$$k_9 = \frac{2.0\sqrt{a\,b}}{a+b} \qquad (4.4.2.11)$$

$$k_8 = \frac{k_9}{\sqrt{1.0 - \frac{(b-a)^2}{(2.0\,c)^2}}} \qquad (4.4.2.12)$$

These equations assume loose coupling and that the substrate is infinitely thick.

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[1] Bandrand, H., *et al.*, "Bias-Variable Characteristics of Coupled Coplanar Waveguide on GaAs Substrate," *Electronics Letters*, Vol. 23, No. 4, February 13, 1987, pp. 171–172.

[2] Chang, Ching Ten, and Graham A. Garcia, "Crosstalk Between Two Coplanar Waveguides," *Archiv Für Elektronik und Übertragungstechnik*, Band 43, Heft 1, 1989, pp. 55–58.

[3] Ghione, Giovanni, and Carlo U. Naldi, "Coplanar Waveguides for MMIC Applications: Effect of Upper Shielding Conductor Backing, Finite-Extent Ground Planes, and Line-to-Line Coupling," *IEEE Transactions on Microwave Theory and Techniques*, Vol. MTT-35, No. 3, March 1987, pp. 260–267.

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4.4.3 Edge-Coupled CPWG

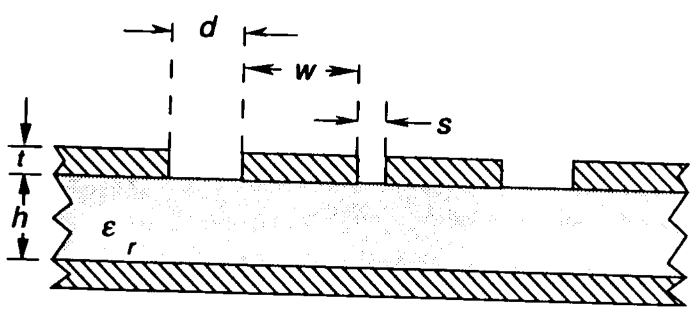

Figure 4.4.3.1: Edge-Coupled CPWG

$$Z_{0,o} = \frac{\eta_0}{\sqrt{\varepsilon_{eff,o}}}\left[\frac{1.0}{2.0\,\frac{K(k_o)}{K'(k_o)} + \frac{K(\beta_1)}{K'(\beta_1)}}\right] \quad (\Omega) \qquad (4.4.3.1)$$

$$Z_{0,e} = \frac{\eta_0}{\sqrt{\varepsilon_{eff,e}}}\left[\frac{1.0}{2.0\,\frac{K(k_e)}{K'(k_e)} + \frac{K(\beta_1 k_1)}{K'(\beta_1 k_1)}}\right] \quad (\Omega) \qquad (4.4.3.2)$$

$$\varepsilon_{eff,o} = \frac{2.0\,\varepsilon_r\,\frac{K(k_o)}{K'(k_o)} + \frac{K(\beta_1)}{K'(\beta_1)}}{2.0\,\frac{K(k_o)}{K'(k_o)} + \frac{K(\beta_1)}{K'(\beta_1)}} \qquad (4.4.3.3)$$

$$\varepsilon_{eff,e} = \frac{2.0\,\varepsilon_r\,\frac{K(k_e)}{K'(k_e)} + \frac{K(\beta_1 k_1)}{K'(\beta_1 k_1)}}{2.0\,\frac{K(k_e)}{K'(k_e)} + \frac{K(\beta_1 k_1)}{K'(\beta_1 k_1)}} \qquad (4.4.3.4)$$

where

$$k_o = \Lambda\,\frac{-\sqrt{\Lambda^2 - t_c^2} + \sqrt{\Lambda^2 - t_B^2}}{t_B\sqrt{\Lambda^2 - t_c^2} + t_c\sqrt{\Lambda^2 - t_B^2}} \qquad (4.4.3.5)$$

$$k_e = \Lambda'\,\frac{-\sqrt{\Lambda'^2 - t'^2_c} + \sqrt{\Lambda'^2 - t'^2_B}}{t'_B\sqrt{\Lambda'^2 - t'^2_c} + t'_c\sqrt{\Lambda'^2 - t'^2_B}} \qquad (4.4.3.6)$$

$$\Lambda = \frac{\sinh^2\left[\frac{\pi\,(s\,/\,2.0 + w + d)}{2.0\,h}\right]}{2} \qquad (4.4.3.7)$$

$$t_c = \sinh^2\left[\frac{\pi\,(s\,/\,2.0 + w)}{2.0\,h}\right] - \Lambda \qquad (4.4.3.8)$$

$$t_B = \sinh^2\left(\frac{\pi\,s}{4.0\,h}\right) - \Lambda \qquad (4.4.3.9)$$

$$\Lambda' = \frac{\cosh^2\left[\dfrac{\pi\,(s\,/\,2.0 + w + d)}{2.0\,h}\right]}{2.0} \qquad (4.4.3.10)$$

$$t'_C = \sinh^2\left[\frac{\pi\,(s\,/\,2.0 + w)}{2.0\,h}\right] - \Lambda' + 1.0 \qquad (4.4.3.11)$$

$$t'_B = \sinh^2\left[\frac{\pi\,s}{4.0\,h}\right] - \Lambda' + 1.0 \qquad (4.4.3.12)$$

To guarantee coplanar propagation,

$$s + 2.0\,w + 2.0\,d \le h.$$

The analysis is a conformal mapping technique, so the equations are exact for low frequency calculation.

REFERENCES

[1] Chang, Ching Ten, and Graham A. Garcia, "Crosstalk Between Two Coplanar Waveguides," *Archiv Für Elektronik und Übertragungstechnik*, Band 43, Heft 1, 1989, pp. 55–58. (Edge-coupled CPW's separated by ground plane.)

[2] Hanna, Victor Fouad, "Parameters of Coplanar Directional Couplers with Lower Ground Plane," *15th European Microwave Conference Proceedings*, 1985, pp. 820–825. ([2] dropped primes in (8), corrected here.)

4.5 COUPLED MICROSTRIP LINES

4.5.1 Edge-Coupled Microstrip Lines

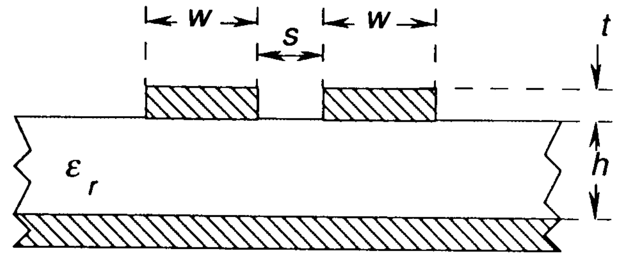

Figure 4.5.1.1: Coupled Microstrip Line

Kirschning and Jansen [8] analyzed this structure with a rigorous spectral-domain hybrid mode calculation. The results of this were then fit numerically. These equations are:

$$Z_{0,e}(0) = \frac{Z_0(0)\sqrt{\dfrac{\varepsilon_{eff}(0)}{\varepsilon_{eff,e}(0)}}}{1.0 - \dfrac{Z_0(0)}{\eta_0}\sqrt{\varepsilon_{eff}(0)}\,Q_4} \qquad (4.5.1.1)$$

$$Z_{0,o}(0) = \frac{Z_0(0)\sqrt{\dfrac{\varepsilon_{eff}(0)}{\varepsilon_{eff,o}(0)}}}{1.0 - \dfrac{Z_0(0)}{\eta_0}\sqrt{\varepsilon_{eff}(0)}\,Q_{10}} \qquad (4.5.1.2)$$

where $Z_0(0)$ is the zero-frequency impedance of a single, isolated strip (3.5.1.1) and

$$Q_1 = 0.8695\,u^{\,0.194} \qquad (4.5.1.3)$$

$$Q_2 = 1.0 + 0.7519\,g + 0.189\,g^{\,2.31} \qquad (4.5.1.4)$$

$$Q_3 = 0.1975 + \left[16.6 + (8.4\,/\,g)^{6.0}\right]^{-0.387} + \frac{\ln\left[\dfrac{g^{10}}{1.0 + (g\,/\,3.4)^{10}}\right]}{241} \qquad (4.5.1.5)$$