1.Introduction to Waveguide

1-1.Waveguide

(1)coaxial line

(2)metallic waveguide

(3)planar waveguide

- (a)strip line
- (b)micro-strip line
- (c)suspended strip line
- (d)co-planar line
- (e)slot line

Waveguide

1-1.Waveguide (-continued)

(4)dielectric waveguide

- (a)image line
- (b)NRD (Non-Radiated Dielectric) guide
- (c)dielectric rod waveguide
- (d)strip line
- (e)buried waveguide
- (f)strip-loaded waveguide
- (g)rib (ridge) waveguide
- (h)metal-cladded waveguide

Transmission line and waveguide

1-2. transmission line and waveguide

(1)for long distance transmission

(2)for constructing devices

required to be low loss

loss : conductor loss
dielectric loss,
radiation loss (scattering, bending)

Waveguide loss: conductor loss

1-3. Waveguide loss

(1)conductor loss

current density (conduction current): $I_c = \sigma E$

$$\nabla \times H = j\omega\varepsilon E + \sigma E \cong \sigma E$$

$$(\because \varepsilon_0 = 8.85 \times 10^{-12} F/m, \omega \approx 10^{10}, \sigma >> \omega\varepsilon)$$

$$\nabla \times \nabla \times E = -\nabla^2 E = -j\omega\mu \nabla \times H$$

$$\nabla^2 E = j\omega\mu(\sigma E)$$

$$\therefore \nabla^2 I_c = j\omega\mu\sigma(I_c)$$

Waveguide loss: conductor loss

current: z-direction (extends in y-z plane)

in a conductor region (x>0)

$$\partial / \partial y, \partial / \partial z << \partial / \partial x$$

$$I_c = I_0 \exp(-\sqrt{j\omega\mu\sigma}\,x) = I_0 \exp\left(-\sqrt{\frac{\omega\mu\sigma}{2}}(1+j)x\right) = I_0 \exp\left(-\frac{x}{d}(1+j)\right)$$

$$d = \sqrt{\frac{2}{\omega\mu\sigma}} = \frac{1}{\sqrt{\pi f \mu\sigma}} \qquad : skin-depth$$

power dissipation

in a sheet current of $\Delta x \times 1 \times 1$ ： $\left(|I_c|\Delta x\right)^2 \times \frac{1}{\sigma}\frac{1}{\Delta x}$

total power dissipation $P_c = \int_0^\infty \frac{1}{\sigma}|I_c|^2 dx = \frac{d}{2\sigma} I_0^2$

Surface resistance

$$I = \int_0^\infty I_c dx = \frac{d}{1+j} I_0$$

$$|I| = \frac{d}{\sqrt{2}} I_0$$

$$P_c = \frac{d}{2\sigma}\left(\frac{\sqrt{2}}{d}|I|\right)^2 = R_s|I|^2$$

$$R_s[\Omega]: \text{surface resistance} \propto \frac{1}{\sigma \mathrm{d}} = \sqrt{\frac{\pi \mathrm{f} \mu}{\sigma}}$$

ex. Cu : σ=5.65×10^7 (S/m) ---> d=0.67μm, R_s=26mΩ (@10GHz)

Ag(4N) : σ=6.14×10^7 (S/m)

Note that σ is temperature-dependent.

Waveguide loss: dielectric loss

(2)dielectric loss

$$\varepsilon_r = \varepsilon_r^{'} - j\varepsilon_r^{''}$$

$$\tan\delta = \frac{\varepsilon_r^{''}}{\varepsilon_r^{'}}$$

propagation constant

$$\Gamma = j\omega\sqrt{\varepsilon_0\mu_0}\sqrt{\varepsilon_r} = j\omega\sqrt{\varepsilon_0\mu_0}\sqrt{|\varepsilon_r|}e^{-j\delta/2}$$

$$= \omega\sqrt{\varepsilon_0\mu_0}\sqrt{|\varepsilon_r|}(j\cos\frac{\delta}{2} + \sin\frac{\delta}{2})$$

power carried by this electro-magnetic wave

$$\left|e^{-\Gamma z}\right|^2$$

attenuation constant

$$2\omega\sqrt{\varepsilon_0\mu_0}\sqrt{|\varepsilon_r|}\sin\frac{\delta}{2} \approx \omega\sqrt{\varepsilon_0\mu_0}\sqrt{|\varepsilon_r|}\delta = k_0\sqrt{|\varepsilon_r|}\delta$$

Waveguide loss: radiation loss

(3) radiation loss

(a)scattering loss due to waveguide inhomogeneity

(i) the boundary roughness

(ii)the inhomogeneity of material, etc…

(b)bending loss in the curved waveguide

conversion between guided and radiation mode