Minimizing Simultaneous Switching Noise (SSN) using Modified Odd/Even Bus Invert Method

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Abstract

In high speed digital circuits, the inductive effect is more dominant compared to capacitive effect. In particular, as the technology is shrinking, the spacing between interconnects becomes less which increases Simultaneous Switching Noise (SSN) or $M\frac{di}{dt}$ *noise. So earlier methods proposed which concentrate on reducing capacitive effect do not hold good. This paper proposes a modified Odd/Even Bus Invert scheme, which reduces the simultaneous switching activity, thereby improving the signal integrity. The performance of the proposed coding scheme has been tested on various benchmarks and it is found that SSN or* $M\frac{di}{dt}$ *is reduced by 28% compared to data transmitted unencoded The proposed Codec has been designed and it has been found that power overhead is 3.3%.*

Keywords

Simultaneous Switching Noise (SSN), Odd Simultaneous Transitions (OST), Even Simultaneous Transitions (EST), Coding, VLSI, Low power.

1. Introduction

The need for higher processing speeds has driven VLSI circuitry to operate in GHz range. As the speed of VLSI circuits are increasing rapidly, the effect of inductive crosstalk in IC packaging is becoming a significant bottleneck in inter chip communications. International Roadmap for Semiconductors (ITRS) has predicted that IC performance is continuing to be doubled every 18 months whereas the package performance is doubling over the next decade [1]. This imbalance is due to the effect of parasitic inductance in packaging. Furthermore, as we approach DSM technology, the spacing between interconnects becomes less, which leads to crosstalk, and thereby deteriorating the signal integrity [7]. To overcome this issue, several methods like shielding, buffer insertion, crosstalk aware routing and differential signaling have been proposed. Even though the aforementioned methods reduce cross talk effectively, the higher power consumption due to the complex nature of their drivers and buffers, limits their usability. Bus Coding is yet another approach to solve the above mentioned problem. Although previous coding techniques aim at reducing the capacitive crosstalk [4, 7, 8], the crosstalk due to inductive effects become more dominant in VLSI connectors. Hence, this paper proposes a modified Odd/Even Bus Invert scheme, which reduces the simultaneous switching Noise.

2. Theory

2.1. Crosstalk noise

Mutual inductance and capacitance are mechanisms that cause crosstalk. Especially in high speed digital design and packaging the effect of mutual inductance is more dominant compared to that of the mutual capacitance.

This paper focuses on reducing the mutual inductance. Mutual inductance L_m induces current from an aggressor line onto a quiet line by means of magnetic field thereby degrading the signal integrity [3]. Especially in DSM the spacing between the lines increases the effect of mutual inductance leading to increasing crosstalk.

A crosstalk may be induced in the voltage of a pin 'i' in which the signal is static, by the adjacent pins in which the signal is varying [5]. This is given by the expression

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$$V^i_{glitch} = \sum_p \pm M_{ip} \frac{di_p}{dt} \quad (1)$$

Where, M_{ip} is the mutual inductance between the i^{th} pin and the p^{th} pin and i_p is the current in the p^{th} pin. The sign of the coupled voltage is positive or negative depending on whether the p^{th} neighboring pin undergoes a rising or falling transition. Furthermore, the crosstalk noise or $M\frac{di}{dt}$ noise is data-pattern dependent. This dependency is exploited by coding the data in such a way that crosstalk is reduced. A two line model showing the various inductance and capacitance is shown in Figure 1. We shall prove the dependency of data pattern on crosstalk.

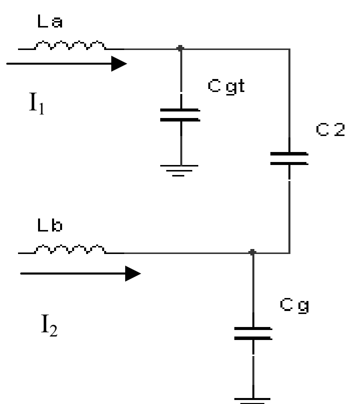

Figure1. Equivalent circuit model for two wire bus

2.1. Odd Mode

Odd-mode propagation mode occurs when two coupled lines are driven with equal magnitude and $180°$ out of phase with one another. Let us assume that $L_{11} = L_{22} = L_0$. Thus in Odd mode propagation the current will be of equal amplitude but flow in opposite direction [2]. The effective Inductance L_{odd} due to odd mode of propagation is given in Eq (2).

$$L_{odd} = L_{11} - L_{12} \quad (2)$$

The pattern of magnetic field of two conductors in odd mode is shown in Fig 2(a).

2.2. Even Mode

Even mode propagation mode occurs when the coupled transmission lines are driven with equal magnitude and are in phase with one another. Thus in even mode propagation the current will be of equal magnitude and flow in the same direction [2]. The effective Inductance L_{even} due to even mode propagation is shown in Eq (3).

$$L_{even} = L_{11} + L_{12} \quad (3)$$

The pattern of magnetic field for a two wire model propagating in even mode is shown in Fig 2(b).

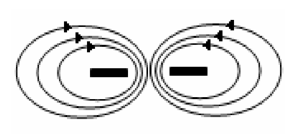

Figure 2(A). Odd Mode

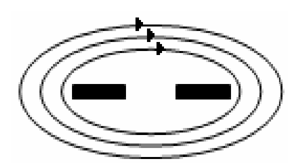

Figure 2(B). Even Mode

Thus the Inductive Crosstalk in bus lines is significantly lower, when propagating in odd mode rather then even mode.

3. Propose Coding scheme

Let the input to the proposed coding scheme at time $(K+1)$ be A^{k+1} and let E^{k+1} be the output at that time. The proposed Coding Scheme is as follows.

1. Calculate the number of Simultaneous Switching Transitions (SST) of A^{k+1} at odd position and denote it by OST (Odd Simultaneous Transitions)
2. Calculate the number of Simultaneous Switching Transitions (SST) of A^{k+1} at even position and denote it by EST (Even Simultaneous Transitions)
3. if (OST>EST)
   begin
   flip odd positioned bits of the data & append with *01* and transmit.

```
 end
 else
 if (OST<EST )
 begin
    flip even positioned bits of the data &
    append with 00 and transmit
 end
else
 begin
   Send as it is with 10 appended
end
```

4. Illustration of the Proposed Coding Scheme

4.1. Example 1

Let the present data on the bus be A^{k+1} = {11111111} or {↑↑↑↑↑↑↑↑}. The number of OST is 4 & EST is 3. Since OST is greater than EST, hence flip the odd positioned bits & append with 01. Thus the data to be transmitted after encoding is E^{k+1} = {01 0101 01}{01} {↓↑↓↑↓↑↓↑}{↓↑}. Thus the Simultaneous transition is reduced from 7 to 0 which reduces the SSN.

4.2. Example 2

Let the present data on the bus be A^{k+1} = {10101010} or {↑↓↑↓↑↓↑↓}. The number of OST & EST is 0. Since OST is equal to EST, the data is transmitted with encoding appending 10. Thus the data to be transmitted after encoding is E^{k+1} = {10101010} {10} {↑↓↑↓↑↓↑↓} {↑↓}. Thus the best case is transmitted as it is without increasing the crosstalk.

5. Hardware Implementation

The Hardware implementation of the proposed CODEC is shown in Figure 3 (a) and Figure 3 (b). OST and EST estimator is a 3-bit ADDER-COUNTER which counts number of even and odd simultaneous transitions respectively. The output of the comparator indicate if OST>EST or OST<EST or OST=EST. If OST >EST then the odd position bits are flipped and bits "01" are appended and transmitted. If OST <EST then the even position bits are flipped and bits "00" are appended and transmitted. If both are equal then the data is sent without encoding by appending "10". A 2 to 4 decoder Figure3 (b) is used to decode the transmitted data.

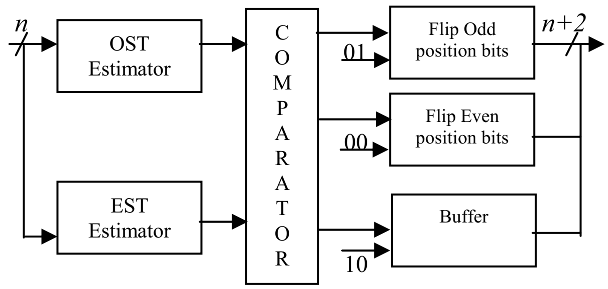

Figure3 (a) Hardware implementation of the proposed Encoder

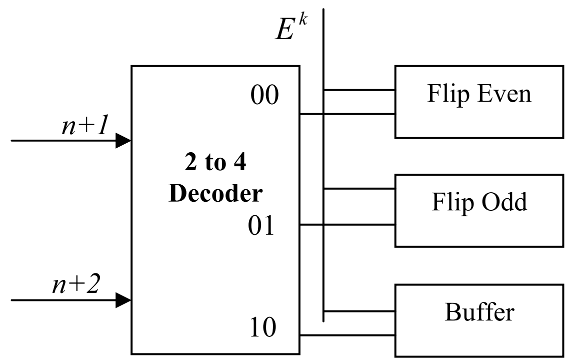

Figure3 (b) Hardware implementation of the decoder

6. Simulation Results

The comparison of the proposed coding scheme with various other coding schemes, with respect to Inductive crosstalk is shown in Table1. It has been found that the proposed method reduces the Simultaneous Switching Noise by 28% on an average, when compared to transmitting the data without encoding.

Bus Coding Methods	**Percentage Of Cross Talk**				
	mpeg	vortex	go	gcc	compress
Unencoded	100	100	100	100	100
BI [4]	85	84	83.5	84	83
CBI [8]	80	78.25	79	80	78.12
MBI [6]	76	75.52	74.2	75	75.26
Proposed Method	**72**	**73.08**	**70.2**	**74.6**	**72.05**

Table1. Comparison of Crosstalk Noise of Various Coding Schemes Tested On SPEC'95 Benchmarks

Power analysis of the various Codecs has been performed using MAGMA tools. The comparison of the relative power overhead of the various coding scheme is shown in Table 2.

Bus Coding Technique	% Relative power
BI [4]	3%
CBI [8]	3.6%
MBI [6]	3.4%
Proposed Coding Method	**3.3%**

Table2. Percent Power Overhead of the Various Coding Schemes With Respect To Unencoded

The proposed codec has been designed using Magma tools and it is shown in Figure5

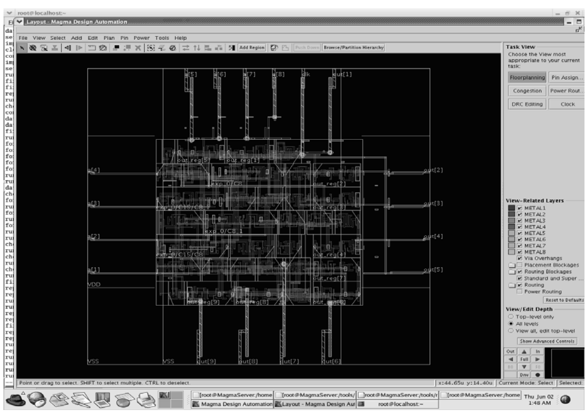

Figure 5: Layout of the proposed CODEC using MAGMA tools

7. Conclusions

The inductive effect in IC packaging is well pronounced in high speed digital circuit which degrades the signal integrity. Addressing this issue with aggressive package design is slow and often too expensive for a majority of applications. This paper proposed a Modified Odd/Even Bus Invert coding and it has been found that SSN or glitching is reduced by 28%. The Codec was designed using Magma and the overhead has been found to be 5%.

8. Acknowledgements

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9. References

[1] International Technology Roadmap For Semiconductors. Website: http://public.itrs.net

[2] Stephen H. Hall, Garrett W. Hall and James A. McCall, *High-Speed Digital System Design*. John Wiley and Sons Inc., 2000

[3] A. P. Chandrakasan and R. W. Brodersen, *Low Power Digital CMOS Design*, Kluwer Academic Publisher, 1995.

[4] Mircea R. Stan and Wayne P. Burleson, *Bus Invert Coding For Low Power I/O.* IEEE Transaction on VLSI Systems, pp. 49-58, March 1995.

[5] B.J. LamMeres and S.P. Khatri. *Encoding-Based Minimization of Inductive Cross-talk For Off-chip Data Transmission*. Proceedings of DATE, pp. 1318–1323, March 2005.

[6] M. Lampropoulos et al., *Minimization of Crosstalk Noise, Delay and Power Using a Modified Bus Invert Technique.* Proceedings of DATE, pp. 1372-1373, Feb 2004.

[7] B. Victor & K. Keutzer, *Bus encoding to prevent crosstalk delay.* Proceedings of IEEE ICCAD, pp. 57–63, Nov 2001

[8] K.-W. Kim and et al., *Coupling-driven signal encoding scheme for low-power interface design*. Proceedings of IEEE ICCAD, pp. 318 –321, Nov. 2000.