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Performance Evaluation of Pulse Position Modulation Scheme in Automatic Dependent Surveillance Broadcast System

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Abstract: this paper presents a new formula for calculating the Bit Error Rate (BER) and the Packet Error Rate (PER) for binary pulse position modulation scheme which had been used in Automatic Dependent Surveillance Broadcast (ADS-B) system, ADS-B system is used in air traffic surveillance and control. ADS-B system uses the Binary Pulse Position Modulation (BPPM) scheme in the link between the aircraft and the ground station. The results show that the simulated bit-error rate and packet error rate are approximately matches the theoretical one; these results have been obtained for both coherent and non-coherent detection. As a result, mathematical formulas to represent the probability of error for BPPM are also derived for both coherent and no-coherent detection scheme.

Keywords: *automatic dependent surveillance broadcast (ADS-B), pulse position modulation (PPM), Bit error rate (BER), packet error rate (PER).*

1. INTRODUCTION

The Air Traffic Control (ATC) is responsible for the safe navigation of the aircrafts and it uses the radar system for this purpose. This system is comprised of Primary Surveillance Radar (PSR) and Secondary Surveillance Radar (SSR), however due to the fact that most radars nowadays suffer from shortcoming such as visibility propagation, noise interference, line-of-sight and voice communication as well as limited digital data links has resulted in the need for a sophisticated system. Fig 1 shows a co-mounted primary and secondary radar system [1, 2].

Fig. 1. Co-mounted primary & secondary radar

The current technology (i.e., primary and secondary radar) used for detecting airplanes and monitoring the airspace is based on radar. This means that radar stations on ground will scan the airspace and this information is then available to control towers which can inform The planes about other planes. The disadvantage of using radar Technology is the accuracy and the fact that radars are only placed on land, which makes it difficult to track airplanes when they are flying over oceans [3, 4]. An example of the consequences of not being able to do this took place in June 2009, where a commercial airplane crashed into the Atlantic Ocean on its way from Rio de Janeiro to Paris.

The exact location of the crash and thereby the search area could not be precisely determined because the plane had left area with radar coverage [5]. It could be very helpful if this location could have been determined more precise. This is just one of the consequences of not being able to determine the precise location of an airplane when it is flying over oceans. Another consequence is that in order to avoid airplanes from crashing into each other planes are flying with a high separation between them. If the precise position of the airplanes could be determined, the separation could be diminished considerably and the density of airplanes could be increased [4].

Automatic Dependent Surveillance–Broadcast (ADS-B) is a vital surveillance technology that has replaced the secondary surveillance radar (SSR) and does not need any command from the pilot or the ground station. The benefits of the ADS-B services include the betterment of the transmission of the air craft position information such as real time positions and flight parameters between the pilots and the ATC system. Moreover, it assists in providing pilots in obtaining weather and traffic information for the surrounding areas.

The advantage that the ADS-B system has over previous traditional air surveillance technologies is due to the fact that this technology utilizes satellite navigation to determine its position allowing aircrafts to update and broadcast information at higher rate. This has helped in the safe navigation of dangerous areas such as mountainous places. The on-board equipment such as ground position system (GPS) receiver, Universal Access Transceiver, antenna and multi-function cockpit display, plays an important role in achieving accurate reception of both weather and traffic data [6]. The ADS-B system is a system on board an airplane or aviation related vehicle which allows this to transmit its position (GPS), speed, etc. On Figs 2 and 3 it can be seen how the system works. The position is determined by the use of GPS. A packet is then made containing relevant information and this is then transmitted every 1 second [7].

This packet containing the state vector can then be received by any ADS-B equipped devices within range of the transmitting device. This means that the packets will not necessary be received by anyone and no acknowledgement from receiving devices is expected. The information carried in the packet can then be used by other airplanes or ground stations to monitor the surrounding airspace or e.g. an airport [8]. The equipment used for ADS-B is also used by airplanes to receive other services called traffic information services-Broadcast (TIS-B) and flight information services broadcast (FIS-B). TIS-B is used to send additional information about the surrounding airspace to airplanes, and is particularly helpful when there are planes which are not equipped with ADS-B. The sent data is obtained by radar technology. FIS-B provides a better image of the surrounding meteorological and aeronautical situation [9]. The ADS-B system is currently only a requirement in Hudson Bay Area, USA, but by the year 2020 it will also be a requirement in Europe, Australia and the entire USA. The ADS-B equipment is estimated to already be implemented in 60 − 70 % of existing planes flying in the airspace above the Hudson Bay Area [10].

In addition, the ADS-B is a surveillance technique in which the aircraft automatically provides via a data link data derived from navigation and position-fixing systems, including aircraft identification, position, altitude, vector , speed , flight number and many other information to the air traffic control centers and other nearby aircraft. Far different from radar, which works by bouncing radio waves from fixed terrestrial antennas off the airborne targets and then interpreting the reflected signals, ADS-B uses conventional Global Navigation Satellite System (GNSS) technology like the Global positioning system (GPS), and a relatively simple broadcast communications link as its fundamental components. The ADS-B signals from the aircraft to the ground stations are transmitted at 1090MHz.They carry 112 bits of data that are encoded using the pulse position modulation (PPM) with a data rate of 1Mbps. The ADS-B message is preceded by a 8 µs preamble which serves to both mark the start of a transmission and to allow the receiver to unambiguously determine the position of the high and low bits within a message [13]. The distribution of 112 bit of the ADS-B packet is clearly depicted in Fig 4.

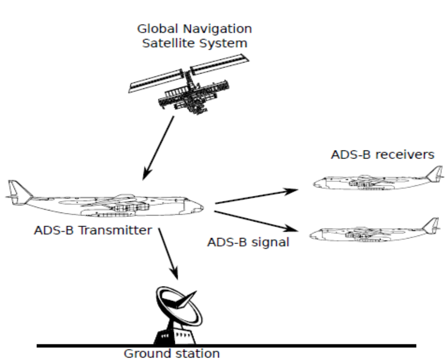

Fig. 2. ADS-B system structure [11, 12].

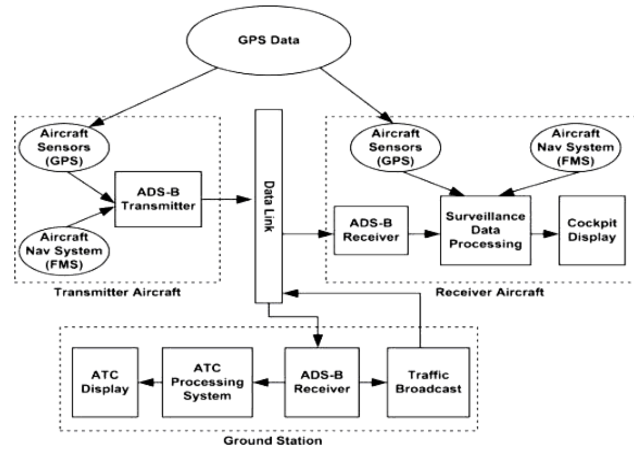

Fig. 3. ADS-B main components [11, 12]

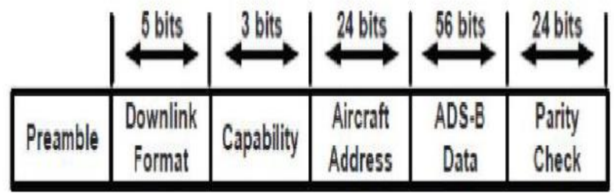

Fig. 4. ADS-B message format

The field of the eight microseconds duration (i.e.; preamble) is a fixed bit sequence which will allow the receiver to identify and synchronize with a message received [13].

1. Pulse Position Modulation

First, ADS-B uses the binary pulse position modulation (BPPM) as a modulation scheme in the system. In BPPM two signal waveforms are used to represent one bit (0 or 1).

$$S1(t) = A\cos\omega t, \qquad 0 \le t \le T_b/2 \qquad (1)$$
$$= 0, \qquad T_b/2 \le t \le T_b$$

For binary '1'

$$S2(t) = 0, \qquad 0 \le t \le T_b/2 \qquad (2)$$
$$= A\cos\omega t, \qquad T_b/2 \le t \le T_b$$

For binary '0'.

The signal wave forms for S1 (t) and S2 (t), are illustrated on Fig 5:

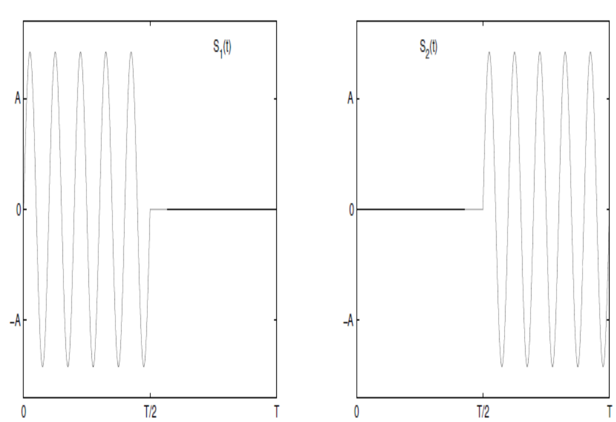

Fig. 5. Signal waveforms of BPPM

$$E_1 = E_2 = \int_0^T S_1^2(t)dt = \int_0^T S_2^2(t)dt \quad (3)$$

$$E_1 = E_2 = \int_0^T (A\cos(\omega t))^2\, dt = A^2 \int_0^{\frac{T}{2}} \cos^2(\omega t)dt \quad (4)$$

$$E_1 = E_2 = \frac{A^2 T}{4} \quad (5)$$

The energy of the PPM signal is clearly half the energy of ASK signal.

2. Probability of Error for Coherent Detection

We will calculate the probability of error for BPPM will be derived from the ASK modulation formula. In the coherent detection, the carrier signal which is using at the transmitter side and the receiver side are in the same phase with each other. By this reason, this detection is called coherent ASK detection (i.e., Synchronous ASK detection).

The diagram in Fig 6 shows the component of a Coherent ASK detector.

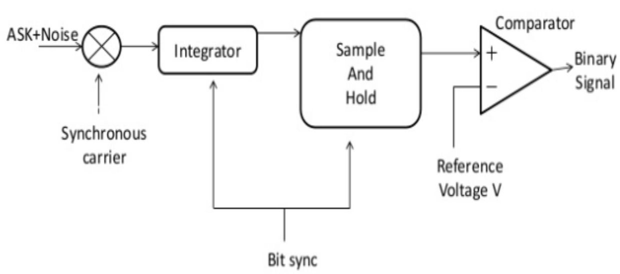

Fig. 6. Coherent detection block diagram [14]

The probability of error for coherent ASK signal is given as [14, 15, 16]:

$$P_{ASK} = Q\left(\sqrt{\frac{E_b}{4N_o}}\right) \quad (6)$$

Since the energy of BPPM is half the energy of ASK as clearly can be seen in Fig 5; therefore, E_b will be substituted by $E_b/2$. As a result, the probability of BPPM in Equation (6) could be reformulated as:

$$P_{BPPM} = Q\left(\sqrt{\frac{E_b}{8N_o}}\right) \quad (7)$$

3. Probability of Error for Non-Coherent Detection

However, in the non-coherent detection, the carrier signal which is using at the transmitter side and receiver side are not in the same phase with each other. By this reason, this detection is called as Non-coherent ASK detection (Asynchronous ASK detection). This demodulation process can be completed by using square law device. The output signal which is generated from the square-law device can be forwarded through a low pass filter to reconstruct the original binary signal as shown in Fig 7.

Fig. 7. Non-coherent detection block diagram [14]

The probability of error for non-coherent ASK signal is given as [17]:

$$P_{ASK} = \frac{1}{2} e^{\frac{E_b}{2N_o}} + \frac{1}{2} Q\left(\sqrt{\frac{E_b}{N_o}}\right) \quad (8)$$

Since the energy of BPPM is half the energy of ASK, E_b will be substituted by $E_b/2$ in Equation (8); As a result, the probability of BPPM can be reformulated as:

$$P_{BPPM} = \frac{1}{2} e^{\frac{E_b}{4N_o}} + \frac{1}{2} Q\left(\sqrt{\frac{E_b}{2N_o}}\right) \quad (9)$$

4. Packet Error Rate in BPPM

The ADS-B packet contains 24 bits Cyclic Redundancy Check (CRC) field as seen in Fig 4. This field is used for error detection of the received ADS-B packets. The utilized CRC code allows the receiver to detect any burst errors within a window of 24 bits. The PER can now be calculated by considering a certain BER value. Assuming that the BER is independent for each bit in a frame, the probability of getting i bit errors in a packet can be expressed using the binomial distribution:

$$\mathrm{P}(\mathrm{x} = \mathrm{i}) = \binom{112}{i} P_{BPPM} (1 - P_{BPPM})^{112-i} \quad (10)$$

Where P_{BPPM} is the probability of error bits; this P_{BPPM} will cause packet error rate according to Equation (10).

Accordingly, the probability of packet error rate is the complement of the probability of getting zero error bit (i.e., i =0, zero errors in the packet). In other words; the probability of getting at least one error in a packet is: 1- No error is detected at all; i.e.,

$$\mathrm{PER} = 1 - \mathrm{P}(\mathrm{x} = \mathrm{i}) = \binom{112}{i} P_{BPPM} (1 - P_{BPPM})^{112-i} \quad (11)$$

$$\mathrm{PER} = 1 - \mathrm{P}(\mathrm{x} = 0) = 1 - \binom{112}{0} P_{BPPM}^0 (1 - P_{BPPM})^{112-0} \quad (12)$$

$$\mathrm{PER} = 1 - \mathrm{P}(\mathrm{x} = 0) = 1 - \binom{112}{0} (1 - P_{BPPM})^{112} \quad (13)$$

5. System Modelling

Fig 8 shows the block diagram of the communication model of the ADS-B system. This model has been used to simulate the results of the BER and PER so as to compare it with the theoretical findings.

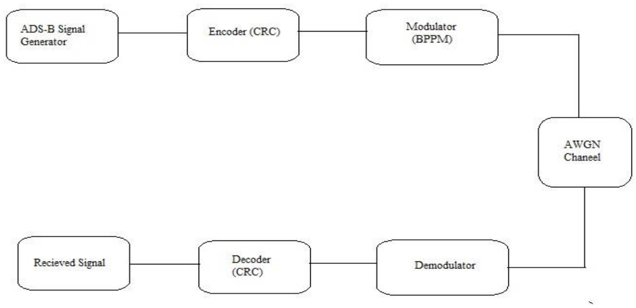

Fig. 8. ADS-B system block diagram

6. Findings and Discussion

Equations 7 and 10 are used to calculate the theoretical BER and PER respectively for coherent detection. Meanwhile, Equations 9 and 10 are used to calculate the theoretical BER and PER non-coherent detection.

However, numerical analysis is also used to simulate the ADS-B system using BPPM modulation for both coherent and non-coherent detection at the receiver side. The simulated results of the BER and PER are plotted versus the theoretical results for each type of detection, as show in the Figs 9, 10, 11, 12 respectively:

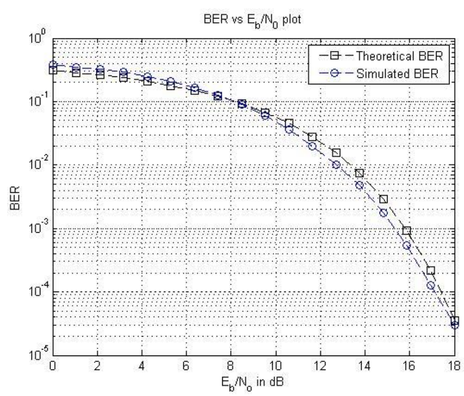

Fig. 9. Theoretical BER and Simulated BER for Coherent detection

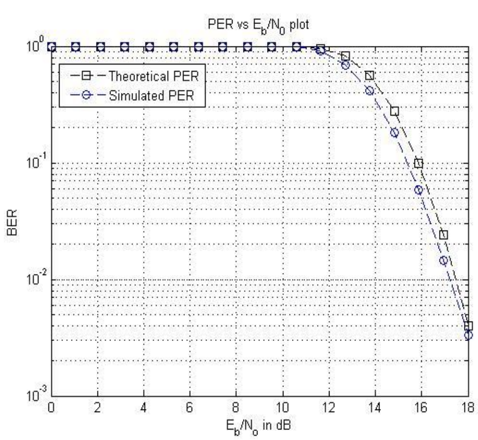

Fig. 10. Theoretical BER and Simulated BER

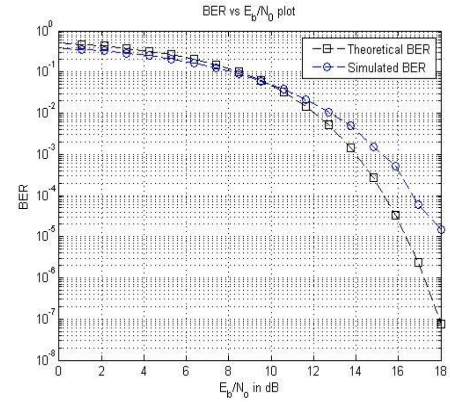

Fig 11: Theoretical BER and Simulated BER for Non-coherent detection

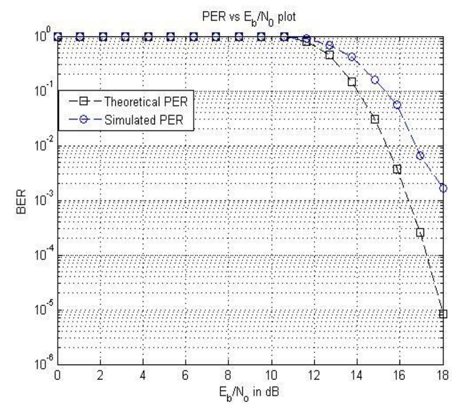

Fig. 12. Theoretical PER and Simulated PER for Non-coherent detection

7. Conclusion and Recommendation

There is acceptable level of coincidence between the simulated results and the theoretical findings. Therefore, Equations (7), (9) and (10) can be used to represent the probability of error BPPM modulation scheme.

8. Future Work

In the future, it is recommended to mathematically modeling the probability of error for BPPM in multipath channel condition.

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