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A Prototype Transceiver for Evaluating a Multipurpose Broadcast Data Link Architecture

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Abstract

The aviation community has recently expressed significant interest in a broadcast mode of data link services. Current proposals for supporting broadcast data link services—Automatic Dependent Surveillance-Broadcast (ADS-B) in particular—involve adaptations of technology originally designed for other functions. This document describes an alternative architecture specifically oriented to broadcast data link services with no preexisting constraints from legacy based systems. A prototype transceiver system is being developed according to this description for research purposes to evaluate this approach and the potential benefits of a multipurpose broadcast data link architecture.

KEYWORDS: ADS-B, air-air, air-ground, broadcast, data link, FIS-B, transceiver

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Table of Contents

Section **Page**

1 Introduction 1-1

1.1 Background 1-1

1.2 Purpose 1-1

1.3 Overview of Prototype Broadcast System 1-1

1.4 Contents 1-2

2 Prototype Transceiver Interfaces 2-1

2.1 RF Interface 2-1

2.1.1 Operating Frequency 2-1

2.1.2 Frequency Stability 2-2

2.1.3 Transmitter Power Output 2-2

2.1.4 Modulation Scheme 2-2

2.1.5 Modulation Rate 2-3

2.1.6 Transmitter Ramp Up/Down 2-3

2.1.7 Synchronization Sequence 2-3

2.1.8 Transmit/Receive Turnaround Time 2-4

2.1.9 Receive/Transmit Turnaround Time 2-4

2.1.10 Burst Formats 2-4

2.1.11 Forward Error Correction 2-4

2.1.11.1 ADS-B Bursts 2-5

2.1.11.2 GND BDCST Burst 2-5

2.1.12 Error Detection 2-6

2.1.13 Media Access Sublayer 2-6

2.1.13.1 Ground Broadcast Segment 2-7

2.1.13.2 ADS-B Segment 2-7

2.1.14 Link Protocol 2-7

2.2 Application Host Interface 2-8

2.2.1 Interface Type 2-8

2.2.2 Message Set 2-8

2.2.3 Byte Stuffing Protocol 2-8

2.2.3.1 Message Transmit Procedure 2-13

2.2.3.2 Message Receive Procedure 2-14

3 Prototype Transceiver Operating Concept 3-1

3.1 Airborne Transceiver Functions 3-1

3.1.1 Airborne Application Host 3-1

3.1.2 Generating the ADS-B Burst Payload 3-2

3.1.3 Initialization 3-2

3.1.4 Heartbeat Message 3-3

Section **Page**

3.1.5 Reporting Status 3-3
3.1.6 Transmission of ADS-B Burst 3-3
3.1.7 Processing Bursts Received Over the RF Interface 3-4
3.1.7.1 Identifying the Burst Type 3-4
3.1.7.2 Determining ADS-B Burst Length 3-4
3.1.7.3 ADS-B Burst Overlap Processing 3-5
3.1.7.4 Message Processing Logic Based on Bursts Received 3-5
3.1.8 Timing Maintenance 3-6
3.2 Ground Transceiver Functions 3-6
3.2.1 Ground Application Host 3-6
3.2.2 Initialization 3-6
3.2.3 Reporting Status 3-7
3.2.4 Heartbeat Message 3-7
3.2.5 Transmission of GND BDCST Burst 3-7
3.2.6 Processing Received Bursts Over the RF Interface 3-8
3.3 BER Test Mode 3-8

4 Ground Network Concept and Architecture 4-1
4.1 Uplink Broadcast 4-1
4.1.1 Providing Coverage 4-1
4.1.2 Tailoring Uplink Transmissions by Product 4-1
4.1.3 Coordination of Ground Stations 4-2
4.1.4 Feeding the Ground Broadcast Server 4-2
4.2 Downlink: Supporting Surveillance 4-4

5 Scaling the Prototype Architecture to an Operational System 5-1
5.1 Parameters for Postulated Scaled Up System 5-1
5.2 Link Margin 5-1
5.2.1 Air/Air Link Budget 5-2
5.2.2 Air/Ground Link Budget 5-2
5.3 Cochannel Interference 5-3
5.4 Transmitted Spectrum 5-3
5.5 Performance Calculations and Assumptions 5-4
5.5.1 Assumptions 5-5
5.5.2 Calculations 5-5

6 Summary 6-1

List of References RE-1

Section		Page
Appendix A	Transceiver Host Interface Message Set	A-1
Appendix B	Procedure for Selecting Pseudorandum ADS-B Burst Transmission Times	B-1
Appendix C	Procedure for Generating Random "Anonymous" 24-Bit Aircraft Address	C-1
Appendix D	GPS Rx Data Format	D-1
Glossary		GL-1

List of Figures

Figure		Page
2-1	UAT Functional Block Diagram	2-2
2-2	ADS-B Burst Format	2-4
2-3	GND BDCST Burst Format	2-5
2-4	Transceiver Timing Structure	2-6
2-5	ADS-B Burst Payload Format	2-9
2-6	GND BDCST Burst Payload Format	2-11
2-7	Message Traffic Overview	2-13
3-1	ARP Display	3-1
3-2	Receiver Burst Processing	3-4
3-3	Data Flow Sequence in BER Test Mode	3-9
4-1	Radio Coverage and Product Coverage Example	4-3
4-2	Ground Station Functional Block Diagram	4-4
5-1	Spectrum of Prototype Transceiver Waveform as Scaled Up	5-4
5-2	Performance with 500 Aircraft Visible	5-6
5-3	Performance with 1000 Aircraft Visible	5-6

List of Tables

Table		Page
2-1	ADS-B Burst Payload Elements	2-10
2-2	GND BDCST Burst Payload Elements	2-12
5-1	Air-Air Link Budget	5-2
5-2	Air-Ground Link Budget	5-3

Section 1

Introduction

1.1 Background

The aviation community has recently expressed significant interest in a broadcast mode of data link services. A broadcast mode of delivery is well suited to applications that are of general interest to many users and for applications that require periodic updating. Broadcast delivery is also attractive because of its protocol simplicity and spectrum efficiency. A data link system supporting broadcast services represents a unique opportunity for rapid implementation of a system with high utility that can be largely independent of existing infrastructure.

Key among the potential broadcast services is Automatic Dependent Surveillance-Broadcast mode (ADS-B). ADS-B is the periodic reporting of aircraft ID, position, and other related data. ADS-B reports are available directly air-air for surveillance of proximate aircraft or to any proximate ground station surveillance receiver. ADS-B is considered a key enabling technology of the Free Flight concept.

Current proposals for supporting broadcast services—ADS-B in particular—involve adaptations of technology originally designed for other functions. The Mode S system [1] is constrained by a short packet length and a radio frequency (RF) channel with potentially high levels of "background" channel occupancy that could limit performance for ADS-B. The Self-organizing Time Division Multiple Access (STDMA) system [2] operates with relatively narrow RF channels—a legacy of air-ground voice operation in the very high frequency (VHF) band; this approach requires a multichannel receiver to support ADS-B in high-density airspace. Any approach for supporting ADS-B will require spectrum to be internationally coordinated to guarantee interoperability and adequate protection from interference.

1.2 Purpose

The purpose of this document is to illustrate an alternative architecture specifically oriented to broadcast services with no preexisting constraints from legacy-based systems. A prototype transceiver system is being developed for research purposes to evaluate this broadcast architecture. This document provides a detailed description of the interfaces and operating concept of this prototype broadcast transceiver to serve as a specific example approach.

1.3 Overview of Prototype Broadcast System

The Universal Access Transceiver (UAT) is a prototype system for evaluating a multipurpose broadcast data link system operating on a single wideband channel. The goal of the UAT project is to demonstrate and evaluate this multipurpose broadcast data link architecture through laboratory and flight testing of a set of prototype UATs. In a more general sense, it is also a goal of the project to expose the aviation community to the concept of a multipurpose broadcast medium and its potential utility to a broad class of users.

Potential applications supportable with a multipurpose broadcast medium are as follows:

- Transmission of ADS-B reports from aircraft in flight or operating on the airport surface. These reports are received by other aircraft directly for air-air surveillance or these reports can be received by ground stations for air-ground surveillance applications.
- Reporting of air-derived meteorological observations as part of the ADS-B message.
- Transmission of products from ground to air that are of a broadcast nature. Examples of such products are listed below:
  - Real-time weather data.
  - Traffic information derived from ground-based radar surveillance systems to augment air-air ADS-B reports during transition.
  - Status information on airports, navaids, special use airspace, and uncharted obstacles.
  - Differential corrections to support ADS-B operation on the airport surface.

1.4 Contents

This document describes the UAT design and operation as well as some of the rationale for the design decisions made.

Section 2 details the interface characteristics of the UAT design. One of these is the RF interface which is the most critical for making comparisons with other system architectures. The other is the application host interface which is provided only for completeness. Sections 3 and 4 describe the high level operational concept for the prototype system. Finally, Section 5 postulates a scaled up version of this data link architecture to the bandwidth that might be required for an operational system. Several performance aspects based on simulation or analysis for this postulated system are presented.

Section 2

Prototype Transceiver Interfaces

Figure 2-1 shows a functional block diagram of the prototype transceiver. As shown, the system contains four main components.

- **A barometric altimeter** to provide the altitude information reported in the ADS-B message.
- **A Global Positioning System (GPS) receiver** to provide position and trend information reported in the ADS-B message and to provide timing for UAT transmissions over the RF Interface.
- **A microcontroller** to compose the ownship ADS-B report and to manage communication.
- **An RF modem** to support transmission and reception of data over the RF Interface.

The prototype transceiver has two external interfaces. The first is the *RF Interface* over which the RF bursts are transmitted and received. The second is the *application host interface* over which the transceiver communicates with its local host computer. In the case of an airborne transceiver installation, this host is referred to as the *Airborne Research Prototype (ARP)*. In the case of a ground transceiver installation, this host computer is referred to as the *Ground Broadcast Server*. Although the ground and airborne transceivers have different functions, the prototypes have been designed to be interchangeable in these roles.

2.1 RF Interface

The RF Interface supports the broadcast transmission of two burst types over the common RF channel. One is referred to as the *GND BDCST Burst* transmitted by ground stations; the other is referred to as the *ADS-B Burst* transmitted by aircraft.

2.1.1 Operating Frequency

The prototype transceiver operates on an experimental frequency assignment of 966 MHz.

Rationale—Use of a single common global channel is the simplest architecture for supporting ADS-B since seamless air-air operation is required. As a result, the channel should offer significant bandwidth to assure adequate capacity and performance. This band was selected due to the wide channelization (1 MHz) that currently exists there and the potential availability of certain channels that could be reserved on a global basis. However, the system is not frequency specific and could operate in any suitable spectrum.

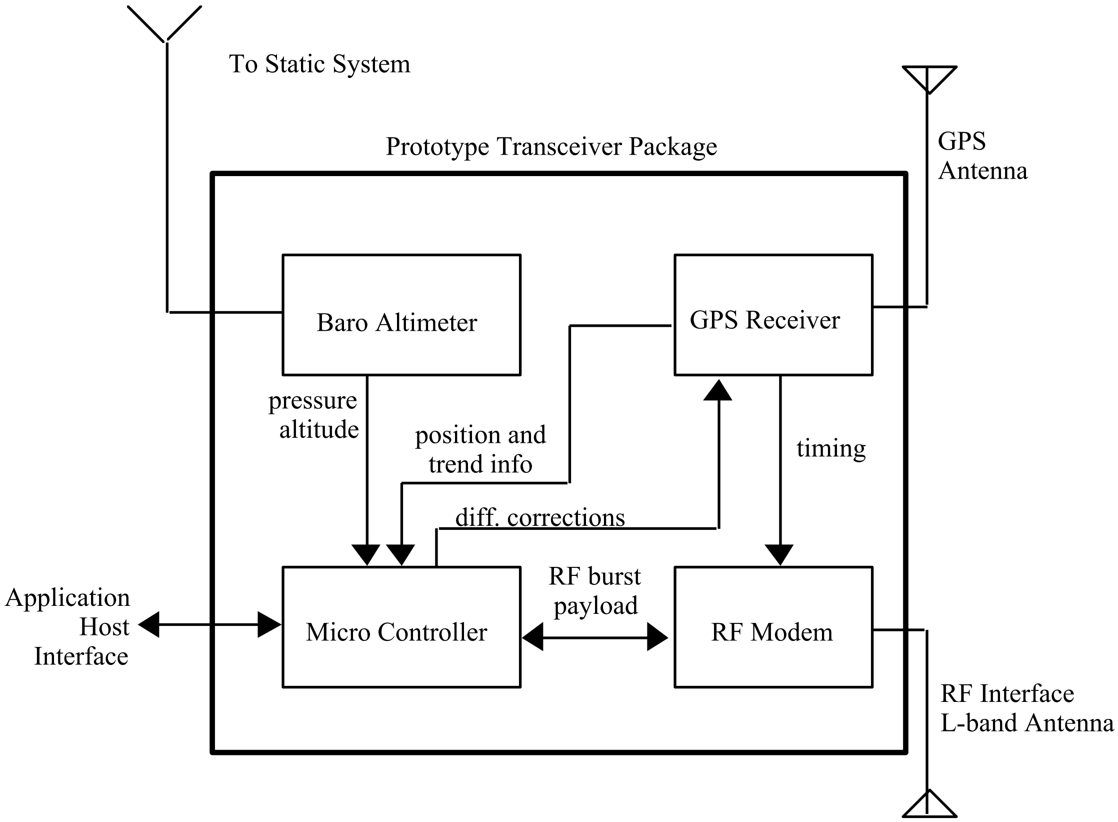


Figure 2-1. UAT Functional Block Diagram

2.1.2 Frequency Stability

Transmitting and receiving functions operate with a stability of +/- 1 ppm.

2.1.3 Transmitter Power Output

A peak power output level of 50 watts is supported. The prototypes operate at a constant fixed output power level.

2.1.4 Modulation Scheme

Data is modulated onto the carrier using a form of binary Continuous Phase Frequency Shift Keying (CPFSK). The modulation index is $h = 0.6$. Thus, if the data rate is R_b, then the nominal frequency separation between a 0 and a 1 is $\Delta f = h \bullet R_b$. A binary 1 is indicated by a shift up in frequency by $\Delta f/2$ and a binary 0 is indicated by a shift of $-\Delta f/2$.

Prior to frequency modulation the baseband signal is passed through a Raised-Cosine (RC) Nyquist filter with roll-off factor a = 0.5. This filtration leads to a reasonably compact transmitted spectrum (as shown in Section 4).

Rationale—This modulation scheme permits relatively simple, inexpensive nonlinear transmitter and receiver implementations. It also offers a relatively high tolerance to self interference.

Note—The modulation described in this section is very similar (in spectrum and performance) to Gaussian Minimum Shift Keying (GMSK). If future trade-off studies indicate that GMSK offers significant improvements in ease (or cost) of implementation, a modulation change may be advisable.

2.1.5 Modulation Rate

The modulation rate is 416.67 kbps ($10^7/24$). This rate, coupled with the modulation index of $h = 0.6$, means that $\Delta f = 250$ kHz.

2.1.6 Transmitter Ramp Up/Down

To allow for receiver stabilization and for control of transient spectral components, the transmitter power will ramp up and down at the beginning and ending of each burst. The maximum time duration of these ramps is no greater than 4 bit periods (each). Ramp time is defined as the time between 90 percent power output and -60 dB power output. During ramp up and down, the modulating data will be all zeros.

2.1.7 Synchronization Sequence

Following ramp up, each data burst will include a 36 bit synchronization sequence. For ADS-B bursts the sequence will be

111010101100110111011010010011100010

with the left most bit transmitted first. This sequence was chosen because of its good autocorrelation properties (i.e., detection performance).

For GND BDCST bursts the polarity of the bits of the synchronization sequence is reversed, i.e., the 1's and 0's are interchanged. This synchronization sequence is

000101010011001000100101101100011101

Note—Because of the close relationship between the two synchronization sequences, the same correlator can search for both simultaneously.

2.1.8 Transmit/Receive Turnaround Time

The time available for turnaround (from the end of the transmitted signal ramp down to the beginning of the received signal ramp up) is [2] ms.

2.1.9 Receive/Transmit Turnaround Time

The receive/transmit turnaround time available (the time from the end of reception to the beginning of the transmit ramp up) is [2] ms.

2.1.10 Burst Formats

Figure 2-2 shows the formats and components for the ADS-B Burst. As indicated in the figure, the payload portion of the burst can take on one of two possible lengths. When the payload is 128 bits, the length identifier is coded as "0F" hex. When the payload is 256 bits, the length identifier is coded as "F0" hex.

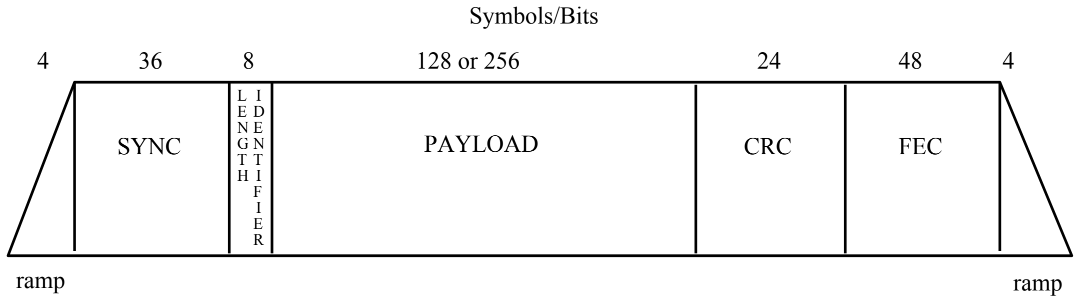


Figure 2-2. ADS-B Burst Format

Figure 2-3 shows the format and components of the GND BDCST Burst. The ground broadcast burst is a single fixed length.

2.1.11 Forward Error Correction

Forward error correction (FEC) is provided for all payload and error detection bits by using Reed-Solomon (RS) coding. The RS code is defined over the finite field GF (2^8). The primitive polynomial is given by

$$P(x) = x^8 + x^7 + x^2 + x + 1;$$

and the generator polynomial is

$$G(x) = \prod_{i=120}^{119+R} \left(x - \alpha^i\right),$$

where R = N - K for a RS(N,K) code. This code conforms to the Intelsat IESS/308 Revision 6B international standard.

2.1.11.1 ADS-B Bursts

FEC for ADS-B burst transmissions is based on the use of reduced versions of the RS (255, 249) code. When the payload is 128 bits, the code is reduced to a RS (25, 19) code. When the payload is 256 bits, the code is reduced to a RS (41, 35) code. In each case, the coded information includes 24 bits for explicit error detection (see Section 2.1.12).

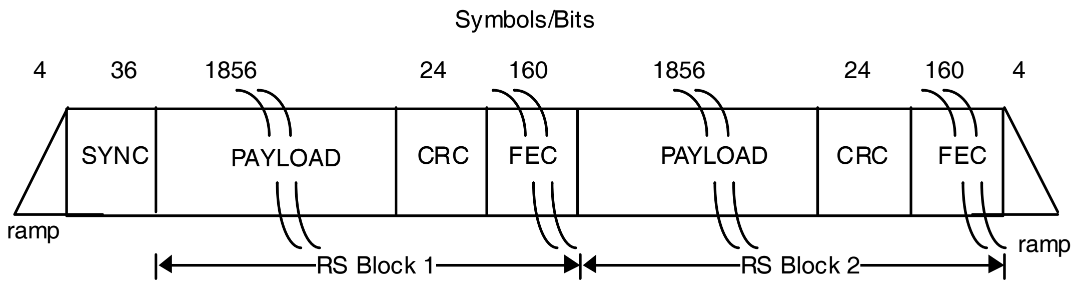


Figure 2-3. GND BDCST Burst Format

2.1.11.2 GND BDCST Burst

FEC for GND BDCST burst transmissions is provided by a RS (255, 235) code. There are two such RS blocks per data burst, so that each burst consists of 4080 bits. Of these, 3760 are information bits. Each RS block is protected by 24 bit error detection code so that the real information in each ground burst is 3712 bits (or 464 octets). Error detection in either block will cause the UAT to discard the entire burst.

Rationale—This form of FEC provides protection against burst errors that could be induced by the pulsed systems that operate in the same band.

2.1.12 Error Detection

Each RS data block is protected by a 24-bit cyclic redundancy check (CRC). The particular code used is the so-called CRC-24Q code, whose generator polynomial is

$$g(x) = x^{24} + x^{23} + x^{18} + x^{17} + x^{14} + x^{11} + x^{10} + x^{7} + x^{6} + x^{5} + x^{4} + x^{3} + x + 1$$

2.1.13 Media Access Sublayer

The transceiver is based on a hybrid Time Division Multiple Access (TDMA) media access approach and a Random Access approach. The *frame* is the most fundamental time unit. Frames are one second in duration and begin on the GPS second. At the next lower level, the frame is divided into two *segments*. Each segment is further subdivided into message start opportunities (MSOs), spaced 0.25 ms apart for a total of 4,000 MSOs per frame. A MSO represents the smallest increment of time control for burst transmissions. The following sections discuss the use of each segment. Figure 2-4 illustrates the timing structure.

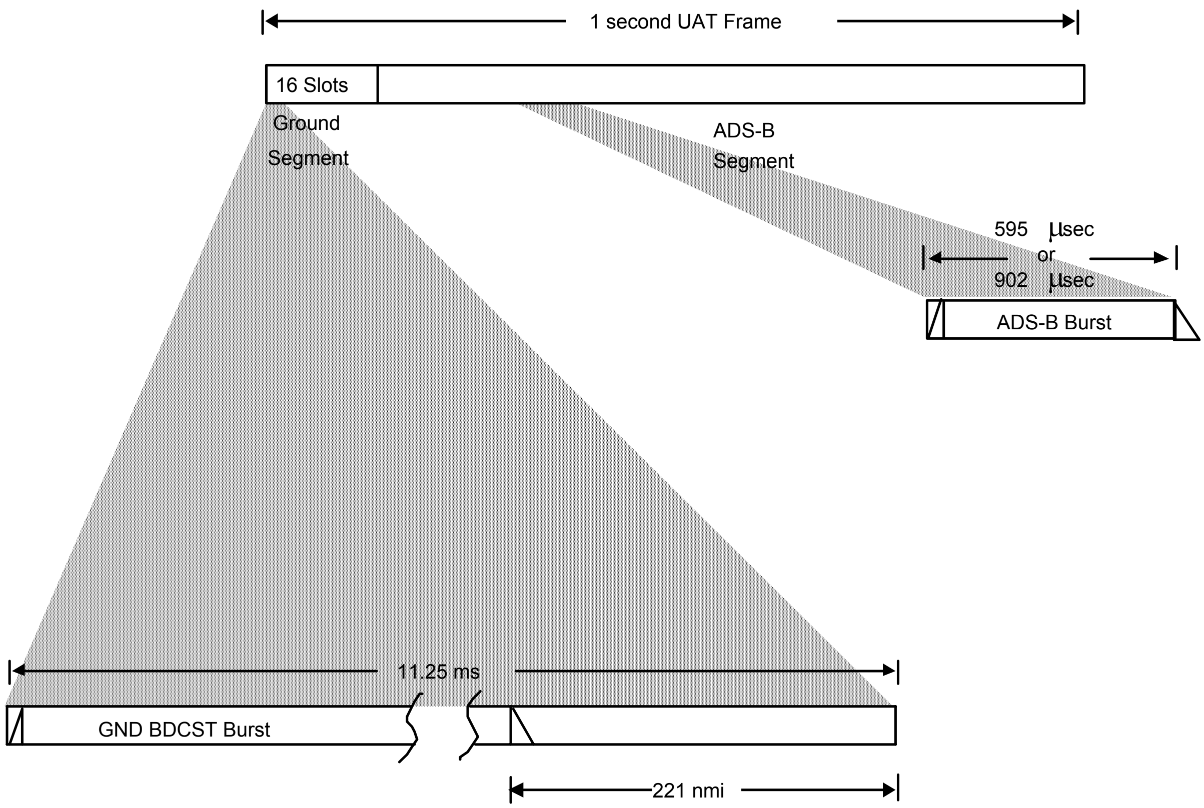


Figure 2-4. Transceiver Timing Structure

2.1.13.1 Ground Broadcast Segment

The Ground Broadcast Segment consists of 760 MSOs, for a total of 190 ms. There are 16 time slots, each 45 MSOs long (11.25 ms). Ground Broadcast bursts can begin at MSO 0 (time slot 0), MSO 45 (time slot 1), MSO 90 (time slot 2), ..., MSO 675 (time slot 15). Time slots are assigned for use by a ground station transmitter in a fixed, static manner by spectrum management procedures to control self-interference and maximize time slot reuse on a geographic basis. A ground station assigned one of these time slots will transmit a GND BDCST burst in its slot in every frame (once per second).

In addition to the 16 time slots, the ground broadcast segment contains 40 MSOs (10 ms) of guard time to allow for a certain amount of drift if airborne users temporarily lose good timing (see Section 3.1.8).

2.1.13.2 ADS-B Segment

The ADS-B Segment consists of 3240 MSOs, for a total of 810 ms. ADS-B bursts can begin at any of the 3200 MSOs from 760 to 3959. Transmission times are selected by aircraft stations based on a new pseudorandom time selection each frame. Pseudorandom transmission should guarantee independent transmission patterns among aircraft in order to avoid continued synchronous interference between aircraft stations. The procedure used by the transceiver to pick MSOs pseudorandomly is provided in Appendix B.

The ADS-B segment also contains 40 MSOs to provide guard time between it and the subsequent ground broadcast segment.

Rationale—A hybrid TDMA and Random Access approach was considered the most simple and effective multiplexing approach. A Frequency Division Multiple Access (FDMA) system would require multiple receive channels and possibly channel management logic that could increase complexity. A Code Division Multiple Access (CDMA) approach suffers from "near-far" problems in the ADS-B environment.

Bursts from proximate ground stations can be coordinated with each other via static time slot assignment procedures.

Random access for ADS-B burst transmissions was chosen for simplicity, robustness, and scaleability at some expense of spectrum efficiency.

2.1.14 Link Protocol

The transceiver link layer protocol for all data transfers over the RF Interface are in an unacknowledged broadcast mode.

Rationale—This significantly simplifies the system design and validation, minimizes link overhead and supports a substantial number of data link applications of a broadcast nature.

The format for the payload portion of the ADS-B Burst is shown in Figure 2-5. The encoding of each of the data elements of the ADS-B Burst is shown in Table 2-1.

The format for the payload portion of the GND BDCST Burst is shown in Figure 2-6. The encoding of each of the data elements of the GND BDCST Burst is shown in Table 2-2.

2.2 Application Host Interface

The transceiver application host interface supports the bidirectional transmission of predefined messages between the transceiver and the local host computer. The attributes of this interface are discussed in the paragraphs below.

2.2.1 Interface Type

The application host interface operates on an asynchronous bidirectional RS232 interface operating at a speed of 38.4 kbps. The parameters of operation are as follows:

- 8 data bits
- 1 stop bit
- No parity
- Configured as DCE

2.2.2 Message Set

A total of nine message types are defined for exchange over the transceiver application host interface. Figure 2-7 provides an overview of the traffic over both transceiver external interfaces. In the case of the application host interface, a summary is provided of the message type, its direction (either to or from the transceiver), and the applicability of the message (i.e., whether it applies to a transceiver configured as an airborne (A) or ground (G) unit). Appendix A lists each message over the application host interface and its constituent components.

2.2.3 Byte Stuffing Protocol

All messages over the application host interface are transmitted in an unacknowledged mode. Either the transceiver or the Host can be the transmitter depending on the message to be sent over the interface. In order to allow the receiver to identify and delimit messages, a "byte stuffing" procedure is employed. This procedure makes no attempt to check the validity of the data transmitted over the serial interface. The paragraphs below detail the procedures to be used for the transmitting and receiving end of the interface.

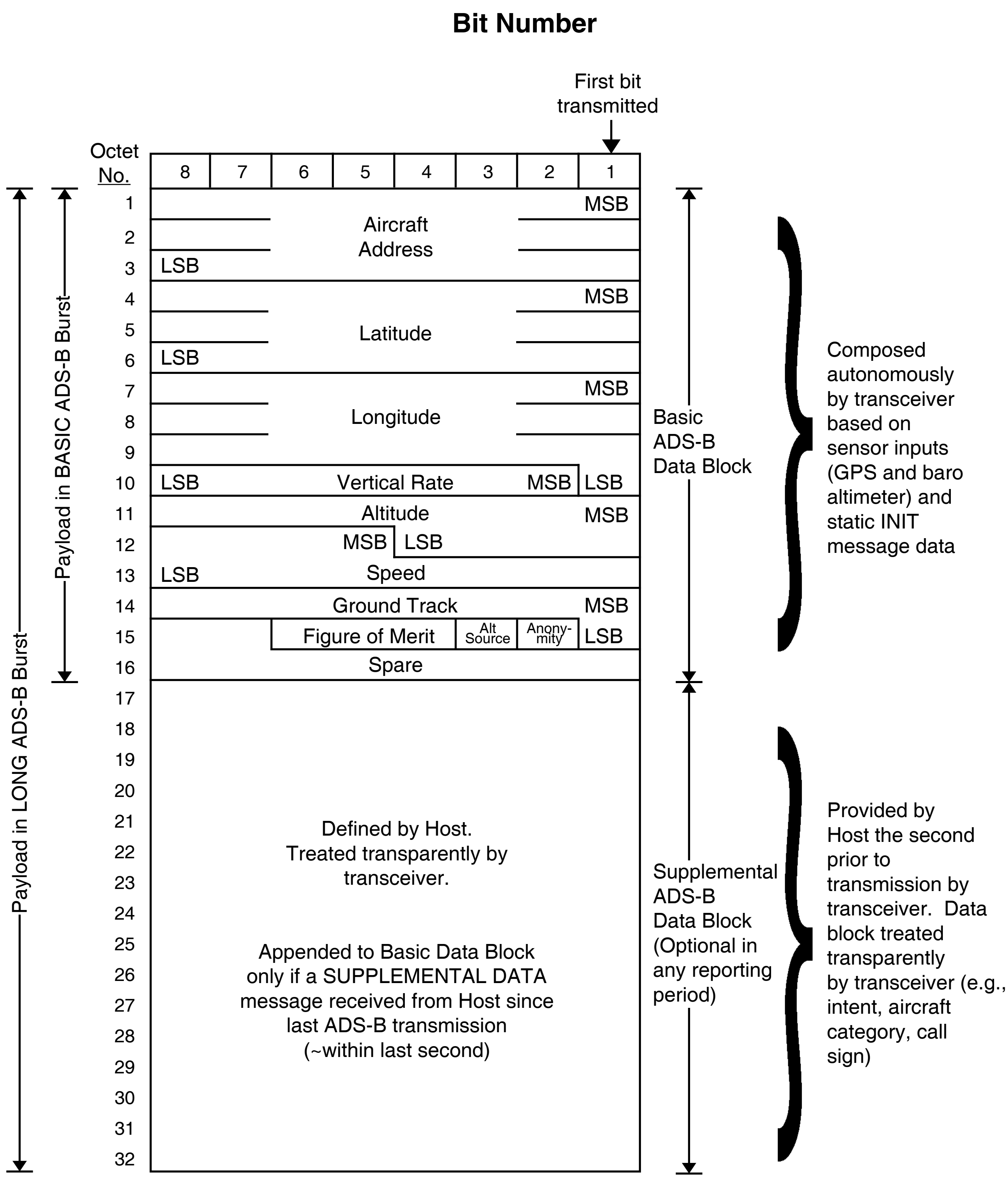
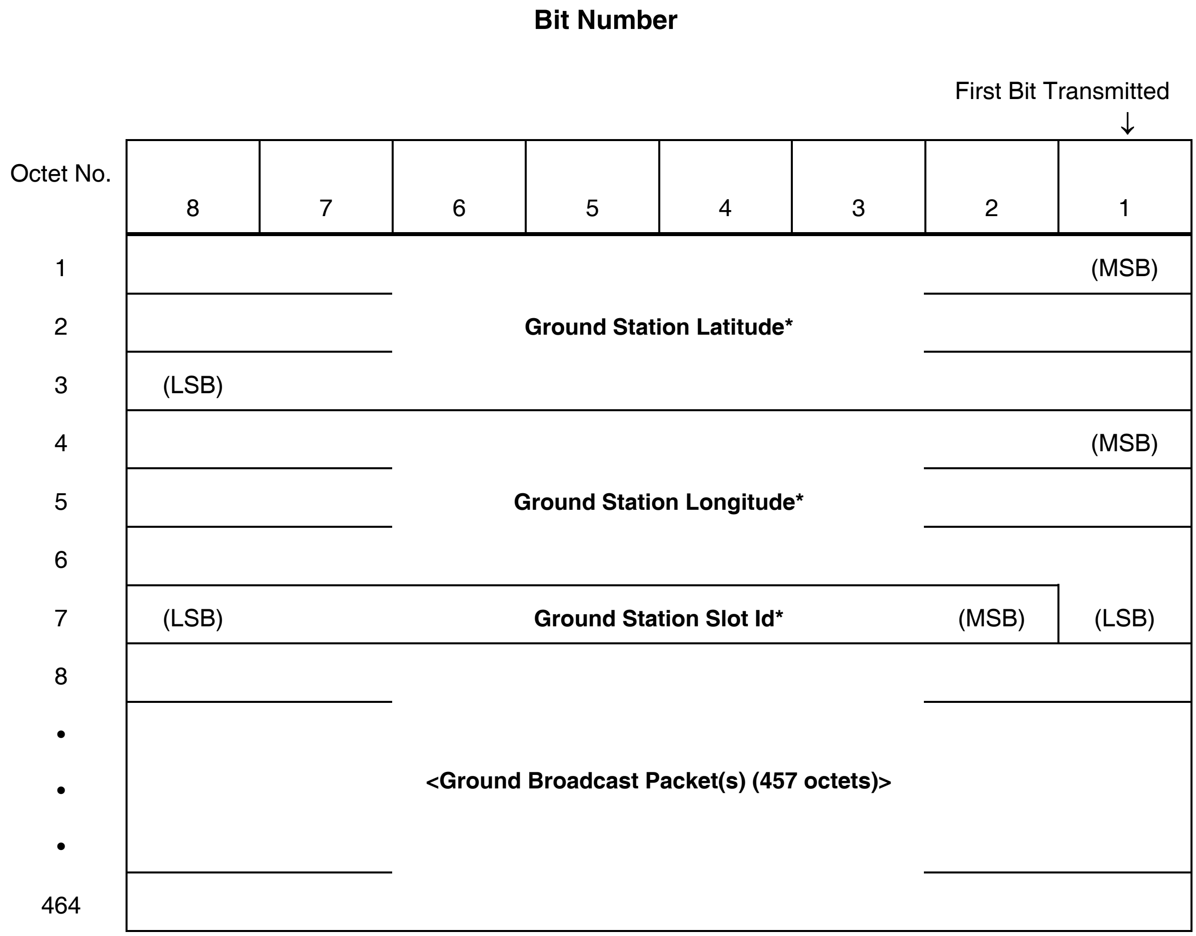


Figure 2-5. ADS-B Burst Payload Format

Table 2-1. ADS-B Burst Payload Elements

Element (bits)	Encoding	
A/C Address (24)	<unique or random identifier>	
Latitude (24)	LSB =$180^o/2^{24}$ Range : $90^oS = 0$ $90^oN = 2^{24}–1$	*Rationale—Specifying position to full resolution unambiguously allows consistent reporting format for airborne and surface operation and avoids the need for compression algorithms.*
Longitude (25)	LSB = $360^o/2^{25}$ Range : $180^oW = 0$ $180^oE = 2^{25}–1$	
Vertical Rate (7)	LSB = 100 ft/min Range : -6300 ft/min = 0 +6400 ft/min = $2^7–1$	
Altitude (12)	LSB = 25 ft Range : -1000 ft = 0 101,375 ft = $2^{12}–1$	
Speed (12)	LSB = 1kt Range : 0–4095 kts	*Rationale—reporting rather than deriving trend information eliminates tracking complexity in the airborne host and improves performance. It also allows every report to stand alone.*
Ground Track (9)	LSB = 1 degree Range : 0 – 359	
Figure of Merit (3)	bit 4: 0=diff. correct. >10 sec. old 1=diff. correct. <10 sec. old bit 5: 0=2D Fix 1=3D Fix bit 6: spare	
Alt Source (1)	0 = Baro 1 = GPS	
Anonymity (1)	0 = Discrete 1 = Anonymous	
Spare (10)	[TBD]	
Supplemental Data (128)	<Host provided, optional>	

Total Payload → 128/256 bits



*Can be used by airborne receiver for backup timing or navigation

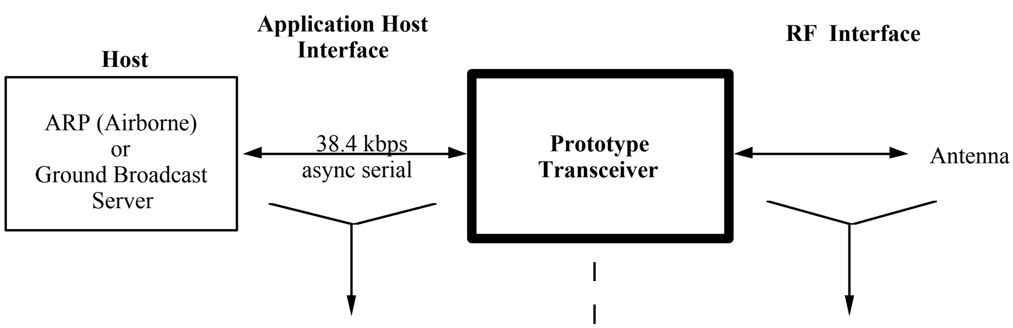
Figure 2-6. GND BDCST Burst Payload Format

Table 2-2. GND BDCST Burst Payload Elements

Element	**Encoding**
Ground Station Latitude (24)	[as per ADS-B burst encoding]
Ground Station Longitude (25)	[as per ADS-B burst encoding]
Slot Id (7)	0–127 (only 0–15 used in Prototype Transceiver)
<ground broadcast packet(s) (457 octets)>	

Notes:

- The GND BDCST Burst may contain one or more ground broadcast packets, each of which may be of any length between 1 and 457 octets.
- The Ground Broadcast Server shall ensure that multiplexing of multiple ground broadcast packets will not exceed the 457 octets allowed per burst.
- The Ground Broadcast Server shall ensure that any unused portion of the 457 octets allowed for in the GND BDCST Burst Format is filled with an alternating one/zero pattern.
- The formats used for individual ground broadcast packet types is transparent to the Transceiver with the exception of the packet type used to uplink differential corrections to correct the internal GPS of the airborne transceiver.



Message #	Message Types	Dir	Applicability
0.	HEARTBEAT	←	A,G
1.	INIT	→	A,G
2.	STATUS REQ.	→	A,G
3.	STATUS	←	A,G
4.	SUPPLEMENTAL DATA	→	A
5.	BASIC ADS-B	←	A,G
6.	LONG ADS-B	←	A,G
	(BER test only)	→	A
7.	GND BDCST	→	G
		←	A,G
8–253.	—UNUSED—		
254.	GND BDCST TEST	←	A
255.	ADS-B TEST	←	G

RF Burst Types	Dir	Applicability
BASIC ADS-B	↔	A
	←	G
LONG ADS-B	↔	A
	←	G
GND BDCST	←	A
	→	G

NOTE: Messages 254 and 255 are used only to support BER testing when the transceiver is initialized in test mode.

Figure 2-7. Message Traffic Overview

2.2.3.1 Message Transmit Procedure

Preparing a message for transmission involves two steps:

(1) The transmitter attaches a predefined flag sequence to the beginning of every message sent. The hexadecimal flag sequence used is the four bytes 01 FF FF FF.

(2) The transmitter inserts 00 after every occurrence of 01 FF FF within the message. If the original data was 01 FF FF FF, the transmission will be 01 FF FF 00 FF. If the data was 01 FF FF 00, the transmission will be 01 FF FF 00 00.

2.2.3.2 Message Receive Procedure

When the receiving end receives new data, it decodes the data using an algorithm that reverses the transmit procedure. The receive process entails the following steps.

(1) The receiver finds the start of a message by looking for the flag sequence (01 FF FF FF).

(2) The receiver reads the following byte, which will be the message header. This message header establishes the length of the message as every message is fixed length (see Appendix A).

(3) The receiver continues reading bytes until all bytes of the message have been read. When a “00” byte is found following “01 FF FF,” the “00” byte is discarded.

(4) Once all bytes of the message are read, the receiver resumes searching for the next flag sequence indicating the start of a message.

Section 3

Prototype Transceiver Operating Concept

The prototype transceiver can operate in normal operational mode or a test mode used to support bit error rate (BER) testing. Sections 3.1 and 3.2 describe the normal operational mode of the system. Section 3.3 describes the specific differences of the test mode.

3.1 Airborne Transceiver Functions

3.1.1 Airborne Application Host

In the planned flight evaluations of the transceiver, the ARP will serve as the application host. A description of the ARP is to be provided in a separate document. Initially, the broadcast data link supports the ARP display of traffic information and uplinked weather information in a moving map format. The display is shown in Figure 3-1.

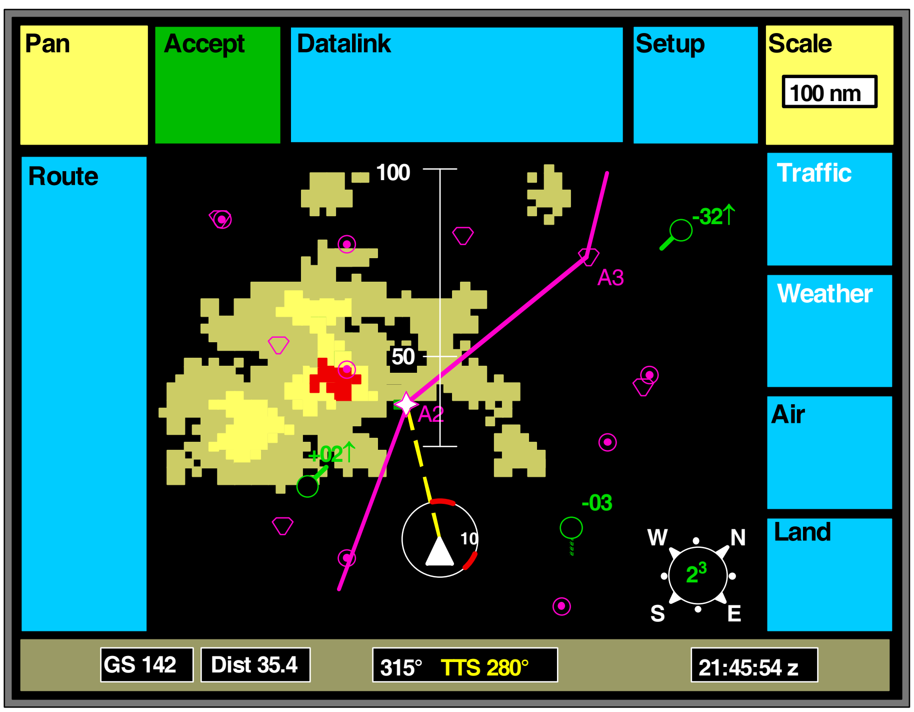


Figure 3-1. ARP Display

3.1.2 Generating the ADS-B Burst Payload

The transceiver generates an ADS-B Burst payload once per second for transmission over the RF Interface. Figure 2-5 shows the elements of the burst payload. One of two ADS-B Burst types will be transmitted in a given reporting interval (i.e., 1 sec.). The BASIC ADS-B Burst contains "core" elements included in every report. These elements are contained in octets 1-16, as shown in Figure 2-5. These elements are generated autonomously every reporting interval by the transceiver based on sensor inputs (e.g., GPS and baro altimeter) and initialization data from the host (e.g., Aircraft Address, Altitude Source, Anonymity).

The LONG ADS-B Burst consists of the BASIC ADS-B data block described above with an additional 16 octets referred to as the Supplemental ADS-B data block.

Receipt of a SUPPLEMENTAL DATA message by the transceiver over the application host interface will result in transmission of a LONG ADS-B Burst over the RF interface in the following reporting interval. Otherwise, a BASIC ADS-B Burst will be transmitted. The contents of the 16 octets of Supplemental Data is treated transparently by the transceiver and is not defined here. This facility is intended for the reporting of data that is less time critical than the contents of the BASIC ADS-B data block. Examples of such data are: Flight ID/Call Sign, Pilot Intent, and Meteorological Observations.

Rationale—In addition to the minimum data that supports ADS-B surveillance, it is also advantageous to include any supplemental information as an appendage on the ADS-B report. This avoids the need for separate accesses or separate media for this information and also supports its seamless air-air availability. Significant flexibility exists in accommodating and scheduling transmission of this supplemental data for maximum link efficiency.

3.1.3 Initialization

Prior to operation the transceiver requires initialization by the application host. This is performed by the host by transmission of the INIT message to the transceiver. Receipt of the INIT message by the transceiver results in the following actions:

- Sets the transceiver for operation as an airborne terminal.
- Sets the altitude source for ADS-B reporting.
- Sets the address type. If set to "discrete address," the 24 bit address field is a unique address preassigned to the aircraft. If set to "anonymous," the 24 bit address is randomly generated by the host at initialization time. The procedure to be used by the host in generating a random anonymous address is described in Appendix C.
- Sets the transceiver for operational or BER testing mode.
- Sets the transceiver for operation in transmit/receive mode or receive only mode.

- Sets the transceiver for operational or demo mode. Demo mode activates software internal to the transceiver to emulate movement of the transceiver for laboratory testing.
- Sets the transmission time offset (only to support interference testing).

Note—Address uniqueness for aircraft desiring anonymity cannot be guaranteed nor is it assumed to be essential. However, address conflicts for aircraft desiring anonymity are highly unlikely.

Note—All initialization actions except the address type are for research flexibility only. Initialization in an operational system would not require these actions.

3.1.4 Heartbeat Message

Message type 0—The HEARTBEAT message will be sent by the transceiver to the host once per second (i.e., frame). Additionally, the HEARTBEAT message will always be the first message transmitted to the host in a given frame. The purpose of the heartbeat message is threefold:

- To serve as a delimiter of data received in different frames.
- To provide UTC timing to the host for offline data analysis.
- To allow the host to monitor the operation of the transceiver in the absence of traffic over the radio link.

3.1.5 Reporting Status

The transceiver will receive a STATUS REQ message from the host when the host wishes to confirm the host settings of the transceiver. This message can be received at any time. The transceiver responds with the STATUS message. The STATUS message simply echoes back all the transceiver settings provided by the host plus data from the internal GPS receiver.

3.1.6 Transmission of ADS-B Burst

The transceiver will generate an ADS-B burst payload for transmission once per second. The payload will have error detection and forward error correction applied by the transceiver prior to transmission over the RF Interface. A time offset for transmission within the ADS-B segment is selected on a random basis independently from frame to frame.

Note—Transmission at a definable fixed time offset is supported but is used only for interference testing purposes.

If a SUPPLEMENTAL DATA Message has been received from the host since the last ADS-B transmission, a LONG ADS-B Burst is transmitted at the pseudorandomly determined time. Otherwise, a BASIC ADS-B Burst is transmitted at the pseudorandomly determined time. Transmission of an ADS-B Burst over the RF interface will also result in transmission of the appropriate ADS-B message to the host. This is the "ownship" message which the host can use to monitor the ADS-B reporting performance of the transceiver. This ownship ADS-B message is generated with the source element encoded as "ownship."

The format of the ADS-B Burst as well as the reporting rate of one/sec remain constant throughout the flight.

Rationale—This offers a simple, consistent, and robust system operation.

3.1.7 Processing Bursts Received Over the RF Interface

3.1.7.1 Identifying the Burst Type

Figure 3-2 shows a functional block diagram of burst detection and processing in the transceiver. The burst acquisition process—through the polarity of the synchronization sequence—will tell the receiver whether the burst is a GND BDCST burst or an ADS-B burst. (A receiver should normally also be able to determine this distinction based on system timing. The dual-polarity synchronization sequences provide independent corroboration.)

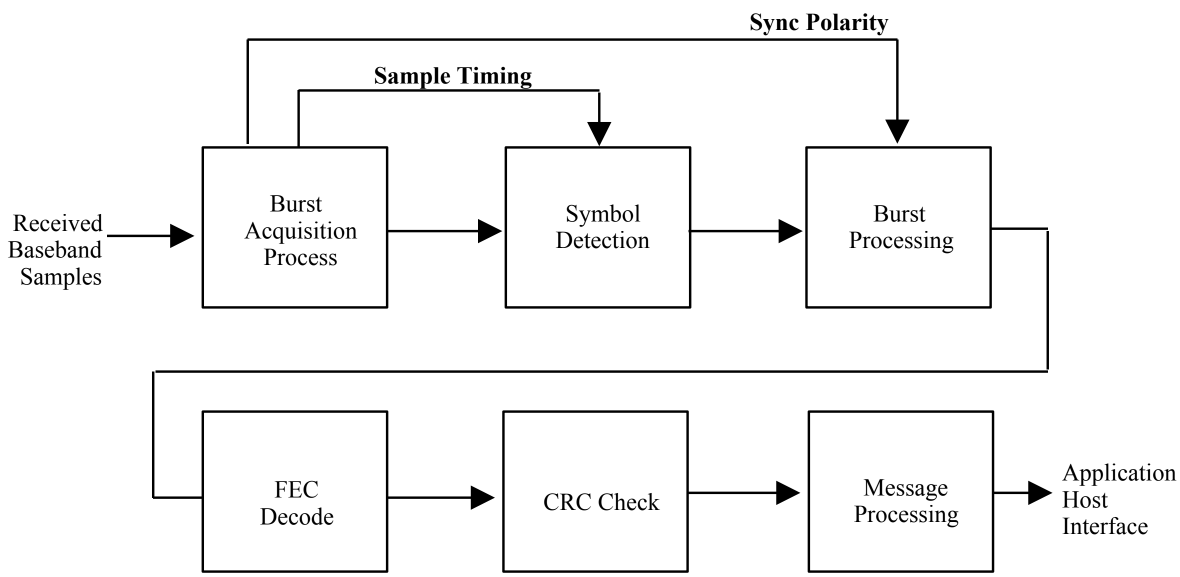


Figure 3-2. Receiver Burst Processing

3.1.7.2 Determining ADS-B Burst Length

If the burst is determined to be an ADS-B burst, the header field must be examined to determine whether the burst is a BASIC ADS-B Burst or a LONG ADS-B Burst. The decision is based on majority rule decoding of the header:

(1) If 5, 6, 7, or 8 bit positions match the pattern 0F, the burst is treated as a BASIC ADS-B Burst.

(2) If 5, 6, 7, or 8 bit positions match the pattern F0, the burst is treated as a LONG ADS-B Burst.

(3) If only 4 bit positions of F0 (or 0F) are matching, the burst is declared a failure.

3.1.7.3 ADS-B Burst Overlap Processing

Because the ADS-B bursts are transmitted in an essentially unslotted, random fashion, transmissions from different aircraft will often overlap. In order to allow for the possibility of receiving a strong ADS-B burst that arrives slightly later than (and overlaps with) a weaker ADS-B burst, the receiver will continually search for new ADS-B signals even if a previous one is already being processed. Whenever a new burst is detected it needs to be processed in the appropriate way.

If the new burst is received with symbol timing which is appreciably different from the first burst, the old burst processing is dropped and replaced with the new one. (In this case, appreciable means approximately half a symbol period.) If the new burst is received with essentially the same symbol timing as the first signal, then both signals can be processed. (Normally, it is expected that only one of them will be a valid signal, able to survive the RS decode and error detection procedures.) This procedure guards against the possibility that the synchronization sequence is contained in a valid data sequence.

Note—This allows the receiver to exploit the capture effect characteristics of the waveform by allowing the detection and decoding of a stronger ADS-B burst (e.g., from a nearby aircraft) that overlaps a weaker burst (e.g., from a distant aircraft).

3.1.7.4 Message Processing Logic Based on Bursts Received

The message processing function block shown in Figure 3-1 takes all bursts that successfully pass the FEC decoding and CRC check and encapsulates them with the appropriate message header and flags for transmission over the host interface.

The payload portion of a received ADS-B Burst is conveyed in the appropriate ADS-B message to its host with the source bit set as "traffic."

The payload portion of a received GND BDCST Burst is also conveyed in the GND BDCST message to its host. In addition, the message processing function must examine the contents of the GND BDCST Burst payload for two items required to support transceiver operation.

- The first is the leading seven octets which contain the location and the slot identifier of the transmitting ground station. The transceiver uses this information as an alternate source of timing information (as a backup to the on-board GPS time reference).

Note—The location and slot id of the transmitting ground station could also allow a crude form of backup navigation to be performed if at least three ground stations with good geometry are being received concurrently. This capability is not supported by the prototype.

- The second item is differential correction data if present as part of the GND BDCST Burst payload. This data is used in the prototype transceiver to correct the internal GPS receiver.

When present in a GND BDCST Burst, a differential correction packet will be proceeded by a packet identifier octet encoded as FF, followed by a packet length octet followed by a Radio Technical Commission for Maritime Services (RTCM) SC104 format correction message. A differential correction message, when present in a GND BDCST Burst, will always be the first message in the burst.

3.1.8 Timing Maintenance

Timing logic to support transceiver frame and slot timing is based upon the internal 1 part per million (PPM) reference oscillator that also establishes the frequency stability of the transceiver. This internal reference is "disciplined" in the following way:

- By the 1 pulse per second (PPS) output of the GPS receiver as the primary source when available.
- By the first GND BDCST burst received in a frame as an alternate source.
- If neither source is available in a given frame, the internal reference "coasts."

Note—The transceiver timing can coast off the 1 PPM internal reference—in the absence of both the primary and alternate disciplining source—for over one hour with a timing uncertainty of only 4 ms in the airborne segment. As a result, an airborne transceiver with only the internal reference can honor the ADS-B segment boundary for a significant period of time by taking advantage of the guard times built into the system architecture.

3.2 Ground Transceiver Functions

3.2.1 Ground Application Host

In the planned flight evaluations of the transceiver, the Ground Broadcast Server will serve as the application host. A description of the Ground Broadcast Server is to be provided in a separate document.

3.2.2 Initialization

Prior to operation the transceiver requires initialization by the application host. This is performed by the host by transmission of the INIT message to the transceiver. Receipt of the INIT message by the transceiver results in the following actions:

- Sets the transceiver for operation as a ground unit.
- Sets the transceiver for operational or BER testing mode.
- Sets the transceiver for operation in transmit/receive mode or receive only mode.
- Sets the transmission time offset (time slot).

Note—The altitude source, aircraft address, and demo mode settings apply only to airborne transceiver operation and are therefore not applicable and are ignored in this case.

3.2.3 Reporting Status

Status is requested and reported in the same manner as that for an airborne transceiver. See Section 3.1.5

Note—The ICAO aircraft address and register value elements are not applicable and can assume any random initialized value.

3.2.4 Heartbeat Message

Message type 0—The HEARTBEAT message will be sent by the transceiver to the host once per second (i.e., frame). Additionally, the HEARTBEAT message will always be the first message transmitted to the host in a given frame. The purpose of the heartbeat message is threefold:

- To serve as a delimiter of data received in different frames.
- To provide UTC timing to the host for offline data analysis.
- To allow the host to monitor the operation of the transceiver in the absence of traffic over the radio link.

3.2.5 Transmission of GND BDCST Burst

The application host will generate a GND BDCST Message to the transceiver once per second. The host will provide the complete burst payload including the ground station location and slot id. The host ensures that the burst payload is exactly 464 octets by filling with an alternating one/zero pattern if necessary.

The burst payload will be segmented into two blocks by the transceiver; each block will have FEC and CRC generated and applied by the transceiver prior to transmission over the RF Interface. If, in a given frame, no GND BDCST Burst is received by the transceiver, the previous GND BDCST Burst is retransmitted in that frame. The transceiver provides a GND BDCST message to the host for every GND BDCST Burst transmitted over the RF interface. This provides a confirmation to the host of burst transmission.

The application payload portion of the burst payload (Figure 2-6) is composed of any of a number of broadcast packet types that are transparent to the transceiver with the exception of the broadcast packet type carrying differential corrections.

3.2.6 Processing Received Bursts Over the RF Interface

Ground transceiver operation is consistent with that of the airborne transceiver as described in Section 3.1.6. The ground transceiver will receive ADS-B reports from all aircraft within range of the ground station.

3.3 BER Test Mode

The BER test mode is established so that a pair of transceivers can operate in a way that special software in the host computers can measure the BER performance of the link. The tests are performed with one transceiver configured as an airborne terminal and the other configured as a ground terminal.

The airborne and ground hosts send test payloads to be transmitted over the RF interface with a LONG ADS-B message and a GND BDCST message, respectively. These messages contain pseudorandom test data that are placed into the burst payload transparently by the transceiver. A LONG ADS-B Burst and a GND BDCST Burst are generated by the respective air and ground transceivers in response to these messages. Normal FEC and CRC encoding procedures are used.

Receipt of each of these bursts at the other end of its RF link will result in two messages being sent to its host. Upon receiving the GND BDCST Burst, it will be processed in the airborne transceiver by the normal operational procedures described in Section 3.1.6. A GND BDCST message to the airborne host will result (if the FEC and CRC checks pass). In addition, the airborne transceiver will also process the received GND BDCST Burst in a way which bypasses the CRC and FEC validation checks. This results in the unvalidated, uncorrected payload being passed to the host as a GND BDCST TEST message type. The payload within this message is used by the host software to make its channel BER measurements. Therefore, when in test mode, receipt of a GND BDCST Burst by an airborne transceiver will result in two messages to the airborne host: a GND BDCST message processed by the transceiver by the normal procedures (if CRC and FEC pass) and a GND BDCST TEST message.

A similar procedure is used by the transceiver configured as a ground terminal. In this way, the BER performance of both link directions can be assessed simultaneously.

Note that this test is limited to a single transceiver pair, one configured as ground, the other as an airborne terminal. No other transceivers should attempt to share the channel during the test. Figure 3-3 shows the data flow sequence of the transceiver pair under test.

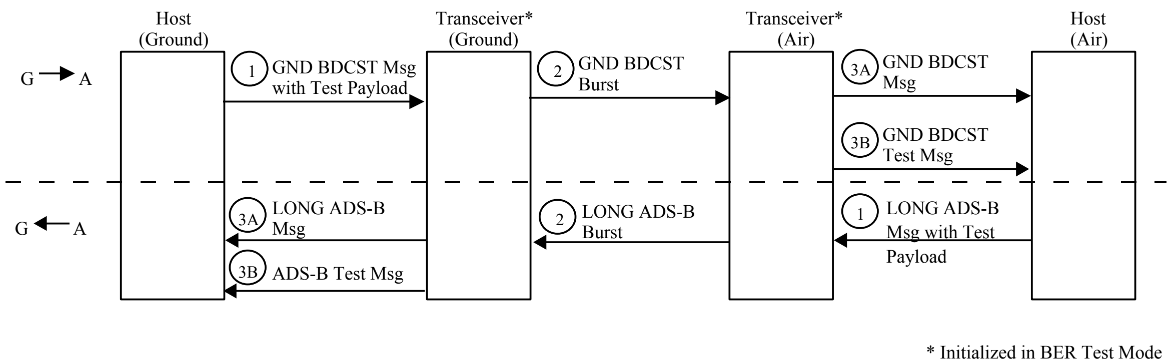


Figure 3-3. Data Flow Sequence in BER Test Mode

Section 4

Ground Network Concept and Architecture

The multipurpose broadcast data link architecture exemplified by the UAT offers significant flexibility in the deployment and functionality of the ground infrastructure. For example, FAA could deploy a set of receivers to support surveillance, while a service provider could provide uplink broadcast with a separate ground network of transmitters. On the other hand, a single ground network of transceivers could provide uplink broadcast transmission and ATC surveillance. Section 4.1 discusses a concept for uplink broadcasts and Section 4.2 discusses support for surveillance downlink.

4.1 Uplink Broadcast

4.1.1 Providing Coverage

The UAT GND BDCST Burst supports the uplink of any information of a broadcast nature. In order to assure a reasonable degree of continuity of service throughout the airspace, a network of ground broadcast transmitting stations would be required.

Each ground transmitting station will have associated with it two types of coverage. One is the *radio coverage* of the transmitted uplink signal. A minimum altitude coverage (ignoring terrain effects) can be reasonably estimated based on the intersite ground station spacing using the 4/3 earth model. For example, a somewhat regular "cellular" pattern of ground stations with a nominal intersite spacing of 100 nmi would assure coverage everywhere down to about 3000 feet above ground level (AGL). This intersite spacing would require a broadcasting range of about 70 nmi.

The other type of coverage associated with the ground station is its *product coverage*. This is simply the geographic scope of responsibility the ground station assumes for each product (such as a weather map) broadcast. The product coverage should always exceed the radio coverage, if possible, in order that significant service overlap will occur between ground station boundaries. This is required in order that site transitions appear seamless to the user.

4.1.2 Tailoring Uplink Transmissions by Product

Significant flexibility exists to tailor the product coverage and update rate to suit the characteristics of individual products. Product coverage for a ground station in terms of geographic area could vary depending on product type. For example, products that are relatively small in terms of total data volume and that are updated infrequently such as Automated Terminal Information Service (ATIS) messages could have a relatively large product coverage such as 500 or 1000 nmi radius of the ground site with a relatively low update rate. On the other hand a product such as real time radar reflectivity data may call for a relatively high update rate and a smaller coverage area—say within a 200 nmi radius of ground site—to keep data link bandwidth requirements at a reasonable level. Figure 4-1 shows the radio coverage and the product coverage concept.

4.1.3 Coordination of Ground Stations

The use of a cellular coverage concept requires the ability to coordinate the transmissions of proximate ground stations such that interference is controlled. The classic method is a *frequency-based* approach where each ground station would be assigned a separate frequency in some regular pattern. Another alternative applicable to the prototype transceiver concept is a *time-based* approach where ground stations are assigned nonconflicting time slots in the Ground Segment of the transceiver frame. The use of these time slots is then coordinated and assigned across ground stations in a similar regular pattern. The higher the system's tolerance to self-interference, the higher the geographic reuse rate of the time slots. The prototype transceiver waveform was selected for a high degree of tolerance to self-interference which should result in a maximum reuse rate for these time slots, hence high overall system capacity. Based on cochannel interference simulations of the waveform, the reuse pattern shown in Figure 3-2 should be possible.

A significant benefit of limiting uplink data to broadcast mode and having all ground stations on the same frequency is that procedures for connection management and channel switching are totally eliminated. As a result, the airborne prototype transceiver simply listens to any and all ground stations within range and forwards all GND BDCST bursts received to the host. Note that a substantial degree of redundancy could exist in the uplink data received from an aircraft in view of multiple ground stations. However, this adds a type of space diversity and hence robustness to the system. It then becomes the responsibility of the airborne application host to purge the redundant information as appropriate for presentation to the pilot.

4.1.4 Feeding the Ground Broadcast Server

Flight Information Services-Broadcast (FIS-B) is the term used to denote the broadcast distribution of weather and aeronautical information. A simple approach for distributing weather and aeronautical information products for broadcast by each ground station is to broadcast via satellite—from an existing commercial source—a national aggregate of each product type desired. This approach minimizes any development efforts, assures updates across sites are available in a synchronous and consistent fashion, and avoids the need for dedicated telco service at the site. Upon receipt of the aggregate national products from the commercial source, the ground site processor is then responsible for extracting the portion corresponding to its product coverage, formatting for uplink transmission, and scheduling for uplink transmission. Figure 4-2 shows a functional block diagram of the ground station.

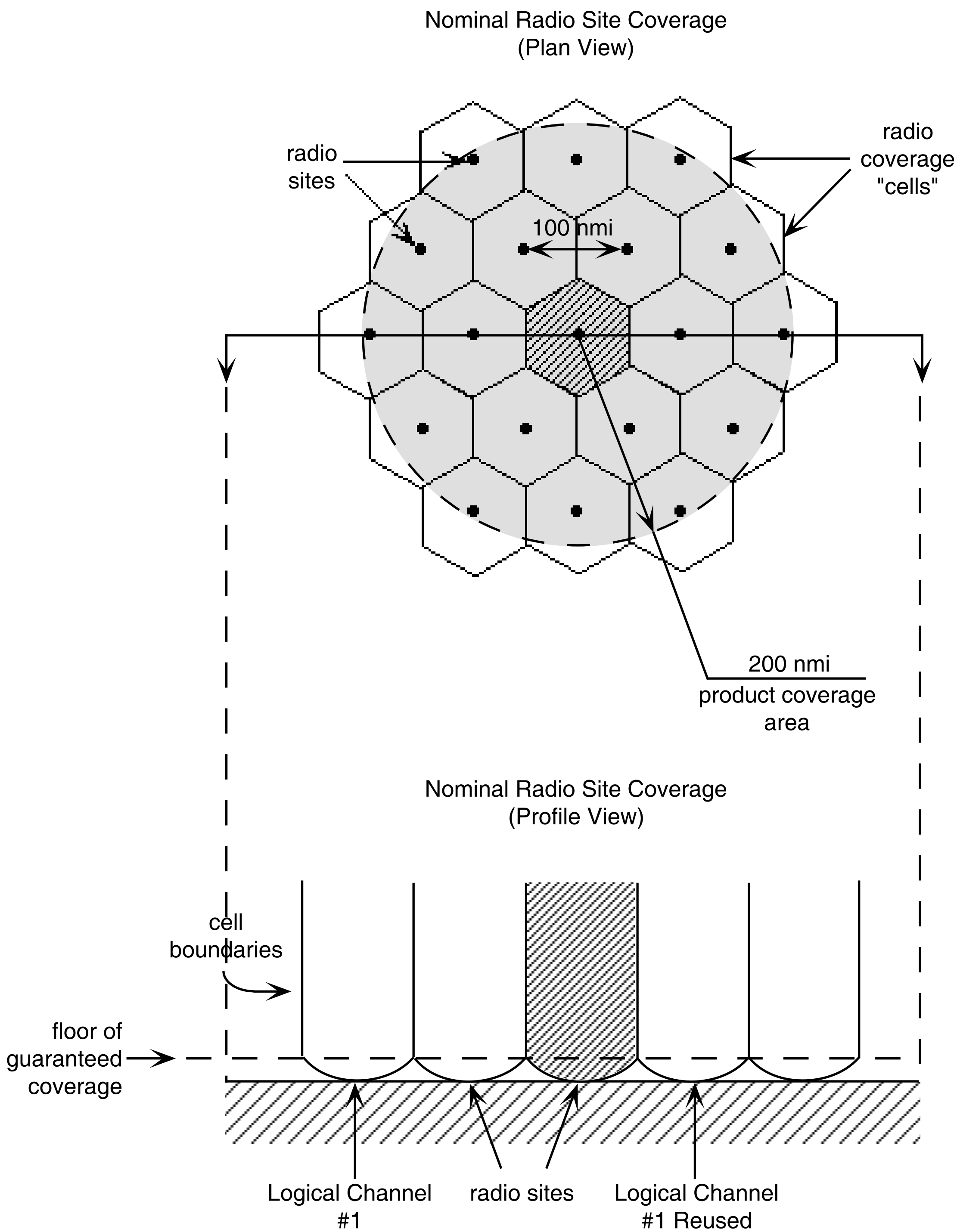


Figure 4-1. Radio Coverage and Product Coverage Example

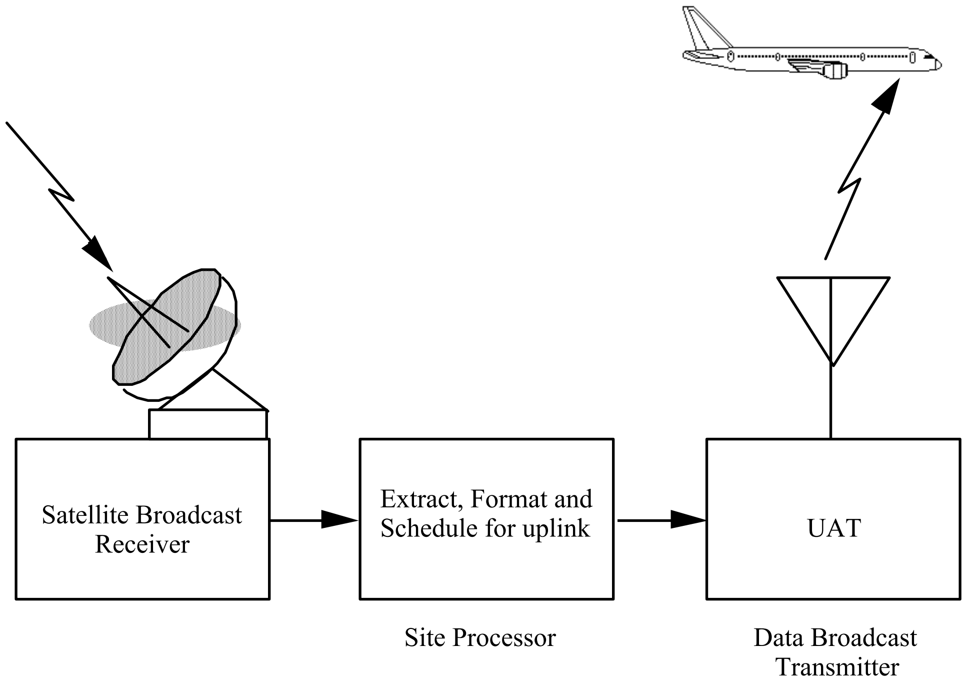


Figure 4-2. Ground Station Functional Block Diagram

Another potential source of information for the Ground Broadcast Server is traffic information from surveillance radar. This is referred to as Traffic Information Service-Broadcast (TIS-B). TIS-B will be important in supporting the transition to a full ADS-B system. A broadcast approach for this uplinked traffic information has the following advantages:

- Can be supported by most existing Secondary Surveillance Radar (SSR).
- Target data is provided with an absolute location reference for easy integration with ADS-B data for presentation on cockpit Traffic Situation Displays (TSD).

Inclusion of this information will be practical only at ground stations that are collocated with the surveillance radars.

4.2 Downlink: Supporting Surveillance

An advantage of the integrated broadcast medium concept is that the same ground station that is supporting uplink broadcast can also support air traffic control (ATC) surveillance through receipt of the ADS-B burst from aircraft within coverage of the ground station. Since ADS-B is broadcast from aircraft to no particular ground station, diversity benefits are possible when an aircraft is in coverage of multiple ground stations. Line-of-sight coverage characteristics for air-ground surveillance will be similar to that described for ground-to-air uplink broadcasts.

Section 5

Scaling the Prototype Architecture to an Operational System

The system capacity of the prototype transceiver described in Section 2 may be inadequate to support an operational ADS-B system in high-density airspace. Fortunately, the architecture of this data link will readily "scale up" with a wider bandwidth with very few specification changes from those described in Section 2. This section presents some performance aspects of the data link in the context of a postulated scaled up version of the prototype. Performance characteristics described in this section are based on analysis and simulation.

5.1 Parameters for Postulated Scaled Up System

The fundamental difference between the postulated scaled up system and the prototype system described in Section 2 is the channel bit rate of 1 Mbps. All burst and message types would remain unchanged and the message set over the application host interface would remain unchanged. As a result of the higher RF bit rate, the burst lengths would become shorter as follows:

BASIC ADS-B	248 μsec
LONG ADS-B	376 μsec
GND BDCST	4120 μsec

These shorter lengths allow for a change in the media access frame structure. With some minor adjustments, the system can support 32 time slots in the Ground Segment without any loss of propagation guard time.

5.2 Link Margin

The system is designed to operate in an environment where the *channel* BER is 10^{-3}. Simulation shows that this BER can be achieved when E_b/N_o is 9.9 dB. There is also an allowance for 2 dB of excess implementation loss included in the budget.

When the channel BER is 10^{-3}, then the message error rate (MER) for the RS (25, 19) code (BASIC ADS-B) is 4×10^{-5}; and for the RS (41, 35) code (LONG ADS-B) it is 3×10^{-4}. Under the same conditions the MER for the RS (255, 235) code (GND BDCST) is 10^{-5}. The CRC-24Q code error detection performance is such that the undetected MER is no greater than 6×10^{-8}.

5.2.1 Air/Air Link Budget

Table 5-1 shows the link budget for the air-air path. Omnidirectional aircraft antennas are assumed. A path length of 60 nmi and a transmit power of 50W is assumed for the evaluation. Flight testing will help determine the actual margin required for a given level of link performance.

Table 5-1. Air-Air Link Budget

Transmitted power	47.0	dBm	50 Watts
Airborne cable	-2.0	dB	
Airborne antenna	0.0	dB	
Propagation	-133.0	dB	60 nmi @ 960 Mhz
Airborne antenna	0.0	dB	
Airborne cable	-2.0	dB	
Received power	-90.0	dBm	
kT	-174.0	dBm/Hz	
R_b	60.0	dBHz	1 Mbps*
F	6.0	dB	Noise figure
Received noise	-108.0	dbm	
Received E_b/N_o	18.0	dB	
Theoretical required E_b/N_o	9.9	dB	2 LFM @ 10-3
Implementation loss	2.0	dB	
Required E_b/N_o	11.9	dB	
Margin	6.1	dB	Allowance for fading, antenna lobing, etc.

* Assumes that receiver bw is matched to data rate. Any difference will be accounted for in implementation loss.

5.2.2 Air/Ground Link Budget

Table 5-2 shows the link budget for the air-ground path. In this case the ground antenna is assumed to be directional with a gain of 6 dB. A path length of 100 nmi and a transmit power of 50W is assumed for the calculations. Flight testing will help determine the actual margin required for a given level of link performance.

Table 5-2. Air-Ground Link Budget

Transmitted power	47.0	dBm	50 Watts
Airborne cable	-2.0	dB	
Airborne antenna	0.0	dB	
Propagation	-137.4	dB	100 nmi @ 960 Mhz
Ground antenna	6.0	dB	Directional antenna
Ground cable	-2.0	dB	
Received power	-88.4	dBm	
kT	-174.0	dBm/Hz	
R_b	60.0	dBHz	1 Mbps*
F	6.0	dB	Noise figure
Received noise	-108.0	dbm	
Received E_b/N_o	19.6	dB	
Theoretical required E_b/N_o	9.9	dB	2 LFM @ 10-3
Implementation loss	2.0	dB	
Required E_b/N_o	11.9	dB	
Margin	7.7	dB	Allowance for fading antenna lobing, etc.

* Assumes that receiver bw is matched to data rate. Any difference will be accounted for in implementation loss.

5.3 Cochannel Interference

Whenever there are two valid signals present, a receiver can receive the stronger of the two signals with channel BER $\leq 10^{-3}$ if S/I $\geq$ 4.4 dB (where S is the received power of the stronger signal and I is the received power of the weaker signal).

Note— This performance level is estimated by computer simulation without any appreciable Additive White Gaussian Noise (AWGN). Experience has shown that actual cochannel performance may be degraded by about 1 - 2 dB.

5.4 Transmitted Spectrum

The spectrum of the scaled up prototype transceiver waveform is shown in Figure 5-1. The width of the spectrum as measured at the -60 dB points (where the spectral density is

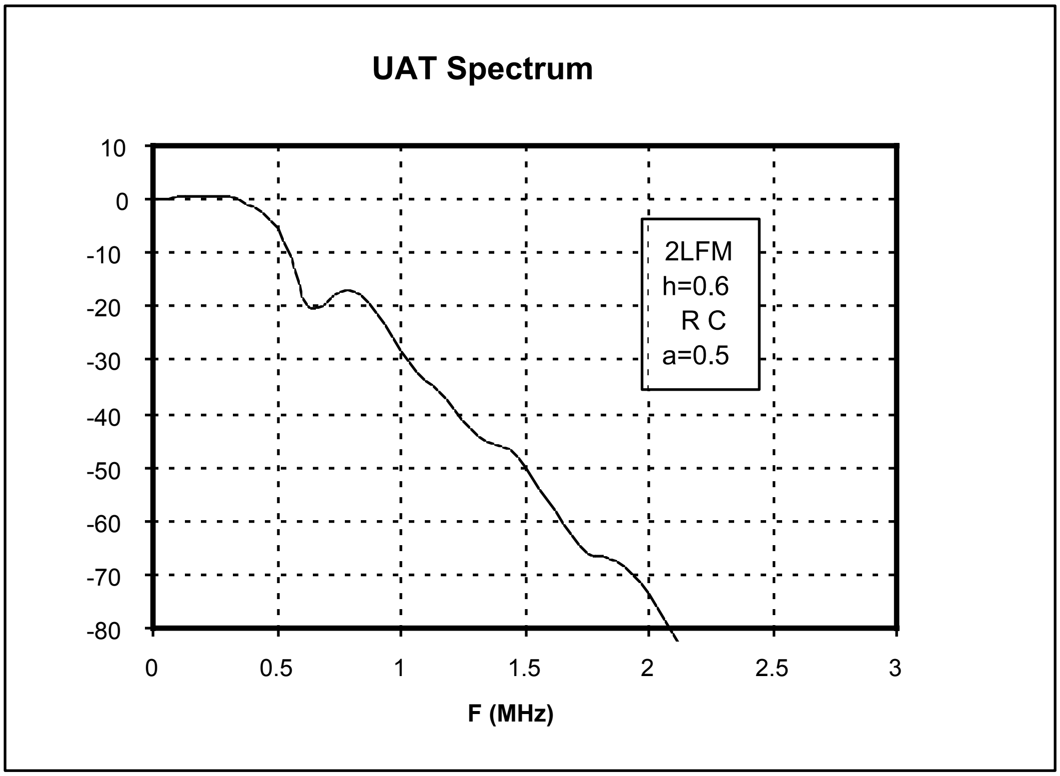


Figure 5-1. Spectrum of Prototype Transceiver Waveform as Scaled Up

60 dB less than the nominal density at zero frequency offset) is approximately 3.3 MHz. Ninety-nine percent of the power is transmitted within +625 kHz of the carrier frequency.

Since the waveform has a constant envelope, a high degree of linearity in the transmitter amplifier is *not* necessary to preserve the spectral containment.

5.5 Performance Calculations and Assumptions

Since the prototype transceiver is a random access system for ADS-B message transmissions, the capacity of the system is interference limited by the probability of message collision with other aircraft within range. In this section, the capacity of the ADS-B segment of the transceiver frame is examined relative to the surveillance performance of the system. Broadcasts from ground stations do not compete for access to the channel with ADS-B burst transmissions and so are excluded from the analysis.

5.5.1 Assumptions

The following assumptions were used in examining the performance of the system for air-air surveillance.

- **A clear channel is available for ADS-B transmissions.** No other type of traffic competes for the channel with ADS-B messages. This is consistent with the frame segmentation of the UAT timing structure.
- **Any aircraft within the assumed "visible" population are capable of interfering with any other if a burst overlap occurs.**
- **Only the air-air case is considered.** This represents the worst interference environment since antennas are omnidirectional and potentially high altitude.
- **A 4.5 ms "blind spot" exists for an airborne receiver due to setup for ADS-B transmission, the ADS-B transmission itself, and the setup time required to resume reception.**

5.5.2 Calculations

Calculation was based on the probability of receiving a given ADS-B burst from an aircraft with no overlap from an other aircraft's transmissions. This probability is given by

$$e^{-2LNr/F}$$

Where

L = ADS-B burst length
N = number of aircraft
r = reporting period (1 Hz)
F = channel allocation factor (0.819)

The channel allocation factor is simply the fraction of the link bandwidth devoted to ADS-B reporting.

Figures 5-2 and 5-3 show the performance of the system for two aircraft population scenarios: 500 aircraft, and 1000 aircraft respectively. Performance is expressed as the probability of at least one successful reception in a given number of seconds.

Specific assumptions for the scaled up version of the prototype transceiver are as follows:

- One ADS-B Burst transmission per second.
- One half of aircraft transmit LONG ADS-B Burst and one half transmit BASIC ADS-B Burst in any one second interval.
- Receiver is trying to receive a LONG ADS-B Burst (worst case).

Number of Aircraft Visible 500

	1	2	3	4	5
Scaled Up Clear Channel UAT	0.649	0.877	0.957	0.985	0.995

Scaled Up Clear Channel UAT
LONG ADS-B Burst length (sec) 3.76E-04
BASIC ADS-B Burst length (sec) 2.48E-04
Channel Allocation Factor =
(ADS-B segment) 0.819
Factor for T/R switching "blind spot" 0.994

ADS-B burst type distribution in any 1 second interval
LONG ADS-B = 0.5
SHORT ADS-B = 0.5

P no short overlap = 0.821606
P no long overlap = 0.790123

P clear decode per second = 0.649

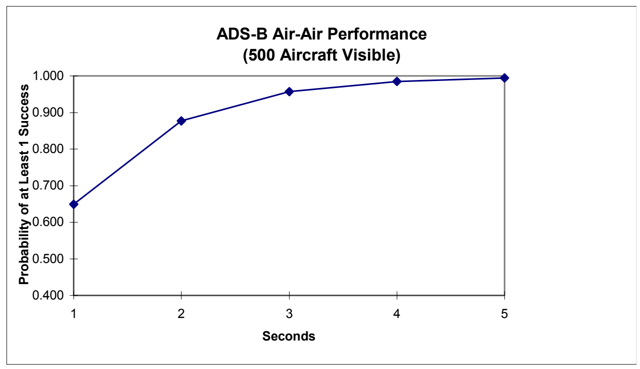


Figure 5-2. Performance with 500 Aircraft Visible

Number of Aircraft Visible 1000

	1	2	3	4	5
Scaled Up Clear Channel UAT	0.427	0.671	0.811	0.892	0.938

Scaled Up Clear Channel UAT
LONG ADS-B Burst length (sec) 3.76E-04
BASIC ADS-B Burst length (sec) 2.48E-04
Channel Allocation Factor =
(ADS-B segment) 0.819
Factor for T/R switching "blind spot" 0.994

ADS-B burst type distribution in any 1 second interval
LONG ADS-B = 0.5
SHORT ADS-B = 0.5

P no short overlap = 0.679111
P no long overlap = 0.628063

P clear decode per second = 0.427

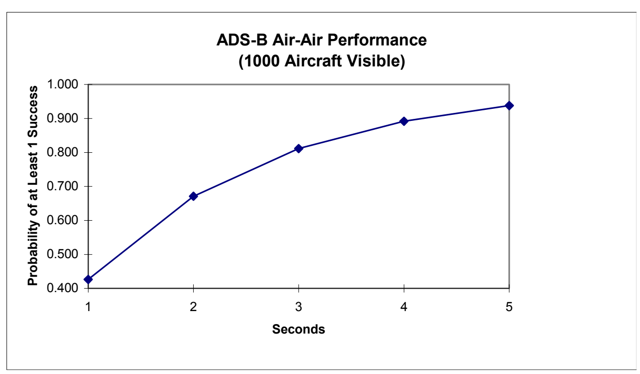


Figure 5-3. Performance with 1000 Aircraft Visible

It should be noted that the probability of receiving very close aircraft should be higher than indicated depending on the capture effect characteristics of the system. This is related to the cochannel interference characteristic discussed in Section 4.2 and was considered a very important characteristic of the prototype transceiver waveform design. Given a good capture effect characteristic, an attribute of a random access ADS-B system is that the effective update rate for air-air surveillance will be a function of range in an interference limited environment. Although all aircraft report at the same rate, close aircraft appear to have a higher update rate than distant aircraft. This may be consistent with operational air-air surveillance needs, particularly if adequate trend information is included in broadcast reports.

Section 6

Summary

This document has presented the design and operating concept for a prototype transceiver system to support multiple broadcast applications. The following are the salient attributes of the transceiver system:

- Capable of supporting ADS-B, TIS-B and FIS-B services in an integrated medium.
- Simple channel access procedures.
- Operates in a consistent fashion throughout all phases of flight.
- Operates in all airspace without the need for connection management or frequency management procedures.

The prototype transceivers will be used for evaluating this integrated broadcast medium concept in a flight environment.

List of References

1. Vincent Orlando, *GPS Squitter*, RTCA Paper No. 168-95/SC186-16, briefing presented at RTCA SC 186.

2. May 1995, *Standards and Recommended Practices (Proposed Draft) for the Application and Use of Self-organizing Time Division Multi Access (STDMA) for VHF Air-Ground Communications,* presented at ICAO AMCP.

Appendix A

Transceiver Host Interface Message Set

Message Number	Message Type	Element	# Octets	Value	Dir.
0	HEARTBEAT				To Host
		msg. header	1	0	
		GPS Rx Data (time only)	3	<see Appendix D>	
			4		
1	INIT	msg. header	1	1	To Transceiver
		A/C address	3	set by host	
		configuration	1		
		bit 0=term type (LSB)		0=gnd. 1=air	
		bit 1=alt source		0=baro 1=GPS	
		bit 2=address type		0=discrete address 1= anonymous	
		bit 3=BER test mode		0=operational mode 1=BER test mode	
		bit 4=transmit status		0=normal 1=receive only	
		bit 5=demo		0=operational mode 1=demo mode	
		bit 6, 7=spare		[TBD]	
		transmission time offset	1	*	
			6		
2	STATUS REQ.				To Transceiver
		msg. header	1	2	
3	STATUS				To Host
		msg. header	1	3	
		A/C address	3	↑ readback of host settings	
		configuration	1		
		transmission time offset	1	↓	
		GPS Rx Data	12	<see Appendix D>	
			18		

* If configured as a ground terminal, values 0–15 are legal and select a fixed time slot in the Ground Segment. If configured as an airborne terminal, the value 0 selects random transmission time in the ADS-B Segment and the values 1–255 are also legal and specify a fixed time offset (in MSOs) following the first MSO of the ADS-B Segment (760).

Message Number	Message Type	Element	# Octets	Value	Dir.
4	SUPPLE-MENTAL DATA				To Transceiver
		msg. header	1	4	
		<supplemental data for LONG ADS-B burst payload>	16	*	
			17		
5	BASIC ADS-B				To Host
		msg. header	1	5	
		source	1	0 = ownship 1= traffic	
		<BASIC ADS-B burst payload>	16	*	
			18		
6	LONG ADS-B				To Host (Op. Mode) To Transceiver (BER Test Mode)
		msg. header	1	6	
		source	1	0 = ownship 1 = traffic	
		<LONG ADS-B burst payload>	32	*	
			34		
7	GND BDCST				To Host To Transceiver
		msg. header	1	7	
		<GND BDCST burst payload>	464	*	
			465		
254	GBD BDCST TEST				To Host
		msg. header	1	254	
		BER test data	510	*	
		correlation value	1		
			512		
255	ADS-B TEST				To Host
		msg. header	1	255	
		BER test data	42	*	
		correlation value	1		
			44		

* Element treated in transparent fashion by transceiver.

Note:

- Messages 254 and 255 are used only to support BER testing when the transceiver is initialized in test mode.
- BER test data includes payload, CRC, FEC and (for ADS-B bursts) the length identifier components.
- Transmitting end shall flag delimit and byte stuff all messages prior to transmission over the serial interface.
- Receiving end shall remove flags and unbyte stuff all messages received over the serial interface.

Appendix B

Procedure for Selecting Pseudorandum ADS-B Burst Transmission Times

ADS-B bursts are transmitted at discrete Message Start Opportunities (MSO) chosen by a pseudorandom process. The specific pseudorandom number chosen by an aircraft depends on the aircraft's current position and on the previously chosen random number. The algorithm is described below.

The desired output of the algorithm is a 12-bit pseudorandom number. Suppose the previous number is R(m-1) and

$$N(1) = 12 \text{ L.S.B.'s of the current latitude}$$

$$N(2) = 12 \text{ L.S.B.'s of the current longitude}$$

where the latitude and longitude are as defined in Table 2-1. The next random number is then given by

$$R(m) = \{4001 \cdot R(m-1) + N(m \bmod 2)\} \bmod 3200$$

Thus, the latitude and longitude alternate in providing a changing "seed" for the pseudorandom number generation.

This algorithm provides anonymity to the aircraft and ensures, with very high probability, that no two aircraft will repeatedly choose the same MSO's.

Appendix C

Procedure for Generating Random "Anonymous" 24-Bit Aircraft Address

Normally, the Aircraft Address field of the ADS-B burst is set to a unique 24-bit address preassigned to the aircraft (e.g., the ICAO address). For a variety of reasons, users may wish to withhold the information contained in the explicit address. This can easily be done by adding to the preassigned address a 24-bit number that depends on the position of the aircraft during initialization. Once having been chosen, the anonymous address does not normally change during a flight.

Let ADDR be the 24-bit preassigned address. Let M(1) and M(2) be the 12 L.S.B.'s of the *initial* latitude and longitude, respectively, of the aircraft. Define the 24-bit number

$$M(3) = 4096 \cdot M(1) + M(2).$$

The anonymous address is simply the modulo 2, bit-by-bit summation of ADDR and M(3); i.e.,

$$\text{ANON ADDR} = \text{ADDR} \oplus M(3)$$

This procedure should guarantee that neither the aircraft's true ADDR nor its true initial position can be determined.

Appendix D

GPS Rx Data Format

Byte #	Element	Range	Resolution	Source*
1	hours	0..23	1	1
2	minutes	0..59	1	1
3	seconds	0..60	1	1
4, 5	current DOP	0..99.9	.1	1
6	number of visible sat	0..12	1	1
7	number of satellites needed	0..6	1	1
8	receiver status msg (msb) Bit 8: Position propagate mode Bit 7: Poor Geometry (DOP >20) Bit 6: 3D Fix Bit 5: Alt hold (2D Fix) Bit 4: Acquiring satellites/Position hold Bit 3: Differential Bit 2: Insufficient visible satellites (lsb) Bit 1: Bad Almanac			1
9, 10	magnetic variation	-180.0 to +180.0 (positive angles east; negative angles west)	.1 deg.	2
11, 12	age of diff. corrections	0..65535	.1 sec	2

* 1 = Position/Status/Data Output Message of Motorola Oncore.
2 = Position/Status/Data/Extension Message of Motorola Oncore.

Bit Number

First bit transmitted (bit 1)

Octet No.	8	7	6	5	4	3	2	1		
1	LSB			<hours>				MSB	part of message 0	part of message #3
2	LSB			<minutes>				MSB		
3	LSB			<seconds>				MSB		
4				<current DOP>				MSB		
5	LSB									
6	LSB			<# of visible sat>				MSB		
7	LSB			<# of sat tracked>				MSB		
8	LSB			<receiver status msg>				MSB		
9				<magnetic variation>				MSB		
10	LSB									
11				<age of diff. corr. data>				MSB		
12	LSB									

Figure D-1. GPS Rx Data

Glossary

ADS-B	Automatic Dependent Surveillance-Broadcast
AGL	above ground level
ARP	Airborne Research Prototype
ATC	air traffic control
ATCRBS	ATC Radar Beacon System
ATIS	Automated Terminal Information Service
AWGN	Additive White Gaussian Noise
BER	bit error rate
bps	bits per second
CDMA	Code Division Multiple Access
CPFSK	Continuous Phase Frequency Shift Keying
CRC	cyclic redundancy check
dB	decibel
FDMA	Frequency Division Multiple Access
FEC	Forward Error Correction
FIS-B	Flight Information Service-Broadcast
GMSK	Gaussian Minimum Shift Keying
GND BDCST	Ground Broadcast
GPS	Global Positioning System
hz	hertz
ICAO	International Civil Aviation Organization
INIT	Initialization
kbps	kilobits per second
kHz	kilohertz
LSB	Least Significant Bit
MER	message error rate
MHz	megahertz
ms	millisecond

MSB	Most Significant Bit
MSO	message start opportunities
nmi	nautical miles
PPM	part per million
PPS	pulse per second
RC	Raised Cosine
RF	Radio Frequency
RS	Reed-Solomon
RTCM	Radio Technical Commission for Maritime Services
SSR	Secondary Surveillance Radar
STDMA	Self-organizing Time Division Multiple Access
TDMA	Time Division Multiple Access
TIS-B	Traffic Information Service-Broadcast
TSD	Traffic Situation Displays
UAT	Universal Access Transceiver
VHF	Very High Frequency

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