Simulink Modeling of Extended Golay Coding Technique for Coaxial Cable Telemetry

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ABSTRACT

One of the major challenges in a digital telemetry system is the recovery of data transmitted over a noisy medium. The error which gets introduced in the channel is due to noise and interference leads to corruption of the system. To overcome these issues different error correction coding techniques such as Block code, Turbo code, Hamming code etc. are used. Extended Golay coding is a known coding technique capable of correcting any combination of three bits or fewer random errors in a block of twenty four bits. It allows high speed data transmission with low latency and enables secure communication. This paper explains the SIMULINK modelling of extended Golay encoder and decoder for a simple coaxial cable telemetry system. Analysis of bit error rate with different noise factor is also incorporated. A comparative study of Golay coding, Hamming and Reed Solomon (RS) coding is also discussed. This model can be used for generating a Simulink model to implement the error correction algorithm of any line coding data over single core coaxial cable.

Keywords: Extended Golay code, Hamming code, Reed Solomon, Bit error rate (BER), Error correction, Error detection, Telemetry

1.INTRODUCTION

A basic digital communication system involves transmission of digital data from transmitter to receiver through wired or wireless medium called channel. The binary data have to be retrieved without any loss, and then the system is said to reliable. Many cases data is corrupted during transmission through the medium. The quality of the communication depends whether the data is received with zero error or some tolerance. Errors are due to noise and interference occurring in the channel. These errors can often be reduced by the use of a number of coding techniques. Channel coding is a technique that allows an increased rate of information transfer with fixed error rate, or a reduced error rate for a fixed transfer rate [1], [2].

Error-control coding (ECC) offers methods to transmit information from sender to receiver with minimum errors, in conjunction with lower power and perhaps even less bandwidth. On the transmitter side, redundancy is added to the data in a controlled fashion, so the receiver can detect and correct the transmission errors. This guarantees high reliability of the transmitted information. Furthermore, this allows the possibility to cancel out the effect of interference from external sources which could not be achieved by increasing the transmit power.

The primary objective of coding is to help decoder to decide whether the received data is valid. It can also detect a code word which has been corrupted by noise and the decoder should be able to decide which code word was sent even if the transmitted code word was corrupted [3], [4]. Block coding is one of the major channel coding technique, in which a block of k information bits is encoded to give a code word of n bits $n > k$. Each sequence of length n is a code word or code block, and contains k information bits. The remaining $n - k$ digits in the code word are called redundant digits or parity-check bits. Golay codes are known perfect block codes that can perform multiple error detection and error correction [5].

This paper explains Simulink modelling of extended Golay coding for the development of a single core coaxial cable telemetry system. Simulink is a Matlab tool which helps to simulate an end to end system. The tool allows integration of Matlab codes and algorithms, so as to perform real time simulation of the telemetry system with Golay encoding and decoding. A white Gaussian noisy channel is modelled to corrupt the transmitted data, which is then received and

perform Golay decoding. To evaluate the system, Bit error rate (BER) is analyzed for different noise strength with Monte-Carlo simulation. A Bit Error Rate comparison with Hamming code and RS code over Extended Golay code is also discussed.

2. NOTATIONS

n = code word or code block
u = (a row matrix of order 24)
w = the received code word of order $1X24$
v = final corrected word
k = information bits
$g1, g2$ = generator polynomials over Galios field
G = Generator matrix
I = identity matrix of order 12
cb = check bit
n = total check bits
p = bit length

3. GOLAY, REED SOLOMON AND HAMMING CODE

A binary Golay code is a type of linear error correcting code used in digital communications. They were introduced by Swiss mathematician and information theorist Marcel Golay in 1949 [5], [6]. A binary Golay code (23,12,7) is a perfect binary code that is able to correct three or fewer errors in a block of 23 bits [7]. This Golay code (G23) can be generated from the generator polynomials g_1, g_2 over Galois field GF [2], where

$$g_1 = x_{11} + x_{10} + x_6 + x_5 + x_4 + x_2 + x_1 \qquad (1)$$

$$g_2 = x_{11} + x_9 + x_7 + x_6 + x_5 + x_1 + 1 \qquad (2)$$

In order to augment the power of the Golay code, an extra bit called parity bit is added to form extended Golay code. The extended binary Golay code is denoted as G24 [25, 12, 8] code that encodes 12 bits of data in a 24 bit word. It can be generated by appending a parity bit with binary Golay code or using generator matrix G which is a $12X24$ matrix of $[I, A]$ where I is the identity matrix of order 12. By analyzing matrix A it can be seen that the second row of matrix A is obtained from the first row of A by cyclic shifting [5]. Similarly every row except last row is right shift of the previous row. The parity check matrix is denoted by H, which is the transpose of G. The extended Golay code has a distance of 8 and the weight of every code is multiple of four.

The extended Golay coding has wide range of applications. It was used in NASA's Voyager mission during its encounters at Jupiter and Saturn [8] and also used to protect the data handling capabilities of NASA's Magellan mission to Venus [9]. It is used in the Automatic Link Establishment protocol ITU-R F.1110 [10], paging protocols and it stays a standard for telemetry [11]. Except the application which uses under maximum-likelihood (ML) decoding with hard decisions, the extended binary Golay code, G24 performs slightly worse power efficient than the binary Golay code G23 which is reported recently by Jon Hamkins [12]. Decoding of Golay code is based on the Iterative maximum likelihood detection (IMLD) algorithm [5]. It determines error pattern u (a row matrix of order 24) and the final corrected code word is given as $v = u + w$, where w is the received code word of order $1X24$.
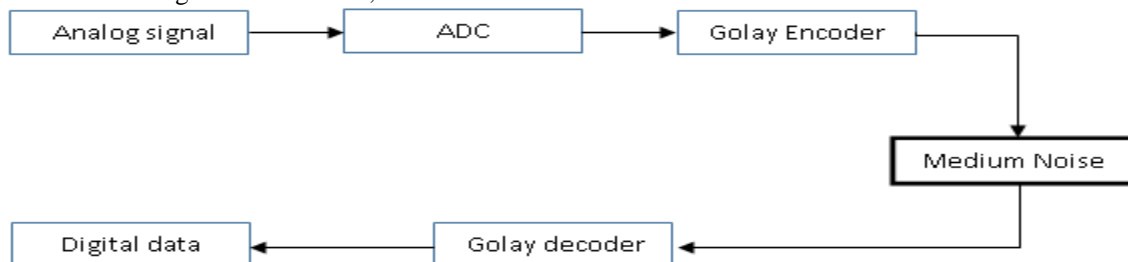

Figure 1 Block diagram of simple telemetry system

According to IMLD algorithm first calculate syndrome $s = \mod(wG^t, 2)$ and its weight. If the weight is less than or equal to three, then error pattern is given as $u = [s, 0]$ otherwise calculate weight of $s + Ai$ for each value of i from 1,2,3 up to 12. For any $s + Ai$, weight is less than or equal to two, then $u = [s + Ai, ei]$, where ei is the ith row of identity matrix of order 12. If error pattern u is not found by above calculation, then compute the second syndrome $s_1 = sA$ and calculate its weight. If this new weight is less than or equal to three, then error pattern is given as $u = [0, s_1]$ otherwise calculate weight of $s + Ai$ for each value of i. For each $s + Ai$, weight is less than or equal to two then $u = [ei, s_1 + Ai]$ If u is not obtained through any computation as explained above, then request for retransmission is required.
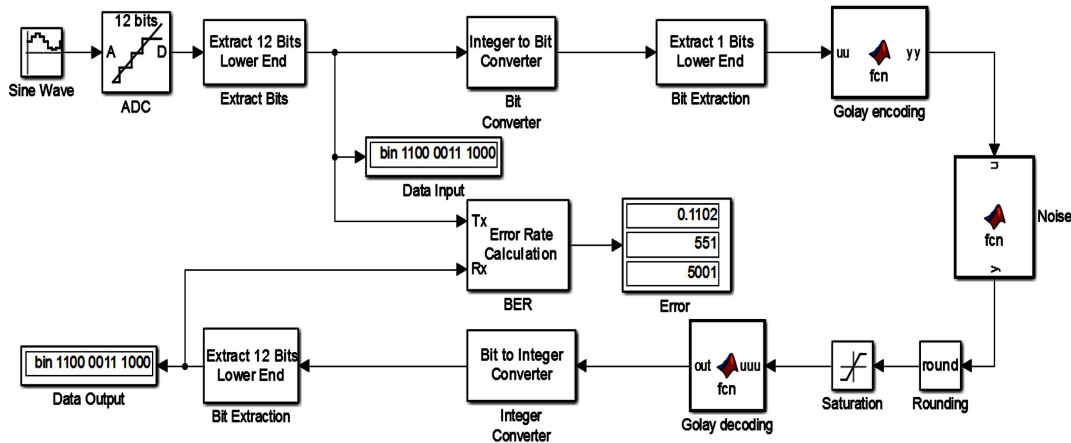

Figure 2 Block diagram of telemetry system with extended Golay coding

RS Coding [13] is an error correcting coding scheme that is used to correcting multiple errors – especially burst type errors [14] in mass storage devices (hard disk drives, DVD, barcode tags), wireless and mobile communications units, satellite links, digital TV, digital video broadcasting (DVB), and modem technologies like xDSL. A Reed-Solomon code is represented as RS (n, k) with s bit symbols. This means that the encoder takes k data symbols of s bits each and adds parity symbols to make an n symbol code word. The RS coding uses t check symbols to the data, an RS code can detect any combination of up to t erroneous symbols, or correct up to $t/2$ symbols [14].

Hamming code [15] a simple error correction code, where parity bits are used to correct the errors. This code is also called a linear error correcting code as it check errors from the first to last bit. The number of check bits depends on the data length [16], which is calculated based on the equation (3).
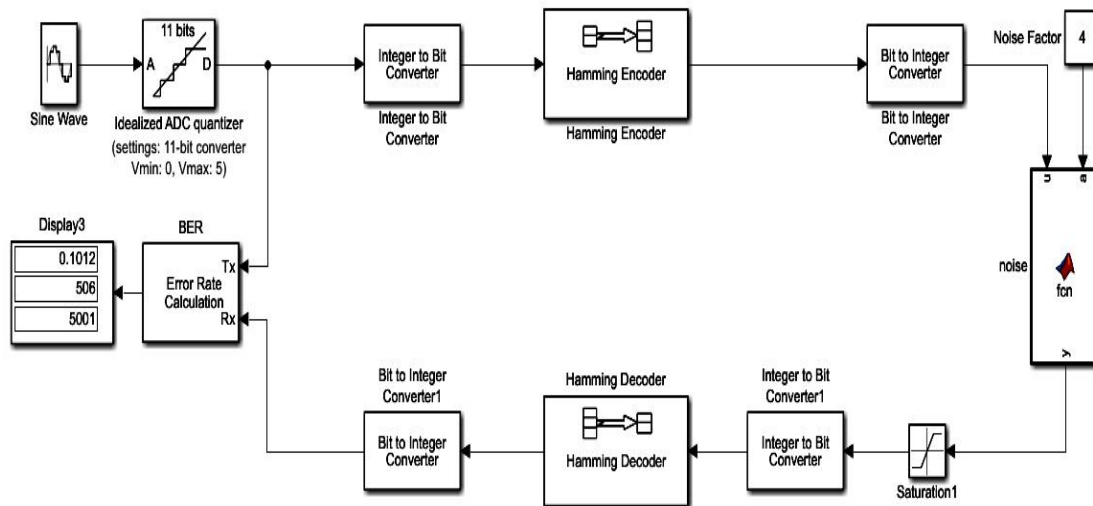
$$cb = 2^n - (n-1) > p \qquad (3)$$

Figure 3 Simulink model of Hamming coding

4. SIMULINK MODELING AND BER PERFORMANCE

Simulink modeling of extended Golay coding, Hamming code and RS coding technique is explained in this section. Simulink is the graphical extension of Matlab for modeling as well as simulation of systems. Using Simulink we can model even nonlinear systems with initial conditions. Simulink based models and BER can be analyzed for different input and medium of communication.
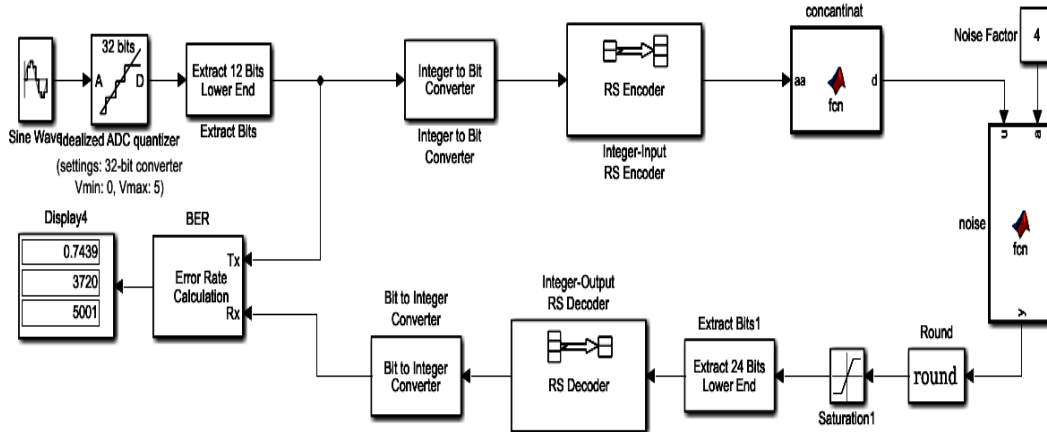

Figure 4 Simulink model of RS coding

The basic block diagram for the simple telemetry system with Golay encoder and decoder is shown in Figure 1. To make the Simulink model of Golay coding, a sinusoidal test input is fed to Analog to Digital Converter (ADC) which quantizes the analog data into set of digital data. This digital data is extracted and convert to integer form. Then do the bit wise extraction. This extracted bit data is fed as input to Golay encoder so that a block of 12 bit data is converted to 24 bits. Out of 24 bits of extended Golay coded data, the first 12 bits MSBs are data itself and remaining 12 bits LSBs are the coded data for the input data. The Golay encoding algorithm is implemented in a Matlab function block. This data is allowed to pass through a noisy environment. The noise implemented is white Gaussian distribution with different standard deviation, which is added to the Golay coded data. The noise is increased by introducing Noise Factor. This noise added Golay coded data is decoded using Golay decoder.

The error correction performance of extended Golay coding is analyzed using bit error rate (BER) and is defined as the ratio of number of error bits to the total number of bits sent [17] in a particular time interval. For ideal medium, the bit error rate will be very small and possibly insignificant and having no impact on the overall system behavior. However in practical case the mediums are affected by noise or interference leads to bit errors.
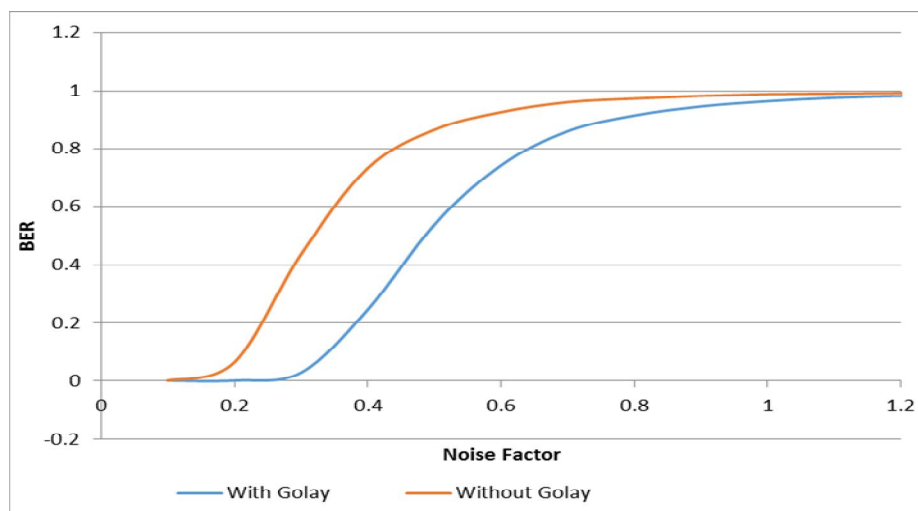

Figure 5 Bit error rate

A comparison of Golay coding with RS coding and hamming code is also carried out. RS encoder and decoder blocks are directly available in Simulink library. The same input to the Golay coding has given to the Simulink model of the RS coding. A 12 bit data at the input of encoder and 24 bit data at the input of coaxial cable noise block for doing the simulation. Hamming code is a single bit error correction code. The Hamming code [15 11] data combination was carried out. So 11 bit of data given at the input of Hamming encoder and 24 bit of data is fed to the input of coaxial cable noise block.
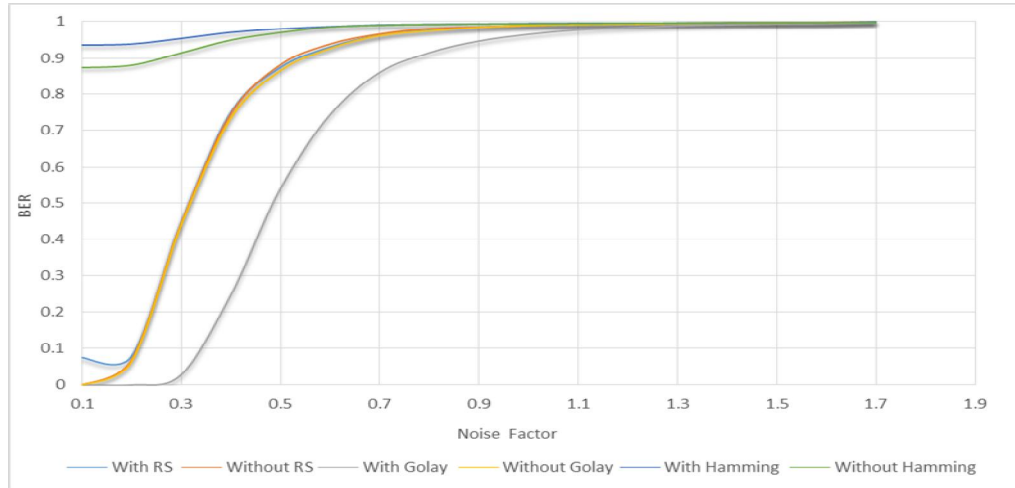

Figure 6 BER comparison of Block coding Schemes

5. SIMULATION RESULTS AND ANALYSIS

The evaluation of a telemetry system with and without Golay coding is done in Simulink. The digital data which is used for a telemetry system is analyzed first by modeling simple communication system without Golay encoder and decoder blocks. Then the coaxial cable system was analyzed by implemented Golay encoder, decoder and different noise factors. Figure 2 shows the simulation block diagram of telemetry system with extended Golay coding. Here sine wave is given as test input signal. The input is then quantized by 12 bit quantizer which is then modeled to pass through a noisy environment (wired or wireless). The noise follows a white Gaussian distribution with different standard deviation (0.1, 0.2, 0.3 etc.). The received signal is decoded using Golay decoder and BER is evaluated. Golay encoding is done by finding modulo function of matrix R of order 24, where R is the result of matrix multiplication of data vector and the generator matrix. Golay decoding is done based on syndrome and weight measurement as explained in IMLD algorithm. Simulation is carried out with different noise factor and corresponding BER measurements for 0.05 ms are tabulated. For each noise factor, the simulation is repeated for 50 iterations and average BER is plotted as shown in Figure 5.

Table 1: Effect of Frequency and BER

Frequency	With RS	Without RS	With Golay	Without Golay	With Hamming	Without Hamming
100	0.7489	0.7253	0.2553	0.7401	0.9686	0.9488
1000	0.7429	0.7465	0.239	0.7335	0.9736	0.9494
10000	0.7451	0.7373	0.242	0.7363	0.9722	0.9574
50000	0.7431	0.7391	0.2484	0.7355	0.9706	0.9502
100000	0.7499	0.7405	0.2507	0.7353	0.9714	0.9528

From Figure 5 it is clear that the system with Golay coding has improved performance than the system without Golay coding. Here total no of bits transmitted are 5001 within 0.5ms. For a noise factor of 0.2, BER of the system without Golay coding is 0.06317, which indicates that 316 bits were corrupted. These 316 error bits are completely corrected by the system with Golay coding. As the noise factor increases, the BER of the system with Golay coding increases but

comparatively lesser than the system without Golay coding. Figure 3 is the simulation block diagram of telemetry system with hamming code and Figure 4 is the simulation block diagram with RS coding.

Figure 6 shows the comparison of BER for different Block coding schemes. It is clear that the Golay coding has very good BER performance as compared to RS coding and Hamming schemes. For a noise factor of 0.2, BER of the RS coding system without RS coding is 0.06779, which indicates that 339 bits were corrupted. The BER with RS coding scheme has total 387 error bits. With the same noise factor of 0.2, the BER without Hamming code is 0.881 and that with Hamming code is 0.9394. Simulation is also done with different frequency input for a noise factor of 0.4, and it is verified that there is no big variation in BER. The measurement results are shown in Table 1.

6. CONCLUSION AND FUTURE WORK

The quality of digital communication relies on faithful reception of data received through a noisy environment. Golay coding is the non-trivial coding technic having wide application in telemetry. Through this paper, we are presenting a Simulink modeling of Golay encoder and decoder using a simple telemetry system. Comparison of BER with and without Golay coding in different noise factor shows that the Golay coding results better BER performance. The BER is found to be zero for system with Golay coding for low noise factors as it corrects up to three bit errors in a block of 24 bits. A comparison of Golay coding over Hamming code and RS coding is carried out. From the study, it is clear that the Golay coding has better BER as compared to other two coding. It is also found that the BER doesn't have much variation with frequency. This model can be incorporated as part of many telemetry (wired or wireless) applications. Future work includes implementation of line coded signal and error correction using Simulink for a single core coaxial cable telemetry system in Airborne and Imaging Sonar telemetry applications.

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