Microwave Engineering MCC121, 7.5hec, 2014

Lecture 4

Challenging
Stimulating
Rewarding

Outline

- Transmission lines and waveguides (Ch3)
  - Summary of hollow waveguides
  - Microstrip lines
  - Striplines
  - Coupled lines

Objectives

On completion of this course unit you should be able to:

- [x] Analyse wave propagating properties of guided wave structures (TE, TM, TEM waves, microstrip, stripline, rectangular and circular waveguides, coupled lines)
- [ ] Apply N-port representations for analysing microwave circuits
- [ ] Apply the Smith chart to evaluate microwave networks
- [ ] Design and evaluate impedance matching networks
- [ ] Design, evaluate and characterise directional couplers and power dividers
- [ ] Design and analyse attenuators, phase shifters and resonators
- [ ] Explain basic properties of ferrite devices (circulators, isolators)

Helmholtz equation

- Assume no sources:

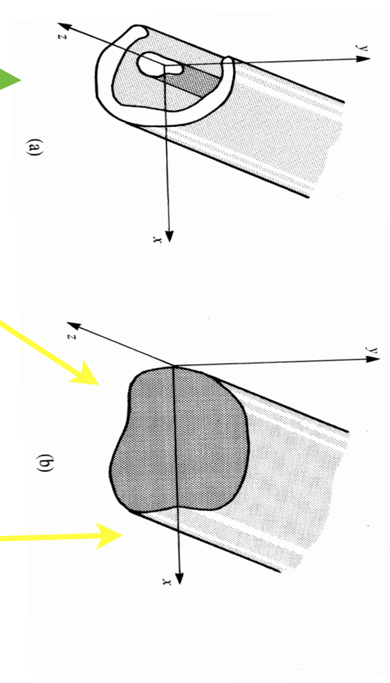
$$\nabla^2 \overline{E} + k_0^2 \overline{E} = 0$$
$$\nabla^2 \overline{H} + k_0^2 \overline{H} = 0$$

$$k = \omega\sqrt{\varepsilon\mu}$$

- Cross section or electrical properties do not vary along z-axis (axial uniformity)
- Separable: assume solution f(z)g(x,y)

Classification of waves

- TEM-Transverse Electromagnetic: no longitudinal field components
- TE-Transverse Electric, or H modes: longitudinal magnetic field component
- TM-Transverse Magnetic, or E modes: longitudinal electric field component



Summary of modes

- TEM waves

  $E_z = H_z = 0$

  Field is a solution to a transverse gradient of a scalar function Φ(x,y), which is a solution of a two-dimensional Laplace equation

- TE waves, H modes

  $e_z = 0$

  All field components are derived from h_z

- TM waves, E modes

  $h_z = 0$

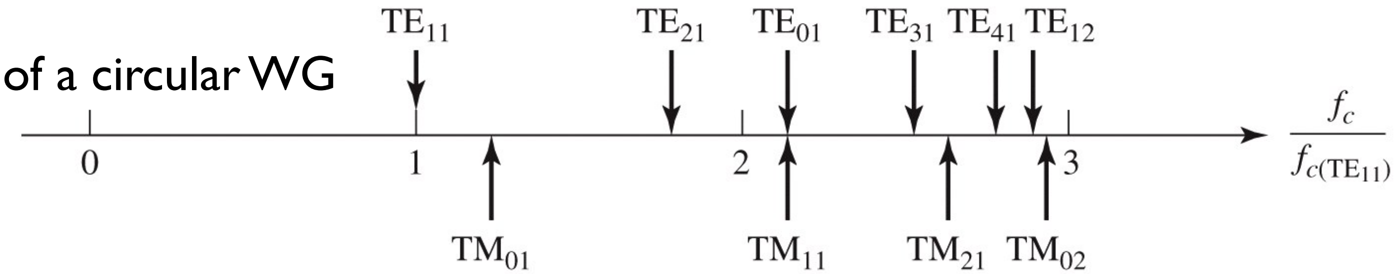
  All field components are derived from e_z

- TE and TM

WG modes

- Principal mode = fundamental mode = dominant mode: lowest cut-off frequency
- Higher order modes, if unwanted also called parasitic modes!

ex) modes of a circular WG



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Lossless transmission lines

- Two or more parallel conductors
- Surrounded by a uniform dielectric

➡TEM as principal wave

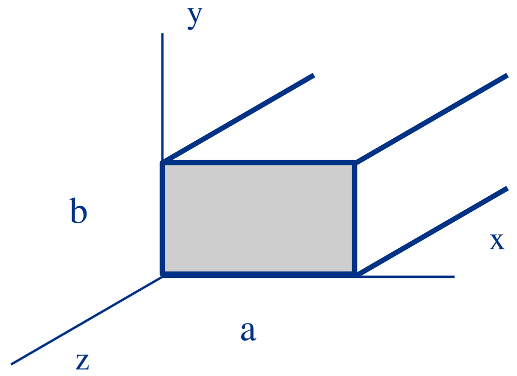
- Microstrip and other planar lines do not have the dielectric medium completely surrounded

➡quasi-TEM waves (low frequency limit)

Attenuation

- Attenuation due to dielectric loss α_d
- Attenuation due to conductor loss, α_c
- Total attenuation: $\alpha = \alpha_c + \alpha_d$

Hollow waveguides



$\bar{e}$ exists if $\bar{h}_z$ exists (TE wave, H mode)
$\bar{h}$ exists if $\bar{e}_z$ exists (TM wave, E mode)

$TE_{n,m}$ and $TM_{n,m}$ modes

The integers n and m pertain to the number of standing-wave interference maxima occuring in the field solutions that describe the variation of the fields along the two transverse coordinates

$f_{c,nm}$ corresponds to cut-off frequency below which the mode does not propagate; it is a geometrical parameter dependent on the waveguide cross-sectional configuration

Propagation factor β

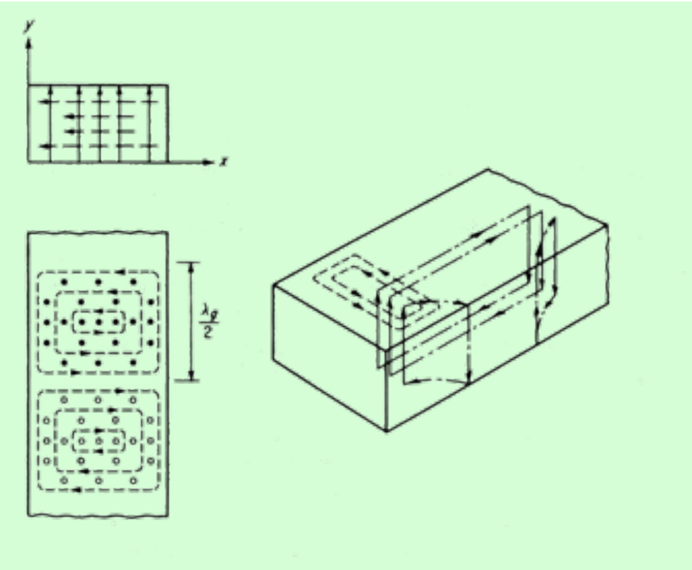
$$\beta = \sqrt{k_0^2 - k_c^2}$$
$$k_0 = 2\pi f \sqrt{\mu_0 \varepsilon},\ k_c = 2\pi f_c \sqrt{\mu_0 \varepsilon}$$

The concept of impedance

The term impedance was first used by Oliver Heaviside in the19th century to describe the complex ratio V/I in AC circuits. In the 1930's Schelkunoff extended this concept to electromagnetic fields and noted that impedance should be regarded as characteristic of the type of field, as well as medium. The impedance may also be dependent on the direction of the propagating wave. The concept of impedance is an important link between field theory and transmission line theory.

- Intrinsic impedance of the medium, $Z_0 = \eta = \sqrt{\frac{\mu}{\varepsilon}}$
- Wave impedance; this impedance is a characteristic of the particular type of wav $Z_w = E/H$ TEM, TE, TM waves each have different wave impedances; they may depend on the type of the line or guide, the material, and frequency,
- Characteristic impedance is the ratio of voltage to current for a travelling wave; voltage and current are uniquely defined only for a TEM wave; TE and TM waves do not have uniquely defined voltage and current, so the characteristic impedanc for such waves may be defined in various ways. $Z_0 = \sqrt{\frac{L}{C}}$

Dominant TE10 mode



$$H_{z,10} = A\cos\frac{\pi x}{a}e^{-j\beta z}$$

$$H_{x,10} = A\frac{j\beta}{k_c}\sin\frac{\pi x}{a}e^{-j\beta z}$$

$$E_{y,10} = -AZ_{h,10}\frac{j\beta}{k_c}\sin\frac{\pi x}{a}e^{-j\beta z}$$

$$k_{c,10} = \frac{\pi}{a},\ \beta_{10} = \sqrt{k_0^2 - \left(\frac{\pi}{a}\right)^2}$$

$$Z_{h,10} = -\frac{E_y}{H_x} = \frac{k_0}{\beta}Z_0$$

$$\lambda_g = \frac{2\pi}{\beta} = \frac{\lambda_0}{\sqrt{1-(\lambda_0/2a)^2}}$$

$$v_p = \frac{\lambda_g}{\lambda_0}c,\ v_g = \frac{\lambda_0}{\lambda_g}c$$

Perturbation method to calculate loss

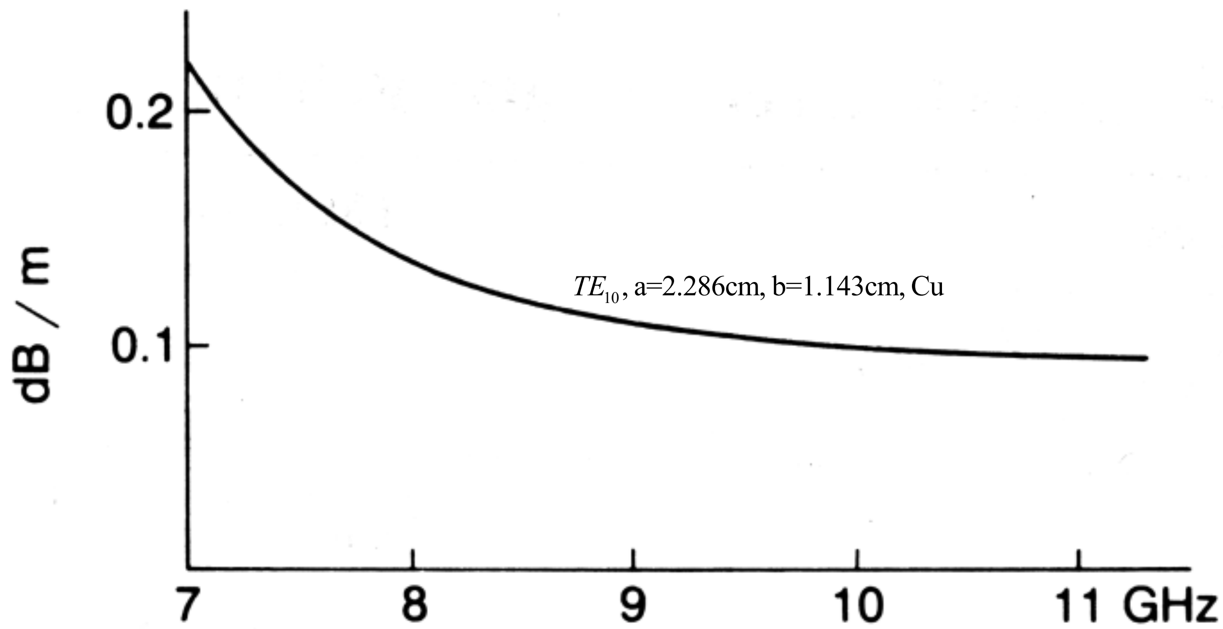
- Assumes that field distribution in lossy line is not different from lossless line.
- Derive method to calculate loss...

$$P(z) = P_o e^{-2\alpha z}$$

$$p_l = \frac{-\partial P}{\partial z} = 2\alpha P(z) \text{ "power loss per unit length"}$$

$$\alpha = \frac{p_l(z)}{2P(z)} = \frac{p_l(z=0)}{2P_o}$$

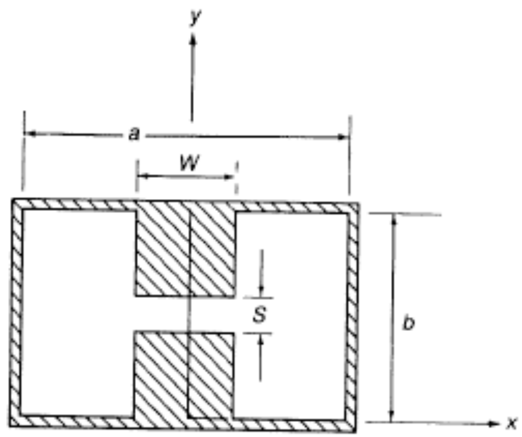
Attenuation



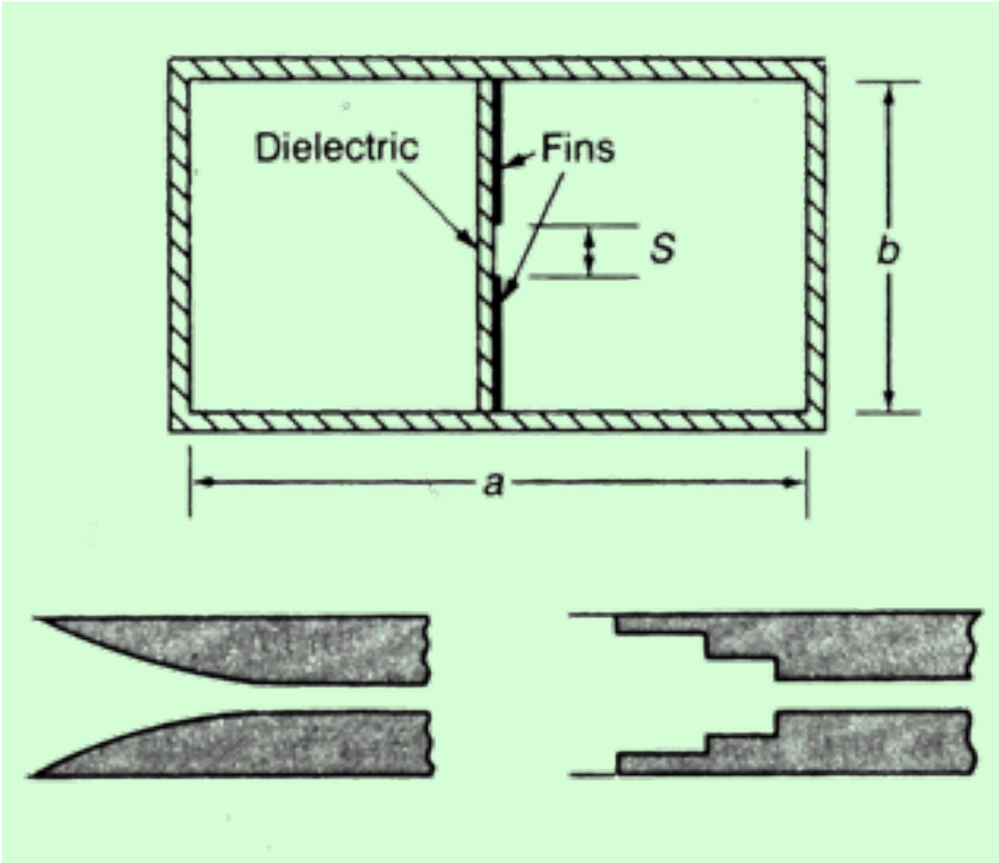
Total losses are assumed to be a sum of metallic and dielectric losses; this is a good approximation for small losses

Ridge waveguide

- Better single mode bandwidth



Finline



Wave velocities

Phase velocity
The phase velocity is the velocity an observer must move with in order to see a constant phase for the wave propagating along the guide.

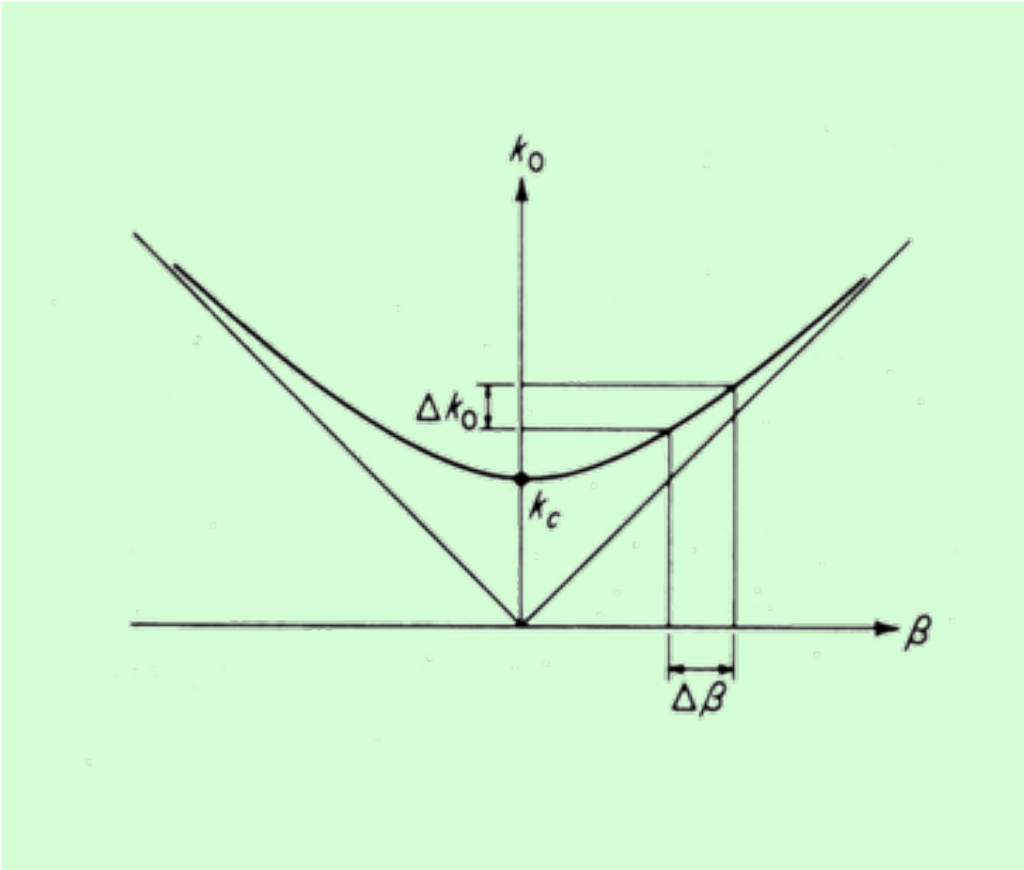
$$v_p = \frac{\lambda_g}{\lambda_0}c,\ \lambda_g > \lambda_0,\ v_p > c \text{ assuming } \varepsilon_r = 1$$

No information can be transmitted with the phase velocity

Group velocity
The group velocity is the velocity with which a signal consisting of a very narrow band of frequency components propagates.

$$v_g = \left(\frac{d\beta}{d\omega}\right)^{-1}$$

Wave velocities - signal distortion

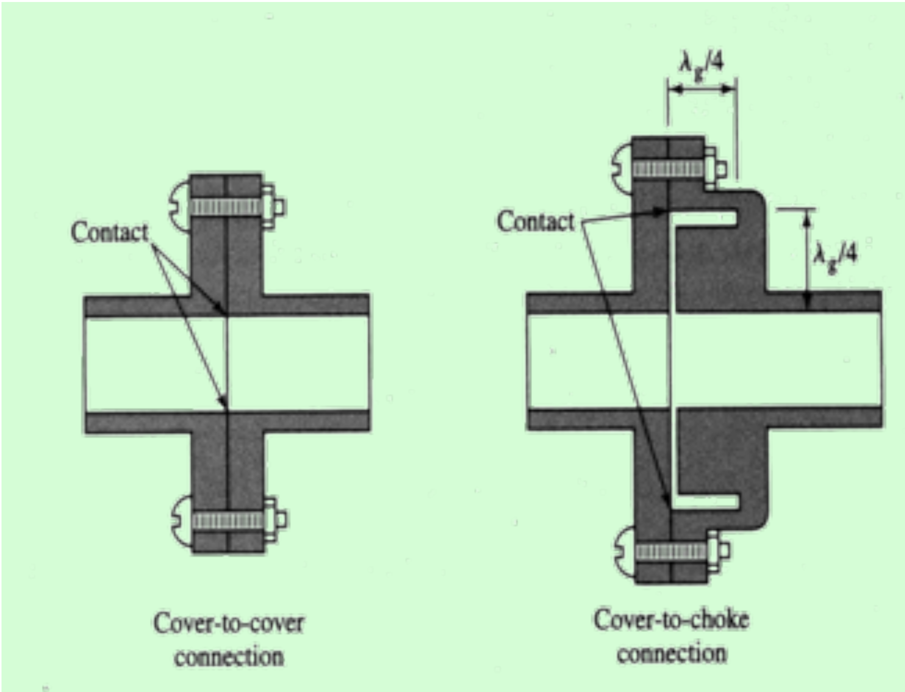


for a waveguide

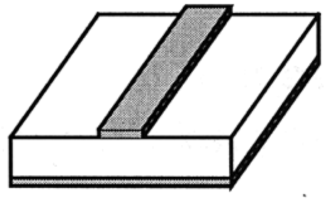
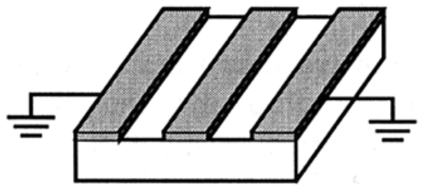
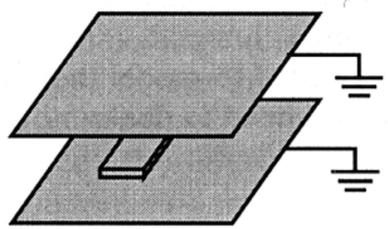
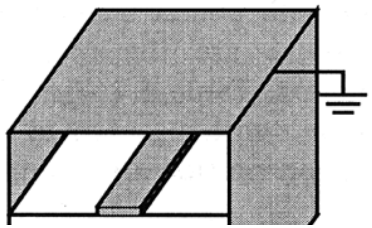
$$v_g = \left(\frac{d\beta}{d\omega}\right)^{-1} = \frac{\lambda_o}{\lambda_g} c$$

$$v_g v_p = c^2$$

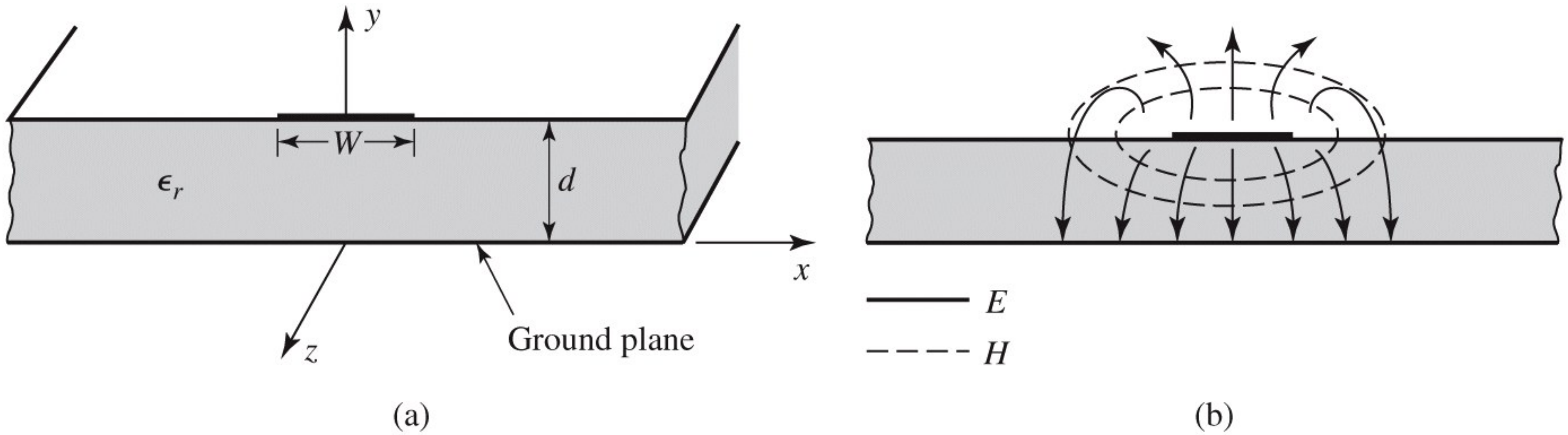
Connection of WGs



Field analysis of transmission lines

Structure	Properties
	The most common type of transmission line, suitable for both hybrids and monolithic circuits. Moderately dispersive at high frequencies. See Section 1.3.3.
	Somewhat lossier and more dispersive than microstrip, but minimizes the parasitic inductance of ground connections. Good transition to coaxial lines. Spurious slotline and microstrip modes are possible. See Section 1.3.4.
	Does not allow convenient mounting of discrete circuit elements; best for passive components. Difficult to cascade with microstrip or other planar transmission lines. Low loss, TEM, good transition to coax. See Section 1.3.5.
	Similar to stripline, but easier to fabricate in many types of circuits. Low loss, low effective dielectric constant, good transition to coax. Waveguide-like modes can be a problem. See Section 1.3.6.

Microstrip



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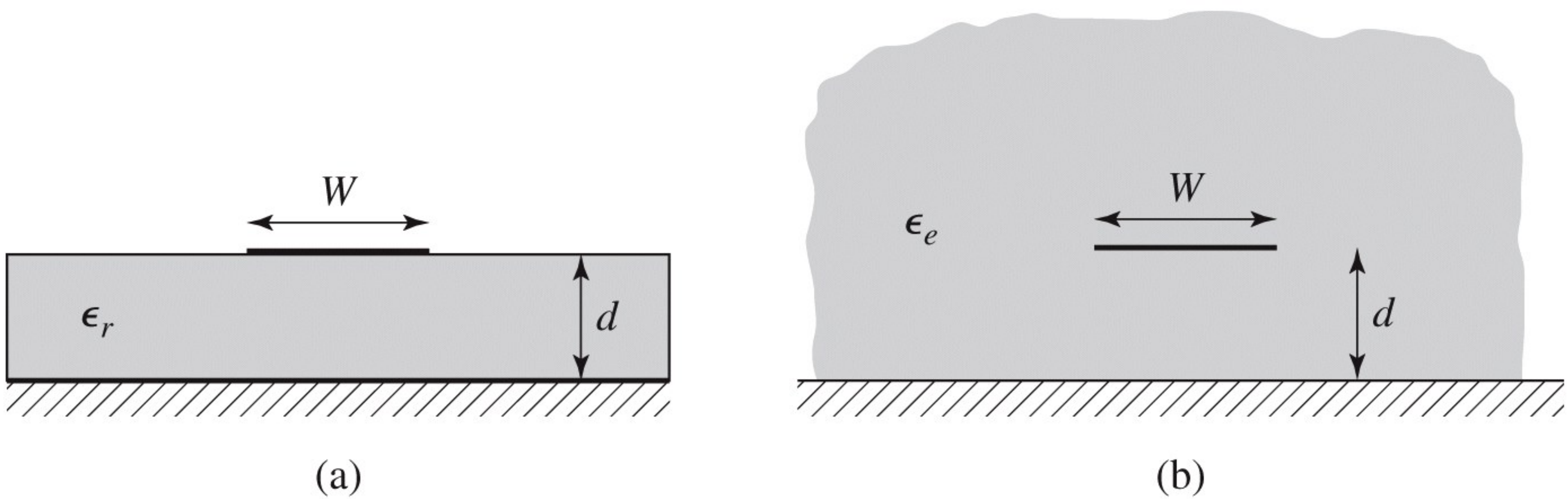
effective dielectric constant



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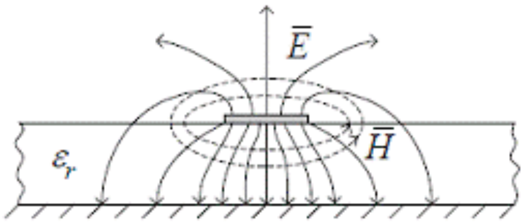
Microstrip lines



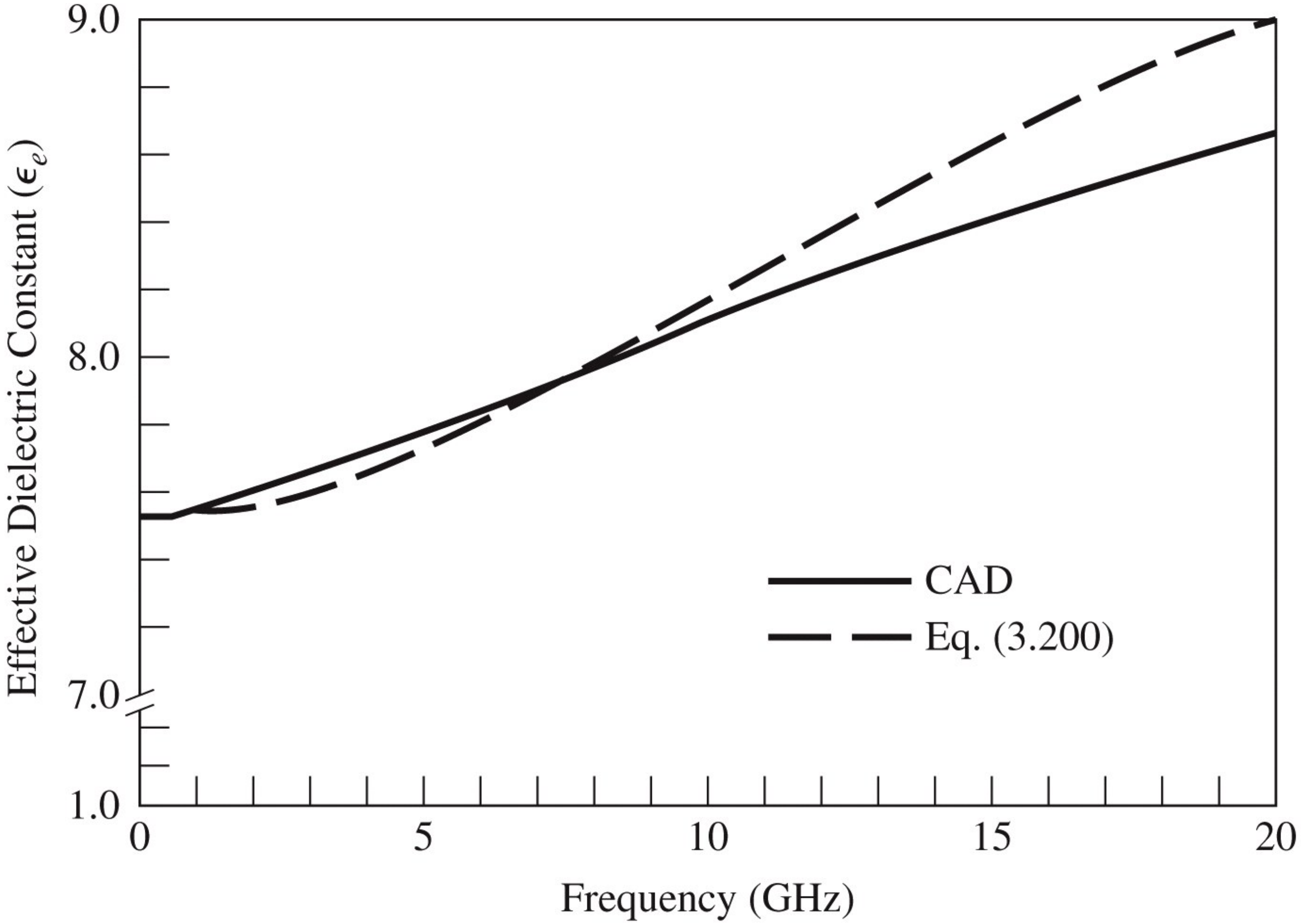
- Exact fields constitute a hybrid TM-TE wave
- For electrically thin substrates (d<<)=> quasi TEM fields. Essentially the same fields as static ones.
- Effective dielectric constant is dependent on substrate thickness and conductor width

$$v_p = \frac{c}{\sqrt{\varepsilon_e}}$$

$$\beta = k_o \sqrt{\varepsilon_e}$$

$$1 < \varepsilon_e < \varepsilon_r$$

effective dielectric constant



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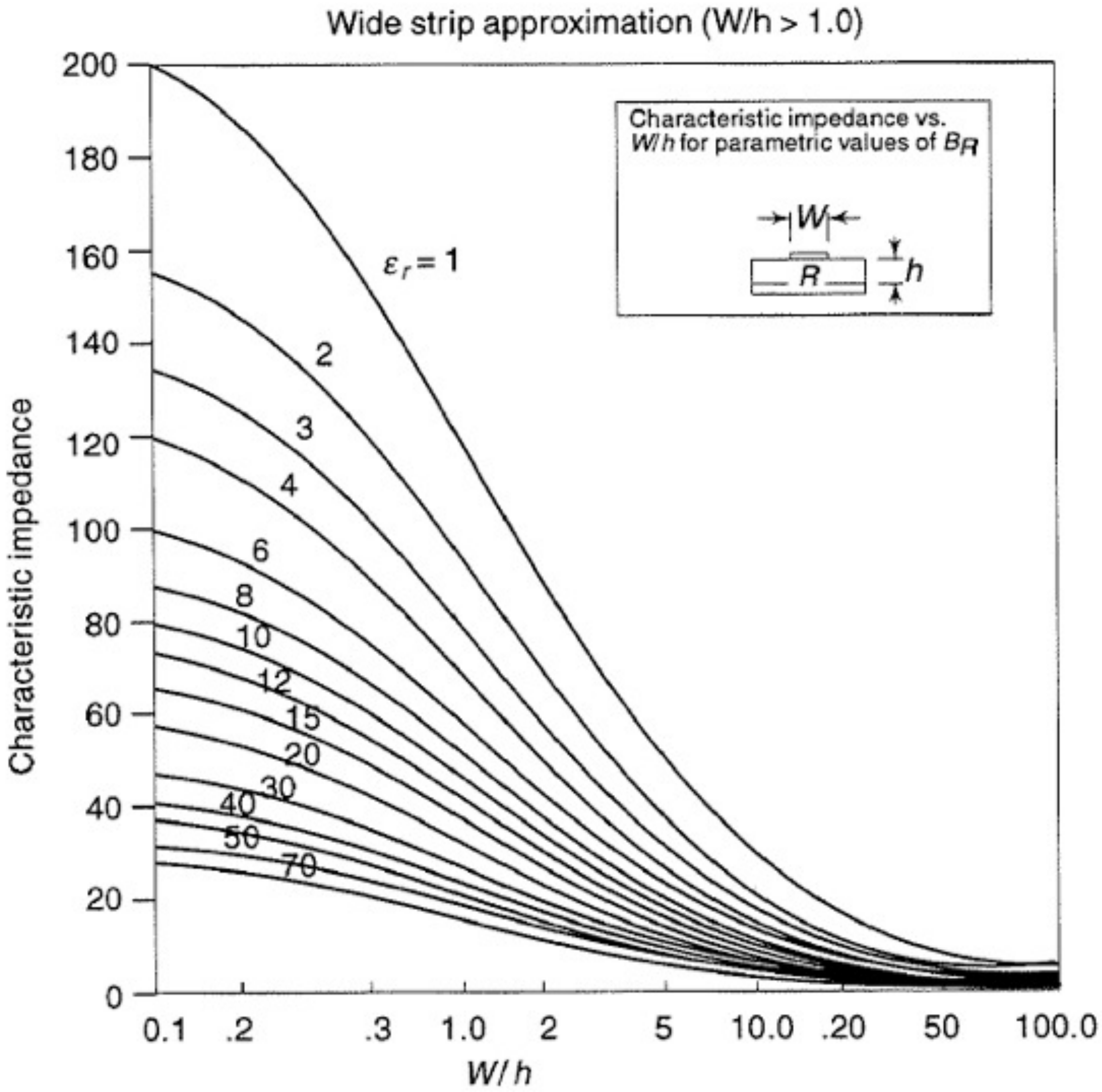
MS: Characteristic impedance



MS: attenuation

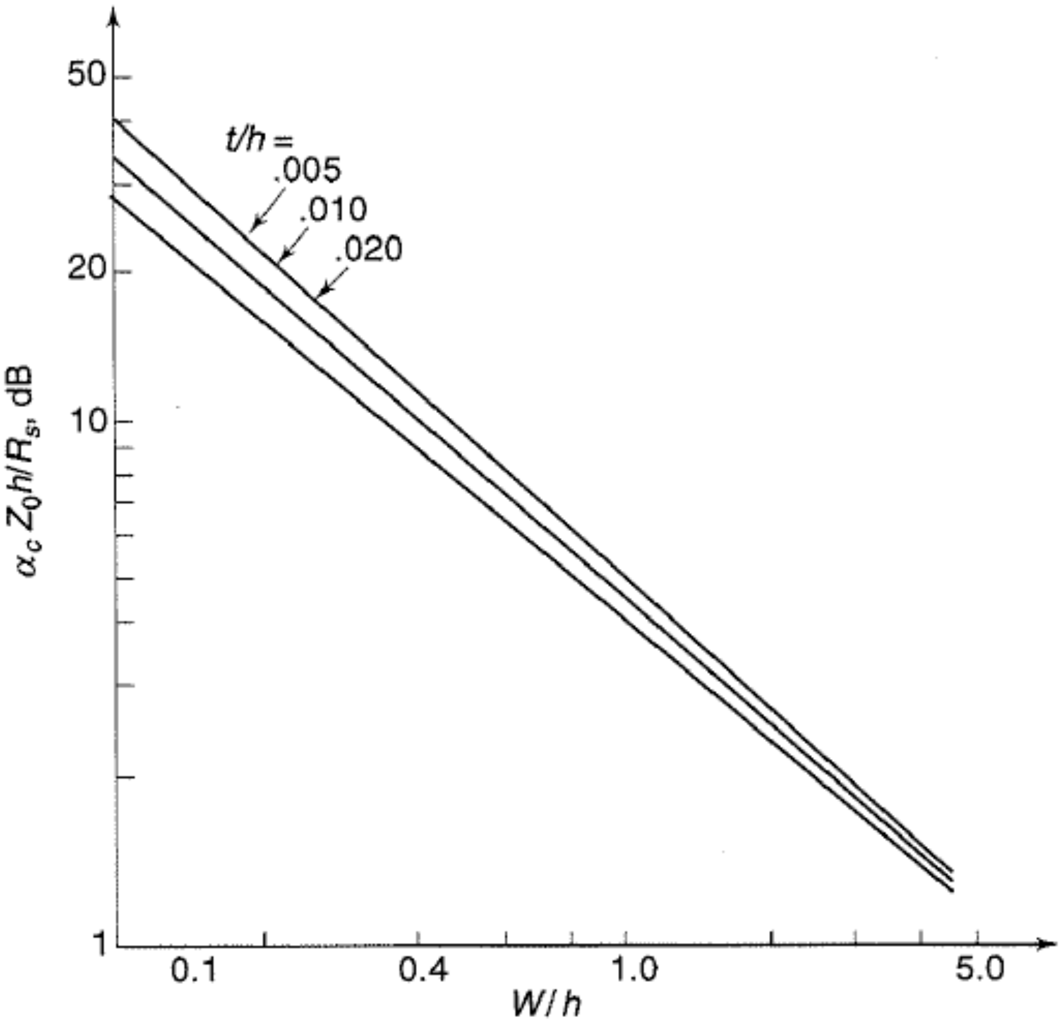
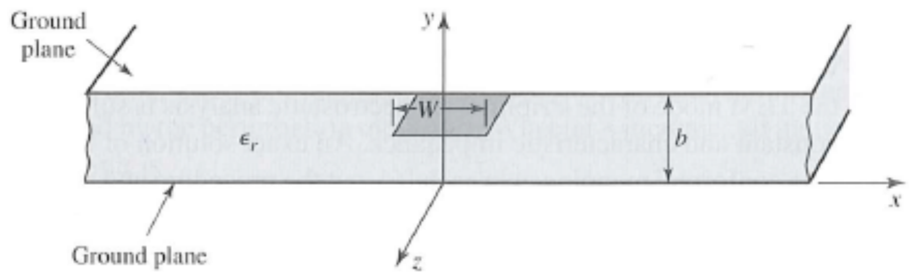
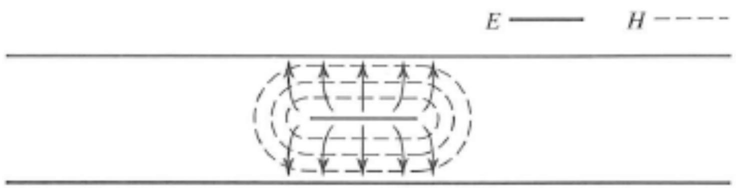


Fig. 4.10 *Variation of attenuation constant with W/h*

Strip line



(a)


(b)

- Supports TEM mode, but can also carry higher-order TE/TM modes

Strip-line: characteristic impedance

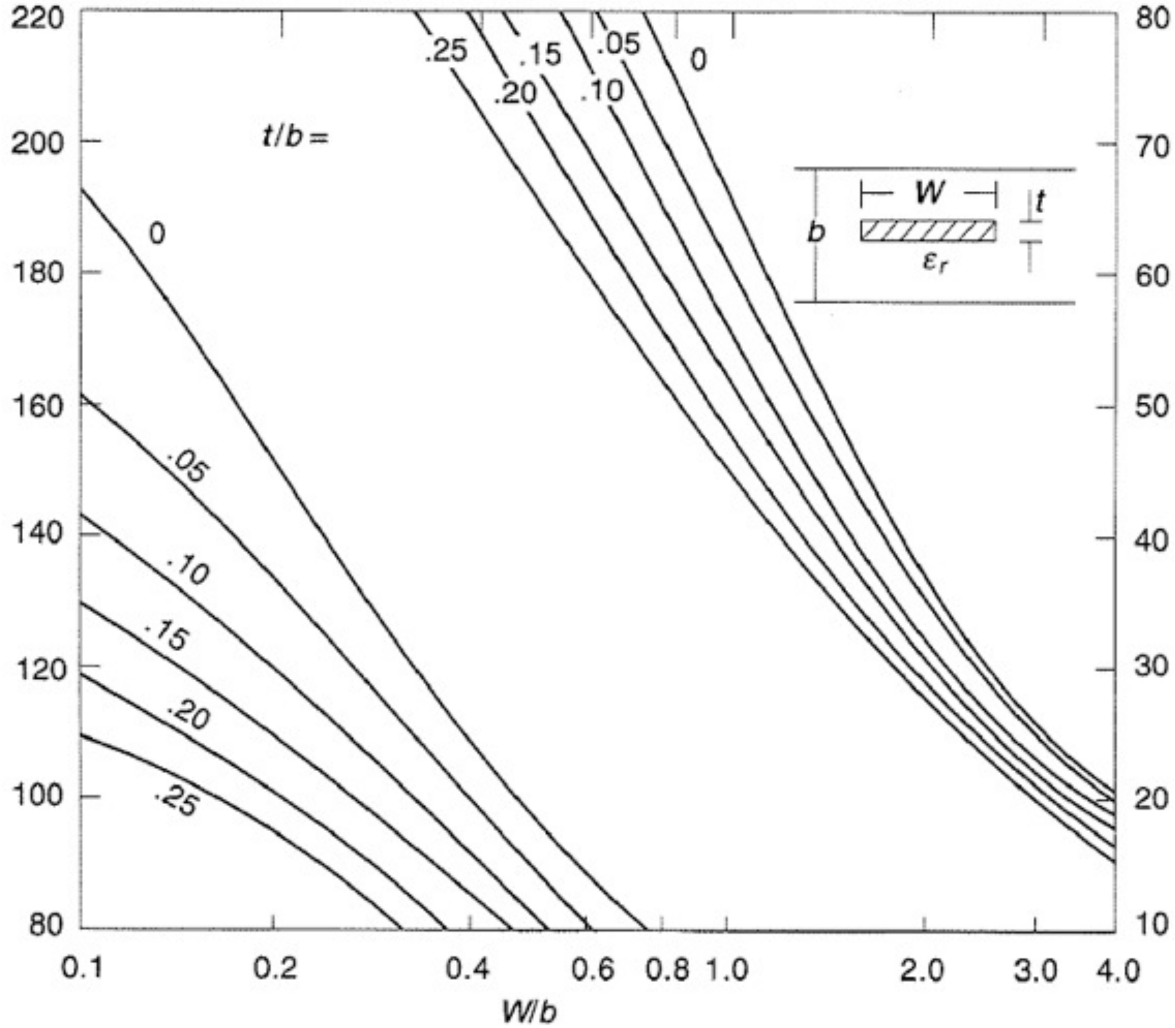
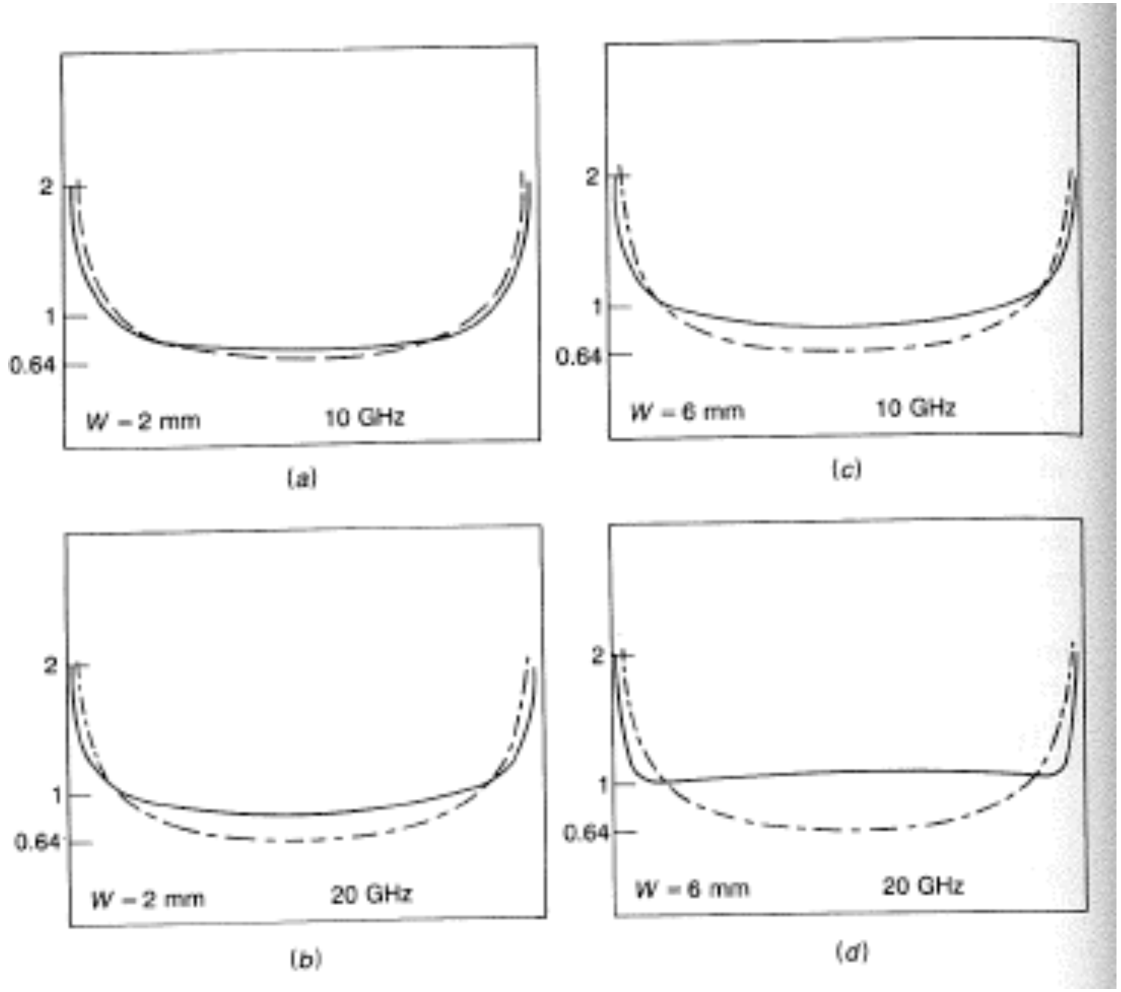


Fig. 4.4 Z_0 vs W/b

Current distribution in MS lines

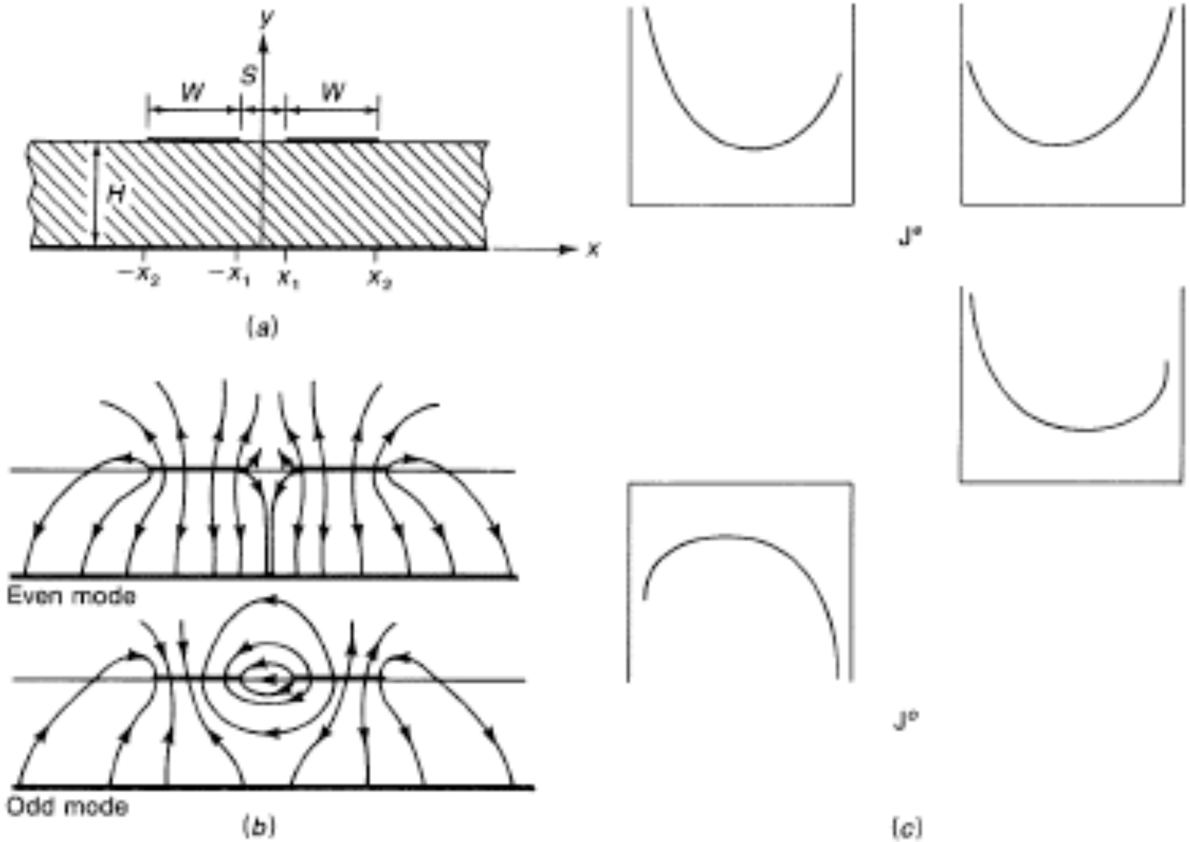


Coupled MS lines

Current distribution

Even mode : Strips being at the same potential, V.

Odd mode : Strips being at the opposite potential, +V and -V.



Coupled MS lines - dispersion

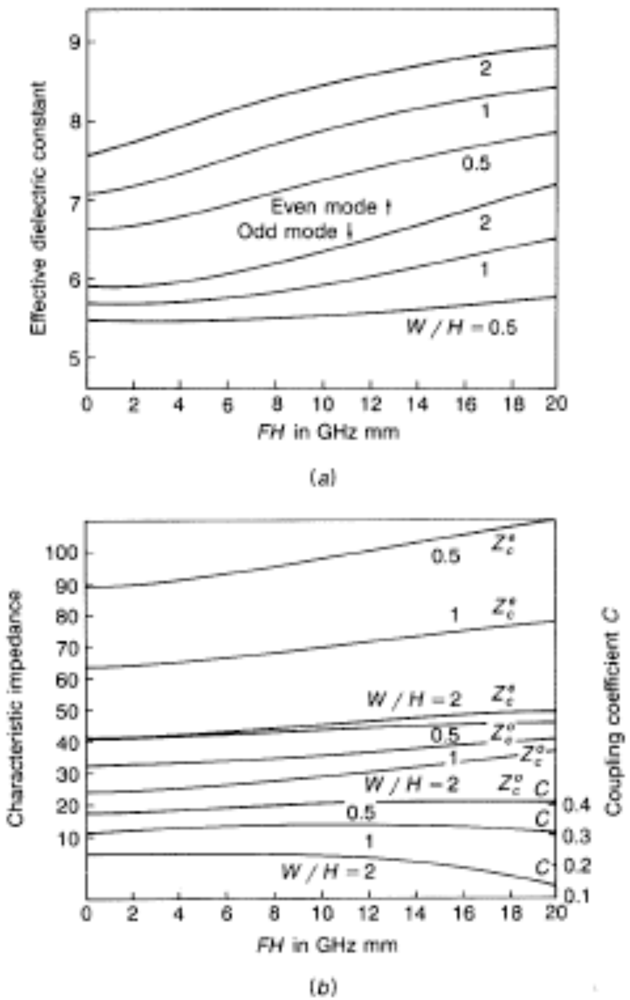


FIGURE 3.31
Dispersion characteristics of a coupled microstrip line on an alumina substrate. $S/H = 0.25$, $\epsilon_r = 9.7$. (*a*) Even- and odd-mode effective dielectric constant; (*b*) even- and odd-mode characteristic impedance and coupling coefficient C.

Used in directional couplers

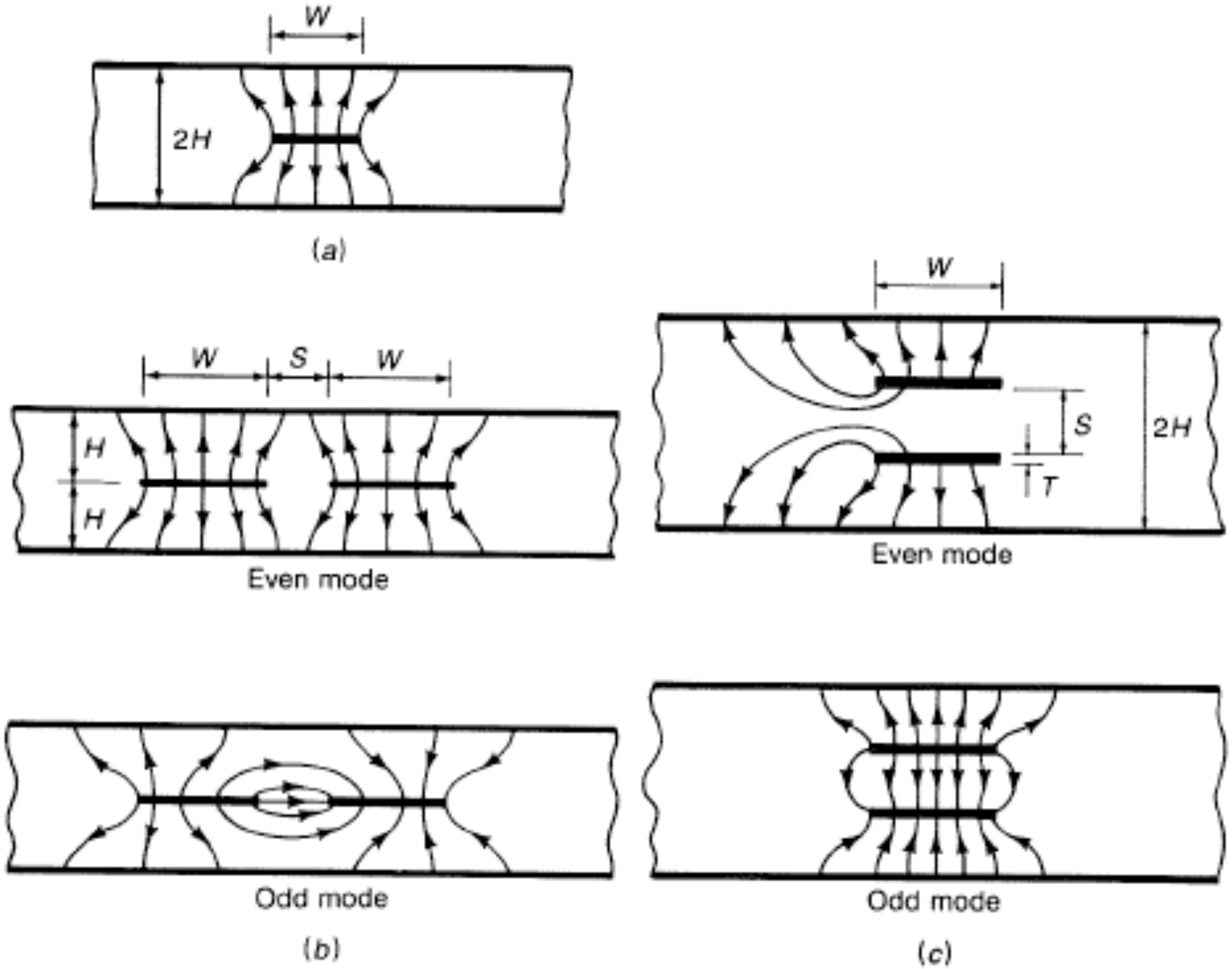
Important parameters:

-Even- and odd-mode effective dielectric constants

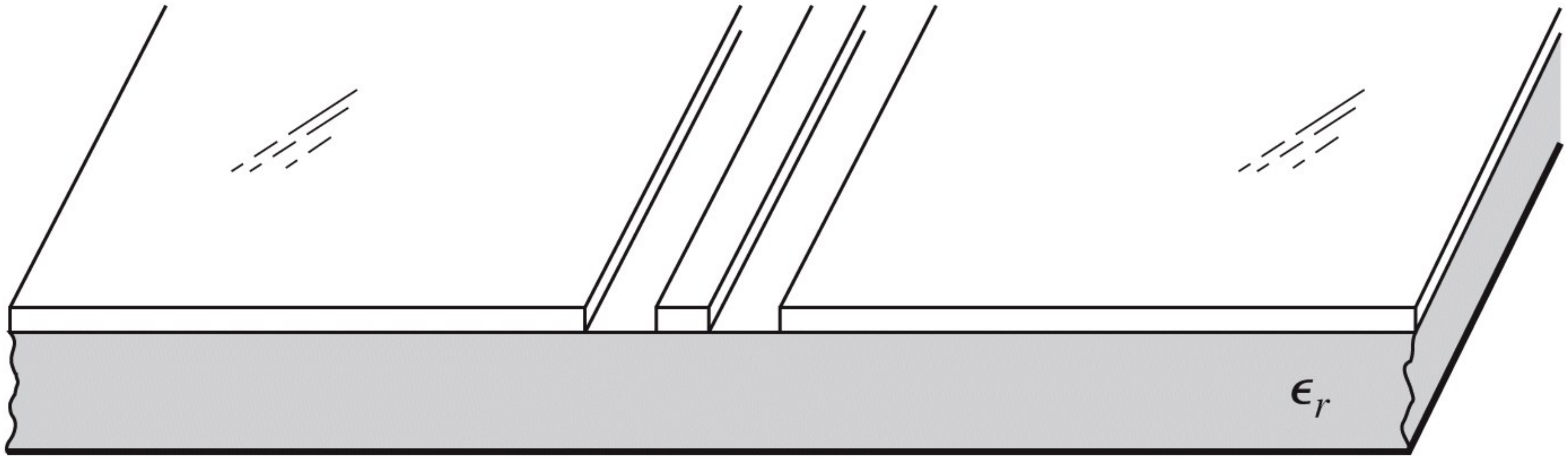
-Even- and odd-mode characteristic impedances

$$C = \frac{Z_c^e - Z_c^o}{Z_c^e + Z_c^o}$$

Coupled strip lines



Coplanar lines



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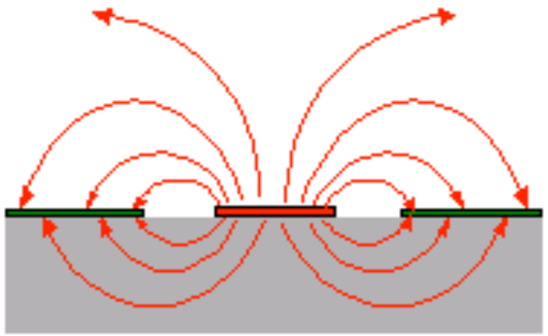
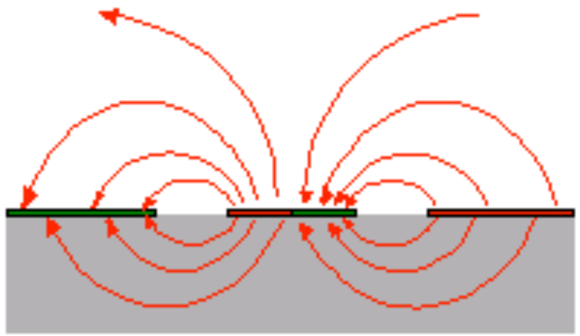
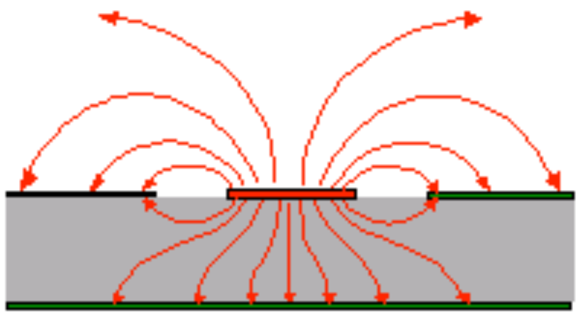
Coplanar lines



Coplanar even mode

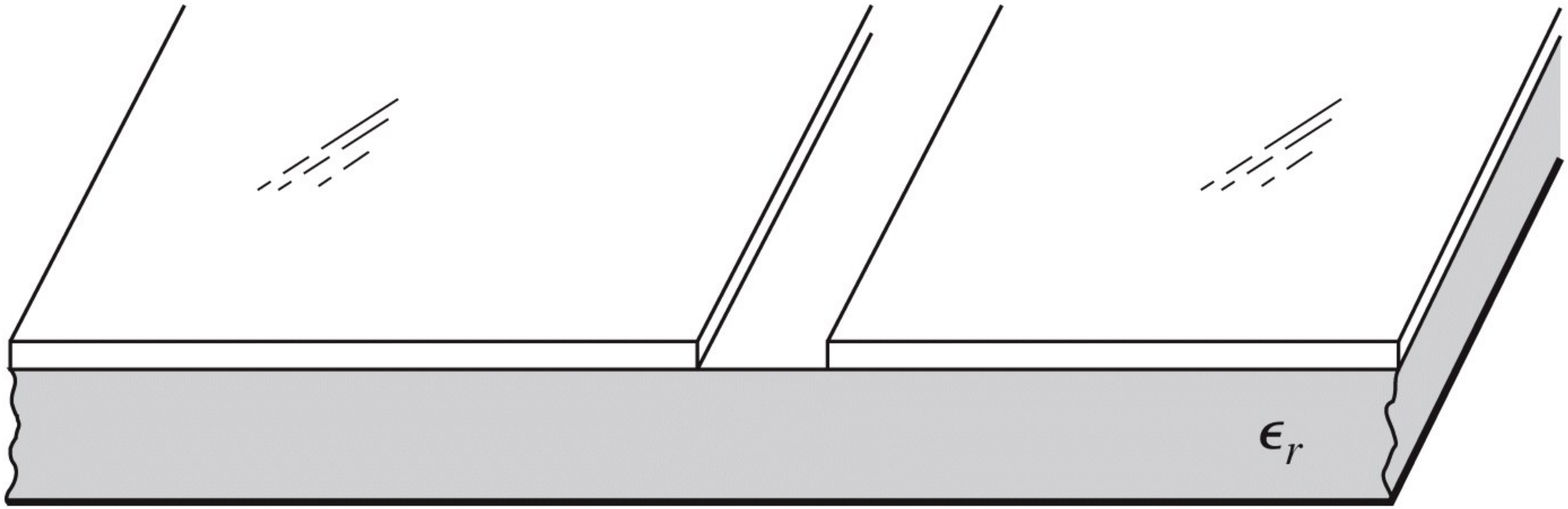


Coplanar odd mode



Parasitic Microstrip Mode on conductor-backed coplanar line

Slotline



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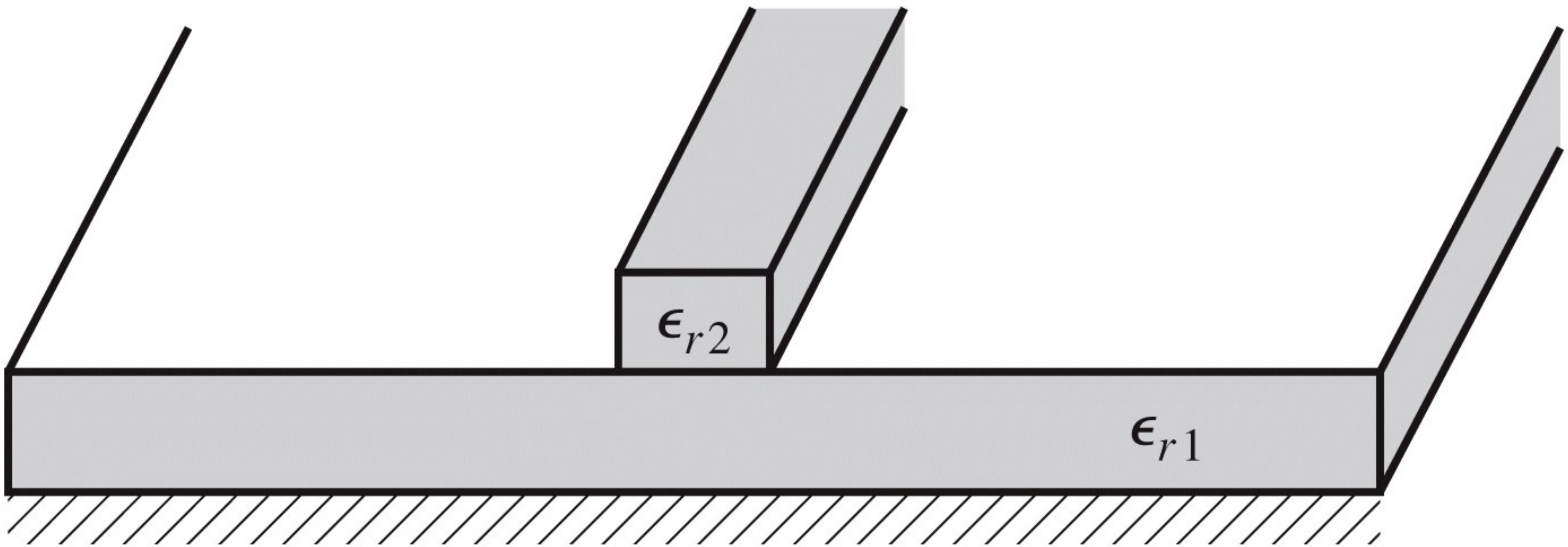
Dielectric waveguide



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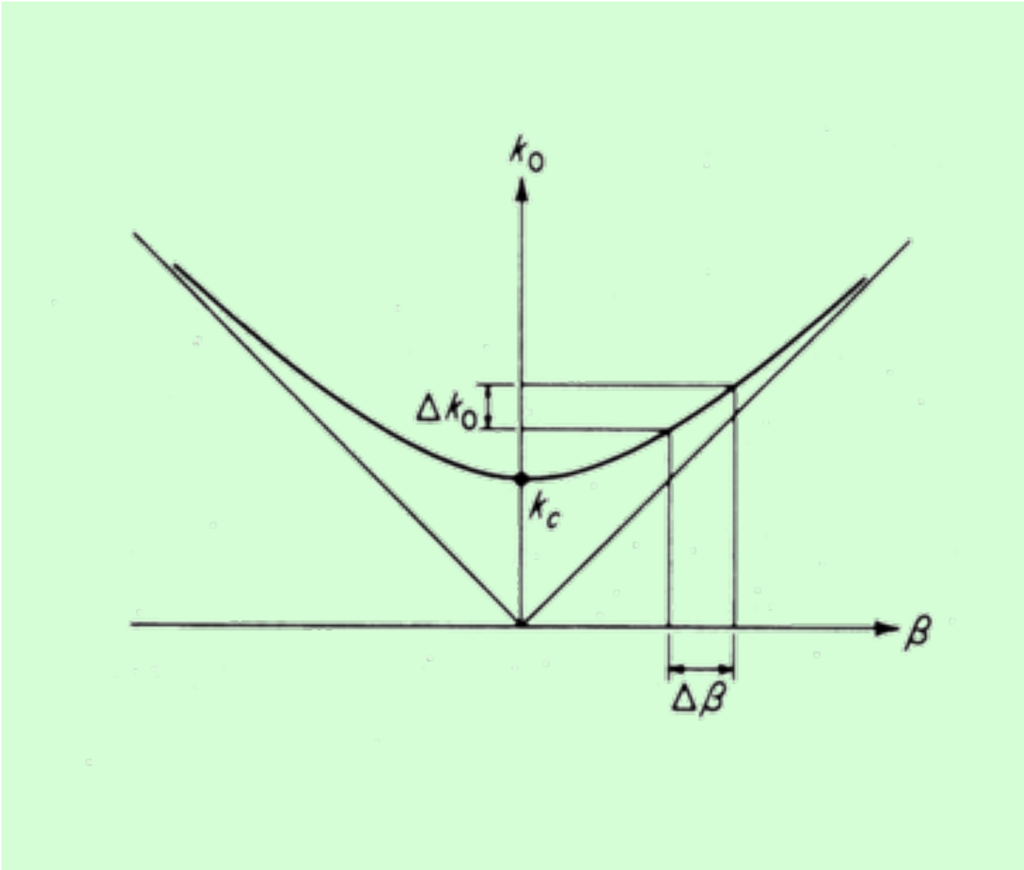
Wave velocities - signal distortion

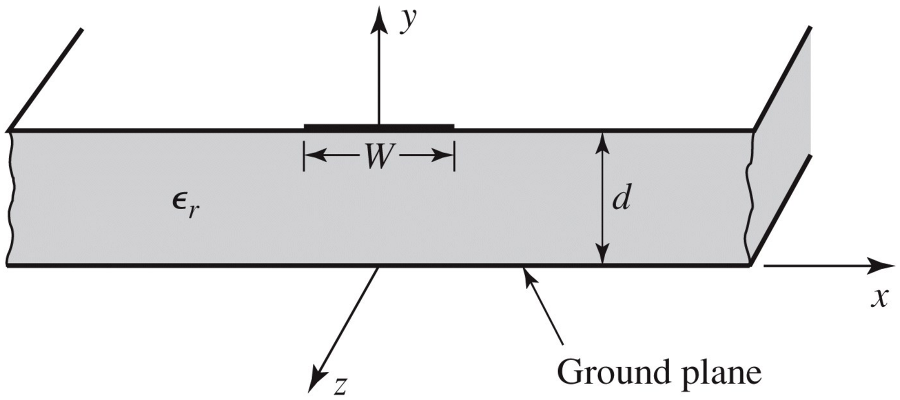


for a waveguide

$$v_g = \left(\frac{d\beta}{d\omega}\right)^{-1} = \frac{\lambda_o}{\lambda_g} c$$

$$v_g v_p = c^2$$

Bandwidth limitations?



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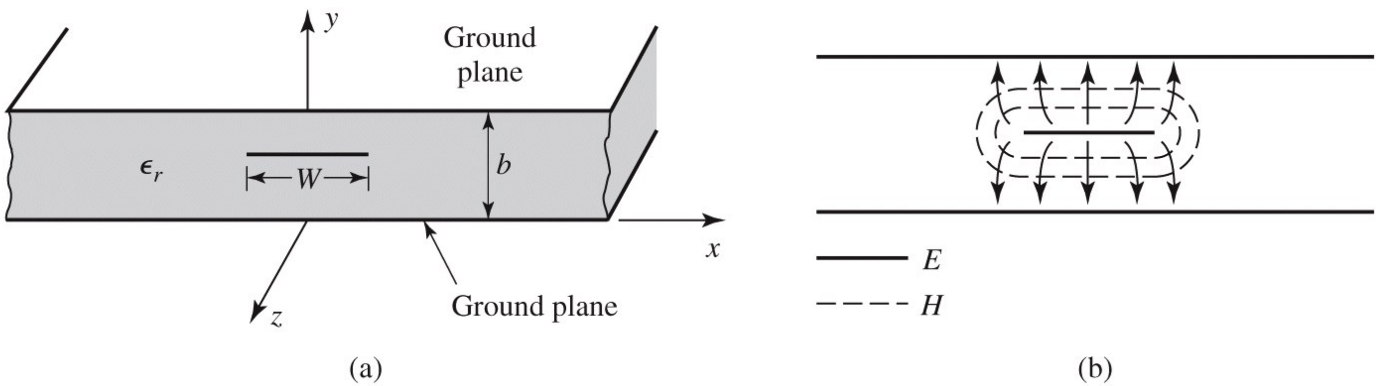
Onset of higher order modes...



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Summary

TABLE 3.6 Comparison of Common Transmission Lines and Waveguides

Characteristic	Coax	Waveguide	Stripline	Microstrip
Modes: Preferred	TEM	TE_{10}	TEM	Quasi-TEM
Other	TM,TE	TM,TE	TM,TE	Hybrid TM,TE
Dispersion	None	Medium	None	Low
Bandwidth	High	Low	High	High
Loss	Medium	Low	High	High
Power capacity	Medium	High	Low	Low
Physical size	Large	Large	Medium	Small
Ease of fabrication	Medium	Medium	Easy	Easy
Integration with	Hard	Hard	Fair	Easy

Table 3.6
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Summary of lecture 4

- Read chapter 3.
  - TEM, TE, and TM modes
  - Coupled lines
  - Hollow waveguides (TE and TM modes)
  - Field analysis on transmission lines
  - Effective dielectric constant
  - Dispersion, characteristic impedance
- Next: Circuit theory (ch4)

Further reading

- R. A. Pucel, "Design Considerations for Monolithic Microwave Circuits," IEEE Trans. Microw. Theory. Tech., vol. 29, no. 6, pp. 513–534, 1981.
- S. B. Cohn, "Shielded Coupled-Strip Transmission Line," Microwave Theory and Techniques, IRE Transactions on, vol. 3, no. 5, pp. 29–38, 1955.