SIMULATION VS CALCULATION OF CROSSTALK

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ABSTRACT

A crosstalk model for high speed MCMs that is shown to be accurate is compared to simulating a design. Results are presented that show that even though the model is accurate, accurate results cannot be obtained without accounting for timing.

I. INTRODUCTION

With the ever increasing clock speeds and decreasing feature sizes on integrated circuits, noise considerations when routing multichip modules are becoming increasingly more important. To compound the noise problem, lower voltages are being used in newer circuits resulting in significantly smaller noise margins.

An accurate crosstalk model is important for two reasons. The first and most important reason is that a crosstalk violation can render a design useless and can require a significant amount of time and money to correct. The second reason is that an overly conservative model can add layers to a design, resulting in increased cost and decreased performance.

However, the question remains of how accurate a model can be without accounting for timing. The following sections discuss an accurate crosstalk model and compares it to simulation results. The results and reasons for the variance in the results is also discussed.

II. CROSSTALK CALCULATIONS

When a voltage is induced in a line, two voltage pulses (traveling in opposite directions) are created. The voltage pulse that travels towards the driver end of the driven line is called backward or near-end crosstalk. The pulse that travels away from the driver end is called forward or far-end crosstalk. The two pulses are different in both shape and magnitude so separate equations are needed for each pulse. The following equations were developed by Feller et. al. in [1] and are also discussed in [3].

The near-end crosstalk is given by:

$$V_{NE}(t) = K_{NE}\left[V_{in}(t) - V_{in}(t - 2t_d)\right] \tag{1}$$

where $V_{in}(t)$ is the input voltage, t_d is the transit time for the signal to cross the coupled region, and K_{NE} is the near-end coupling coefficient. K_{NE} is given by:

$$K_{NE} = \frac{1}{4t_d}\left(\frac{L_m}{Z_o} + C_m Z_o\right) \tag{2}$$

where L_m is the mutual inductance, C_m is the mutual capacitance, and Z_o is the characteristic impedance of the lines.

The far-end crosstalk is given by:

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$$V_{FE}(t) = K_{FE}\ell\frac{d}{dt}\left[V_{in}(t - t_d)\right] \tag{3}$$

where ℓ is the length of the coupled region and K_{FE} is the far-end coupling coefficient. K_{FE} is given by:

$$K_{FE} = -\frac{1}{2}\left(\frac{L_m}{Z_o} - C_m Z_o\right) \tag{4}$$

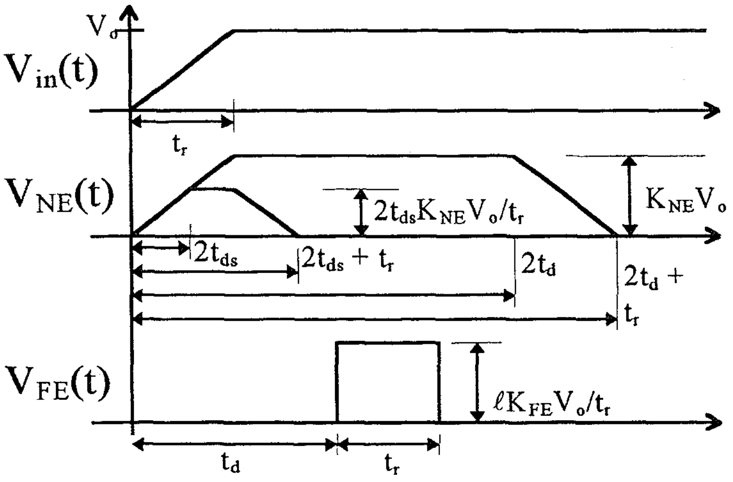


Figure 1. Primitive Crosstalk Pulses [3].

Figure 1 shows the wave forms of both the backward and forward crosstalk pulses. $V_{NE}(t)$ has two possible pulses. The smaller pulse is for short lines, and the larger pulse is for long lines. The term t_{ds} represents t_d of the short line. The polarity of $V_{FE}(t)$ is assumed to be positive in the chart but is not necessarily the case.

Usually, only the nearest neighbor of any particular conductor needs to be considered when calculating crosstalk, because at low frequencies the effects of other conductors tend to be negligible. However, for very high speed MCM systems this may not be true. Consider an eight bit bus (lines 0-7). Let line 3 be quiet while the other lines are driven. In order to make the crosstalk calculations as accurate as possible, it is necessary to include not only the next-nearest-neighbors like lines 1 and 5, but also the *next-next-nearest-neighbors* like lines 0 and 6 in the crosstalk calculations.

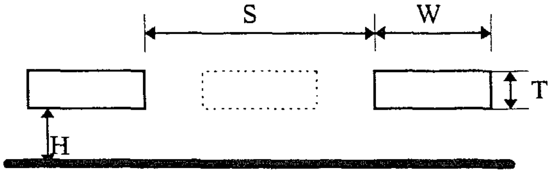


Figure 2. Wiring Geometry.

One problem with trying to calculate the crosstalk between two lines that have another line in between them is that the line in the middle partially shields them from each other (as in Figure 2). In order to determine the amount of shielding, we start with the relationship $C_m \propto L_m$ for a given frequency. From this relationship and the equations above, it can be shown that $V_{NE} \propto C_m$ and $V_{FE} \propto C_m$. Using the mutual capacitance approximation by Sakurai in [2] and assuming that the $0.07(T/H)^{0.222}$ term is negligible, the following ratio can be derived:

$$\frac{C_{mwo}}{C_{mw}} = \frac{\varepsilon_{wo}}{\varepsilon_{w}}\left[1+27.27\frac{T}{H}\right] \tag{5}$$

where C_{mw} is the mutual capacitance with the intermediate line present, C_{mwo} is the mutual capacitance without the intermediate line present, and ε_w and ε_{wo} are the dielectric constants with and without the intermediate line present, respectively.

Notice that the equation does not directly depend on distance. This means that the calculated crosstalk between any two wires that have another wire in between must be divided by the factor above regardless of the relative position of the shielding wire.

III. CALCULATION VS. SIMULATION

When using equations to calculate the crosstalk values, the worst case must be assumed. The worst case is that all induced crosstalk pulses overlap. However, this is not always the case. Figure 2 shows one common situation where the crosstalk pulses may not overlap. The uncoupled region of net 1 creates a temporal space between the two pulses associated with the two coupled regions. A crosstalk pulse induced on net 1 must travel through the uncoupled region while the crosstalk pulse in the second region is being induced. The gap between the two pulses increases linearly with the length of the uncoupled region. Therefore, the crosstalk induced between net 1 and net 4 may actually be less than the equations predict.

Simulation accounts for these temporal spaces caused by uncoupled regions. This is why it is important to simulate designs. Without accounting for these temporal spaces, it is impractical to use a more complex crosstalk model than the one described here.

IV. RESULTS

The first test was to compare the calculation's crosstalk values with ContecSPICE's values for small test cases. These test cases were created manually to represent net configurations commonly seen in typical designs. Two of these test cases are shown in Figure 4.

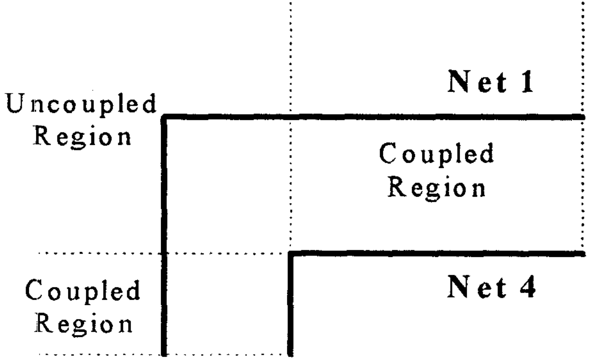
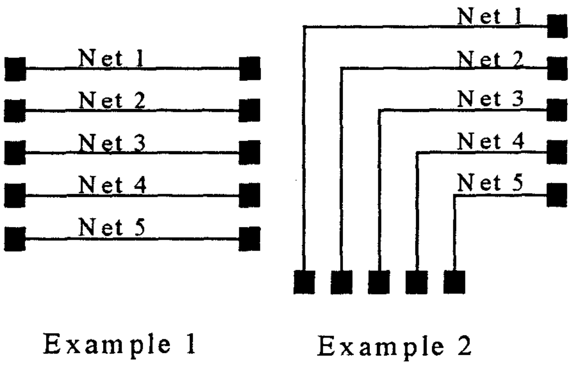


Figure 3. Uncoupled Portion of Nets.



Example 1 Example 2

Figure 4. Examples for Crosstalk Calculations.

A small sample of the results for example 1 and example 2 are in Table 1 and Table 2 (values are in volts). Each example was run many times varying which nets were present and the lengths. These tables show that the crosstalk calculations are quite accurate. These results also verify the model used for shielding effects. They are certainly accurate enough to use as a first estimate until the design is simulated. In many cases, these calculations are accurate enough to stand alone. The data in these tables also show that the calculations generally miss on the conservative side of the true crosstalk value. Notice that the larger errors occur in example 2 on net 1 when net 2 is not present. This is caused by the temporal spaces discussed earlier.

The next step in comparing simulation to calculation was to test the code on an actual design. Figure 6 shows the crosstalk estimates for a 4-chip design (provided by the Mayo Foundation) versus the values from ContecSPICE. The chart shows that the calculations are conservative (higher than actual). On some nets, the calculations estimate the crosstalk to be approximately double that of the ContecSPICE value. Since Table 1 shows

Table 1. Results from Example 1.

	ContecSPICE	Calc	% Difference
Net 1	0.04426	0.04558	3.0
Net 2	0.08323	0.08635	3.7
Net 3	0.08538	0.08892	4.1
Net 4	0.08323	0.08635	3.7
Net 5	0.04426	0.04558	3.0
Net 1	0.00804	0.00849	5.6
Net 3	0.05007	0.05184	3.5
Net 4	0.08102	0.08266	2.0
Net 5	0.04381	0.04446	1.5
Net 1	0.04199	0.04189	-0.2
Net 2	0.04814	0.04927	2.3
Net 4	0.04814	0.04927	2.3
Net 5	0.04199	0.04189	-0.2
Net 1	0.00217	0.00223	2.8
Net 4	0.04241	0.04300	1.4
Net 5	0.0411	0.04077	-0.8

Table 2. Results from Example 2.

	ContecSPICE	Calc	% Difference
Net 1	0.04574	0.04649	1.6
Net 2	0.08251	0.08380	1.6
Net 3	0.07679	0.07769	1.2
Net 4	0.06626	0.06708	1.2
Net 5	0.03265	0.03297	1.0
Net 1	0.00738	0.00801	8.5
Net 3	0.04299	0.04341	1.0
Net 4	0.06437	0.06394	-0.7
Net 5	0.03232	0.03214	-0.6
Net 1	0.04347	0.04297	-1.2
Net 2	0.04833	0.04913	1.7
Net 4	0.03637	0.03662	0.7
Net 5	0.03100	0.03022	-2.5
Net 1	0.00172	0.00190	10.5
Net 4	0.03159	0.03129	-0.9
Net 5	0.03040	0.02939	-3.3

that the calculations are accurate for straight wires, this error, for the most part, is due to the irregular shapes of the nets and the effects of the temporal spaces. The potential for overestimating crosstalk increases with the irregularity of the shape of the net.

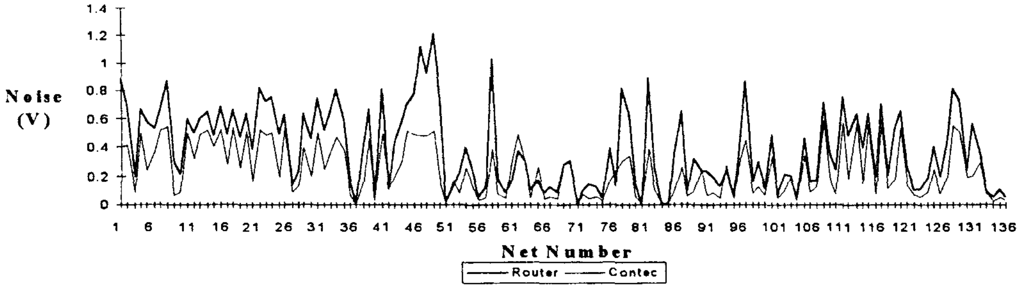


Figure 5. Crosstalk Model VS. ContecSPICE.

V. CONCLUSIONS

This crosstalk model appears to be as accurate as practical without accounting for the temporal spaces created from the bends in nets. MCM design examples provided to date have validated the accuracy of the model and demonstrated the need of including coupling from non-neighboring wires. The data indicates that any significant increase in the accuracy of the noise calculations will be in the form of a simulator, because the actual timing of the noise pulses plays a crucial part in the actual noise induced in a net.

VI. REFERENCES

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[2] Sakurai, T. and K. Tamaru. "Simple Formulas for Two- and Three-Dimensional Capacitances." In Stuart K. Tewksbury, editor. Microelectronics System Interconnections: Performance and Modeling. New York: IEEE Press, 1994.

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