

Transmission lines

Wavelength of EM waves in a vacuum

$$\lambda = \frac{c}{f}$$

where c is the speed of EM waves and f is the frequency.

Wavelength of EM waves in a medium

The speed of EM waves depends on the substrate material because it takes time for the charges in the substrate to align to the waves.

$$v = \frac{c}{\sqrt{\epsilon_r}}$$

$$\lambda = \frac{c}{f \sqrt{\epsilon_{eff}}}$$

If the length of an interconnect is greater than $\frac{1}{20}$ of the wavelength, RF behaviors must be considered.

Striplines and microstrips

Striplines are sandwiched between two copper reference planes.

Microstrips are placed above a copper reference plane and a dielectric.

Embedded microstrips are microstrips covered by a solder mask.

In a stripline, the fields exist between the stripline and the reference planes over and under the stripline. Therefore, the EM waves that travel along a stripline are TEM waves.

In a microstrip, the fields mostly exist between the strip and the reference plane below, but some of the fields fringe out into the air. Therefore, the waves are quasi-TEM waves.

Transmission lines

Transmission lines are designed to carry as much of the input power as possible to the load.

Characteristic impedance

$$Z_0 = \sqrt{\frac{R + j\omega L}{G + j\omega C}} \approx \sqrt{\frac{L}{C}}$$

where R is the resistance in series with the inductance L , and G is the conductance in series with the capacitance C .

Loss

$$\alpha_t = \alpha_c + \alpha_d + \alpha_r$$

where α_t is total loss, α_c is the conductor loss (due to resistance R), α_d is the dielectric loss (due to conductance G), and α_r is the radiation loss due to radiation propagating into space (in microstrips).

Loss parameters in stripline

$$\alpha_d = 27.3 \sqrt{\epsilon_r} \frac{\tan \delta}{\lambda} \quad \delta = D_f$$

References

- <https://www.youtube.com/watch?v=bVdwu1IoX4k>
- <https://www.youtube.com/watch?v=GuJVkZgAloI>

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