2.1 1-D Waveguides: Striplines

This section calculates characteristics for a stripline, modeled as a one dimensional waveguide. Cutoff frequency, propagation constant, characteristic impedance and maximum average power are calculated. Alternately, you can find stripline dimensions that yield a given impedance and maximum transmitted power. The variables available for modification are:

- μ, the permeability of the substrate
- ε, the permittivity of the substrate
- **a** , the height of the substrate
- **w** , the width of the stripline
- **E0**, the breakdown electric field strength

Background

A stripline is a type of one-dimensional parallel plate waveguide commonly used to conduct signals in microwave integrated circuits. (All calculations refer to figure below.)

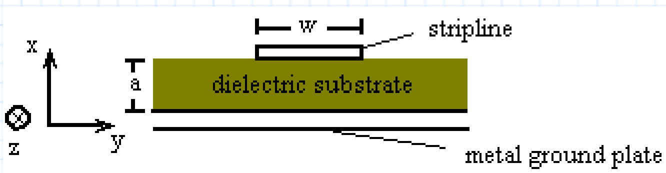

Fig 2.1.1 A stripline

Cutoff Frequencies

We are interested in waves propagating in the positive z-direction. The propagation constant, **kz**, for these waves obeys

$$k_z = \sqrt{\omega^2 \cdot \mu \cdot \varepsilon - k_x^2}$$

Under this definition, some values of **kz** will be imaginary, indicating that there will be a maximum wavelength, or minimum frequency which will propagate in the guide without decaying. This is known as the cutoff wavelength or frequency; there will be a different cutoff frequency for each transverse mode (**m**).

Valid Modes

The calculations for maximum transmitted power in this section refer only to the TM0 or TEM mode of propagation in a 1-D guide, in which the electric field is polarized in the x-direction only, and **m** = 0, so that any frequency may propagate in the guide.

Valid Dimensions

It is important to remember that the 1-D waveguide equations assume an infinite width in the y direction, and that this approximation is only good for striplines in which the dimension **w** exceeds **a** by some reasonable margin (>4 or 5 times). In such a case, the fringing fields at the edges of the stripline are negligible compared to the field strength over the width of the guide.

Mathcad Implementation

The equations that follow define propagation characteristics for a stripline.

$$\varepsilon 0_0 := 8.854 \cdot 10^{-12}\ \frac{F}{m} \qquad \mu 0_0 := 4 \cdot \pi \cdot 10^{-7}\ \frac{H}{m}$$

First, enter **substrate-dependent** values for the following constants:

$$\mu := 1.0 \cdot \mu 0_0 \qquad \varepsilon := 2.5 \cdot \varepsilon 0_0 \qquad E_0 := 1 \cdot 10^5\ V \cdot m^{-1}$$

E0 is the maximum electric field amplitude the stripline will withstand before the substrate breaks down. (The number shown has a safety margin of 10 built in.)

Enter the dimensions corresponding to the stripline, the mode number, and the operating frequency:

$$a := 0.1\ cm \qquad w := 0.4\ cm$$

$$\omega := 2 \cdot \pi \cdot 100\ GHz \qquad m := 1$$

Given these values, calculations for the intrinsic impedance, the propagation constant, and the cutoff frequency of the stripline are as follows:

$$\eta := \sqrt{\frac{\mu}{\varepsilon}} \qquad k_z := \sqrt{\left(\omega^2 \cdot \mu \cdot \varepsilon\right) - \left(\frac{m \cdot \pi}{a}\right)^2}$$

$$f_c := \frac{1}{2 \cdot a \cdot \sqrt{\mu \cdot \varepsilon}}$$

Example 2.1.1 Power and Impedance Given Dimensions

First find the characteristic impedance and the maximum average transmitted power for a TEM propagation mode. An analytical expression for power is derived by calculating the Poynting vector, and then integrating it over the cross section of the stripline.

$$Z_0(a,w) := \eta \cdot \frac{a}{w} \qquad P_{ave}(a,w) := \frac{{E_0}^2 \cdot a \cdot w}{2 \cdot \eta}$$

For this example, the characteristic impedance and average power are:

$$Z_0(a,w) = 59.567 \ \Omega$$

and

$$P_{ave}(a,w) = 83.939 \ W$$

To calculate power for a non-TEM case, Mathcad will readily perform the necessary functions to find a Poynting vector and do the numerical integration required. Just define the electric and magnetic field vectors as column matrices, and allow Mathcad to do the rest.

Finding Dimensions Given Power and Impedance

To solve for the stripline dimensions, given the characteristic impedance of the line, and the maximum average power, set **a** and **w** above to approximate values and use a **solve block** to find **a** and **w**.

Guess Values

$$a := .001 \cdot m \qquad w := .004 \cdot m$$

Constraints

$$Z_0(a,w) = 50 \ \Omega \qquad P_{ave}(a,w) = 2 \cdot 10^2 \ W$$

Solver

$$\begin{bmatrix} a \\ w \end{bmatrix} := \mathbf{Find}(a, w)$$

Yielding: $\begin{bmatrix} a \\ w \end{bmatrix} = \begin{bmatrix} 0.141 \\ 0.674 \end{bmatrix} cm$

Check that the value for **w** exceeds **a** by at least a factor of 4 or 5. This allows us to use the one-dimensional model.

Also, check the starting values:

$$Z_0(a,w) = 50 \ \Omega \qquad P_{ave}(a,w) = 200 \ W$$