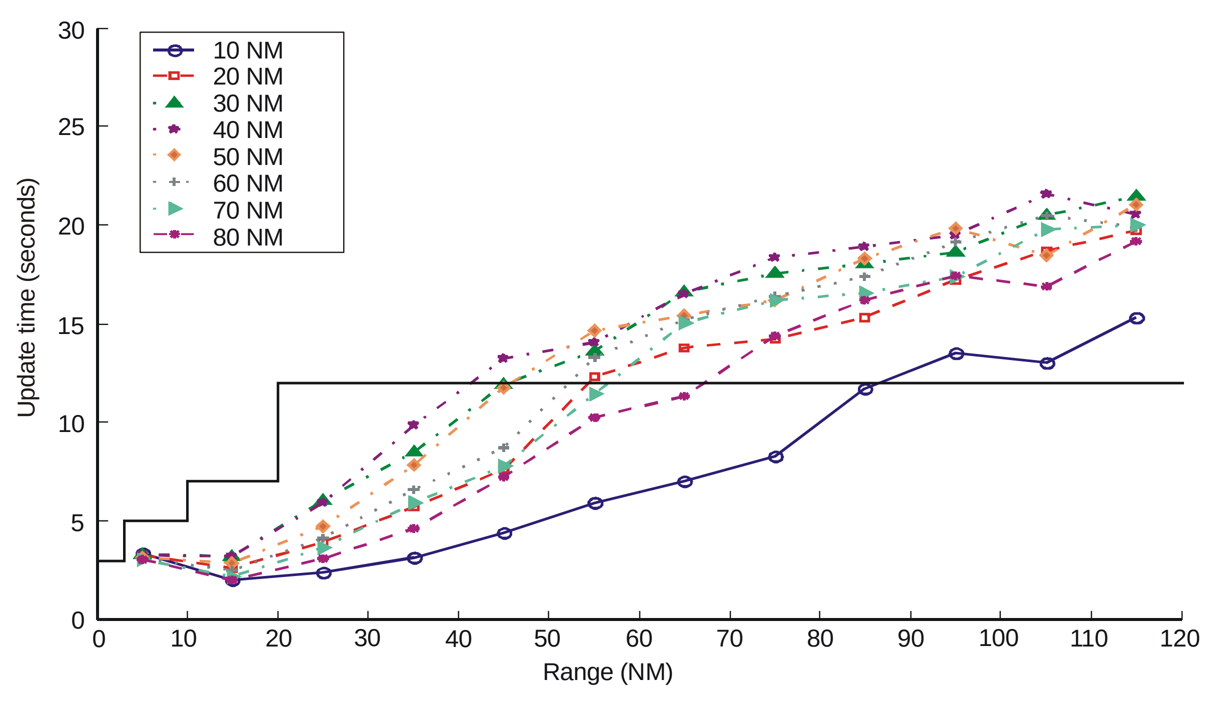


Figure II-A-42. 95 per cent state vector update times for an A3 receiver at 40 000 feet receiving A3 transmissions in the presence of a ground station at various ranges broadcasting 1 000 TIS-B messages per second

4.7.2.7 Figure II-A-42 shows 8 curves for ADS-B air-to-air 95 per cent state vector update times which correspond to varying the distance between the ground station and the receiving aircraft. Note that the worst case appears at a distance of around 40 NM, which is due to the combination of the signal propagation loss and the ground station antenna peak.

4.7.2.8 Figure II-A-43 shows the effect of decreasing the uplink rate for TIS-B transmissions. In this figure, 500 messages are uplinked each second, which might correspond to transmitting TIS-B information for 1 000 targets every other second or to sending up the closest 500 targets once per second. Results at all ranges from the ground transmitter are compliant with the requirements in Appendix K to farther than 120 NM.

4.7.2.9 In both Figures II-A-42 and II-A-43, the 95th percentile update time is highest at all Class A3 to A3 ranges when the ground station is 40 NM away from the receiver. Based on this result, another simulation with a different transmit rate (800 uplinks per second) was run with the ground station 40 NM away from the receiver, in an attempt to estimate the uplink rate at which compliance with UAT requirements breaks down. The results from the previous figures are compared with the 800 messages per second results in Figure II-A-44. The 800 uplink messages per second results show what appears to be minimal compliance with UAT requirements.

4.7.2.10 These results provide guidance for a potential limit on the TIS-B uplink transmission rate that can be supported in this high-density air traffic type of environment. In principle, the analysis shows that, during the period of transition from no ADS-B equipage to more substantial equipage rates, a level of 800 uplink messages per second from a single UAT ground station should allow the UAT required update rates to be achieved for air-air reception.

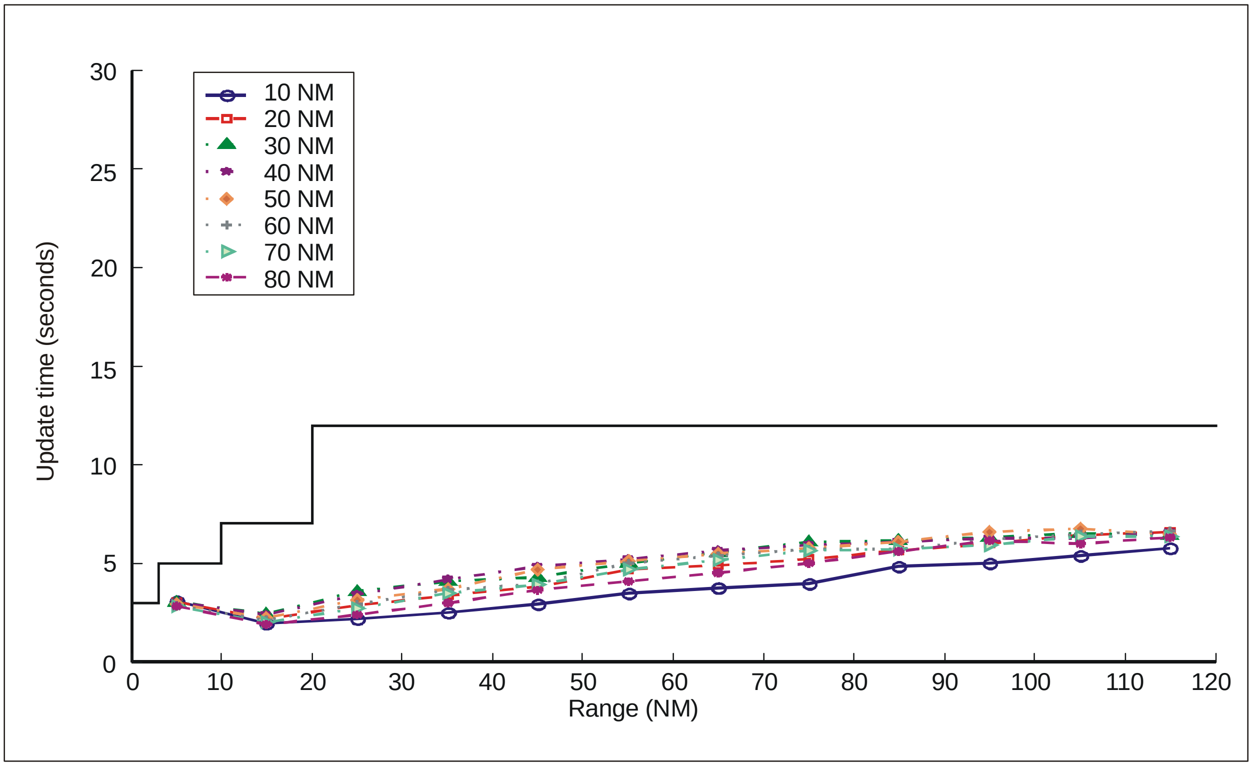


Figure II-A-43. 95 per cent and state vector update times for an A3 receiver at 40 000 feet receiving A3 transmissions in the presence of a ground station at various ranges broadcasting 500 RIS-B messages per second

5. MODEL VALIDATION

5.1 The validation effort for MAUS focused on reproducing a complete interference environment. The United States Federal Aviation Administration's (FAA) William J. Hughes Technical Centre (FAATC) developed a UAT interference simulator, which was capable of reproducing both the LA 2020 and CE 2015 UAT self-interference environments. The additional capability of simultaneously inserting DME and Link 16 interference along with the UAT self-interference was also implemented, resulting in emulation of high-density, stressful environments containing a combination of all three types of interference. This simulator, along with "desired" UAT messages was combined and fed into UAT MOPS-compliant UAT receivers. The message success rate (MSR) was then measured as a function of desired signal level for various combinations of interference and compared with predictions of the MAUS for identical circumstances and assumptions. In all cases, the predictions of the MAUS were in agreement with the measured results, within the experimental uncertainties. An example of this comparison is shown in Figure II-A-45 for the LA 2020 UAT self-interference environment. The results comparing measurements taken at the FAATC and the Joint Spectrum Centre of the Defense Information Systems Agency (JSC) on UAT MOPS-compliant equipment with MAUS simulation results are shown in Figure II-A-45.

5.2 As is evident from Figure II-A-45, there is very little difference between the bench-test data and the predictions of the MAUS. The two sets of data are quite consistent with each other within the limits of measurement. It is important to note that there were no free parameters that needed to be adjusted to achieve this agreement. This type of validation provides an increased measure of confidence in the simulation predictions.

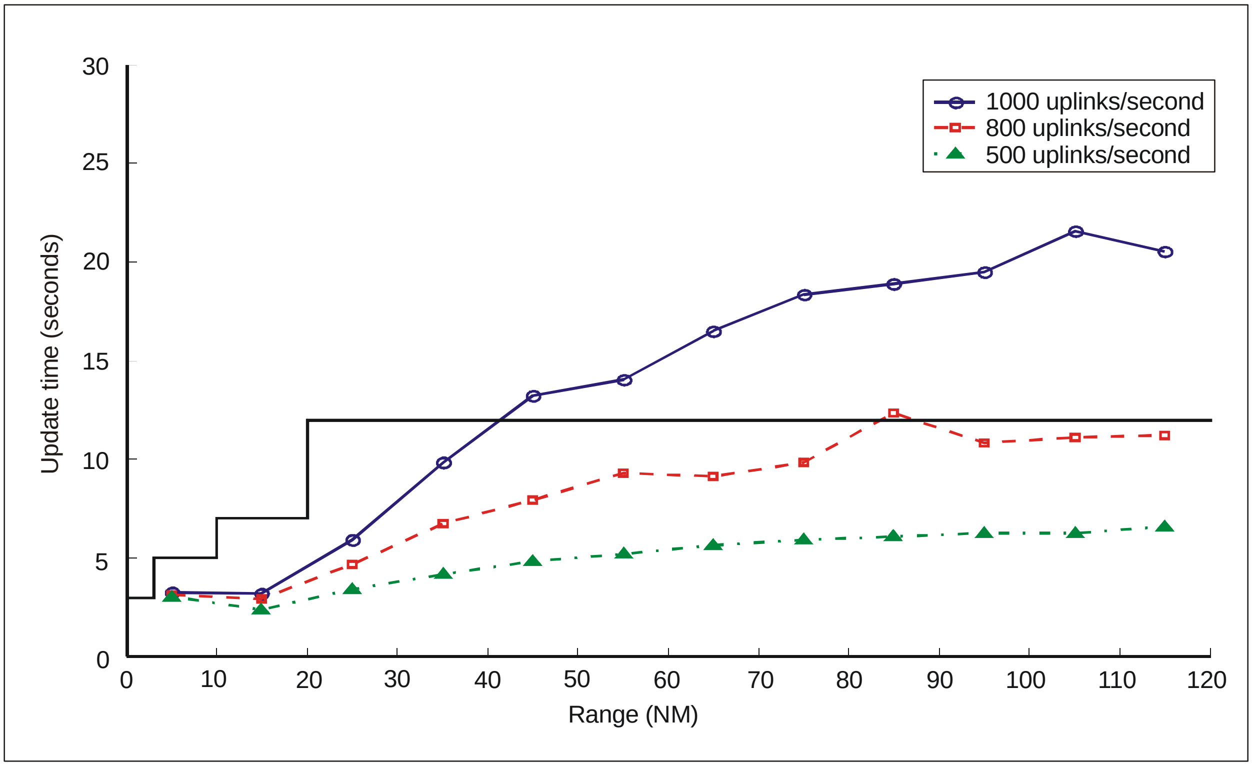


Figure II-A-44. 95th percentile state vector updates times for an A3 receiver at 40 000 feet receiving A3 transmissions in the presence of a ground station 40 NM away at various uplink rates

5.3 Bench-test measurements were also made of the Core Europe environment, which included UAT self-interference, DME/TACAN interference and Link 16 interference. Results of these measurements are shown in Figures II-A-46 and II-A-47. Figure II-A-46 shows the measurement results for the 0.8-MHz filter receiver, which is to be used for A3 class equipment. The addition of Link 16 interference to the DME/TACAN and UAT interference results in a reduction in MSR of up to around 10 per cent for a given desired signal level, although the curves are much closer than that over much of the signal range. Simulation results have not been run for comparison in this scenario; however, there is a slight reduction in performance when Link 16 interference is added to the identical Core Europe scenario.

5.4 Figure II-A-47 shows the results for measurements taken with the 1.2-MHz receiver filter, which corresponds to the receiver used for all equipage classes other than A3. These results are similar in nature to those for the Core Europe scenario shown in Figure II-A-46, in that the addition of Link 16 interference results in a small reduction of the MSR at a given desired signal level.

6. UAT A1S PERFORMANCE ANALYSIS

6.1 A new category of aircraft type has been defined for this version of this document, the A1 single antenna (A1S). The A1S is required to have a medium transmit power as defined in RTCA DO-282B, Table 2-2, but it will use a single bottom-mounted antenna. An evaluation of this category of equipage has been performed in a highly stressful environment. The three challenging situations that were specified for this analysis were:

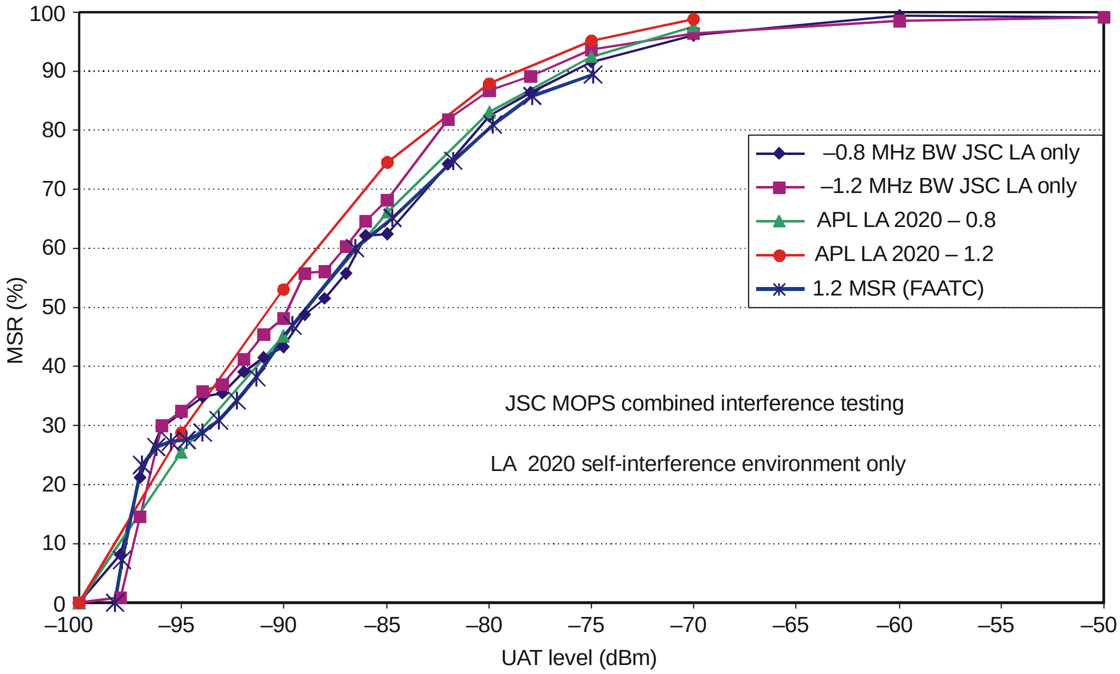


Figure II-A-45. Comparison of bench-test measurements of MOPS-compliant UAT reception in LA 2020 self-interference with predictions by MAUS

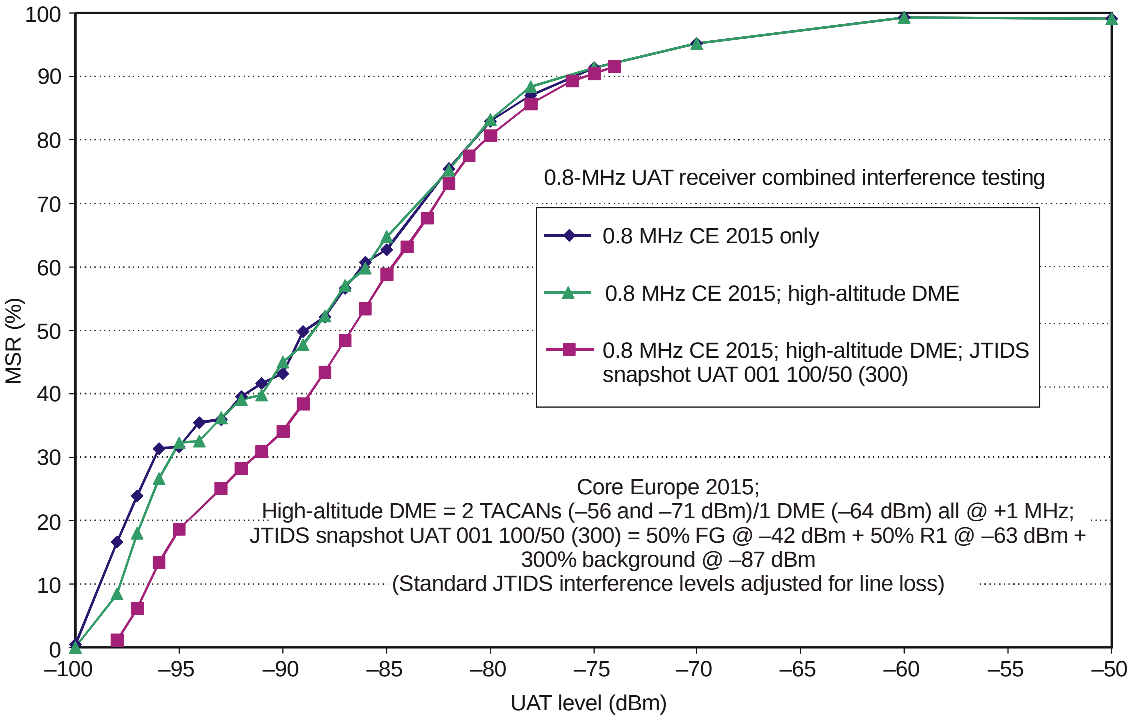


Figure II-A-46. Bench-test measurements of UAT performance in Core Europe UAT self-interference, combined with DME/TACAN and Link 16 interference

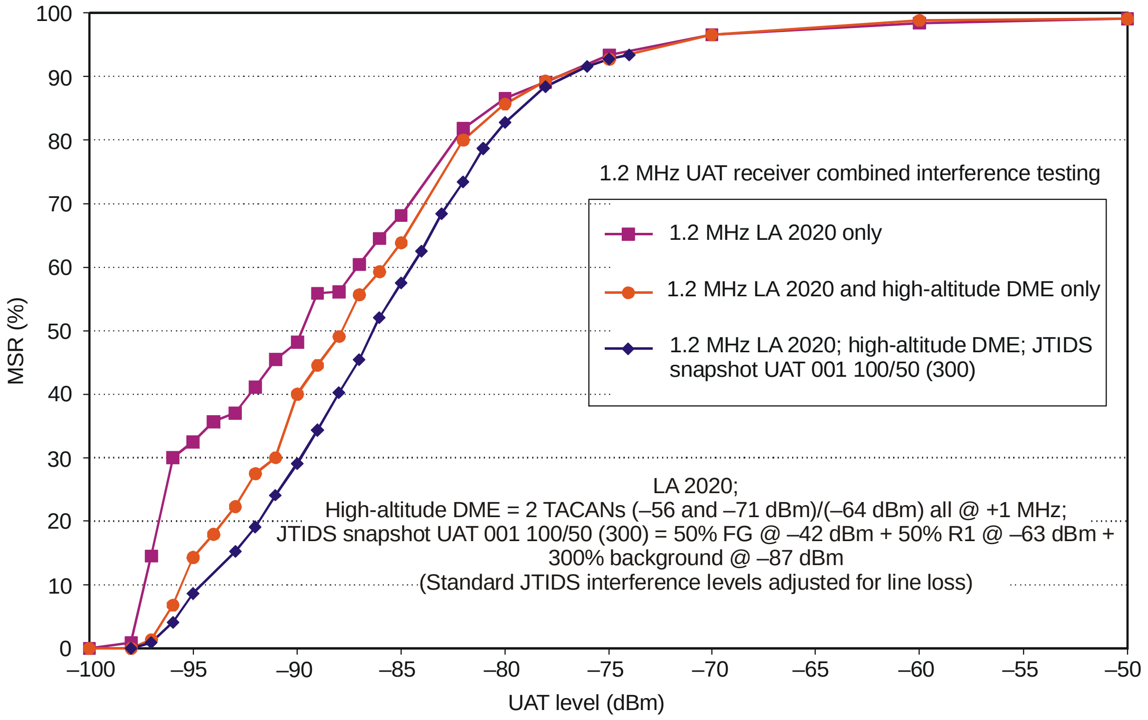


Figure II-A-47. Bench-test measurements of UAT performance in the LA 2020 UAT self-interference, combined with DME/TACAN and Link 16 interference

a) A stationary A1S aircraft on the surface of LAX attempting to receive ADS-R being broadcast by the ground infrastructure. A DME/TACAN antenna pattern at low power is used for the ground transmitting antenna. Scenario 1 focuses on surface transmissions from the ground infrastructure and assumes that there is no interference from other ground station transmissions.

b) An A1 aircraft on approach attempting to receive ADS-B transmissions from an A1S aircraft on the surface of a GA airport. An A1 aircraft is chosen because the alternating receive antenna is expected to provide the worst case. Scenario 2 includes a heavy load of ADS-R and TIS-B transmissions from nearby ground stations.

c) A bottom-mounted A1S banking away from a ground receiver at various bank angles, with various multipath losses. For this scenario, the aircraft is assumed to be moving in a circle with constant speed and bank angle; thus it is always facing away from the ground receive antenna. Scenario 3 includes a heavy load of ground transmissions as receiver blanking of the ground station.

6.2 The air traffic scenario used for this analysis is the LA2020 scenario developed for the TLAT. This scenario is based on the LA Basin 1999 maximum estimate. It is assumed that air traffic in this area would increase by a few per cent each year until 2020, when it would be 50 per cent higher than in 1999. The distribution of aircraft in the scenario is based on approximations of measured altitude and range density distributions. For the purposes of this study, it is assumed that UAT comprises all airborne A0 (replaced by A1S for this analysis) and around 65 per cent of airborne A1 aircraft in the scenario, for a total of 1 232 aircraft below FL180 and within 400 NM of LAX. In addition, 113 aircraft are located on the ground at LAX and other airports in the region. For the LAX ground scenario, it is assumed that there are 10 ground vehicles equipped with 1090 ES that are being transmitted over UAT via ADS-R. The approach scenario also assumes that there are 3 ground vehicles transmitting directly over UAT.

6.3 For A1S equipage, the model simulates transmission and reception on a bottom antenna. When on the surface, aircraft with top antennas transmit from those antennas without switching. The simulation assumes a single multipath ground reflection.

Scenario 1. For this scenario, the ground transmit power is varied between 1 watt and 1 kilowatt, and the ranges examined are 1, 3 and 5 NM between ground transmitter and A1S receiver on the ground. It is assumed that there is a single multipath ground reflection. The values used in the multipath calculation were provided by Stan Jones of Mitre Corporation in a personal conversation. The metric used is the standard 95 per cent update interval. Results are shown in Table II-A-6.

Table II-A-6. 95 per cent update interval for Scenario 1 as a function of range and transmit power

	Ground transmitter power				
Range		1 w	10 w	100 w	1000 w
	1 NM	2.0 s	1.2 s	X	X
	3 NM	X	3.0 s	2.0 s	X
	5 NM	X	X	6.9 s	2.1 s

In Table II-A-6, “X” is used to indicate that this case was not evaluated. These results should be compared to a required 95 per cent update interval of 2 seconds for the ASSA and FAROA applications (as described in RTCA DO-289). Table II A-6 indicates that, for a surface separation of no more than 1 NM, a 1-watt transmitter would meet the 2-second update interval, while it is likely that a 10-watt transmitter would be needed if the distance were 2 NM.

Scenarios 2a and 2b. For Scenario 2a, there is an A1S on a GA airport surface transmitting ADS-B to an A1 dual-antenna aircraft five miles away on approach to the airport at 1 200 feet. There is also a high power (100 w) ground transmitter 5 NM from the A1 receiver, which interferes with the reception of transmissions by the A1S on the ground. There is a variable single multipath ground reflection used by the model, since the model itself predicts no multipath effect at 5 NM. The metric used is the standard 95 per cent update interval. Results are shown Table II-A-7.

Table II-A-7. 95 per cent update interval for Scenario 2a as a function of multipath effect and ground transmissions

	Number of ground station messages per second		
Multipath effect		0	400
	0 dB	2.0 s	3.4 s
	–10 dB	2.1 s	4.0 s
	–20 dB	6.5 s	12.8 s

The results in Table II-A-7 should be compared to a required 95 per cent update interval of two seconds for the ASSA and FAROA applications.

Scenario 2b was also run for the case of the aircraft on approach 3 NM away from the airport, altitude also 1 200 feet. The results are shown in Table II-A-8.

Table II-A-8. 95 per cent update interval for Scenario 2b as a function of multipath effect and ground transmissions

	Number of ground station messages per second		
Multipath effect		0	400
	0 dB	2.1 s	3.9 s
	–10 dB	2.1 s	3.9 s
	–20 dB	3.0 s	5.9 s

The results in Table II-A-8 should be compared to a required 95 per cent update interval of two seconds for the ASSA and FAROA applications.

Scenario 3. For this scenario, there is an A1S at FL 120 at variable range from a ground receiver. The A1S is banking at a variable angle away from the ground receive antenna. The ground uplink transmissions (0 or 100 uplinks/second) prevent simultaneous reception of the A1S ADS-B transmissions. The ranges examined are 10, 30 and 50 NM.

For all ranges, the A1S achieved a 95 per cent update interval less than 3 seconds (3 seconds is required in the terminal domain) with no bank angle and no ground uplinks. Adding 100 ground uplinks resulted in an increase in the 95 per cent update interval to around 5 seconds at 10 NM and around 6 seconds at 50 NM. Increasing the bank angle resulted in a gradual increase in update interval up to a critical angle, where the curve experiences a sharp rise (see Figure II-A-48). The critical angle varies with the range from the receive antenna: a greater range corresponds to a smaller critical angle.

Note that the critical angle for the case in Figure II-A-48 is around 40 degrees. Also, the effect of the addition of 100 uplink transmissions is shown.

Note.— This analysis assumes a constant orientation with respect to the ground station throughout the entire update interval, an assumption made to simplify this analysis and ensure that the result was conservative. Note that in an operational situation, an aircraft with a single antenna on the bottom of the fuselage banking away from one ground station may be banking toward another ground station. Note also that standard-rate turns have bank angles less than the critical angles in this analysis (at 90 knots, 14 degrees; at 120 knots, 18 degrees; at 180 knots, 26 degrees). Time spent in steeper-than-standard-rate turns is short.

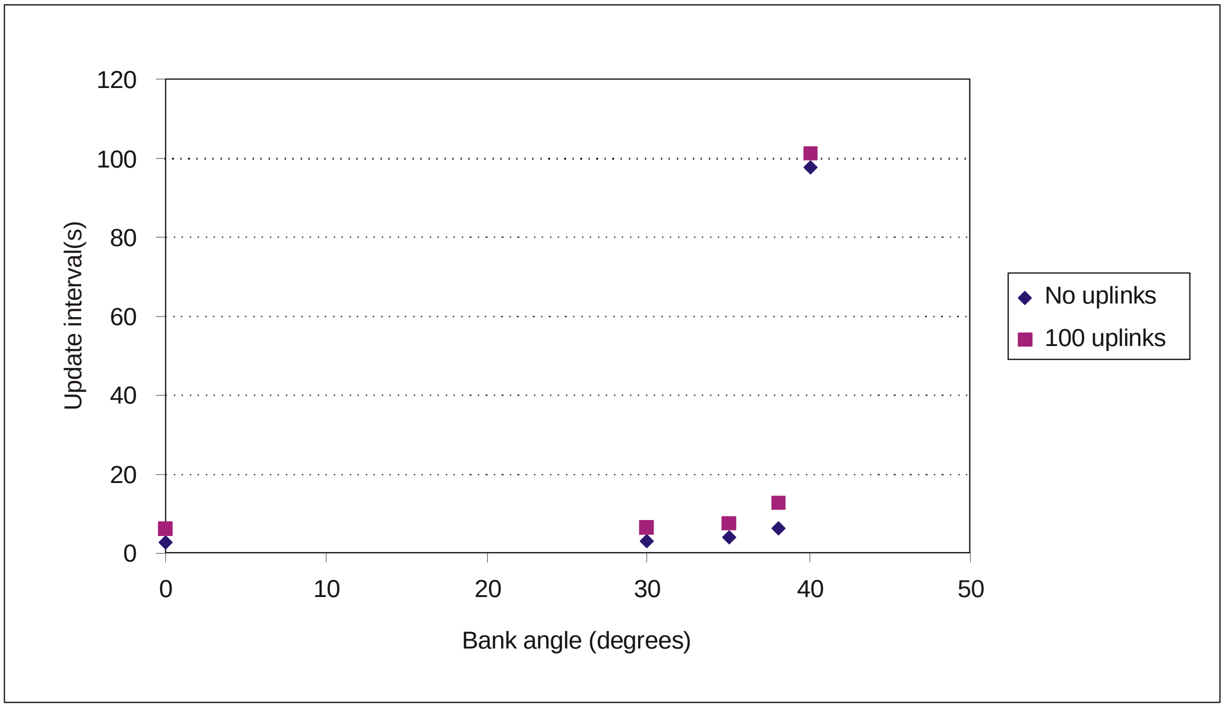


Figure II-A-48. Typical result for Scenario 3 for update interval as a function of bank angle

Appendix B

STANDARD INTERFERENCE ENVIRONMENTS

1. BACKGROUND

1.1 The universal access transceiver (UAT) is designed to operate in the lower portion of the 960 to 1 215 MHz aeronautical radio navigation service (ARNS) band. This portion of the band is heavily utilized throughout the world for International Civil Aviation Organization (ICAO) standard systems such as distance measuring equipment (DME) and military systems such as tactical air navigation (TACAN) and, in some countries, the joint tactical information distribution system/multifunctional information distribution systems (JTIDS/MIDS). Each of these systems share a common characteristic in that they utilize pulses that are short in relation to UAT pulses. As a result, the UAT waveform and receiver front-end has been specifically tailored to tolerate a high-density pulsed environment. In addition, the random-start nature of the UAT ADS-B access protocol results in self-interference. The extent of this interference is dependent on the number of aircraft visible to the "victim" UAT.

1.2 Because of the complexity of the potential interference environment, UAT performance in an operational environment was determined through the use of high-fidelity computer simulations. Those simulations were based on two specific inputs:

a) the performance of the UAT receiver in the presence of interference[1] as a function of signal-to-interference and desired-to-undesired signal overlap; and

b) the time/amplitude distribution of interfering signals.

This appendix will address the assumptions driving the latter input, while the UAT test specifications (RTCA DO-282A, 2.4) will ensure that UAT equipment meeting the UAT MOPS (RTCA DO-282A) can match the assumed UAT performance.

2. OPERATIONAL ENVIRONMENTS

2.1 The operating frequency of UAT at 978 MHz was selected to minimize the impact to existing DME/TACAN use. That DME/TACAN channel (17X) is reserved worldwide for "emergency use," and as a result there exist very few operational 978-MHz DME/TACAN systems. In the United States for example, both 978 MHz and 979 MHz are reserved for DME "ramp tester" equipment. Such an application is very low power, offering no interference to UAT usage[2]. Europe however uses both 978 MHz and 979 MHz for operational DME/TACAN, so European scenarios considered DME/TACAN as an interference source. It should be noted that early test and analysis results indicated that, for off-board DME/TACAN, only those that were co-frequency and/or first adjacent-frequency to the UAT (i.e. on 978 or 979 MHz) need be considered. This accrued as a result of the narrow spectral content of the DME/TACAN signals, in concert with the good frequency rejection properties of the UAT receiver. While the UAT SARPs in Annex 10, Volume III, contain a rejection of pulsed interference requirement for 980-MHz DMEs as well as DMEs operating at frequencies above 980 MHz, the impact of this interference on overall UAT system performance is projected to be negligible.

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[1] This performance was quantified through high-fidelity bench test measurements.

[2] Testing and analysis has also shown that co-frequency UAT usage will not interfere with ramp tester implementation.

2.2 Driven by the diverse environments in which UAT would operate, a number of different interference scenarios were postulated and simulated. The goal was to ensure that the UAT design would provide the necessary performance as UAT traffic increases in the future and to ensure that UAT receivers are measured against the most challenging interference environment from JTIDS/MIDS[3] and DME sources. Within a given scenario, UAT receiver locations were chosen to represent the most challenging geographic areas.

2.3 Aircraft distributions were based on scenarios developed by the joint United States Federal Aviation Administration (FAA)/Eurocontrol Technical Link Assessment Team (TLAT) to assess candidate ADS-B links. One scenario was intended to represent a low-density air traffic environment, while another mimicked introducing UAT into today's Core Europe setting. The final two "future" scenarios predicted Los Angeles Basin 2020 and Core Europe 2015 environments respectively. Together these scenarios provided diverse assessments of UAT performance, and their characteristics are catalogued in Table II-B-1. Note that to fully assess the resulting performance of a victim UAT receiver, practical UAT receiver implementation limitations that impact receiver availability are also included.

2.4 To analyse DME interference in Core Europe, ICAO's database[4] of existing and planned DME/TACAN assignments was examined. While the underlying assumption for DME/TACAN is that co-channel assignments will eventually need to be moved in order to achieve full operational UAT performance, it is also recognized that, in the near-term, low-density UAT self-interference environments offer performance margins that could be used to accommodate co-channel DME/TACAN interference. Geographic analysis of existing DME/TACAN assignments (i.e. quantifying the number and power of received DME/TACAN signals at geographic points in space) resulted in development of the environments shown in Table II-B-2 to capture current worst-case DME/TACAN conditions. In recognition of future environments, the UAT design was tailored to ensure that UAT could provide an adequate level of performance as 978-MHz DME/TACANs are reassigned over time. As part of this, noting that current "planned" assignments allow latitude for regulators to expand usage of 979-MHz, assumptions were made to predict future DME/TACAN interference. In particular, for the Core Europe 2015 scenario, it was assumed that while all 978-MHz DME/TACANs were reassigned, all planned 979-MHz assignments in the ICAO database had become operational. Details of the resultant environments are captured in Table II-B-3. In total, the goal of each of the test scenarios was to reasonably over-bound any operational environment the UAT could be expected to experience.

Sample derivation

2.5 Figure II-B-1 illustrates a scenario in today's environment focusing on an aircraft at 40 000 feet flying over Germany. Using the DME/TACAN emitter location and power information from the ICAO database, the DME and TACAN normalized ground station antenna patterns shown in Figures II-B-2 and II-B-3, relative emitter-aircraft geometry, and propagation loss equations, the values in Table II-B-4[5] can be derived. Repeating for various locations/geometries allowed the worst-case positions to be determined and utilized for compatibility analyses.

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[3] JITDS/MIDS scenarios are defined in terms of source time slot duty factor (a measure of number of pulses per second), and source received power level. For the MOPS effort a number of operational JTIDS/MIDS scenarios were provided by the United States Department of Defense as representing postulated training needs. These were included as part of the standard interference environment as shown in Table II-B-1.

[4] Listings were reviewed/verified by Eurocontrol.

[5] Note these levels are also reflected in row 4 of Table II-B-2. The "All Germany" emitter reflects a mobile TACAN. For the purpose of this assessment it was placed in the worst-case location allowed by channel assignment rules.

3. CO-SITE ENVIRONMENT

In addition to all the scenarios for the external interference environment, effects were included to account for on-board sources of interference from systems operating in the 960 MHz to 1 215 MHz band. The components of this co-site environment were estimated during the TLAT deliberations and have been further refined for the expected UAT aircraft installations. This environment was selected to be conservative and consistent for all aircraft classes, which resulted in including, for example, the assumption that A0 aircraft could be equipped with airborne collision avoidance systems (ACAS). The co-site environment is defined in Table II-B-5, depicting the assumptions of transmission duration and rates of on-board transmitters operating in the 960 MHz to 1 215 MHz band, including signals from on-board DME equipment, ACAS and transponders. Also noted is the allowance made for receiver recovery time under the assumption that pulse suppression circuitry is employed.

Table II-B-1. Interference scenarios and implementation assumptions

		Scenarios			
		Core Europe 2015	Core Europe current	LA 2020	Low density
Standard interference environment	UAT self-interference	Per TLAT Core Europe 2015 (2 091 aircraft in 300-NM radius) + 100 surface vehicles per major airport @ 28–32 dBm and 1 basic message per second	1 193 aircraft 500 ground vehicles 300-NM radius	Per TLAT LA 2020 (2 694 aircraft in 400-NM radius) + 100 surface vehicles per major airport @ 28–32 dBm and 1 basic message per second	Per TLAT low density (360 aircraft in 400-NM radius) + no surface vehicles
	DME	All currently planned 979 assignments See Table II-B-3	All current 978 MHz and 979 MHz assignments See Table II-B-2	None	Same DME environment as CE 2015
	JTIDS (levels seen at UAT victim antenna port)	TSDF 50% @ –39 dBm + TSDF 50% @ –60 dBm + TSDF 300% @ –84.5 dBm	TSDF 50% @ –39 dBm + TSDF 50% @ –60 dBm + TSDF 300% @ –84.5 dBm	TSDF 50% @ –39 dBm + TSDF 50% @ –60 dBm + TSDF 300% @ –84.5 dBm	TSDF 50% @ –39 dBm + TSDF 50% @ –60 dBm + TSDF 150% @ –78 dBm + TSDF 150% @ –82 dBm
Installation and Implementation assumptions	Co-site	See Table II-B-5 (scenario independent)			
	UAT implementation effects (Applies to all classes)	Re-trigger capable			
		T/R switching results in 2 millisecond receiver blanking immediately before and after ownship transmissions			
		–20 dBc pedestal for 4 μs duration immediately before and after ownship transmission			
		“Pulse stretching” effects from high-level DME seen in bench-tests of “pre-MOPS” units included in model			

Table II-B-2. Received power levels (dBm) for current European DME/TACAN environment

Aircraft (latitude/longitude)	*Altitude (ft)*	*Ahlhorn*	*Metz/Frescaty*	*Furstenfeldbruck*	*All Germany*	*Bruggen*	*Geilenkirchen*
50.9°, 4.5°	40 000	–76	–72		–79	Not operational	–66
50.9°, 4.5°	15 000		–75				–69
50.5°, 9.3°	40 000	–74	–74	–74	–57		–75
50.5°, 9.3°	15 000	–76	–76	–77	–53		–78

Table II-B-3. Received power levels (dBm) for 2015 European DME/TACAN environment

Aircraft (latitude/longitude)	*Alt (ft)*	*Ahlhorn*	*Metz/Frescaty*	*Furstenfeldbruck*	*All Germany*	*Bruggen*	*Geilenkirchen*
50.9°, 4.5°	40 000	Assumed cleared			–77	–76	–66
50.9°, 4.5°	15 000				–68	–76	–69
51.0°, 6.0°	40 000				–70	–76	–62
51.0°, 6.0°	15 000				–72	–72	–56

Table II-B-4. Signal level analysis of the sample scenario

	Ahlhorn	*Furstenfeldbruck*	*Metz/Frescaty*	*Geilenkirchen*	*All Germany*
Type	*TAC*	*TAC*	*TAC*	*TAC*	*Mobile TAC*
Longitude (degrees)	8.233	11.150	6.133	6.017	9.298
Latitude (degrees)	52.883	48.217	49.067	50.967	50.525
Frequency (MHz)	978	978	978	979	979
Ground distance (NM)	148.7	155.2	150.1	128.0	1.5
Elevation angle (degrees)	2.54	2.43	2.51	2.94	77.13
EIRP (dBm)	70	70	70	67	70
Normalized ground antenna gain (dB)	–2.67	–2.81	–2.71	–2.19	–13.25
Free-space propagation loss (dB)	–141.05	–141.42	–141.14	–139.77	–114.19
Rec. power at aircraft antenna (dBm)	–73.72	–74.23	–73.85	–74.96	–57.44

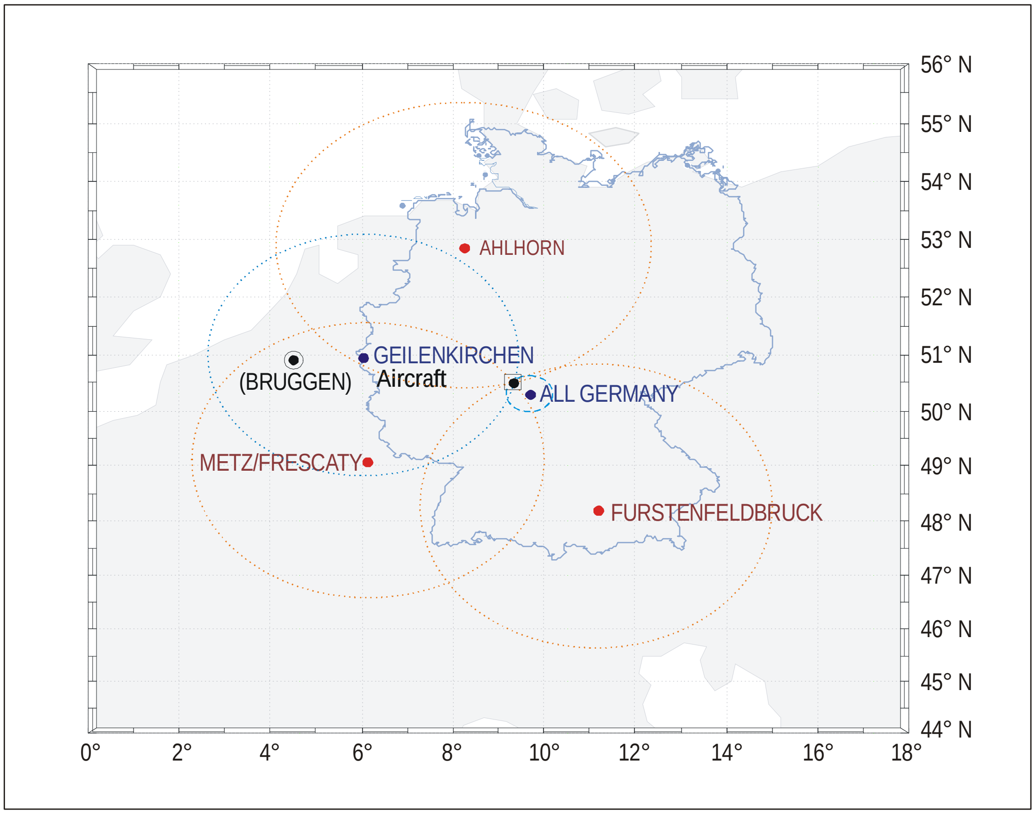

Figure II-B-1. Sample scenario

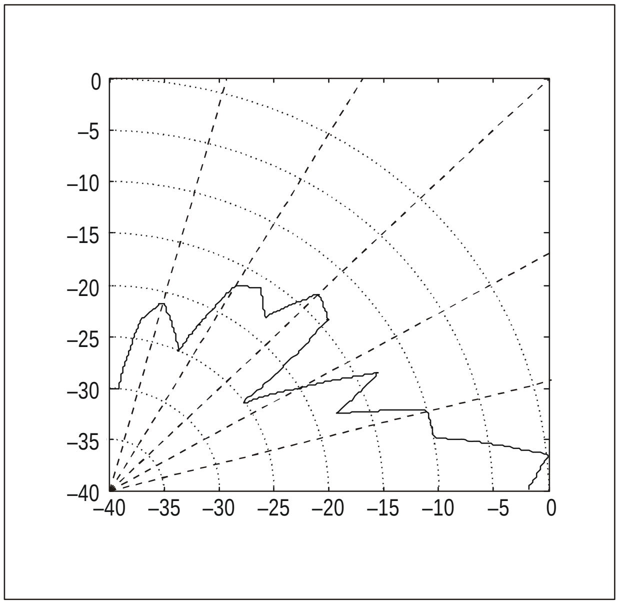

Figure II-B-2. Normalized DME pattern

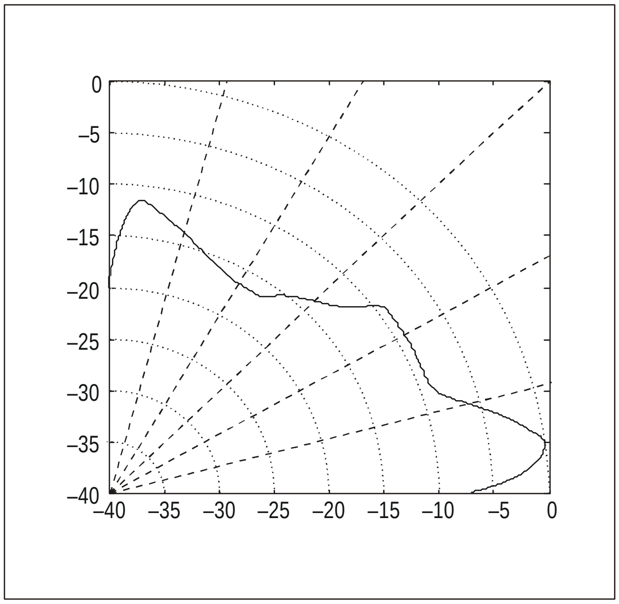

Figure II-B-3. Normalized TACAN pattern

Table II-B-5. Co-site environment

	Event blanking interval (µs)		*Events per second*			
Event	*Event duration*	*Additional blanking due to Rx recovery*	*A0*	*A1 (L)/(H)*	*A2*	*A3*
DME interrogations	19	15 µs	70	70	70	70
ATCRBS replies	20	15 µs	200	200	200	200
Mode S replies	64	15 µs	4.5	4.5	4.5	4.5
Mode S interrogations	20	15 µs	5	5	5	5
Whisper-shout interrogations	25	15 µs	80	80	80	80

4. SCENARIO ASSESSMENTS

4.1 With the preceding environments established, ADS-B reception performance was assessed for various receiver types in various locations within the environment[6]. The primary metric was the update interval achieved at a 95 per cent confidence level for 95 per cent of the aircraft population of interest. In early assessments of air-air surveillance performance, the aircraft population of interest was limited in elevation relative to the own aircraft in order to eliminate from consideration targets that were of no operational interest (see Figure II-B-4). However, this limitation of the aircraft population of interest was not used in the performance assessment reported in the UAT MOPS, RTCA DO-282A, Appendix J, because an alternate method of using "probes" was employed as described in that appendix.

4.2 Table II-B-6 is a matrix delineating the individual simulations performed in making design decisions for the UAT MOPS, RTCA DO-282A. Results from a select subset of these simulation runs are provided in Appendix A to indicate performance that can be expected of a UAT built to the standards of the UAT MOPS, RTCA DO-282A.

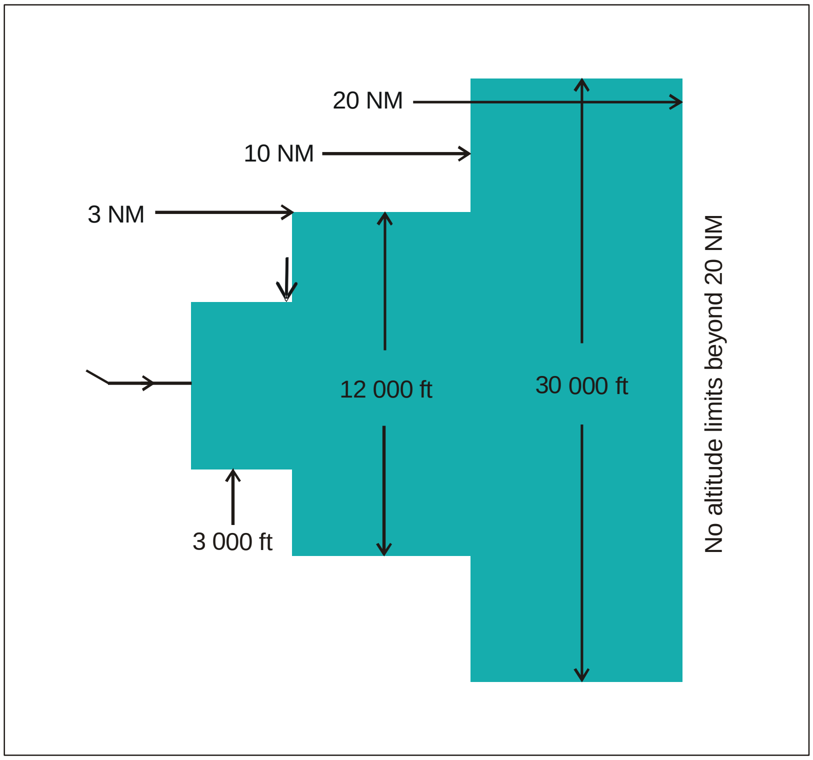

Figure II-B-4. Targets of interest for computing update interval

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[6] It is recognized that UAT ground stations in close geographic proximity to 978 or 979 MHz DME/TACAN transponders may require special siting to ensure proper operation of the UAT equipment.

Table II-B-6. Overview of scenario assessments

Perspective of victim receiver			*Scenario*			
Location	*Altitude*	*Rx type*	*Core Europe 2015*	*Core Europe Current*	*LA 2020*	*Low density*
At scenario centre	40 000 ft	A3	x	x	x	x
		A2	x	x	x	
		A1	x (H)	x(H)	x (H)	
	15 000 ft	A2/A3	x	x	x	
		A1	x	x	x	
		A0	x	x	x	
	On approach (2 000 ft)	A0-A3[1]	x	x	x	
	On surface (979 MHz DME @ –10 dBm)	A0[2]	x		x[3]	
		Ground station	x		x[4]	
		Ground station[5]	x			
At worst-case DME	40 000 ft	A3	x	x		x
		A2	x	x		
		A1	x(H)	x(H)		
	15 000 ft	A2/A3	x	x		
		A1	x	x		
		A0	x	x		

1. Update intervals based on aircraft “probe” approaching from 20 miles.
2. Update intervals based on aircraft “probe” approaching from 20 miles at 2000 ft.
3. No DME interference included in this case.
4. No DME interference included in this case.
5. With cavity filter in line that is assumed to reduce DME interference to that equivalent of on-channel DME at –50 dBm. Filter assumed to introduce insertion loss of 4 dB.

Appendix C

UAT RECEIVER PERFORMANCE IN THE PRESENCE OF DME/TACAN, JTIDS/MIDS AND SELF-INTERFERENCE

1. INTRODUCTION

Tests were conducted during the early standards work of UAT to ensure that the UAT system provides acceptable performance in the intended future worst-case environments. Results of testing with the standard interference environment described in Appendix B are summarized in Appendix A. Extensive testing was conducted on prototype UAT receivers, and additional testing was conducted on production-level equipment to characterize UAT receiver performance and validate acceptable performance of equipment that is designed to the developed standards. As described in Appendix C, sources of interference to the UAT receiver include on-channel self-interference from other UAT transmitters, DME on-channel or adjacent channel and JTIDS/MIDS signals that periodically occupy the frequency band at or near the 978 MHz UAT centre frequency. The following test results contain data that were collected to assess UAT receiver performance against each interference source individually and in combination.

2. PRE-PRODUCTION TESTING

Testing was conducted during the development of the RTCA UAT MOPS (RTCA/DO-282A) to characterize UAT receiver performance when subjected to signals from systems that could impact UAT receiver performance. Testing also served to ensure that receiver requirements specified resulted in expected performance. Pre-production units (which will be referred to here as “pre-MOPS” units) were produced and used as victim receivers subjected to various interference scenarios to characterize and validate performance. Pre-MOPS receivers that were tested included both the standard receiver and the high-performance receiver. For the purposes of the data presented in this section, the standard receiver is referred to as the 1.2-MHz receiver and the high-performance receiver is the 0.8 MHz receiver denoting the receiver filter bandwidths of each pre-MOPS receiver type.

2.1 DME/TACAN testing

2.1.1 Testing was conducted subjecting the pre-MOPS receivers to various DME and TACAN signal powers and rates to assess impact. DME frequencies were selected to assess impact of on-channel DME interference, 1-MHz adjacent channel and 2-MHz off-channel DME signals. In each of the series of test runs, a desired UAT signal was subjected to the DME or TACAN interference where the desired signal level was varied, typically in 1-dB steps, from below receiver sensitivity to above a power level where receiver performance was no longer impacted by the interference source.

2.1.2 The following data present results from subjecting the UAT receiver with DME pulse pairs at various rates and amplitudes. The results of receiver performance with DME at 2 700 pulse pairs per second 2 MHz from the UAT frequency are contained in Figure II-C-1. Power levels of the DME interference injected were –15, –21, –27 and –34 dBm. The results indicate that the standard receiver provides slightly better performance to DME signals 2 MHz above the UAT frequency.

2.1.3 Figures II-C-2 and II-C-3 contain results from subjecting the standard receiver and the high-performance receiver, respectively, to DME at 2 700 pulse pairs per second 1 MHz above the UAT frequency at various amplitudes.

2.1.4 Figures II-C-4 and II-C-5 contain results from subjecting the standard receiver and the high-performance receiver, respectively, to DME at 2 700 pulse pairs per second on the UAT frequency at various amplitudes.

2.1.5 Figures II-C-6 through II-C-12 contain similar results except that the DME pulse pairs were injected at the higher 3 600 pulse pairs per second rate.

2.1.6 Figure II-C-13 shows a comparison between DME and TACAN interference to both the basic and high-performance UAT receivers. A simulated DME station at 3 600 pulse pairs per second (DME signals are normally not transmitted at this rate) is compared to TACAN at 2 700. The power level of –60 dBm was applied to the UAT receiver at a frequency offset of 1 MHz from the UAT operating frequency. Figure II-C-13 shows comparable performance between DME and TACAN interference at the same amplitude; the number of pulses pairs is the dominant performance consideration. Comparison of UAT basic and high-performance receivers indicates improved performance with the high-performance receiver when subjected to DME/TACAN pulse pairs that are 1-MHz offset from UAT.

2.2 JTIDS/MIDS testing

2.2.1 Testing was conducted subjecting the prototype receivers to various JTIDS/MIDS scenarios. These scenarios were derived and utilized in the development of the standard interference environment as described in Appendix B.

2.2.2 Two scenarios were developed and used to test UAT performance against JTIDS/MIDS. A first scenario, depicted in the first three columns of Table II-B-1, is a scenario that was utilized in all prior JTIDS/MIDS and DME compatibility testing. A second scenario, depicted in the fourth column of Table II-B-1, consisted of a denser JTIDS/MIDS environment. Both scenarios represented multiple JTIDS/MIDS signal levels with one or more users and allocated JTIDS/MIDS pulses into groups each with an assigned duty factor and amplitude level. JTIDS/MIDS transmissions occur in time slots that are assigned randomly by the transmitter, so the scenarios were defined by the percentage occupation of legal time slots. The strongest amplitudes are the foreground transmissions followed by up to 4 rings, each with decreasing power level. Each ring is assigned a time slot duty factor (TSDF). The first scenario consisted of a 300 per cent JTIDS/MIDS background density.

2.2.3 Figure II-C-14 shows the performance of the UAT receiver as a function of desired signal level when subjected to the first JTIDS/MIDS scenario. Both the standard receiver and the high-performance receiver results are depicted. In general, the entire set of JTIDS/MIDS scenario runs yielded similar results in terms of impact on UAT receiver performance.

2.3 UAT self-interference testing

UAT self-interference testing was conducted under the future high-density Core Europe 2015 and LA 2020 scenarios described in Appendix B. Results of self-interference testing with the pre-MOPS units are shown in Appendix A.

2.4 Combined interference testing

UAT combined interference testing, including the effects of self-interference, TACAN/DME and JTIDS/MIDS, was conducted under the future high-density Core Europe 2015 and LA 2020 scenarios described in Appendix B. Results of combined interference testing with the pre-MOPS units are shown in Appendix A.

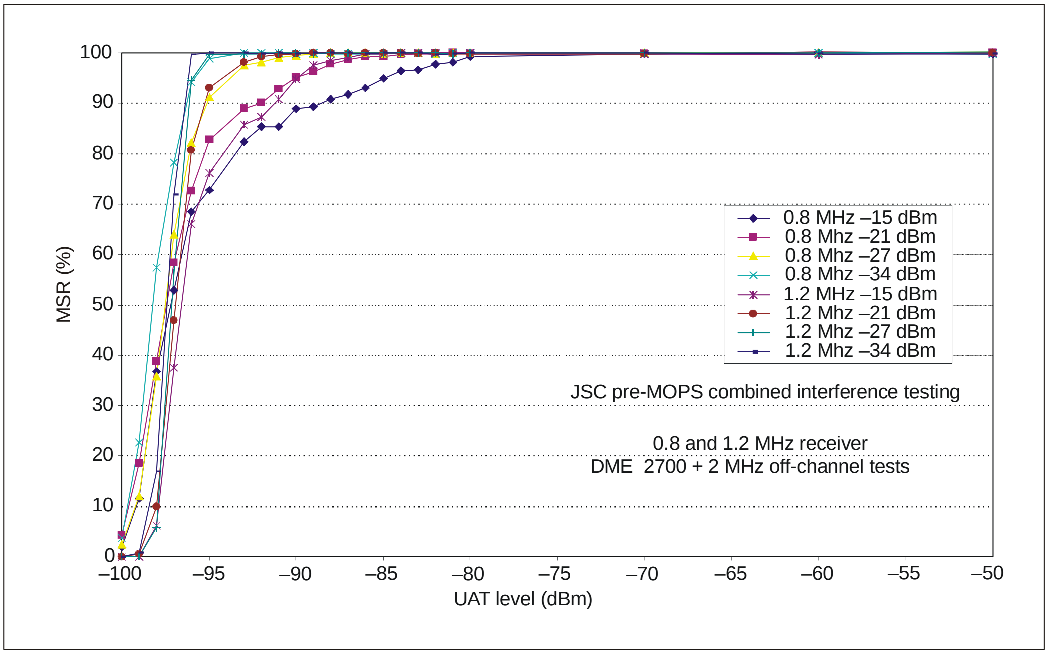

Figure II-C-1. UAT receiver performance DME 2 700 pulse pairs at +2 MHz

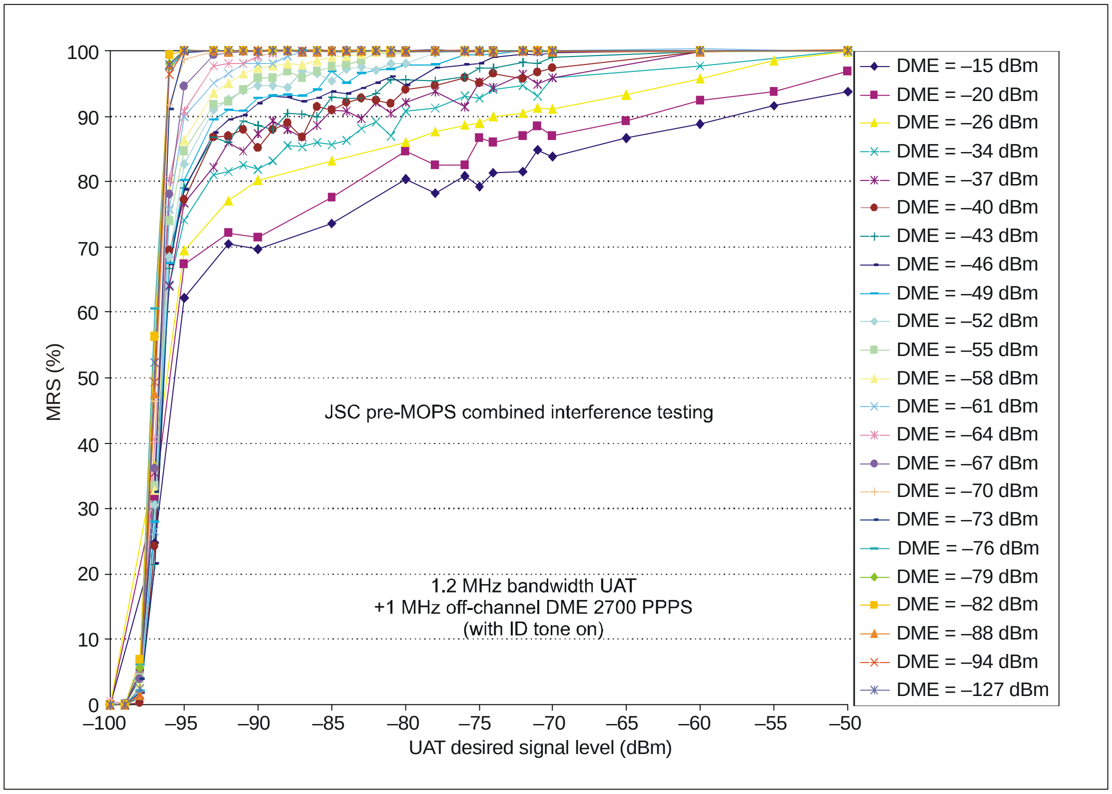

Figure II-C-2. UAT standard receiver performance DME 2 700 pulse pairs at +1 MHz

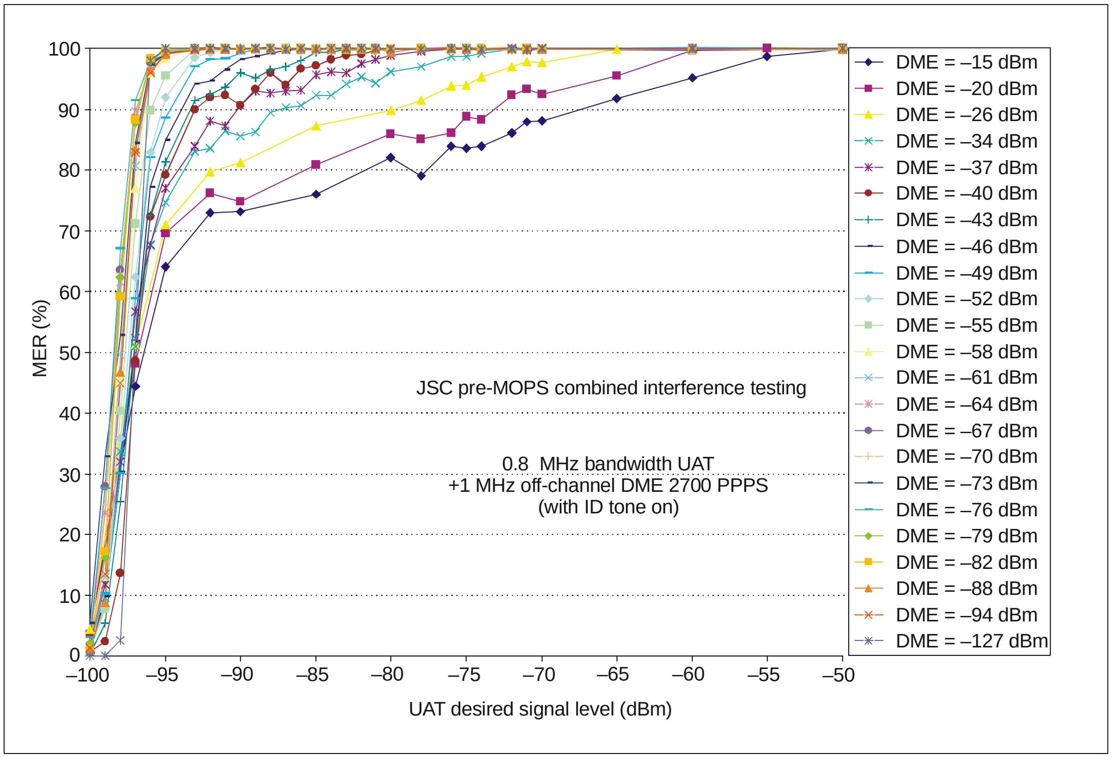

Figure II-C-3. UAT high-performance receiver with DME 2 700 pulse pairs at +1 MHz

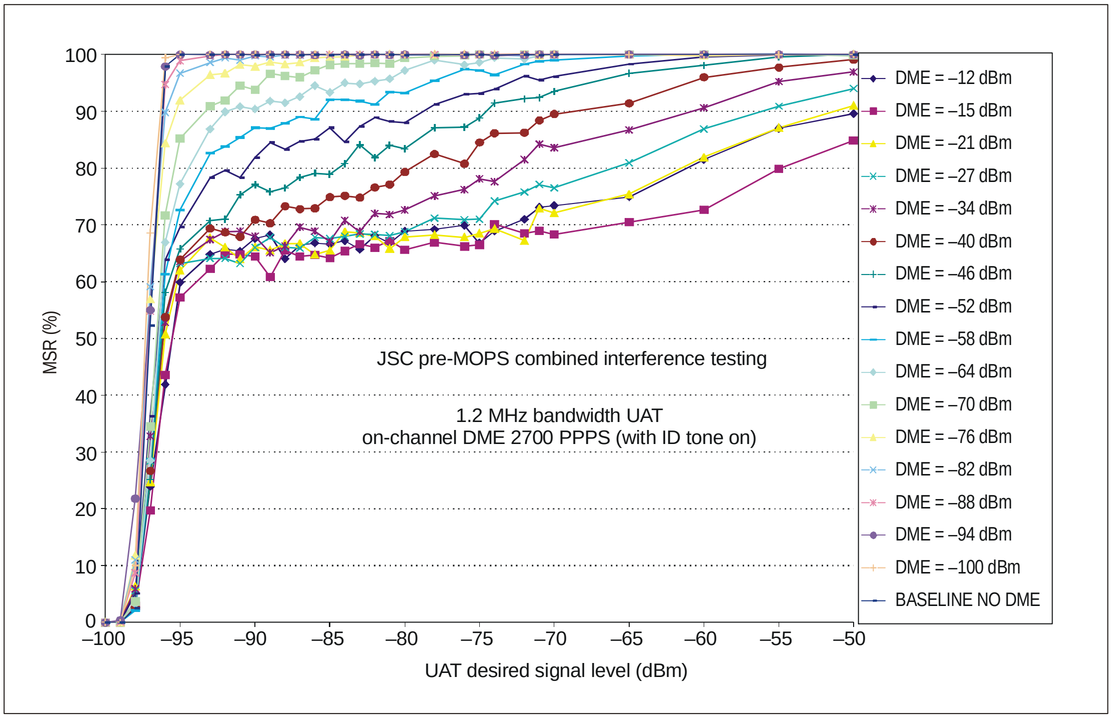

Figure II-C-4. UAT standard receiver performance DME 2 700 pulse pairs on frequency

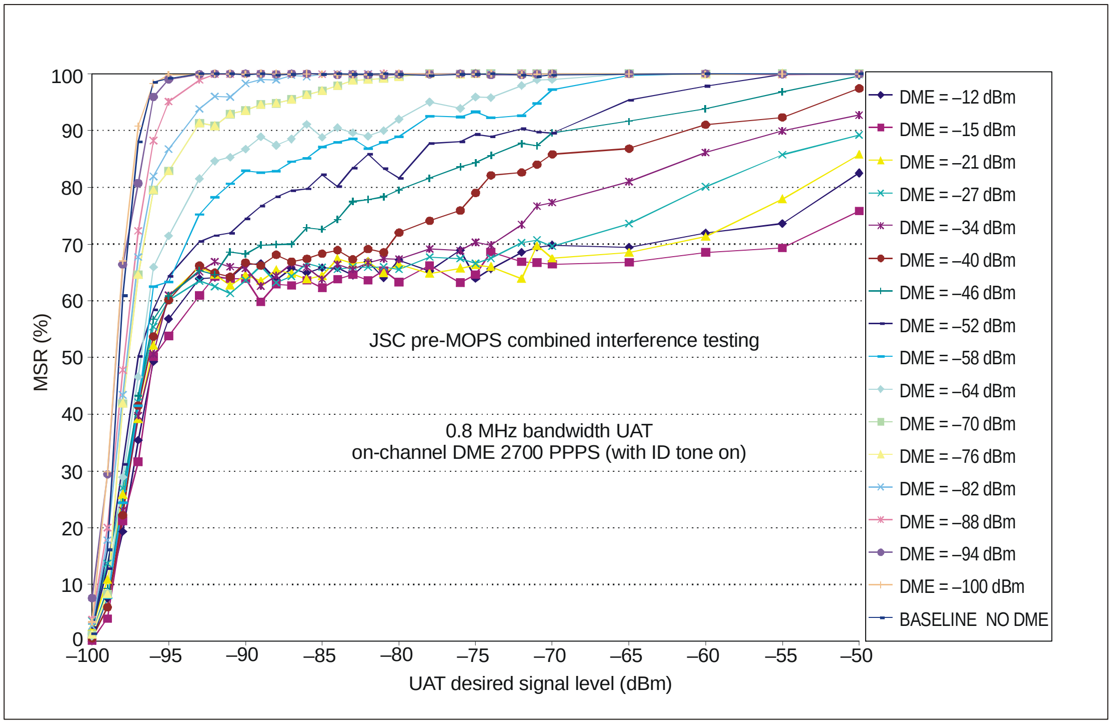

Figure II-C-5. UAT high-performance receiver DME 2 700 pulse pairs on frequency

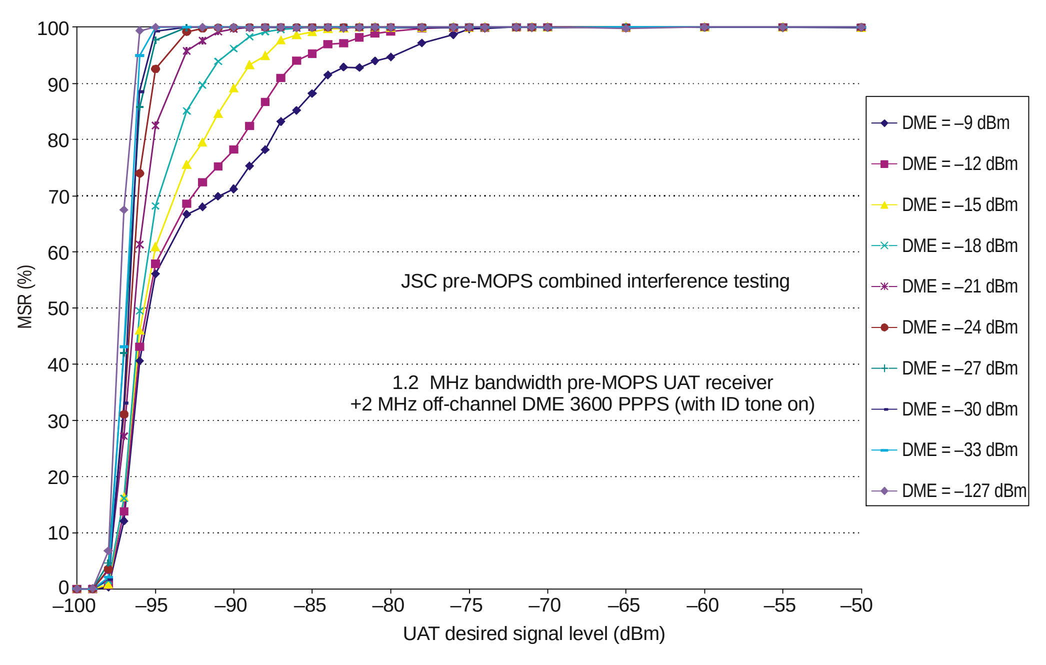

Figure II-C-6. UAT standard receiver performance DME 3 600 pulse pairs at +2 MHz

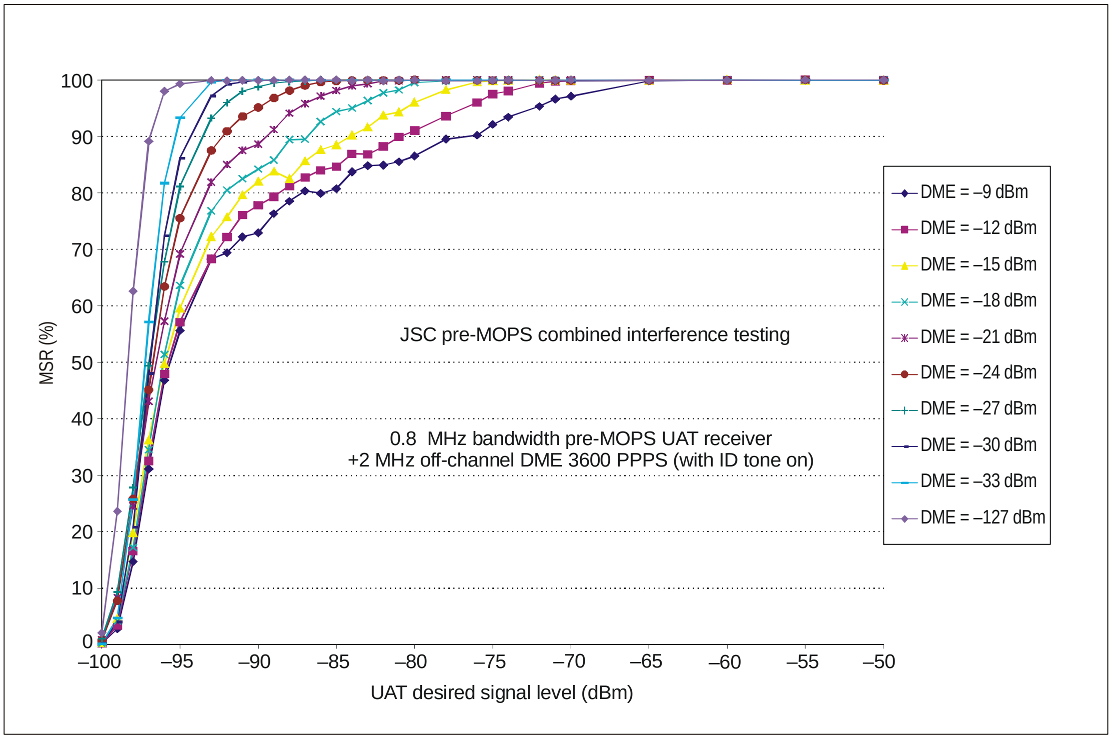

Figure II-C-7. UAT high-performance receiver DME 3 600 pulse pairs at +2 MHz

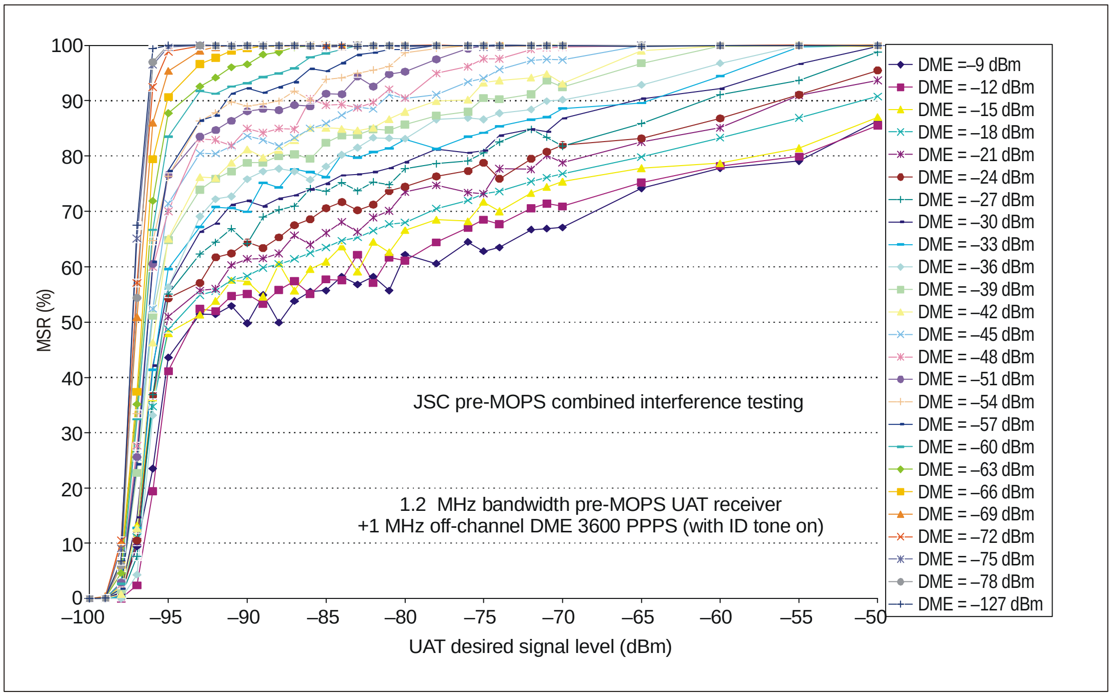

Figure II-C-8. UAT standard receiver performance DME 3 600 pulse pairs at +1 MHz

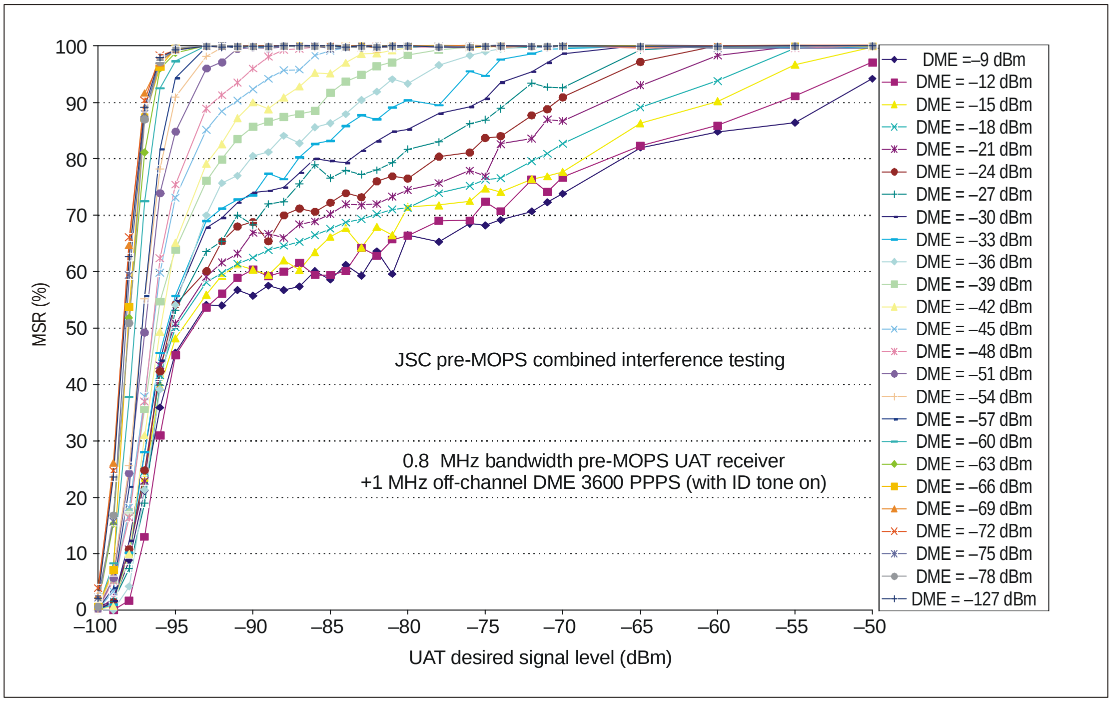

Figure II-C-9. UAT high-performance receiver DME 3 600 pulse pairs at +1 MHz

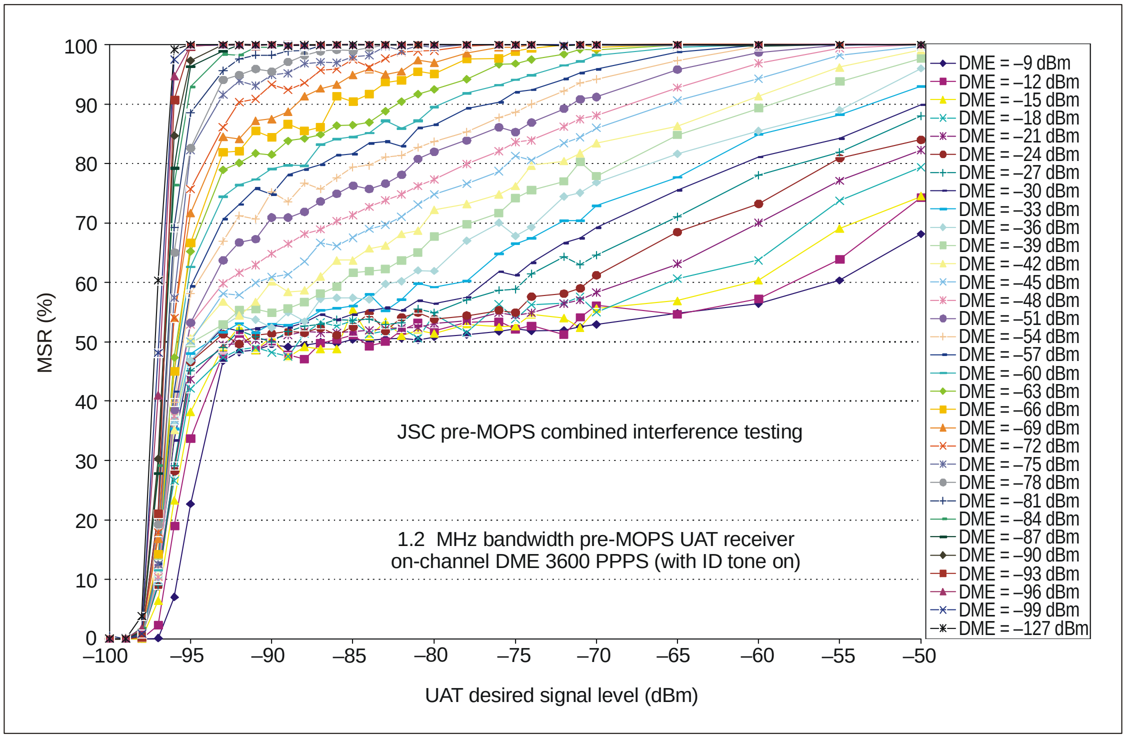

Figure II-C-10. UAT standard receiver performance DME 3 600 pulse pairs on frequency

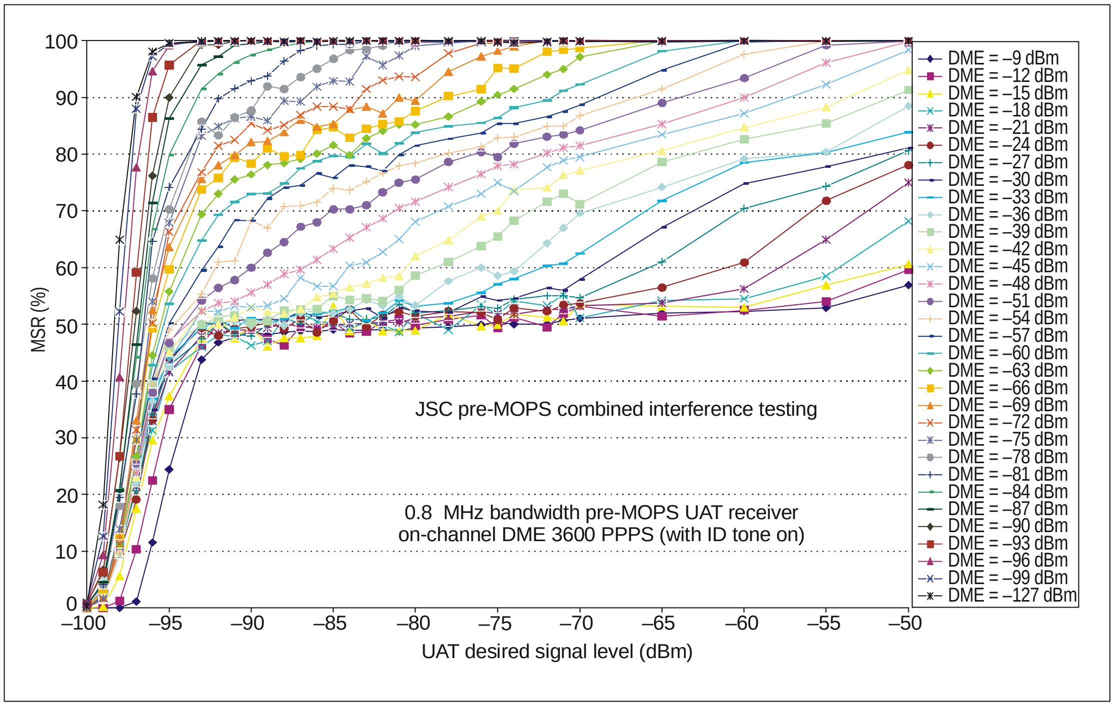

Figure II-C-11. UAT high-performance receiver DME 3 600 pulse pairs on frequency

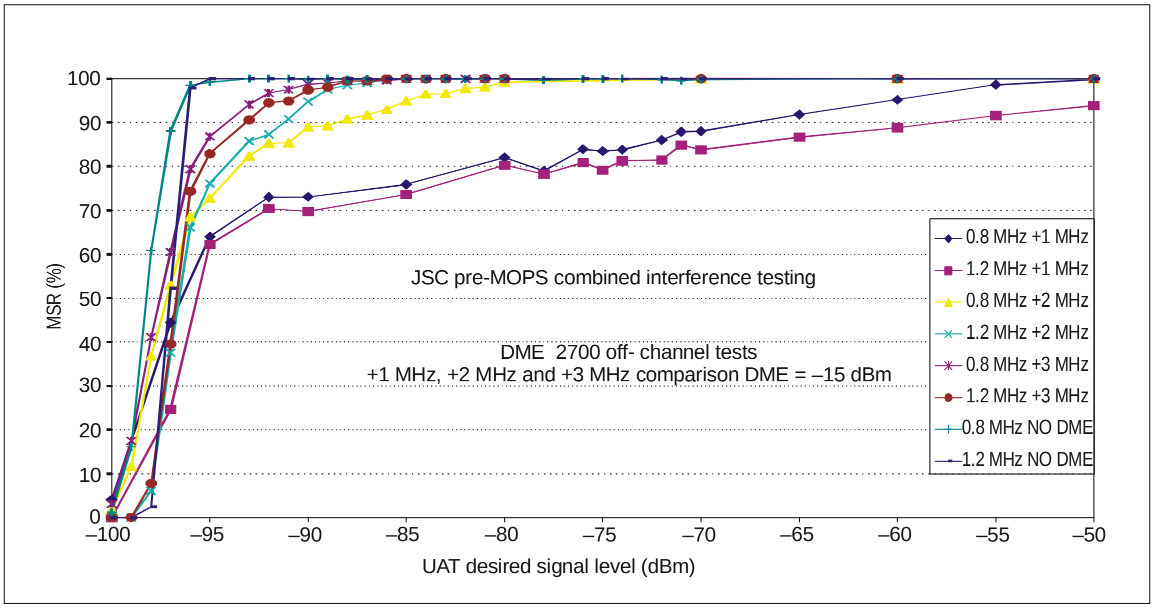

Figure II-C-12. UAT receiver performance DME 2 700 pulse pairs offset in frequency

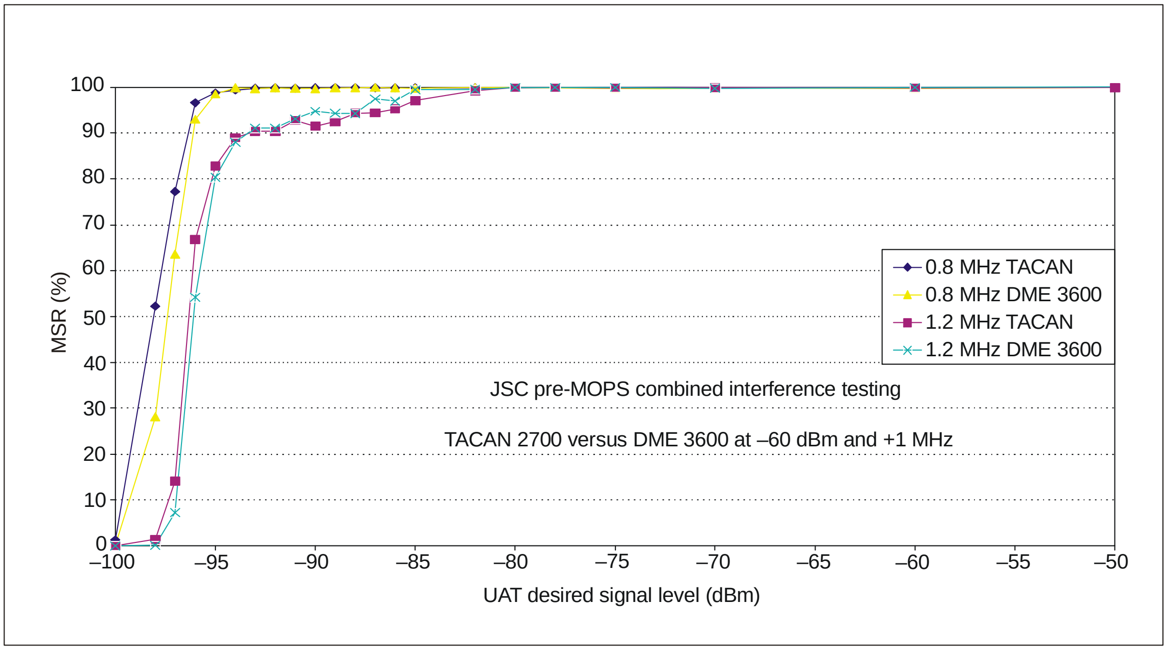

Figure II-C-13. UAT receiver performance TACAN 2 700 and DME 3 600 pulse pairs at +1 MHz

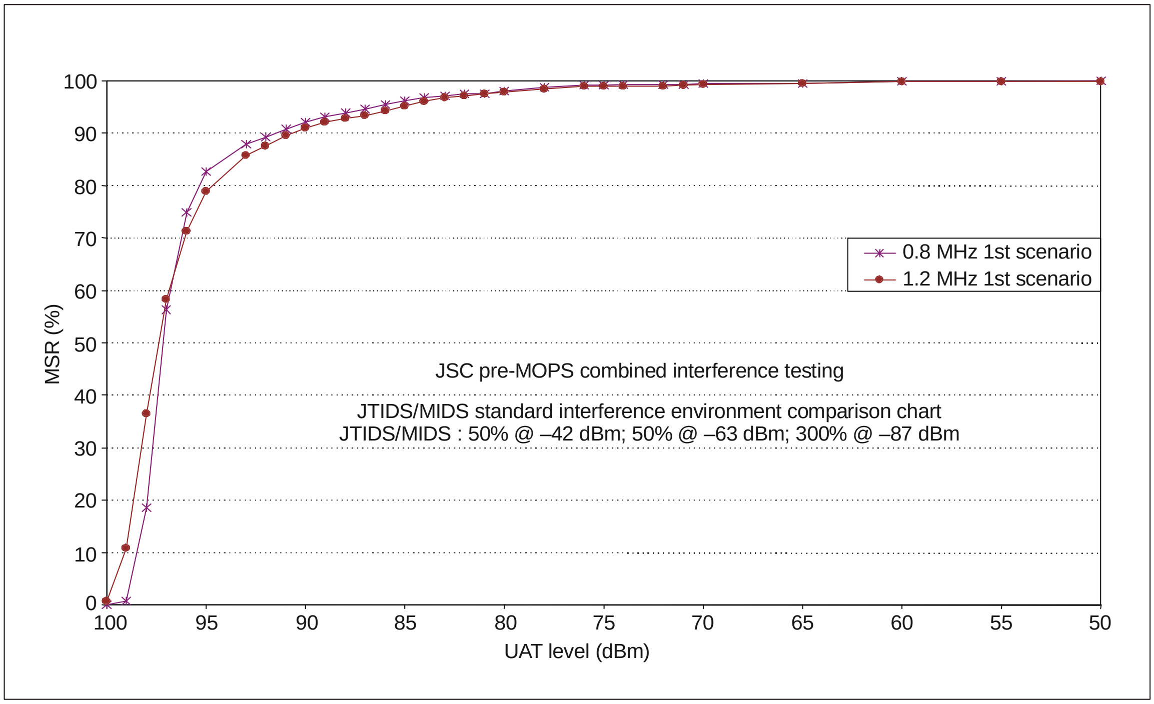

Figure II-C-14. UAT receiver performance with the first JTIDS/MIDS scenario

3. PRODUCTION TESTING

3.1 General

3.1.1 Testing was conducted on production UAT airborne avionics since units produced under United States Federal Aviation Administration (FAA) Technical Standard Order (TSO) C154, which conform to the UAT MOPS, RTCA/DO-282A, became available during the UAT SARPs validation phase. These units, the Garmin UAT Model GDL90, were certified as Class A1H type airborne transceivers. These units were bench-tested to verify requirements related to interference rejection including self-interference and DME/TACAN. Since these units were tested according to the test procedures stipulated in the RTCA UAT MOPS, DO-282A, TSO test results related to DME interference rejection were used to demonstrate compliance with the UAT SARPs of Annex 10, Volume III.

3.1.2 Also, the receiver was subjected to future high-density self-interference scenarios equivalent to those used to validate the pre-MOPS receiver units used during the development of the UAT MOPS. Therefore, comparison of the future high-density scenario test results from tests that were conducted on the pre-MOPS 1.2-MHz filter, the equivalent to the Class A1H standard receiver, can be made to validate the requirements of the UAT SARPs of Annex 10, Volume III. It would be expected that the production Class A1H standard receiver would result in acceptable performance when subjected to the future scenarios in which the UAT system will be operating. The self-interference performance measured on the production units would be expected to meet or exceed the performance of the pre-MOPS units. These test results are described in the following sections.

3.1.3 Although a certified production Class A3 transceiver was not available for production testing, production Class A1H units were modified with a narrow filter to conform to the receiver selectivity requirements of the Class A3 high-performance receiver. Although the unit was not modified to conform to either the Class A3 transmitter requirements or the antenna diversity requirements, it served as a testable unit that could validate Class A3 receiver performance. Results of testing with these units are described below.

3.2 DME/TACAN testing

Testing was conducted subjecting the production standard receiver to the DME/TACAN pulsed interference requirements stipulated in the UAT SARPs. DME interference on frequency at 978 MHz, first adjacent channel at 979-MHz and second adjacent channel at 980-MHz frequencies were selected to assess impact of on-channel DME interference, 1-MHz adjacent channel and 2-MHz off-channel DME signals.

3.3 UAT self-interference testing

3.3.1 UAT self-interference testing was conducted under the future high-density Core Europe 2015 scenario, the identical scenario used in the pre-production testing described in section 2.2. Results of self-interference testing with the Class A1H production units are plotted in Figure II-C-15. The plot includes the data from the standard receiver equivalent, the pre-MOPS 1.2-MHz receiver filter, to verify that the certified Class A1H receiver meets, or exceeds, the performance achieved from the pre-MOPS units. As shown in Figure II-C-15, performance of the Class A1H production unit comfortably exceeded the performance of the pre-MOPS unit.

3.3.2 Results of self-interference testing with the UAT SARPs Class A3 receiver, the certified production Class A1H receiver unit modified with the Class A3 high-performance receiver filter characteristics, are plotted in Figure II-C-16. The plot includes the data from the high-performance receiver equivalent, the pre-MOPS 0.8-MHz receiver filter, to verify that a UAT receiver meets, or exceeds, the performance achieved from the pre-MOPS units. As shown in Figure II-C-16, performance of the Class A3 unit comfortably exceeded the performance of the pre-MOPS unit.

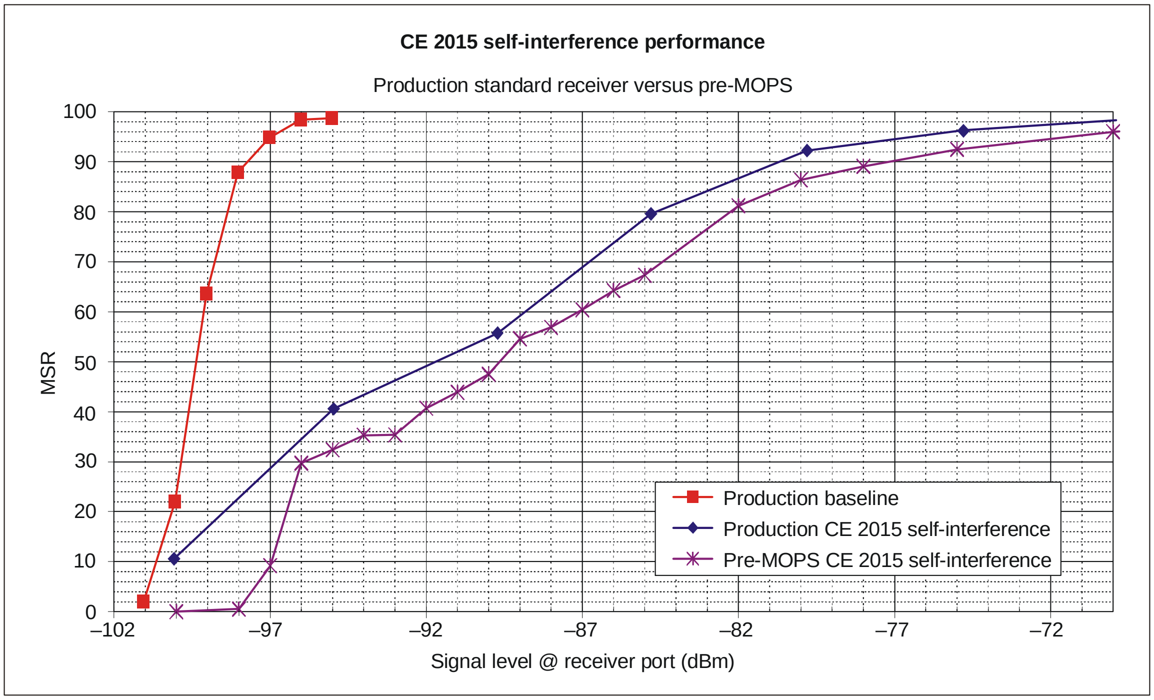

Figure II-C-15. UAT production standard receiver performance comparison with the Core Europe 2015 self-interference scenario

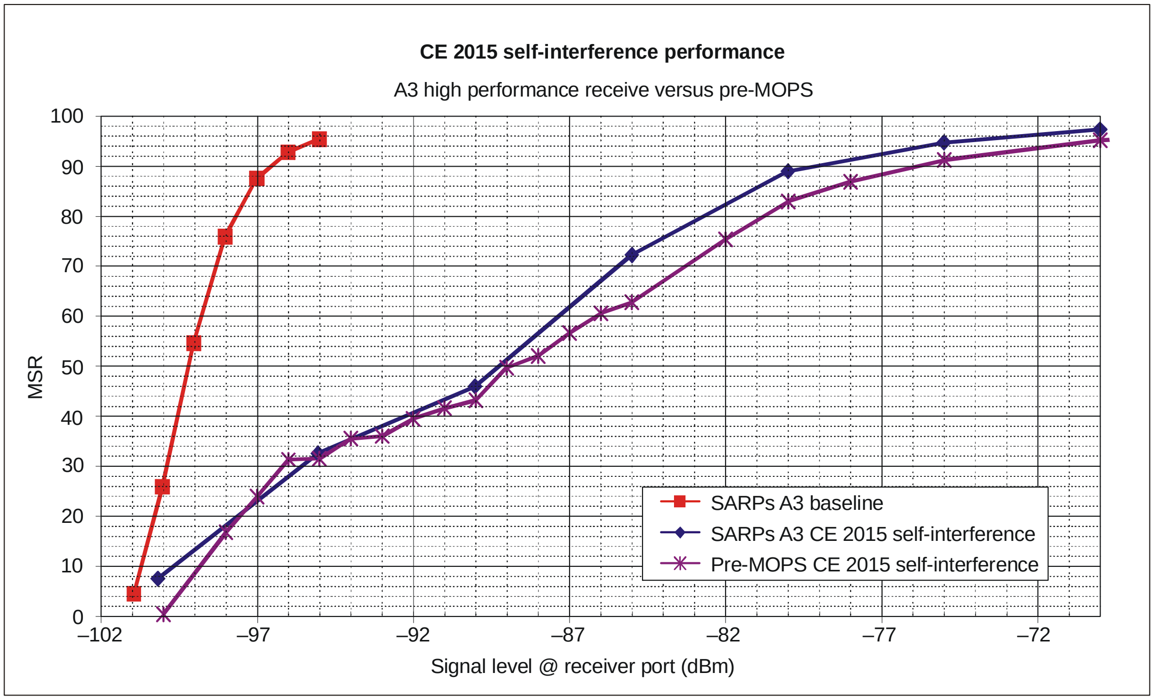

Figure II-C-16. UAT A3 receiver performance comparison with the Core Europe 2015 self-interference scenario

4. SUMMARY

The results of bench-tests conducted with prototype basic and high-performance UAT receivers, with the interference sources that UAT will be subjected to, verify that acceptable performance was achieved by the receiver design developed from the pre-MOPS testing. These characteristics, when implemented, as shown by the results of testing of the certified production Class A1H standard receiver, verify that when implementing the UAT SARPs requirements of Annex 10, Volume III, acceptable performance is achieved.

Appendix D

UAT ERROR DETECTION AND CORRECTION PERFORMANCE

1. This appendix provides information on the performance of the Reed Solomon (RS) codes used by the various message types of UAT. The basic UAT ADS-B message is an RS (30, 18) code word; the long UAT ADS-B message is an RS (48, 34) code word; and the UAT ground uplink message is six RS (92, 72) code words. These codes provide very strong error correction. Also, the error detection provided by these codes is sufficient to provide a maximum undetected error rate that is less than 10^{-8} for each of the message types, so additional CRC coding is not needed. Note that this excellent undetected error performance is due, in part, to the use of hard decision decoding. Schemes involving erasures might have considerably larger (i.e. degraded) undetected error rates.

2. The total word error rate for an RS (n, k) code is given by the formula:

$$P_E = \sum\nolimits_{j=t+1}^{n} \tfrac{n!}{j!(n-j)!}\, p_S \quad {}^{j}(1-p_S)^{n-j},$$

where t=(n – k)/2 and is the symbol error rate (SER). P_E includes both undetected and detected word error probabilities. Because there are 8 bits per symbol, the connection between the SER and the channel bit error rate (BER) is given by:

$$p_S = 1 - (1-p)^8$$

where p is the channel BER.

3. The asymptotic value for the undetected word error rate (achieved when the channel bit error rate is 0.5) for an RS (n, k) code can be calculated using the formula:

$$P_U = \frac{256^k - 1}{256^n} \sum_{j=0}^{t} \frac{n!}{j!\,(n-j)!}\ 255^j$$

where t=(n – k)/2. The results are given in Table II-D-1.

Table II-D-1. Maximum undetected RS word error rates

Code	*Maximum undetected word error rate*
RS (30, 18)	2.06E–9
RS (48, 34)	9.95E–10
RS (92, 72)	5.74E–12

4. The undetected error performance of an RS code as a function of channel bit error rate can also be calculated, but the mathematical complexity is much greater[1]. The results are shown in Figures II-D-1 through II-D-3. These graphs show total word error rate together with undetected word error rate. The detected word error rate, P_D, is just the difference between the two curves. If the correct word error rate is defined as P_C, then all the probabilities are related by:

$$1 = P_E + P_C = P_U + P_D + P_C.$$

5. Note that for the UAT ADS-B messages, the word error rate is equal to the message error rate because there is one word per message. This is not true for the UAT ground uplink message. Figure II-D-3 shows the performance of a single RS (92, 72) word. The performance of an entire message, consisting of six words, is given by:

$$P_{UBurst} = (1 - P_E + P_U)^6 - (1 - P_E)^6 = (P_C + P_U)^6 - P_C{}^6$$

and

$$P_{EBurst} = 1 - (1 - P_E)^6 = 1 - P_C{}^6.$$

6. Again, P_E is the total word error rate, and P_U is the undetected word error rate. A graph of the undetected message error rate versus the channel BER is shown in Figure II-D-4, which indicates that the maximum undetected error rate is about 1.3E–12, which occurs when the channel BER is about 0.012. To see why there is a maximum, consider the following approximation:

$$P_{UBurst} \approx 6P_U(1 - P_E)^5.$$

The P_U term is small at low BER and the $\left(1-P_E\right)^5$ term is small at high BER (because P_E is nearly 1 in that case). For completeness, a graph of the total uplink message error rate versus channel BER is also provided in Figure II-D-5.

7. Up to this point the discussion has dealt with the performance of the RS codes in the presence of noise that generates random bit errors. However, in addition to protecting against errors created by stationary and non-stationary interference (see Appendix A), the RS codes are also used as the sole means to differentiate between long and basic UAT ADS-B messages. It is of interest to investigate the performance of this identification process. In order to analyse this issue, it is useful to have a clear picture of the ADS-B reception process as defined in this document. The logical flow of the process is as shown in Figure II-D-6.

8. After each successful detection of an ADS-B synchronization pattern, the receiver will first check if the RS (48, 34) decoding process is successful. If so, the receiver will determine that a long UAT ADS-B message was actually sent. However, if this decoding process fails, the receiver will check if the RS (30, 18) decoding process is successful. If it is, the message is a candidate basic UAT ADS-B message. As a final safeguard, the receiver will check if the 5 bits of the MESSAGE DATA BLOCK TYPE CODE field are all zeros. If this test is successful, the receiver will determine that a basic UAT ADS-B message was actually sent. If the MESSAGE DATA BLOCK TYPE CODE test fails or if the RS (30, 18) decoding process fails, the entire message is discarded. (Note that this is a logical flow only. It is possible, for example, for the two RS decodes to be done in any time order.)

9. For this investigation there are two possible failure modes of interest. First, an actual basic UAT ADS-B message could be perceived as a long UAT ADS-B message. Second, a long UAT ADS-B message could be perceived as a basic UAT ADS-B message. These two will be discussed separately.

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[1] Kasami, T., and S. Lin, 1984, *On the Probability of Undetected Error for Maximum Distance Separable Codes*, IEEE Trans. Comm., COM-32, 998–1006.

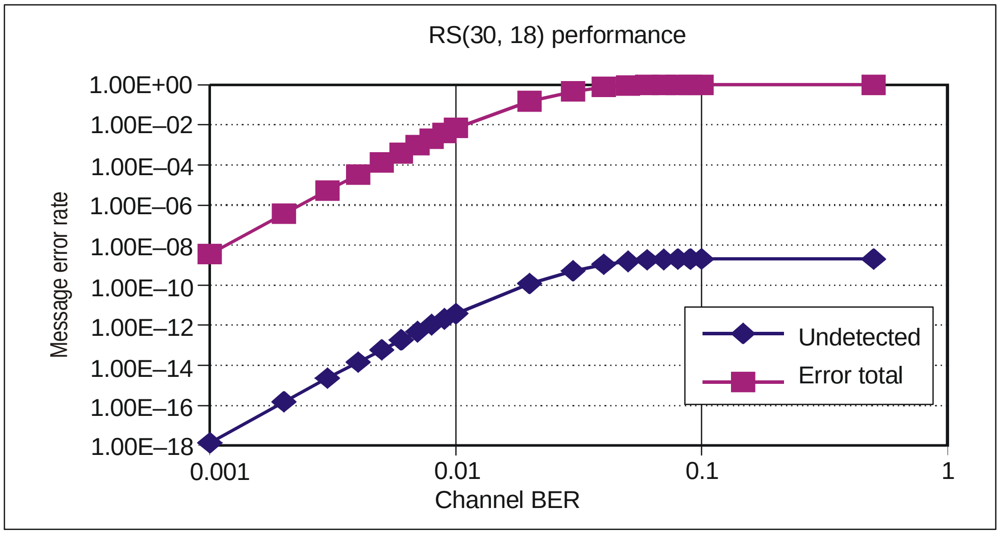


Figure II-D-1. Basic UAT ADS-B message performance
(“Undetected” = P_U; “Error total” = P_E)

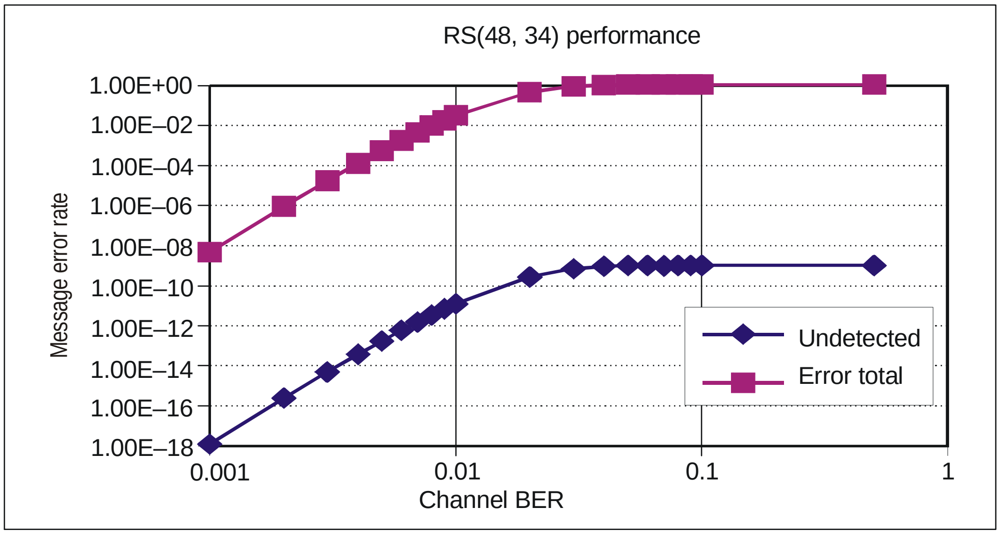


Figure II-D-2. Long UAT ADS-B message performance
(“Undetected” = P_U; “Error total” = P_E)

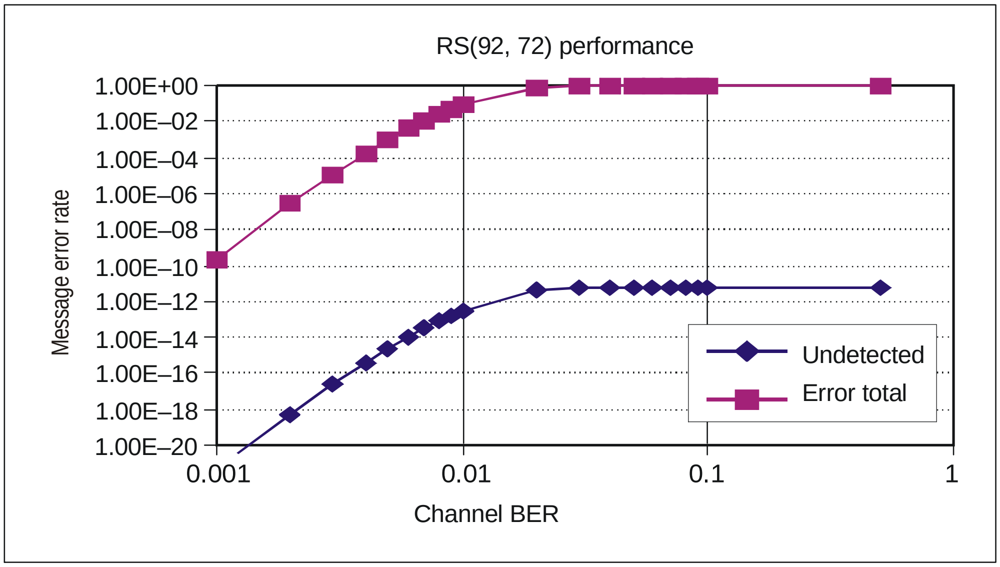


Figure II-D-3. UAT ground uplink message performance
(“Undetected” = P_U; “Error total” = P_E)

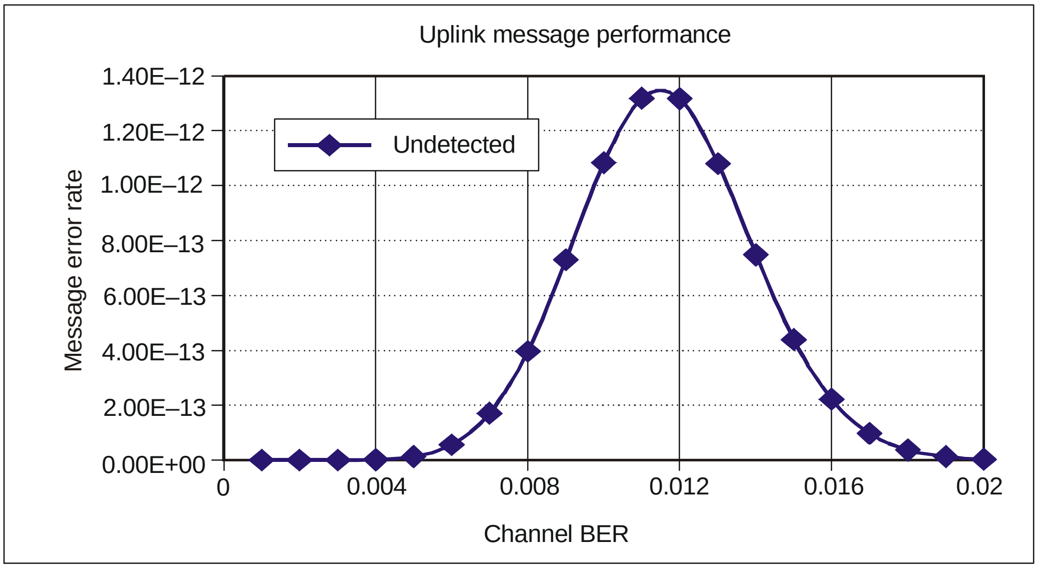


Figure II-D-4. UAT ground uplink message undetected message error rate
(“Undetected” = P_{UBurst})

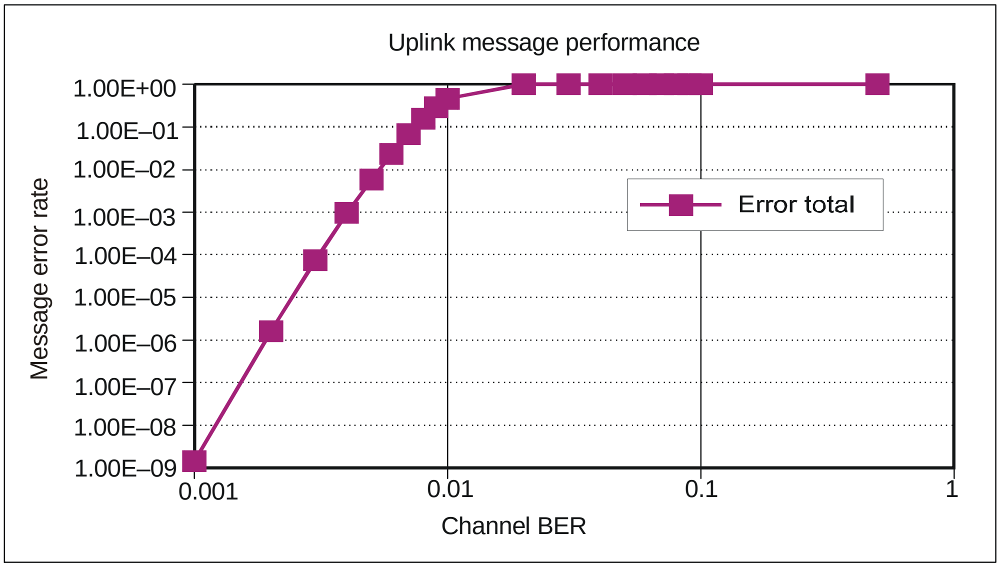


Figure II-D-5. UAT ground uplink message total message error rate
(“Error total” = P_{EBurst})

10. When a basic UAT ADS-B message is received, it is first subjected to the RS (48, 34) decoding process. The input to the decoder will be the 30 bytes of the basic UAT ADS-B message (assumed to have no bit errors) plus 18 bytes of random data. Because the random part of the input to the decoder includes the entire parity check sequence, the probability of a successful decode is the same as the maximum undetected error rate reported in Table II-D-1, i.e. 9.95 x 10^{-10}. Thus, there is about one chance in one billion that a particular basic message will appear to be a long UAT ADS-B message.

11. Note that in the case above, an RS (30, 18) decoding attempt would have been successful if carried out, since there are assumed to be no bit errors. However, the decoding rules give precedence to a successful long UAT ADS-B decision.

12. When a long UAT ADS-B message is received, it also is subjected initially to the RS (48, 34) decoding process. If there are no bit errors, then the decoding will succeed, and the message will correctly be determined to be a long UAT ADS-B message. However, the process will not succeed if there are more than 7 incorrect bytes. In that case the decoder may produce (with probability no greater than 9.95 x 10^{-10}) an undetected error, i.e. it will produce a long UAT ADS-B message different from the one that was sent. It is far more likely that the decoder will fail to produce any result, and the RS (30,18) decoding process will be attempted next.

13. From the point of view of the RS (30, 18) decoder, the first 30 bytes of the long UAT ADS-B message are equivalent to a random sequence of 240 bits, except that the first five bits (the location of the MESSAGE DATA BLOCK TYPE CODE field) are not 00000. Thus, the decoding process must change the first byte to include 00000 in order to succeed. The probability of this occurring is given by the following equation:

$$p = \frac{8}{256^{12}} \cdot \sum_{k=0}^{5} \binom{29}{k} 255^k = 1.29 \times 10^{-11}.$$

Checking for the correct MESSAGE DATA BLOCK TYPE CODE lowers the false decode probability from 2.06 × 10^{-9} to 1.29 × 10^{-11}.

14. During the development of UAT there was some concern that there might be an abnormally high probability of misinterpreting a long UAT ADS-B message as a basic UAT ADS-B message if there were a preponderance of zeros (0) in the message data block. This might happen if many of the fields were "stuffed" with zeros due to the unavailability of data. Since "all-zeros" is a valid RS code word and the RS (30, 18) code can correct up to 6 erroneous bytes, the first 30 bytes of a long UAT ADS-B message will "successfully" decode to the all-zero basic UAT ADS-B message whenever 6 or less of the 30 bytes are non-zero. Because the RS (48, 34) decoding process has precedence, this scenario requires that the long decoding process must fail and the basic decoding process must succeed. Normally, a BER high enough to cause the RS (48, 34) decoding process to fail would turn enough of the zero bytes into non-zero bytes so that the RS (30, 18) decoding process would also fail. However, it is possible that interference (e.g. another UAT ADS-B message) could overlap only the tail end of a long UAT ADS-B message, leaving the first 30 bytes essentially intact. It is difficult to assess the likelihood that such a situation would arise since it depends on the number of potential interference sources and their relative signal strengths.

15. Whatever their probability might be, if the conditions described in the previous paragraph should prevail, the decoding process will incorrectly result in an all-zero basic UAT ADS-B message. This decoded message will pass the MESSAGE DATA BLOCK TYPE CODE test; however, this should not generate an operational problem because such a message will necessarily contain the all-zero ICAO address, which is invalid. Thus, in order to cope with this (very unlikely) situation, any application that uses a decoded UAT ADS-B message could check the validity of the ICAO address before processing the remainder of the information.

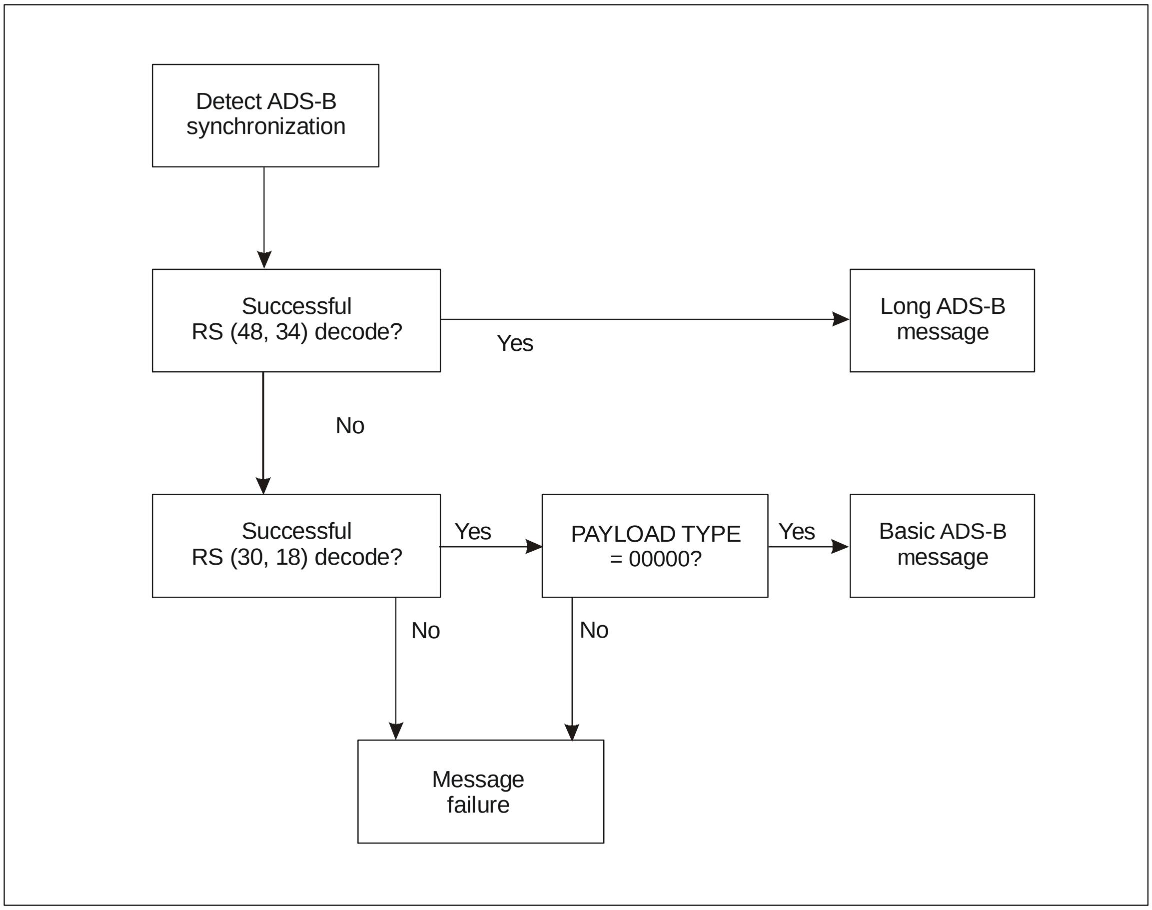


Figure II-D-6. Logical flow of ADS-B reception

16. As a final note it should be pointed out that the receiver could, as an option, check the MESSAGE DATA BLOCK TYPE CODE field of candidate long ADS-B messages as well as of candidate basic UAT ADS-B messages. Checking that the MESSAGE DATA BLOCK TYPE CODE field is not 00000 will lower very slightly (by a factor of 31/32) the probability of undetected error in the presence of random bit errors. It will also lower the probability of interpreting a basic UAT ADS-B message as a long UAT ADS-B message by a factor of about 7; this probability is given by the following formula:

$$p = \frac{248}{256^{14}} \cdot \sum_{k=0}^{6} \binom{47}{k} 255^k = 1.41 \times 10^{-10}.$$

This check is not a requirement since the improvement it provides is rather modest.

17. The information contained in this appendix is summarized in Table II-D-2. The numbers presented are upper limits on the likelihood of potential UAT ADS-B messages being misinterpreted. The first two rows assume that the input bit stream is corrupted by strong interference, and the entries are upper bounds on the probabilities of interpreting a long (basic) UAT ADS-B message as an incorrect long (basic) UAT ADS-B message. The other rows provide upper limits on the probabilities of incorrectly interchanging long and basic. The shaded cells represent the results obtained by using the optional check of the MESSAGE DATA BLOCK TYPE CODE field for long UAT ADS-B message candidates. Table II-D-2 does not address the likelihood of a successful synchronization being followed by a very high BER for all or part of the remaining message; the probability of encountering the interference conditions necessary for misinterpreting message length is certainly much less than 1.

Table II-D-2. Upper bounds on undetected message error probabilities

Transmission	*Perceived reception*	*Raw probability of undetected error*	*Probability with MESSAGE DATA BLOCK TYPE CODE check*
Long	Long	9.95E–10	9.64E–10
Basic	Basic	2.06E–9	6.45E–11
Basic	Long	9.95E–10	1.41E–10
Long	Basic	2.06E–9	1.29E–11

Appendix E

DME OPERATION IN THE PRESENCE OF UAT SIGNALS

1. This appendix provides a summary of testing and analysis that verifies UAT compatibility with distance measuring equipment (DME) and that DME equipment will operate without degradation in the presence of UAT signals.

2. The goal of the DME testing, conducted as a part of the UAT MOPS development, was to verify that UAT signals do not interfere with the proper operation of DMEs, which operate in the band in which UAT will operate. The focus of the bench-testing herein was to conduct tests on DME units that were representative of the vast majority of the DMEs used in the different categories of aviation equipage. However, due to the large number of different manufacturers and types of DMEs, it was unrealistic to test all of the possible DMEs in the system. Four DME units were selected based on availability and representing the different categories of avionics instrumentation. The specific models used in the testing were:

a) Bendix King KD-7000;

b) Narco DME-890;

c) Rockwell-Collins DME-900; and

d) Honeywell 706-A.

The latter two were selected to represent units currently in use in the European Union.

3. The first phase of testing was to determine the impact of overlapping UAT signals onto the DME pulse pairs. The test configuration consisted of a victim DME interrogator connected to a DME ground station simulator and a UAT message source generating long ADS-B UAT messages. The DME ground station simulator received interrogations from the DME unit under test and transmitted replies as well as unsolicited pulse pairs to closely match the operation of an actual ground simulator. Since the selected frequency for UAT does not reside in the interrogation frequency band, the testing was configured with a clear interrogation channel. This assumption is consistent with standard DME interrogator test procedures, and any interference on the interrogator channel would be manifested in the system as a reduction in transponder reply efficiency. The UAT frequency was tested co-channel with the DME reply frequency, and testing was also conducted with DMEs located on adjacent DME channels. On the reply channel, every reply was completely overlapped with the same level of UAT interference. This is much more severe than any real-world interference environment, but is appropriate for the purposes of the bench-testing where performance under extreme conditions provides the data required to model real-world scenario performance. A data point consists of measuring both the interfering signal level that prohibits the DME to acquire a track (acquire stable operating point (ASOP)) and the level that causes the DME to lose a track that it has already acquired (break stable operating point (BSOP)). In general, it was found that these two levels were separated by approximately 1 dB.

4. One especially informative measurement was taken where ASOP and BSOP were determined as a function of the reply efficiency of the ground station. The simulator utilized in the test configuration had the capability to randomly reply to 0 to 100 per cent of the interrogations it received. The measurements showed that the DME interrogator could acquire and track in the presence of the same level of UAT interference as long as at least 30 per cent of its interrogations elicit replies. Each DME model tested could tolerate relatively high-amplitude UAT interference, although each unit tolerated a slightly different level of interference. This seems to indicate that as long as a DME is able to

receive more than 30 per cent of the replies from its interrogations with interference less than the ASOP/BSOP point particular to that DME unit, it will operate. It is important to note that although this was a consistent characteristic of the four DME units tested, this may not be true of all DME units operating in the system. However, given the significant margin with respect to the 70 per cent reply efficiency monitor limit, there is enough of a margin to have the confidence to apply these results to operational DMEs in the system.

5. The results of the bench-test conducted are depicted in the following figures. Figure II-E-1 summarizes the data results of co-channel and adjacent channel DME operation of the Bendix King KD-7000 DME. The DME levels utilized were –68 dBm and –83 dBm and reply efficiency was set at 100 per cent.

6. Figure II-E-2 depicts the performance of the Bendix King KD-7000 DME as a function of reply efficiency. DME levels of –68 dBm and –83 dBm were utilized and these signals were co-channel. This plot shows the consistent behaviour of the DME as a function of reply efficiency above 30 per cent. Figure II-E-3 depicts the performance of the Bendix King when subjected to CW with a DME level of –83 dBm. The results are very similar to the UAT signal interference results as a function of frequency offset.

7. Figure II-E-4 summarizes the data results of co-channel and adjacent channel DME operation of the Narco DME-890. The DME levels utilized were –60 dBm and –75 dBm. These amplitude levels were chosen to allow comparison with the other DME units at comparable levels above sensitivity. The Narco DME-890 had the least sensitive receiver of the four units that were measured at –81 dBm.

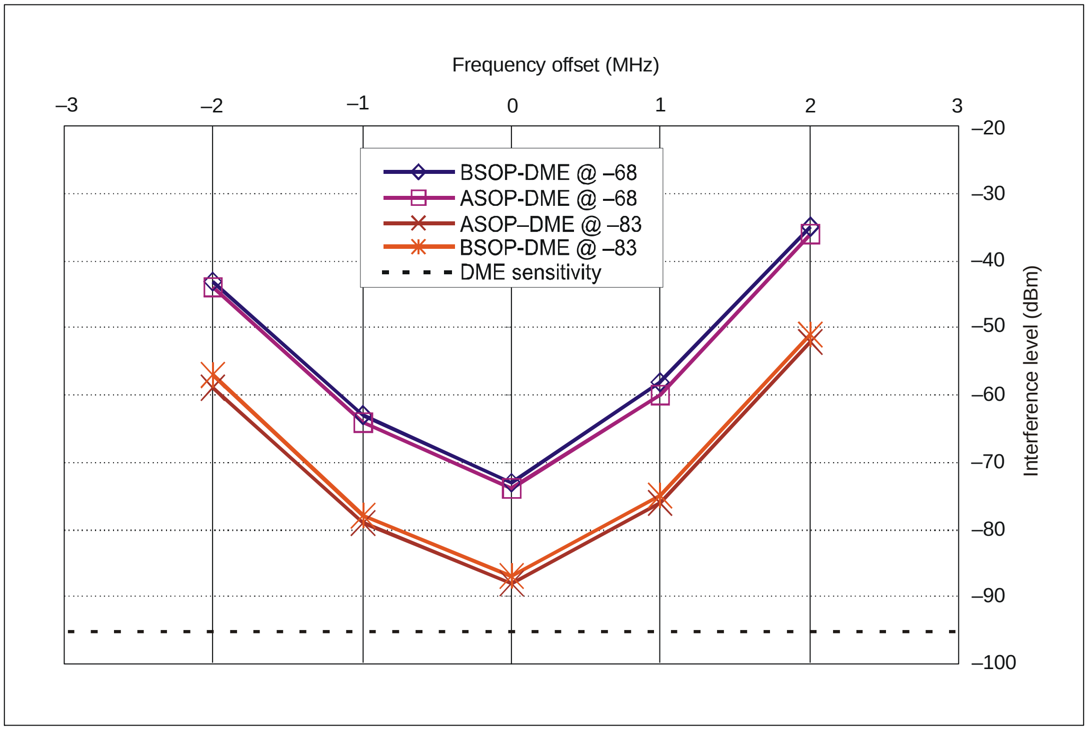


Figure II-E-1. Bendix King KD-7000 frequency offset test

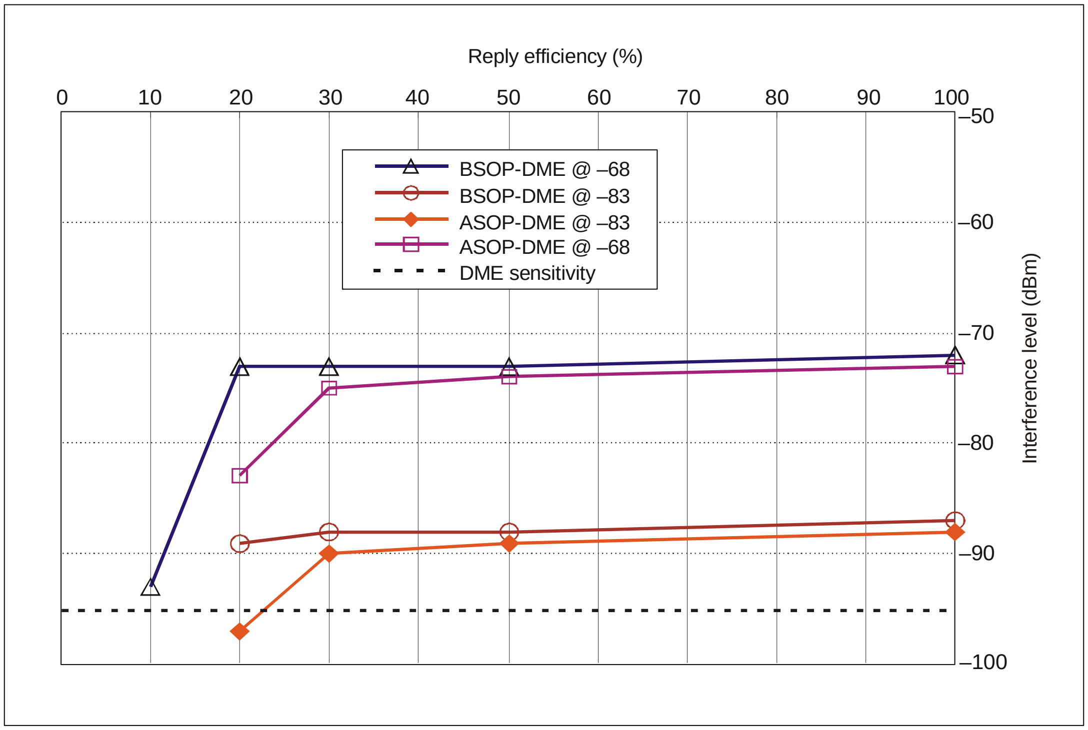


Figure II-E-2. Bendix King KD-7000 reply efficiency test

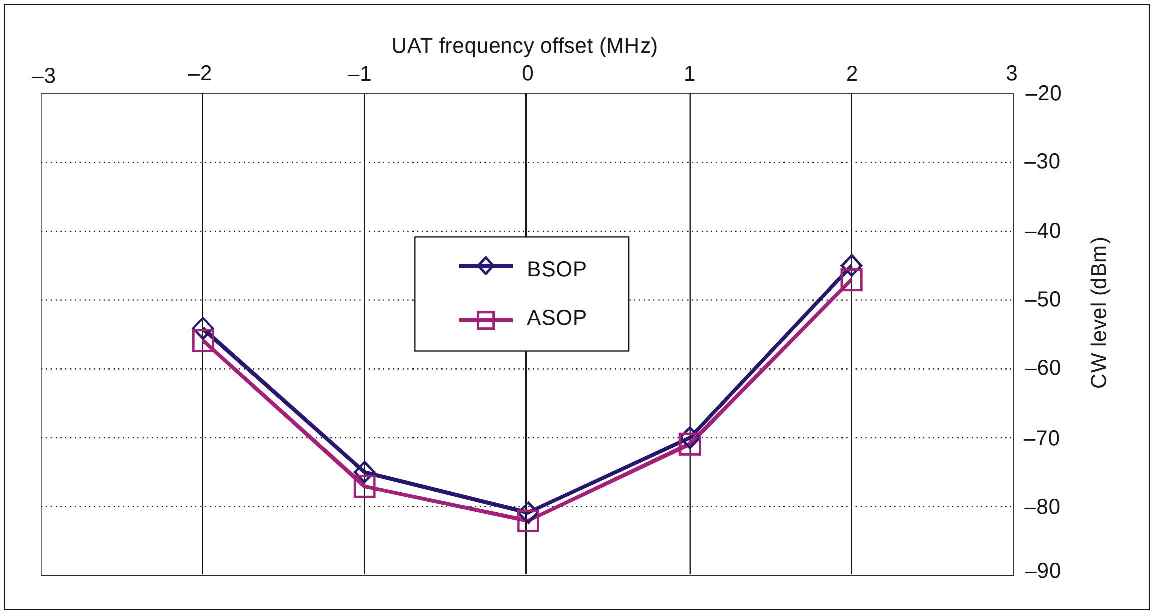


Figure II-E-3. Bendix King KD-7000 CW testing: DME level –83 dBm

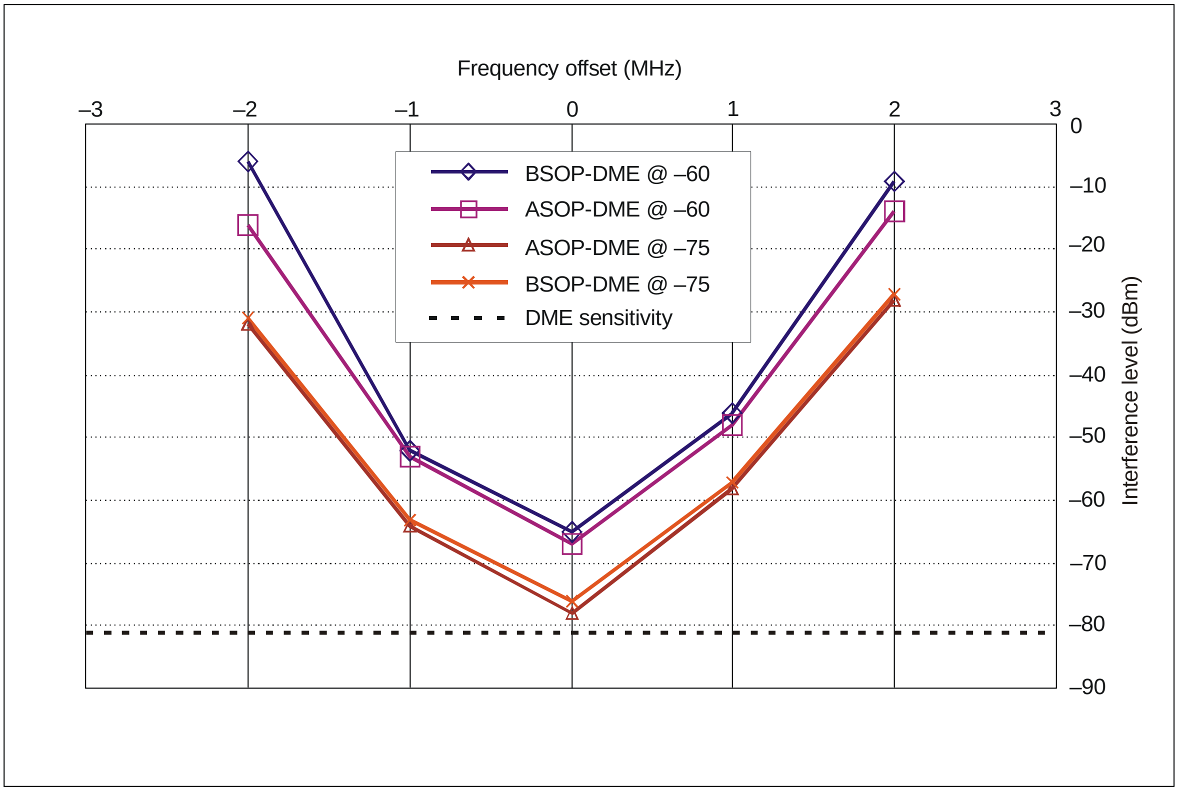


Figure II-E-4. Narco DME-890 frequency offset test

8. Figure II-E-5 depicts the performance of the Narco DME-890 as a function of reply efficiency. DME levels of –60 dBm and –75 dBm were utilized and these signals were co-channel. As also seen in the behaviour of Bendix King KD-7000, the performance is consistent as a function of reply efficiency above 30 per cent. Figure II-E-6 depicts the performance of the Narco DME-890 when subjected to CW with a DME level of –75 dBm.

9. Figure II-E-7 summarizes the data results of co-channel and adjacent channel DME operation of the Honeywell KDM-706A DME. The DME levels utilized were –68 dBm and –83 dBm and reply efficiency was set at 100 per cent. Figure II-E-8 depicts the performance of the Honeywell KDM-706A DME as a function of reply efficiency. DME levels of –68 dBm and –83 dBm were utilized and these signals were co-channel.

10. Figure II-E-9 depicts the performance of the Honeywell KDM-706A DME when subjected to CW with a DME level of –83 dBm. As with the previous DME units, the results are very similar to the UAT signal interference results as a function of frequency offset. Figures II-E-10 through II-E-12 summarize the data results of the Rockwell-Collins DME-900.

11. The comparisons of all four DME units tested are depicted in the following figures. Figure II-E-13 summarizes the data results of co-channel and adjacent channel DME operation of the four DMEs. Figure II-E-14 depicts the performance of the four DMEs as a function of reply efficiency. Figure II-E-15 depicts the performance of all four DMEs when subjected to CW. As can be seen by the co-channel results in Figures II-E-13 and II-E-15, the KDM-706A had the worst signal to interference rejection.

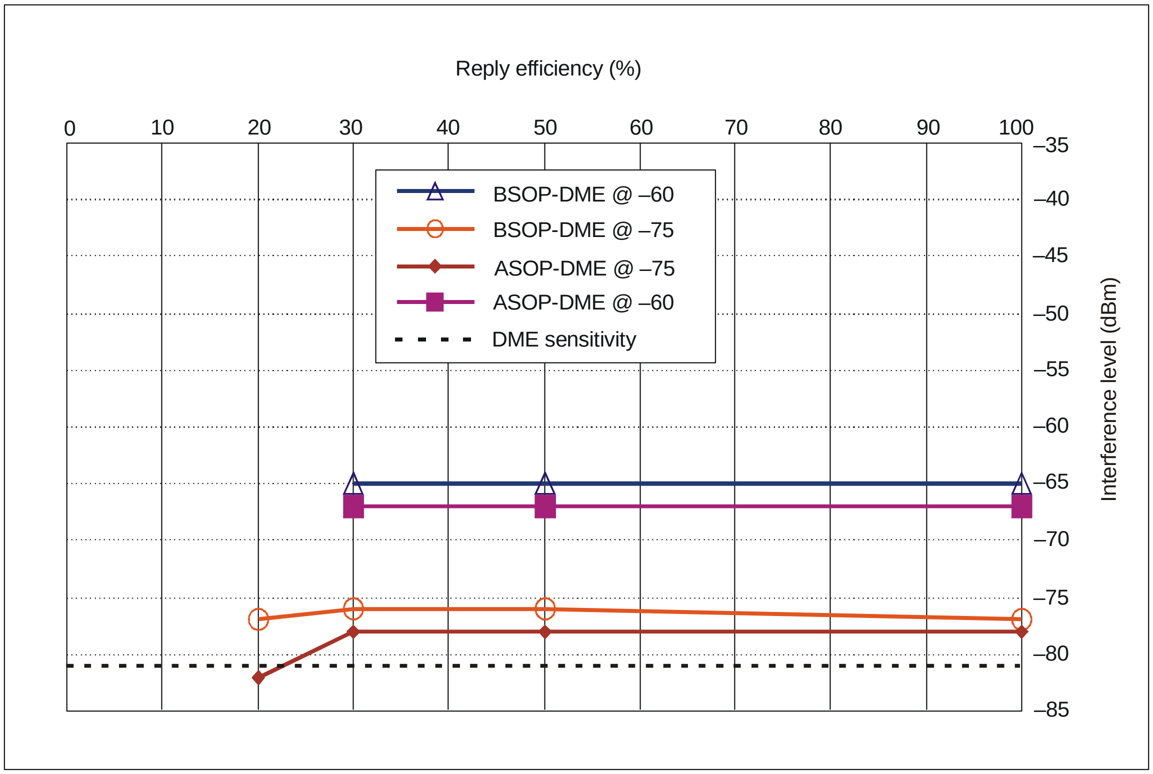


Figure II-E-5. Narco DME-890 reply efficiency test

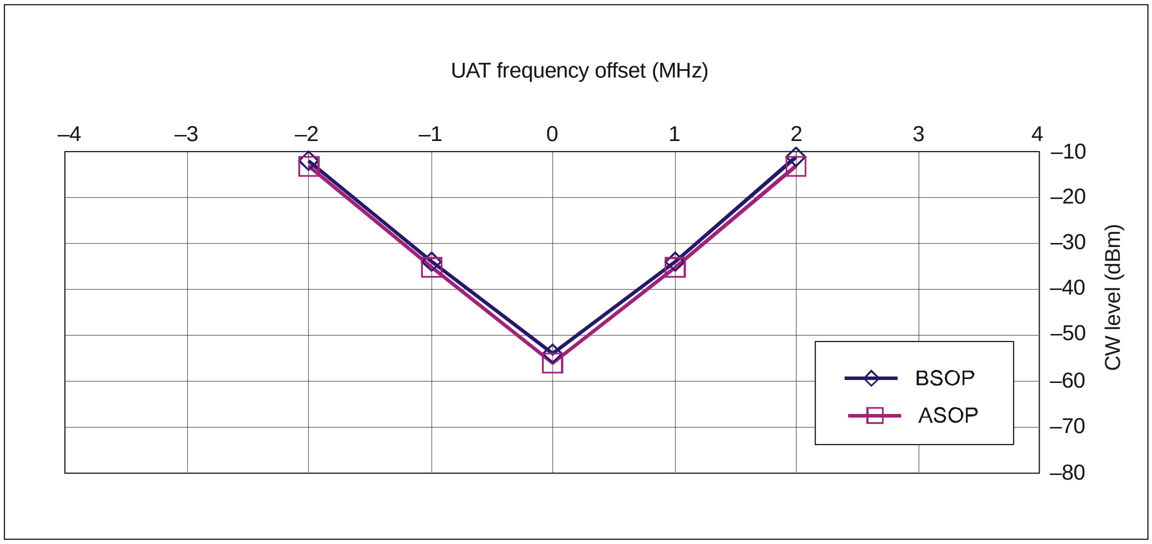


Figure II-E-6. Narco DME-890 CW testing: DME level –75 dBm

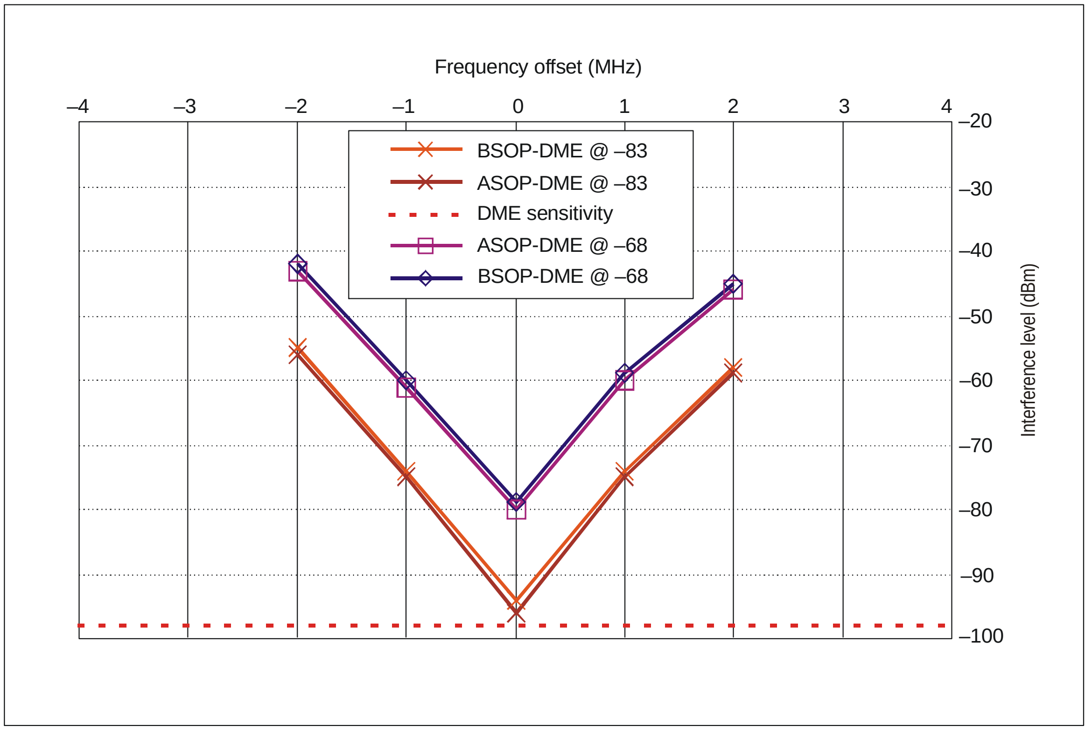


Figure II-E-7. Honeywell KDM-706A frequency offset test

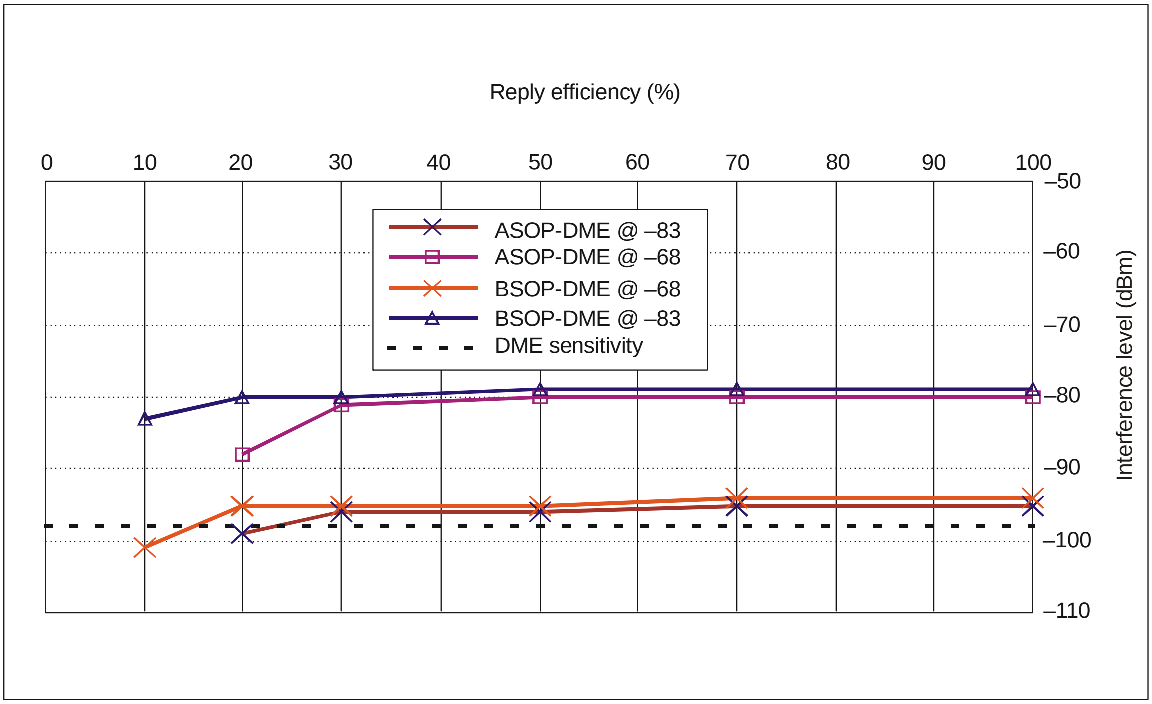


Figure II-E-8. Honeywell KDM-706A reply efficiency test

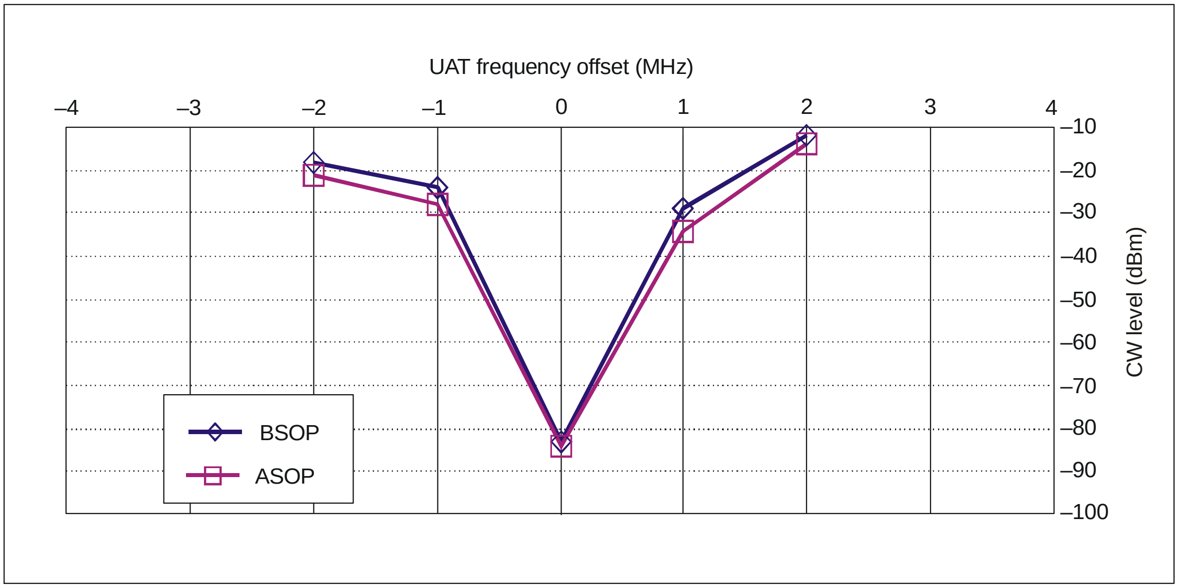


Figure II-E-9. Honeywell KDM-706A CW testing: DME level –83 dBm

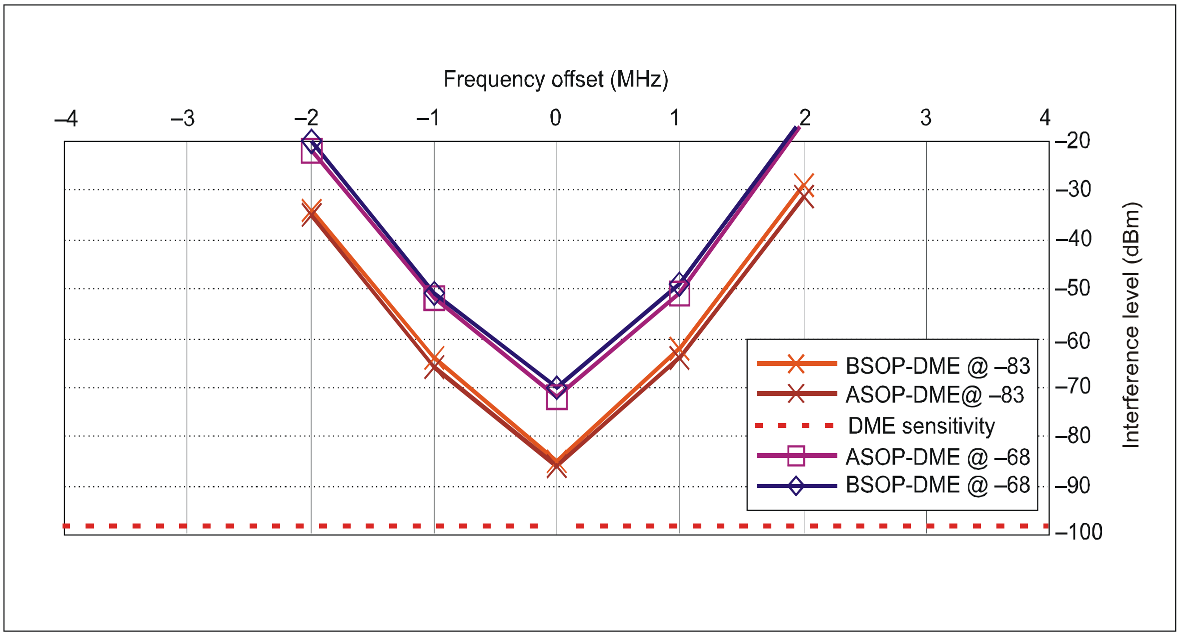


Figure II-E-10. Rockwell-Collins DME-900 frequency offset test

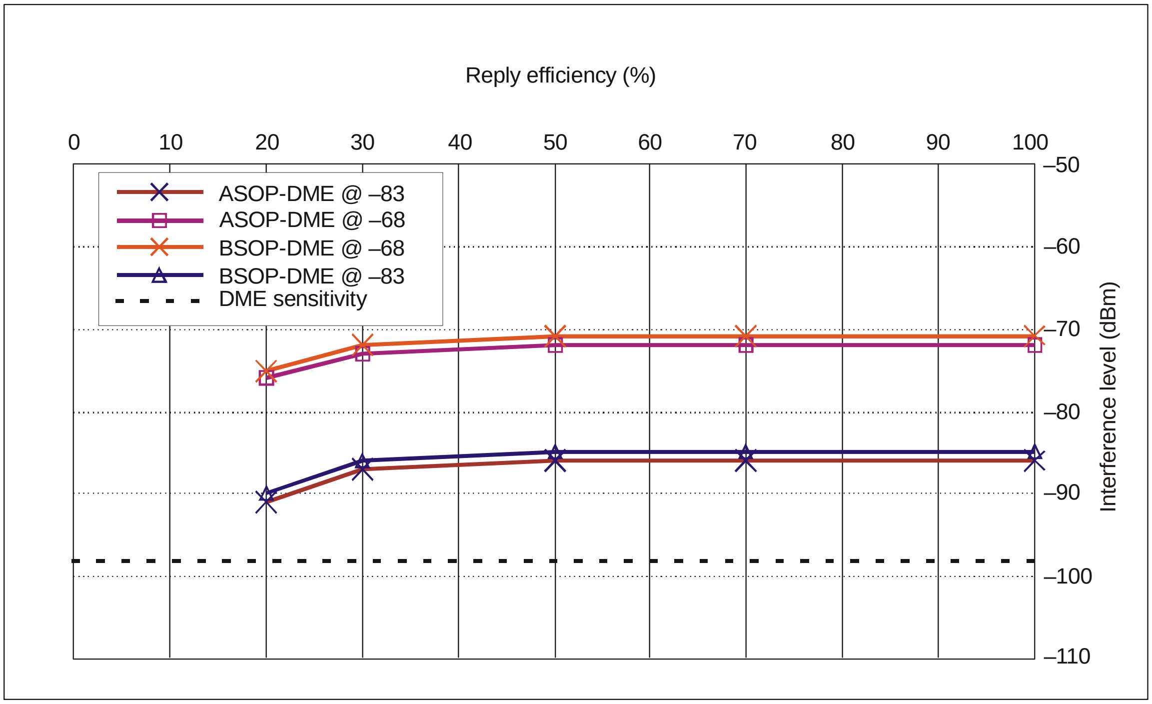


Figure II-E-11. Rockwell-Collins DME-900 reply efficiency test

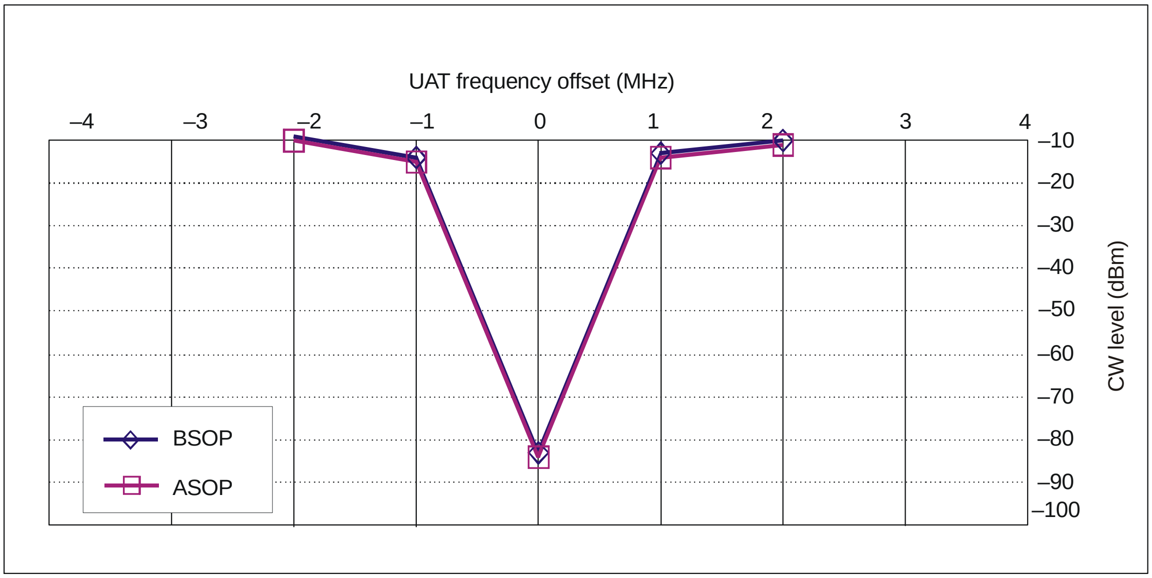


Figure II-E-12. Rockwell-Collins DME-900 CW testing: DME level –83 dBm

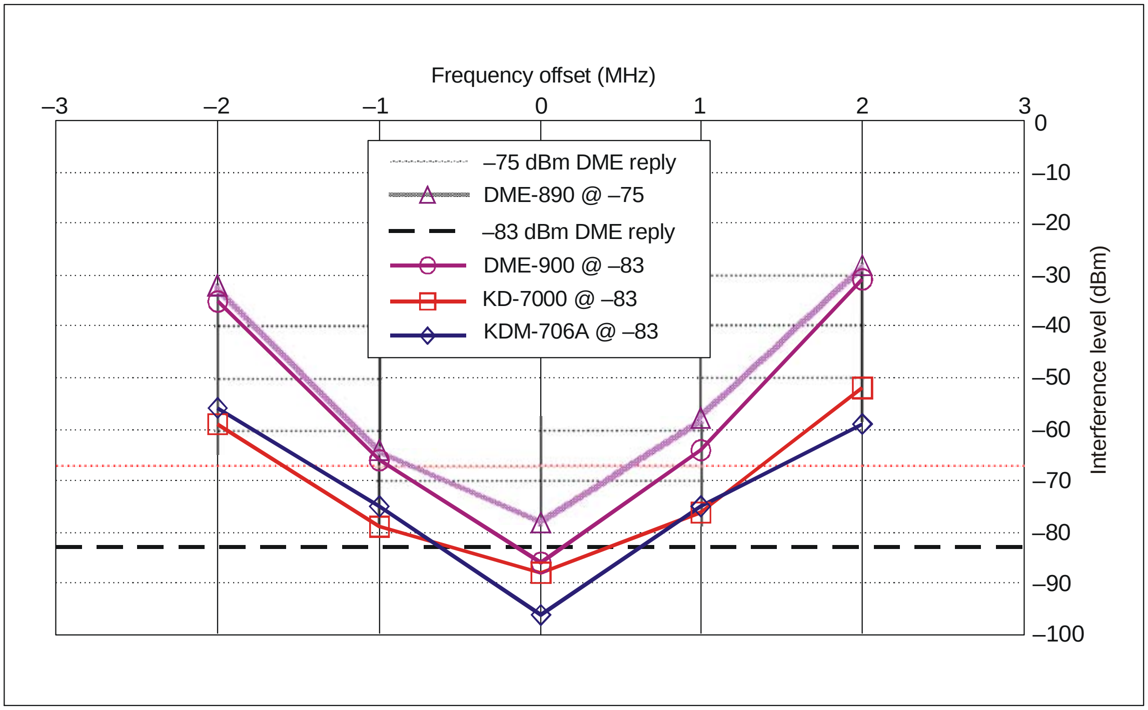


Figure II-E-13. Comparison of all DME frequency offset tests

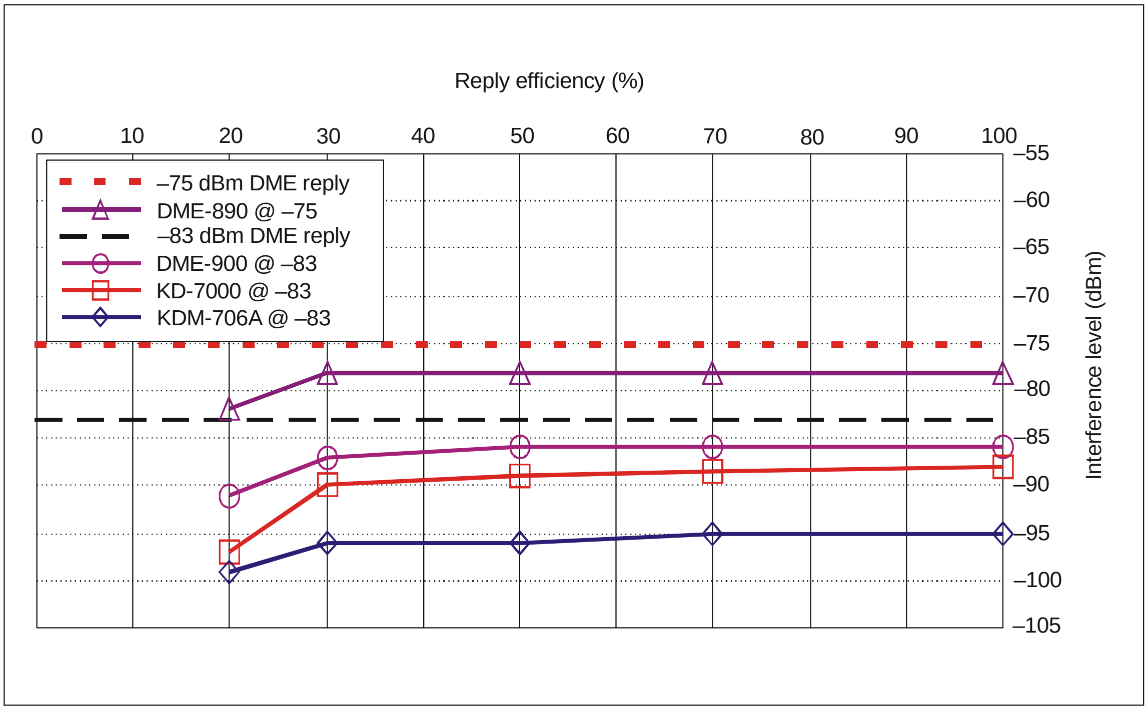


Figure II-E-14. Comparison of all DME reply efficiency tests

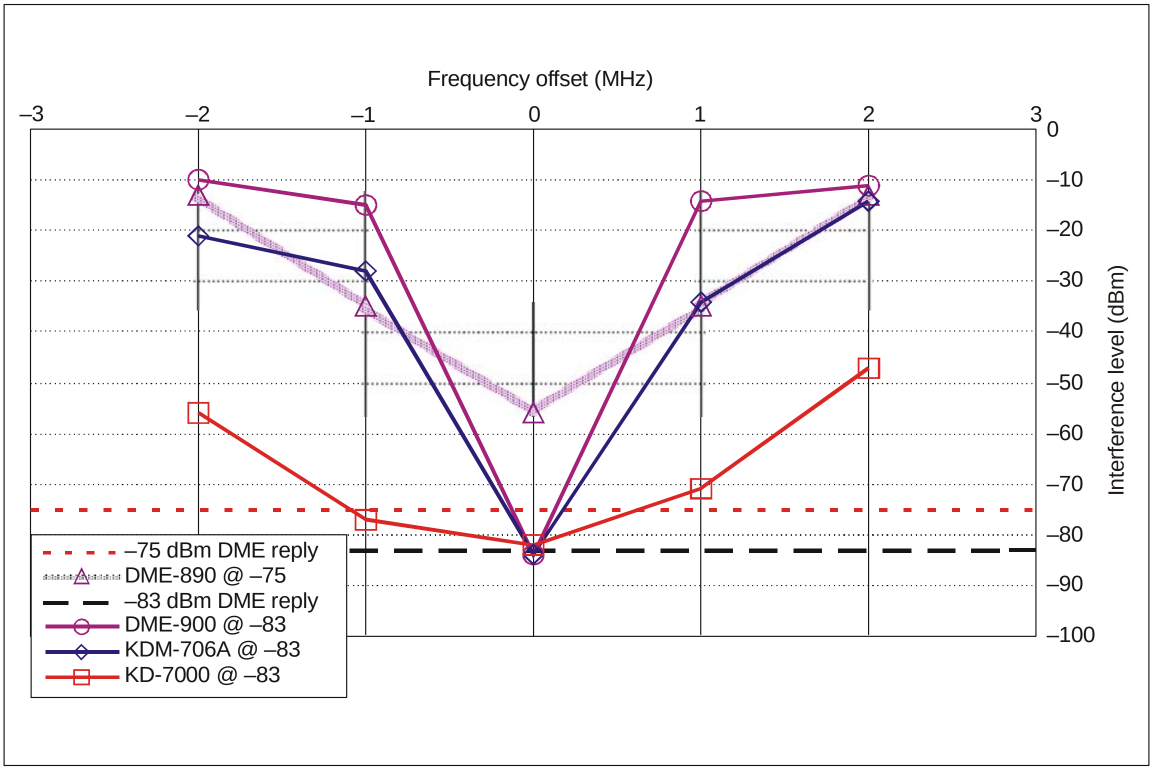


Figure II-E-15. Comparison of all DME CW interference tests

12. Using the combined data from the aforementioned bench-testing and simulated high-density UAT traffic scenarios, the basis for making some basic conclusions on UAT and DME compatibility can be made. It can be determined, for example, at what desired signal level, which can then be converted into a range, that a particular DME can be expected to stop working in a specified UAT environment. It can also provide a measure of how much of a margin is left for DME performance after UAT interference and other DME interference sources are considered. As shown by the bench results where all DME pulse pairs are directly overlapped by UAT messages, the DMEs exhibit exceptional immunity to even co-channel UAT interference. The UAT/DME environments that must be considered span different time frames. In the near term, over approximately a ten-year time interval, DMEs operating at 978 MHz are expected to be moved. However, over this time span, there will be DMEs operating at 978-MHz co-channel with UAT in a number of European locations. In the longer term after these DMEs are moved, the closest DME will be 1 MHz away from the UAT 978-MHz frequency. Upon examining the bench-test results, the consistent behaviour of the DMEs at a given UAT interference level down to reply efficiency of 30 per cent, can be utilized to make conclusions of the UAT effect on DME in the projected environments. If one analyses the Core Europe 2015 scenario to determine the probability of overlapping a DME pulse pair at or above the UAT interference level that would cause loss of operation, it can be determined that the DME will operate without any measurable degradation in that environment. For example, taking the co-channel Honeywell KD-7000 DME unit results with a desired signal level of –83 dBm, UAT signals at or above –96 dBm could potentially impair DME operation if the reply efficiency reduced to 30 per cent or below. Taking the Core Europe 2015 scenario and looking at the number of UAT messages at a level of –96 dBm or above, on average, less than 900 messages per second would be received if a DME receiver is positioned over Brussels at 40 000 feet. This is the same aircraft location used in the high-density Core Europe 2015 analysis in Appendix J. The probability of overlap is significantly less than the minimum probability that would cause probability of reception to be reduced to the level that would impact DME operation. Since the co-channel case would not

occur at the aircraft densities produced by the Core Europe 2015 scenario, the operation of DMEs on 978 MHz can be safely achieved. Since the co-channel DME case is validated for Core Europe 2015, the DME channels 1 MHz or more from the UAT occupied frequency will not be impacted given there is on average 10 dB additional protection shown by the bench-test results when the DME is 1 MHz away from UAT signals.

13. The UAT environment described in Appendix A, the Core Europe 2015 scenario, represents the future environment under which DMEs and UAT were examined to verify that proper operation would be maintained. A bench measurement with a DME unit subjecting the victim DME to the Core Europe 2015 UAT environment was performed to validate that DMEs would properly operate in the future UAT environment. Utilizing a UAT message generator, which produced UAT signal environments for model validation efforts described in Appendix A, the Core Europe 2015 UAT messages that would be experienced by a victim airborne DME receiver were input to the DME receiver. Performance as a function of DME signal amplitude was examined. Rate, timing and amplitudes of UAT messages for this scenario represent a more realistic worst-case scenario than the conditions under which the bench-tests were conducted. The testing was conducted on the Narco DME-890 and the results were measured to determine the DME level to achieve ASOP. This was compared to the measured sensitivity of the DME unit without interference. The results indicated that when the DME unit was subjected to the future UAT environment, it was able to achieve ASOP within 1 dB of its normal sensitivity without UAT interference.

14. Further examination of the effect of UAT on DME was performed to examine the combined effect of UAT and JTIDS/MIDS on DME. Since the bench results and analysis indicated significant margin before UAT would impact DME operation, it was not expected that UAT combined with JTIDS/MIDS would result in an impact on DME operation. An analysis was performed to determine quantitatively how much interference JTIDS/MIDS could produce relative to the UAT signal interference produced by the Core Europe 2015 environment. Figure II-E-16 depicts the incremental change in interference that would be experienced by a DME receiver by the combined effect of UAT and JTIDS/MIDS when compared to UAT interference alone in the ADS-B segment of the UAT frame. The CDF is a measure of the percentage time that interference is experienced by the victim DME receiver at or below the corresponding interference signal level. This analysis was performed with the DME and UAT co-channel in the Core Europe 2015 scenario and the JTIDS/MIDS Baseline B scenario described in Appendix F. As observed by the results, the combination of JTIDS/MIDS and UAT is not significantly different than UAT interference alone.

15. In summary, a significant amount of testing on 4 models of DME equipment representative of the existing equipment population was performed to validate proper operation of DMEs when subjected to UAT signals. This testing has shown the DME interrogators to be very tolerant of the UAT signal even when operated co-channel with UAT. Based on tests conducted to date, no compatibility issues are expected with DME operation even when operated co-channel with UAT and even with very high levels of future UAT/ADS-B equipage in high-density European airspace.

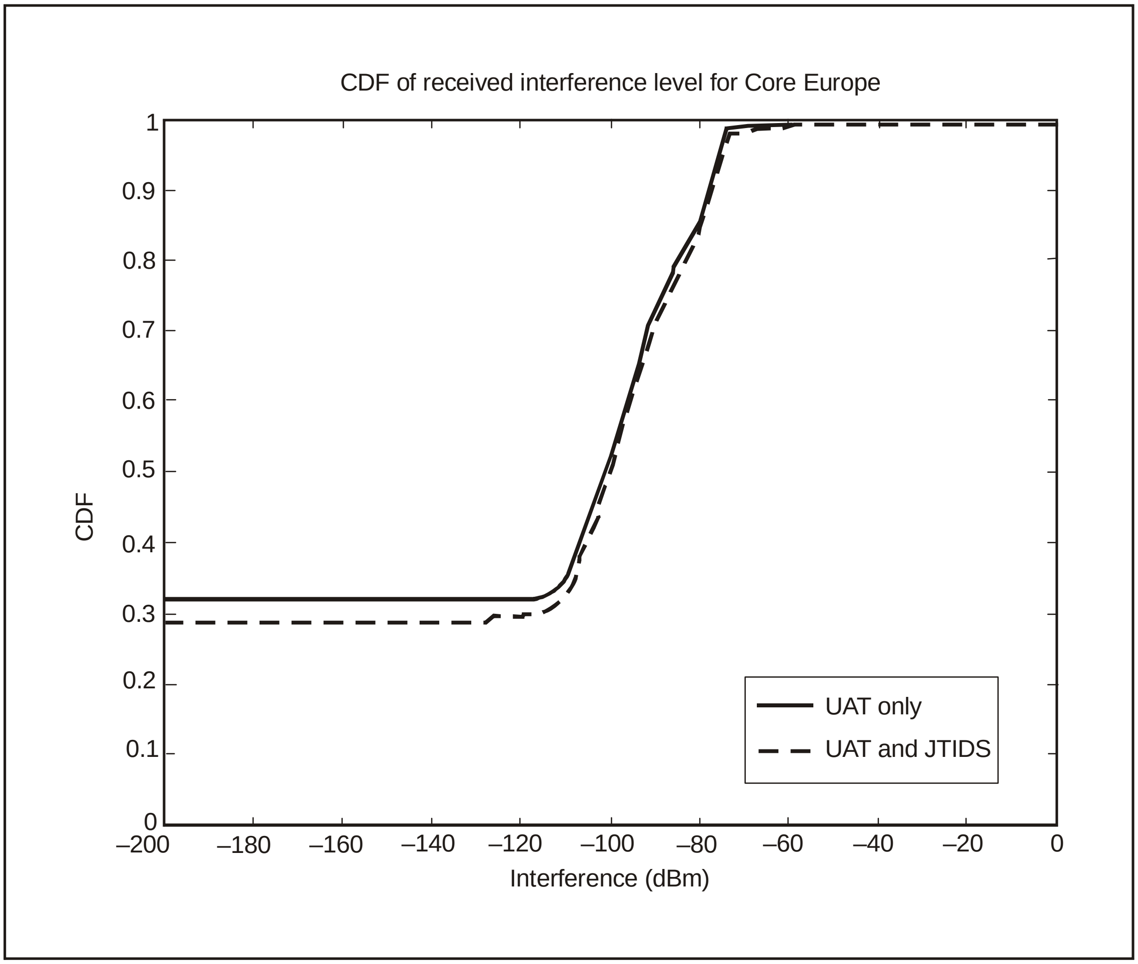


Figure II-E-16. JTIDS/MIDS and UAT combined interference analysis

Appendix F

EXAMPLE UAT ADS-B MESSAGE ENCODING

1. REED SOLOMON ENCODING OF MESSAGE DATA BLOCK

1.1 The encoding is accomplished by means of a systematic RS 256-ary code with 8-bit code symbols (bytes). The first parity symbol out of the FEC encoder is treated as the most significant symbol of the parity sequence. The parity check symbols are appended to the trailing end of the sequence of data symbols.

1.2 The ordering of the bytes is from MSB to LSB, left to right, as they enter and exit the Reed Solomon encoder, as is the ordering of the bits within each byte (MSB to LSB). When treated as polynomial coefficients this is equivalent to transmitting the high order coefficient(s) first. Since the systematic Reed Solomon Code is defined over the Galois Field, GF(2^8), using the primitive polynomial (with binary coefficients, i.e. GF(2)) given as:

$$p(x) = x^8 + x^7 + x^2 + x + 1$$

all of the non-zero elements of the extension field GF(256) can be described as powers of a root of *p(x)*; that is, for α such that *p*(α) = 0, the non-zero elements of GF(256) are given as α^m, for m = 0, 1, 2 ... 254 (where $\alpha^{255} = \alpha^0 = 1$). For example,

$$\alpha^8 \equiv \alpha^7 + \alpha^2 + \alpha + 1 = (1,0,0,0,0,1,1,1) \text{ as a binary 8-tuple (byte).}$$

1.3 To complete the description of the extension field elements, the “zero” element (additive identity) is denoted as **0** = (0,0,0,0,0,0,0,0).

1.4 The generator polynomial for the Reed Solomon Codes is given as:

$$G(x) = \prod_{i=120}^{P} \left(x - \alpha^i\right)$$

where P = 131 for RS (30, 18) and P = 133 for RS (48, 34) codes used for two ADS-B messages.

2. REED SOLOMON ENCODING OF BASIC TYPE 0
UAT ADS-B MESSAGE DATA BLOCK

2.1 The generator polynomial for the RS (30, 18) Reed Solomon Code is given as:

$$G(x) = x^{12} + \alpha^{76}x^{11} + \alpha^{66}x^{10} + \alpha^{157}x^9 + \alpha^{28}x^8 + \alpha^{92}x^7 + \alpha^{220}x^6 + \alpha^{88}x^5$$
$$+\alpha^{20}x^4 + \alpha^{145}x^3 + \alpha^{50}x^2 + \alpha^{56}x + \alpha^{231}$$

2.2 Table II-F-1 represents an example of a basic ADS-B message data block with selected values for individual fields and the equivalent bit-oriented representation. Each data field from Table II-F-1 is arranged in sequence as shown to depict the transmitted basic UAT ADS-B message data sequence.

Transmitted basic UAT ADS-B message data byte #

MSB 1	2	3	4	5	6	7
0000 0000	1111 1010	1010 0001	0010 0011	0101 0101	0101 0101	0101 0101
8	9	10	11	12	13	14
1100 0000	0000 0000	0000 0000	0000 0011	0101 0100	0000 0110	0100 0100
15	16	17	18			
0011 0010	1100 0000	0010 1000	0000 0000$_{\text{LSB}}$			

Table II-F-1. Example of basic UAT ADS-B message data blocks

Data field	*Value*	*Bit-oriented equivalent*
Message data block type code	0	0 0000
Address qualifier	0	000
Aircraft address	FAA123 (HEX)	1111 1010 1010 0001 0010 0011
Latitude (WGS-84)	60° north	010 1010 1010 1010 1010 1010
Longitude (WGS-84)	45° west	1110 0000 0000 0000 0000 0000
Altitude type	0	0
Altitude	300 ft	0000 0011 0101
NIC	4	0100
Air/ground state	0	00
[Reserved bit]	0	0
North velocity or ground speed	400 kt north	001 1001 0001
East velocity or heading	100 kt east	000 0110 0101
Vertical velocity	+64 ft/min (UP)	100 0000 0010
UTC coupled	1(YES)	1
[Reserved bits]	0	000
[Reserved byte]	0	0000 0000

Note.— The message data block field definition of UAT ADS-B type 0 and type 1 messages in Table II-F-1 is current as of issue of the UAT MOPS (RTCA/DO-282B). These two messages are given as an example to describe how the field element is defined within each symbol and how the data symbols sequence enter RS encoder and exit with FEC parity sequence at its trailing end.

2.3 In generating the FEC, the UAT ADS-B message data bits are arranged into eight bit bytes assuming that the leftmost byte is the most significant byte. The encoder accepts the 18 information symbols (bytes) as:

$$\leftarrow \left[\underline{0}, \alpha^{165}, \alpha^{124}, \alpha^{232}, \alpha^{84}, \alpha^{84}, \alpha^{84}, \alpha^{105}, \underline{0}, \underline{0}, \alpha^{99}, \alpha^{214}, \alpha^{100}, \alpha^{143}, \alpha^{222}, \alpha^{105}, \alpha^{201}, \underline{0}\right]$$

and generates the 12 symbols parity sequence:

$$\leftarrow [\alpha^{60}, \alpha^{145}, \alpha^{41}, \alpha^{128}, \alpha^{120}, \alpha^{183}, \alpha^{138}, \alpha^{76}, \alpha^{220}, \alpha^{90}, \alpha^{175}, \alpha^{71}]$$

The parity sequence is then appended to the (right) end of the information sequence to complete the 30-symbol code word for transmission (left symbol first).

MSB ADS-B basic message data block bits + FEC parity bits
0000 0000 1111 1010 1010 0001 0010 0011 0101 0101 0101 0101 0101 0101 1100 0000 0000 0000
0000 0000 0000 0011 0101 0100 0000 0110 0100 0100 0011 0010 1100 0000 0010 1000 0000 0000
1111 1110 1001 0111 1100 0100 0011 0100 1110 0001 1111 1111 0101 0011 0110 0101 1100 1111
1000 1111 1010 1111 1110 0100$_{\text{LSB}}$

3. REED SOLOMON ENCODING OF LONG TYPE 1 UAT ADS-B MESSAGE DATA BLOCKS

3.1 The generator polynomial for the RS (48, 34) Reed Solomon Code is given as:

$$G(x) = x^{14} + \alpha^{82}x^{13} + \alpha^{49}x^{12} + \alpha^{21}x^{11} + \alpha^{70}x^{10} + \alpha^{26}x^{9} + \alpha^{140}x^{8} + \alpha^{135}x^{7} + \alpha^{138}\alpha^{6}$$
$$+\alpha^{22}x^{5} + \alpha^{64}x^{4} + \alpha^{13}x^{3} + \alpha^{39}x^{2} + \alpha^{70}x + \alpha^{241}$$

3.2 Table II-F-2 represents an example of long type 1 UAT ADS-B message data blocks (basic ADS-B state vector plus MS (mode status) elements, and AUX state vector report elements fields) and the equivalent bit-oriented representation.

Table II-F-2. Example of long type 1 UAT ADS-B message data blocks

Data field	*Value*	*Bit-oriented equivalent*
Message data block type code	1	0 0001
Address qualifier	0	000
Aircraft address	FAA123 (HEX)	1111 1010 1010 0001 0010 0011
Latitude (WGS-84)	60° north	010 1010 1010 1010 1010 1010
Longitude (WGS-84)	45° west	1110 0000 0000 0000 0000 0000
Altitude type	0	0
Altitude	+300 ft	0000 0011 0101
NIC	4	0100
Air/ground state	0	00
[Reserved bit]	0	0
North velocity or ground speed	400 kt north	001 1001 0001
East velocity or heading	100 kt east	000 0110 0101
Vertical velocity	+64 ft/min(UP)	100 0000 0010
UTC coupled	1(YES)	1
[Reserved bits]	0	000
Emitter category code and call sign characters #1 and #2	2 (small) and “AB”	0000 1110 0001 1011
Call sign characters #3, #4 and #5	“CD1”	0100 1101 0000 1001
Call sign characters #6, #7 and #8	“234”	0000 1100 1111 1100
Emergency	0	000
MOPS version	2	010
SIL	0	00
TMSO (6 LSBs of 12-bit MSO #)	1 250 (only 6 LSBs are transmitted)	10 0010
System design assurance (SDA)	0	00
NAC_P	7	0111
NAC_V	2	010
NIC_{BARO}	0	0
Capability class (CC) codes	0	000
Operational mode (OM) codes	0	000
CSID	0	0
SIL supplement	0	0
Geometric vertical accuracy	0	00
Single antenna flag	0	0
NIC supplement	0	0
[Reserved bits]	0	0000 0000 0000
Secondary altitude	+300 ft	0000 0011 0101
[Reserved bits]	0	0000 0000 0000 0000 0000 0000 0000

Note.— The message data block field definition of UAT ADS-B type 0 and type 1 messages in Table II-F-2 is current as of issue of the UAT MOPS (RTCA/DO-282B). These two messages are given as an example to describe how the field element is defined within each symbol and how the data symbols sequence enter RS encoder and exit with FEC parity sequence at its trailing end.

3.3 Each data field from Table II-F-2 is arranged in sequence as shown to depict the transmitted long type 1 UAT ADS-B message data sequence.

Transmitted long type 1 UAT ADS-B message data bytes #

$_{\text{MSB}}$----1	2	3	4	5	6	7
0000 1000	1111 1010	1010 0001	0010 0011	0101 0101	0101 0101	0101 0101
8	9	10	11	12	13	14
1100 0000	0000 0000	0000 0000	0000 0011	0101 0100	0000 0110	0100 0100
15	16	17	18	19	20	21
0011 0010	1100 0000	0010 1000	0000 1110	0001 1011	0100 1101	0000 1001
22	23	24	25	26	27	28
0000 1100	1111 1100	0000 1000	1000 1000	0111 0100	0000 0000	0000 0000
29	30	31	32	33	34	
0000 0000	0000 0011	0101 0000	0000 0000	0000 0000	0000 0000$_{\text{LSB}}$	

3.4 In generating the FEC, the UAT ADS-B message data bits are arranged into eight bit bytes assuming that the leftmost byte is the most significant byte. The encoder accepts the 34 information symbols (bytes) as:

$$\leftarrow [\alpha^{3}, \alpha^{165}, \alpha^{124}, \alpha^{232}, \alpha^{84}, \alpha^{84}, \alpha^{84}, \alpha^{105}, \underline{0}, \underline{0}, \alpha^{99}, \alpha^{214}, \alpha^{100}, \alpha^{143}, \alpha^{222}, \alpha^{105}, \alpha^{201}, \alpha^{107},$$
$$\alpha^{49}, \alpha^{117}, \alpha^{205}, \alpha^{101}, \alpha^{58}, \alpha^{3}, \alpha^{144}, \alpha^{34}, \underline{0}, \underline{0}, \underline{0}, \alpha^{99}, \alpha^{202}, \underline{0}, \underline{0}, \underline{0}]$$

and generates the 14-symbol parity sequence:

$$\leftarrow [\alpha^{92}, \alpha^{6}, \alpha^{210}, \alpha^{90}, \alpha^{198}, \alpha^{26}, \alpha^{197}, \alpha^{119}, \alpha^{86}, \alpha^{230}, \alpha^{16}, \alpha^{195}, \alpha^{16}, \alpha^{115}]$$

The parity sequence is then appended to the (right) end of the information sequence to complete the 48-symbol code word for transmission (left symbol first).

$_{\text{MSB}}$ Long type 1 UAT ADS-B message data block bits + FEC parity bits
0000 1000 1111 1010 1010 0001 0010 0011 0101 0101 0101 0101 0101 0101 1100 0000 0000 0000
0000 0000 0000 0011 0101 0100 0000 0110 0100 0100 0011 0010 1100 0000 0010 1000 0000 1110
0001 1011 0100 1101 0000 1001 0000 1100 1111 1100 0000 1000 1000 1000 0111 0100 0000 0000
0000 0000 0000 0000 0000 0011 0101 0000 0000 0000 0000 0000 0000 0000 1011 0101 0100 0000
1010 0111 1000 1111 0000 0101 0100 0011 1100 0001 1011 0011 1101 0011 0110 1001 0110 1111
1001 0010 0110 1111 1011 0001 $_{\text{LSB}}$

4. REFERENCES

References for forward error coding and the Galois Field are listed below:

1. Peterson, W.W., and E.J. Weldon, Jr., *Error-Correcting Codes*, 2nd ed., MIT Press, Cambridge, MA, 1972.

2. Michelson, A. M., and A. H. Levesque, *Error-Control Techniques for Digital Communication*, John Wiley & Sons, New York, NY 1985.

Appendix G

AIRCRAFT ANTENNAS

1. ANTENNA CHARACTERISTICS

1.1 General

The UAT system is expected to be able to utilize any standard transponder/DME antenna. Potential sharing of existing transponder antennas is discussed in Section 3. The antenna must be suitable to receive and transmit vertically polarized signals at 978 MHz. The VSWR produced by the antenna into a manufacturer specified load must not exceed 1.7:1 at 978 MHz ±1 MHz.

1.2 Radiation patterns

Performance of the UAT ADS-B system was estimated using a model of antenna gain that was developed for the United States Federal Aviation Administration (FAA) Safe Flight – 21 (SF-21) Technical Link Assessment Team (TLAT) Report. See Appendix A to this manual. In practice, equipment designers assume 0.5 dB less average gain in the azimuth plane than that given in the TLAT antenna gain model. However, in data links such as UAT, which are interference limited, this difference should not be expected to affect the performance presented in Appendix A to this manual.

1.3 Directional gain radiation patterns

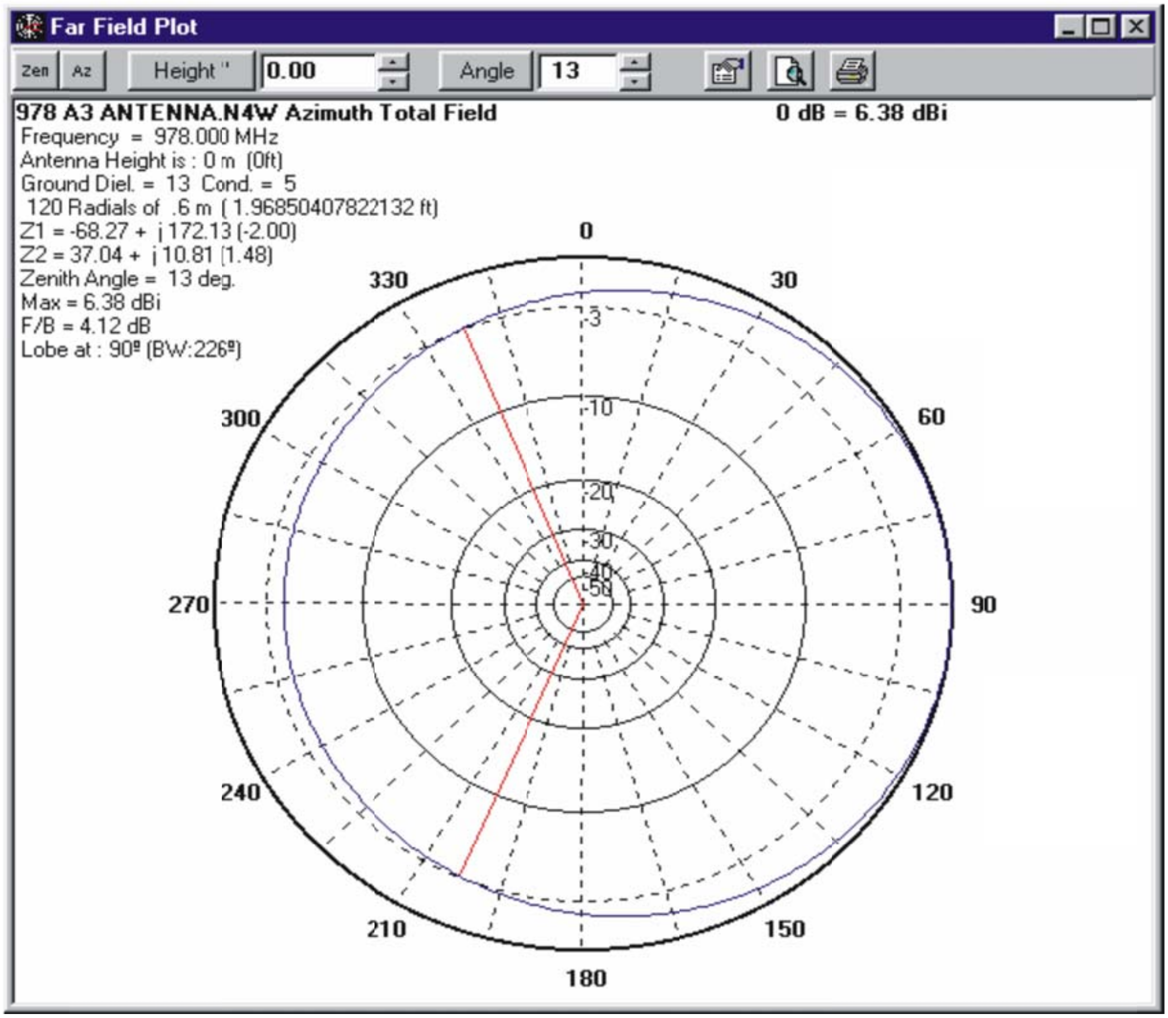
1.3.1 For some applications (such as applications specific to Class A3 equipment), it may be suitable to use antennas with directional gain patterns to increase the range in the forward direction. Limitations on such directional gain antennas include not creating undesired nulls in the azimuth pattern, maintaining the minimum air-to-air range in the aft direction, and ensuring that any future requirements for minimum air-to-ground range are met.

1.3.2 Figure II-G-1 shows a theoretical antenna that uses a pair of active driven elements to achieve directional gain while creating a uniform pattern. This antenna consists of a pair of quarter-wave resonant elements spaced at 1/8 wavelength and driven 45 degrees out of phase. This antenna design achieves 6.4 dBi of gain at an elevation angle of 13 degrees, with an F/B ratio of 4 dB.

2. TYPICAL VSWR MEASUREMENTS OF EXISTING TRANSPONDER/DME ANTENNAS

2.1 General

2.1.1 There are several varieties of existing antennas that are suitable for use with the UAT data link. These are summarized in Table II-G-1.



Height " 0.00

Angle 13

```
978 A3 ANTENNA.N4W Azimuth Total Field                    0 dB = 6.38 dBi
 Frequency  =  978.000 MHz
 Antenna Height is : 0 m  (0ft)
 Ground Diel. =  13  Cond. =  5
  120 Radials of  .6 m  ( 1.96850407822132 ft)
 Z1 = -68.27 +  j 172.13 (-2.00)
 Z2 = 37.04 +  j 10.81 (1.48)
 Zenith Angle =  13 deg.
 Max = 6.38 dBi
 F/B = 4.12 dB
 Lobe at : 90º (BW:226º)
```

Figure II-G-1. Gain array antenna azimuth pattern

Table II-G-1. Typical antennas

FAA TSO	*RTCA/EUROCAE*	*Equipment type*	*VSWR and frequency*
TSO-C66c	DO-189	DME	2:1 from 960 to 1 215
TSO-C74d	DO-144A	SSR transponder	1.5:1 on 1 030, 1 090
TSO-C112c	DO-181E/ ED-73E	SSR Mode A/C/S	1.5:1 from 1 030 to 1 090

2.1.2 Typically, antennas that comply with TSO-C112c are specified with VSWR < 1.5:1 from 1 030 MHz to 1 090 MHz, and VSWR < 1.7:1 over the remainder of the band from 978 MHz to 1 215 MHz. Certain types of transponder antennas that utilize very thin radiator elements are only intended for use at 1 030 MHz and 1 090 MHz. These types of antennas should be evaluated on a model-by-model basis to determine their suitability as UAT data link antennas.

2.1.3 Note that RF system performance is not strongly affected by VSWR values. A VSWR value as high as 2:1 does not increase the losses in the transmitted signal by more than 0.5 dB. This lack of sensitivity in system performance to VSWR values should be kept in mind when evaluating antennas for UAT applications. The following paragraphs illustrate these VSWR characteristics for specific antenna models. These measurements were performed with the antenna mounted in the centre of a 4-foot diameter conductive ground plane.

2.2 Sensor systems L band blade antenna P/N S65-5366-7L

The antenna in Figure II-G-2 is typical of those found on jet transport aircraft and is rated for TSO C66b, C74d and C112c. This antenna would be suitable as a UAT antenna.

2.3 AeroAntenna P/N AT-130-1

The antenna in Figure II-G-3 was designed for the FAA Alaska Capstone programme as a dedicated UAT antenna.

2.4 ¼ wave whip antenna

The data in Figure II-G-4 represent a typical GA-application thin whip antenna, such as a RAMI Model AV-22 (TSO C-74d). Note that although not specified for performance outside of the 1 030 to 1 090 MHz range, it actually performs best at frequencies lower than 1 030 MHz. This antenna would be a suitable UAT data link antenna and illustrates the need to look at the characteristics of each candidate antenna closely.

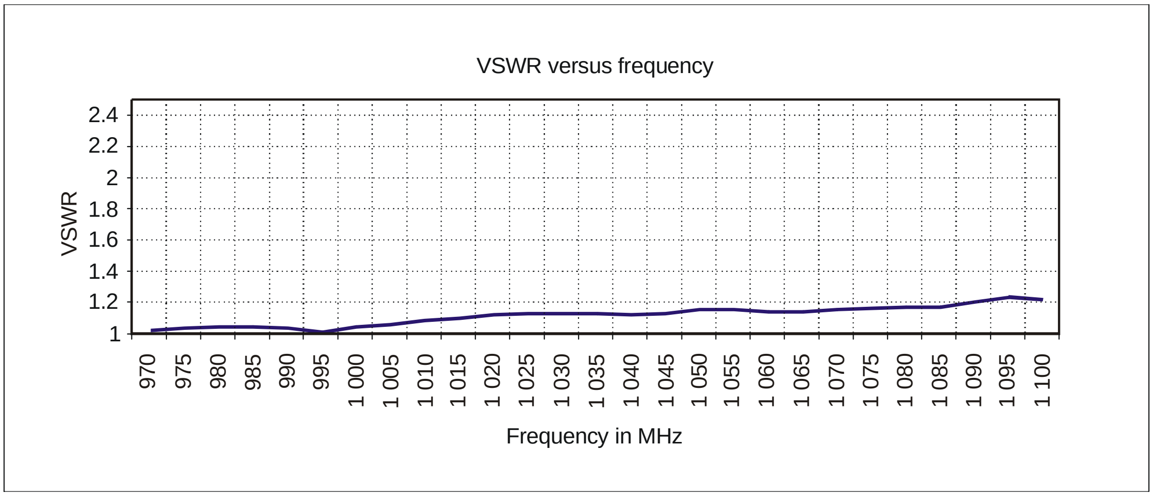


Figure II-G-2. Jet transport antenna

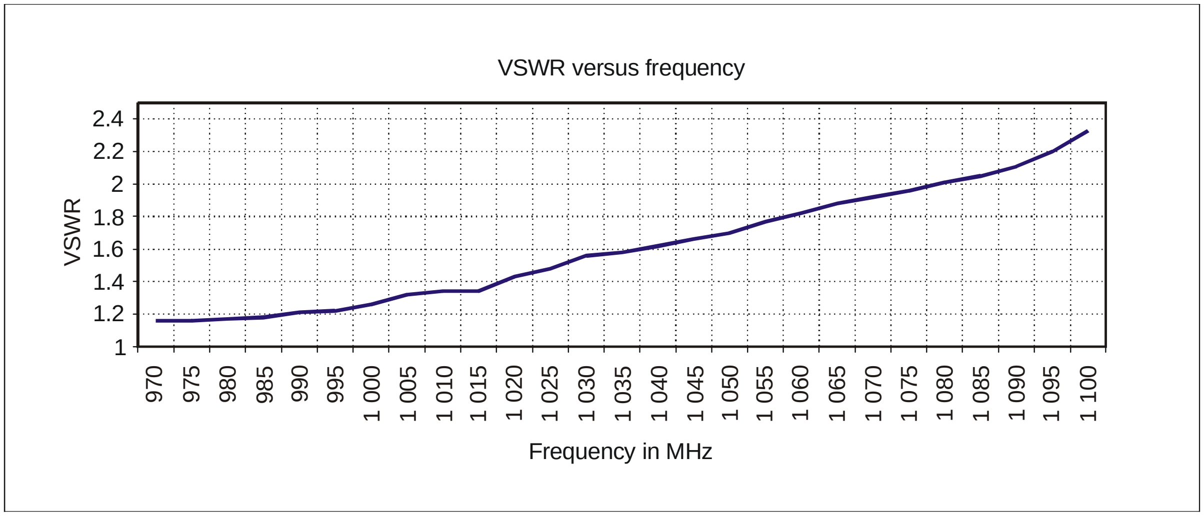


Figure II-G-3. Capstone antenna

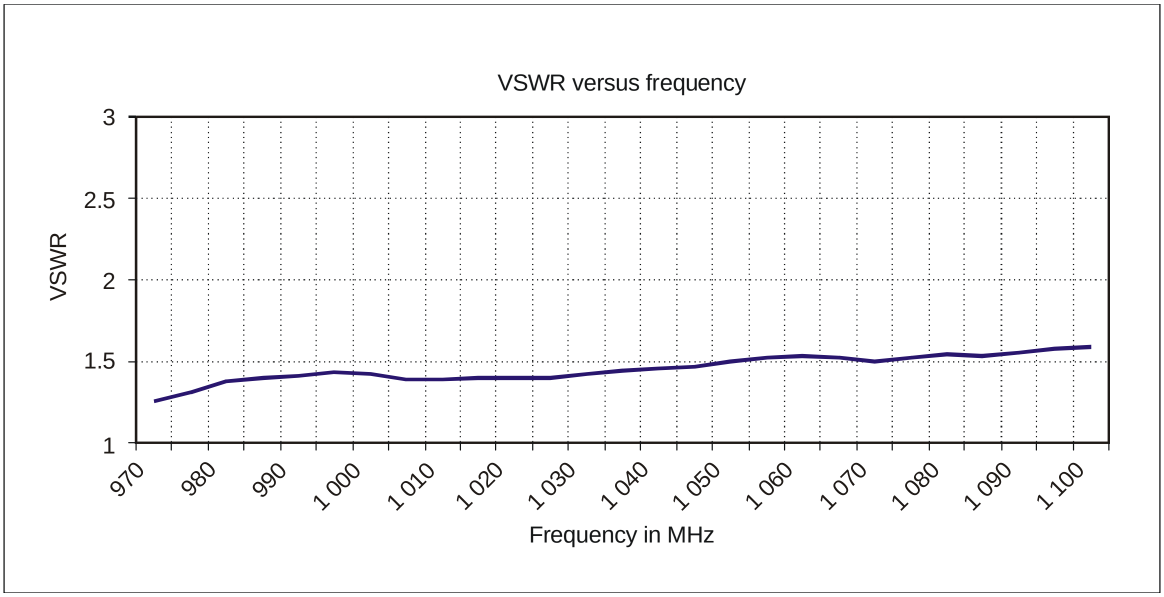


Figure II-G-4. ¼ wave whip antenna

3. PASSIVE ANTENNA DIPLEXER

3.1 Characteristics

3.1.1 A potential method of providing an antenna for the UAT is to use a passive frequency diplexer that is installed between an existing transponder and its antenna. Allowing the use of a diplexer to operate UAT equipment and the on-board SSR transponder required extensive validation to verify that the use of a diplexer would not degrade the operation of either system. A test effort utilizing a prototype diplexer conforming to the requirements of the UAT MOPS (RTCA/DO-282B, 2.2.14.3) was utilized to conduct the necessary testing.

3.1.2 Upon initial investigation into the concept of antenna sharing by use of a diplexer, certain characteristics were critical to enable use of a diplexer. The power loss across the diplexer was an important consideration. The typical loss that installations allow between the transponder and antenna is 3 dB. The diplexer cannot use up a significant portion of this allocation without eliminating most existing transponder installations as candidates for UAT antenna sharing. The requirement that the diplexer loss cannot exceed 0.5 dB is expected to enable most existing installations to use a diplexer and share the transponder antenna. The goals of the diplexer design were to support a transponder port that would minimize the insertion loss in the 1 030 to 1 090-MHz band and possessing adequate passband so that 1 030-MHz interrogation signals and 1 090-MHz reply signals were unaffected by the diplexer. An optional DC path in the diplexer's transponder channel is allowed so that installations that require antenna sensing can maintain the capability to sense the presence of an antenna. The diplexer's transponder channel will attenuate signals at 978 MHz, providing isolation from the UAT. In some cases, diplexer isolation actually exceeds the level of isolation obtained by using separate transponder and UAT antennas. The latter is a function of distance between antennas. The UAT's diplexer port can provide minimal insertion loss to the antenna at 978 MHz, while manifesting a high impedance at the 1 030/1 090-MHz band.

3.2 Antenna diplexer testing

3.2.1 Tests were conducted to validate the performance of ATC transponders sharing an aircraft antenna with a UAT by incorporating a diplexer into the installation. The purpose of the tests was to ensure that both the UAT equipment and transponders perform according to the applicable standards and that the diplexer does not introduce any signal distortions on the 978-MHz frequency of UAT and the 1 030/1 090-MHz frequencies of ATC transponders. A selected set of tests was performed to measure any potential degradation of equipment performance due to the diplexer installation. The tests measured the effect of both the UAT/diplexer on the performance of the transponder and the effect of the transponder/diplexer on the performance of the UAT system.

SSR transponder testing

3.2.2 Tests were conducted to measure the effect of the diplexer installation on the performance of ATC transponders. Two prototype diplexers built by two different manufacturers were tested. Each diplexer was tested with seven different transponders including 3 SSR Mode S and 4 SSR Mode A/C transponders.

3.2.3 A comprehensive set of tests was run on each transponder to measure transmitter and receiver characteristics, reply pulse characteristics, side lobe suppression, undesired replies and pulse decoder characteristics. Each test was performed both with and without the diplexer installed to measure the relative effects of the diplexer. Where appropriate, with the diplexer installation, the UAT system was connected and transmitting.

3.2.4 Table II-G-2 shows a summary of the test results. Parameters labelled "none" under measured effects showed no measurable effect within the accuracy of the test system. The test system measurement accuracy either met or exceeded the specified test conditions in the appropriate MOPS.

Table II-G-2. Diplexer testing with ATC transponders

Test parameter	*Measured effect*
Reply power	0.2 to 0.4 dB loss
Reply frequency	None
Reply delay (SSR Mode A/C/S)	Increased 0.01 to 0.018 microseconds
Reply delay jitter (SSR Mode A/C/S)	None
Reply pulse spacing (SSR Mode A/C/S)	None
Reply pulse shape (SSR Mode A/C/S)	None
Undesired replies	UAT transmission triggered SSR Mode A/C/S replies with some units
Sensitivity (SSR Mode A/C/S)	0.25 to 0.35 dB loss
Dynamic range	None
Sensitivity variation with frequency	None
Bandwidth	None
Pulse position tolerance (SSR Mode A/C/S)	None
Pulse duration tolerance (SSR Mode A/C/S)	None
Pulse level tolerance P4 (SSR Mode A/C/S)	None
Synchronization phase reversal position tolerance (SSR Mode S)	None
SLS decoding (SSR Mode A/C/S)	None
SLS pulse ratio (SSR Mode A/C/S)	None
Suppression duration	None
Suppression re-initiation	None
Recovery from suppression	None
SSR Mode S SLS	None
SSR Mode A/C desensitization pulse and recovery	None

3.2.5 The reply power and receiver sensitivity of the transponders were reduced a fraction of a dB through the diplexer. This is expected due to the insertion loss of the transponder channel of the diplexer that is specified to be 0.5 dB maximum. This should not be a detriment to proper operation as long as the installation accounts for the additional loss.

3.2.6 The reply delay showed an increase of about 10 to almost 20 nanoseconds average for all diplexer and transponder combinations. This is an effect of the sum of the 1 030-MHz interrogation and the subsequent 1 090-MHz reply each being delayed through the diplexer about 5 to 10 nanoseconds.

3.2.7 The undesired reply rate was measured by monitoring SSR Mode A/C and SSR Mode S reply transmissions without interrogating the transponder. With the diplexer and UAT installed and operating with the transponder, some of the transponder/diplexer combinations resulted in unsolicited SSR replies. This was caused by the low-level UAT signal leakage into the transponder channel of the diplexer. This occurred significantly more with one of the diplexers than with the other and it varied with the transponder type. The worst case measured was at an average rate of about 0.75 SSR Mode A/C replies per UAT transmission. There were no unsolicited SSR Mode S replies with any of the test configurations. The undesired reply rate for SSR Mode A/C modes is required to be 5 replies per second or less averaged over a 30-second interval. (This is the requirement for SSR Mode S transponders — RTCA DO-181E/ED-73E.) The MOPS for Airborne ATC Transponder Systems (RTCA DO-144A) requires that the random triggering rate not exceed 30 replies per second. This latter requirement is after installation with all possible interfering equipment operating. Although the undesired reply rate caused by the UAT transmissions were within the requirements, it was not desirable to trigger transponder emissions by the UAT signal. This issue was not solely a diplexer issue, since depending upon UAT antenna and transponder antenna proximity in an installation, UAT transmissions could cause transponder responses during UAT transmissions without a diplexer. For this reason, UAT equipment is required to output a suppression pulse to the transponder to inhibit the transponder receiver during UAT transmissions.

3.2.8 Measurements also indicated that the diplexer installation does affect VSWR. With SSR Mode A/C transponders, the change in VSWR altered the transponder reply frequency. SSR Mode S transponders were more immune to VSWR variations.

3.2.9 Since the passive diplexer integrates UAT equipment with the SSR transponder on the aircraft, it was necessary to coordinate the use of a diplexer with the Surveillance and Conflict Resolution Systems Panel (SCRSP) of the International Civil Aviation Organization (ICAO). SCRSP, which was replaced by the ICAO Aeronautical Surveillance Panel (ASP), produces and maintains international standards for the SSR systems. The results of the extensive tests that were conducted to verify proper operation of the SSR transponder with a passive diplexer were made available to SCRSP to evaluate the performance of the SSR transponder through the diplexer.

3.2.10 An additional set of tests was recommended by SCRSP to investigate the performance of an SSR Mode S transponder with the use of a diplexer and its ability to properly decode SSR Mode S interrogations with numerous differential phase shift keying (DPSK) phase shifts. These tests would verify that the bandwidth of the diplexer does not cause distortion of the interrogation signal that would degrade the ability of the SSR Mode S transponder receiver to properly decode these interrogations. In order to evaluate the diplexer impact on DPSK, the transponder receiver sensitivity was tested as interrogation frequency was varied. Three SSR Mode S type transponders were tested both with and without the diplexer installed in order to make a direct comparison of the diplexer's effect. The transponders tested were from three different manufacturers. The installation of the diplexer affects the voltage standing wave ratio (VSWR) of the antenna ports, so a slotted line and stub tuner were used to monitor and control VSWR. The stub tuner was used to set the VSWR to the same minimum value obtainable with and without the diplexer. This was done to minimize the VSWR influence on the sensitivity measurements.

3.2.11 Figure II-G-5 shows a plot of the sensitivity variation with frequency measurements for one of the transponders tested. The interrogation consisted of a legal uplink format defined by the first five bits of the interrogation. All other data bits equal to binary "1" except the address parity (AP) field, which was properly coded to elicit a response from the transponder. The all binary ones format was used to maximize the number of phase shifts in the uplink interrogation. This was the primary interrogation format used to test all three transponders.

3.2.12 The data show a consistent average reduction in sensitivity of about 0.2 dBm, the loss through the diplexer, which does not vary significantly with frequency. Additional tests were conducted with all variable data bits equal to binary "0" to minimize the number of phase shifts with nearly identical results.

3.2.13 All three tested SSR Mode S transponders yielded similar results. The conclusion from running these tests is that other than the expected reduction in the transponder receiver sensitivity from the loss across the diplexer, the SSR Mode S sensitivity is not affected as a function of frequency within the operating bandwidth of the transponders. The diplexer bandwidth characteristics for the SSR transponder channel adequately handles 1 030 MHz SSR Mode S interrogation signals with excessive DPSK phase variations.

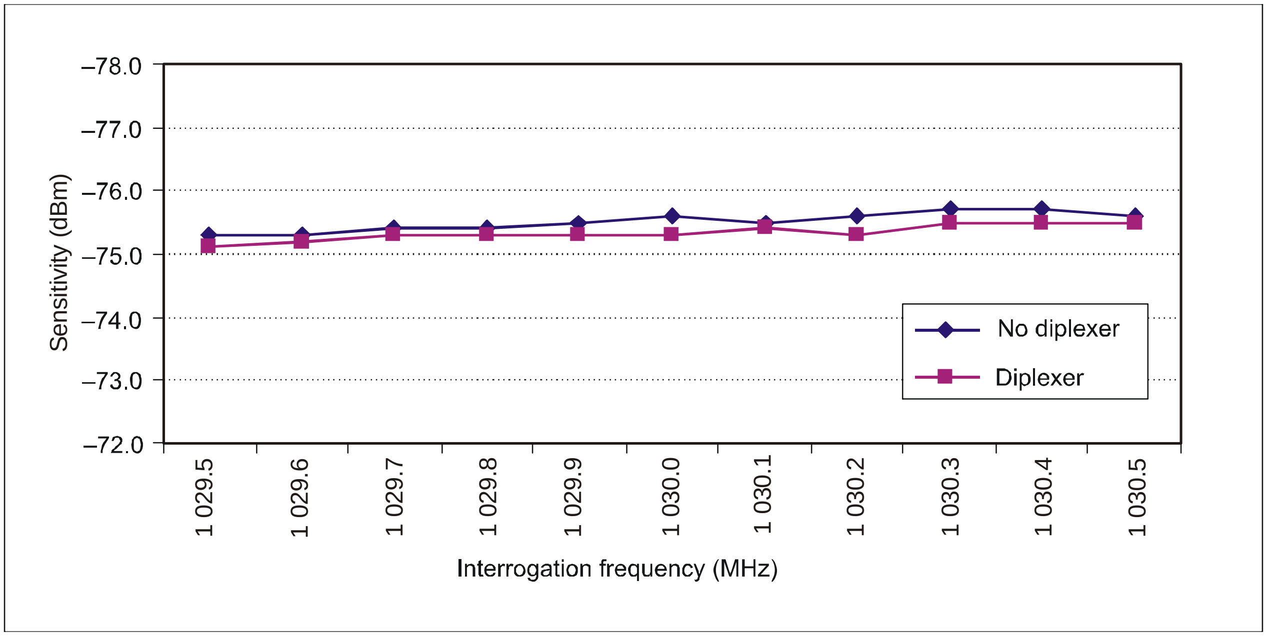


Figure II-G-5. Sensitivity variation with frequency, all ones interrogation, transponder MS-1

UAT diplexer testing

3.2.14 A variety of tests were conducted to determine the effects of UAT signals through a diplexer. Testing was facilitated using nine different configurations to test various combinations of remote or on-board UAT receivers, remote ground uplink transmissions, interference to UAT from remote or on-board SSR Mode S or SSR Mode A/C transponders, as well as on-board transponder leakage, in circuit with an implemented antenna diplexer.

3.2.15 Since no performance difference was measured looking at UAT reception at the on-board UAT receiver, nor remotely when looking at UAT signals from the on-board transmitter through the diplexer, the severe case of on-board interference from SSR Mode S or SSR Mode A/C transmissions through the transponder port of a diplexer to a UAT receiver was investigated. Even though the assumptions for the UAT performance model assume no UAT receptions when UAT signals are overlapped by on-board SSR transmissions, the test results show that the diplexer provides sufficient isolation from the on-board 1 030-MHz and 1 090-MHz transmissions to enable a high probability of successful reception of low-level UAT messages. In all of the test cases where SSR Mode A/C/S transmissions interfered with UAT message receptions, the test was particularly severe. The transponder transmissions were overlaid in time with the UAT messages 100 per cent of the time, yet the UAT receiver, isolated by the antenna diplexer, performed with no significant degradation.

Prototype diplexer performance

3.2.16 The following figures show measured data obtained from a prototype diplexer. Figure II-G-6 shows the performance between the antenna and UAT ports. Figure II-G-7 shows the performance between the antenna and transponder ports.

3.2.17 Figure II-G-8 shows the isolation between the UAT and transponder ports. Note that the isolation between the ports at the UAT frequency is 25 dB, and the isolation at the transponder frequencies is 42 dB at 1 030 MHz and 64 dB at 1 090 MHz.

3.3 Typical installation diagram

Figure II-G-9 illustrates how a UAT might be added to a typical existing transponder installation by using frequency diplexer/combiner. Shaded boxes indicate the new components added to the existing installation. The diplexer can be added anywhere in the antenna's feedline. The most logical place for this addition would be in the aircraft's equipment bay in close proximity to both the UAT and transponder units. This way, existing feedlines would not have to be re-routed or altered.

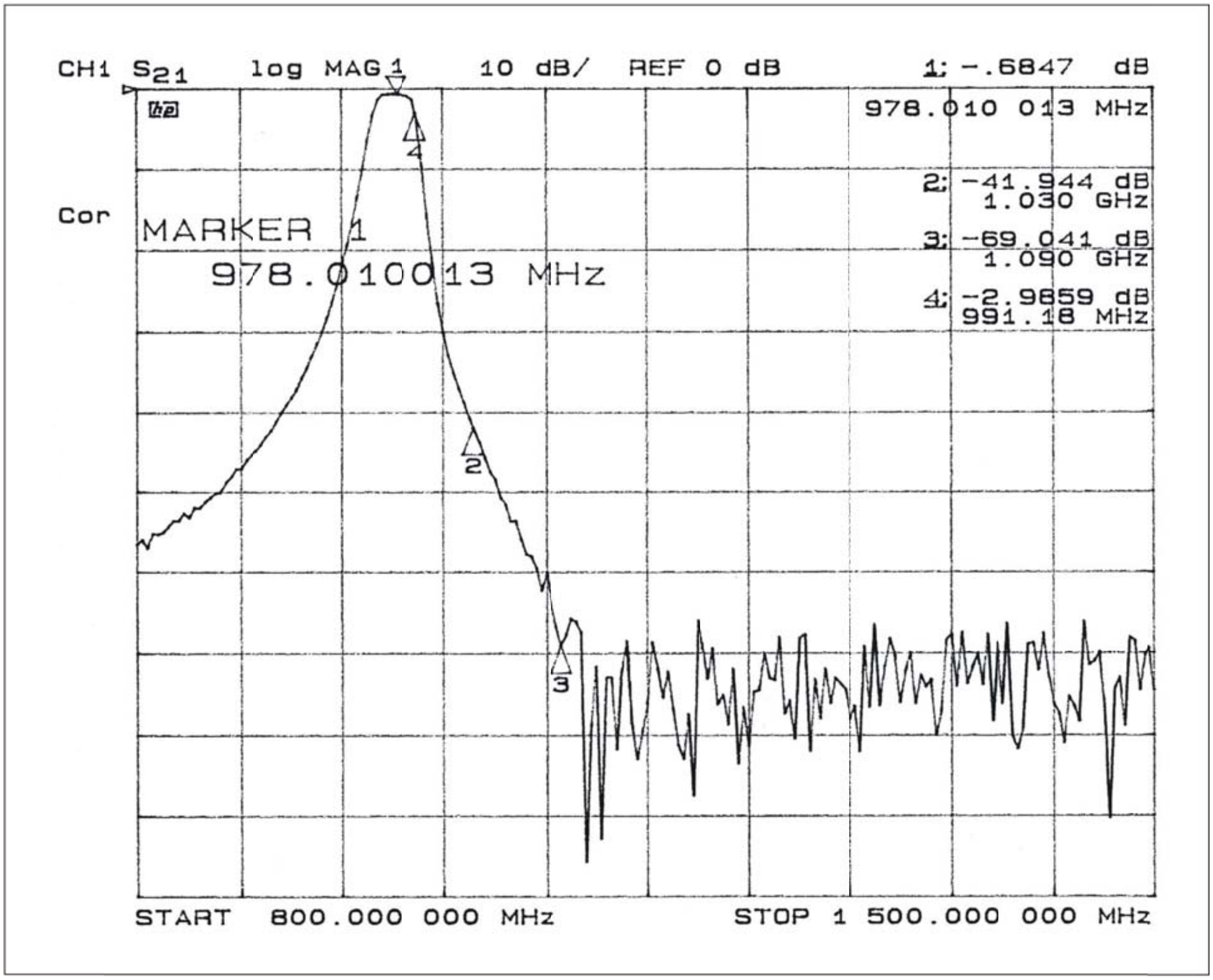


Figure II-G-6. Diplexer UAT port

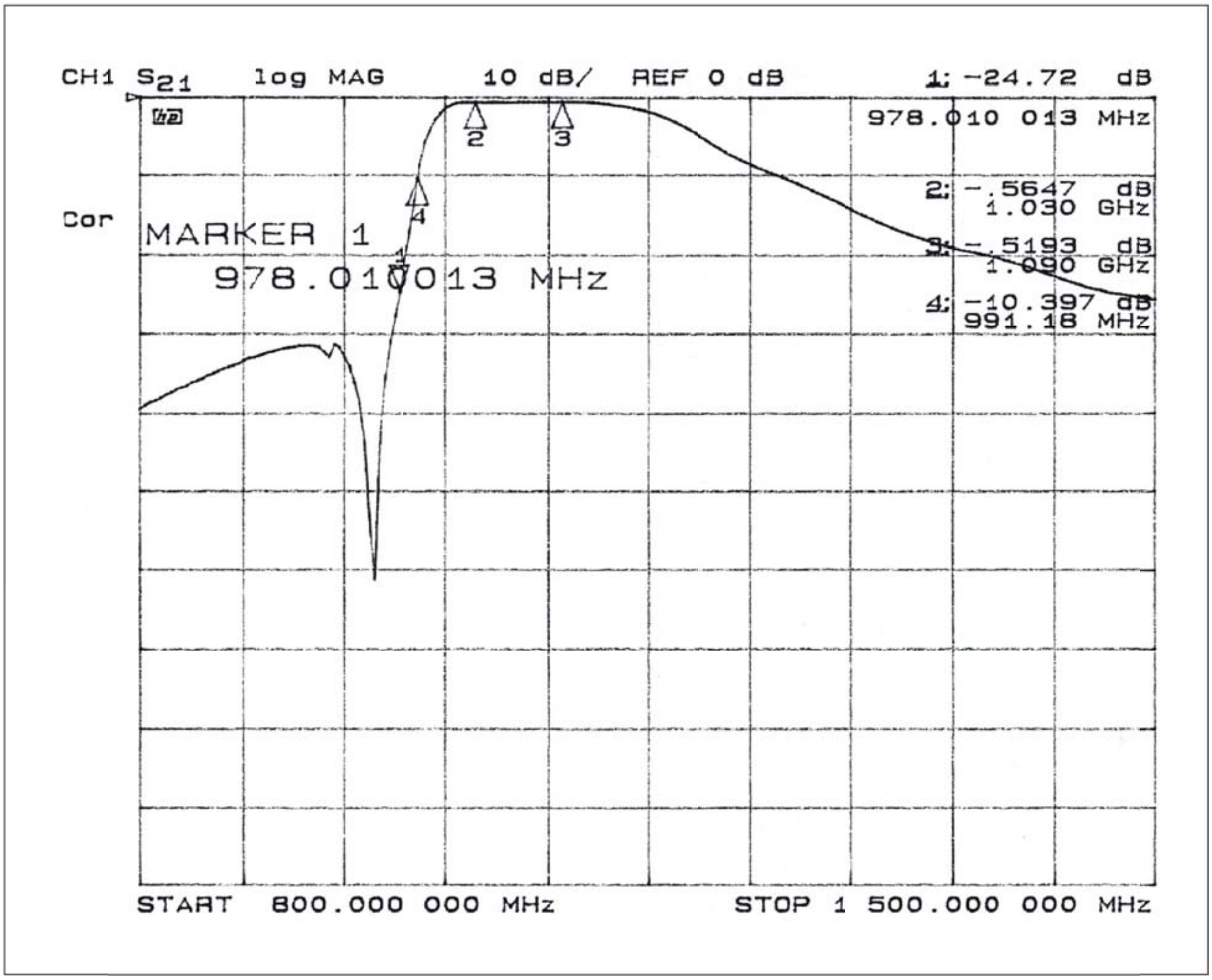


Figure II-G-7. Diplexer transponder port

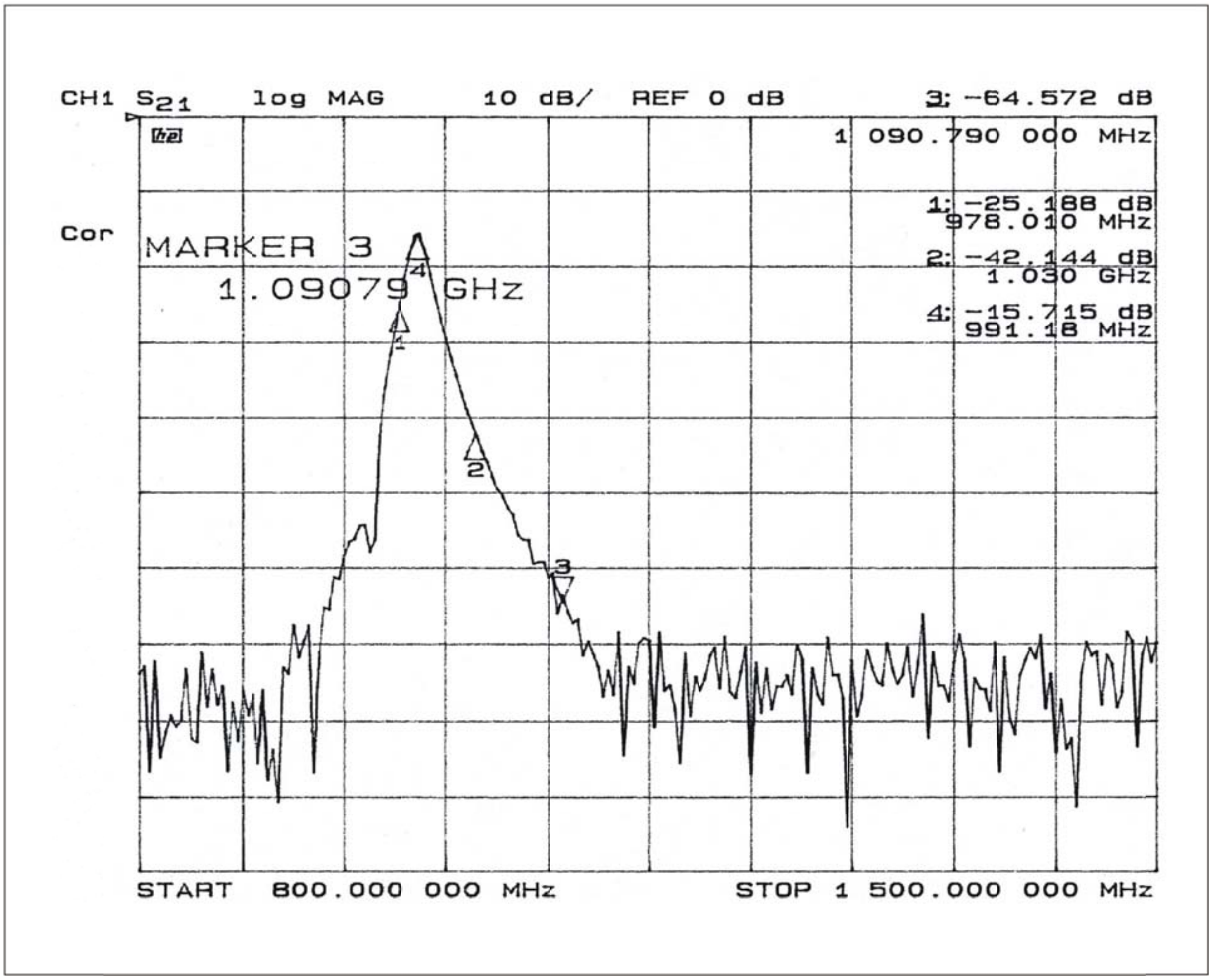


Figure II-G-8. Diplexer UAT-to-transponder port isolation

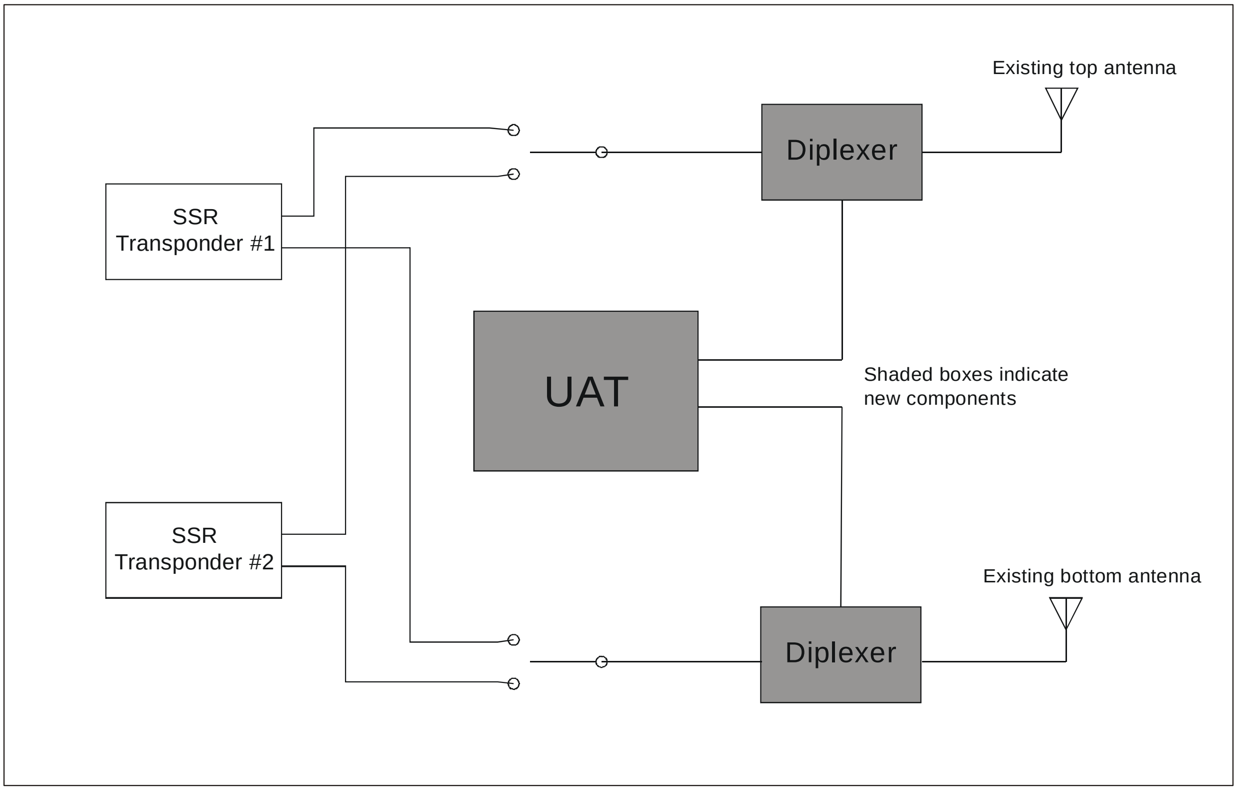


Figure II-G-9. Diplexer installation

Appendix H

SIMULATED RESULTS FOR DELIVERY OF FOUR TRAJECTORY CHANGE REPORTS OVER UAT IN CORE EUROPE 2015

1. INTRODUCTION

1.1 The use of ADS-B for exchange of intent information has been viewed as a possibility that could enable long-range airborne applications such as conflict detection and avoidance. The ADS-B MASPS (RTCA/DO-242A) outlines some guidelines for transmission of some intent information, but does not specify requirements for the transmission of trajectory change reports (TCRs). The current UAT MOPS (RTCA/DO-282B) discuss the transmission of two TCRs. This appendix contains a description of how up to four (4) TCRs may be supported by the UAT system. The purpose is to examine the performance of several potential schemes for transmission of multiple TCRs over UAT, with the intention of facilitating future discussions of broadcasting intent over UAT.

1.2 Three paths for different transmission schemes for Class A3-equipped aircraft were proposed for consideration:

a) changing the current four-second transmission epoch to five seconds, with four TCR messages plus a mode status message;

b) maintaining the four-second epoch, which currently results in a total of twelve TCR transmissions in sixteen seconds (eight TC0 and four TC1) and modifying the current TCR transmission schedule to cycle through 3 or 4 different TCRs; and, finally,

c) re-defining the TCR information, to determine whether the actual data requirements would be less than those currently suggested by RTCA, leading to the possibility of including two TCRs in a single ADS-B message. This last course was not carried out for this analysis.

The results of the analysis using the first two techniques will each be described in more detail in the sections below.

2. INTENT RESULTS USING FOUR-SECOND EPOCH

2.1 Currently, the Class A3 equipage level transmission schedule, as outlined in the Part I, Chapter 2, 2.1.3, and in Part II, Chapter 3, 3.1.1, specifies that the four-message sequence consists of:

a) message type 1, which contains no intent information;

b) two message type 4, which can contain TC+0, the next trajectory change point for the aircraft;

c) message type 5, which can contain TC+1, a second trajectory change point for the aircraft to be reached after TC+0.

2.2 These messages are to be transmitted in the following sequence, over the course of 16 seconds, as indicated in Chapter 3, 3.1.2:

1-4-4-5-5-1-4-4-4-5-1-4-4-4-5-1.

This is done in order to ensure that each message is transmitted and received from both top and bottom antennas in a uniform manner.

2.3 The analysis in this section makes use of the sixteen-message sequence listed above, with the message types 4 and 5 replaced by “any intent message”, so that the sequence becomes:

1-N-N-N-N-1-N-N-N-N-1-N-N-N-N-1,

with N representing a message containing the information for a trajectory change report, with N=4 (TC+0), 5 (TC+1), 7 (TC+2), or 8 (TC+3). Intent messages to be transmitted are cycled in order. This means that for four TC transmissions, the scheduler cycles through 4-5-7-8 as it reaches each N message, while for three TCs, it cycles through 4-5-7. This scheme results in three of each TC being transmitted every 16 seconds for the four-TC case, and four of each TC going out every 16 seconds for the three-TC case.

2.4 The multi-aircraft UAT simulation (MAUS) was run to assess received TCR performance for these two cases, and the results are summarized in Figure II-H-1. These simulation runs were made for a Class A3 receiver over Brussels (in the Core Europe 2015 air traffic scenario with all aircraft equipped with UAT and including JTIDS/MIDS and DME interference) receiving Class A3 intent transmissions. Since each TC is transmitted in the same pattern, the data were accumulated to show the TC 95th percentile update time for receiving any of the four TCRs as a function of range. The dashed line represents guidance on desired TCR reception provided by Eurocontrol, while the solid line is the requirement of the RTCA/DO-242A, ADS-B MASPS, for the TCR containing the TC+0 information.

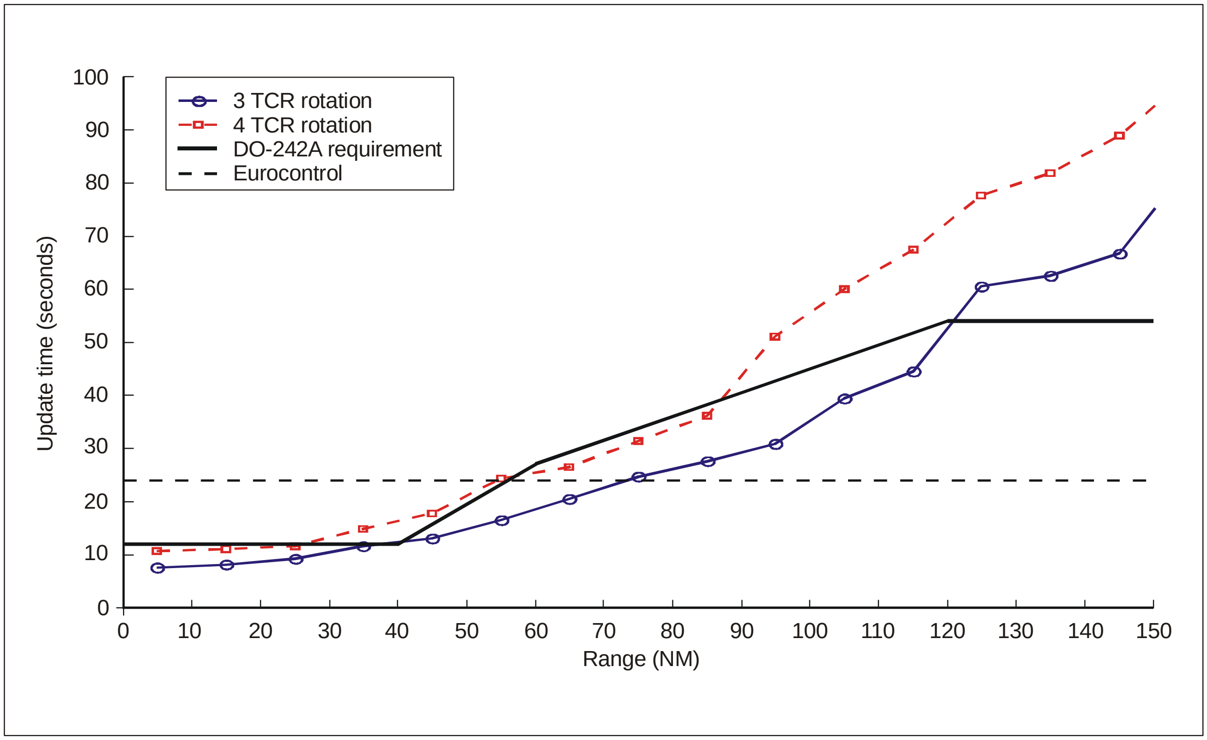


Figure II-H-1. 95th percentile trajectory change report update times for an A3 receiver at high altitude in CE 2015 over Brussels using TC rotation to deliver messages containing information for 3 or 4 TCRs

2.5 As expected, the three-TC case performs better than the four-TC case, since each message is transmitted more frequently when only three TCs are used. It should be noted that no attempt has been made to optimize TC transmissions.

3. INTENT RESULTS USING FIVE-SECOND EPOCH

3.1 The MAUS was modified to allow for a five-second epoch for transmissions from aircraft equipped with Class A3 UAT avionics, defined with the following sequence:

1-4-5-7-8,

repeated continuously.

3.2 A set of MAUS runs was made using this modified version with the exact same air traffic scenario as described in the previous section: Class A3 reception of Class A3 intent information, over Brussels in the same interference conditions. The results are presented in Figure II-H-2.

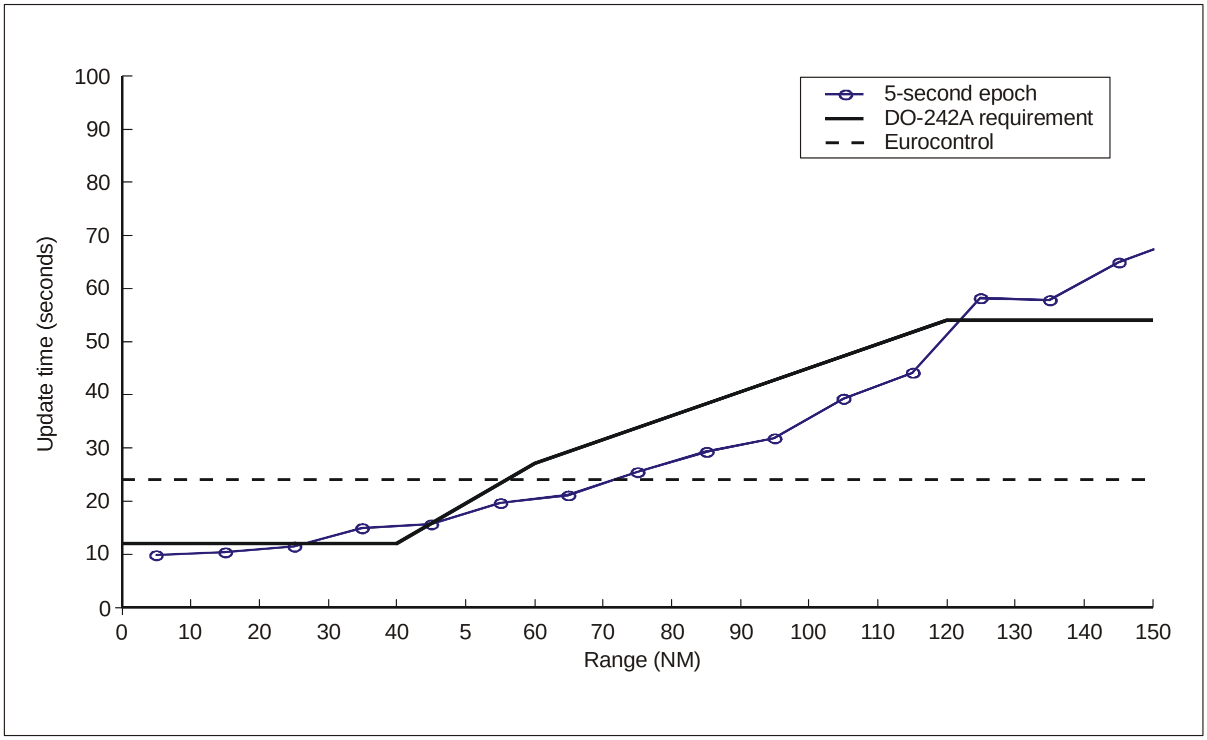


Figure II-H-2. 95th percentile trajectory change report update times for an A3 receiver at high altitude in CE 201 5 over Brussels using a five-second epoch to deliver 4 TC messages

3.3 As in the previous section, these results show the TC 95th percentile update time for receiving any of the four TCRs as a function of range. The dashed line represents the guidance received from Eurocontrol on the desired update rate, while the solid line is the requirement of the RTCA/DO-242A ADS-B MASPS for the TCR containing information on TC+0.

3.4 Figure II-H-3 compares the performance of the two techniques outlined here for the transmission of four TC messages over UAT. Once again, it should be noted that these results represent only an initial attempt to accommodate four TC transmissions. No effort has been made to improve or optimize the techniques used. In addition, reception of intent information by a receiver on the ground has not been studied.

3.5 From Figure II-H-3, it appears that as defined for this analysis, the five-second epoch technique used produces better results than that used with the four-second epoch. This might have been anticipated, since the five-second epoch results in three repetitions of each TCR every 15 seconds, while the four-second epoch supplies three copies of each TCR every 16 seconds. These results supply a rough guideline for comparing the two techniques. It should be noted that the use of the five-second epoch results in the transmission of mode status information, once every five seconds instead of once every four seconds. The operational impact, if any, of this difference has not been evaluated.

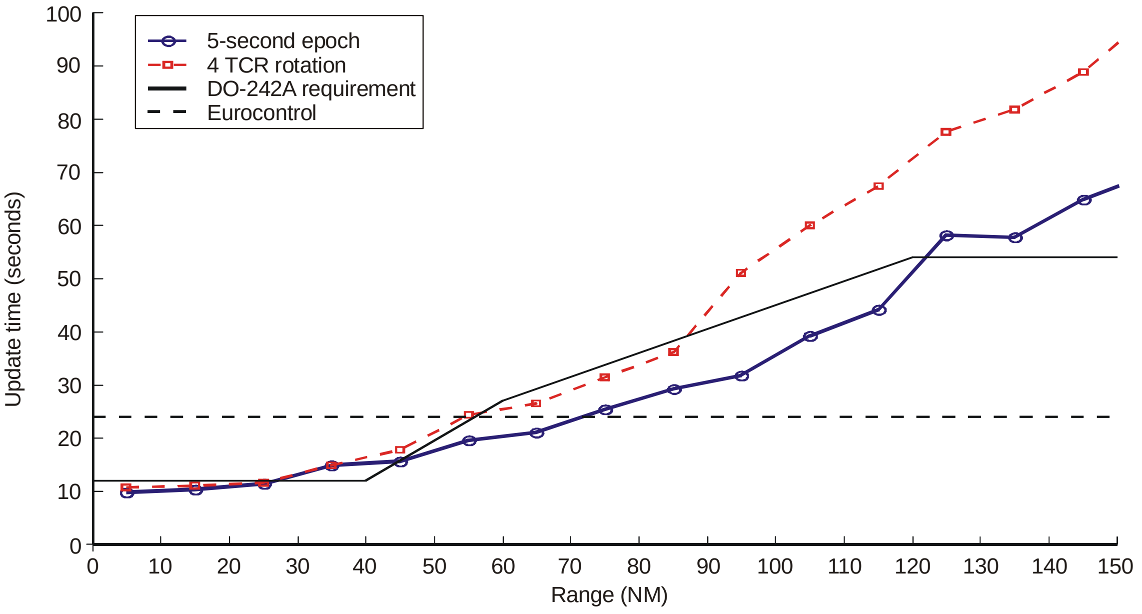


Figure II-H-3. 95th percentile target change report update times for an A3 receiver at high altitude in CE 2015 over Brussels comparing both methods for delivering 4 TC messages

Appendix I

UAT GROUND STATION DATA CHANNEL ASSIGNMENT GUIDANCE

1. INTRODUCTION

1.1 This appendix describes one method that could be used to coordinate the assignment of uplink resources from UAT ground stations within a region. In developing this assignment method, the guiding operational objective was limited to providing a user with connectivity to at least one ground station (GS) at any point within the combined service area of the network. Additionally, it is assumed this GS need not be any particular ground station — each ground station will transmit products of interest to any user likely to receive them. Finally, this assignment method relies on horizon blockage of the undesired signal rather than relying on a specific desired to undesired (D/U) signal ratio.

1.2 In order to maximize the volume of airspace within which aircraft equipped with UAT receivers can receive uplinked information from the GS, the location of the GS must be carefully chosen. In addition, the service volume depends critically on the way the ground uplink segment resources (32 data channels) are distributed among the GS. One or more data channels assigned to a UAT ground station is called the station's "data channel block" (DCB). The reason this maximization is not trivial is that there are two conflicting criteria that must be satisfied. In order to provide low-level coverage, GS must be spaced closely together due to line-of-sight (LOS) considerations. On the other hand, aircraft at high altitudes will see many of the closely-spaced GS. Thus, in order to avoid unwanted interference, all the GS within view of a particular aircraft should, to the degree possible, use separate DCBs. This means that if a wide range of altitudes is to be supported, there may need to be many different DCBs. However, the number of such sets is very limited. Assume, for the moment, that each GS has four data channels' worth of information to transmit each second (see 2.2 for a discussion of unequal DCBs). In that case, there will be only 8 DCBs. In what follows it will be shown that the way these DCBs are assigned to the GS can have a profound impact on the overall system performance.

1.3 In Section 2 an ideal case where the Earth is assumed to be a smooth sphere and where ground sites can be freely chosen to be on a nearly perfect hexagonal grid is considered. In Section 3 a more realistic approach is considered, where siting is constrained and terrain effects come into play.

2. IDEAL CASE

2.1 There are well-known rules for assigning resources on a hexagonal grid. Normally, the resource is a frequency assignment, but in this case it is a DCB assignment. The rules are the same. There are certain allowable patterns such as the 7-fold pattern commonly used in cellular telephone systems. All the patterns employ a number of separate resources given by:

$$N = m^2 + mn + n^2$$

where *m* and *n* are any two non-negative integers. Below, the focus will be on patterns with N = 3, N = 4 and N = 7. Each pattern will be referred to by its value of N. For instance pattern (7) corresponds to *m* = 2 and *n* = 1.

2.2 Figure II-I-1 shows pattern (4). (Only part of the grid is filled out. The remainder should be obvious.) The DCB assignments are labelled A, B, C and D. Note that two of the A cells have been singled out by colouring them red and blue. These two have the potential to interfere with one another; however, if the distances and altitudes are such that the radio horizon of the blue cell (shown as the blue circle) lies entirely outside the red cell, it will not materially interfere with reception from the red ground site within the red cell. If the intersite distance is D, then the radius of the blue circle is 3 *D*/2, and the radius of the red circle is *D*/√3. These two radii can be related to the highest altitude (service ceiling) of the cells that provides no interference and the lowest altitude of the cells that has complete coverage (service floor). These are given by:

$$\frac{3D}{2} = 1.23\sqrt{H_c}$$
$$\frac{D}{\sqrt{3}} = 1.23\sqrt{H_f}$$

with *H* given in feet and *D* given in nautical miles. In this case the ratio of the service ceiling to the service floor is just:

$$\frac{H_c}{H_f} = \frac{27}{4}.$$

Thus, if the service ceiling height were 54 000 feet, the service floor would be at 8 000 feet.

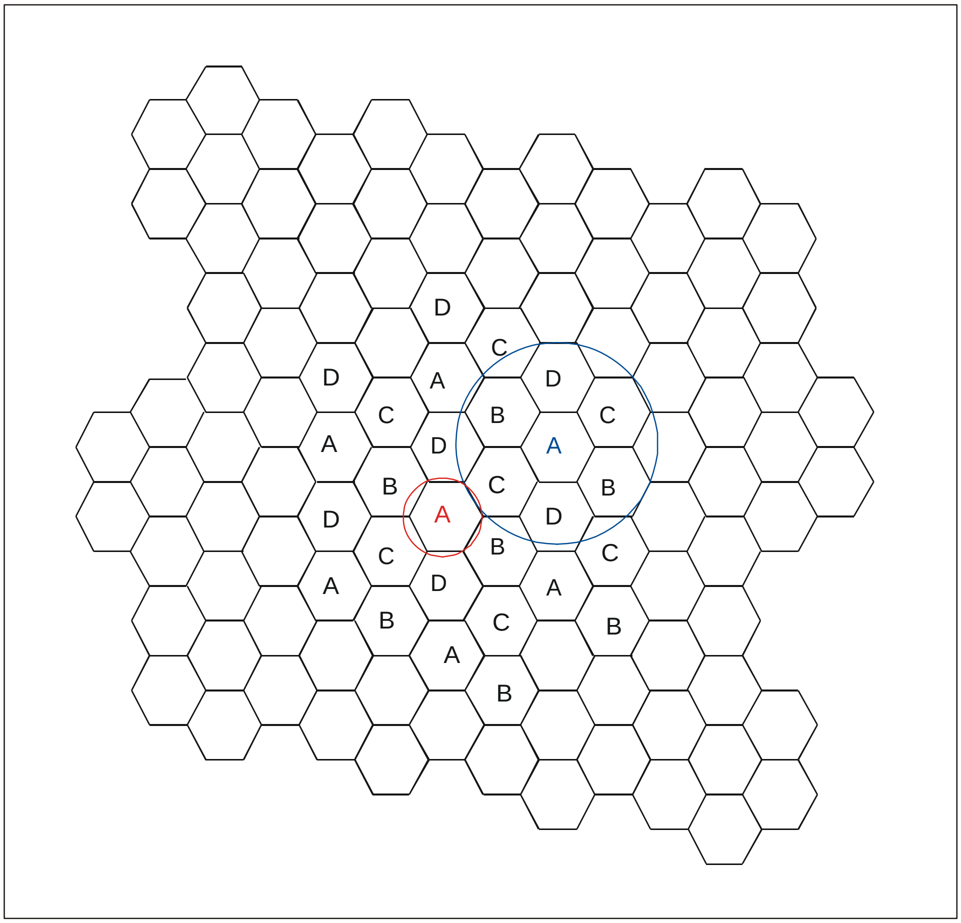


Figure II-I-1. Basic pattern (4)

2.3 A similar analysis for pattern (7) shows that the ratio of service ceiling to service floor would be 13. For example, if the service ceiling were 39 000 feet the service floor would be 3 000 feet. This may appear to be the limit of service floor/ceiling performance given the restriction to no more than 8 DCBs; however, there is a way to extend this range by adopting a tiered approach.

2.4 Suppose, for example, that there is an array of widely-spaced GS in pattern (4) to cover an upper tier (tier 1) from 54 000 feet to 8 000 feet (as above). A second set of sites that are more closely spaced can then be used to fill in the low-level gaps in coverage provided by the first set. The second layer of coverage is called tier 2. If tier 2 is also laid out in pattern (4), the result may appear as shown in Figure II-I-2. This pattern is designated pattern (4, 4). The sites supporting tier 1 are given upper-case letters, and the sites supporting tier 2 are given lower-case letters.[1]. Note that only the letters a, b and c are used in Figure II-I-2, making it appear as though this would be more correctly called a pattern (4, 3). However an important point is that sites that support tier 1 also support tier 2. In other words, if the upper-case letters are replaced with the letter “d”, the result is pattern (4). The fact that the potential “d” sites employ 4 different DCBs will only lower the possibility of interference between them (below the lowered service ceiling of tier 2). (See Section 3 for further explanation.)

Note.—The tier 1 cells (capital letters) serve double duty; they also form the fourth DCB of tier 2, thus the designation as pattern (4, 4).

2.5 If D_1 is the intersite spacing of the tier 1 cells and D_2 is the intersite spacing of the tier 2 cells, then

$$D_2 = D_1/2.$$

It is critical to note that the service ceiling of the tier 2 sites is 13 500 feet and the service floor is at 2 000 feet. Because the service floor of tier 1 is lower than the service ceiling of tier 2, there are no gaps in coverage. Also, the total range of altitudes covered is larger than the range provided by the single-tiered approach using pattern (7).

2.6 An exhaustive search of all the possible tiered patterns using no more than 8 DCBs shows that the best GS layout is given by the three-tiered array designated as pattern (4, 3, 3). This uses all 8 available DCBs. (Recall that each of the lower tiers uses only two additional DCBs.) If the spacing between the closest sites is 60.25 NM, the pattern provides gapless coverage for all altitudes from 800 feet to 48 600 feet (a ratio of 60.75).

3. ALTERNATIVE VIEW OF THE IDEAL CASE

3.1 In the previous section, a top-down description of the proposed pattern (4, 3, 3) was provided. It may be instructive to include a description from the bottom up. Figure II-I-3 shows a standard set of pattern (3) hexagons labelled 1, 2 and 3. These will constitute the tier 3 sites. If they are separated by 60.25 NM they will provide coverage from 800 feet to 3 200 feet.

3.2 For coverage above 3 200 feet, the sites labelled 3 in Figure II-I-3 are re-labelled as a, b or c as shown in Figure II-I-4. These tier 2 sites are separated by 104.35 NM and provide coverage from 2 400 feet to 9 600 feet.

3.3 Finally, tier 1 is constructed by re-labelling the tier 2 sites labelled c with A, B, C or D to give Figure II-I-5. These tier 1 sites are separated by 180.75 NM and provide coverage from 7 200 feet to 48 600 feet. Figure II-I-6 illustrates the general shape of the effective service volumes of cells from each tier.

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[1] To this point DCBs have been consistently referred to using only capital letters. Within the remainder of this appendix, the concept of groups of DCBs (each oriented to altitude tiers) is developed. To clearly delineate each of these groups, capital letters, small letters and numbers are all used to represent DCBs belonging to three groups (tiers).

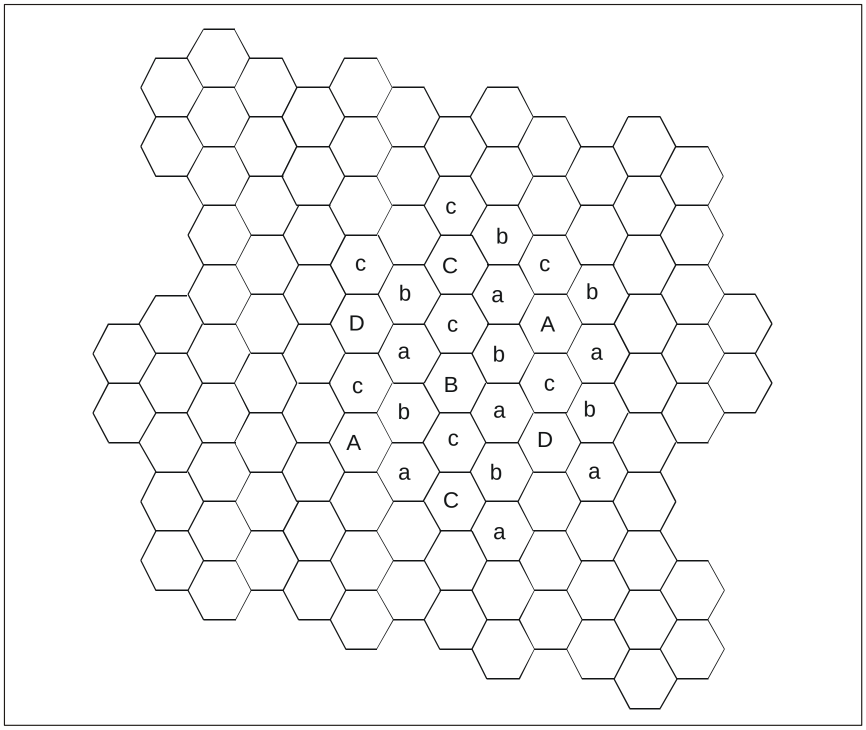

Figure II-I-2. The (4, 4) pattern for tiers 1 and 2

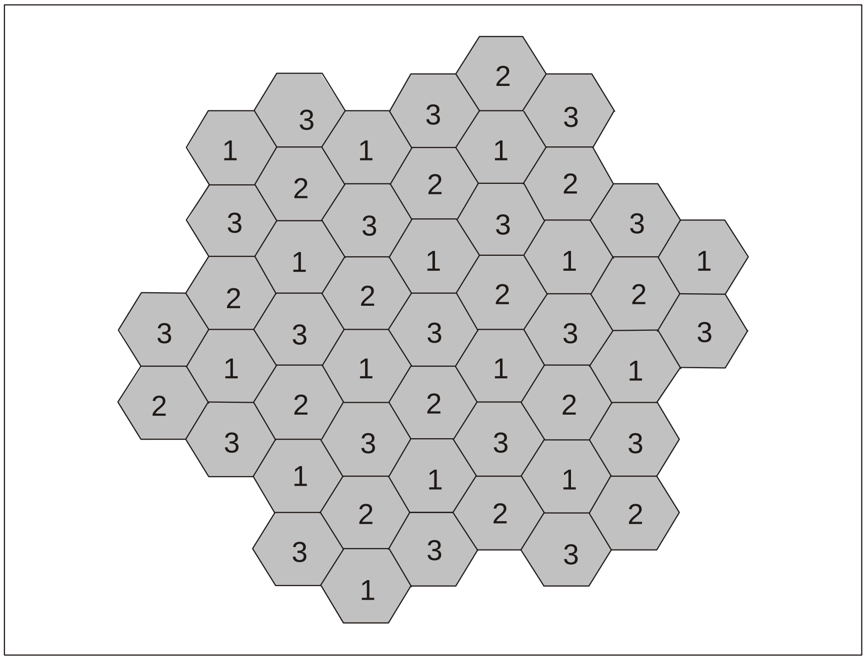

Figure II-I-3. Tier 3 of pattern (4, 3, 3)

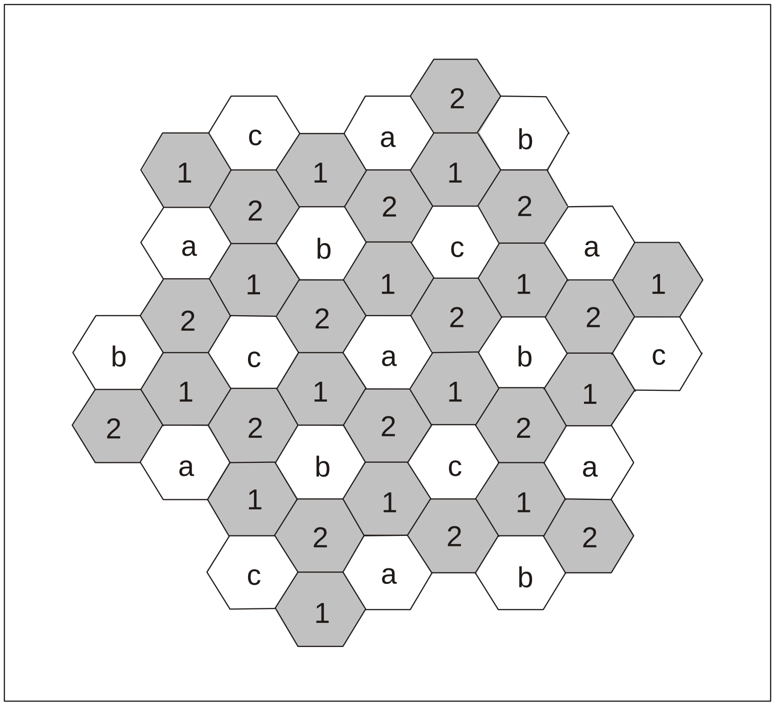

Figure II-I-4. Tiers 2 and 3 of pattern (4, 3, 3)

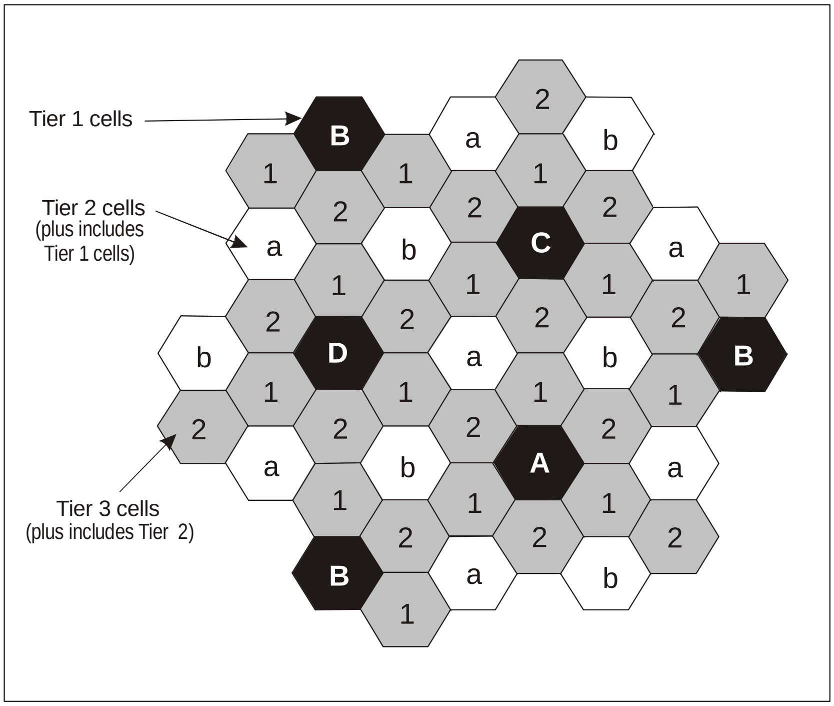

Figure II-I-5. Complete pattern (4, 3, 3)

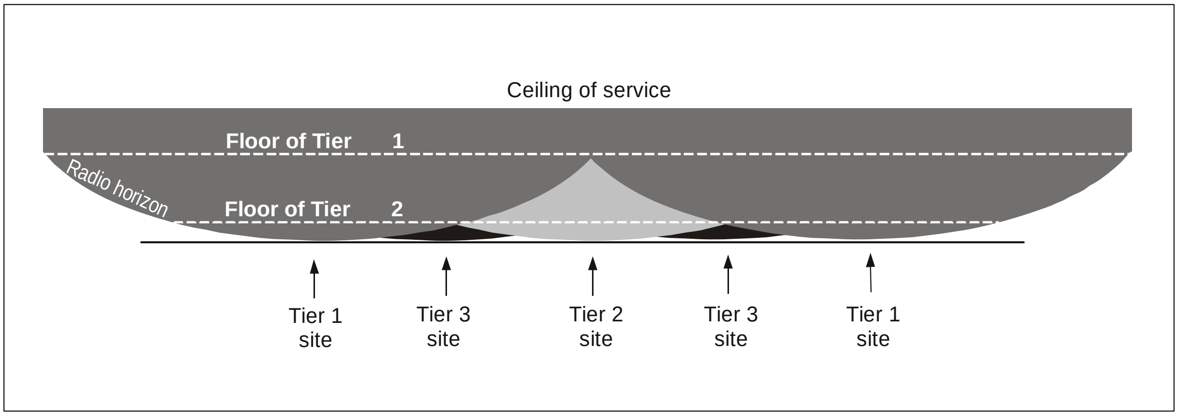

Figure II-I-6. Conceptual view of uplink service volume in cross section

4. ALTERNATIVE DCB ASSIGNMENTS

4.1 Up to this point it has been assumed that the DCBs assigned to the different ground sites all have the same capacity, i.e. they all consist of 4 data channels. However, it seems likely that the sites servicing the larger volumes (the higher tiers) will have more information to convey. Thus, it may be advantageous to assign the capacity unevenly. For example, for the pattern (4, 3, 3) the numbers of data channels assigned per site might be 5, 4 and 2 (going from tier 1 to tier 3). If that were the case, then the total number of data channels assigned would be 5 x 4 + 4 x 2 + 2 x 2 = 32; all the data channels would be assigned to one type of site or another.

4.2 In the original case where each DCB consists of 4 data channels, the data channels assigned to each DCB can always be allocated to GS so that in each second individual GS can transmit on a schedule with evenly-spaced transmissions 8 data channels apart. This will ease the uplink transmitter design by keeping the short-term duty factor low. However, for the 5-4-2 plan described in 4.1, this is not possible. For this data channel usage plan the schedule in Table II-I-1 ensures that successive transmissions from any GS are no closer than 6 data channels. (Data channels are numbered from 1 to 32.) Of course, the actual slots are rotated on a second-by-second basis according the rules of Part I, Chapter 3, 3.2.2.2.

Table II-I-1. Data channel mapping to DCB for the 5-4-2 plan

DCB	*Data channel*
1	1, 17
2	9, 25
a	3, 11, 19, 27
b	7, 15, 23, 31
A	5, 12, 18, 24, 30
B	2, 8, 14, 21, 28
C	4, 10, 16, 22, 29
D	6, 13, 20, 26, 32

4.3 In an actual deployment, site selection for UAT will tend to be limited to ground locations that are already available to the service provider. Also, varying terrain may enhance radio line-of-sight (LOS) range if a site is at a high elevation or limit it if a site is surrounded by mountains, for example. Thus, the coverage of the ground sites will be anything but regular, and a perfect cellular layout will not be possible. Nevertheless, it seems that the method of providing a tiered approach may still be a good one. The question is how to most efficiently construct the tiers.

4.4 Important parameters that will determine the solution of the data channel assignment problem are the desired service ceiling and service floor altitudes. The achievable service floor is largely determined by the intersite spacing. If the spacing between any two sites is large, the bottom of the coverage between them will be high. To achieve a low service floor will require close spacing. That, in turn, may require a large number of ground sites to cover a given geographical region. Of course, low-level coverage may be necessary only in selected locations, so the number of sites could be reduced. On the other hand, the effects of terrain variation may increase the number of sites needed.

4.5 One strategy for data channel assignment would be to begin with all the available sites and attempt to create tier 1. An initial site for assignment of DCB "A" could be chosen near the edge of the overall coverage area, and then a second site could be chosen such that its LOS did not impinge upon the desired service volume of the initial site and the LOS of the initial site did not impinge upon the desired service volume of the second site. To do this it is necessary to define what is meant by the "desired service volume" of a site. That depends on the ideal pattern being approximated. Suppose it is pattern (4, 3, 3). If the target tier 3 intersite distance, D_3, is taken to be 60.25 NM (as in Section 2), then the next reuse of DCB "A" would be about $2D_1 = 6D_3 = 361$ NM away, and the desired LOS would be somewhere between $D_1/2 = 90$ NM and $D_1/\sqrt{3} = 104$ NM. Choose the closest site that meets the non-interference criteria. The next site to use DCB "A" should be the one of the remaining sites that is closest to the first two and also obeys the non-interference criteria. In this case "closest" could mean the one for which the sum of the distances to the two nearest sites using DCB "A" is the least. This process should continue until no more DCB "A" sites can be assigned. This process should then be repeated using B, C and D DCBs. When choosing these sites, care should be taken to pick locations that most closely approximate the desired hexagonal effect. If all goes well, this process will provide total coverage from 48 600 feet down to an altitude below the service ceiling of tier 2. Tier 2 can now be populated using a similar method. For selected locations that need particularly low-altitude coverage, tier 3 locations can also be identified using similar techniques.

5. AN IMPLEMENTATION EXAMPLE

The process described in the previous plan has been used on a limited basis to make DCB assignments for a deployment of 30 GS in the southeastern part of the United States. Using the top-down approach it was relatively easy to define the tier 1 sites with the proper spacing. The tier 2 sites were more difficult to define since the available sites were not evenly distributed geographically. It was nearly impossible to assign tier 3 sites according to the rule of the ideal model. These were assigned on a more ad hoc basis by trying to maximize the distance between any two sites using the same slot set, independent of their relation to the pattern of the top two tiers. The performance of the resulting assignment plan can be judged by observing the coverage at altitudes of 40 000 feet, 10 000 feet and 3 000 feet shown in Figures II-I-7, II-I-8 and II-I-9. The shaded portions denote areas with coverage by at least one GS. Note that at the highest altitude the coverage is determined with respect to altitude above mean sea level (AMSL), while the coverage at the lower two altitudes was above ground level (AGL). In these figures terrain effects have been taken into account, which explains the sometimes irregular shapes of the individual service volumes.

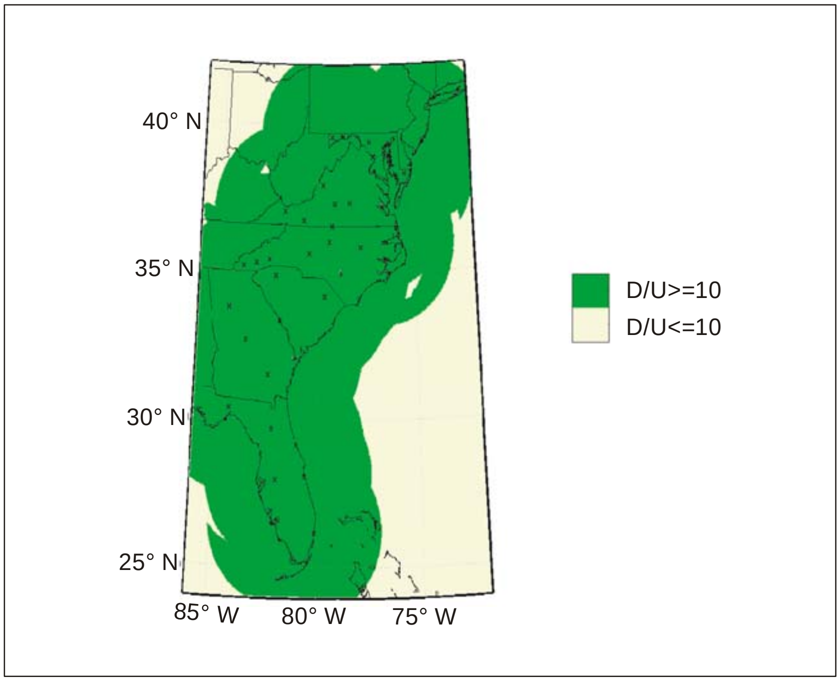

Figure II-I-7. USA East Coast coverage at 40 000 feet AMSL

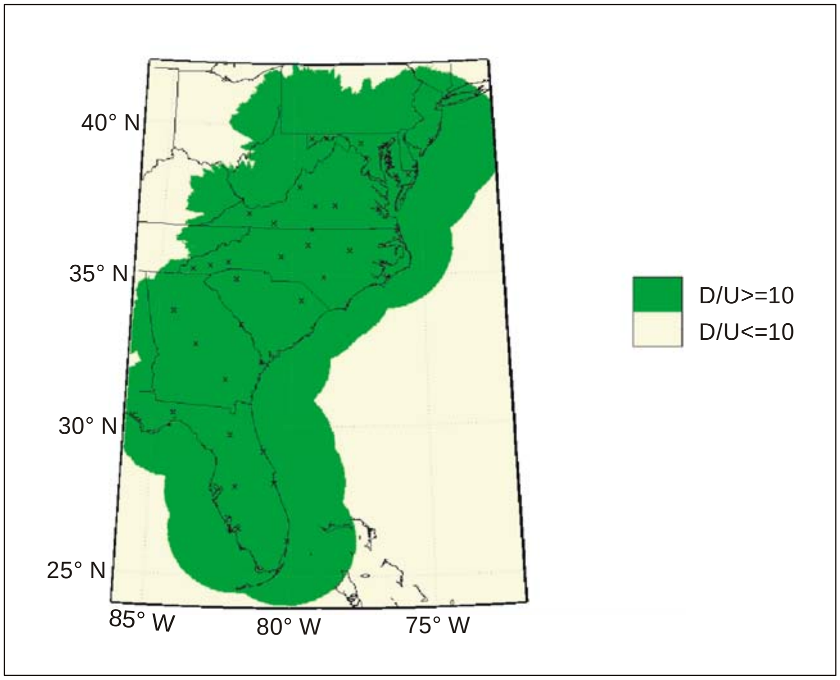

Figure II-I-8. USA East Coast coverage at 10 000 feet AGL

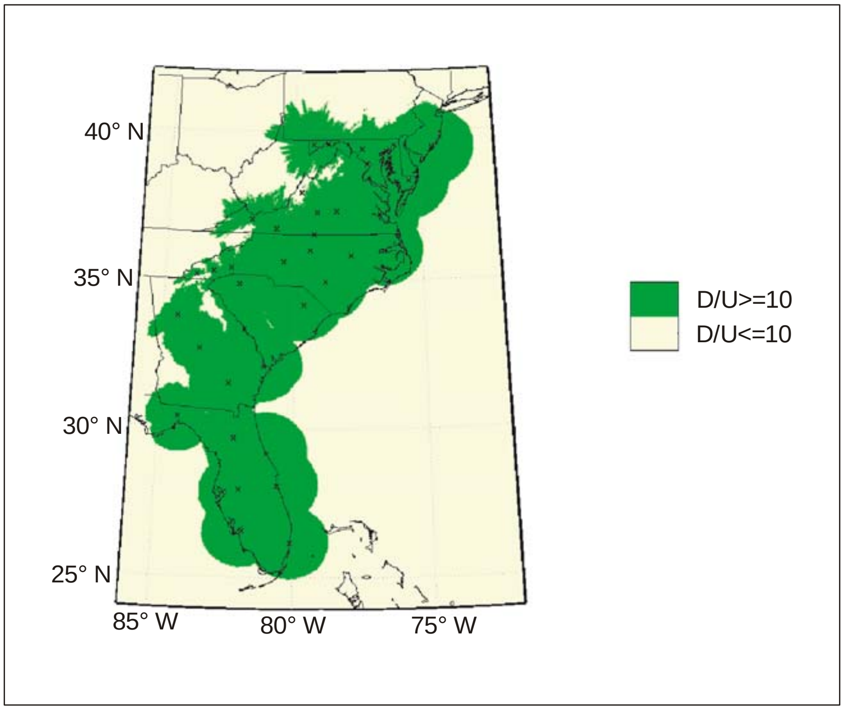

Figure II-I-9. USA East Coast coverage at 3 000 feet AGL

Appendix J

FUTURE RANGE VALIDATION OF UAT MESSAGES

1. BACKGROUND

1.1 Part I of this manual contains timing requirements related to both the transmission of UAT ADS-B messages and reception of UAT ADS-B and UAT ground uplink messages. These timing requirements ensure the separation of the UAT ground uplink segment and UAT ADS-B segment and also synchronize MSO timing. The primary objective of the timing resolution in these requirements is to support a future capability of range measurement between UAT ADS-B transmitting and receiving subsystems that is independent of the ADS-B reported position data. This range calculation can be made from knowledge of the precise time of message transmission (TOMT) and time of message receipt (TOMR) of UAT ADS-B messages. An ADS-B validation technique can compare this one-way time of propagation range measurement with the range determined from the UAT ADS-B message to increase confidence that the message came from a bona fide transmitter. As an example, certain pairwise procedures may only be authorized when the range to the other aircraft in the pair passes appropriate validation tests.

1.2 This ADS-B validation technique should only be used in cases where both the transmitting and receiving stations are UTC-coupled, that is, they are receiving time from a GPS/GNSS source or equivalent. A non-UTC coupled condition can occur due to a temporary unavailability of the GPS/GNSS source or equivalent. At any given time, a UAT transmitter is obligated to announce whether or not it is in the UTC-coupled condition.

1.3 The purposes of the following sections are to:

a) document the expected total installed end-to-end timing performance as guidance to UAT installers and to developers of ADS-B validation applications;

b) provide rationale for the timing-related requirements given in Part I of this manual in the context of the expected total installed performance;

c) list additional considerations for developing ADS-B validation techniques.

2. INSTALLED END-END TIMING PERFORMANCE

2.1 Listed below are the identified components of possible timing errors and their assumed worst-case values using the GPS component of GNSS as an example.

a) *Errors due to the GPS signal in space.* This is assumed bounded by the performance specifications of the GPS standard positioning service with SA OFF. Uncertainty range = –100 to +100 ns.

b) *GPS antenna and coax effects.* This is assumed bounded by a 20-metre maximum installed cable length. Uncertainty range = 0 to +66 ns.

c) *GPS-UTC time offsets.* This is applicable to GPS receivers that output GPS time instead of UTC time. Since GPS sensors that may be used for ADS-B are not required to make the UTC correction, this offset must be included. The GNSS SARPs in Annex 10, Volume I, Appendix B, 3.1.4, allow GPS time to deviate from UTC time by up to 1 microsecond. This is expected to be very conservative. Uncertainty range = –1000 ns to +1000 ns.

d) *Delays due to interconnection of GPS sensor and UAT.* This component applies to installations with a UTC-coupled time source that is external to the UAT equipment. Allowance is needed for delays induced in lightning protection filters and interconnect cable capacitance between the GPS/GNSS sensor and the UAT. Total uncertainty range based on tests performed by an avionics manufacturer has been determined to be equal to 0 to +800 ns.

e) *UAT Tx/Rx time errors.* These are errors due to control of transmitter turn on and marking message time of arrival within the receiver. An uncertainty range specifically for this component is established in Part I of this manual. Uncertainty range = –500 ns to +500 ns.

f) *UAT antenna/coax effects.* This is assumed bounded by a maximum installed cable length and optional use of a diplexer. Uncertainty range = 0 to +66 ns.

2.2 Table II-J-1 shows the worst-case timing offset possible between a transmitting UAT ADS-B system participant and a receiving UAT ADS-B system participant given the individual error components listed above. This suggests that a value just under 0.7 NM would represent the absolute worst-case range measurement error due to timing offsets between transmitter and receiver under normal (UTC-coupled) conditions.

2.3 For comparison, note that if both the transmitter and receiver use GPS time where the GPS receiver is internal to the UAT equipment, then two of the major components, (c) and (d) in Table II-J-1, of timing offset error are largely eliminated. In this case the absolute worst-case range measurement error due to timing offsets between transmitter and receiver would be about 0.25 NM.

Table II-J-1. Worst-case timing offset

Error component	*Transmitting ADS-B system participant (nanoseconds)*		*Receiving ADS-B system participant (nanoseconds)*		*Worst-case transmitter-to-receiver relative timing offset (nanoseconds)*	
	Min.	*Max.*	*Min.*	*Max.*	*Min.*	*Max.*
a) GPS signal in space	–100	+100	–100	+100	–200	+200
b) GPS cable delay	0	+66	0	+66	–66	+66
c) GPS-UTC time offset	–1 000	+1 000	–1 000	+1 000	–2 000	+2 000
d) GPS-UAT interconnect delay	0	+800	0	+800	–800	+800
e) UAT Tx time accuracy	–500	+500	N/A	N/A	–500	+500
f) UAT Rx time stamp accuracy	N/A	N/A	–500	+500	–500	+500
g) UAT cable delay	0	+66	0	+66	–66	+66
Total worst-case of all components →					–4 132	+4 132

3. UAT TIMING REQUIREMENTS

There are essentially two requirements in Part I of this manual related to timing: one related to control of UAT ADS-B message transmission and one related to time-stamping of message receipt. The requirements are treated separately depending on whether the UTC time source is internal or external to the UAT equipment.

3.1 Message transmission timing

Part I, Chapter 3, 3.1.2.2, specifies the requirement for UAT ADS-B message transmission timing:

a) When an internal UTC time source is used, the requirement and test is designed to verify uncertainty components c) (GPS-UTC) and e) (UAT Tx time). This is accomplished by applying an actual or simulated GPS input to the UAT such that the GPS signal presents minimal timing uncertainty. The maximum timing error allowed is 500 nanoseconds.

b) When an external UTC time source is used, the requirement and test is designed essentially to account only for part of component d) (GPS interconnection delays) and component e) (UAT Tx time). This is accomplished by applying a test 1 PPS or time mark input that is essentially free of uncertainty components a), b), c) and most of d). The maximum timing error allowed is 500 nanoseconds.

3.2 Accuracy of time stamping on message receipt

Part I Chapter 5, 5.1.1, specifies the requirement for time-stamping of received messages:

a) When an internal UTC time source is used, the requirement and test is designed to verify uncertainty components c) (GPS-UTC) and e) (UAT Rx time stamp). This is accomplished by applying an actual or simulated GPS input to the UAT such that the GPS signal presents minimal timing uncertainty. The maximum timing error allowed is 500 nanoseconds.

b) When an external UTC time source is used, the requirement and test is designed essentially to account only for part of component d) (GPS interconnection delay) and component e) (UAT Rx time stamp). This is accomplished by applying a test 1 PPS or time mark input that is essentially free of uncertainty components a), b), c) and most of d). The maximum timing error allowed is 500 nanoseconds.

4. CONSIDERATIONS FOR ADS-B VALIDATION TECHNIQUES

4.1 Receiver time of message receipt (TOMR)

4.1.1 Part I of this manual details the requirements for accuracy and resolution of making the raw measurements on which a range calculation can be made. TOMR is relative to the start of the UTC second and is reported in units of 100 nanoseconds.

4.1.2 The UAT receiver, or an external application, can directly calculate the range to the target by knowing how many whole and fractions of an MSO (250 microseconds) elapsed between transmission and receipt of the message. The fractional portion is directly calculated from each state vector (SV) report received, which gives fine-scale resolution to about 30 metres (100 nanoseconds unit size times 3.0E+8 metres per second). The integer portion provides resolution of about 40.47 NM (250 microseconds times 3.0E+8 metres per second). The UAT ADS-B message contains the six least-significant bits of the MSO number used for its transmission.

4.2 Acquisition of full TOMR range

4.2.1 The full TOMR range (integer and fractional parts) can be determined once a long UAT ADS-B message containing the transmission epoch field has been received (the long type 1 UAT ADS-B message). The transmission epoch field has sufficient span to unambiguously identify in which MSO the message was transmitted. The receiving UAT or the external application can then calculate the integer portion of the TOMR and derive the full TOMR value.

4.2.2 Once the full TOMR range has been acquired, the fractional portion can be used to maintain a track of the range value during the interval between receipt of a message containing the transmission epoch.

4.3 TOMR range filtering

The raw TOMR range values will likely require some filtering prior to use. An alpha-beta recursive filter, which allows for uneven time between message receptions (because of dropped messages, etc.) can be used to both smooth and predict range values.

4.4 Correlation of TOMR range versus SV-based range

4.4.1 *Slant range.* The filtered range value includes the slant range effects and will normally exceed the great-circle range calculated from the SV position of the target and the ownship SV position. The correlation of the target's range will require either some compensation of the great-circle range to include an estimate of the slant range, or a correlation window that has greater tolerance for increased slant range at high elevation angles. Since it is possible that some targets may not be reporting their altitude, provision must be made for cases where slant range compensation is not possible.

4.4.2 *Data link latency.* One other phenomenon affecting the TOMR range calculation is that the range measured is based on the time of transmission, while the SV-based range calculation is based on the message time of applicability. This can lead to some additional variation between the measured and calculated range, which would be particularly noticeable in head-on or reciprocal encounters at high velocity. For example, at a closing rate of 1 200 knots, the range closes at about 620 metres per second. The range differential amounts to, at most, 0.33 NM.

4.4.3 Note that for a given pair of aircraft, most of the timing errors can either be compensated for, or are fixed intervals. This allows the possibility that the residual range differential (after removal of fixed or compensable errors) could be used as an independent means of closure rate measurement.

Appendix K

REQUIREMENTS AND DESIRABLE FEATURES FOR THE UNIVERSAL ACCESS TRANSCEIVER (UAT) SYSTEM

1. INTRODUCTION

This appendix is divided into the following subsections:

a) general characteristics and functional capabilities of the universal access transceiver (UAT) that are considered essential;

b) UAT support of the automatic dependent surveillance — broadcast (ADS-B) function for both air-to-air and air-to-ground applications; and

c) UAT support of ground uplink services related to surveillance and situational awareness.

2. GENERAL UAT CHARACTERISTICS AND FUNCTIONAL CAPABILITIES

2.1 No degradation of safety

A fundamental requirement is that any new system shall not cause a degradation in safety when introduced; however, there is an overall objective to improve safety.

2.2 System capacity

UAT capacity must be sufficient to support its intended functions in future high-density air traffic environments with realistic self-interference/interference environments. UAT should support a capability with sufficient growth potential to support new ADS-B and situational awareness applications as they are understood.

2.3 Low cost of airborne equipment

The system design shall seek to minimize the complexity and cost of the installed airborne system to the minimum level practical compared to present/alternative avionics costs. It is desirable that sharing of existing aircraft transponder antennas be facilitated whenever possible.

2.4 Ground infrastructure

The ground infrastructure required for UAT shall be implementable on an incremental capacity/capability basis, with an acceptable cost and complexity.

2.5 Human/machine interface

The UAT system design shall exhibit a simple human/machine interface for aircrew inputs and for ensuring that error inducing mechanisms are not introduced.

2.6 Minimization of workload

Where possible, UAT functions shall be automated so as not to increase pilot workload.

2.7 Aircraft speed

Air-ground operation

2.7.1 The UAT shall support air-ground communication for aircraft with any ground speed of up to 850 knots.

Air-to-air operation

2.7.2 The UAT shall serve air-to-air communication for aircraft with any relative air-to-air speed of up to 1 200 knots.

2.8 UAT range/coverage

UAT air-to-ground communication for ADS-B shall be supported up to line-of-sight limitations (or at least 150 NM for potential long-range air-to-ground applications) from a single ground station in future high-density environments (e.g. at least Core Europe 2015 and Los Angeles 2020). UAT air-to-air range shall be sufficient to support intended ADS-B and situational awareness applications, including future high-density environments.

2.9 Radio frequency compatibility with existing systems

UAT shall not create interference with existing in-band (960 to 1 215 MHz) systems (e.g. distance measuring equipment (DME) on adjacent channels, JTIDS/MIDS) that degrades the performance of those systems in an operationally significant manner. It is assumed in the end-state that the UAT channel itself will not be used by DME/TACAN in high-density continental airspace. UAT shall be capable of operating to its intended level of performance in the presence of anticipated levels of interference from existing systems.

2.10 Transition

The UAT system design shall provide for an orderly transition to an ADS-B end-state in which the large majority of aircraft are ADS-B-equipped, including future high-density aircraft environments. The UAT system design shall support traffic information services — broadcast (TIS-B) to accommodate ADS-B environments in which multiple ADS-B links are employed.

2.11 Validation of received ADS-B positions

The UAT system shall support a means, without reliance on ground stations, for validating received ADS-B positions, using ownship position in combination with a time-based ranging capability. This capability is primarily directed toward air-to-air use of ADS-B in environments without air traffic service (ATS) ground stations.

2.12 Service availability

The UAT system design shall support a surveillance service availability of 99.999 per cent.

2.13 UAT system integrity

The probability of an undetected error in a UAT transmission shall be no greater than 10^{-8} per ADS-B or ground uplink message.

2.14 Support of all classes of users

The UAT system design shall support multiple configurations (e.g. power, antenna installation) to facilitate ADS-B participation by all classes of airspace users.

3. UAT SUPPORT OF THE ADS-B FUNCTION

3.1 ADS-B requirements

ADS-B information exchange

3.1.1 The UAT system shall support the transmission and reception of state vector (to include position, velocity and identifying information), mode status and intent information from appropriately equipped ADS-B system participants.

State vector (SV)

3.1.2 State vector information shall include at least the following: three-dimensional position, horizontal and vertical velocity, ADS-B participant address, air/ground state and state vector integrity information.

3.1.3 An entire state vector should be included in each UAT transmission. Table II-K-1 provides desired performance for receipt of state vector transmissions for air-to-air ADS-B applications. UAT shall support, including in future high-density airspace, receipt by a single ground station of ADS-B airborne state vector transmissions at a 95 per cent update interval of 5 seconds for aircraft within 60 NM and 12 seconds for aircraft within 150 NM.

Mode status information exchange

3.1.4 Mode status information includes ADS-B emitter category information, call sign, state vector accuracy information, UAT equipment capability codes, operational mode information and an integrity indication for barometric information.

3.1.5 Table II-K-2 provides desired performance for the acquisition of mode status information transmissions to support air-to-air ADS-B applications. Consistent with these application needs, acquisition of mode status information by UAT ground stations should be achieved, at the 95th percentile, within 20 seconds for aircraft within 60 NM and 48 seconds for aircraft within 150 NM.

Table II-K-1. State vector accuracy, update interval and acquisition range requirements

Operational domain →	Terminal, en route and oceanic/remote non-radar ↓				Approach ↓	Airport surface ↓ (Note 4)
Applicable range →	R ≤ 10 NM	10 NM < R ≤ 20 NM	20 NM < R ≤ 40 NM	40 NM < R ≤ 90 NM	R ≤ 10 NM	(R ≤ 5 NM)
Equipage class → (Note 5)	Appropriate	Appropriate	Appropriate	Appropriate	As appropriate	Appropriate
Example applications →	Airborne conflict management (ACM)		Merging, conflict management, in-trail climb	Long-range conflict management	AILS, paired approach	Surface situational awareness
	Enhanced visual acquisition	Station keeping				
Required 95th percentile SV acquisition range	10 NM	20 NM	40 NM (Note 12) (50 NM desired)	90 NM (Notes 3, 10) (120 NM to 150 NM desired)	10 NM	5 NM
Required SV nominal update interval (95th percentile) (Note 5)	≤ 3 s (3 NM) (1 s desired, Note 2) ≤ 5 s (10 NM) (Note 11)	≤ 5 s (10 NM) ≤ 7 s (20 NM)	≤ 7 s (20 NM) ≤ 12 s (40 NM)	≤ 12 s	≤ 1.5 s (1 000 ft runway separation) ≤ 3 s (1 s desired) (2 500 ft runway separation)	≤ 1.5 s
Required 99th percentile SV received update period (coast interval)	≤ 6s (3 NM) ≤ 10 s (10 NM) (Note 11)	≤ 10 s (10 NM) ≤ 14 s (20 NM)	≤ 14 s (20 NM) ≤ 24 s (40 NM)	≤ 24 s	≤ 3s (1 000 ft runway separation) (1 s desired, Note 2) ≤ 7s (2 500 ft runway separation)	≤ 3 s
Example permitted total SV errors required to support application (1 sigma, 1D)	σ_{hp} = 200 m σ_{hv} = N/A σ_{vp} = 32 ft σ_{vv} = 1 fps	σ_{hp} = 20 m / 50 m (Note 1) σ_{hv} = 0.6/ 0.75 m/s (Note 1) σ_{vp} = 32 ft σ_{vv} = 1 fps	σ_{hp} = 20/ 50 m (Note 1) σ_{hv} = 0.3/0.75 m/s (Note 1) σ_{vp} = 32 ft σ_{vv} = 1 fps	σ_{hp} = 200 m σ_{hv} = 5 m/s σ_{vp} = 32 ft σ_{vv} = 1 fps	σ_{hp} = 20 m σ_{hv} = 0.3 m/s σ_{vp} = 32 ft σ_{vv} = 1 fps	σ_{hp} = 2.5 m (Note 6) σ_{hv} = 0.3 m/sσ σ_{vp} = N/A σ_{vv} = N/A
Max. error due to ADS-B (1 sigma, 1D) (Note 7)	σ_{hp} = 20 m σ_{hv} = 0.25 m/s (Note 8) σ_{vp} = 30 ft σ_{vv} = 1 fps					σ_{hp} = 2.5 m (Note 6) σ_{hv} = 0.25 m/s σ_{vp} = N/A σ_{vv} = N/A

σhp: standard deviation of horizontal position error
σhv: standard deviation of horizontal velocity error
σvp: standard deviation of vertical position error
σvv: standard deviation of vertical velocity error

Notes.—

1. *The lower number represents the desired accuracy for best operational performance and maximum advantage of ADS-B. The higher number, representative of GPS standard positioning service, represents an acceptable level of ADS-B performance, when combined with barometric altimeter.*
2. *A three-second report received update period for the full state vector should yield improvements in both safety and alert rate relative to ACAS, which does not measure velocity. Further improvement in these measures can be achieved by providing a one-second report received update rate. Further definition of ADS-B-based separation and conflict avoidance system(s) may result in refinements to the values in the table.*
3. *The 90-NM range requirement applies in the forward direction (that is, the direction of the own aircraft's heading). The required range aft is 40 NM. The required range 45 degrees to port and starboard of the own aircraft's heading is 64 NM. The required range 90 degrees to port and starboard of the own aircraft's heading is 45 NM. (The 120-NM desired range applies in the forward direction. The desired range aft is 42 NM. The desired range 45 degrees to port and starboard of the own-aircraft's heading is 85 NM.)*
4. *The requirements apply to both aircraft and vehicles.*
5. *Equipage classes may be defined, with differing performance levels, to satisfy the needs of particular types of surveillance and situational awareness applications in particular types of air traffic environments (e.g. low-density en route, medium-density continental, high-density terminal).*
6. *The position error requirement for aircraft on the airport surface is stated with respect to the aircraft's ADS-B position reference point. For further elaboration, see RTCA DO-289, Minimum Aviation System Performance Standards for Aircraft Surveillance Applications.*
7. *This row represents the allowable contribution to total state vector error from ADS-B.*
8. *The requirements on horizontal velocity error (σhv,) apply to aircraft speeds of up to 600 knots. Accuracies required for velocities above 600 knots are to be determined.*
9. *Specific system parameter requirements in Table II-K-1 can be waived provided that the system designer shows that the application design goals or equivalent system level performance can be achieved.*
10. *Air-to-air ranges extending to 90 NM are intended to support the application of flight path deconfliction planning, cooperative separation in oceanic/low-density en-route airspace. The operational concept and constraints associated with using ADS-B for separation assurance and sequencing have not been fully validated. It is possible that longer ranges may be necessary. Also, the minimum range required may apply even in high interference environments, such as overflight of terminal areas with high-density traffic.*
11. *Requirements for applications at ranges less than 10 NM are under development. The three-second update period is required for aircraft pairs with horizontal separation less than 1.1 NM and vertical separation less than 1 000 ft. The three-second update period is also required to support ACM for aircraft pairs within 3 NM lateral separation and 6 000 feet vertical separation that are converging at a rate of greater than 500 feet per minute vertically or greater than 6 000 feet per minute horizontally. The update rate can be reduced to once per 5 seconds (95 per cent) for aircraft pairs that are not within these geometrical constraints and for applications other than ACM. Requirements for ACM are under development. Requirements for future applications may differ from those stated here.*
12. *Separation standards of more than 2 NM may require longer acquisition ranges to provide adequate alerting times.*

Table II-K-2. Mode status accuracy and acquisition range requirements

Operational domain →	Terminal, en route and oceanic/remote non-radar ↓				Approach ↓	Airport surface ↓ (Note 1)
Applicable range →	R ≤ 10 NM	10 NM < R ≤ 20 NM	20 NM < R ≤ 40 NM	40 NM < R ≤ 90 NM	R ≤ 10 NM	(R ≤ 5 NM)
Equipage class →	Appropriate	Appropriate	Appropriate	Appropriate	As appropriate	Appropriate
Example applications →	Airborne conflict management (ACM)		Merging, conflict management, in-trail climb	Long-range conflict management	AILS, paired approach	Surface situational awareness
	Enhanced visual acquisition	Station keeping				
Required 95th percentile MS acquisition range	10 NM	20 NM	40 NM (Note 6) (50 NM desired)	90 NM (Notes 2, 3) (120 NM desired)	10 NM	5 NM
Required 99th percentile MS acquisition range (Notes 4, 5)	8 NM	17 NM	34 NM (Note 6)	N/A	N/A	N/A

Notes.—

1. *Requirements apply to both aircraft and vehicles.*
2. *The 90-NM range requirement applies in the forward direction (that is, the direction of the own aircraft's heading). The required range aft is 40 NM. The required range 45 degrees to port and starboard of the own aircraft's heading is 64 NM (see RTCA/DO-242A, Appendix G). The required range 90 degrees to port and starboard of the own aircraft's heading is 45 NM. (The 120-NM desired range applies in the forward direction. The desired range aft is 42 NM. The desired range 45 degrees to port and starboard of the own-aircraft's heading is 85 NM.)*
3. *Air-to-air ranges extending to 90 NM are intended to support the application of flight path deconfliction planning, cooperative separation in oceanic/low-density en-route airspace. The operational concept and constraints associated with using ADS-B for separation assurance and sequencing have not been fully validated. It is possible that longer ranges may be necessary. Also, the minimum range required may apply even in high interference environments, such as overflight of terminal areas with high-density traffic.*
4. *These requirements are to be met for essential level applications. As these applications are developed, these requirements may be further refined in terms of more stringent ranges and acquisition probability.*
5. *It is assumed that the population for which these acquisition requirements are to be met are aircraft that have been operating and broadcasting MS reports within radio line-of-sight at ranges significantly greater than the acquisition range.*
6. *Separation standards of more than 2 NM may require longer acquisition ranges to provide adequate alerting times.*

Intent Information

3.1.6 Intent information, the third category of ADS-B information after state vector and mode status information, is of two types:

a) target state information (short-term intent based upon either target heading/track angle or target altitude); and

b) trajectory change point information to include at least trajectory change point longitude, latitude, altitude and time-to-go.

Target state information is provided to applications using ADS-B in target state reports (TSRs). Trajectory change point information is provided to applications using ADS-B in trajectory change reports (TCRs).

3.1.7 UAT shall support the transmission and receipt of target state information consistent with Table II-K-3. UAT shall support the transmission and receipt of trajectory change information for an appropriately equipped ADS-B system participant's next trajectory change point (TCR+0) at a 95th percentile update rate of 12 seconds at ranges of up to 40 NM, with the update rate increasing with increasing range to a rate of 56 seconds at a range of 120 NM. It is further desirable that UAT support exchange of information for up to 4 trajectory change points with air-to-air and air-to-ground range of up to 150 NM in future high-density airspace, with such information being received every 24 seconds upon change and every two minutes when such information is not changing, given that information acquisition requirements are met for the ADS-B applications being served.

Table II-K-3. Summary of target state report acquisition range and update interval requirements

Operational domain →	Terminal, en route and oceanic/remote non-radar ↓				
Applicable range →	R ≤ 20 NM	R = 40 NM	R = 50 NM	R = 90 NM	R = 120 NM
Equipage class →	As appropriate.	As appropriate.	As appropriate	As appropriate	As appropriate
TS report acquisition range	20 NM (A1 optional)	40 NM (A2, A3 required)	50 NM (A2, A3 desired)	Not required	Not required
TS report state change update period (Note 3)	12 s	12 s desired (See Note 2 to Table II-L-2.)	12 s desired	Not required	Not required
TS report nominal update period	12 s	18 s	23 s desired	Not required	Not required

Notes.—

1. *Table II-K-3 is based on an air-air en-route scenario between two aircraft closing at 1 200 knots, which is considered a worst-case scenario for deriving range requirements for ADS-B conflict alerting.*
2. *Reserved.*
3. *Trigger conditions for the desired broadcasting of target state reports at the "state change" update rate are specified.*

3.2 Additional ADS-B requirements

Latency

3.2.1 For UAT ADS-B reports with normal accuracy/integrity, ADS-B latency of the reported information shall be less than 1.2 seconds with 95 per cent confidence. For reports with “precision” accuracy/integrity, ADS-B latency shall be less than 0.4 seconds with 95 per cent confidence. The standard deviation of the ADS-B report time error shall be less than 0.5 seconds (1 sigma). The mean report time error for position shall not exceed 0.5 seconds. The mean report time error for velocity shall not exceed 1.5 seconds. Differential delay errors should be considered and, if necessary, compensated for by the using application. All necessary information to perform compensation for differential delays must be included in the UAT ADS-B state vector report.

Continuity of function

3.2.2 The probability that the UAT system, for a given UAT message generation function and in-range UAT ADS-B report generation processing function, is unavailable during an operation, presuming that the UAT system was available at the start of that operation, shall be no more than 2×10^{-4} per hour of flight.

3.3 Supported ADS-B operational applications

The requirements in Section 3.1 were derived based upon supporting the potential air-to-air and air-to-ground applications of ADS-B summarized in the attachment to this appendix.

4. UAT SUPPORT OF GROUND UPLINK SERVICES RELATED TO SURVEILLANCE AND SITUATIONAL AWARENESS

4.1 General

The UAT system shall support ground uplink services to include TIS-B and flight information service — broadcast (FIS-B). The UAT system shall be capable of providing ground uplink services without interference from UAT broadcasts from aircraft. The UAT ground-based infrastructure should be designed to support channelization of ground uplink services to avoid interference between those services. It is also desirable that the ground-based infrastructure and ground uplink subsystem design support secondary navigation and timing.

4.2 TIS-B

TIS-B shall be supported by the UAT system, either through:

a) emulation of ADS-B messages from aircraft; or

b) use of a portion of the UAT bandwidth that has no interference from UAT broadcasts from aircraft.

The TIS-B service volume provided by a single ground station should be flexible so that cost-effective ground infrastructure implementations can be made for various airspace traffic densities. If alternative a) is used, the UAT system shall be capable of providing TIS-B data within the envelopes used for UAT ADS-B transmissions from aircraft. TIS-B data shall be clearly identified as such.

4.3 Flight information services — broadcast (FIS-B)

The FIS-B function shall not degrade the required performance of other higher priority, more safety-critical ADS-B and TIS-B applications supported by UAT. Moreover, FIS-B information supplied to UAT ground stations shall be uplinked without change of that information by the UAT system. The probability of an undetected error in a UAT FIS-B ground uplink message shall be no greater than 1.5×10^{-5}.

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Attachment to Appendix K

ADS-B APPLICATIONS TO BE SUPPORTED BY UAT

1. REFERENCES

1. CARE/ASAS Activity 5 Description of a First Package of GS/AS Applications, Version 2.2, September 30, 2002.
2. *Procedures for Air Navigation Services — Air Traffic Management* (PANS-ATM, Doc 4444).
3. RTCA DO-242A, *Minimum Aviation System Performance Standards (MASPS) for Automatic Dependent Surveillance — Broadcast*, June 25, 2002.
4. RTCA DO-260B (EUROCAE ED-102A), *Minimum Operational Performance Standards for 1090 MHz Extended Squitter Automatic Dependent Surveillance — Broadcast (ADS-B) and Traffic Information Services — Broadcast (TIS-B)*, December 2, 2009.
5. RTCA DO-282B, *Minimum Operational Performance Standards for Universal Access Transceiver (UAT) Automatic Dependent Surveillance — Broadcast*, December 2, 2009.
6. RTCA DO-289, *Minimum Aviation System Performance Standards for Aircraft Surveillance Applications (ASA MASPS)*, December 9, 2003.
7. RTCA DO-303 (EUROCAE ED-126), *Safety, Performance and Interoperability Requirements for the ADS-B Non-Radar Airspace (NRA) Application*, December 13, 2006.
8. RTCA DO-312 (EUROCAE ED-159), *Safety, Performance and Interoperability Requirements for the In-Trail Procedure in Oceanic Airspace (ATSA-ITP) Application*, June 19, 2008.
9. RTCA DO-314 (EUROCAE ED-160), *Safety, Performance and Interoperability Requirements for the Enhanced Visual Separation on Approach (ATSA-VSA) Application*, December 16, 2008.
10. RTCA DO-317, *Minimum Operational Performance Standards for the Aircraft Surveillance Application System (ASAS)*, April 14, 2009.
11. RTCA DO-318 (EUROCAE ED-161), *Safety, Performance and Interoperability Requirements for Enhanced Air Traffic Services in Radar Controlled Areas Using ADS-B Surveillance (ADS-B-RAD)*, September 9, 2009.

2. AIR-TO-AIR APPLICATIONS

Enhanced visual acquisition for see and avoid (see RTCA DO-317)
Enhanced successive visual approaches (see RTCA DO-314 [EUROCAE ED-160] and RTCA DO-317)
Enhanced sequencing and merging operations; Interval management
Enhanced traffic situation awareness on the airport surface
Enhanced CDTI-based flight rules (see RTCA DO-317)
In-trail procedure in oceanic airspace (see RTCA DO-312/EUROCAE ED-159)
Enhanced closely spaced parallel approaches
Flight path deconfliction/airborne conflict management

3. AIR-TO-GROUND APPLICATIONS

ATC surveillance for en-route airspace (see RTCA DO-318 [EUROCAE ED-161])
ATC surveillance in terminal areas (see RTCA DO-318 [EUROCAE ED-161])
ATC surveillance in non-radar areas (see RTCA DO-303 [EUROCAE ED-126])
Airport surface surveillance
Aircraft-derived data for ATC tools

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