ENEE 381 Problem Set #5 continued
Solutions. Worked out using Mathcad

(8) Enter stripline parameters

$d := 10^{-4}$ spacing

$w := 5\cdot 10^{-3}$ width

$\varepsilon_1 := 4$ $\tan\delta := 0.02$ $\tan\delta = \varepsilon 11/\varepsilon 1$

$\varepsilon_{11} := \varepsilon_1 \cdot \tan\delta$

$\varepsilon_{11} = 0.08$ Note that $\varepsilon 11 << \varepsilon 1$

$\sigma := 10^7$ conductivity

$c_0 := 2.998\cdot 10^8$ velocity of light in a vacuum

$\varepsilon_0 := 8.854 \times 10^{-12}$

$\mu_0 := 4\cdot\pi\cdot 10^{-7}$

$Z_0 := 376.7$ characteristic impedance of free space

$\nu := 10^9$ Pick a reasonable high frequency for the calculation

$\delta := \frac{1}{\sqrt{\pi\cdot\nu\cdot\mu_0\cdot\sigma}}$ skin depth

$\delta = 5.03292 \times 10^{-6}$

$R_s := \frac{1}{\sigma\cdot\delta}$ $R_s = 0.01987$ surface resistance

$R := \frac{R_s}{w}\cdot 2$ Resistance per unit length

$C := \varepsilon_0\cdot\varepsilon_1\cdot\frac{w}{d}$ capacitance per unit length

$C = 1.7708 \times 10^{-9}$

$L := \mu_0\cdot\frac{d}{w}$ $L = 2.51327 \times 10^{-8}$ inductance per unit length

$\varepsilon_{11} = \frac{\sigma_d}{\omega\cdot\varepsilon_0}$ gives equivalent conductivity of dielectric

$\sigma_d := 2\cdot\pi\,\nu\cdot\varepsilon_0\cdot\varepsilon_{11}$ $\sigma_d = 4.45051 \times 10^{-3}$

$$R_p := \frac{d}{\sigma_d \cdot w}$$ parallel leakage resistance of line

$$R_p = 4.49387$$

$$G := \frac{1}{R_p}$$

$$Z := \sqrt{\frac{L}{C}}$$ characteristic impedance of line

$$Z = 3.76734$$

Note that we get the same answer from

$$\frac{Z_0}{\sqrt{\varepsilon_1}} \cdot \frac{d}{w} = 3.767$$

From Eq.(5.22)

$$\alpha := \frac{1}{2} \cdot \left(G \cdot Z + \frac{R}{Z} \right)$$

$\alpha = 1.47398$ units of m^{-1} includes both conductor and dielectric loss

Alternative solution

conductor attenuation Eq.(8.5.7)

$$\alpha_c := \frac{R_s \cdot \sqrt{\varepsilon_1}}{Z_0 \cdot d}$$ $\alpha_c = 1.05491$

Dielectric loss Eq.(8.5.2)

$$\alpha_d := \left[\frac{\left(2 \cdot \pi \cdot \nu \cdot \sqrt{\mu_0 \cdot \varepsilon_0 \cdot \varepsilon_1} \right)}{2} \right] \cdot \frac{\varepsilon_{11}}{\varepsilon_1}$$

$$\alpha_d = 0.41916$$

$\alpha_c + \alpha_d = 1.47407$ Same answer as before

(9) $d := 10^{-2}$ thickness $\varepsilon_r := 8$

$$\lambda_0 := \frac{c_0}{3\cdot 10^9}$$

$\lambda_0 = 0.09993$

$$\theta_2(\theta) := \operatorname{asin}\left(\frac{\sin(\theta)}{\sqrt{\varepsilon_r}}\right) \qquad \frac{\theta_2(30\cdot \mathrm{deg})}{\mathrm{deg}} = 10.18207$$

angle of refraction at 30 degrees

$$k2d(\theta) := 2\cdot\frac{\pi}{\lambda_0}\cdot\sqrt{\varepsilon_r}\cdot\cos(\theta_2(\theta))\cdot d$$

effective phase shift through slab

Calculate impedance of TE waves at angle of incidence θ

$$Z1S(\theta) := \frac{376.7}{\cos(\theta)} \qquad Z2S(\theta) := \frac{376.7}{\sqrt{\varepsilon_r}\cdot\cos(\theta_2(\theta))}$$

$Z3S(\theta) := Z1S(\theta)$ $\quad Z1S(0) = 376.7$ $\quad Z2S(0) = 133.18356$

Generalized transformed impedance for a TE wave at angle of incidence θ

$$Z3S11(\theta) := Z2S(\theta)\cdot\frac{(Z3S(\theta)\cdot\cos(k2d(\theta)) + i\cdot Z2S(\theta)\cdot\sin(k2d(\theta)))}{Z2S(\theta)\cdot\cos(k2d(\theta)) + i\cdot Z3S(\theta)\cdot\sin(k2d(\theta))}$$

$Z3S11(0) = 48.90437 + 24.40417i$

$Z3S11(30\cdot \mathrm{deg}) = 43.34279 + 22.11111i$

$$\rho_0 := \frac{Z3S11(0) - Z1S(0)}{Z3S11(0) + Z1S(0)}$$

zero degrees incidence

$\rho_0 = -0.76439 + 0.10117i$

$T := 1 - (|\rho_0|)^2$

$T = 0.40548$ Fraction through

$$\rho_{30} := \frac{Z3S11(30\cdot \mathrm{deg}) - Z1S(30\cdot \mathrm{deg})}{Z3S11(30\cdot \mathrm{deg}) + Z1S(30\cdot \mathrm{deg})}$$

$\rho_{30} = -0.81489 + 0.0839i$

$T := 1 - (|\rho_{30}|)^2$

$T = 0.32891$ Fraction through at 30 degrees

(10) Generalized transmission line problems

$C1 := 100 \cdot 10^{-12}$ $L1 := 10 \cdot 10^{-6}$ $C2 := 200 \cdot 10^{-12}$ $L2 := 15 \cdot 10^{-6}$

$\omega c1 := \sqrt{\frac{1}{L1 \cdot C1}}$ $\omega c2 := \sqrt{\frac{1}{L2 \cdot C2}}$ cutoff frequencies

$\omega c1 = 3.16228 \times 10^{7}$ $\omega c2 = 1.82574 \times 10^{7}$

$i := 1, 2 .. 1000$ Running integer to give different frequencies on plots

Use designations 1 for the low frequency band, 2 for the middle band, 3 for the high frequency band

$\omega_i := i \cdot \frac{5 \cdot 10^8}{1000}$ $\omega 1_i := i \cdot \frac{\omega c2}{1001}$ $\omega 2_i := \omega c2 + i \cdot \frac{(\omega c1 - \omega c2)}{1001}$ $\omega 3_i := \omega c1 + i \cdot \frac{\omega c1}{1001}$

In a pass band γ is imaginary, in a stop band it is real

(a) SERIES L1
SHUNT L2 and C2 in series

$$Y_i := \frac{1}{i \cdot \omega_i \cdot L2 + \frac{1}{i \cdot \omega_i \cdot C2}}$$

$$Z_i := i \cdot \omega_i \cdot L1$$

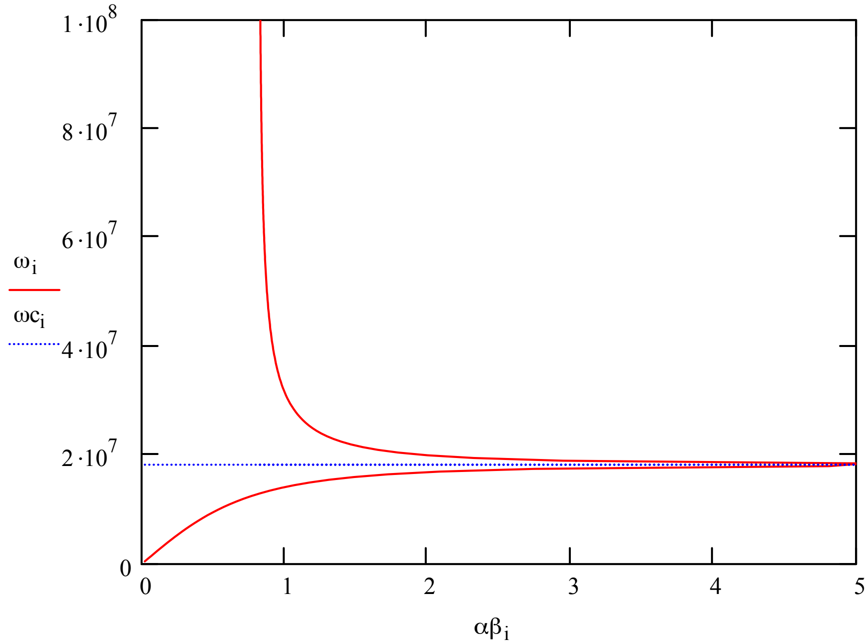
$$\gamma_i := \sqrt{i \cdot \omega_i \cdot L1 \cdot \frac{1}{i \cdot \omega_i \cdot L2 + \frac{1}{i \cdot \omega_i \cdot C2}}} \qquad \omega c := \frac{1}{\sqrt{L2 \cdot C2}}$$

$$\gamma_i := i \cdot \omega_i \cdot \sqrt{L1 \cdot C2} \cdot \sqrt{\frac{1}{1 - \frac{(\omega_i)^2}{\omega c^2}}}$$

For $\omega < \omega c1$ there is a passband
for $\omega > \omega c1$ there is a stopband

$\alpha\beta_i := \text{if}(\omega_i < \omega c, \text{Im}(\gamma_i), -\text{Re}(\gamma_i))$ Plots both α in the stopband and β in the passband

$\omega c_i := \omega c$ Draws the horizontal line at $\omega c1$



Note that the pass band is in the bottom, and the stop band in the top of the graph.
The α is symptotic to a value

$$\alpha_{asymptotic} := \omega c \cdot \sqrt{L1 \cdot C2}$$

(b) SERIES L1 and C1 in parallel

SHUNT L2 and C2 in parallel

$$Z_i := \frac{1}{i \cdot \omega_i \cdot C1 + \frac{1}{i \cdot \omega_i \cdot L1}} \qquad Y_i := i \cdot \omega_i \cdot C2 + \frac{1}{i \cdot \omega_i L2}$$

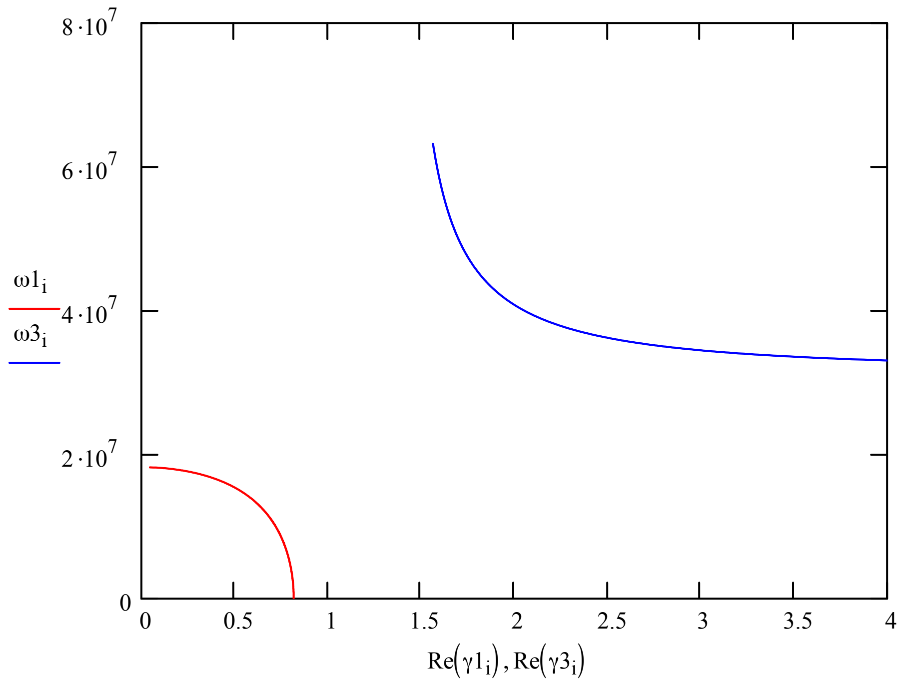
$$Z1_i := \frac{1}{i \cdot \omega 1_i \cdot C1 + \frac{1}{i \cdot \omega 1_i \cdot L1}} \quad Y1_i := i \cdot \omega 1_i \cdot C2 + \frac{1}{i \cdot \omega 1_i L2}$$

$$Z2_i := \frac{1}{i \cdot \omega 2_i \cdot C1 + \frac{1}{i \cdot \omega 2_i \cdot L1}} \quad Y2_i := i \cdot \omega 2_i \cdot C2 + \frac{1}{i \cdot \omega 2_i L2}$$

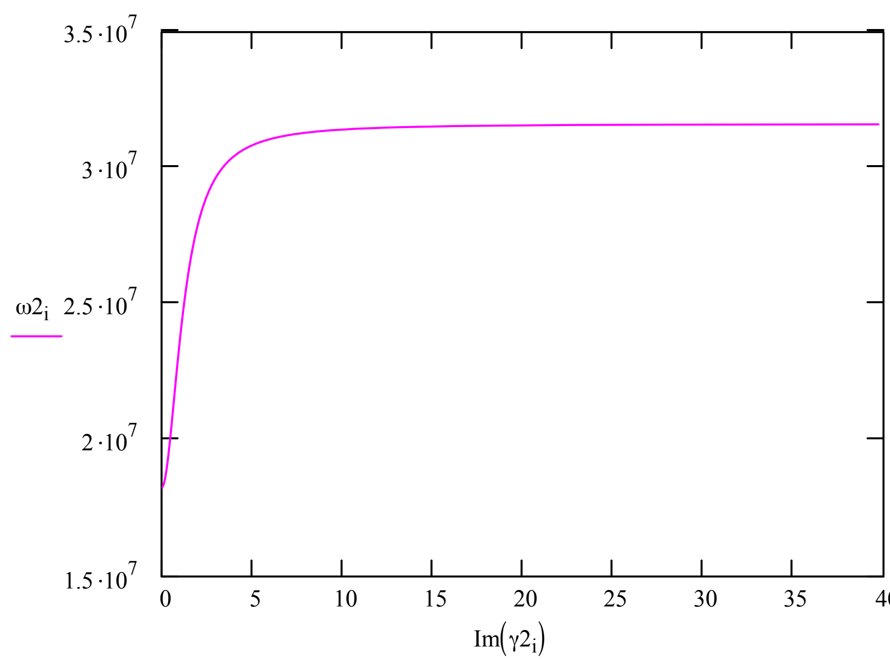
$$Z3_i := \frac{1}{i \cdot \omega 3_i \cdot C1 + \frac{1}{i \cdot \omega 3_i \cdot L1}} \quad Y3_i := i \cdot \omega 3_i \cdot C2 + \frac{1}{i \cdot \omega 3_i L2}$$

$\gamma_i := \sqrt{Z_i \cdot Y_i}$ $\quad \gamma1_i := \sqrt{Z1_i \cdot Y1_i}$ $\quad \gamma2_i := \sqrt{Z2_i \cdot Y2_i}$ $\quad \gamma3_i := \sqrt{Z3_i \cdot Y3_i}$

alpha in the stop bands



beta in the pass band



(c) SERIES L1 and C1 in series

SHUNT L2 and C2 in parallel

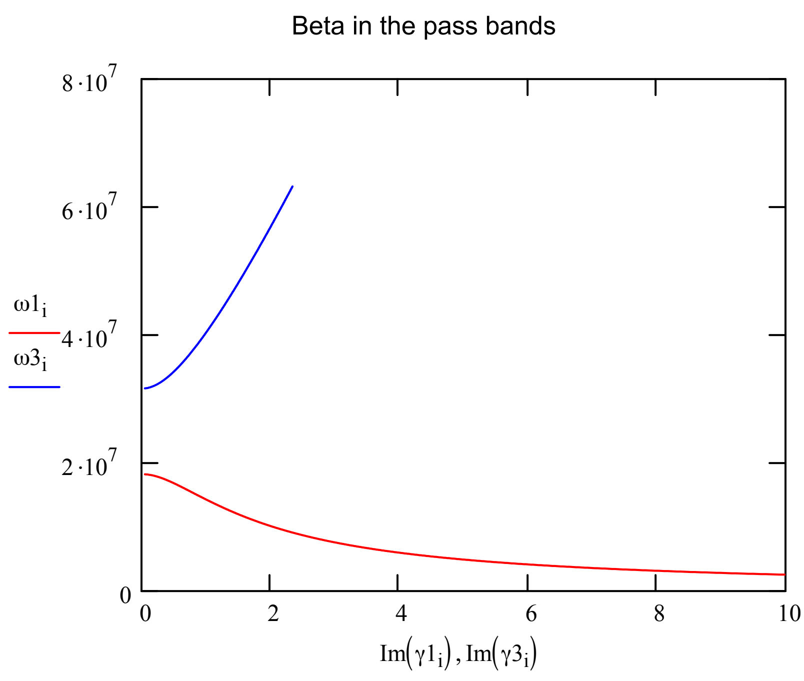
$$Z_i := i\cdot\omega_i L1 + \frac{1}{i\cdot\omega_i\cdot C1} \qquad Y_i := (i\cdot\omega_i\cdot C2) + \frac{1}{i\cdot\omega_i\cdot L2}$$

$$Z1_i := i\cdot\omega 1_i L1 + \frac{1}{i\cdot\omega 1_i\cdot C1} \qquad Y1_i := (i\cdot\omega 1_i\cdot C2) + \frac{1}{i\cdot\omega 1_i\cdot L2}$$

$$Z2_i := i\cdot\omega 2_i L1 + \frac{1}{i\cdot\omega 2_i\cdot C1} \qquad Y2_i := (i\cdot\omega 2_i\cdot C2) + \frac{1}{i\cdot\omega 2_i\cdot L2}$$

$$Z3_i := i\cdot\omega 3_i L1 + \frac{1}{i\cdot\omega 3_i\cdot C1} \qquad Y3_i := (i\cdot\omega 3_i\cdot C2) + \frac{1}{i\cdot\omega 3_i\cdot L2}$$

$$\gamma_i := \sqrt{Z_i\cdot Y_i} \qquad \gamma 1_i := \sqrt{Z1_i\cdot Y1_i} \qquad \gamma 2_i := \sqrt{Z2_i\cdot Y2_i} \qquad \gamma 3_i := \sqrt{Z3_i\cdot Y3_i}$$



Alpha in the stop band