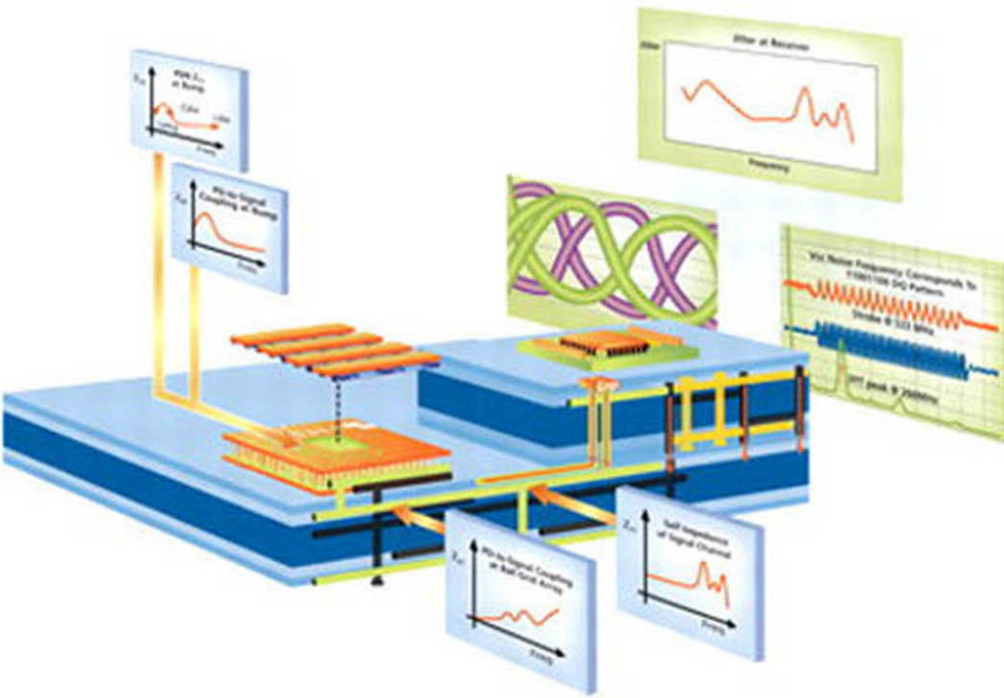
Power Integrity for I/O Interfaces:

With Signal Integrity/Power Integrity Co-Design



Foreword by Joungho Kim

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Modern Semiconductor Design Series
Signal Integrity Library

Power Integrity for I/O Interfaces

With Signal Integrity/ Power Integrity Co-Design

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$$\varepsilon_{re} = 1 + \frac{\varepsilon_r - 1}{2} \frac{K(k')}{K(k)} \frac{K(k_1)}{K(k_1')} \tag{4.32}$$

k=a/b, and, $k' = \sqrt{1-k^2}$

$$k = \sinh\left(\frac{\pi a}{2h}\right) / \sinh\left(\frac{\pi b}{2h}\right), \text{ and, } k_1' = \sqrt{1-k_1^{\,2}}$$

4.4.1.4 Coupled Lines

For a differential I/O interface, two coupled lines are used from transmitter to receiver. The coupling between two lines is more dependent on the distance between the two lines than other geometrical parameters. For a situation where the reference plane is far away, the coupling between the two lines is stronger than that between the signal line and reference ground. Figure 4.32 shows a coupled microstrip line [37].

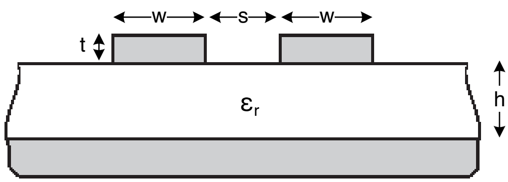

Figure 4.32 Coupled microstrip line

The following equations for the quasistatic solutions provide accuracy within 1% in the rage of parameters 0.1≤u≤10, 0.1≤g≤10, and 1≤ ε_r ≤18. The even mode effective dielectric constant is given by

$$\varepsilon_{ree}(0) = 0.5(\varepsilon_r + 1) + 0.5(\varepsilon_r - 1)\cdot(1 + 10/v)^{-a_e(v)\cdot b_e(\varepsilon_r)} \tag{4.33}$$

where

$$v = u(20 + g^2)/(10 + g^2) + g \cdot \exp(-g) \tag{4.34}$$

$$a_e(v) = 1 + \ln\left(\left(v^4 + (v/52)^2\right)/\left(v^4 + 0.432\right)\right)/49 + \ln\left(1 + (v/18.1)^3\right)/18.7 \quad (4.35)$$

$$b_e(\varepsilon_r) = 0.564\left((\varepsilon_r - 0.9)/(\varepsilon_r + 3)\right)^{0.053} \quad (4.36)$$

$$u = W/h,\ g = S/h$$

The quasistatic odd-mode effective dielectric constant for an infinitesimally thin conductor is similarly given by

$$\varepsilon_{reo}(0) = \left[0.5(\varepsilon_r + 1) + a_0(u, \varepsilon_r) - \varepsilon_{re}(0)\right] \cdot \exp\left(-c_0 g^{d_0}\right) + \varepsilon_{re}(0) \quad (4.37)$$

where

$$a_0(u, \varepsilon_r) = 0.7287\left(\varepsilon_{re}(0) - 0.5(\varepsilon_r + 1)\right) \cdot \left(1 - \exp(-0.179u)\right) \quad (4.38)$$

$$b_0(\varepsilon_r) = 0.747\varepsilon_r / (0.15 + \varepsilon_r) \quad (4.39)$$

$$c_0 = b_0(\varepsilon_r) - \left(b_0(\varepsilon_r) - 0.207\right) \cdot \exp(-0.414u) \quad (4.40)$$

$$d_0 = 0.593 + 0.694 \cdot \exp(-0.562u) \quad (4.41)$$

Here, $\varepsilon_{re}(0)$ denotes the effective dielectric constant of a single microstrip with width *W*.

The quasistatic even-mode characteristic impedance of coupled microstrip lines is given by

$$Z_{0e}(0) = Z_0\sqrt{\frac{\varepsilon_{re}(0)}{\varepsilon_{ree}(0)}}\frac{1}{\left(1 - \left(Z_0(0)/377\right)\left(\varepsilon_{re}(0)\right)^{0.5} Q_4\right)} \quad (4.42)$$

where

$$Q_1 = 0.8695 \cdot u^{0.194} \tag{4.43}$$

$$Q_2 = 1 + 0.7519g + 0.189 \cdot g^{2.31} \tag{4.44}$$

$$Q_3 = 0.1975 + \left(16.6 + \left(8.4 / g\right)^6\right)^{-0.387} + \ln\left(g^{10} / \left(1 + \left(g / 3.4\right)^{10}\right)\right) / 241 \tag{4.45}$$

$$Q_4 = \left(2Q_1 / Q_2\right) \cdot \left(\exp\left(-g\right) \cdot u^{Q_3} + \left(2 - \exp\left(-g\right)\right) \cdot u^{-Q_3}\right)^{-1} \tag{4.46}$$

The quasistatic odd-mode characteristic impedance of coupled microstrip lines is given by

$$Z_{0o}(0) = Z_0 \sqrt{\frac{\varepsilon_{re}\left(0\right)}{\varepsilon_{reo}\left(0\right)}} \frac{1}{\left(1 - \left(Z_0\left(0\right) / 377\right)\left(\varepsilon_{re}\left(0\right)\right)^{0.5} Q_{10}\right)} \tag{4.47}$$

where

$$Q_5 = 1.794 + 1.14 \cdot \ln\left(1 + 0.638 / \left(g + 0.517g^{2.43}\right)\right) \tag{4.48}$$

$$Q_6 = 0.2305 + \ln\left(g^{10} / \left(1 + \left(g / 5.8\right)^{10}\right)\right) / 281.3 + \ln\left(1 + 0.598g^{1.154}\right) / 5.1 \tag{4.49}$$

$$Q_7 = \left(10 + 190g^2\right) / \left(1 + 82.3g^3\right) \tag{4.50}$$

$$Q_8 = \exp\left(-6.5 - 0.95\ln\left(g\right) - \left(g / 0.15\right)^5\right) \tag{4.51}$$

$$Q_9 = \ln\left(Q_7\right) \cdot \left(Q_8 + 1 / 16.5\right) \tag{4.52}$$

$$Q_{10} = Q_2^{-1} \cdot \left(Q_2 Q_4 - Q_5 \cdot \exp\left(\ln\left(u\right) \cdot Q_6 \cdot u^{-Q_9}\right)\right) \tag{4.53}$$

Here, the odd-mode parameters are less sensitive to frequency variation than the even-mode parameters, and characteristic impedance is less sensitive to frequency variation than effective dielectric constant. Differential signaling also suffers some amount of dispersion as in single-ended signaling. Figure 4.33 shows the frequency-dependent behavior of even and odd-mode dielectric constants and characteristic impedance. This phenomenon serves as a cause of mode conversion in differential signaling.

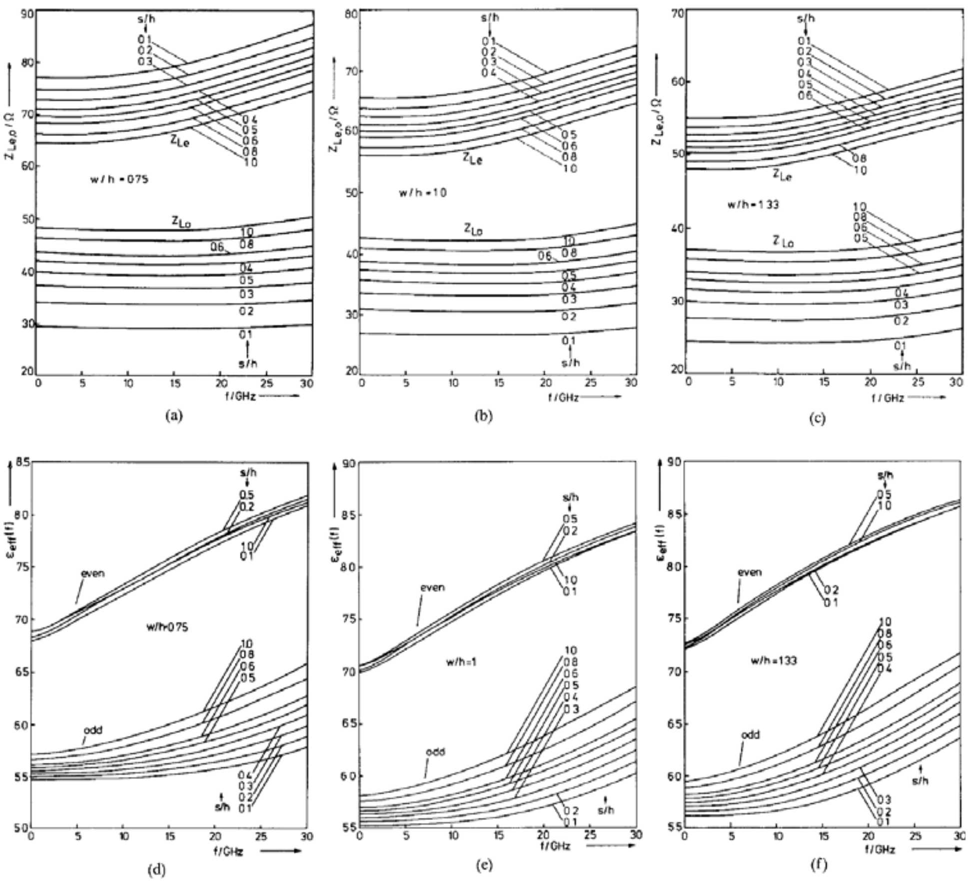

Figure 4.33 The frequency dependent even- and odd-mode effective dielectric constants and characteristic impedances of coupled microstrip lines on a ceramic substrate (alumina, er=9.70, h=0.64mm). (a), (d) w/h=0.75. (b), (e) w/h=1.0. (c), (f) w/h=1.33.

Source: M. Kirschning, and R.H. Jansen, "Accurate Wide-Range Design Equations for the Frequency-Dependent Characteristic of Parallel Coupled Microstrip Lines," Microwave Theory and Techniques, IEEE Transactions on Volume 32, Issue 1, Jan 1984 pp 83–90 © [1984] IEEE.

Figures 4.34 and 4.35 show two types of coupled striplines. In the first type, the two lines are on the same plane. In the second type, they are in a different plane. This type is also known as broadside stripline. The choices of stripline depend on the application and signal integrity requirements. To match the propagation delay, care has to be taken to route the two coupled lines in an identical fashion. Even with this routing, there may be skew between the two broadside coupled lines because of the manufacturing difference between the dielectric constant of different layers, especially at higher speeds.

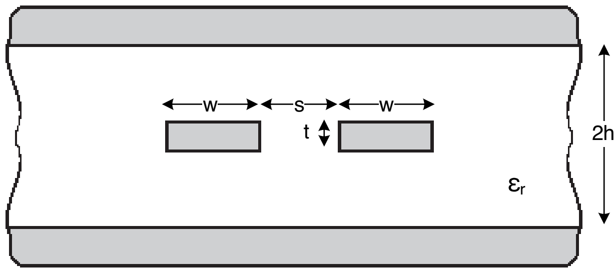

Figure 4.34 Coupled stripline

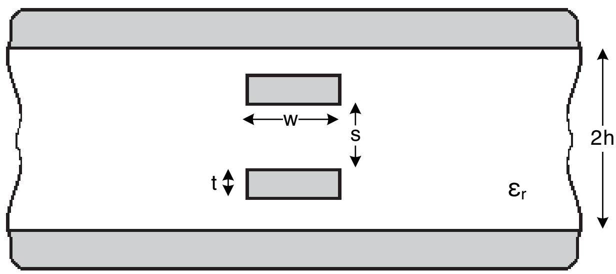

Figure 4.35 Coupled stripline—broadside

The solutions of the above equations for microstrip line, stripline, and coupled line are closer to the TEM approximation. In other words, we can easily predict the characteristic constants of the uniform TEM transmission lines using a 2-D EM modeler. Using a 3-D full-wave EM field solver, however, electromagnetic interference (EMI) and interconnects coupling (signal-to-signal & power-to-signal)—due to discontinuous reference for the IO signaling interfaces—are predicted and analyzed.

4.4.2 Package Signal Distribution Network

Package signal distribution provides signal routes from on-die circuits to the socket or PCB. With increasing speed, smaller size, and cost-saving features, package signal routing occupies a bigger portion in the entire system budget. Especially, mobile devices with higher integration use more of the packaging features to increase its efficiencies in power and device density. Formerly ignored delay and dispersion characteristics should be fully optimized to achieve maximum performance with given materials. Figure 4.36 shows an example of the assembly of different components from die to PCB level.

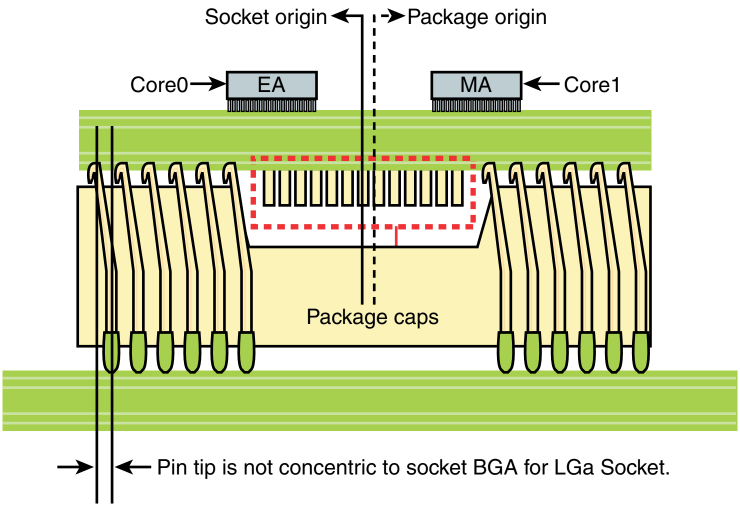

Figure 4.36 Cross-sectional view of core, package, socket, and PCB

Sources: M. Manusharow, A. Hasan, T.W. Chao, and M. Guzy, "Dual die Pentium D package technology development," Electronic Components and Technology Conference, 2006. Proceedings. 56th, pp 7. © [2006] IEEE.

Figure 4.37 shows an example of transmission line routing on a package. Even though package signal distribution follows the same configurations as in a PCB, smaller dimensions and tolerance should be carefully considered.

For the microstrip implementation on a package, due to routing constraints not all signals can land on the top layer. Therefore some signals may land on internal layers and be routed for a small distance before they can come back on the top layer. The microstrip implementation is typically single referenced. For a single-referenced implementation, the power or ground reference is maintained on all the