Modified Physical Configuration to Compensate Parasitic Effects in High Speed Systems
Saad Bin Abul Kashem¹, Salahuddin Raju², and Md Ishfaqur Raza³

¹,³Department of Electrical and Electronic Engineering.
East-West University, Bangladesh
²Department of Electrical and Electronic Engineering.
American International University-Bangladesh, Bangladesh
E-mail: ²raju@aiub.edu, ³iraza@ewubd.edu

Abstract – With systems operating at higher frequencies, parasitic effects are taking larger shares of the voltage and timing budget of a circuit. Also smaller devices have shrunken landscape for components, increasing coupling between critical physical features. These undesired loading on otherwise uniform transmission lines introduce impedance discontinuities which degrades signal quality and strains the performance metrics. This paper introduces a concept of compensating coupling effects by modifying transmission line physical characteristics. The modification in the line dimensions is calibrated to compensate the lumped equivalent of the coupling effect. High speed system spice simulation and S-parameter analysis has demonstrated the effectiveness of this methodology.

I. Introduction
The effect of parasitics in the performance of a circuit is a function of the frequency content of the signals in the system. With microwave circuits operating at GHz frequencies and the evolution of typical circuit applications into GHz ranges, the management of the impact of parasitic effect is vital to the efficient operations of these circuits. Size of circuits is also decreasing rapidly resulting in very close proximity of components in a circuit. Busy board layouts force the placements of vital traces next to pins, solder balls, and vias [1]. In a much smaller landscape, as in nanometre scale integrated circuits, with decreasing sizes of transistors, increased number of devices in a chip, and lower power supply voltage, the issue of coupling becomes more acute. Due to smaller dimensions and crowded landscape, metal in VLSI circuits are placed closer, increasing capacitive coupling. This results in the inevitable coupling between metal layers, wires, and vias.

With the power supply decreasing, the budget of the device that is attributed to coupling noise is shrinking. Overall, the effect of coupling is set to grow precipitously with advances in board and circuits designs. Often architects and designers provide and follow guidelines designed to reduce coupling effects. However, too often, physical constraints make it impossible to follow those design rules. These constraints, such as pin pitch and wire pitch are not negotiable and hence, coupling and crosstalk become unavoidable, straining on the budget of the circuit and the device, penalizing performance of the circuit [2].

The impact of coupling to a transmission line is the change in the characteristic impedance of the transmission line. The discontinuity in the impedance is due to the increase in reactive loading of the line at the point of cross coupling between the line and the parasitic component. The increased reactive loading changes the transmission line impedance at the coupling point. This issue is typically tackled with design rules that require minimum separation between lines and components. Some designs require select material, such as low-k dielectric in higher metal layers in VLSI designs to reduce coupling coefficient between lines.

Fig. 1. T model representation of a transmission line

This paper presents a concept to compensate the impact of coupling by modifying transmission line physical design. Spice modelling of a transmission line system along with s-parameter analyses is done to demonstrate the compensation technique.

II. Compensation Technique
In engineering analysis at radio and microwave frequencies, a transmission line is defined by the telegrapher’s equation instead of circuit theory, as the component dimensions become comparable to signal wavelength. With frequencies in the range of 0.1-10 GHz, typical components lengths that can be considered to be lumped will be no longer then several millimetres long. Fig. 1 shows the pi model representation of a segment of a transmission line [3].
The characteristic impedance is a function of the resistance \( R \), inductance \( L \), conductance \( G \), and capacitance \( C \), all in per unit length values. At high frequencies, both the resistive and conductive element is neglected as those parameters are negligible compared to the reactive elements. The impedance is written as,

\[
Z = \frac{R + jwL}{G + jwC} = \frac{L}{C}
\]

The characteristic impedance of a segment of the transmission line considered as a lumped element is defined by the inductance \( L_{\text{line}} \) and capacitance \( C_{\text{line}} \) of that segment.

\[
Z_{\text{unpl}} = \sqrt{\frac{L_{\text{line}}}{C_{\text{line}}}}
\]

When the line is placed close to a device or component, the coupling component \( C_{\text{coup}} \) is introduced, which is in this case capacitive. The impedance of the segment \( Z_{\text{total}} \) of the line will be reduced because of the increased capacitance \( C_{\text{total}} \), which is equal to \( C_{\text{line}} + C_{\text{coup}} \).

\[
C_{\text{total}} = C_{\text{line}} + C_{\text{coup}}
\]

\[
L_{\text{coup}} = L_{\text{line}}
\]

\[
Z_{\text{total}} = \sqrt{\frac{L_{\text{line}}}{C_{\text{total}}}}
\]

\[
Z_{\text{total}} = \sqrt{\frac{L_{\text{line}}}{C_{\text{line}} + C_{\text{coup}}}}
\]

In this paper, a compensation technique is introduced where the line capacitance is reduced to compensate for the coupled capacitance. With the reduced line capacitance, the total capacitance will now equal the initial line capacitance. The overall impedance of that segment of the transmission line will be corrected and thus discontinuity removed.

### III. Transmission Line Analysis

Consider a differential strip line, which is built of two parallel and equally spaced lines, both of uniform width and cross section. It is assumed that one of the lines is adjacent to a pin which has resulted in coupling between one of the differential line and the pin.
Table 1: Characteristic parameters of a micro strip line

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dielectric Constant Er</td>
<td>4.4</td>
</tr>
<tr>
<td>Dielectric Thickness (mils) H</td>
<td>6.0</td>
</tr>
<tr>
<td>Trace Width (mils) W</td>
<td>9.0</td>
</tr>
<tr>
<td>Trace Spacing (mils) S</td>
<td>8.0</td>
</tr>
<tr>
<td>Finished Copper Weight (mils) T</td>
<td>1.4</td>
</tr>
<tr>
<td>Impedance Zo (Ohms)</td>
<td>51.56</td>
</tr>
<tr>
<td>Inductance/Inch Lo (nH/in)</td>
<td>7.244</td>
</tr>
<tr>
<td>Capacitance/Inch Co (pF/in)</td>
<td>2.725</td>
</tr>
<tr>
<td>Propagation Delay Tpd (nS/in)</td>
<td>0.1406</td>
</tr>
</tbody>
</table>

Fig. 5. Transmission line frequency response (modified trace width = 5 mil, reduced from 9 mil)

In this experiment, a 0.220 pF capacitance is coupled to the transmission line. The effect of the parasitic is demonstrated in both Fig. 5 and 6. The S11, reflection parameter at port is calculated in the simulation and illustrated. It is seen that across the large bandwidth (0-30 GHz), S11 is consistently below 20 dB, which is a rather well matched transmission line. With the coupling included the S11 is severely degraded (closer to 0dB). At higher frequencies, around 5 GHz, the S11 has increased to -10dB, indicating significant reflection and impedance mismatch due to the impedance discontinuity.

Compensation technique is then used to demonstrate the proposed concept. Two cases where the trace width at the coupled segment is reduced to 5 and 6 mils are presented here. At 5 mils width, it is calculated that the reduction in the trace capacitance is similar to the amount of coupling capacitance added to the segment. With the compensation added, in Fig. 5, the S11 parameter accounting for reflection at the coupled segment has significantly improved up to 8 GHz, where S11 has dropped by about 12 dB when comparing with the coupled data. This demonstrates the effectiveness of the proposed scheme. The analysis is done again with a trace width of 6 mil. The result is shown in Fig. 6.

Fig. 6. Transmission line frequency response (modified trace = 6 mil)

It is shown that the S11 parameter is improved from the coupled case, reducing by about 5 dB. This demonstrates the need to calculate the added capacitance and how the transmission line segment should be modified to compensate the coupled effect, as shown in Fig. 7. For this analysis, the capacitance and inductance of the micro strip is calculated using the following equations, which states the per unit length capacitance of transmission line, $C_o = \frac{0.67(e_r + 1.41)}{\ln\left(\frac{5.98H}{0.8W + T}\right)}$.

V. Time Domain Simulation

The impact of impedance discontinuity is observed in the form of degraded signal integrity in a high speed system. The degradation of the signal quality translates in to smaller eye opening, which results in higher bit error rates in data transmissions. The discontinuity results in both reduced transmitted signal and greater reflections back to the source.
The reflections not only translate into higher standing wave ratio and losses, but also intersymbol interference, where reflection from a symbol or data affects the reliability of later data symbols. Degraded transmission translates into reduced signal swings at the receiver which will result in the receiver recording erroneous data.

In this simulation analysis, a strip line transmission line system is modeled (as shown in Fig. 8). The system is driven by a differential signal. In this case, a via was placed outside the differential line pair. The coupling thus only affects one of the wires in the differential line. To avoid complexity, the coupling capacitance between via and adjacent trace of via is considered at the center point of the trace segment. The coupled capacitance is calculated considering the interface between the trace and via and using the equation, where A is the area of the interface and d is the gap (a crude approximation),

\[ C_0 = \frac{eA}{d} \]

The model that was used in the simulation are defined by parameters in Table 2. The impedance, capacitance, and inductance of the differential strip line are given by

\[
Z_o = \frac{60 \ln \left( \frac{1.9(2H + T)}{0.8W + T} \right)}{\sqrt{\varepsilon_r}}
\]

\[
C_0 = \frac{1.41\varepsilon_r}{\ln \left( \frac{3.81H}{0.8W + T} \right)}
\]

\[
L_0 = 0.001C_0 Z_o^2
\]

\[
Z_{\text{diff}} = 2Z_o \left( 1 - 0.347e^{-\frac{2.9S}{W}} \right)
\]

The result of the time-domain signal integrity analysis is shown in Fig. 9. The waveform in this data is observed before the coupled segment, which highlights the effect of coupling on the reflection coefficient, instead of transmission coefficient. As can be seen in the signal data swing, the best coupling compensation is achieved with the 5 mil trace. It should be noted that without compensation the effect of reflection reduces the signal strength, which is due to the negative reflection coefficient, as a result of impedance being lower then the characteristic impedance. The impedance is lower due to the increase in overall capacitance of the segment with the addition of the coupled capacitance.

VI. Conclusion and Future Work

The data has shown very conclusively the benefit of transmission line modifications to compensate the effect of parasitic capacitance. It is also observed that the advantages are bandwidth constrained. For the dimensions discussed in this paper, the proposed methodology is good up to frequencies around 12 GHz. It can be further improved if the interface between the coupling feature and the transmission line is minimized. The application of this methodology should be considered for inclusion into CAD tools where designers would automatically modify transmission line definitions to compensate for coupling. For future work, the methodology should be demonstrated in the lab. The proposed should also be extended to microwave design where susceptibility to impedance discontinuity is more significant.

References


