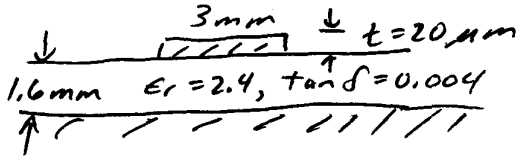
A microstrip TL is made using a gold ($\sigma = 4 \times 10^7$ S/m) land that is 3 mm wide and 20 μm thick on a 1.6 mm thick dielectric substrate ($\varepsilon_r = 2.4$, $\tan\delta = 0.004$) with a 2 oz. copper ground plane for operation at 5 GHz. For this microstrip, find the: a) effective relative permittivity, b) phase velocity, c) phase constant, d) characteristic impedance, and e) overall attenuation constant (Np/m & dB/m).

$d = 1.6\,mm$, $W = 3\,mm$



a) Per (3.195), $\epsilon_{re} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\frac{1}{\sqrt{1+12\,d/w}}$

$\epsilon_{re} = \frac{2.4+1}{2} + \frac{2.4-1}{2}\frac{1}{\sqrt{1+12(1.6/3)}} \Rightarrow \underline{\epsilon_{re} = 1.9573}$

b) Per (3.193), $v_p = \frac{c}{\sqrt{\epsilon_{re}}} = \frac{2.9979\times10^8}{\sqrt{1.9573}} \Rightarrow \underline{v_p = 2.143\times10^8\,m/s}$

c) Per (3.194), $\beta = \omega\sqrt{\mu_0\epsilon_{re}\epsilon_0} = \frac{\omega}{v_p} = \frac{2\pi(5\times10^9)}{2.143\times10^8} \Rightarrow \underline{\beta = 146.609\,\frac{rad}{m}}$

d) $w/d = \frac{3}{1.6} = 1.875 > 1 \Rightarrow$ Use second (3.196) eq'n

$$Z_0 = \frac{120\pi}{\sqrt{\epsilon_{re}}\left[w/d + 1.393 + 0.667\ln(w/d + 1.44)\right]}$$

$$= \frac{120\pi}{\sqrt{1.9573}\left[1.875 + 1.393 + 0.667\ln(1.875+1.44)\right]} \Rightarrow \underline{Z_0 = 66.25\,\Omega}$$

e) $k_0 = \omega/c = \frac{2\pi\,5\times10^9}{2.9979\times10^8} = 104.79225\ rad/m$

Per (3.198), $\alpha_d = \frac{k_0\epsilon_r(\epsilon_{re}-1)\tan\delta}{2\sqrt{\epsilon_{re}}(\epsilon_r-1)} = \frac{104.79(2.4)(1.9573-1)0.004}{2\sqrt{1.9573}(2.4-1)}$

$\alpha_d = 0.24585\ Np/m$

$R_s = \sqrt{\frac{\omega\mu_0}{2\sigma}} = \sqrt{\frac{2\pi(5\times10^9)4\pi\times10^{-7}}{2(4\times10^7)}} = 0.02221\,\Omega$

(3.199) $\alpha_c = \frac{R_s}{Z_0 w} = \frac{0.02221}{66.25(0.003)} = 0.11177\ Np/m$

$\alpha = \alpha_c + \alpha_d = 0.11177 + 0.24585 \Rightarrow \underline{\alpha = 0.3576\,\frac{Np}{m} = 3.106\,\frac{dB}{m}}$