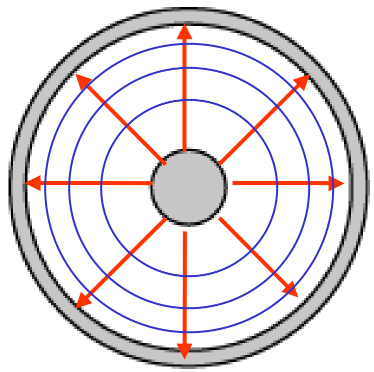
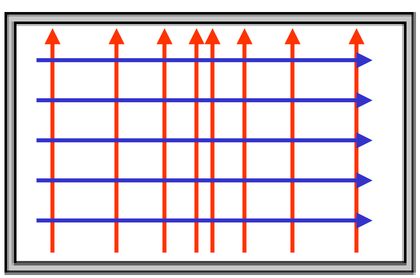
1.Introduction to Waveguide

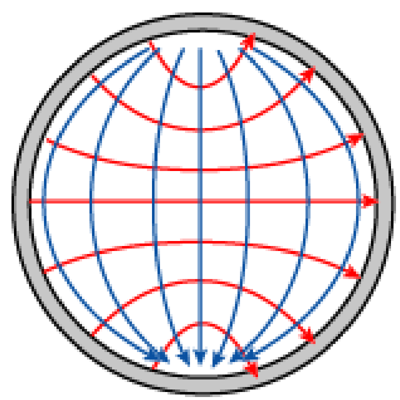
1-1.Waveguide

(1)coaxial line



(2)metallic waveguide

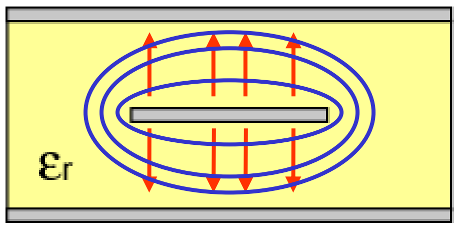




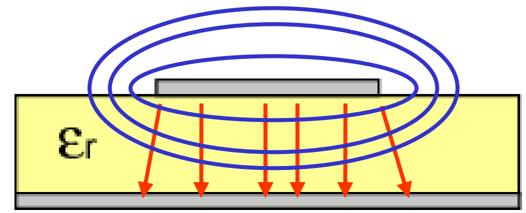
Waveguide (-continued)

(3)planar waveguide

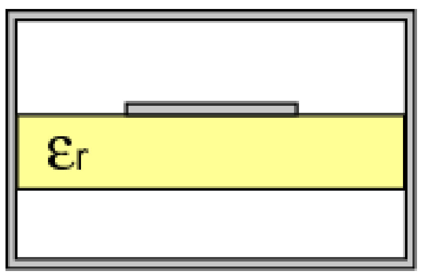
(a)strip line



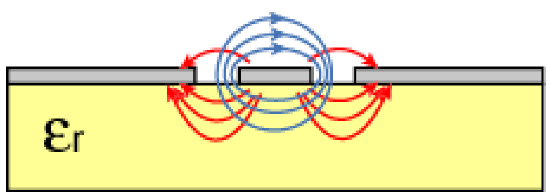
(b)micro-strip line



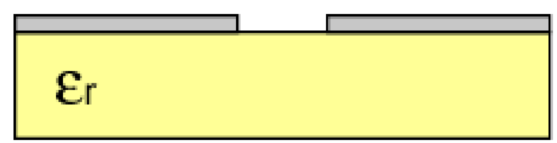
(c)suspended strip line



(d)co-planar line



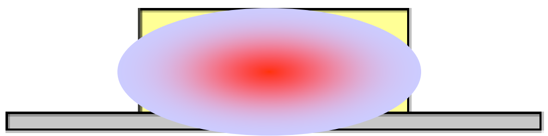
(e)slot line



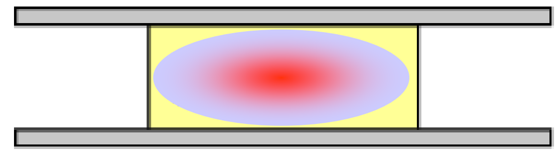
Waveguide (-continued)

(4)dielectric waveguide

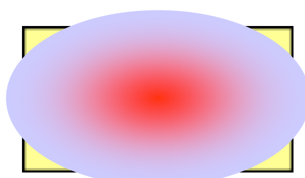
(a)image line



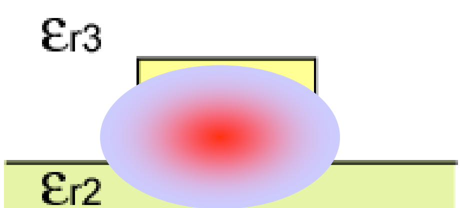
(b)NRD (Non-Radiated Dielectric) guide



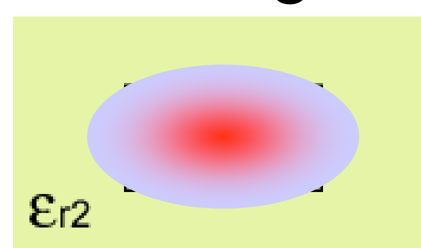
(c)dielectric rod



(d)strip line



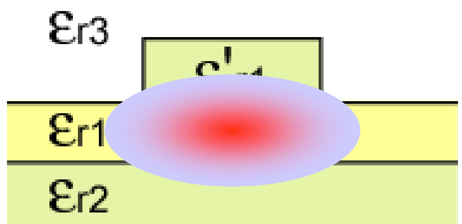
(e)buried waveguide



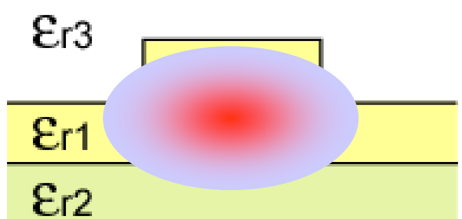
Waveguide (-continued)

(4)dielectric waveguide

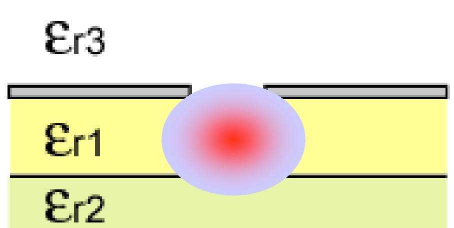
(f)strip-loaded waveguide



(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)

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

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

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

power dissipation

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

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

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 : $\sigma = 5.65 \times 10^7$ (S/m) --> d=$0.67\mu\mathrm{m}$, $R_s = 26\mathrm{m}\Omega$ (@10GHz)

Ag(4N) : $\sigma = 6.14 \times 10^7$ (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