Design and Implement of a Configurable ADS-B Out System Complying with RTCA DO-260 B and C

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Abstract
Automatic Dependent Surveillance-Broadcast (ADS-B) is a surveillance system installed on airplanes, aerodrome mobiles, and other objects to periodically broadcast and/or receive their identification, velocity, position, and additional data by Mode S-Extended Squitter (1090ES) data link. ADS-B systems have 2 subsystems: ADS-B In and ADS-B Out. In the International Civil Aviation Organization (ICAO) definitions of ADS-B subsystems, ADS-B Out broadcasts aircraft state vectors and navigation information. ADS-B In, as the complementary of ADS-B Out subsystem, provides air-to-air awareness of situations to pilots. A fully operational ADS-B system (ADS-B Out and ADS-B In) must comply with the avionics and navigation standards. The RTCA DO-260 standard includes minimum operational performance requirements for airborne equipment for ADS-B systems using 1090ES. An operational ADS-B Out system must be certified by RTCA DO-260 standard. Compliance with DO-260 standards is recommended by designers, manufacturers, and users as one of the essential means of assuring that the equipment will satisfactorily perform its intended functions under conditions encountered in normal aviation operations. Versions B and C of DO-260 were released in December 2011 and December 2020, respectively. Therefore, there are differences in the operational registers of these two versions. Hence, the proposed ADS-B Out system is designed to be compliant with DO-260 standard versions B and C. The proposed system can easily toggle between two DO-260 standard versions. The experimental assessments demonstrate the reliable operation of the manufactured ADS-B Out.

Keywords: *Aircraft, Surveillance System, Air Traffic Control, Ground Station, DO-260 standard, ADS-B.*

1. Introduction

Automatic Dependent Surveillance-Broadcast (ADS-B) is a surveillance system installed on airplanes and aerodrome mobiles to automatically send and/or receive important information including identification, velocity, position, and additional data in a broadcast mode via a data link. ADS-B is automatic because no external stimulus is required [1-7]. It is dependent because it relies on on-board horizontal position sources and on-board broadcast transmission systems to provide navigation and surveillance information to other users. The airplane originating the broadcast will have no knowledge of which users are receiving its broadcast. ADS-B system on an aircraft is categorized into ADS-B Out and ADS-B In services [7]. Based on the International Civil Aviation Organization (ICAO) definitions of ADS-B subsystems, ADS-B Out periodically transmits aircraft-related information provided by sensors and navigation systems installed on the aircraft. ADS-B In receives the broadcasted data of ADS-B Out and weather information. ADS-B also need ground stations to receive the broadcasted data from aircraft. The ground station decodes the received information and sends them to Air Traffic Control (ATC) automation systems for display on the screens of air traffic controllers. An illustration of the ADS-B system is illustrated in Fig. 1. With ADS-B, an aircraft position is detected by an onboard Global Navigation Satellite System (GNSS) [7,8]. ADS-B Out broadcasts the aircraft's position along with other data such as path, heading, altitude, and velocity to the ground station and other nearby ADS-B In equipped aircraft within its range. Any user, either aircraft or ground-based, within the range of the broadcast, may choose to process the

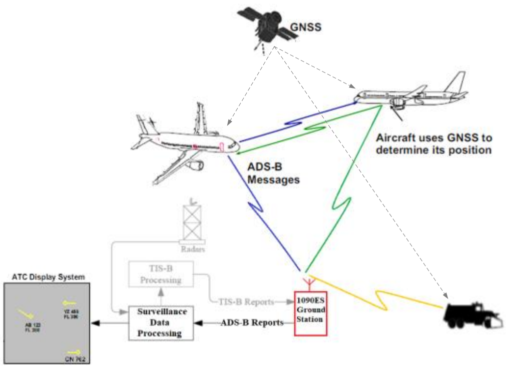

Fig. 1: An illustration of the ADS-B system includes ADS-B In, ADS-B Out, and ground station.

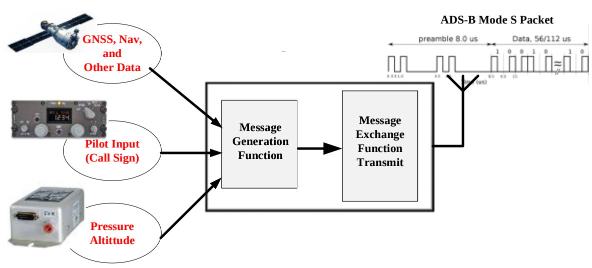

Fig. 2: The schematic diagram of an ADS-B Out system [1,2].

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received ADS-B surveillance information. The ground station sends the received ADS-B messages to a surveillance data processing system for utilization by the ATC system [3,4] & [7-10].

A fully operational ADS-B system (ADS-B Out and ADS-B In) must comply with the avionics and navigation standards. The RTCA DO-260 standard includes minimum operational performance requirements for airborne equipment for ADS-B systems using 1090ES. An operational ADS-B Out system must be certified by RTCA DO-260 standard. Compliance with DO-260 standards is recommended to ensure that the aircraft equipped with ADS-B Out will satisfactorily perform its intended functions under conditions encountered in normal aviation operations. Versions B and C of DO-260 were released in December 2011 and December 2020, respectively. Therefore, there are differences in the operational registers of these two versions. In this paper an ADS-B Out system is presented to be compliant with DO-260 standard versions B and C. The proposed system can easily toggle between two DO-260 standard versions.

The rest of this paper is organized as follows: The ADS-B Out system is introduced in section 2. Section 3 presents the ADS-B Out message formats. In section 4, the experimental results are shown, and the operational compliance table is presented. Finally, the paper is concluded in section 5.

2. ADS-B Out System

Fig. 2 depicts the schematic diagram of an ADS-B Out system. As shown in Fig. 2, the ADS-B Out comprises two main blocks: Message Generation Function (MGF) and Message Exchange Function Transmit (MEFG). An ADS-B Out system gathers the position, velocity, identification, and status information from associated systems installed on an aircraft and then broadcasts this information in Mode S-Extended Squitter (ES) on 1090 MHz. The input data to an ADS-B Out system can be provided by a GNSS system, an Altitude encoder system, and/or a control box module. The pilot can deliver the call sign input by the control box module. In Fig. 3 and 4, these two main building blocks of ADS-B Out are illustrated in more detail [1,2].

Message Generation Function block collects and organizes the information transmitted through 1090ES. This block includes two sub-blocks of Input Interface & buffer and Message Assembler & Encoder [5,6].

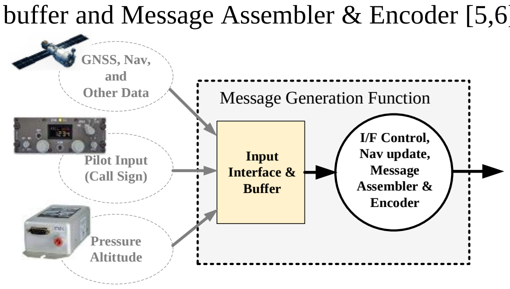


Fig. 3: The schematic diagram of the Message Generation Function block [1,2].

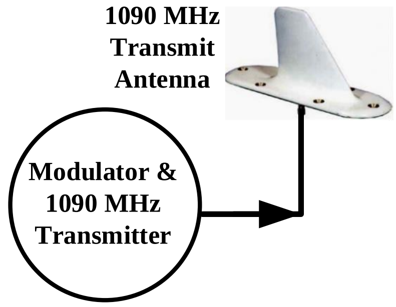


Fig. 4: The schematic diagram of the Message Assembler & Encoder block [1,2].

As shown in Fig.3, in the Input Interface & buffer sub-block, either input data is delivered directly through the supplied data sources (e.g., the GNSS, the altitude encoder, and the control box) or through a data concentrator which is an interface between the transponder and the input data.

The 1090 MHz ES data is transmitted by the Message Assembler & Encoder block. As depicted in Fig.4, this block includes a Modulator & 1090 MHz Transmitter and 1090 MHz Transmit Antenna. The Modulator & 1090 MHz Transmitter performs the pulse position modulation (PPM) on ADS-B Out message based on EUROCAE standard [5,6]. Fig. 5 shows the ADS-B Out message format. As shown in Fig. 5, the ADS-B Out message is formed of four preamble pulses followed by the PPM encoding of the message data. In PPM encoding, a pulse transmitted in the first half of the interval represents “1” while a pulse transmitted in the second half represents “0”. By utilizing the PPM encoding, the message contents are preserved by parity checking in the coding algorithm. Besides, using the PPM encoding protects the ADS-B Out message from air traffic control radar beacon system (ATCRBS) signal interferences. Finally, the ADS-B Out PPM message is transmitted by the 1090 MHz Transmit Antenna unit.

In ADS-B, the position and state vector estimations are sourced in the aircraft and data-linked to the ground. Depending on the equipment and positioning method, the accuracy and integrity may vary between aircraft and over time. Therefore, the accuracy and integrity of information are provided as variables in the ADS-B message and determined by NIC, NUC, and SIL variables [1,2] & [5,6].

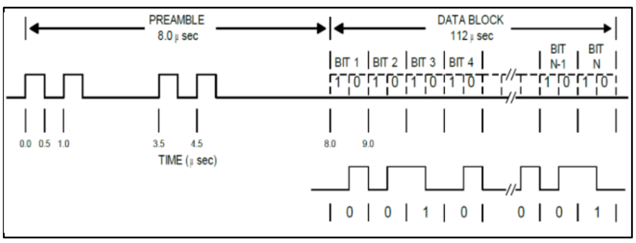


Fig. 5: the ADS-B Out message signal composed of four preamble pulses followed by the PPM encoding message data [1,2].

Navigation Integrity Category (NIC) is a coded parameter in the ADS-B message that is used to report the maximum position error that may not be detected. Navigation Uncertainty Category (NUC) is a coded variable in the ADS-B message that is used to reflect the maximum position error that may not be detected with a predefined probability. NUC originates in the position-determining system and is broadcasted by aircraft complying with DO-260/ED-102 or amendment no. 77 to Annex 10.
Surveillance Integrity Limit (SIL) is a variable that indicates the probability that the position error is greater than NIC and undetected. NIC and SIL are broadcasted by aircraft complying with DO-260 [1,2].

3. The ADS-B Out message formats

The ADS-B Out message is sent at 1090 MHz ES data link. The contents of the ADS-B Out message are the provided data by state sensors and navigation systems installed on the aircraft. Data from state sensors and navigation systems are stored in various registers. Therefore, these registers are accessible when an ADS-B Out message is generated. The ADS-B Out message format is shown in Figure 6. The message contains 112 bits. As shown in Fig. 6, the middle 56 bits, message bits 33 through 88, are called Message Extended Squitter (ME). The registered values of state sensors and navigation systems are inserted in the ME field. The 56 remainder bits include 8 control bits (i.e., DF and CA), 24 ICAO address bits (i.e., AA: message bits 9 through 32), and 24 error detection parity bits (i.e., PI: message bits 89 through 112). The CA field describes the capabilities of the Mode S transponder, the AA field holds the transponder's 24-bit ICAO address, the ME field holds the body of the ADS-B Out Message, and the PI field holds parity check bits [1,2].

3.1. The ME field

According to Fig. 6, the contents of the ME field are 56 bits and constitute the body of the ADS-B Out message. Therefore, the ME field is sent in each transmitted message and carries most of the ADS-B Out message data. The first five bits of the ME field are called Type Code. Also, the two or three bits after Type Code (i.e., bits 6 and 7 of ME) form the Subtype Code. The Type Code value and Subtype Code values (if any) determine which of several messages ADS-B Out are carried and sent by this structure [1,2].
The ME field is different for various ADS-B Out messages in DO-260 versions B and C. The designed and manufactured ADS-B complies with these two versions. Therefore, by using a jumper switch, the manufactured ADS-B Out can operate under DO-260 versions B or C.
In the next section, the main differences between DO-260 versions B and C are explained.

Bit #	1 --- 5	6 --- 8	9 --- 32	33 --- 88	89 --- 112
DF=17 Field Names	DF=17 [5]	CA [3]	AA: ICAO Address [24]	ADS-B Out Message "ME" Field [56]	PI [24]

Fig. 6: the ADS-B Out message format

3.2. Determining the type of ADS-B Out messages

All ADS-B out broadcasted messages have a basic structure. In this format, the TYPE Code field categorizes the 1090ES messages into several distinct classes. These classes are airborne position, airborne velocity, surface position, identification and category, aircraft intent, aircraft status, etc. Besides, each of these classes has its unique structure. In addition, the Type Code field defines the value of the reference NIC used to report the position. Because the amount of NIC in surveillance applications determines whether the reported horizontal position from Radius of Containment (R_C) is optimal for the intended application. Also, the Type Code format divides broadcasted messages into two categories based on height measurements: the transmitted messages include barometric pressure altitude, and the transmitted messages include geometric altitude [1,2].
The structure of the ADS-B Out messages sent in DO-260 B and DO-260 C contains the differences that are described in Table 1 to 4. The differences are related to the increase in the position resolutions and adding some additional registers in the two versions of the DO260 standard.

Table 1: The differences between the Subtype codes of DO-260 B and DO-260 C.

Type code	**Subtype code of DO-260 C**	**Subtype code of DO-260 B**
19	0	0
	1-2	1-4
	3-4	
	5-7	5-7

Table 2: The differences between the RC and NIC values in DO-260 B and DO-260 C.

Type code	**R_C of DO-260 C**	**NIC of DO-260 C**	**R_C of DO-260 B**	**NIC of DO-260 B**
22	R_C<1111.2 m	NIC=6	$R_C \geq$ 25 m or unknown	NIC=0
	R_C< 1852 m	NIC=5		
	R_C< 3.704 km	NIC=4		
	$R_C \geq$ 3.704 km or unknown	NIC=0		

Table 3: The differences between the NIC Supplement in DO-260 B and DO-260 C.

Type code	**NIC Supplement of DO-260 C**				**NIC Supplement of DO-260 B**		
	A	B	C	D	A	B	**C**
20	--	--	--	3	0	0	-
	--	--	--	2			
	--	--	--	1			
	--	--	--	0			

Table 4: The differences between message type in DO-260 B and DO-260 C.

Type code	Subtype Code of DO-260 C	Format (message type) of DO-260 C	Subtype Code of DO-260 B	Format (message type) of DO-260 B
25	0	HVA Position Message	----	Reserved
	1	HVA Velocity Message		
	2-3	Reserved		
26	0	(ADS-B Wx) Aircraft State	----	Reserved
	1	(ADS-B Wx) Weather State		
	2	(ADS-B Wx) Alternate Weather State		
	3	Reserved		

4. The designed ADS-B Out Structure and Experimental Assessment

The schematic diagram of the proposed ADS-B Out system is depicted in Fig. 7. The proposed system benefits from an on-board GNSS module. The manufactured ADS-B Out system also contains two ARINC 429 data labels for the required information to be obtained from avionics buses. Table 5 summarize the main specifications of the manufactured ADS-B Out.

The test setup of the manufactured ADS-B Out system is shown in Fig. 8. The setup test consists of the manufactured ADS-B Out, a GNSS and altitude encoder simulator, and the ADS497 ground station and the ATC system manufactured by Havayee-industry company. The manufactured ADS-B Out system with the address field (AA) of "ABC727" is programmed. Fig. 9 (a) and (b) show the real-time ADS-B Out broadcasted data in the ATC monitor system. The ground station receives and processes the ADS-B Out messages. The information extracted by the ground station is then delivered to the ATC system under the ASTRIX Cat-21 EUROCONTROL protocol to be plotted on the screen.

5. Concluding Remarks

In this paper, an ADS-B Out system was presented. The ADS-B Out system was proposed to be installed on any aircraft and aerodrome mobile. This system periodically broadcasts the identification, velocity, and position information in compliance with RTCA DO-260 standard. The RTCA DO-260 standard includes minimum operational performance requirements for airborne equipment using 1090ES. Versions B and C of DO-260 were released in December 2011 and December 2020, respectively. Therefore, there were differences in the operational registers of these two versions. The proposed system was manufactured in compliance with DO-260 standard versions. The experimental assessments showed the reliable operation of the manufactured ADS-B Out.

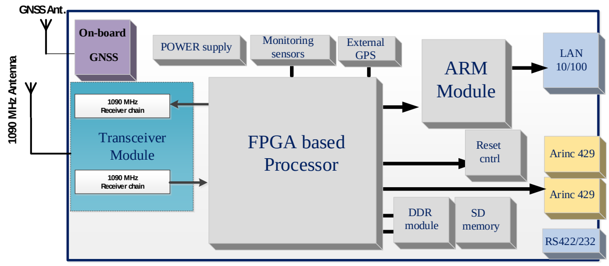


Fig. 7: The schematic diagram of the proposed ADS-B Out system

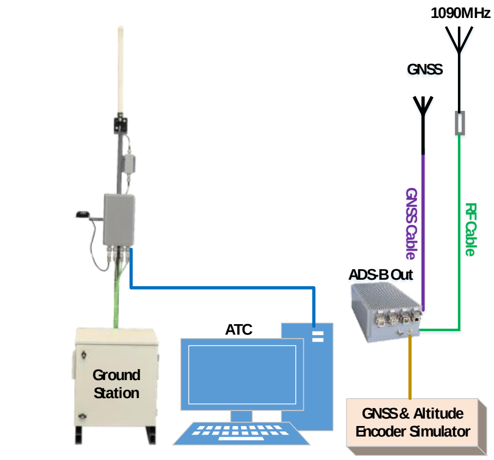
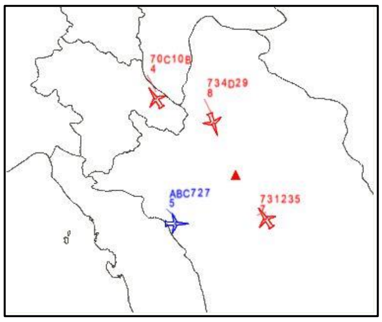
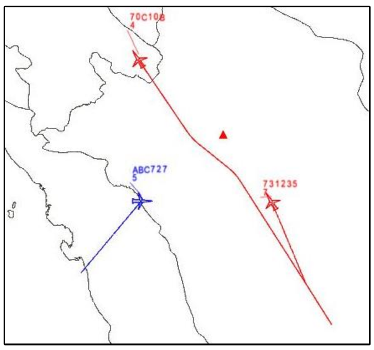


Fig. 8: The test setup of the ADS-B Out system



(a)



(b)

Fig. 9: The ADS-B Out broadcasted data programmed with AA= "ABC727" in the ATC monitor system: (a) real-time position plot, (b) historical position plot.

Table 5: The specifications of the manufactured ADS-B Out system.

<table>
<tr><th>Item</th><th>Specification</th><th colspan="2">Value</th></tr>
<tr><td>1</td><td>Type</td><td colspan="2">ADS-B Out</td></tr>
<tr><td>2</td><td>Compliance</td><td colspan="2">DO-260 B, DO-260 C, ED-73F, ED-102B, DO-181F, DO-242</td></tr>
<tr><td colspan="4">ADS-B Out Transmitter Characteristics</td></tr>
<tr><td>3</td><td>Carrier Frequency</td><td colspan="2">1090 ±1 MHz</td></tr>
<tr><td>4</td><td>RF Peak Output Power</td><td colspan="2">Min:51 dBm (125 W)
Max: 57 dBm (500 W)</td></tr>
<tr><td>5</td><td>Modulation</td><td colspan="2">Pulse Position Modulation (PPM)</td></tr>
<tr><td>6</td><td>Pulse Shapes</td><td colspan="2">Rise Time < 0.1µsec
Decay Time < 0.2µsec</td></tr>
<tr><td rowspan="5">7</td><td rowspan="5">ADS-B Out Transmission Message Spectrum</td><td>Frequency difference (MHz from 1090 MHz)</td><td>Maximum Relative Response (dB Down From Peak)</td></tr>
<tr><td>≥ 1.3 and <7</td><td>3</td></tr>
<tr><td>≥ 7 and <23</td><td>20</td></tr>
<tr><td>≥ 23 and <78</td><td>40</td></tr>
<tr><td>≥ 78</td><td>60</td></tr>
</table>

6. References

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