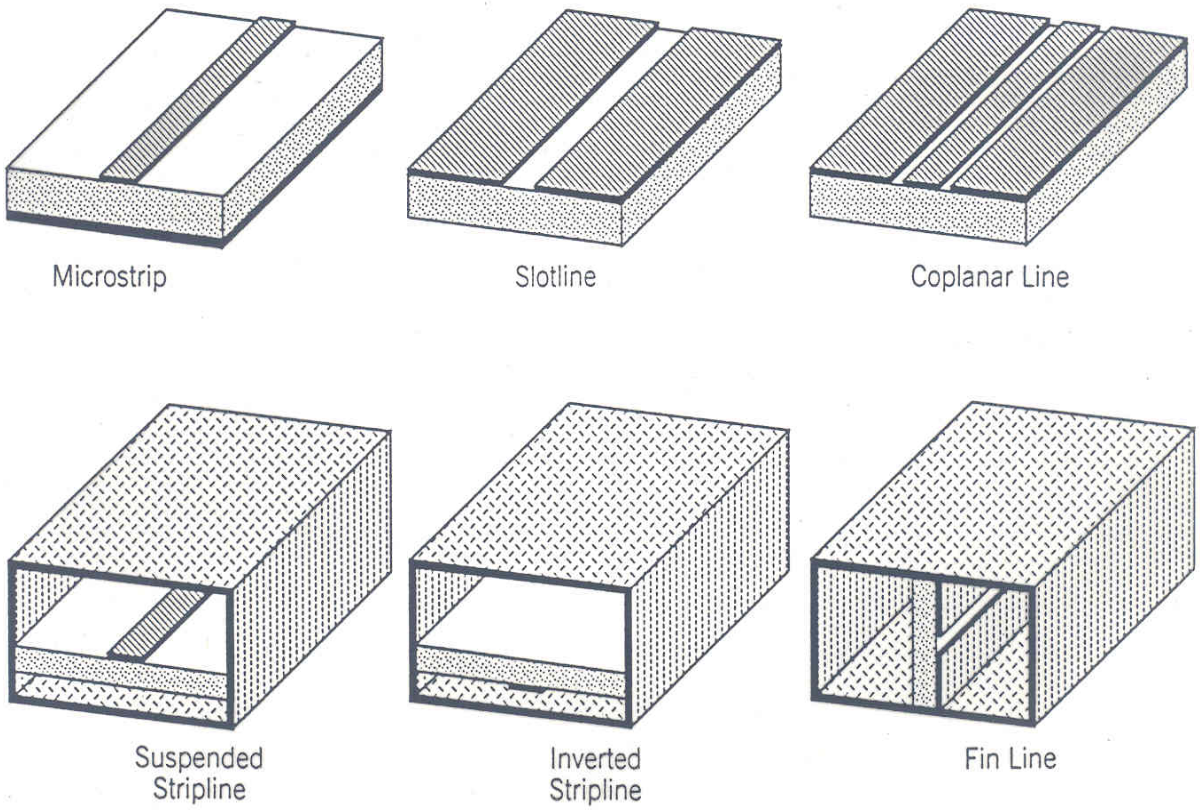
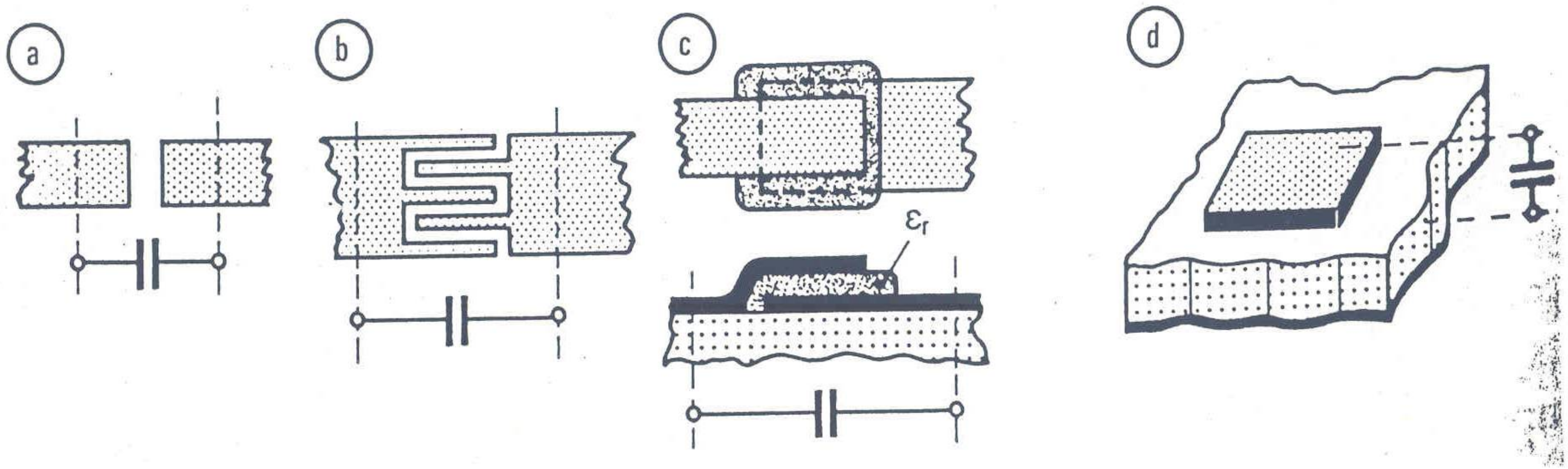
Printed lines

- microstrip lines
- slot lines
- striplines
- coplanar waveguides

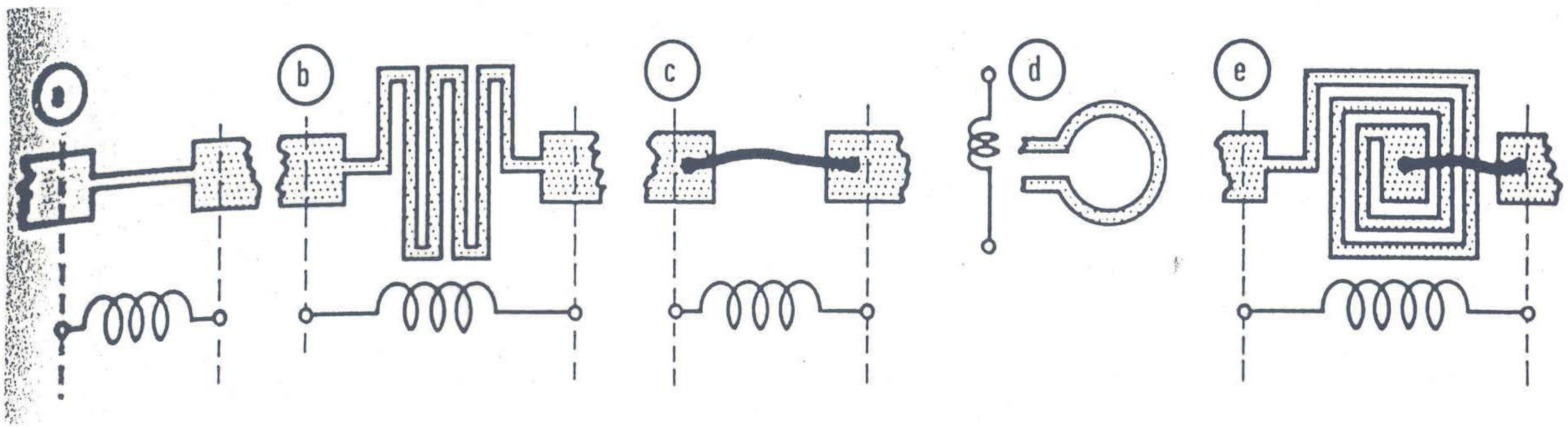
Printed lines



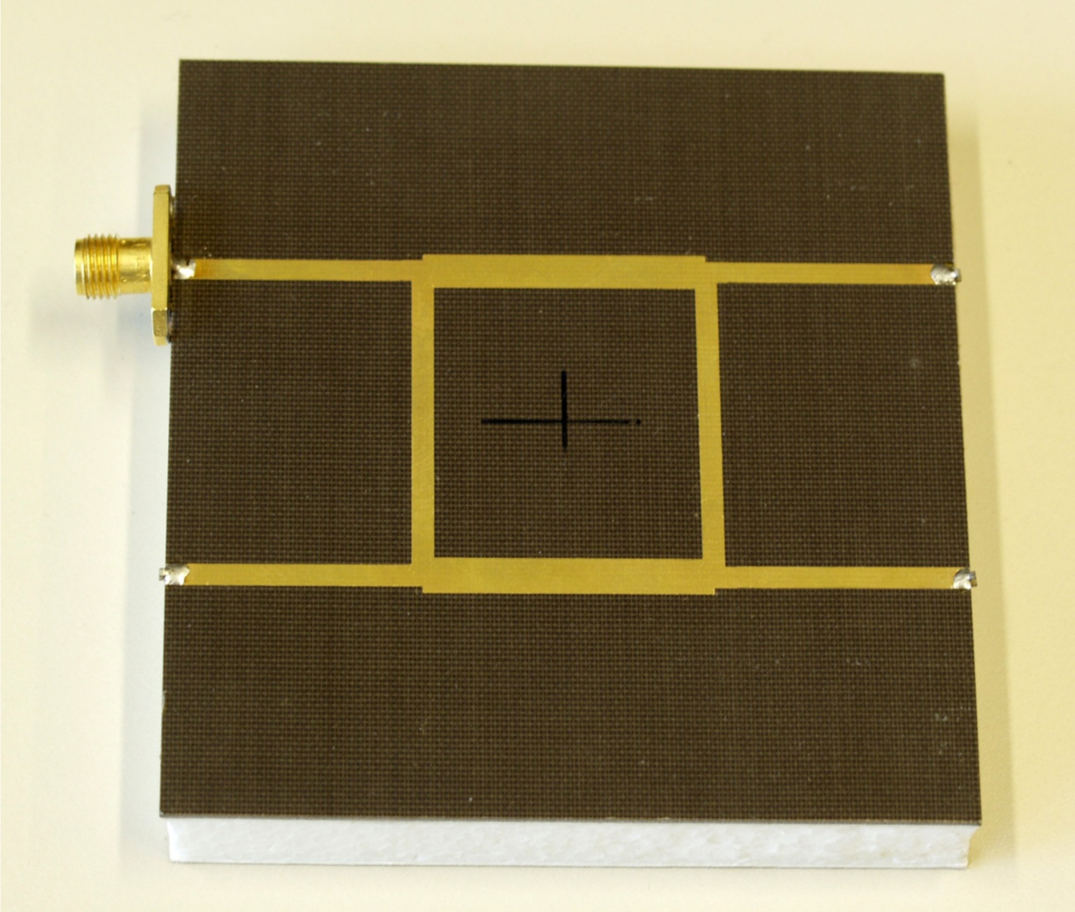
Printed lines

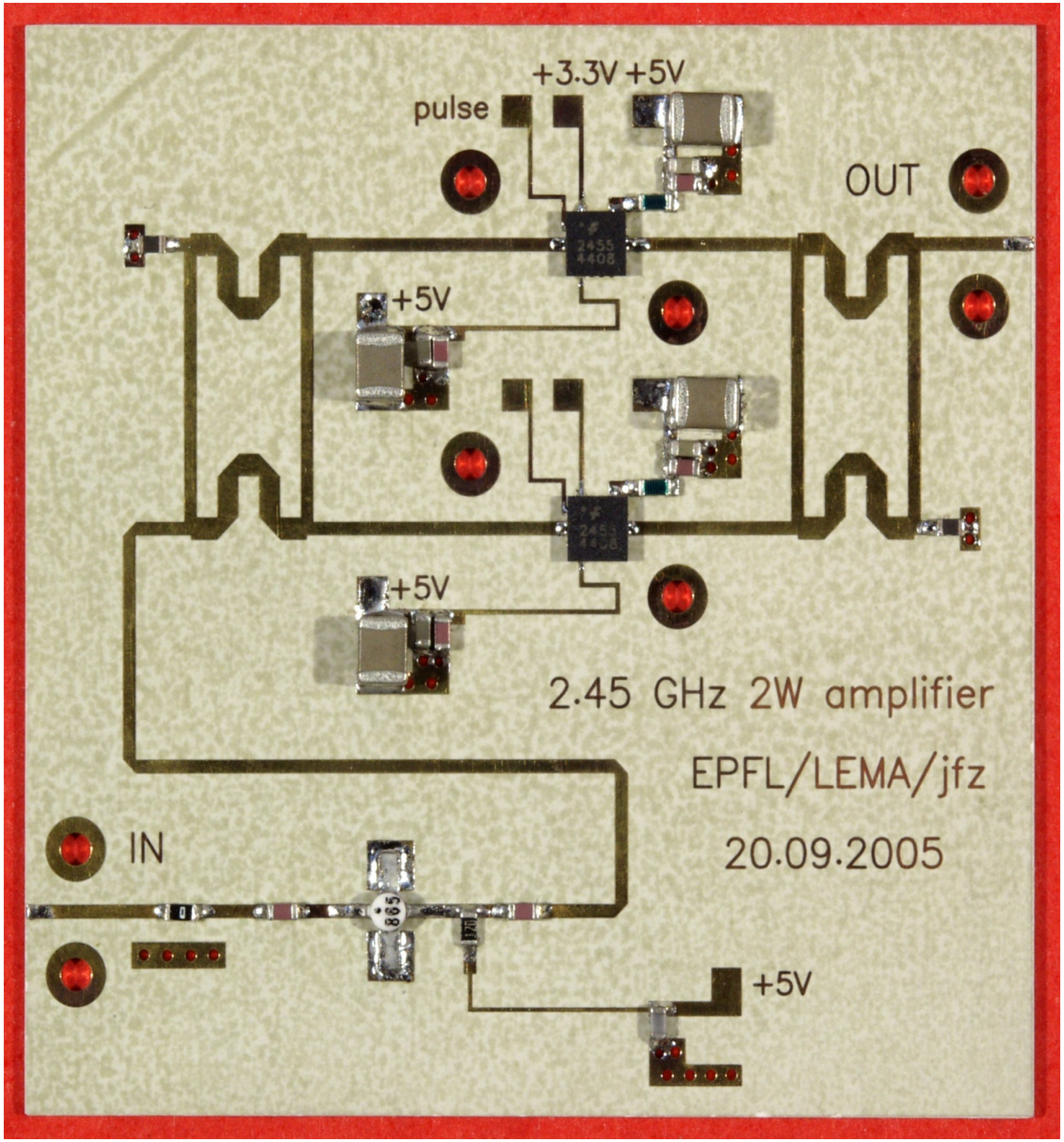


Printed lines

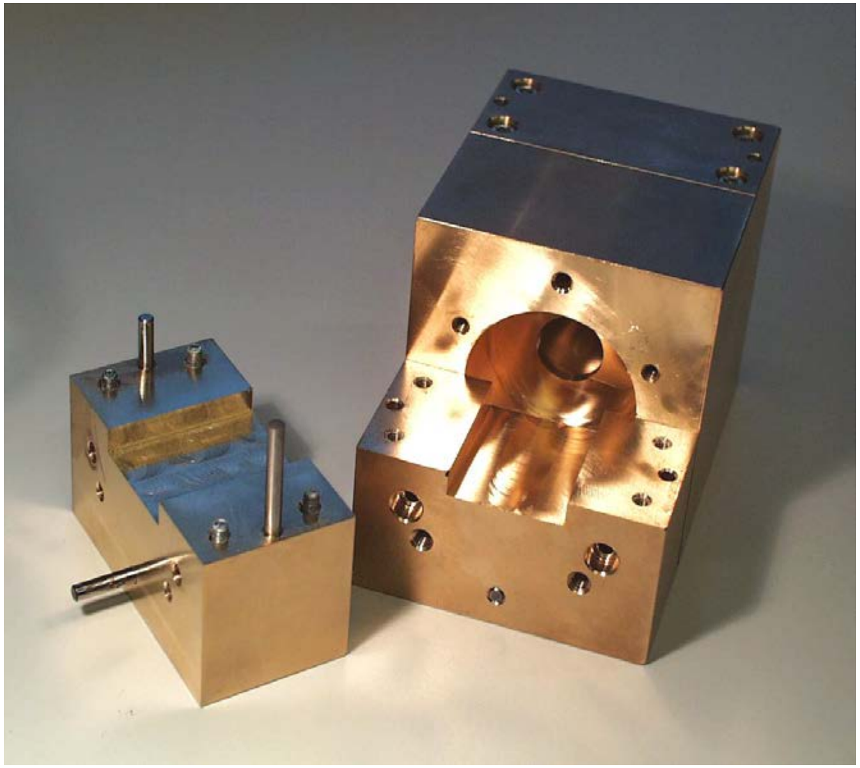


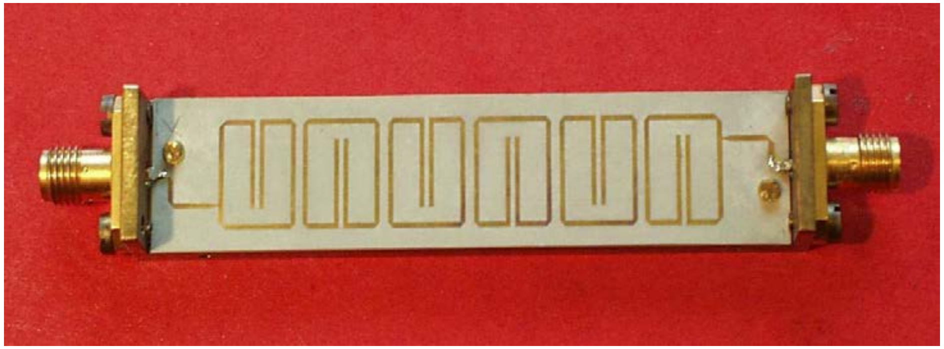
Printed lines



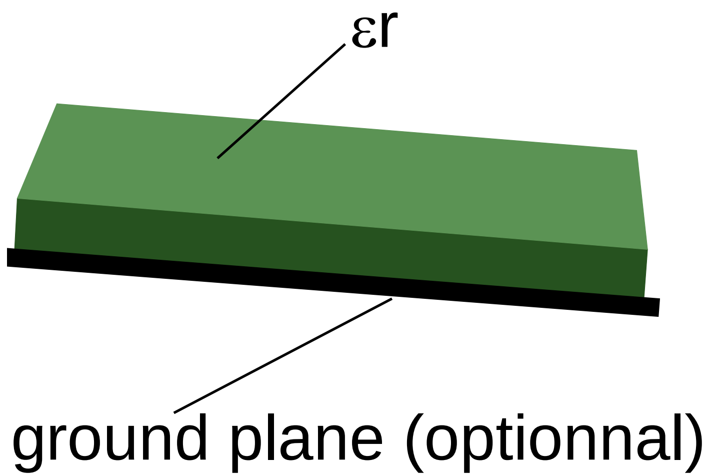

pulse
+3.3V +5V
OUT
+5V
+5V
2.45 GHz 2W amplifier
EPFL/LEMA/jfz
20.09.2005
IN
+5V

Printed lines





Dielectric substrate



$\mu_r = 1$

Usual substrates : ceramics

- Ceramics : Alumina (Al_2O_3) and Beryllium Oxydes (BeO)
  - $6<\varepsilon_r<10$ $2\ 10^{-4} < \tan\delta < 4\ 10^{-4}$
- Synthetic materials

Usual substrates : synthetic materials

- Polystyren, polyolfin, polyester, polytetrafluoretylen (Teflon)
  - $2 < \varepsilon_r < 3$ tan δ around $5\ 10^{-4}$
- Synthetic materials charged with ceramic powder or glass fibres
  - $2 < \varepsilon_r < 10$ tan δ around $1\ 10^{-3}$
- FR4
  - $\varepsilon_r = 4.4$ tan δ around $2\ 10^{-2}$

Usual substrates : integrated circuit substrates

- Silicon

  $\varepsilon_r = 11.9$ tan δ around $4\ 10^{-4}$

- Gallium Arsenide

  $\varepsilon_r = 13$ tan δ around $6\ 10^{-4}$

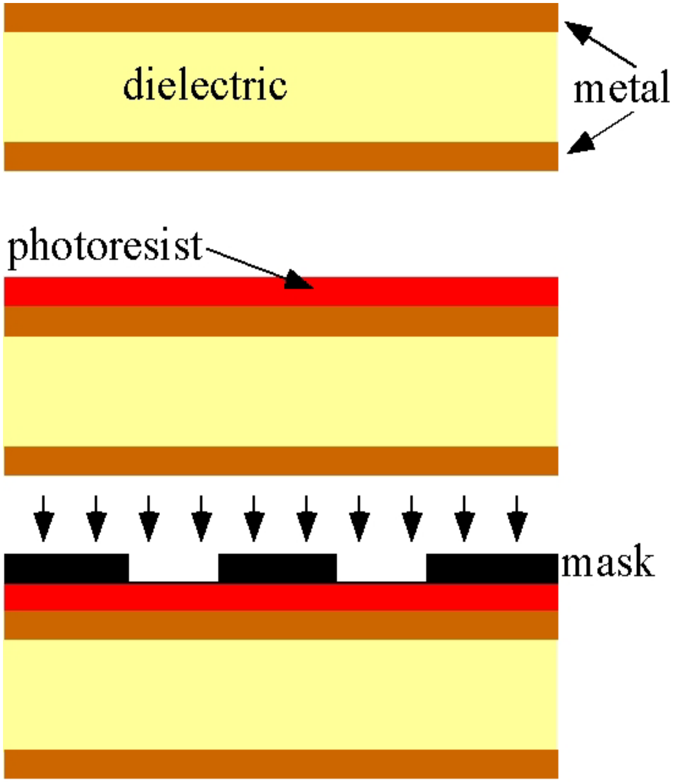
Printed microwave lines : advantages

- Cheap
- easy to manufacture
- good repetability
- Light in weight, lowprofile
- Compatible with integrated circuits

Printed microwave lines : drawbacks

- relative high losses
- dispersion
- inhomogeneous structures , thus difficult to analyze

Thinn film manufacturing process

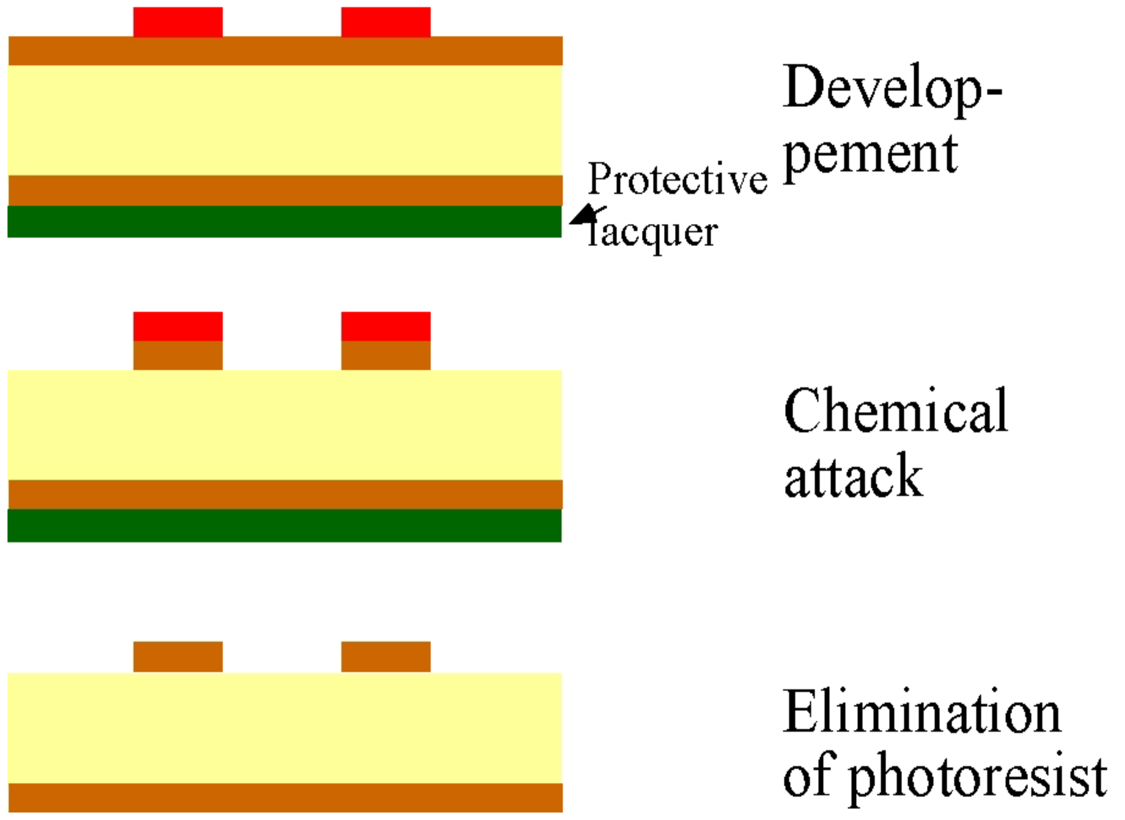


Initial material

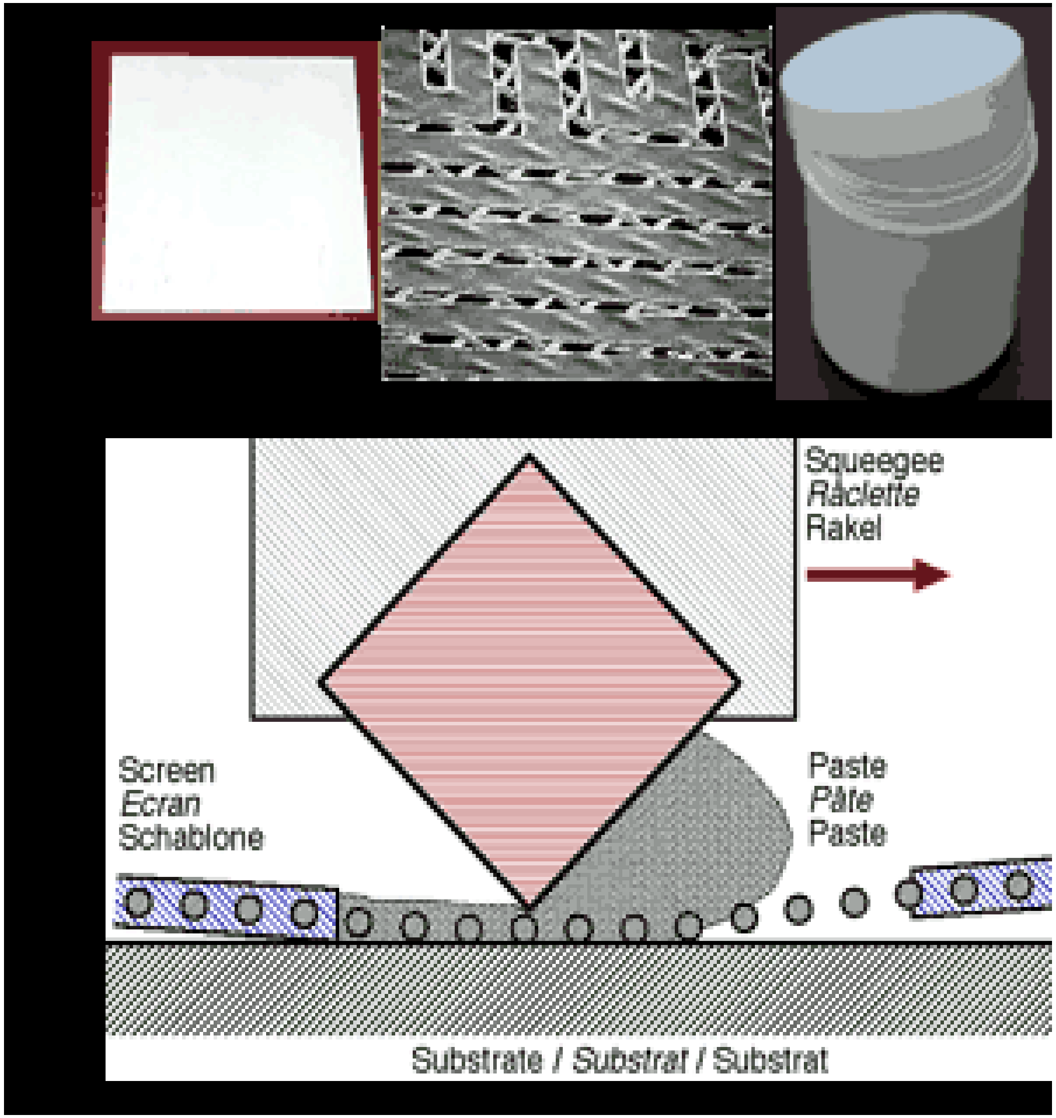
Deposition of Photoresist

UV insolation

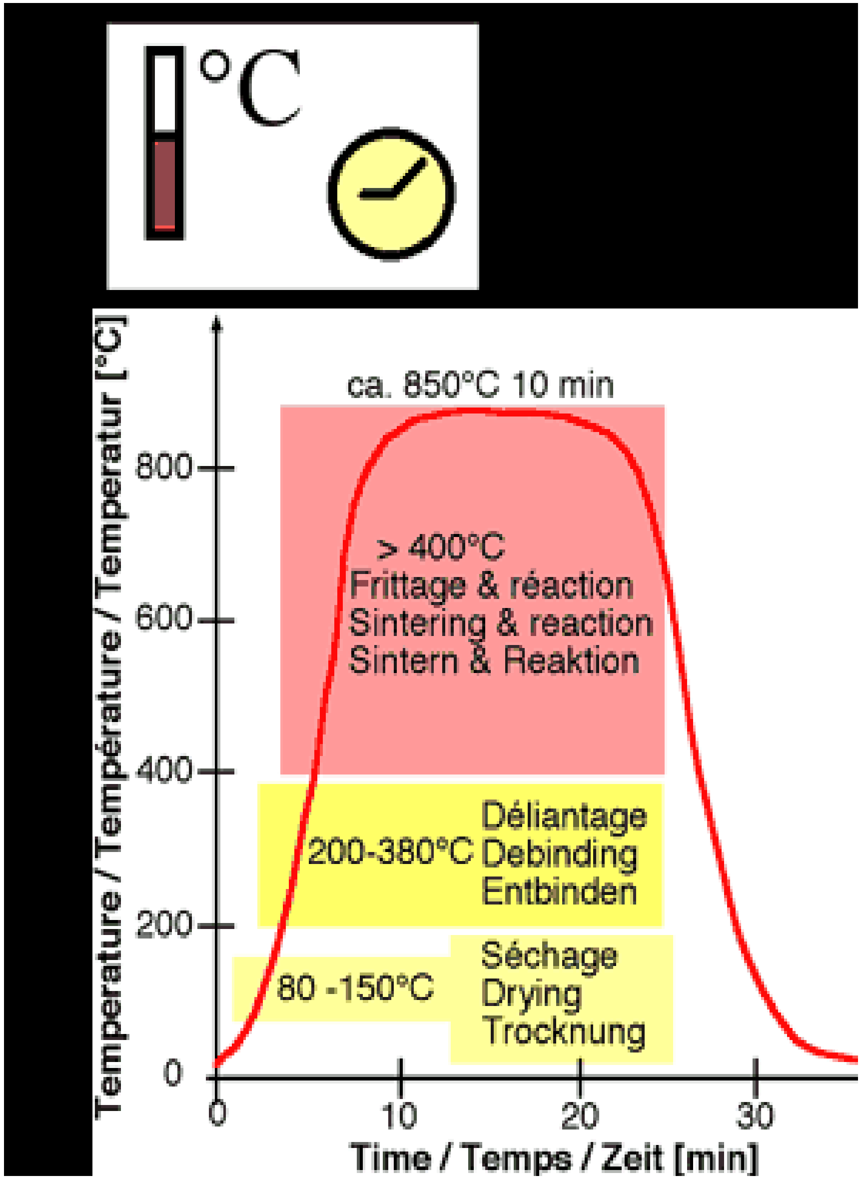
Thinn film manufacturing process



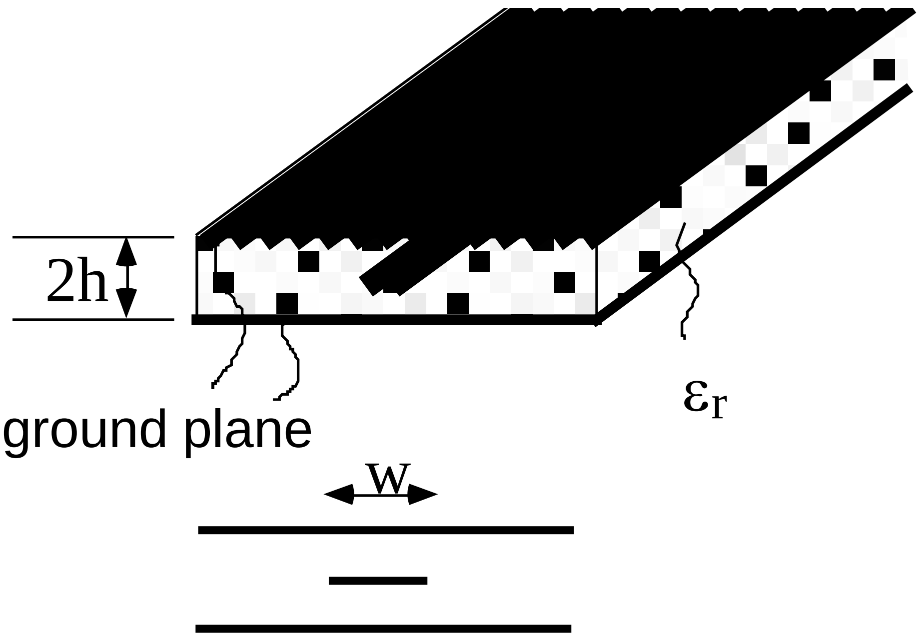
Thick film


Squeegee
Raclette
Rakel
Screen
Ecran
Schablone
Paste
Pâte
Paste
Substrate / *Substrat* / Substrat

Thick film


°C
ca. 850°C 10 min
> 400°C
Frittage & réaction
Sintering & reaction
Sintern & Reaktion
200-380°C
Déliantage
Debinding
Entbinden
80 -150°C
Séchage
Drying
Trocknung
Temperature / Température / Temperatur [°C]
800
600
400
200
0
0
10
20
30
Time / Temps / Zeit [min]

Stripline



stripline

- homogeneous dielectric
- two distinct conductors

TEM mode is supported

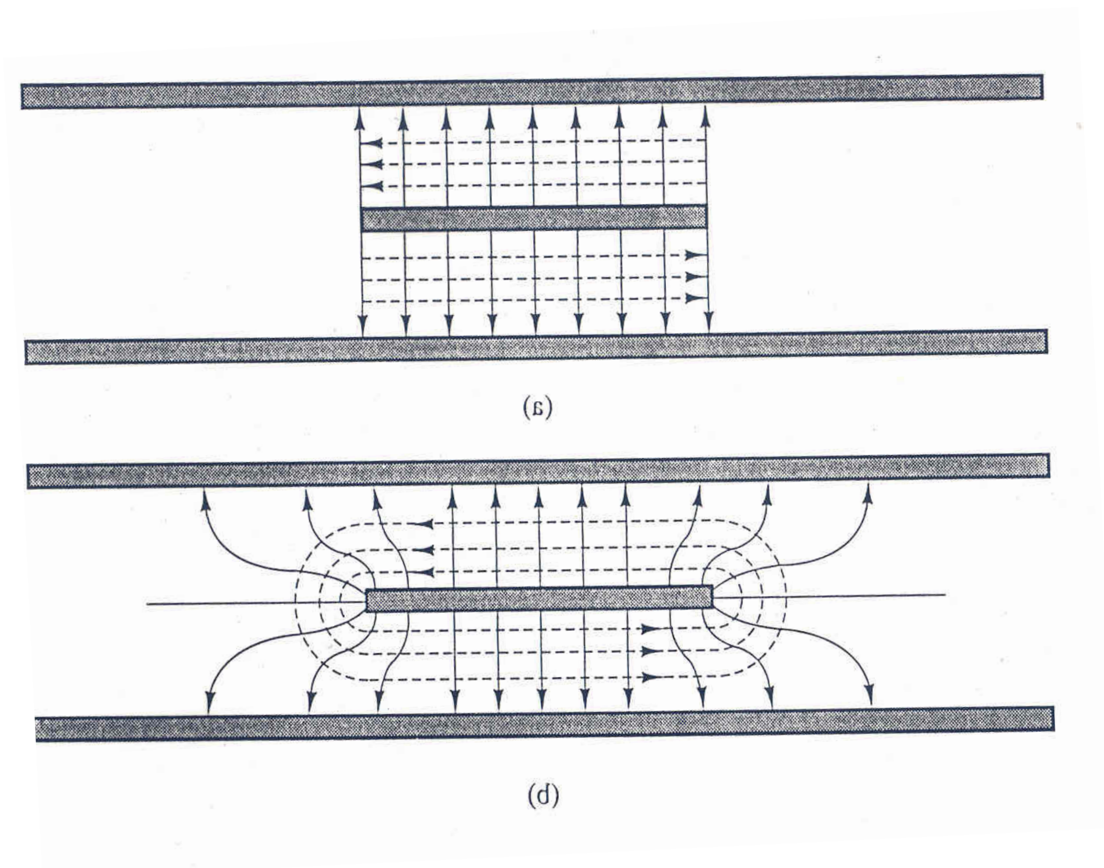
stripline : TEM modes

- We want to know :
  - Characteristic impedance
  - group velocity
  - phase velocity
  - propagation constant
  - guided wavelength

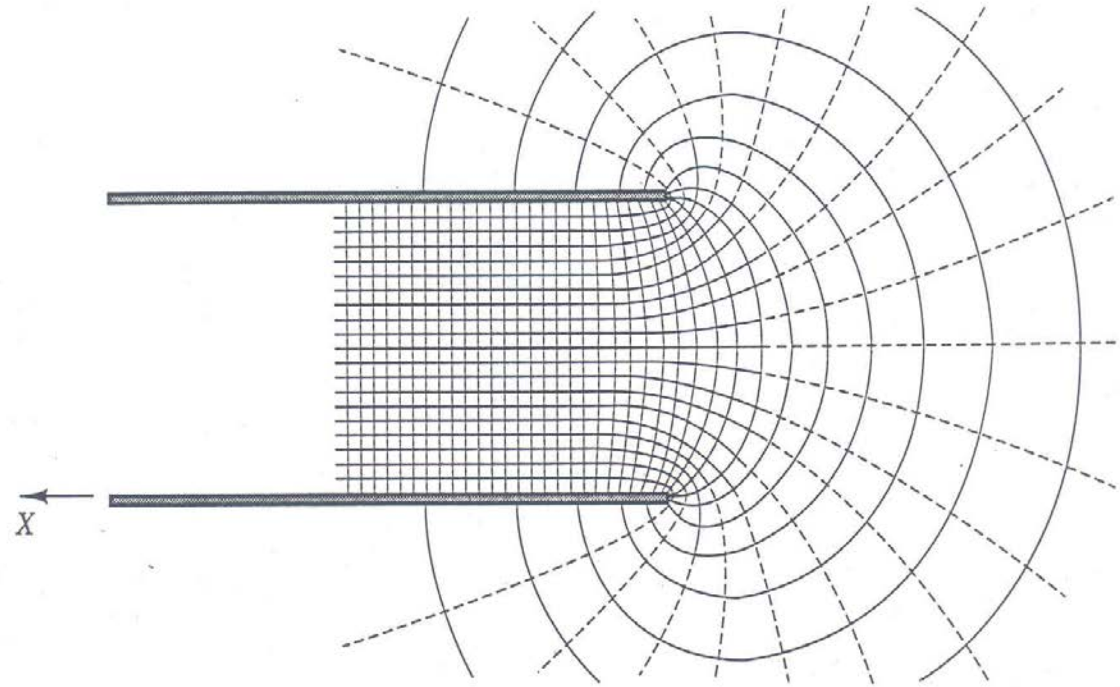
Stripline : approximation

Stripline equivalent to two parallel plate waveguides in parallel

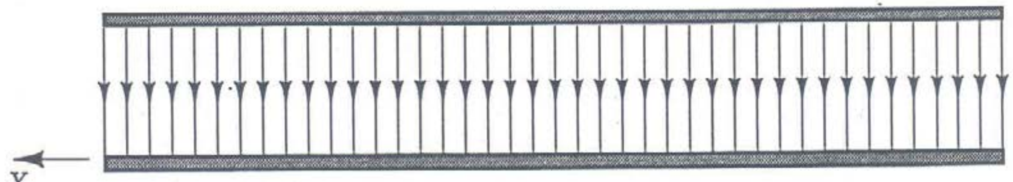
Stripline : approximation



Parallel plate waveguide



(b)



(c)

Parallel plate waveguide : TEM mode

$$\beta = \omega\sqrt{\varepsilon_r \varepsilon_o \mu_o} = \sqrt{\varepsilon_r}\, k_o$$

$$v_\varphi = \frac{\omega}{\beta} = \frac{1}{\sqrt{\varepsilon_r \varepsilon_o \mu_o}} = \frac{c}{\sqrt{\varepsilon_r}}$$

$$v_g = \left(\frac{\partial \beta}{\partial \omega}\right)^{-1} = \frac{1}{\sqrt{\varepsilon_r \varepsilon_o \mu_o}} = \frac{c}{\sqrt{\varepsilon_r}}$$

$$\lambda = \frac{2\pi v_\varphi}{\omega} = \frac{\lambda_o}{\sqrt{\varepsilon_r}}$$

Parallel plate waveguide : TEM mode

Characterisitc impedance

$$u(z) = -\int_{y=0}^{y=b} \mathbf{E}\cdot\mathbf{dl} = V_o\,\mathrm{e}^{-\gamma z}$$

$$i(z) = \oint_{1conduct} \mathbf{H}\cdot\mathbf{dl} = \frac{\sqrt{\varepsilon_r\varepsilon_o}V_o}{\sqrt{\mu_o}}\frac{w}{b}\mathrm{e}^{-\gamma z}$$

Z_o=120 π

$$Z_c = \frac{u}{i} = \frac{b}{w}\frac{\sqrt{\mu_o}}{\sqrt{\varepsilon_r\varepsilon_o}} = \frac{b}{w}\frac{Z_o}{\sqrt{\varepsilon_r}}$$

Stripline

Propagation coeff., phase and group velocities, wavelength identical to parallel plate waveguide

$$\beta = \omega\sqrt{\varepsilon_r \varepsilon_o \mu_o} = \sqrt{\varepsilon_r} k_o$$

$$v_\varphi = \frac{\omega}{\beta} = \frac{1}{\sqrt{\varepsilon_r \varepsilon_o \mu_o}} = \frac{c}{\sqrt{\varepsilon_r}}$$

$$v_g = \left(\frac{\partial \beta}{\partial \omega}\right)^{-1} = \frac{1}{\sqrt{\varepsilon_r \varepsilon_o \mu_o}} = \frac{c}{\sqrt{\varepsilon_r}}$$

$$\lambda = \frac{2\pi v_\varphi}{\omega} = \frac{\lambda_o}{\sqrt{\varepsilon_r}}$$

Stripline

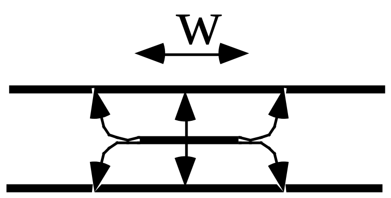
Characterisitic impedance corresponding in first approximation to two parallel plate waveguides in parallel

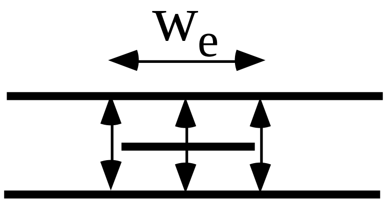
$$Z_c = \left(\frac{1}{Z_c^{paral.}} + \frac{1}{Z_c^{paral.}} \right)^{-1} = \frac{h}{2w} \frac{Z_o}{\sqrt{\varepsilon_r}}$$

Stripline : second order approximation (analysis)

$$Z_c = \frac{30\pi}{\sqrt{\varepsilon_r}} \frac{2h}{w_e + 0.441(2h)}$$

$$\frac{w_e}{2h} = \frac{w}{2h} - \begin{cases} 0 \quad pour \quad \dfrac{w}{2h} > 0.35 \\ \left(0.35 - \dfrac{w}{2h}\right)^2 \quad pour \quad \dfrac{w}{2h} < 0.35 \end{cases}$$

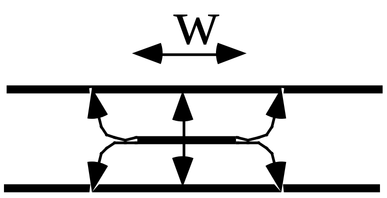


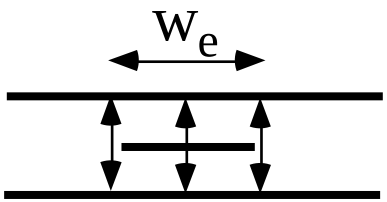


Stripline : second order approximation (synthesis)

$$\frac{w}{2h} = \begin{cases} x \quad pour \quad \sqrt{\varepsilon_r} Z_c < 120 \\ 0.85 - \sqrt{0.6 - x} \quad pour \quad \sqrt{\varepsilon_r} Z_c > 120 \end{cases}$$

$$x = \frac{30\pi}{\sqrt{\varepsilon_r} Z_c} - 0.441$$





Stripline : attenuation

$$\alpha = \alpha_d + \alpha_c \quad [Np/m]$$

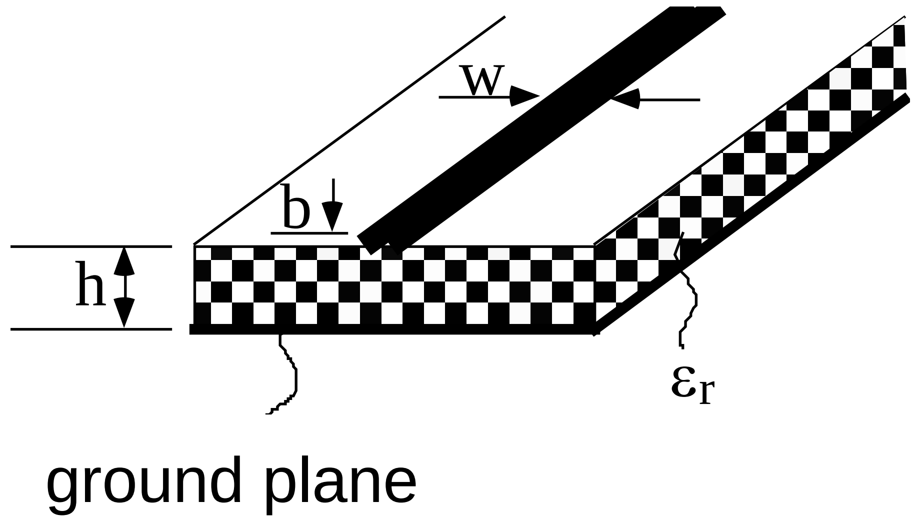
$$\alpha_d = \frac{k \tan\delta}{2} \quad [Np/m]$$

$$\alpha_c = \begin{cases} \dfrac{0.0027 R_s \varepsilon_r Z_c}{30\pi(2h-t)} A & pour \quad \sqrt{\varepsilon_r} Z_c < 120 \\ \dfrac{0.16 R_s}{Z_c 2h} B & pour \quad \sqrt{\varepsilon_r} Z_c > 120 \end{cases} \quad [Np/m]$$

$$A = 1 + \frac{2w}{2h-t} + \frac{2h+t}{\pi(2h-t)} \ln\left(\frac{4h-t}{t}\right) \qquad R_s = \sqrt{\frac{\omega\mu}{2\sigma}}$$

$$B = 1 + \frac{2h}{(0.5w+0.7t)}\left(0.5 + \frac{0.414t}{w} + \frac{1}{2\pi}\ln\frac{4\pi w}{t}\right)$$

microstrip line

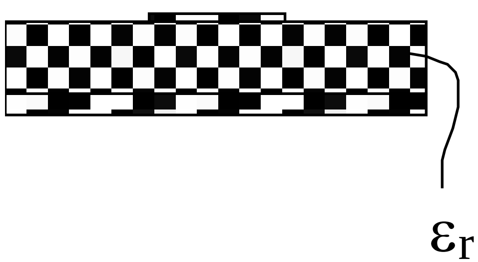


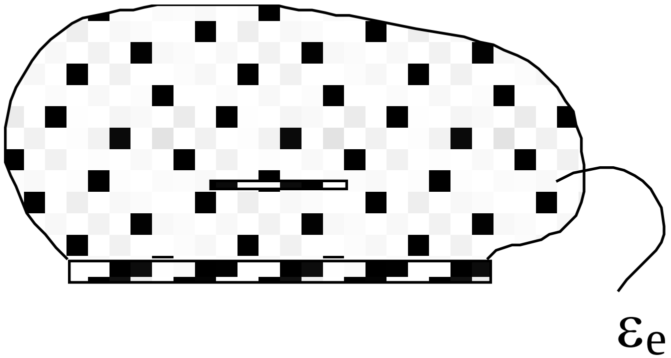
microstrip line

- inhomogeneous line, but two conductors (line and ground plane)

Quasi TEM mode

microstrip line : effective permittivity





$$v_\varphi = \frac{c}{\sqrt{\varepsilon_\mathrm{e}}}$$

$$\beta = k_o \sqrt{\varepsilon_\mathrm{e}}$$

$$1 < \varepsilon_\mathrm{e} < \varepsilon_r$$

microstrip line : effective permittivity

$$\varepsilon_{\mathrm{e}} = \frac{1}{2}\left(\varepsilon_r + 1\right) + \frac{1}{2}\left(\varepsilon_r - 1\right)\left[\left(1 + 12\frac{h}{w}\right)^{-0.5} + 0.04\left(1 - \frac{w}{h}\right)^{2}\right] \quad pour \quad \frac{w}{h} \leq 1$$

$$\varepsilon_{\mathrm{e}} = \frac{1}{2}\left(\varepsilon_r + 1\right) + \frac{1}{2}\left(\varepsilon_r - 1\right)\left(1 + 12\frac{h}{w}\right)^{-0.5} \quad pour \quad \frac{w}{h} \geq 1$$

microstrip line : effective permittivity

Error : less than 1 % for $0.05 \leq w/h \leq 20$ et $\varepsilon_r \leq 16$

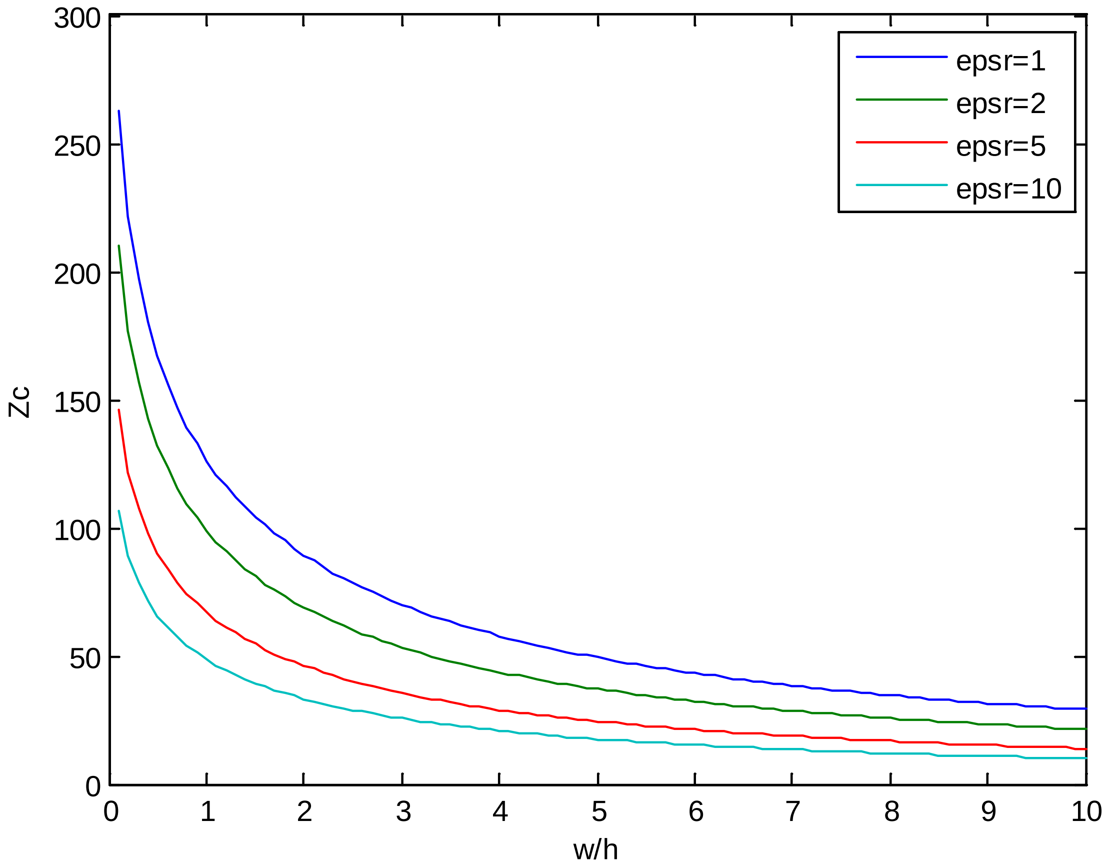
microstrip line : characteristic impedance (analysis)

$$Z_c = \frac{Z_o}{2\pi\sqrt{\varepsilon_{\mathrm{e}}}}\ln\left(\frac{8h}{w}+\frac{w}{4h}\right) \quad pour \quad \frac{w}{h}\leq 1$$

$$Z_c = \frac{Z_o}{\sqrt{\varepsilon_{\mathrm{e}}}}\left(\frac{w}{h}+1.393+0.667\ln\left(\frac{w}{h}+1.444\right)\right)^{-1} \quad pour \quad \frac{w}{h}>1$$

where $Z_o = 120\pi$ is the charactersitic impedance of the vacuum

microstrip line : characteristic impedance (analysis)



microstrip line : characteristic impedance (synthesis)

$$\frac{w}{h} = 4\left[\frac{1}{2}\mathrm{e}^{A} - \mathrm{e}^{-A}\right]^{-1} \quad pour \quad \frac{w}{h} \leq 2$$

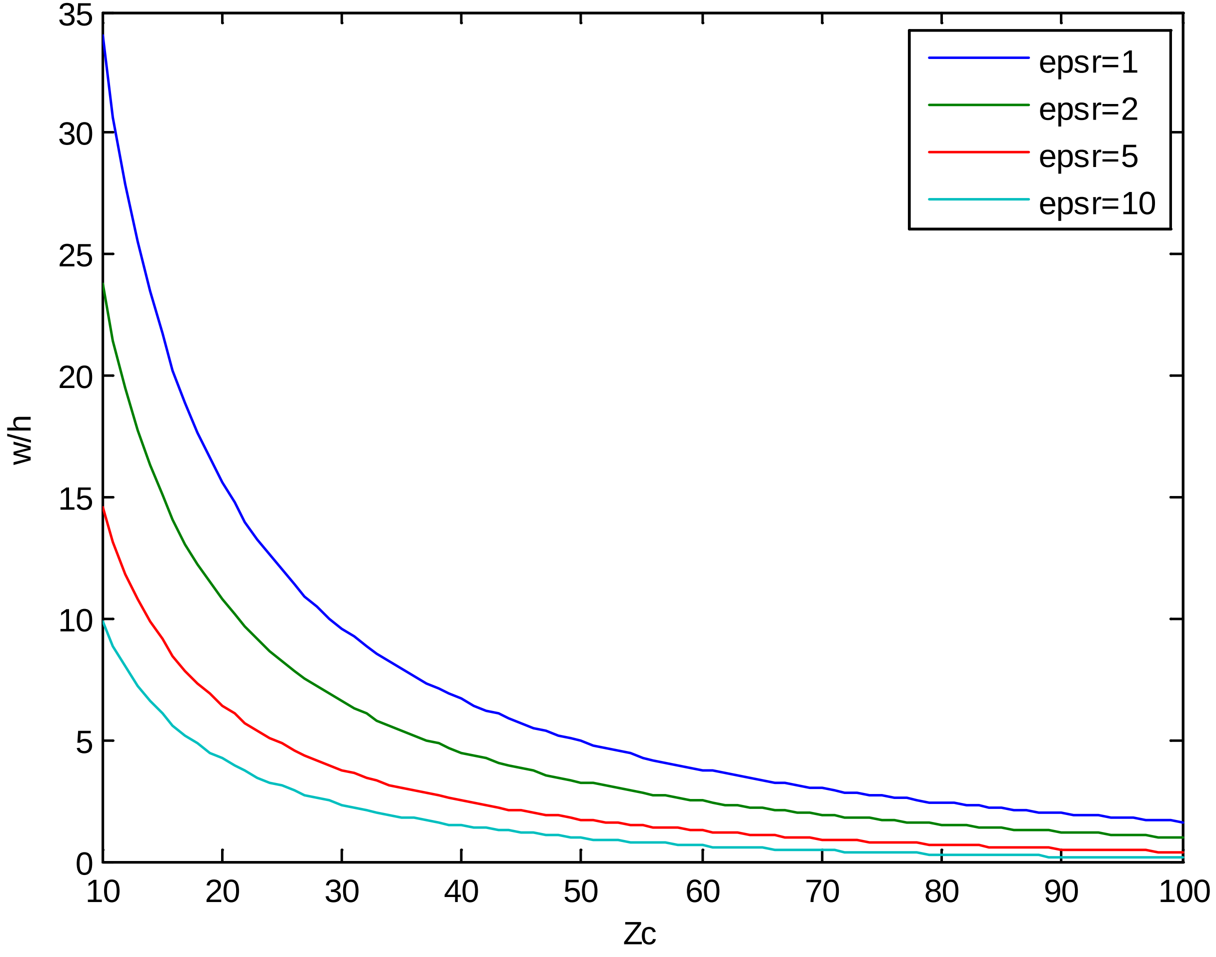
$$\frac{w}{h} = \frac{\varepsilon_r - 1}{\pi\varepsilon_r}\left(\ln(B-1) + 0.39 - \frac{0.61}{\varepsilon_r}\right) + \frac{2}{\pi}\left(B - 1 - \ln(2B-1)\right) \quad pour \quad \frac{w}{h} \geq 2$$

with

$$A = \frac{Z_c}{Z_o}\pi\sqrt{2(\varepsilon_r + 1)} + \frac{\varepsilon_r - 1}{\varepsilon_r + 1}\left(0.23 + \frac{0.11}{\varepsilon_r}\right)$$

$$B = \frac{\pi}{2\sqrt{\varepsilon_r}}\frac{Z_o}{Z_c}$$

microstrip line : characteristic impedance (synthesis)



Attenuation in a microstrip line

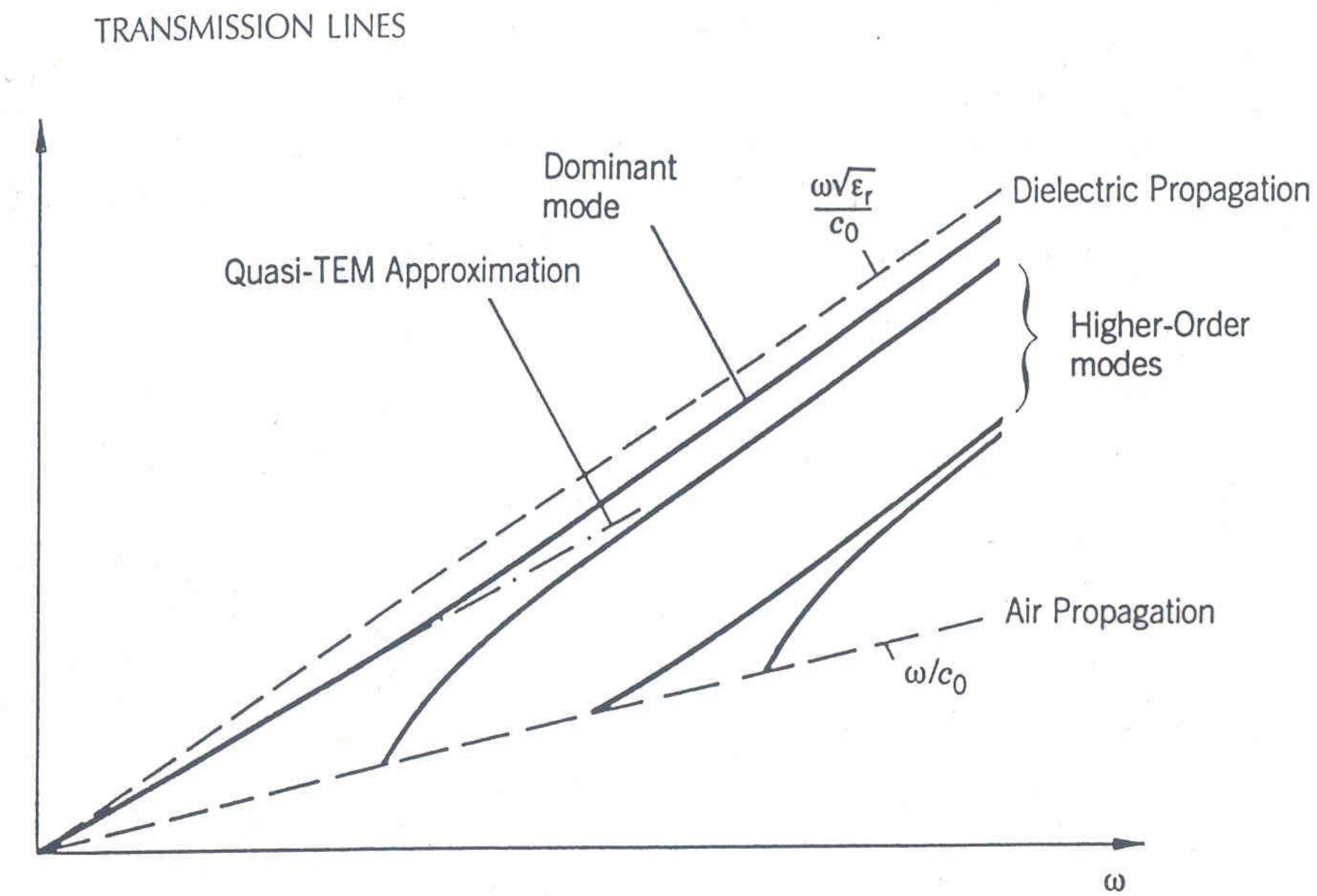
$$\alpha = \alpha_d + \alpha_c \quad [Np/m]$$

$$\alpha_d = \frac{k_o \varepsilon_r (\varepsilon_e - 1) \tan\delta}{2\sqrt{\varepsilon_e}(\varepsilon_r - 1)} \quad [Np/m]$$

$$\alpha_c = \frac{R_s}{wZ_c} \quad [Np/m]$$

$$R_s = \sqrt{\frac{\omega\mu}{2\sigma}}$$

Modes in a microstrip line



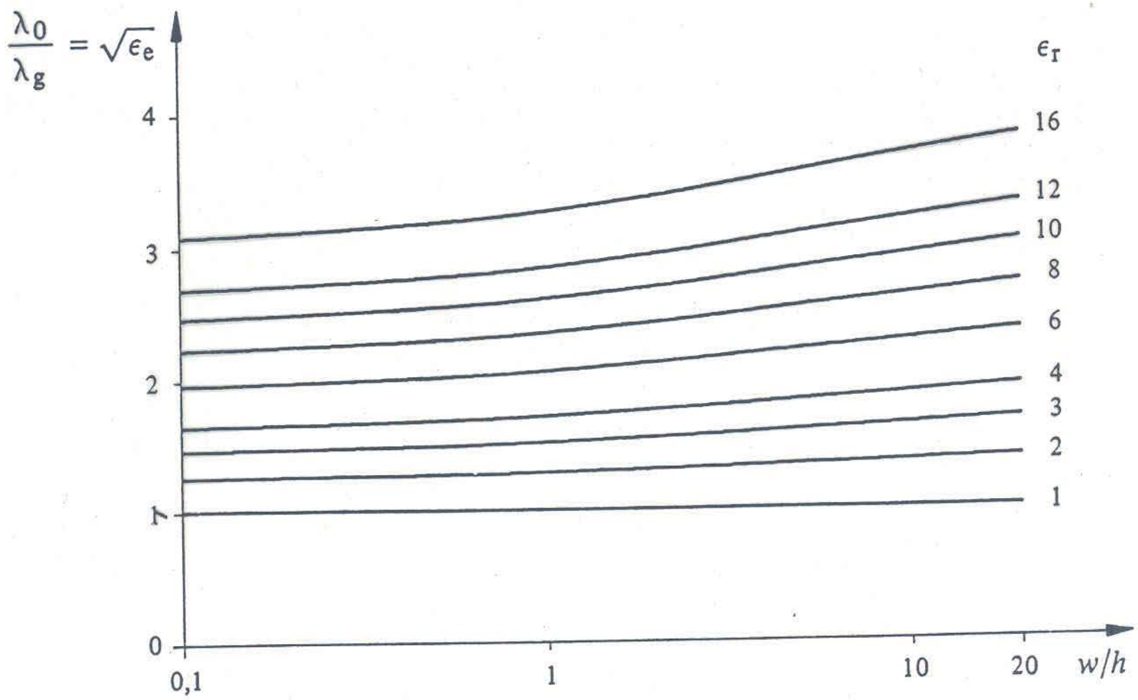
Dispersion in a microstrip line

$$\varepsilon_{\mathrm{ed}}(f) = \varepsilon_r - \frac{\varepsilon_r - \varepsilon_{\mathrm{e}}}{1 + \left(\frac{f}{f_p}\right)^2 G}$$

$$f_p = \frac{Z_c}{2h\mu_o}$$

$$G = 0.6 + 0.009 Z_c$$

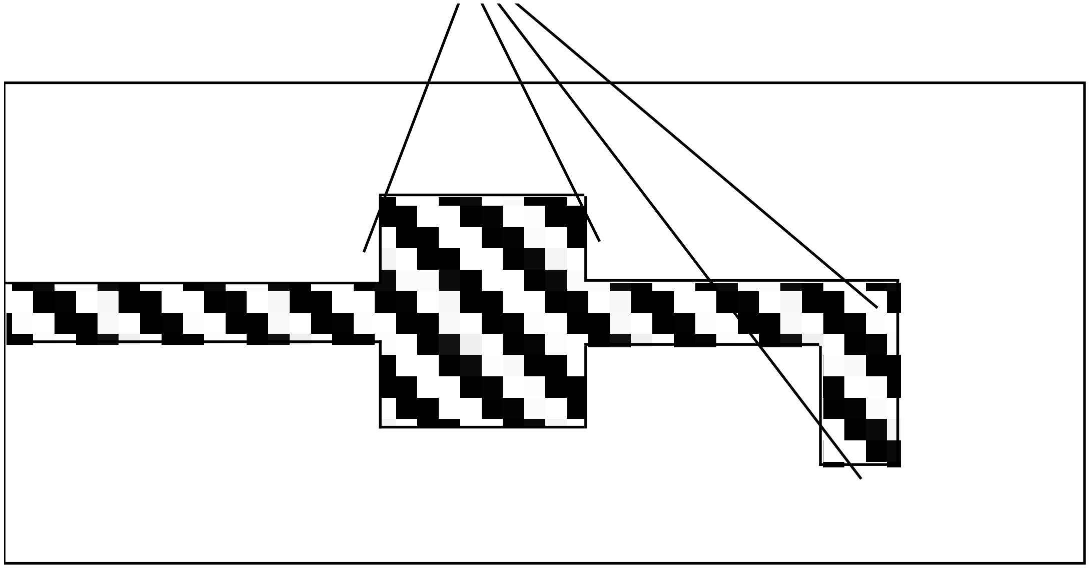
Dispersion in a microstrip line



Radiation of a microstrip line

A TEM mode does not radiate => radiation occurs when higher order modes are excited

Local excitation of higher order modes

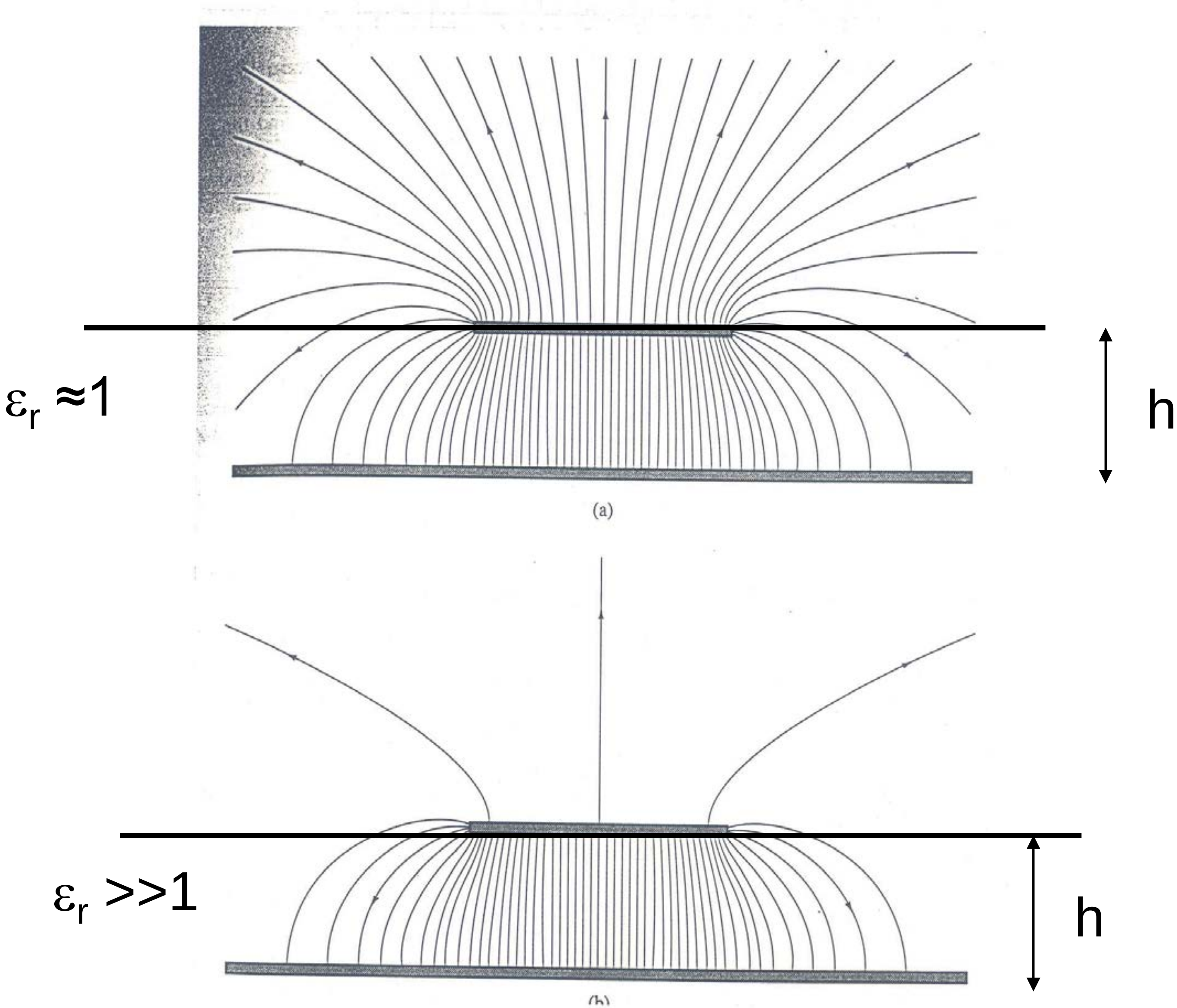


Radiation of a microstrip line

For a 50 Ω line, the frequency f_m for which the radiated power remains lower than 1 % of the total power is given by :

$$f_m\left[GHz\right] = \frac{2.14\sqrt[4]{\varepsilon_r}}{h\left[mm\right]}$$

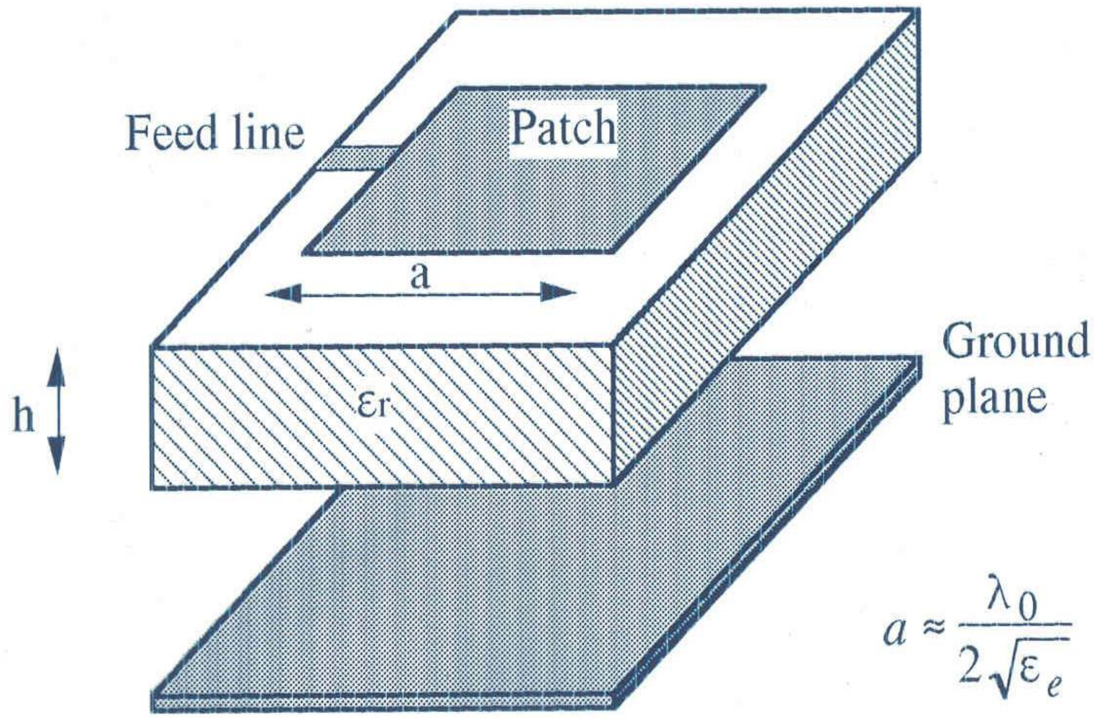
Radiation of a microstrip line



Radiation of a microstrip line

	h/λ_o	ε_r
Guided waves	↓	↑
Radiated waves	↑	↓

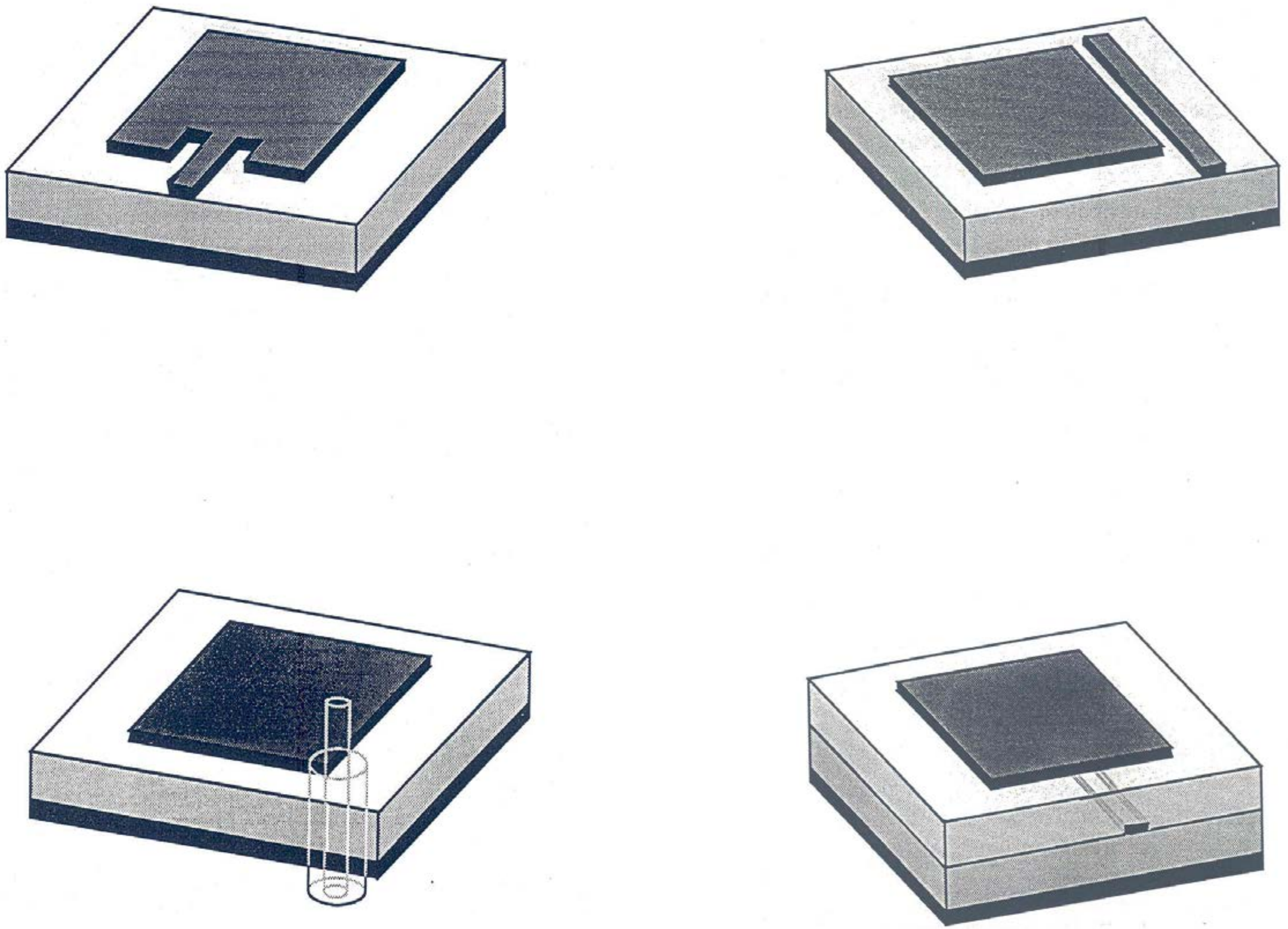
microstrip antenna



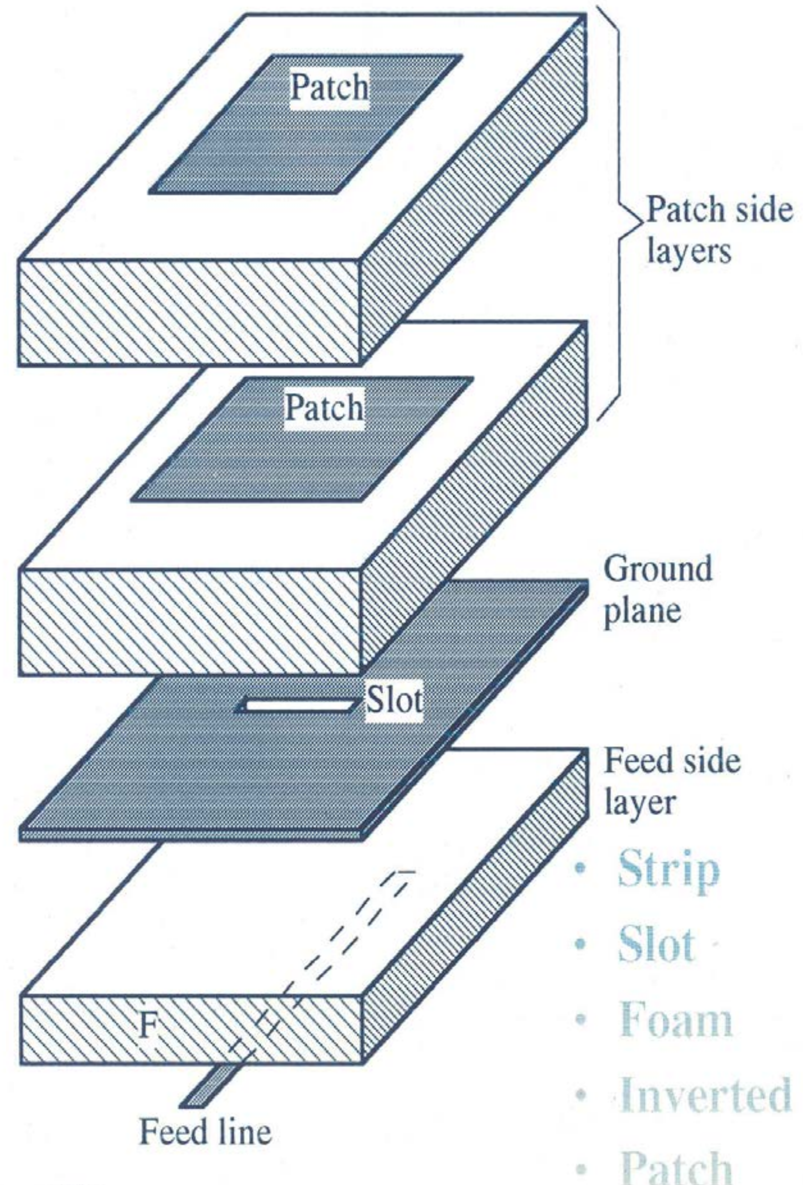
$$a \approx \frac{\lambda_0}{2\sqrt{\varepsilon_e}}$$

$$1 < \varepsilon_e < \varepsilon_r$$

microstrip antenna

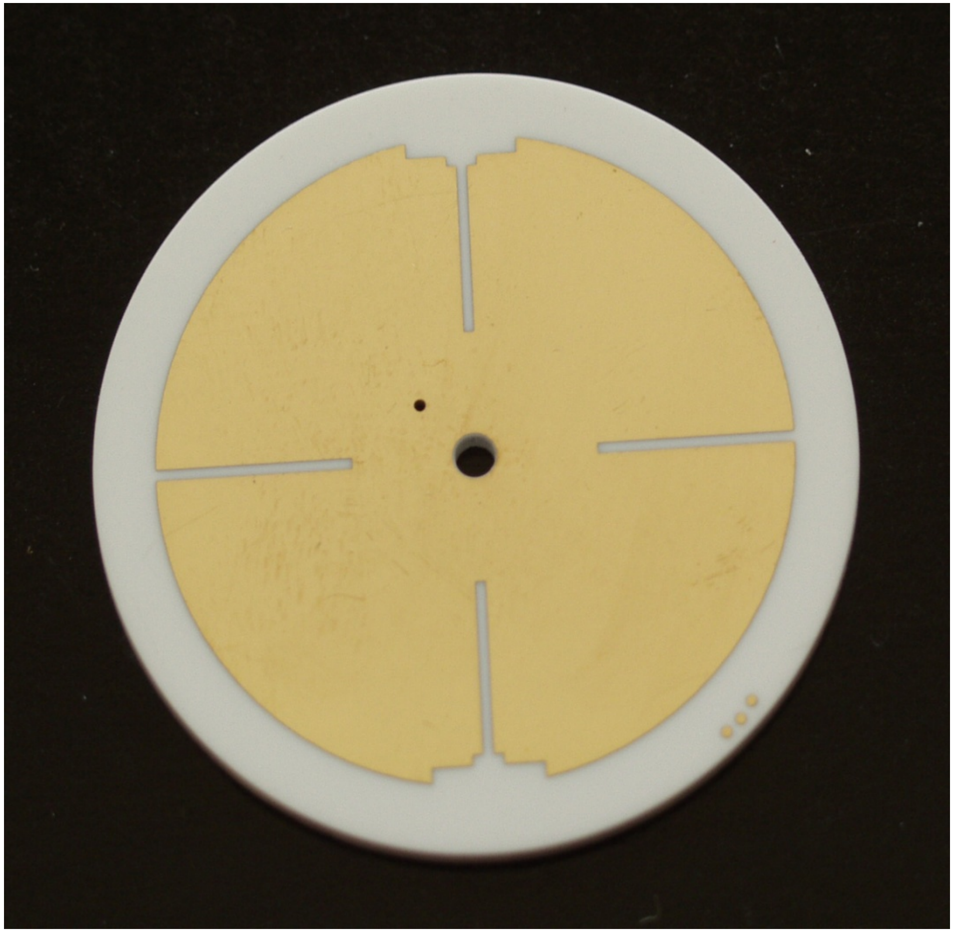


microstrip antenna



Microstrip antenna

Microstrip antenna



	coaxial cable	Waveguide	stripline	microstrip
Dom. mode	TEM	TE_{10}	TEM	Quasi TEM
other	TE, TM	TE, TM	TE, TM	Hybrid
Dispersion	none	medium	none	low
Bandwidth	high	low	high	high
Lossess	medium	low	high	high
Max Power	medium	high	low	low
Size	big	big	medium	small
Manufactur.	medium	difficult	easy	easy
Component	difficult	difficult	medium	easy