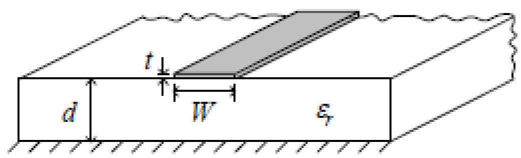
# PLANAR TRANSMISSION LINES

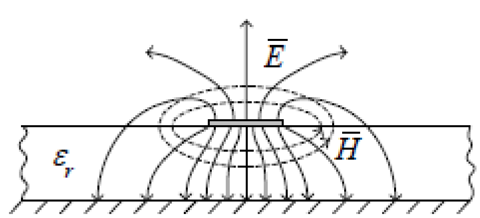
Definition: A planar TL is a TL with conducting metal strips that lie entirely in parallel planes. The most common structure is one or more parallel metal strips placed on a dielectric substrate material adjacent to a conducting ground plane. A planar TL that is widely used is the microstip line.




It consists of a single conducting strip of width $W$ placed on a dielectric substrate of thickness $d$ and located on a ground plane.

## MICROSTRIP TRANSMISSION LINE

In a microstrip TL the dielectric material does not completely surround the metallic strip and hence the fundamental mode of propagation is not a pure TEM mode. At low frequencies, typically a few gigahertzes, for practical microstip lines, $E_z$ and $H_z$ have far smaller amplitudes than the corresponding transverse components. So, the mode is a quasi-TEM mode.



In most practical applications, the dielectric substrate is electrically very thin $(d << \lambda)$, and so the fields are quasi-TEM. In other words, the fields are essentially the same as those of the static case.

Quasi – TEM Approximation (Low frequency approximation)

1) Pozar's Approximation

   The phase velocity and the propagation constant can be expressed as:

   $v_p = \frac{c}{\sqrt{\varepsilon_e}}$, $\beta = k_0\sqrt{\varepsilon_e}$ where

   $\varepsilon_e$ = effective dielectric constant of the microstip line and

   $1 < \varepsilon_e < \varepsilon_r$

   $$\varepsilon_e = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \cdot \frac{1}{\sqrt{1 + 12\frac{d}{w}}}$$

The characteristic impedance:

$$Z_0 = \begin{cases} \frac{60}{\sqrt{\varepsilon_e}} \ln\left(\frac{8d}{w} + \frac{w}{4d}\right) & for\ \frac{w}{d} \le 1 \\ \frac{120\pi}{\sqrt{\varepsilon_e}\left[\frac{w}{d} + 1.393 + 0.667\ln(\frac{w}{d} + 1.444)\right]} & for\ \frac{w}{d} \ge 1 \end{cases}$$

For a given $Z_0$ and $\varepsilon_r$, the $\frac{w}{d}$ ratio can be found from:

$$\frac{w}{d} = \begin{cases} \dfrac{8e^A}{e^{2A} - 2}, & \text{for } \dfrac{w}{d} < 2 \\ \dfrac{2}{\pi}\left[ B - 1 - \ln(2B-1) + \dfrac{\varepsilon_r - 1}{2\varepsilon_r}\left\{ \ln(B-1) + 0.39 - \dfrac{0.61}{\varepsilon_r} \right\} \right], & \text{for } \dfrac{w}{d} > 2 \end{cases}$$

Where

$$A = \frac{Z_0}{60}\sqrt{\frac{\varepsilon_r + 1}{2}} + \frac{\varepsilon_r - 1}{\varepsilon_r + 1}\left( 0.23 + \frac{0.11}{\varepsilon_r} \right)$$

$$B = \frac{377\pi}{2Z_0\sqrt{\varepsilon_r}}$$

The attenuation can be calculated from:

$$\alpha_d = \frac{k_0 \varepsilon_r (\varepsilon_e - 1)}{2\sqrt{\varepsilon_e}(\varepsilon_r - 1)} \tan\delta \quad (Np/m)$$

$$\alpha_c = \frac{R_s}{Z_0 w} \quad (Np/m)$$

2) Collin's Approximation

$$\varepsilon_e = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left( 1 + \frac{12d}{w} \right)^{-1/2} + F(\varepsilon_r, d) - 0.217(\varepsilon_r - 1)\frac{t}{\sqrt{wd}}$$

Where

$$F(\varepsilon_r, d) = \begin{cases} 0.02(\varepsilon_r - 1)\left(1 - \frac{w}{d}\right)^2 & for\ \frac{w}{d} < 1 \\ 0 & for\ \frac{w}{d} > 1 \end{cases}$$

$$Z_0 = \left(\frac{\varepsilon_0 \mu_0}{\varepsilon_e}\right)^{1/2} \frac{1}{C_a}$$

$$C_a = \begin{cases} \dfrac{2\pi\varepsilon_0}{\ln\left(\dfrac{8d}{w} + \dfrac{w}{4d}\right)}, & \dfrac{w}{d} \le 1 \\ \varepsilon_0\left[\dfrac{w}{d} + 1.393 + 0.667\ln\left(\dfrac{w}{d}1.444\right)\right] & \dfrac{w}{d} > 1 \end{cases}$$

Example:

A microstrip line uses a substrate with $\varepsilon_r = 9.7$ (alumina) and $d = 0.5mm$. The strip width is $w = 0.5mm$. Find $\varepsilon_e, Z_0$ and the microstrip wavelength at $f = 2GHz$.

Solution:

<u>Pozar:</u>

$$\varepsilon_e = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \cdot \frac{1}{\sqrt{1 + 12\frac{d}{w}}}$$

$$\varepsilon_e = \frac{9.7+1}{2} + \frac{9.7-1}{2} . \frac{1}{\sqrt{1+12}} = 6.556$$

$$Z_0 = \frac{60}{\sqrt{\varepsilon_e}} \ln\left(\frac{8d}{w} + \frac{w}{4d}\right)$$

$$Z_0 = \frac{60}{\sqrt{6.556}} \ln\left(8 + \frac{1}{4}\right) = 49.449\Omega$$

$$\lambda = \frac{2\pi}{\beta} = \frac{2\pi}{k_0\sqrt{\varepsilon_e}} = \frac{\lambda_0}{\sqrt{\varepsilon_e}}$$

$$\lambda_0 = \frac{c}{f} = \frac{3X10^8}{2X10^9} = 15cm$$

$$\lambda = \frac{\lambda_0}{\sqrt{\varepsilon_e}} = \frac{15}{\sqrt{6.556}} = 5.858cm$$

Collin

Since $F(\varepsilon_r, d) = 0$, we have the same results.

Example:

Consider the microstip line in the above example. Assume $\tan\delta = 2X10^{-4}$ and $t = 0.02\,mm$. If $f = 4GHz$, calculate the total attenuation (assume copper).

Solution:

$$\varepsilon_e = 6.556,\ Z_0 = 49.449\Omega,\ \lambda_0 = 7.5cm$$

$$\alpha_d = \frac{\pi}{\lambda_0}\frac{\varepsilon_r}{\sqrt{\varepsilon_e}}\left(\frac{\varepsilon_e - 1}{\varepsilon_r - 1}\right)\tan\delta = \frac{\pi}{7.5}\frac{9.7}{\sqrt{6.556}}\left(\frac{6.556-1}{9.7-1}\right)2X10^{-4}$$

$$\alpha_d = 2.02X10^{-4}(Np/cm)$$

$$\alpha_c = \frac{R_s}{Z_0 w}$$

$$R_s = \sqrt{\frac{\omega\mu}{2\sigma}} = \sqrt{\frac{\pi f \mu_0}{\sigma}} = \sqrt{\frac{\pi X 4X10^9 X 4\pi X10^{-7}}{5.7X10^7}} = 16.64X10^{-3}\Omega$$

$$\alpha_c = \frac{16.64X10^{-3}}{49.449X0.5X10^{-3}} = 0.673\,Np/m = 67.3X10^{-4}(Np/cm)$$

$$\alpha = \alpha_c + \alpha_d = 69.32\,X10^{-4}(Np/cm)$$