Data Encryption and Decryption using Reed-Muller Techniques

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***Abstract* –Reed-Muller codes play an important role in communication. In communication, security and error free data transmission are two major problems. In this paper, we propose a eight bit original data is encoded using distinct Reed-Muller techniques such as positive polarity Reed-Muller(PPRM), negative polarity Reed-Muller(NPRM), fixed polarity Reed-Muller(FPRM) for secure data communication and also we can compare these techniques in terms of cost. The eight bit encoded data which is obtains from these Reed-Muller techniques are encoded again using hamming code for error free communication. It is found that among all these techniques fixed polarity Reed-Muller is the best technique which gives less cost .We can also observes that secure and error free communication is possible between transmitter and receiver. The data encryption and decryption process has been simulated using Isim simulator and the code is written in Verilog HDL.**

Keyword –Reed- Muller, Hamming code, Encoder, Decoder, Verilog HDL.

I. INTRODUCTION

Reed-Muller expansion plays an important role in logic synthesis and circuit design. AND-EXOR circuits are used for representing Reed-Muller expressions. These circuits requires less AND gates than AND-OR circuits [1]. It produces the Boolean functions with highly testable. It creates the unique representations of a Boolean function. It mainly used in arithmetic and telecommunication applications. In communication, secure and error free data transmission from transmitter to receiver are the major issues. There are different techniques for secure and error free data communication. In [2], the eight bit data was encoded using positive polarity Reed-Muller (PPRM), negative polarity Reed-Muller (NPRM) techniques. There are two problems raises due to these techniques. First problem is that when we encode the data using PPRM, NPRM techniques, it gives more number of product terms leading to high power dissipation (high cost).In order to overcome this problem we use fixed polarity Reed-Muller(FPRM) technique. Here FPRM gives less or equal number of product terms than PPRM. Second problem is that when the encoded is transmitted through the channel, there might be a chance for occurrence of error if the channel is noisy. So, there is no possibility to detect and then correct the error. In this paper we propose a method which provides secure and error free data encryption and decryption process. The original eight bit data is encoded using PPRM, NPRM and FPRM techniques for obtaining secure communication. Again the data which is obtained from these techniques are encoded using hamming code for error free communication. In this paper, section II describes the proposed encryption and decryption process. Section III gives the simulation results and then section IV concludes the paper.

II. PROPOSED DATA ENCRYPTION AND DECRYPTION PROCESS

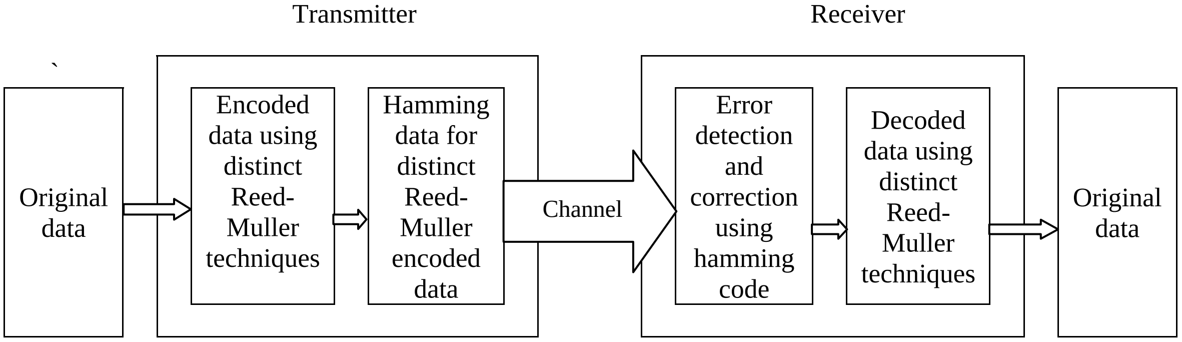

Transmitter
Receiver
Original data
Encoded data using distinct Reed-Muller techniques
Hamming data for distinct Reed-Muller encoded data
Channel
Error detection and correction using hamming code
Decoded data using distinct Reed-Muller techniques
Original data

Fig.1.Block diagram for data encryption and decryption

The original eight bit data is encoded using distinct types of Reed-Muller techniques such as positive polarity Reed-Muller(PPRM), negative polarity Reed-Muller(NPRM), fixed polarity Reed-Muller(FPRM).The encoded data which is obtained from these Reed-Muller techniques are encoded again using hamming code for error detection and correction. This encoded hamming data is send through the channel and then receiver receives the data and then detects and corrects the data if the channel is noisy. This noise free data is then decoded using hamming code and again decoded by distinct Reed –Muller techniques and then finally got the original eight bit data. Let us consider the 3-variable function.

$$g(y_1, y_2, y_3) = \sum(0,1,3,4,5,6,7) \tag{1}$$

Truth table for the function (1) is shown in the Table I.

TABLE I. Truth table

$y_1\ y_2\ y_3$	$g(y_1, y_2, y_3)$
000	1
001	1
010	0
011	1
100	1
101	1
110	1
111	1

A. Data Encryption Process

Encryption is the process of encoding a message so that its meaning is not obvious.

1) *Data Encoding using Positive Polarity Reed-Muller:* In an PPRM expression of a given function $g(y_1,y_2...y_n)$, every variable appears in an uncomplimented form. In PPRM expression, we apply positive davio expansion on each variable of a function. The output vector obtained from Table I is taken as original eight bit data. It is encoded by using positive davio (pD) expansion as shown in Fig.2.

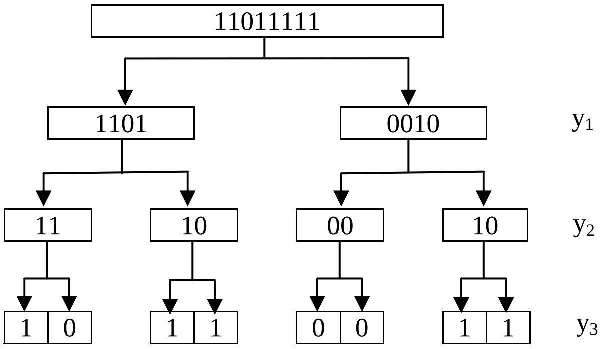


Fig.2.Positive davio expansion

If we apply positive davio expansion on the variable y_1, then g_0 goes to the left child of the root which is obtained from equation (2), g_1 is obtained from equation (3),g_2 goes to the right child of the root which is obtained by performing EX-OR operation between g_0 and g_1 as in equation (4).

$$g_0 = g(y_1, .. y_{j-1}, 0, y_{j+1}, ... y_n) \tag{2}$$

$$g_1 = g(y_1, .. y_{j-1}, 1, y_{j+1}, ... y_n) \tag{3}$$

$$g_2 = g_0 \oplus g_1 \tag{4}$$

Similarly we perform positive davio expansion on the variables y_2, y_3. The resulting expression is obtained by considering the ones of the leaves of the tree and their corresponding input combination [2],[3]. The resulting PPRM expression for the function (1) is

$$g(y_{1,}y_{2,}y_3) = 1 \oplus y_2 \oplus y_2y_3 \oplus\ y_1y_2 \oplus\ y_1y_2y_3$$

2) *Data Encoding using Negative Polarity Reed-Muller:* In an NPRM expression of a given function g $(y_1,y_2...y_n)$, every variable appears in an complimented form. In NPRM expression, we apply negative davio(nD) expansion on each variable of a function. The output vector obtained from Table I is taken as original data and it is encoded by using negative davio expansion as shown in Fig.3.

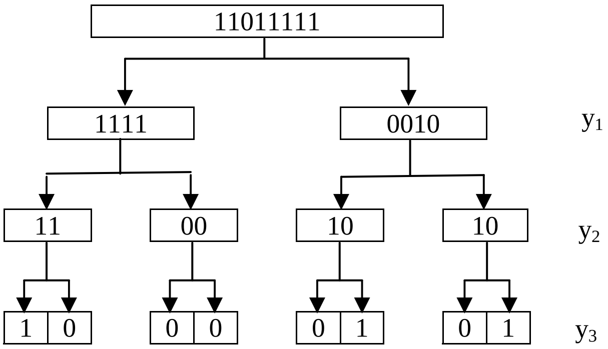


Fig.3.Negative davio expansion

If we apply negative davio expansion on the variable y_1, then g_1 goes to the left child of the root which is obtained from equation (3), g_2 goes to the right child of the root which is obtained by performing ex-or operation between g_0 and g_1 as in equation (4). Similarly we perform negative davio expansion on the variables y_2 and y_3. The resulting expression is obtained by considering the ones of the leaves of the tree and their corresponding input combination [2].The resulting NPRM expression for the function (1) is

$$g(y_1, y_2, y_3) = 1 \oplus y_1' y_3' \oplus y_1' y_2' y_3'$$

3) *Data Encoding using Fixed Polarity Reed-Muller:* In an FPRM expression of a given function g (y_1,y_2...y_n), every variable appears either uncomplimented or complimented form but never exists in both forms. In an FPRM expression we apply combination of both positive davio and negative davio expansions on variables of a function. In FPRM, there are 2^n different polarity vectors for n-variables. Different polarity vectors give different FPRM expressions with different cost [4],[5]. The output vector of function (1) is taken as original data and then it is encoded for the polarity vector P= (101) as shown in Fig.4.

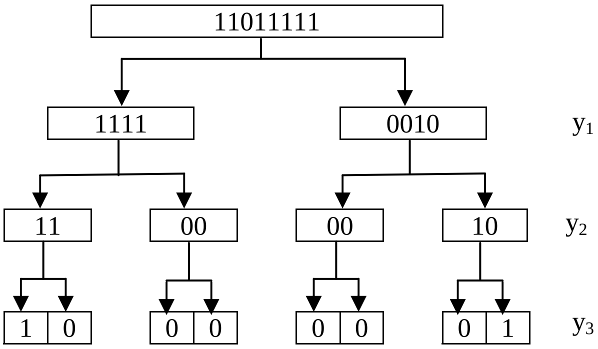


Fig.4.Both positive and negative davio expansions

In the polarity vector P= (101), we apply negative davio expansion on the variables y_1 and y_3 and then apply positive davio expansion on the variable y_2. The resulting FPRM expression for equation (1)is

$$g(y_1, y_2, y_3) = 1 \oplus y_1' y_2 y_3'$$

4) *Data Encoding using Hamming Code for Distinct Reed-Muller Encoded Data:* Hamming code is a linear block code. It can be used to identify single and two bit errors and to correct single bit error. The number of redundancy bits are calculated by using the formula is given as

$$2^r \geq n + r + 1 \tag{5}$$

n=number of data bits, r=number of redundancy bits.

1	2	3	4	5	6	7	8	9	10	11	12
r_1	r_2	d_0	r_3	d_1	d_2	d_3	r_4	d_4	d_5	d_6	d_7
Encoded data 10110011 1 2 3 4 5 6 7 8 9 10 11 12											
		1		0	1	1		0	0	1	1
Adding redundancy bit r_1											
1		1		0	1	1		0	0	1	1
Adding redundancy bit r_2											
	0	1		0	1	1		0	0	1	1
Adding redundancy bit r_3											
		1	1	0	1	1		0	0	1	1
Adding redundancy bit r_4											
		1		0	1	1	0	0	0	1	1
Encoded Hamming codeword 101101100011											

Fig.5.Calculation of redundancy bits

Encoded data 10000101											
		1		0	0	0		0	1	0	1
Encoded hamming code word											
1	0	1	1	0	0	0	0	0	1	0	1
Encoded data 10000001											
		1		0	0	0		0	0	0	1
Encoded hamming code word											
1	1	1	1	0	0	0	1	0	0	0	1

Fig.6. Hamming code word

Here n+r represents the total number of bits which are to be transmitted. Hence 2^r must be greater than or equal to n+r+1.The number of redundancy bits r can be calculated by placing the value of n[6],[7].If n is 8,then the number of redundancy bits are 4 which is obtained from equation (5). Hence total number of transmitted bits is 12.The Data which is obtained from Fig.2.is taken as Data bits for calculating redundancy bits. The redundant bit r_1 is the combination of data bits are d_0, d_1, d_3, d_4, $d_6$as shown in Fig.5.The redundant bit r_2 is the combination of data bits are d_0, d_2, d_3, d_5 ,$d_6$as shown in Fig.5.The redundant bit r_3 is the combination of data bits are d_1, d_2, d_3,$d_7$as shown in Fig.5.The redundant bit r_4 is the combination of data bits are d_4, d_5, d_6, $d_7$as shown in Fig.5.Hence the encoded Hamming code word is101101100011 which is obtained from Fig.5. Similarly, The Data which is obtained from Fig.3, Fig.4 are taken as Data bits for calculating redundancy bits and then their corresponding encoded hamming code word is 101100000101,111100010001 as shown in Fig.6.These Encoded Hamming code words are send through the channel.

B. *Data Decryption Process*

1) *Error Detection and Correction Process:* The receiver receives the data which is transmitted through the channel. If the channel is noisy, then there is a corruption of data occurs. In order to find the location of the error, the redundant bits are recalculated by using the data bits which is used by the sender plus their relevant redundant bit [6],[7]. The redundant bit r_1 is calculated by using the bits r_1, d_0, d_1, d_3, d_4, d_6.The redundant bit r_2 is calculated by using the bits r_2, d_0, d_2, d_3, d_5,d_6.

Received Data											
1	2	3	4	5	6	7	8	9	10	11	12
1	0	1	1	0	1	1	0	0	1	1	1
Calculation of r_1											
1		1		0		1		0		1	
Calculation of r_2											
	0	1			1	1			1	1	
Calculation of r_3											
			1		0	1	1				1
Calculation of r_4											
							0	0	1	1	1
Error bit position											
						1	0	1	0		
Modified data											
1	0	1	1	0	1	1	0	0	0	1	1
Extraction of data											
		1	0	1	1	0	0	1	1		

Fig.7.Error detection and correction procedure

Received Data											
1	0	1	1	0	0	0	0	1	1	0	1
Error											
				1	0	0	1				
Modified data											
1	0	1	1	0	0	0	0	0	1	0	1
Extraction of data											
		1	0	0	0	0	1	0	1		
Received Data											
1	1	1	1	0	0	0	1	0	1	0	1
Error											
				1	0	1	0				
Modified data											
1	1	1	1	0	0	0	1	0	0	0	1
Extraction of data											
		1	0	0	0	0	0	0	1		

Fig.8. Error detection and correction for distinct Reed-Muller data

The redundant bit r_3 is calculated by using the bits r_3, d_1, d_2, d_3,d_7.The redundant bit r_4 is calculated by using the bits r_4, d_4, d_5, d_6,$d_7$as shown in Fig.7.Hence the error bit Position is calculated by $r_4r_3r_2r_1$.Once the error position is identified, then that bit value in that error position is complimented. The Encoded Hamming code word which is obtained from Fig.5, Fig.6 is send through the channel. Then the receiver receives the data, if there is any error occurs, it can be corrected by complimenting those bit value and then extract the data bits as shown in Fig.7, Fig.8.

2) *Data Decoding using Positive Polarity Reed-Muller:* The extracted data bits 10110011 which are obtained from Fig.7 are taken as input. If we perform positive davio expansion on y_1,then b_0, b_2,b_4,b_6 are remain unchanged and b_0 ,b_2,b_4,b_6 are perform bitwise ex-or operation with the corresponding bits b_1 ,b_3,b_5,b_7. Similarly same procedure is applied on the variables y_2 and y_3 as shown in Fig.9.

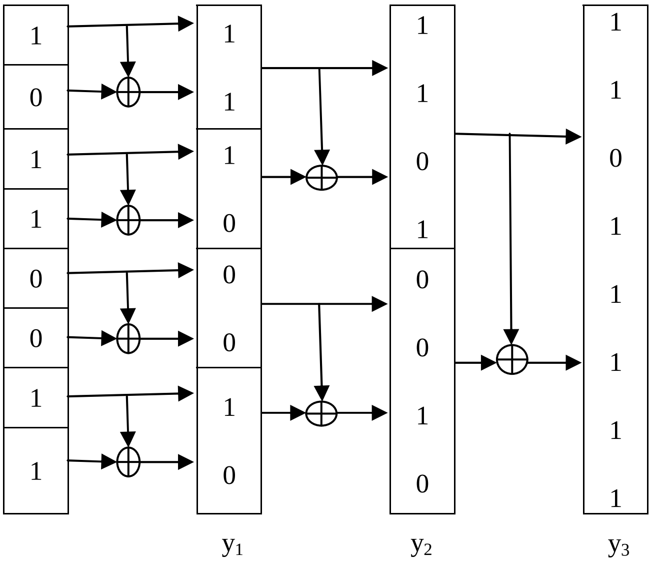


Fig.9.Data decoding using positive davio expansion

3) *Data Decoding using Negative Polarity Reed-Muller:* The extracted data bits 10000101 which are obtained from Fig.8 are taken as input. If we perform negative davio expansion on y_1,then b_0 ,b_2,b_4,b_6 are perform bitwise ex-or operation with the corresponding bits b_1 ,b_3,b_5,b_7 and then b_0, b_2,b_4,b_6 are remain unchanged. Similarly same procedure is applied on the variables y_2 and y_3 as shown in Fig.10.

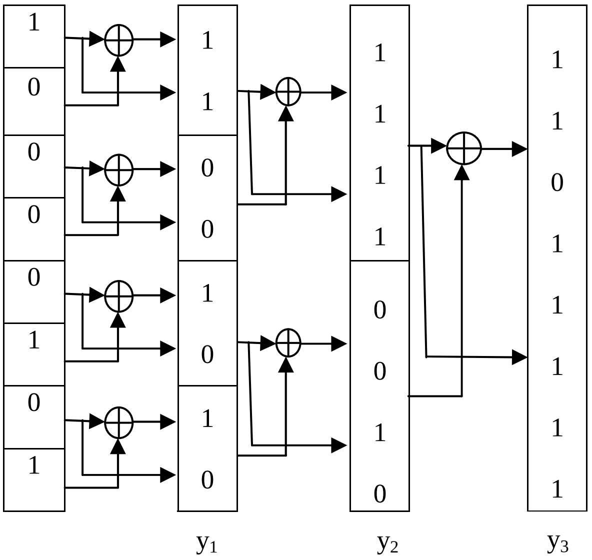


Fig.10.Data decoding using negative davio expansion

4) *Data Decoding using Fixed Polarity Reed-Muller:* The extracted data bits 10000001 which are obtained from Fig.8 are taken as input and Negative davio expansion is performed on the variables y_1 and $y_3$then b_0, b_2,b_4,b_6 are perform bitwise ex-or operation with the corresponding bits b_1 ,b_3,b_5,b_7 and then b_0, b_2,b_4,b_6 are remain unchanged . Similarly, positive davio expansion is performed on the variable y_2 for polarity vector P= (101) as shown in Fig.11.

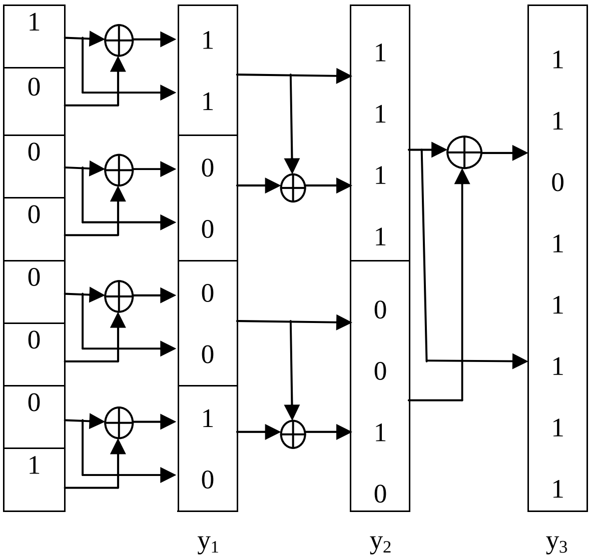


Fig.11.Data decoding using both pD and nD expansion

III. SIMULATION RESULTS

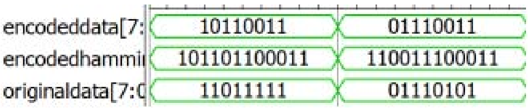
In this section, we compared the distinct types of Reed-Muller techniques such as positive polarity Reed-Muller, Negative polarity Reed-Muller, Fixed polarity Reed-Muller technique in terms of cost. Different techniques will give different cost. The cost is determined by finding number of ones in the vector. Among those Reed-Muller techniques Fixed polarity Reed-Muller gives less cost as shown in Table II.

TABLE II. Comparison Between Different Reed-Muller Techniques

Data	NPRM cost	PPRM cost	FPRM Cost
00001101	6	3	2
00010011	4	3	2
00010101	4	3	2
00011011	4	3	3

A. *Data Encoding using Positive Polarity Reed-Muller*

The original data which is to be transmitted is 11011111.The encoded hamming code word is 101101100011 which is obtained from Fig.5 for the encoded positive polarity reed-muller data is 10110011 as shown in Fig.2.These 12 bit encoded hamming code word is send through the channel as shown in Fig.12.

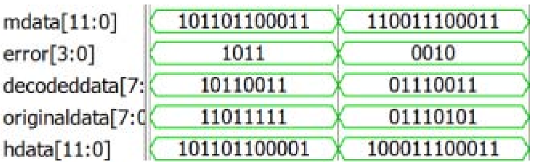


```
encodeddata[7:   10110011        01110011
encodedhammi     101101100011    110011100011
originaldata[7:0 11011111        01110101
```

Fig.12.Data encoding using PPRM

B. *Data Decoding using Positive Polarity Reed-Muller*

The encoded 12 bit hamming code word is sent through the channel as shown in Fig.12 but the receiver receives the data as 101101100001.Hence, the receiver detect and then correct the data if there is an error occurs and then extract the data. Again this extracted data is further decoded using positive polarity reed-muller technique as shown in Fig.9. Finally, we got the original data as shown in Fig.13.

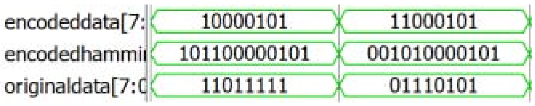


```
mdata[11:0]      101101100011    110011100011
error[3:0]       1011            0010
decodeddata[7:   10110011        01110011
originaldata[7:0 11011111        01110101
hdata[11:0]      101101100001    100011100011
```

Fig.13.Data decoding using PPRM

C. Data Encoding using Negative Polarity Reed-Muller

The original data which is to be transmitted is 11011111.If we perform negative polarity reed-Muller technique, then the resulting encoded data is 10000101as in Fig.3.The encoded hamming code word is 101100000101 which is obtained from Fig.6 which is send through the channel as shown in Fig.14.

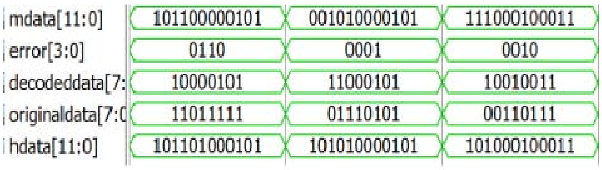


encodeddata[7:	10000101	11000101
encodedhammi	101100000101	001010000101
originaldata[7:0	11011111	01110101

Fig.14.Data encoding using NPRM

D. Data Decoding using Negative Polarity Reed-Muller

The receiver receives the data which is sent through the channel as shown in Fig.14.If the channel is noisy, then there is a chance to error occurs at the reception. The receiver can detect and correct the data and then extract the data bits from the hamming code word as shown in Fig.8. Again this extracted data is further decoded using negative polarity reed-muller technique as shown in Fig.10. Finally, we got the original data as shown in Fig.15.

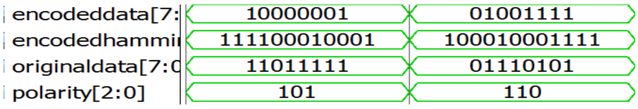


mdata[11:0]	101100000101	001010000101	111000100011
error[3:0]	0110	0001	0010
decodeddata[7:	10000101	11000101	10010011
originaldata[7:0	11011111	01110101	00110111
hdata[11:0]	101101000101	101010000101	101000100011

Fig.15.Data decoding using NPRM

E. Data Encoding using Fixed Polarity Reed-Muller

The original data which is to be transmitted is 11011111.The encoded hamming code word is 111100010001 which is obtained from Fig.6 for the encoded fixed polarity reed-muller data is 10000001 as shown in Fig.4.These 12 bit encoded hamming code word is send through the channel as shown in Fig.16.

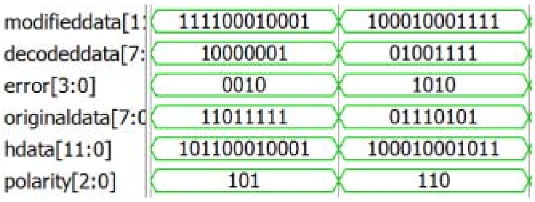


encodeddata[7:	10000001	01001111
encodedhammi	111100010001	100010001111
originaldata[7:0	11011111	01110101
polarity[2:0]	101	110

Fig.16.Data encoding using FPRM

F. Data Decoding using Fixed Polarity Reed-Muller

The receiver receives the data which is sent through the channel as shown in Fig.16.If the channel is noisy, then there is a chance to error occurs at the reception. The receiver can detect and correct the data and then extract the data bits from the hamming code word as shown in Fig.8.Again this extracted data is further decoded using fixed polarity reed-muller technique as shown in Fig.11. Finally, we got the original data as shown in Fig.17.



modifieddata[1:	111100010001	100010001111
decodeddata[7:	10000001	01001111
error[3:0]	0010	1010
originaldata[7:0	11011111	01110101
hdata[11:0]	101100010001	100010001011
polarity[2:0]	101	110

Fig.17.Data decoding using FPRM

IV. CONCLUSION

Secure and error free data transmission from transmitter to receiver is two important factors in the field of communication. In this paper, we proposed a technique which provides both secure and error free data communication. Secure data transmission obtained by encoding original data using distinct types of Reed-Muller techniques such as PPRM,NPRM,FPRM and also we compared these techniques in terms of cost. Among those Fixed polarity Reed-Muller technique gave less cost. Error free data communication is obtained by again encoding the encoded data which is obtained from distinct Reed-Muller techniques using hamming code. Single error is corrected but multiple errors cannot be corrected using hamming code. To overcome this we can use LDPC, Reed-solmon codes.

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