CHAPTER 4

DATA CODING TO MINIMIZING TRANSITION ACTIVITY

4.1 INTRODUCTION

Advances in VLSI technology have enabled the implementation of complex digital circuits in single chip, reducing size and power consumption of the system. In low power CMOS VLSI circuits, the energy dissipation is caused by charging and discharging of internal node capacitances due to transition activity, which is one of the major factors that also affect the dynamic power dissipation. This work proposes power reduction analyzed through algorithmic level and logic circuit level. In algorithm level the main key aspect of reducing power dissipation is by minimizing transition activity and is achieved by introducing data coding technique. So Multi coding technique is introduced to improve the efficiency of transition activity on the data bus lines which will automatically reduce the dynamic power dissipation.

4.2 BUS ENERGY MODEL

The DSM model of data bus coding uses simple electrical model (Sotiriadis et al 2000) in which lines are replaced by parasitic resistors and capacitors are shown in Figure 4.1. Here, C_S and Cc are the self and coupling capacitances, *R* represents the on-off resistance, V_n^i and V_n^f denote the initial and final voltages in the n^{th} interconnect (Sainarayana et al 2006).

Let V_1^i , V_2^i, ----V_n^i are initial voltages of n bit data bus wire and V_1^f, V_2^f , ----V_n^f are final voltages of n bit data bus wire. Here V_1^i ---V_n^i and V_1^f ----V_n^f can be either V_{DD} or Gnd potential. The approximate energy expression for the self and coupling transitions considering n- bit data bus can be expressed as (Sotiriadis et al, 2000)

$$E_1 = [(1 + \lambda)(V_1^f - V_1^i) - \lambda (V_2^f - V_2^i)]V_1^f \quad (4.1)$$

$$E_2 = [-\lambda(V_1^f - V_1^i) + (1 + 2\lambda)(V_2^f - V_2^i) - \lambda (V_3^f - V_3^i)]V_2^f \quad (4.2)$$

$$E_3 = [-\lambda(V_2^f - V_2^i) + (1 + 2\lambda)(V_3^f - V_3^i) - \lambda (V_4^f - V_4^i)]V_3^f \quad (4.3)$$

$$E_4 = [-\lambda (V_3^f - V_3^i)(1 + \lambda)(V_4^f - V_4^i)]V_4^f \quad (4.4)$$

$$E_n = [-\lambda (V_{n-1}^f - V_{n-1}^i)(1 + \lambda)(V_n^f - V_n^i)]V_n^f \quad (4.5)$$

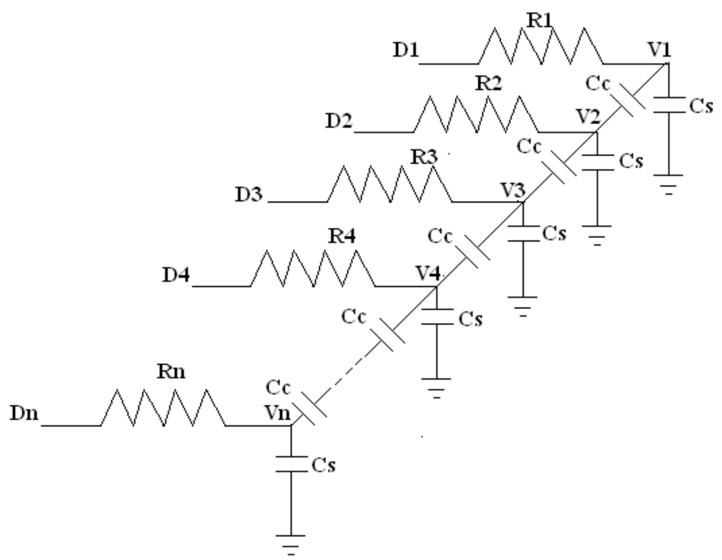

Figure 4.1 Deep submicron model for N bit data bus

Finally the percentage of energy saved due to reduction of transitions is calculated by

$$\% \text{ of Energy saved} = \left(\frac{T_{unc} - T_{cod}}{T_{unc}}\right) \times 100 \qquad (4.6)$$

4.3 TRANSITION ACTIVITY

The dynamic power dissipation has two components in a complex design, like the internal node power and the capacitive load power. The internal node power consists of the power dissipated by the internal capacitive nodes. Sometimes the internal short circuit power is added to the internal node dynamic power. So the dynamic power cannot be estimated by the simple expression $C_L V_{DD}^2 f$. because it might not always switch when the clock is switching. The transition activity determines how often this transition occurs on a capacitive node. For N periods of 0 – V_{DD} and V_{DD} – 0 transitions, the transition activity E determines how many 0-V_{DD}^2 transitions occur at the output. In other words the activity E represents the probability[2] that a transition 0 – V_{DD} will occur during the period T= 1/f (Abdellatif Bellaonat et al 1996) The average dynamic power of a complex design due to the output load capacitance is given by

$$P_D = E\, C_L\, V_{DD}^2 f \qquad (4.7)$$

The internal power dissipation, due to internal nodes, the internal dynamic power of a cell is given by;

$$P_{int\text{-}dyn} = \sum_{i=1}^{\propto} E_i C_i V_i V_{DD} f \qquad (4.8)$$

It is defined as due to charging and discharging the data changed from 1 to 0 or from 0 to 1 vice versa between adjacent bus wires or on the same bus wire. Based on it is classified in to two types

- Self Transition
- Coupling Transition

4.3.1 Self Transition

A Self Transition (ST) is defined as a transition from 0 → 1 or 1 → 0 on bus with reference to the previous data on it. Energy transition analysis is shown in Table 4.1.

Table 4.1 Energy transition analysis for self capacitance, Yan Zhang et al 2002

Transition of bits	State	Energy stored initially	Energy stored finally	Energy dissipated	Energy consumed
0 → 1	charge	0	$E_S/2$	$E_S/2$	E_S
1 → 0	discharge	$E_S/2$	0	$E_S/2$	0

4.3.2 Coupling Transition

A Coupling Transition (CT) is defined as a transition from 0 → 1 or 1 → 0, between two adjacent bus wires. The corresponding energy transition analysis is shown in Table 4.2.

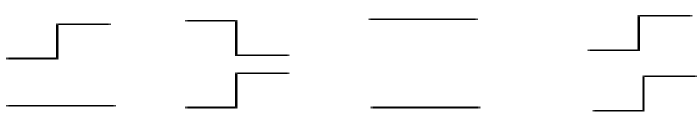

Table 4.2 Energy transition analysis for coupling capacitance, Yan Zhang et al 2002

Transition of bits	State	Energy stored initially	Energy stored finally	Energy dissipated	Energy consumed
00 → 00	-	0	0	0	0
00 → 01	charge	0	$E_C/2$	$E_C/2$	E_C
00 → 10	charge	0	$E_C/2$	$E_C/2$	E_C
00 → 11	-	0	0	0	0
01 → 00	discharge	$E_C/2$	0	$E_C/2$	0
01 → 01	-	0	0	0	0
01 → 10	Toggle	$E_C/2$	$E_C/2$	$2E_C$	$2E_C$
01 → 11	discharge	$E_C/2$	0	$E_C/2$	0
10 → 00	discharge	$E_C/2$	0	$E_C/2$	0
10 → 01	Toggle	$E_C/2$	$E_C/2$	$2E_C$	$2E_C$
10 → 10	-	0	0	0	0
10 → 11	discharge	$E_C/2$	0	$E_C/2$	0
11 → 00	-	0	0	0	0
11 → 01	Charge	0	$E_C/2$	$E_C/2$	E_C
11 → 10	Charge	0	$E_C/2$	$E_C/2$	E_C
11 → 11	-	0	0	0	0

4.4 BASICS OF DATA CODING TECHNIQUE

Representation of information is a fundamental aspect of all communication from bird song to human language to modern communication system. Data coding is the process of information change from one format to another format for possible transmission of bits. Low power coding techniques are widely used technique to reduce dynamic power through the reduction of self and coupling transition activities on data buses. Minimizing transition activity at high level is one way to reduce the power dissipation of digital circuits (Abdellatif Bellaonat et al 1996). This can have an influence on the power reduction especially when the transition signals have large capacitance. One method to minimize the transition activity is to use an appropriate coding for the signals rather than straight binary signal transmission on data buses. In this research work multi coding technique is proposed to code data. Here input data has been chosen randomly and coded in eight different ways such as Invert, Swap, Invert even position, Invert odd position, Rotate left with invert, circular left Shift, Rotate right with invert, and circular right shift.

4.5 PROPOSED MULTI CODING TECHNIQUE

Let B^k be the n bit wide data present on the bus at time instant k is defined as $B^k = (b^k_{n-1}, b^k_{n-2}, \ldots b^k_1 , b^k_2)$.. Let $B^{(k-1)enc}$ be the Reference data transmitted on the bus. Let d be the Hamming distance between the buses. (Reference data and present data) M_d is the minimum Hamming distance between the coded data's Here the coding techniques are grouped as four, each having two coding techniques. Hamming distance d is calculated for all the coding methods. With respect to the minimum Hamming distance, one coding technique is selected and another is discarded Also the same method is applied to the remaining three groups. Here from the eight coding techniques is reduced to four coding techniques. Again based on the minimum Hamming distance, chose one among the remaining four coding techniques and the finally selected data will be transmitted to the receiver with three control bits for easy recovery. The control bit representation is shown in Table 4.3.

4.5.1 Algorithm of Multi Coding Scheme

Group 1

Step 1: It consists of two coding method named as invert and swapping.

Step 2: Invert the data bits of B^k then append the control bit '000'. The new data is defined as $B^{k\,(inv)}$

Step 3: Swapping the adjacent bits of B^k and append a control bit '001'. The new data is defined as $B^{k\,(swap)}$

Group 2

Step 1: It consists of two coding method named as invert Even and Odd Position.

Step 2: Invert the even bits of B^{k} and append a control bit ‘010’. The new data is defined as $B^{k (even)}$

Step 3: Invert the odd bits of B^{k} and append a control bit’011’. The new data is defined as $B^{k (odd)}$

Group 3

Step 1: It consists of two coding method named as invert Rotate Left with Invert and Rotate Right with Invert

Step 2: Rotate left by one bit of B^{k} then invert and append a control bit ‘100’. The new data is defined as $B^{k (RLinv)}$

Step 3: Rotate right by one bit of B^{k} and append a control bit ‘101’. The new data is defined as $B^{k (RRinv)}$

Group 4

Step 1: It consists of two coding method named as circular shift left and shift right.

Step 2: Circularly Shift Left the bits of B^{k} and appends a control bit ‘110’. The new data is defined as $B^{k (SL)}$

Step 3: Circularly shift right the bits of B^{k} and append a control bit ‘111’. The new data is defined as $B^{k (SR)}$

Calculate the Hamming distance between $B^{k(coded)}$ and $B^{k-1(enc)}$ is given by d ($B^{k(coded)}$, $B^{k-1(enc)}$) for all groups will give a number of bits differ from each other. Then calculate minimum Hamming distance M_d[Group1($B^{k(inv)}$,$B^{k(swap)}$)],M_d[Group2($B^{k (even)}$, $B^{k (odd)}$)], M_d [Group3($B^{k (RLinv)}$, $B^{k RRinv)}$], M_d [Group4($B^{k (SL)}$, $B^{k (SR)}$)] from the each group one coding technique will be selected and other will be discarded. Thus, finally among eight only four coding techniques is provided to the Comparator. Then comparator compares and sends a least Hamming distance coding along with control bit transmitted through the bus.

Table 4.3 Three bit representations of control signal

Sl.No	Coding Method	Control Bit
1	Invert	000
2	Swap	001
3	Invert Even Line	010
4	Invert Odd Line	011
5	Rotate Left with Invert	100
6	Rotate Right with Invert	101
7	Circular Left shift	110
8	Circular Right shift	111

4.6 BLOCK DIAGRAM OF PROPOSED MULTI CODING TECHNIQUE

The block diagram of proposed multi coding technique is shown in Figure 4.2. This module consists of three sections named as multi coding, Hamming distance estimator and comparator. It is a modified and improved version of the design proposed to reduce the transition activity and power dissipation on data buses. Here the random input samples are initially coded in eight different ways, then Hamming distance is calculated between the data are by using XOR stack, then the count is calculated by Hamming distance estimator which is implemented using array of single bit full adders. Finally the comparator will compare and transmit the least Hamming distance coding method to the output with three bit control signal for easy recovery.

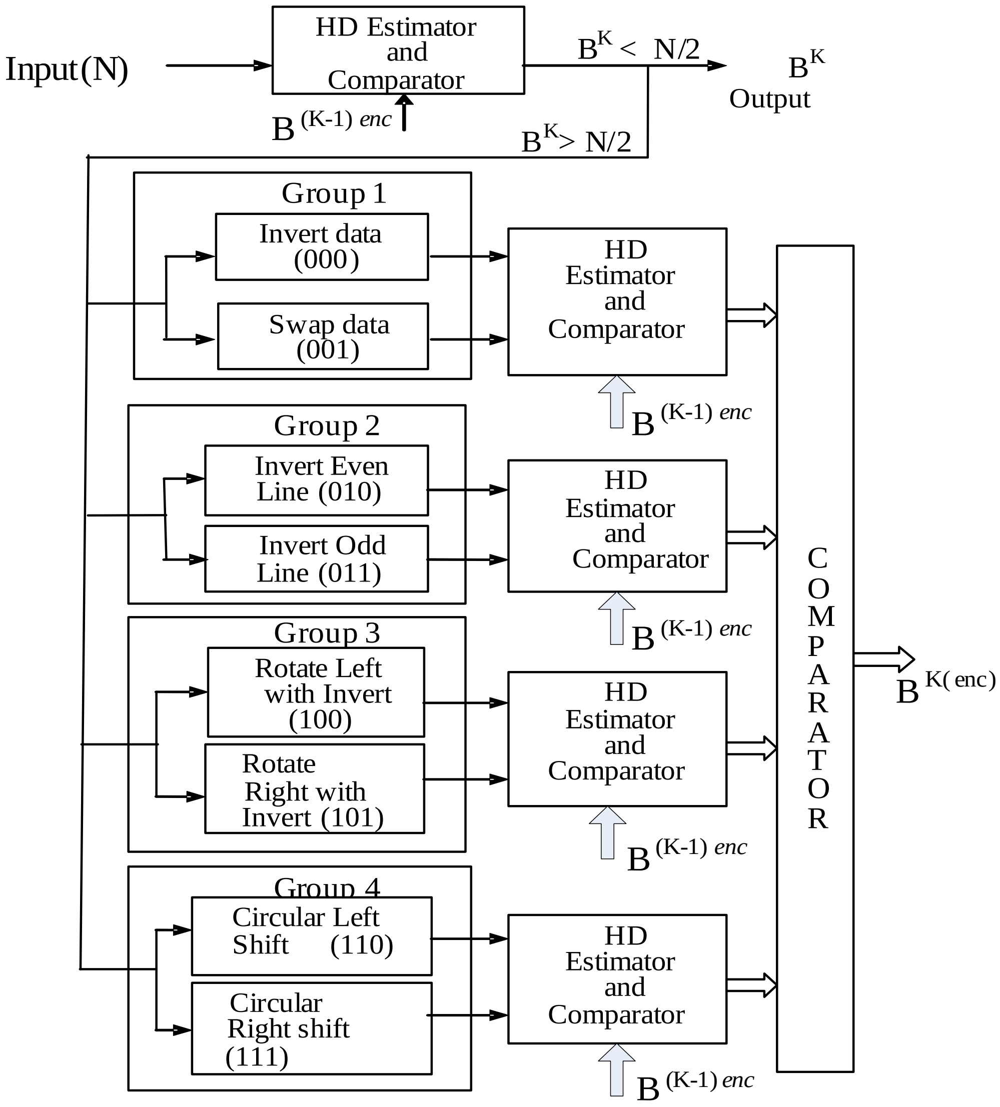

Figure 4.2 Block diagram of proposed multi coding technique

4.7 WORKING PRINCIPLE OF HAMMING DISTANCE ESTIMATOR

Hamming distance between two code vectors or strings of equal length is the number of position at which the corresponding symbols are different. In another way, it measures the minimum number of substitutions required to change one string in to other, or the minimum number of errors that could have transformed one string in to other. The following examples explain how to calculate the Hamming distance.

Example1:

Let X = 10111011

Let Y = 11110010

Hamming distance between X and Y is defined by;

X = $1\underline{0}11\underline{1}01\underline{1}$

Y = $1\underline{1}11\underline{0}01\underline{0}$

Here only three bits differ from each other,

Hence Hd (X, Y) = 3

Example 2:

Let X = “tones”

Let Y = “roses”

Hamming distance between X and Y is defined by;

X = $\underline{t}$ o $\underline{n}$ e s

Y = $\underline{r}$ o $\underline{s}$ e s

Here only two bits differ from each other,

Hence Hd (X, Y) = 2

The internal block diagram of eleven bit Hamming distance Estimator is shown in Figure 4.3. The input binary vectors are B_0, B_1, B_2, B_3, B_4, B_5, B_6, B_7, B_8, B_9, B_{10} and the array of output binary vectors are O_0, O_1, O_2, O_3. In order to minimize the critical delay the concept of parallel adders are used here. The array of XOR stack is shown in Figure 4.4 performs the action of a coincidence circuit. The input vectors are b^{k-1}, which is previous encoded data at a time (t-1) and the other inputs are the array of present encoded data $b_k = (b_{0,} b_1, b_{2,} ----b_n)$ In this particular example, it can be seen that for a eleven bit Hamming distance estimation, a 4 bit output is generated. This module separately calculates the Hamming distance between the coded data and the reference data for each coding method by using XOR stack and Hamming distance estimator (HD). Then compare all coding method which is having minimum transition activity. By using this concept, among the eight, four methods are discarded and remaining four methods are again compared and the code having least transition count will be transmitted via data bus. Based on the transition activity on the buses will reduce the total power dissipation on the data bus.

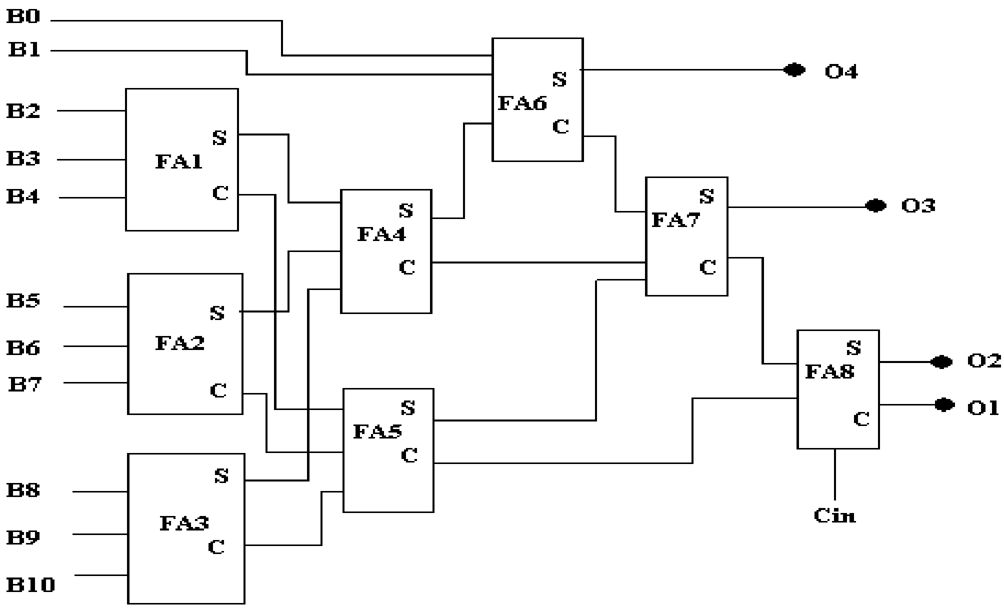

Figure 4.3 Hamming distance estimator

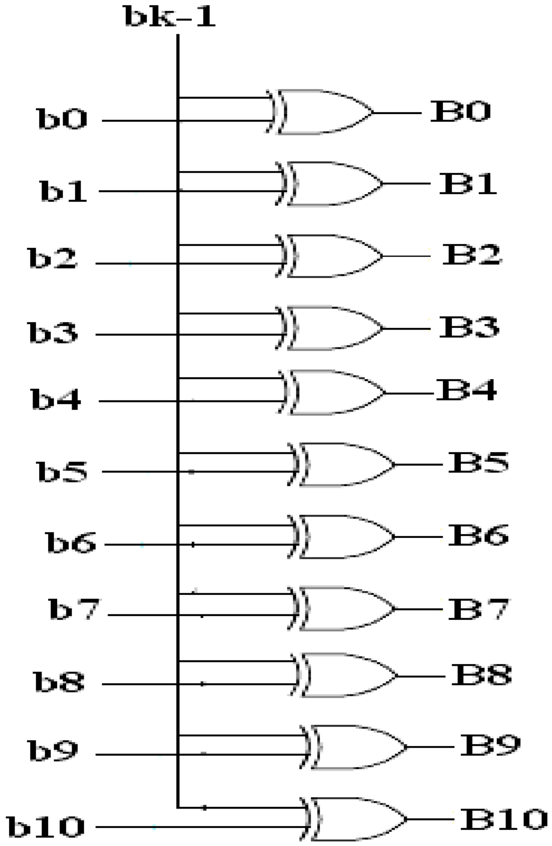

Figure 4.4 XOR stack

4.8 RESULTS AND DISCUSSIONS

The proposed multi coding technique has been implemented using verilog HDL and the transition activity is simulated using Modelsim simulator with 8 bit random samples. The random input data are B_1^k = 01011011, B_2^k = 01000100, B_3^k = 00111001, B_4^k = 00010010, B_5^k = 01010011. To evaluate the effectiveness of multi coding technique transition count, Comparison of transition count and Energy saving percentages were calculated and listed in the following Tables and Figures from Table 4.4 to 4.9 and Figure 4.5 to 4.10.

4.8.1 Transition Count

Transition is due to charging and discharging of the data on the bus changed from 1 to 0 and 0 to 1 vice versa between adjacent bus wires or on the same bus wire. Transition activity is calculated by Hamming distance estimator. Hamming distance between two code vectors are equal to the number of elements in which they differ. Hamming distance count is equal to the transition count on the bus; the result is analyzed and tabulated from Table 4.4 to 4.7 and Figure 4.6 to 4.8.

Assume an 8 bit data 01011011 is given to the encoder via input bus to calculate the transition count, the Table 4.4 shows how the proposed technique reduces the number of transitions. From this analysis it is decided that the data is encoded using invert method is transmitted to the output bus. Since the invert coding method has least transitions compare to other coding methods is shown in Figure 4.5.

Table 4.4 Transition count for input B_1^k (01011011)

Sl.No	Type of Coding	Coded Data	HD	Least HD	Least Transition
1	Invert	10100100000	2	2	2 (Invert data)
2	Swap	10100111001	3		
3	Invert Even Line	00001101010	5	5	
4	Invert Odd Line	11110001011	8		
5	Rotate Left with Invert	01001001100	5	5	
6	Rotate Right with Invert	01010010101	8		
7	Circular Left Shift	10110110110	4	3	
8	Circular Right Shift	10101101111	3		

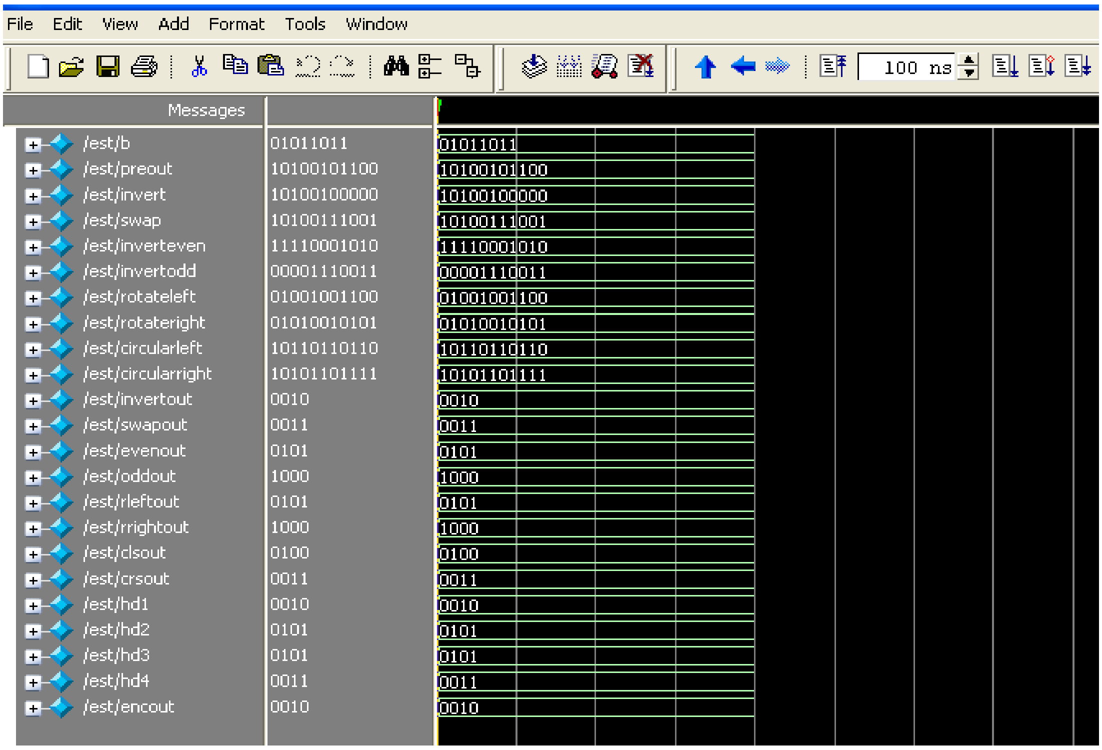

Figure 4.5 Simulation output for input data B_1^k (01011011)

Assume an 8 bit data 01000100 is given to the encoder via input bus to calculate the transition count, the Table 4.5 shows how the proposed technique reduces the number of transitions. From this analysis it is decided that the data is encoded using Rotate Left with invert method is transmitted to the output bus. Since the Rotate Left with invert coding method has least transitions compared to other coding methods is shown in Figure 4.6.

Table 4.5 Transition count for input data B_2^k (01000100)

Sl.No	Type of Coding	Coded Data	HD	Least HD	Least Transition
1	Invert	10111011000	5	5	4 (Rotate Left with Invert)
2	Swap	10001000001	6		
3	Invert Even Line	11101110010	6	6	
4	Invert Odd Line	00010001011	7		
5	Rotate Left with Invert	01110111100	4	4	
6	Rotate Right with Invert	11011101101	5		
7	Circular Left Shift	10001000110	5	5	
8	Circular Right shift	00100010111	6		

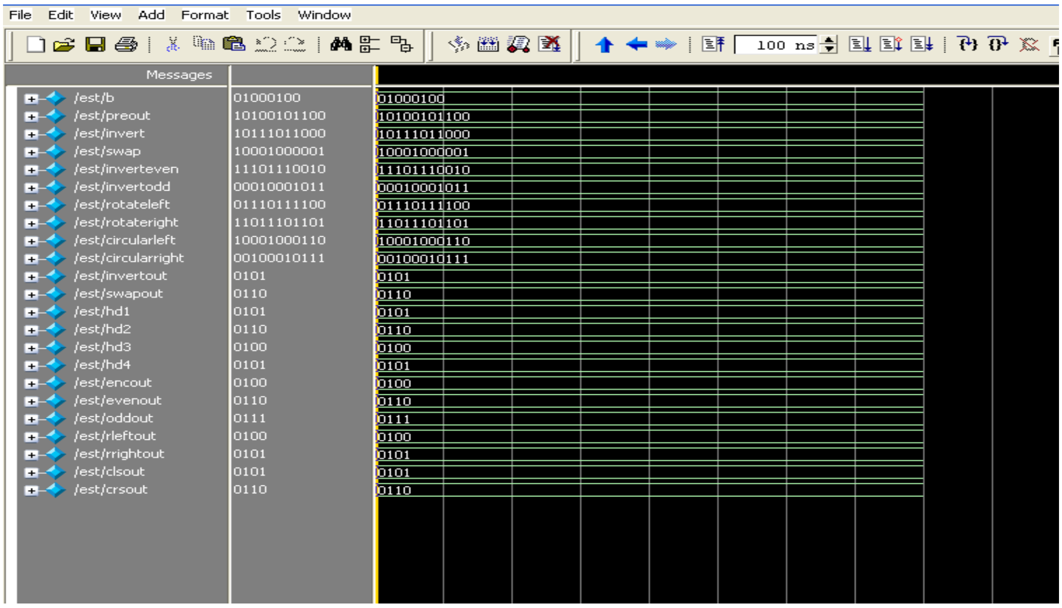

Figure 4.6 Simulation output for input data B_2^k (01000100)

Assume an 8 bit data 00111001 is given to the encoder via input bus to calculate the transition count, the Table 4.6 shows how the proposed technique reduces the number of transitions. From this analysis it is decided that the data is encoded using Rotate Left with invert method is transmitted to the output bus. Since the Rotate Left with invert coding method has least transitions compared to other coding methods is shown in Figure 4.7.

Table 4.6 Transition count for input data B_3^k (00111001)

Sl. No	Type of Coding	Coded Data	HD	Least HD	Least Transition
1	Invert	11000110000	5	5	2 (Rotate Left with Invert)
2	Swap	00110110001	6		
3	Invert Even Line	10010011010	6	6	
4	Invert Odd Line	01101100011	7		
5	Rotate Left with Invert	10001101100	2	2	
6	Rotate Right with Invert	01100011101	5		
7	Circular Left Shift	01110010110	7	6	
8	Circular Right shift	10011100111	6		

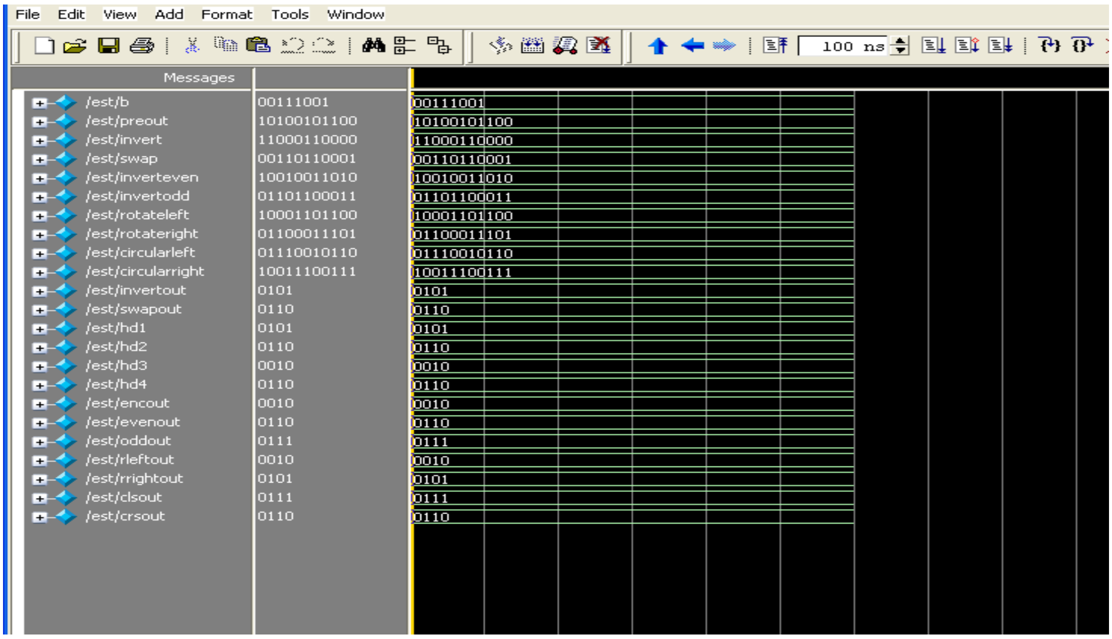

Figure 4.7 Simulation output for input data B_3^k (00111001)

4.8.2 Comparison of Transition Count

In the proposed multi coding technique the input data are coded in eight different ways each like invert, swap, Invert even line, Invert odd line, Rotate left with invert, Rotate right with invert, Circular left shift and Circular right shift are having different transition count are Listed in the Table 4.7 and Figure 4.8. From this result it is decided among all coding technique which is having least Transition activity for each random 8 bit data on the bus. Input data1and data 5 the invert method gives least transition activity. The input data 2 and data 3 rotate left with invert method gives least transition activity. Input data 4 invert and circular left shift both gives least transition activity.

Table 4.7 Comparison of transition count in multi coding technique

Data	**Number of Transitions**							
	Invert	**Swap**	**IEL**	**IOL**	**RLI**	**RRI**	**CLS**	**CRS**
Input 1	2	3	5	8	5	8	4	5
Input 2	5	6	6	7	4	5	6	5
Input 3	5	6	6	7	2	5	7	6
Input 4	3	6	6	7	6	5	3	6
Input 5	3	4	7	6	6	7	4	5

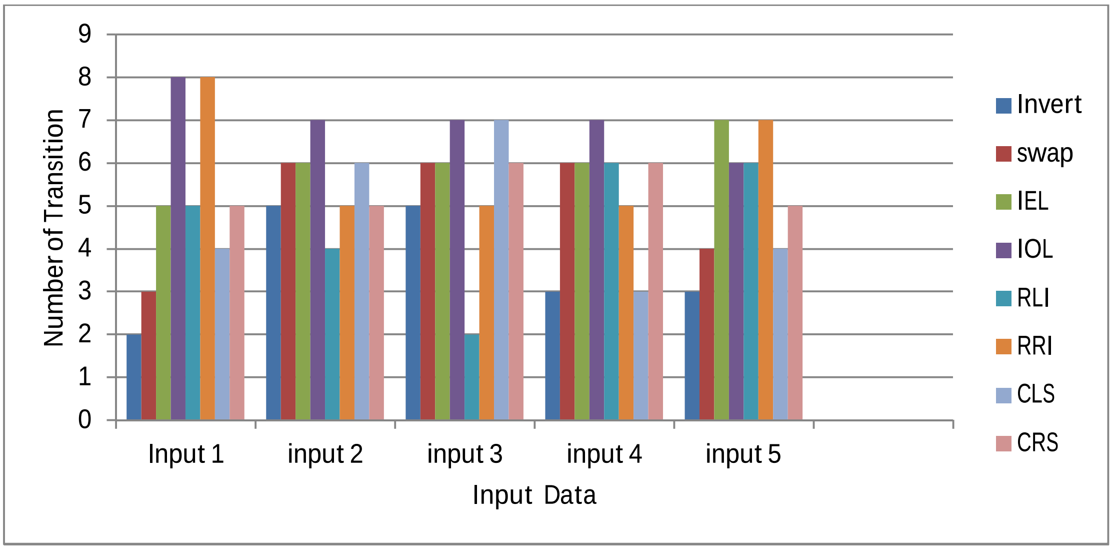

Figure 4.8 Comparison of transition count in multi coding technique

4.8.3 Energy Saving

It is defined as the ratio between numbers of transitions due to coded data to number of transitions due to uncoded data. The percentage of energy saved due to reduction of transitions is calculated by

$$\text{Energy saved} = \left(\frac{T_{unc-}\ T_{coded}}{T_{unc}}\right) \times 100$$

T_{unc} - Number of transitions due to uncoded data

T_{coded} - Number of transitions due to coded data

Table 4.8 Percentage of energy saved in multi coding technique

Data	% of Energy saved							
	Invert	**Swap**	**IEL**	**IOL**	**RLI**	**RRI**	**CLS**	**CRS**
Input 1	66.66	50	16.66	-33.33	16.66	-33.33	33.33	16.66
Input 2	16.66	0	0	-16.66	33.33	16.66	0	16.66
Input 3	16.66	0	0	-16.66	66.66	16.66	-16.66	0
Input 4	62.5	25	25	12.5	25	37.5	62.5	25
Input 5	62.5	50	12.5	25	25	12.5	50	37.5

The 8 bit input samples are analyzed and the percentage of energy saved is calculated and recorded in the Table 4.8 and Figure 4.9. From this table for input data1 and data 5 the invert coding technique saves the energy up to 66.66 % and 62. 5 %. For input data 2 and data 3 Rotate left with invert technique save the energy up to 33.33 % and 66.6%. For input data 4 both invert and circular left shift save energy up to 62.5 %. By using multi coding technique maximum percentage of energy can be saved up to 66.66%.

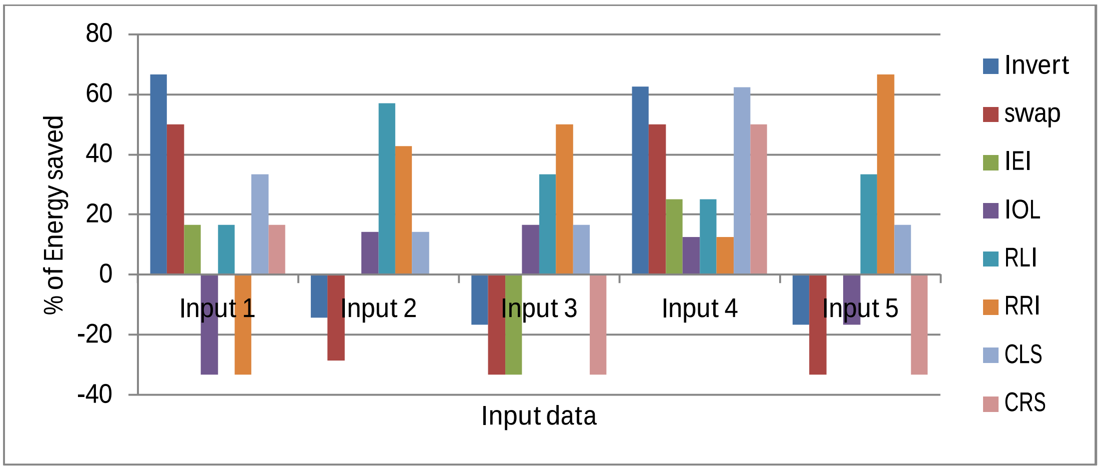

Figure 4.9 Percentage of energy saved in multi coding technique

Table 4.9 Comparison of energy saving percentage of multi coding technique with other existing coding techniques

Sl. No	Coding methods	% of Energy saved
1	BI	27.4
2	Shift inv	31.4
3	Rotate	48.89
4	MDSMBC	21
5	NBCMEI	26
6	MCT(Proposed method)	66.6

To justify the efficiency of proposed multi coding technique, various existing coding techniques are compared with this proposed technique. Table 4.9 and Figure 4.10 show comparison of energy saving percentage for various existing coding technique with proposed multi coding technique. From this table the percentage of energy saved in the proposed technique is much higher than the existing methods. Hence the proposed multi coding technique is more power efficient than other existing methods.

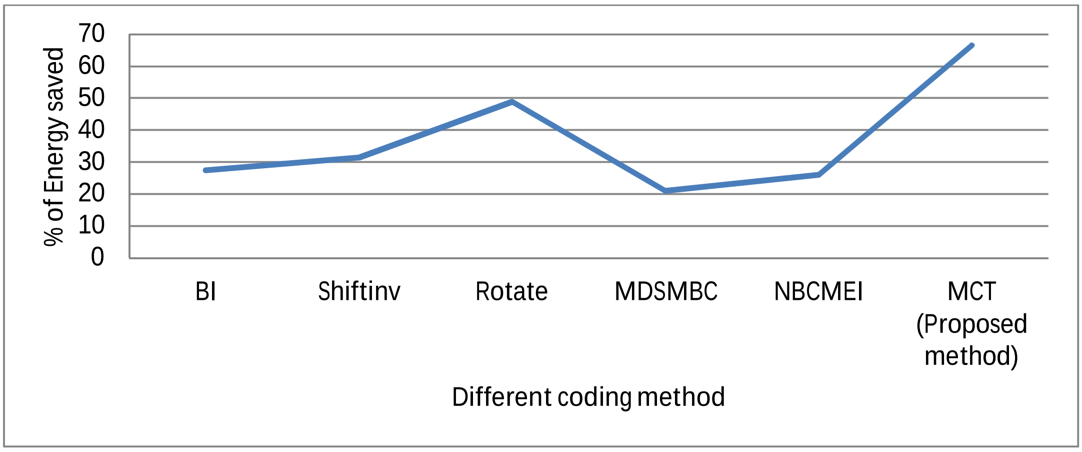

Figure 4.10 Comparison of energy saving percentage

4.9 CONCLUSION

The main objective of the proposed multi coding technique is to reduce the power dissipation due to data transitions on the bus wires. The performance can be analyzed and listed in table from Table 4.4 to 4.9 and Figure 4.5 to 4.10. In all existing data encoding techniques the data are encoded in either one way or other. But in proposed multi coding technique the random data is encoded in eight different ways and very least transition would be achieved from any one of the eight different methods. From this analysis it is concluded that multi coding technique is the very best method because it reduces the number of transitions and will give very significant reduction in power dissipation among all existing encoding techniques while comparing with the transition count and energy saving percentage.