Automatic Dependent Surveillance-Broadcast In (ADS-B In) system for Air Traffic Control

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Abstract— **ADS-B system allows the aircraft to periodically broadcast its identification, position, velocity and other information to the nearby aircraft and the ground station in order to provide better situational awareness. ADS-B system uses Reed Solomon code to encrypt the message data and it modulates the data using Continuous Phase Frequency Shift Keying (CPFSK) technique. This paper presents the MATLAB implementation of the receiver system which must be capable of extracting from a file ADS-B message and ground uplink message along with Synchronization bits, Payload, FEC parity bits from each aircraft. Demodulate the data and finally display the corresponding fields of each element in MATLAB GUI along with each aircraft's Flight ID and position of the flight on a grid. The message transmitted by the ADS-B Out system is received correctly by the ADS-B In system.**

Keywords-ADS-B, RS Codes, CPFSK

I. INTRODUCTION

ADS-B is a system by which aircraft and the ground station periodically broadcasts its state vector (identification/ horizontal/vertical position /velocity) and other intended information. ADS-B is automatic in the sense that no pilot or controller action is required for the Information to be broadcast. It is dependent surveillance in the sense that the aircraft State Vector and additional surveillance-type information is derived from on-board navigation equipment.

ADS-B "In" is the reception by aircraft of Flight Information Service – Broadcast (FIS-B) and Traffic Information Service – Broadcast (TIS-B) data and other ADS-B data such as direct communication from nearby aircraft. ADS-B In, receives ADS-B messages from other ADS-B Out users, and provides this information to the Cockpit Display of Traffic Information (CDTI).This helps to improve situational awareness, conflict detection and conflict resolution in the cockpit.

ADS-B uses two FAA-approved data links: 1090 MHz Extended Squitter (ES) (also known as Mode-S ES), and Universal Access Transceiver (UAT) that operates at 978 MHz [1]. The former is typically used by air carriers and high-performance aircraft, while the latter is designed for General Aviation (GA) users. In this work data is broadcasted using the UAT.

II. UAT SYSYTEM OVERVIEW

The UAT is a wideband multi-purpose data link intended to operate globally on a single channel with a channel signaling rate of just over 1Mbps. By design, UAT supports multiple broadcast services including FIS-B and TIS-B in addition to ADS-B.

There are two basic types of message on the UAT channel: The ADS-B Message, and Ground Uplink Message [2]. The ADS-B Message is broadcast by an aircraft to convey its State Vector and other information. There are two types of UAT ADS-B Messages, namely the Basic ADS-B Message and the Long ADS-B Message. The Ground Uplink Message is used by ground stations to uplink flight information such as text and graphical weather data, advisories, and other aeronautical information, to any aircraft that may be in the service volume of the ground station. Regardless of type, each message has two fundamental components: the message payload that contains user information, and message overhead, principally consisting of forward error correction code parity, that supports the transfer of the data.

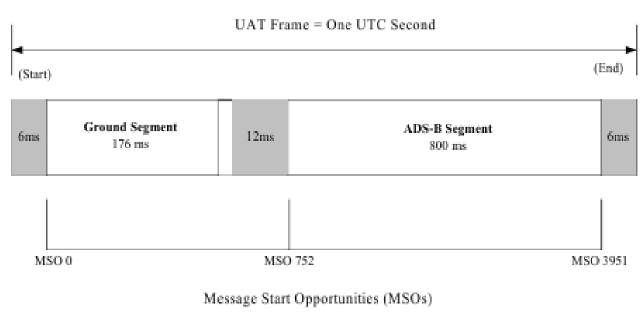

Figure1. UAT Frame

Figure 1 illustrates the basic UAT Message timing structure called a UAT frame. A frame is one second long and begins at the start of each UTC second. Each frame is divided into two segments: a Ground Segment in which Ground Uplink Messages are broadcast in one or more of 32 slots, and an

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ADS-B Segment in which ADS-B Messages are broadcast by aircraft. Guard times are incorporated between the segments to allow for signal propagation and timing drift. The UAT frame is further divided into Message Start Opportunities (MSOs) that are spaced at 250 micro seconds intervals. This spacing represents the smallest time increment used by UAT for scheduling message transmissions, and all such transmissions must start only at a valid MSO.

III. CONTINUOUS PHASE FREQUENCY SHIFT KEYING (CPFSK)

Continuous Phase Frequency Shift Keying (CPFSK) refers to a family of continuous phase modulation schemes that allows use of highly power-efficient non-linear power amplifiers.

Linear modulation schemes without memory like Quadrature Phase Shift Keying (QPSK), Orthogonal QPSK (OQPSK), Differential PSK (DPSK) and Frequency Shift Keying (FSK) exhibit phase discontinuity in the modulated waveform. These phase transitions cause problems for band limited and power-efficient transmission especially in an interference limited environment. The sharp phase changes in the modulated signal cause relatively prominent side-lobe levels of the signal spectrum compared to the main lobe. The abrupt phase transitions generate frequency components that have significant amplitudes. Thus the resultant power in the side-lobes causes co-channel and inter-channel interference.

This may be avoided if the message signal frequency modulates a single carrier continuously. The resultant FM signal is phase-continuous FSK and the phase of the carrier is constrained to be continuous. This class of continuous phase modulated signal is expressed as [3]:

$$s(t) = \sqrt{\frac{2E}{T}}\cos(2\Pi f_C t + \phi(t;I) + \theta_1) \quad (1)$$

where T is the bit interval, E is the energy expended during the bit interval, f_c is the carrier frequency and φ (t;I) is the time-varying phase of the carrier which is determined by the input data.

$$\phi(t;I) = 2\Pi T f_d \int_{-\infty}^{\tau} d(\tau)d\tau \quad (2)$$

f_d = peak frequency deviation ; θ_1 = initial phase.

Let, $$d(t) = \sum_{-\infty}^{\infty} I_n g(t - nT) \quad (3)$$

where $\{I_n\}$ is the sequence of amplitudes obtained by mapping k bit blocks of binary digits from the information sequence $\{a_n\}$ into amplitude levels ±1, ±3, …± (M-1). g(t) is a rectangular pulse of amplitude 1/2T and duration T. The signal d(t) is used to frequency modulate the carrier.

A. Coherent detection of CPFSK

In the coherent detection, the decision is made on the first bit by observing the waveform during this bit time and n - 1 additional bit times. The data are assumed to be random =±1's and the interference is additive white Gaussian noise.

The CPFSK waveform during the first bit interval can be expressed as

$$s(t) = \cos(\omega_C t + \frac{a_1 \Pi ht}{T} + \theta_1) \qquad 0 \le t \le T \quad (4)$$

where a_1 is the data, θ_1 is the phase of the RF carrier at the beginning of the observation interval, and h is the modulation index, is the peak-to-peak frequency deviation divided by the bit rate. In accord with the continuity of phase, the waveform during the i^{th} bit time of the observation interval can be written as

$$s(t) = \cos(\omega_C t + \frac{a_i \Pi h(t-(i-1)T}{T} + \sum_{j=1}^{i-1} a_j \Pi h + \theta_1)$$

Where (i-1) T ≤ t ≤ iT (5)

For the case of coherent detection θ_1 is assumed to be known and set to zero [4].

Let the signal waveform during the observation interval be denoted by $s(t,a_1,A_k)$ where A_k represents a particular data sequence, and the actual waveform is given by (5). The detection problem is then to observe $s(t,a_1,Ak)$ in noise and produce an optimum decision as to the polarity of a_1. The solution to this problem is known to be the likelihood ratio test and for the CPFSK waveform the likelihood ratio l, can be expressed as,

$$l = \frac{\exp(\frac{2}{N_0}\int_0^{nT} r(t)s(t,1,A_1)dt) + ... + \exp(\frac{2}{N_0}\int_0^{nT} r(t)s(t,1,A_m)dt)}{\exp(\frac{2}{N_0}\int_0^{nT} r(t)s(t,-1,A_1)dt) + ... + \exp(\frac{2}{N_0}\int_0^{nT} r(t)s(t,-1,A_m)dt)} \quad (6)$$

Where $m=2^{n-1}$

The receiver structure is shown in Figure 2. The receiver correlates the received waveform with each of the m possible transmitted signals beginning with data 1, and then forms the sum of exp (c_j) where c_j is the correlation of the received waveform with the j^{th} signal waveform beginning with a data 1. A similar operation of correlating and summing for the m possible waveforms beginning with a data -1 is performed and the decision is based on the polarity of the difference in the two sums.

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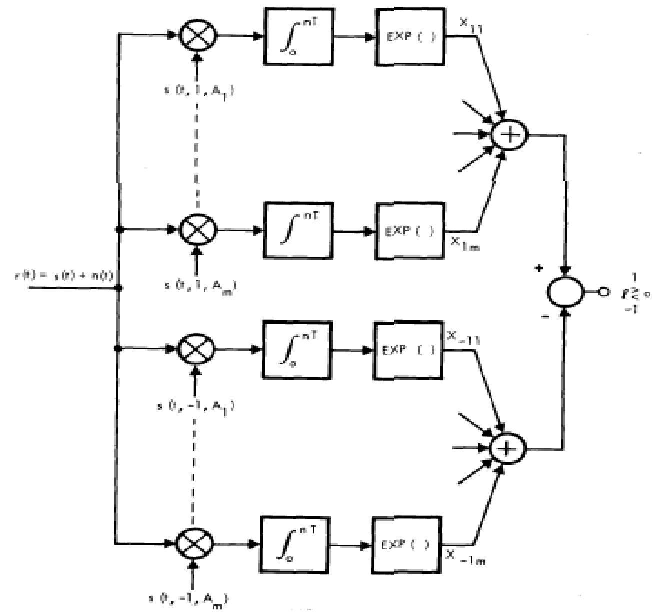

Figure 2.Block diagram of optimum coherent receiver

IV. REED SOLOMON CODE

RS codes is a Forward Error Correction code, a technique in which redundant information is added to the signal to allow the receiver to detect and correct errors that may have occurred in transmission.

It is optimal in the sense that the minimum distance has the maximum value possible for a linear code of size (*n*, *k*). Such a code is also called a Maximum Distance Separable (MDS) code [5]. RS codes have multi-bit symbols. This makes the code particularly good at dealing with bursts of errors because, although a symbol may have all its bits in error, this counts as only one symbol error in terms of the correction capacity of the code.

The RS(n, k) code is shown in Figure 3.

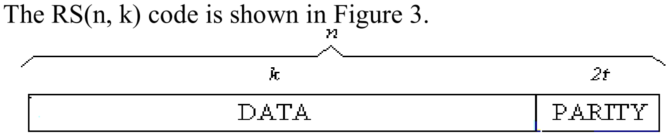

Figure 3.RS Codeword

Where, n: codeword symbols
k: data symbols(original message)
n-k: parity symbols = 2t
m: message bits
t: maximum of symbol error corrected.

A. RS Decoder

The Reed-Solomon decoder tries to correct errors and/or erasures by calculating the syndromes for each codeword. Based upon the syndromes the decoder is able to determine the number of errors in the received block. If there are errors present, the decoder tries to find the locations of the errors

using the Euclidean algorithm by creating an error locator polynomial. The roots of this polynomial are found using the Chien search algorithm. Using Forney's algorithm, the symbol error values are found and corrected. This is illustrated in Figure 4. For an RS (n, k) code where n - k = 2t, the decoder can correct up to t symbol errors in the code word [5].

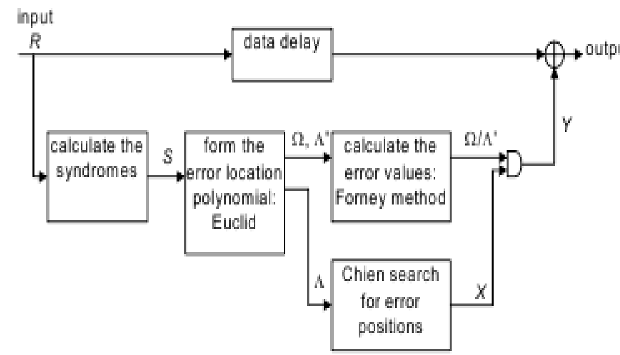

Figure 4.Block diagram of Reed Solomon Decoder

B. The Syndrome

The transmitted code word is always divisible by the generator polynomial without remainder and this property extends to the individual factors of the generator polynomial [6]. Therefore the first step in the decoding process is to divide the received polynomial by each of the factors $(x+\alpha^i)$ of the generator polynomial .This produces a quotient and a remainder, that is

$$\frac{R(x)}{x+\alpha^i} = Q_i(x) + \frac{S_i}{x+\alpha^i} \qquad \text{for } b \le I \le b+2t-1 \quad (7)$$

The remainders S_i resulting from these divisions are known as the syndromes and, for b=0, syndrome can be written as S_0 .... S_{2t-1}.

C. The Error locator polynomial

The next step is to find the error locator polynomial and error evaluator polynomial.

The error locator polynomial is given as

$$\Lambda(x) = (1+X_1x)(1+X_2x) \ldots(1+X_vx) = 1+ \Lambda_1x+\ldots+ \Lambda_{v-1}x^{v-1}+ \Lambda_vx^v \quad (8)$$

The error magnitude polynomial can be written as:

$$\Omega(x) = \Omega_{v-1}x^{v-1} +\ldots + \Omega_1x + \Omega_0 \quad (9)$$

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D. Finding the co-efficient of error locator polynomial using Eucledian algorithm

An efficient technique for obtaining the coefficients of the error location polynomial is based on Euclid's method for finding the highest common factor of two numbers. This uses the relationship between the errors magnitude and the syndromes expressed in the form of an equation based on polynomials.
The key equation can then be written as:

$$\Omega(x) = [S(x)\,\Lambda(x)] \bmod x^{2t} \quad (10)$$

where S(x) is the syndrome polynomial and Λ(x) is the error locator polynomial [7]. Any terms of degree x^{2t} or higher in the product are ignored, so that

$$\Omega_0 = S_b$$
$$\Omega_1 = S_{b+1} + S_b\Lambda_1$$
$$:$$
$$\Omega_{v-1} = S_{b+v-1} + S_{b+v-2}\Lambda_1 + ... + S_b\Lambda_{v-1}.$$

The Euclidean algorithm

t = number of parities
$R_0 = x^t$
S_0 = syndrome polynomial
$A_0 = 1$
$B_0 = 0$
$i = 0$
while degree of $S_i \geq (t/2)$
$Q = R_i / S_i$
$S_{i+1} = R_i - Q\,S_i = R_i$ modulo S_i
$A_{i+1} = Q\,A_i + B_i$
$R_{i+1} = S_i$
$B_{i+1} = A_i$
$i = i + 1$
$\Lambda(x) = A_i / A_i(0)$
$\Omega(x) = (-1)^{\deg A_i} S_i / A_i(0)$
$A_i(0)$ is the constant (least significant) term of A_i.

E. Chien Search algorithm

Chien search algorithm evaluates the error locator polynomial Λ(x) to find its roots. It is a brute search over all the elements in the field. It runs all possible input values of the GF (256) and then checks to see if the output is zero. A value of zero at the output indicates an error at that location.
The error locator polynomial is written in the form:

$$\Lambda(x) = X_1(x + X_1^{-1})\,X_2(x + X_2^{-1})$$

The function value will be zero if $x = X_1^{-1}, X_2^{-1}$...
The roots, and hence the values of X_1.... X_v, are found by trial and error, known as the Chien search, in which all the possible values of the roots (the field values α^i, $0 \leq i \leq n-1$) are substituted into equation (8) and the results are evaluated. If the expression reduces to zero, then that value of x is a root and identifies the error position.

F. The Forney algorithm

Forney algorithm is used to calculate the error value Y_j having established the error locator polynomial Λ(x) and the error value polynomial Ω(x).
According to Forney's algorithm, the error value is given by:

$$Y_j = X_j^{1-b} \frac{\Omega(X_j^{-1})}{\Lambda'(X_j^{-1})} \quad (11)$$

where $\Lambda'(X_j^{-1})$ is the derivative of Λ(x) for $x = X_j^{-1}$. When b=1, the X_j^{1-b} term disappears, so the formula is often quoted in the literature as simply Ω/Λ'. Equation (11) only gives valid results for symbol positions containing an error.

G. Error correction

Having located the symbols containing errors, identified by X_j, and calculated the values Y_j of those errors, the errors can be corrected by adding the error polynomial E(x) to the received polynomial R(x).

V. Result

The results obtained are as follows.
CPFSK Demodulation:
Transmission frequency =978MHz
Modulation Rate= 1.041667megabits per second
Modulation index h= 0.6

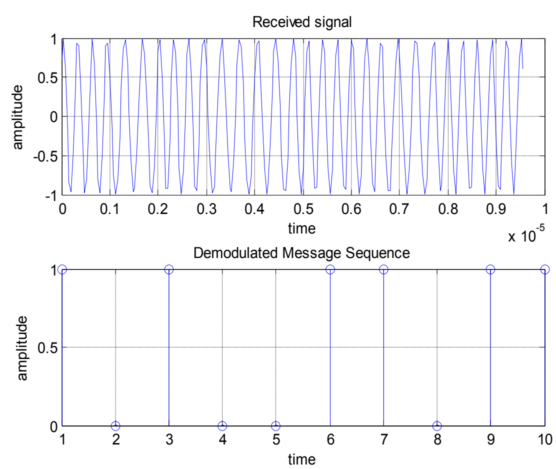

Figure 5. Results of CPFSK demodulation

RS Decoder
The transmitted signal is the RS encoded ADS-B message signal. The message signal is appended with the parity bytes. This example uses RS(30,18) code.

Transmitted_msg =

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0 250 161 35 85 85 85 192 0 0 3 84 6 68 50 192 40 0 254 151 196 52 225 255 83 101 207 143 175 228

The underlined message bytes indicate the appended parity bytes.

Errors =
1 2 3 4 5 6 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

Error_msgcode =
1 248 162 39 80 83 85 192 0 0 3 84
6 68 50 192 40 0 254 151 196 52 225 255
83 101 207 143 175 228

Correction_poly =
1 2 3 4 5 6 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0

Corrected_msg =
0 250 161 35 85 85 85 192 0 0 3 84
6 68 50 192 40 0 254 151 196 52 225 255
83 101 207 143 175 228

Decoded_msg =
0 250 161 35 85 85 85 192 0 0 3 84
6 68 50 192 40 0

The Decoded message is same as the transmitted message. It can correct up to 6 ((30-18)/2) errors.

GUI display system:

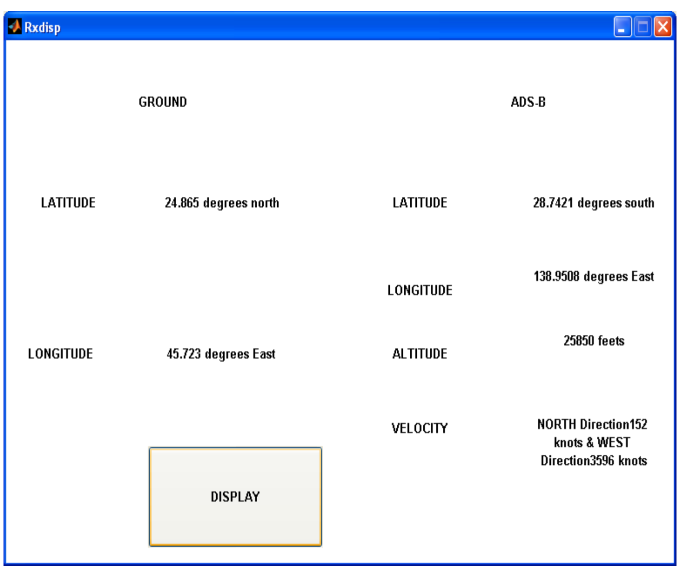

Figure 6. GUI of ADS-B In system

ADS-B In, receives ADS-B messages from other ADS-B Out users, and provides this information to the Cockpit Display of Traffic Information (CDTI). Figure 5 shows the GUI of the receiver system which displays the state vector of the target aircraft and ground station.

VI. CONCLUSION

ADS-B In system has been developed and simulated using MATLAB. The message transmitted by the ADS-B Out system is received correctly by the ADS-B In system. ADS-B receiver performs CPFSK demodulation. RS Decoder corrects the symbols and then removes the redundant parity symbols from the code word and produces the original input message. It was found that even if the error is in parity symbols, the decoder is capable to detect the output and it is of no matter to the decoder that in which symbols the error is present.

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