

Basic Interconnects at High Frequencies

(Part 2)

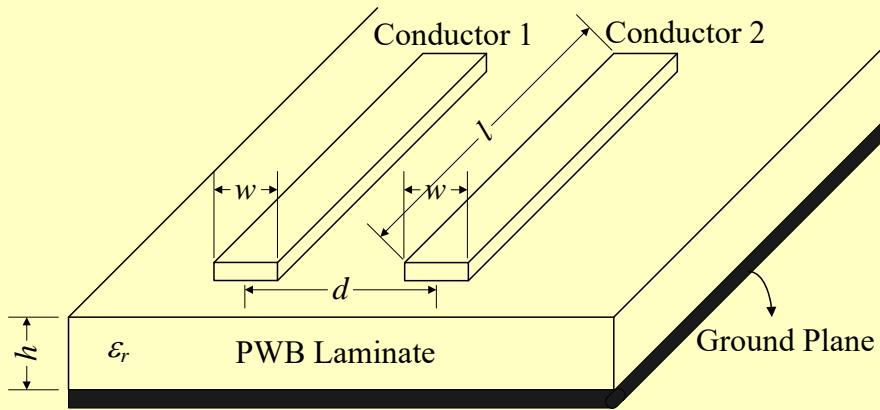
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Outline

- Walker's formulae for 2-coupled microstrip lines
- Variation of the LC-parameters with the separation of the lines
- Variation of Z_o with the separation of the lines
- Variation of v_p with the separation of the lines
- Conclusions

Two-Coupled Microstrip Lines

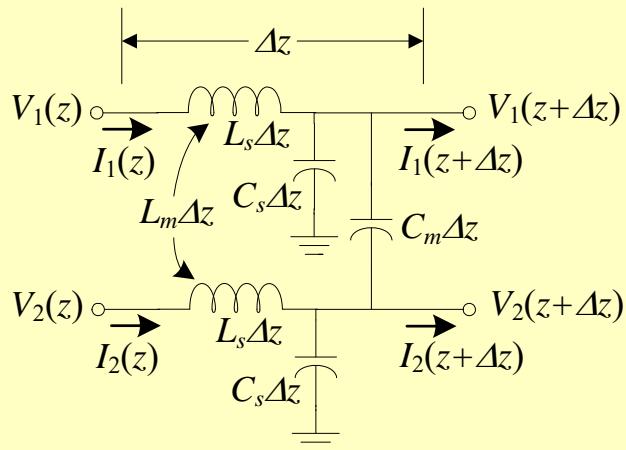


In the following analysis, we neglect the thickness of each conductor and the losses

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Lossless Transmission Line Model



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Z_o and v_p for Even and Odd Modes

- If Z_o is the characteristic impedance of each isolated conductor, and v_p is the propagation velocity or wave speed in each isolated conductor

$$Z_o = \sqrt{\frac{L_s}{C_s}} \quad v_p = \frac{1}{\sqrt{L_s C_s}}$$

- Since

$$Z_{o-even} = \sqrt{\frac{L_s + L_m}{C_s}} \quad v_{p-even} = \frac{1}{\sqrt{(L_s + L_m)C_s}}$$

$$Z_{o-odd} = \sqrt{\frac{L_s - L_m}{C_s + 2C_m}} \quad v_{p-odd} = \frac{1}{\sqrt{(L_s - L_m)(C_s + 2C_m)}}$$

- then

$$Z_{o-odd} < Z_o < Z_{o-even} \quad v_{p-even} < v_{p-odd} < v_p$$

Walker's Formulae for L_s , C_s , L_m and C_m

$$C_s = \epsilon_r \epsilon_o K_C \left(\frac{w}{h} \right) \text{ F/m}$$

$$\epsilon_o = 8.854 \times 10^{-12} \text{ (F/m)}$$

$$\mu_o = 4\pi \times 10^{-7} \text{ (H/m)}$$

$$L_s = \frac{\mu_r \mu_o}{K_L} \left(\frac{h}{w} \right) \text{ H/m}$$

$$C_m = \frac{\epsilon_r \epsilon_o}{4\pi} K_C K_L \left(\frac{w}{h} \right)^2 \ln \left[1 + \left(\frac{2h}{d} \right)^2 \right] \text{ F/m}$$

$$L_m = \frac{\mu_r \mu_o}{4\pi} \ln \left[1 + \left(\frac{2h}{d} \right)^2 \right] \text{ H/m}$$

where K_C and K_L are the fringing factors given by ...

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Walker's Formulae (cont.)

$$K_C = \left[\frac{120\pi}{Z_{o(\varepsilon_r=1)}} \left(\frac{h}{w} \right) \sqrt{\frac{\varepsilon_e}{K_L \varepsilon_r}} \right]^2 \quad K_L = \frac{120\pi}{Z_{o(\varepsilon_r=1)}} \left(\frac{h}{w} \right)$$

where

$$\varepsilon_e = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \frac{1}{\sqrt{1 + 10h/w}}$$

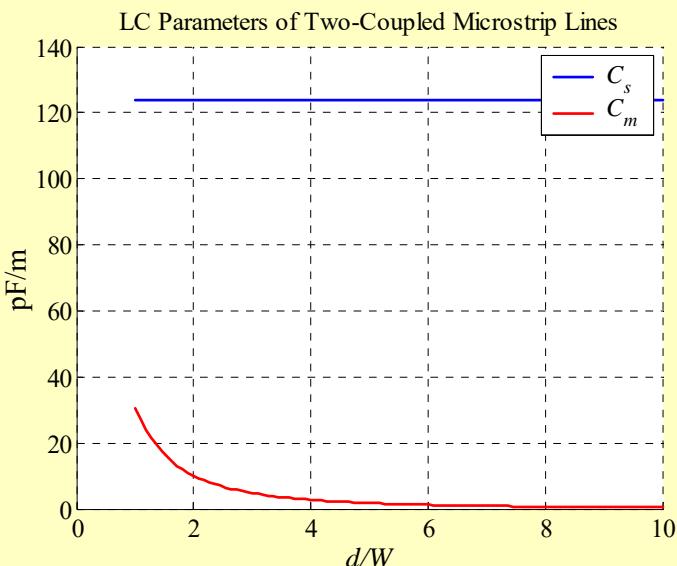
$$\text{if } \frac{w}{h} \leq 1, \quad Z_{o(\varepsilon_r=1)} = 60 \ln \left(\frac{8h}{w} + \frac{w}{4h} \right) \Omega$$

$$\text{if } \frac{w}{h} \geq 1, \quad Z_{o(\varepsilon_r=1)} = \frac{120\pi}{\left(\frac{w}{h} \right) + 2.42 - 0.44 \left(\frac{h}{w} \right) + \left(1 - \frac{h}{w} \right)^6} \Omega$$

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(C.S. Walker, *Capacitance, Inductance and Crosstalk Analysis*; Artech House, 1990) 7

Variation of Capacitances – Example



$W = 74.65\text{mil}; H = 40\text{mil}; \varepsilon_r = 4.5$

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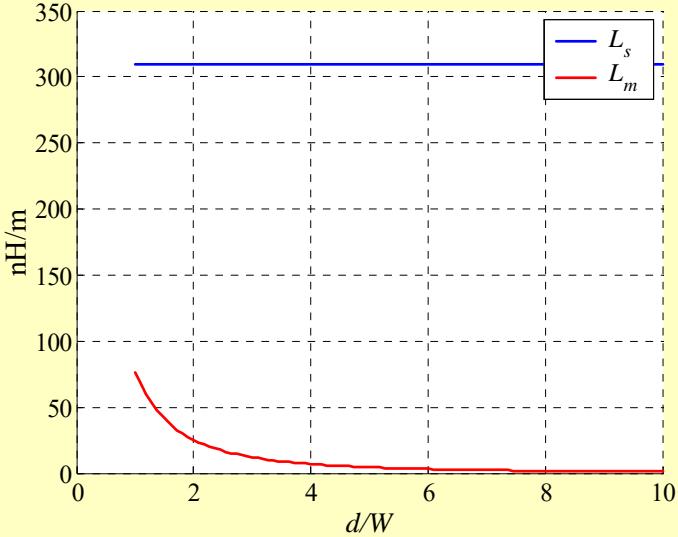
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Variation of Inductances – Example

LC Parameters of Two-Coupled Microstrip Lines



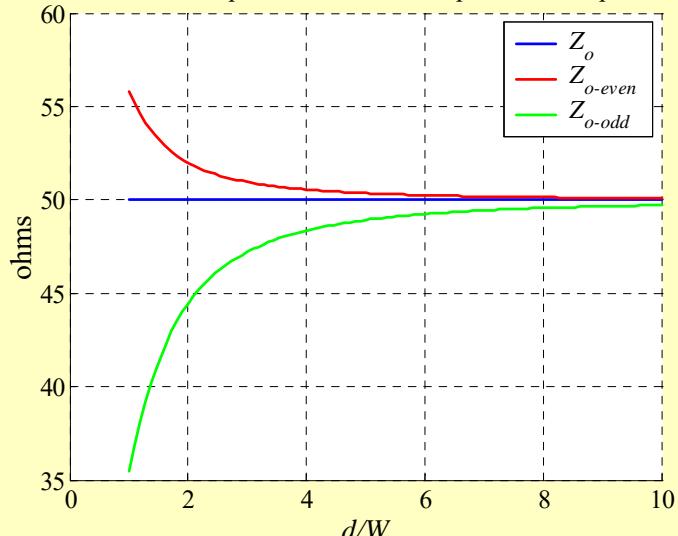
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$W = 74.65\text{mil}$; $H = 40\text{mil}$; $\epsilon_r = 4.5$

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Variation of Z_o for Even and Odd Modes

Characteristic Impedance for Two-Coupled Microstrip Lines



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$W = 74.65\text{mil}$; $H = 40\text{mil}$; $\epsilon_r = 4.5$

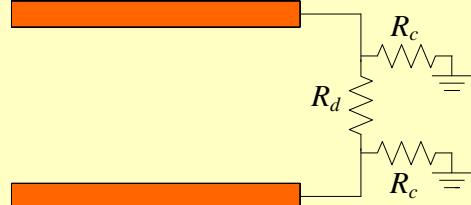
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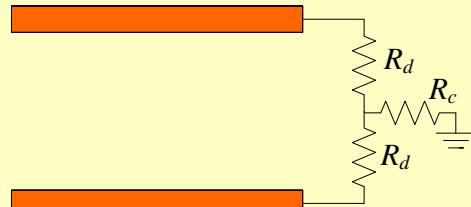
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Differential Terminations



$$R_c = Z_{o-even}$$

$$R_d = \frac{2Z_{o-even}Z_{o-odd}}{Z_{o-even} - Z_{o-odd}}$$



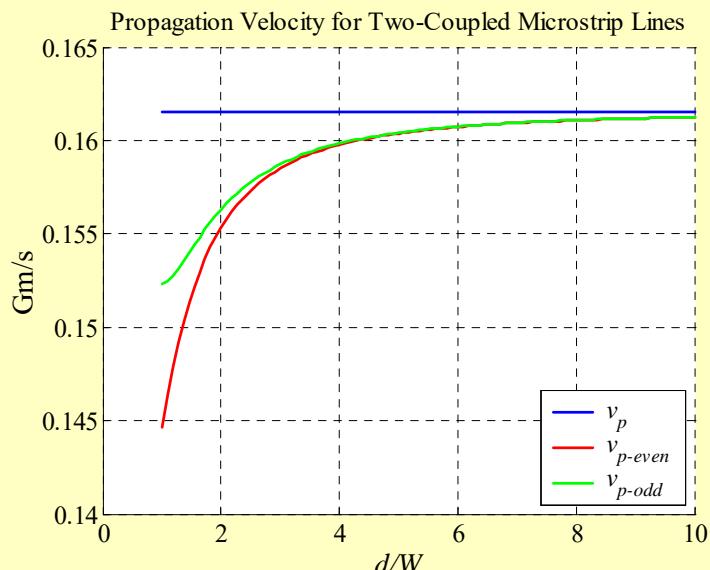
$$R_c = \frac{1}{2}(Z_{o-even} - Z_{o-odd})$$

$$R_d = Z_{o-odd}$$

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Variation of v_p for Even and Odd Modes



$W = 74.65\text{mil}; H = 40\text{mil}; \epsilon_r = 4.5$

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Conclusions

- It has been verified that

$$Z_{o-odd} < Z_o < Z_{o-even} \quad v_{p-even} < v_{p-odd} < v_p$$

- If the coupled lines are very separated (large d)

$$C_m, L_m \rightarrow 0 \quad Z_{o-odd}, Z_{o-even} \rightarrow Z_o \quad v_{p-odd}, v_{p-even} \rightarrow v_p$$