Feeding Networks

Basic Concepts, Principal Devices

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Outline

Introduction
Transmission Lines Architecture
Some Feeding Devices

Printed líne

A printed line Consists of:

Line :

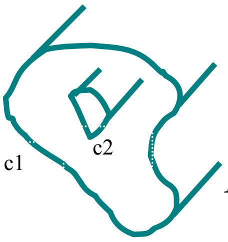
- Metallic surface
- Extremely thin surface (thickness: 10 – 50μm ⇒ typical: 18μm y 35μm)

Substrate :

- Dielectric layer. Thickness: 0.003λ - 0.05λ
- Dielectric Constants within the range: $1 \le \varepsilon_r \le 12$

Ground plane.

Transmission Line Theory



TEM Mode

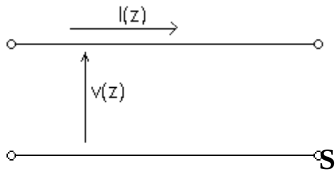
$$\left.\begin{aligned}\vec{E}_t(u_1,u_2,z) &= (-\nabla\phi)e^{-\gamma_o z}\\ \vec{H}_t(u_1,u_2,z) &= \frac{\hat{z}\wedge(-\nabla\phi)e^{-\gamma_o z}}{\eta}\end{aligned}\right\} \rightarrow$$

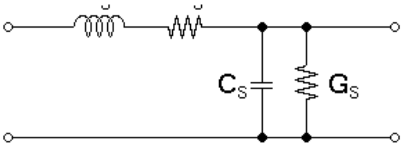
$$\int_{c1}^{c2}\nabla\phi e^{-\gamma_o z}\cdot d\vec{l} = V(z) \longleftarrow \textbf{POTENTIAL WAVE}$$

$$I(z) = \int_{c2} j_s dl = \int_{c2}\hat{n}_s \wedge \hat{H}_t dl = \int_{c2}\frac{-\nabla\phi\cdot\hat{n}_s}{\eta}e^{-\gamma_o z}dl$$

$\uparrow$ **CURRENT WAVE**

Transmission line model:





Primary Parameters :

$$Z = \frac{V(z)}{I(z)} = \eta\frac{\int_{c1}^{c2}\nabla\phi e^{-\gamma_o z}\cdot d\vec{l}}{\int_{c2}\frac{-\nabla\phi\cdot\hat{n}_s}{\eta}e^{-\gamma_o z}d\vec{l}} = \overset{\substack{\text{Characteristic}\\ \text{Impedance}\\ \downarrow}}{\eta}\cdot k_g \leftarrow \text{Geometric Constant}$$

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

Secondary Parameters :

$$Cs = \frac{\varepsilon}{k_g} \qquad Ls = k_g\mu \qquad Gs = \omega C tg\delta$$

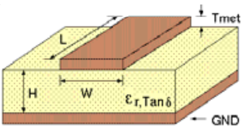
Introduction

Transmission Lines Architecture

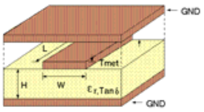
Some Feeding Devices

Basic Models

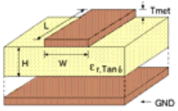
- Microstrip Line



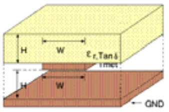
  - Covered microstrip line



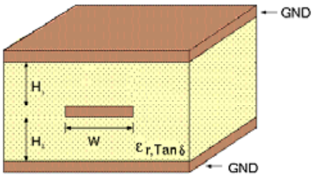
  - Suspended microstrip line



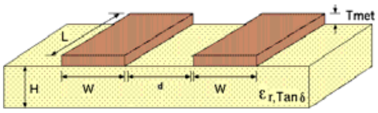
  - Inverted microstrip line



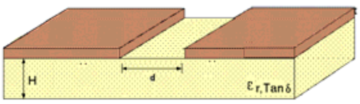
- Stripline



- Coplanar



- Slot



Features

- Basic Features:
  - Line width w
  - Line thickness t
  - Line losses α_c
  - Substrate thickness h
  - Substrate dielectric constant ε_r
  - Substrate losses: loss tangent $tan(\delta)$
  - Radiation losses α_r
- Main parameters:
  - Characteristic impedance Z
  - Effective dielectric Constant ε_{eff}

[1] B. C. Wadell, “Transmission Line Design Handbook”, Artech House, London, 1991

Features

- Phase velocity v_p : $$v_p = \frac{c_0}{\sqrt{\mu_r \varepsilon_r}}$$
- Layer Wavelength λ_g : $$\lambda_g = \frac{\lambda_0}{\sqrt{\mu_r \varepsilon_r}}$$

Non-homogeneous dielectric:

$$\lambda_g = \frac{\lambda_0}{\sqrt{\varepsilon_{eff}}} \qquad v_{pg} = \frac{c_0}{\sqrt{\varepsilon_{eff}}}$$

- Non-homogeneous dielectrics: when we have several dielectric layers (multilayer structure) or even when ε_r, μ_r change, depending on the dielectric layer position.
- The effective dielectric layer ε_{eff} takes into account the wave propagation inside non-homogeneous dielectric layers.

Limitations

⇒ We have to Adopt a compromise solution

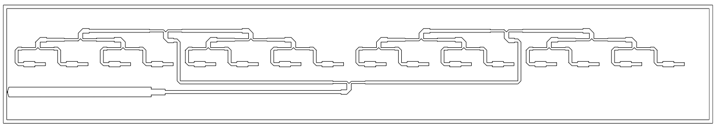
Layer thickness h
- Reduce surface wave losses ⇒ h ↘
- Increase bandwidth⇒ h ↗

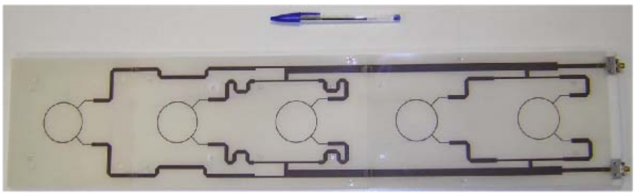
Substrate dielectric constant ε_r
- Tiny structures ⇒ ε_r ↗

Line width w
- $w << \lambda_g/2$
- Decrease undesired line radiation ⇒ $w << \lambda_g/2$

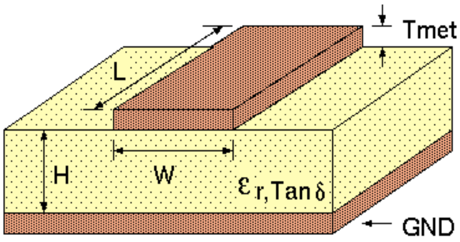
Applications

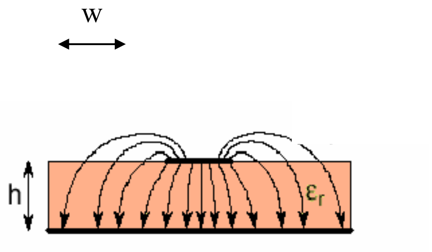
- Feeding network:
  - For antennas
- Printed circuits:
  - Filters
  - Dividers
  - Mixers
  - …





Microstrip Line





- The most common transmission structure for planar antennas.
- The main working mode is quasi-TEM ⇒ almost all the field is concentrated inside the substrate.
- To avoid surface waves → electrically thin substrate ($0.003\lambda < h < 0.05\ \lambda$)
- Dielectric constant ε_r : $2.2 < \varepsilon_r < 12$.

Microstrip Line

•Features:

➢Characteristic line impedance Z : ⇒ $0.05 \le w/h \le 100$, $\varepsilon_r \le 16$ ⇒ 0.2% error

$$Z = \overset{\substack{\text{Layer}\\\text{Impedance}\\\downarrow}}{\frac{\eta_0}{\sqrt{\varepsilon_{eff}}}}\ \overset{\substack{\text{Geometric}\\\text{constant}\\\downarrow}}{K_g} = \frac{\sqrt{\frac{\mu_0}{\varepsilon_0}}}{2\pi\sqrt{\varepsilon_{eff}}}\ln\left(\frac{6+(2\pi-6)\cdot e^{\left(-\left(\frac{30.666\cdot h}{w}\right)^{0.7528}\right)}\cdot h}{w}+\sqrt{1+\frac{4\cdot h^2}{w^2}}\right)$$

Effective dielectric constant ε_{eff} : ⇒ $\varepsilon_r \le 16$, $0.05 \le w/h \le 20$ ⇒ 1% error

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2}+\frac{\varepsilon_r-1}{2}\left[\left(1+\frac{12\cdot h}{w}\right)^{-\frac{1}{2}}+0.04\left(1+\frac{w}{h}\right)^2\right] \qquad w/h < 1$$

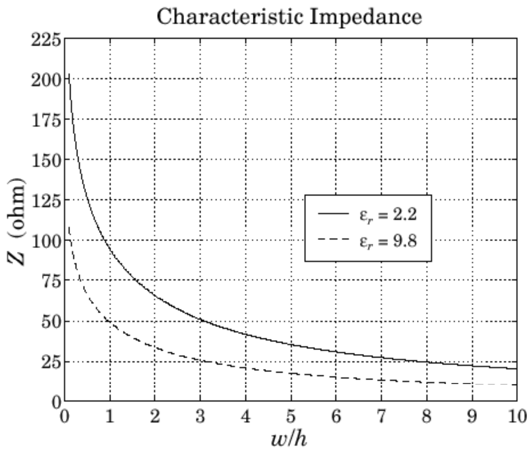
$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2}+\frac{\varepsilon_r-1}{2}\left(1+\frac{12\cdot h}{w}\right)^{-\frac{1}{2}} \qquad w/h \ge 1$$

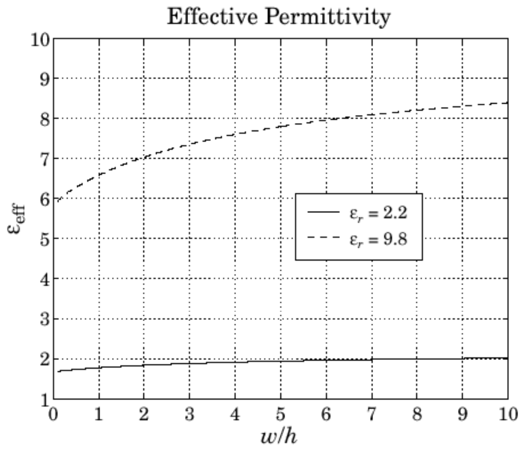
- ▪ < 2% error considering $\varepsilon_r > 16$
- ▪ < 2% error considering $\frac{w}{h} < 0.05$

[1] B. C. Wadell, “Transmission Line Design Handbook”, Artech House, London, 1991.

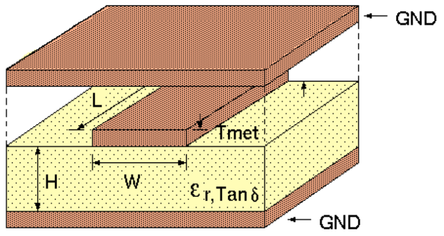
Microstrip Line

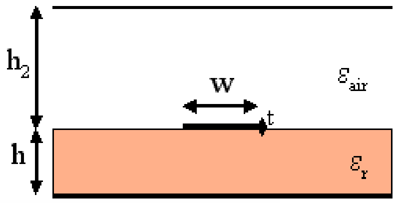
- Typical dielectric substrates used to perform microstrip lines are:
  - RT-Duroid 5880 $\varepsilon_r = 2.2$
  - Alumina (ceramic, Al_2O_4 (97%)) $\varepsilon_r = 9.8$
- Real prototype width/thickness values within the range $0.1 \le \frac{w}{h} \le 10$
- Real prototype characteristic impedance in the range $10 \le Z \le 200$ ohms





Covered microstrip line





- Considering the same dimensions as in a conventional microstrip, the covered microstrip line has a lower impedance, due to the existence of a new ground plane.
- For the same impedance Z (as in the conventional microstrip) $\Rightarrow$ the line width is smaller.
- The effective dielectric constant ε_{eff} for the same dimensions (as in conventional microstrip) is lower.
- When $h_2 \nearrow \Rightarrow$ microstrip line
- When $h_2 \searrow \Rightarrow Z \searrow$ y $\varepsilon_{eff} \searrow$

[1] B. C. Wadell, “Transmission Line Design Handbook”, Artech House, London, 1991.

Covered microstrip line

•**Features :**

➢Characteristic impedance Z :

$$Z = \overset{\substack{\text{Layer}\\ \text{impedance}\\ \downarrow}}{\frac{\eta_0}{\sqrt{\varepsilon_{eff}}}}\overset{\substack{\text{geometric}\\ \text{constant}\\ \downarrow}}{K_g} = \underbrace{\frac{\sqrt{\frac{\mu_0}{\varepsilon_0}}}{2\pi\sqrt{\varepsilon_{eff}}}\ln\left(\frac{6+(2\pi-6)\cdot e^{\left(-\left(\frac{30.666\cdot h}{w}\right)^{0.7528}\right)}\cdot h}{w}+\sqrt{1+\frac{4\cdot h^2}{w^2}}\right)}_{Z_{líneamicrostrip}} - \frac{\Delta Z}{\sqrt{\varepsilon_{eff}}}$$

$$\Delta Z = \left(270\left[1-\tanh\left(1.192+0.706\sqrt{1-\frac{h_2}{h}}-\frac{1.389}{1+\frac{h_2}{h}}\right)\right]\right)\cdot 1.0109-\tanh^{-1}\left(\frac{0.012\frac{w}{h}+0.177\left(\frac{w}{h}\right)^2-0.027\left(\frac{w}{h}\right)^3}{\left(1+\frac{h_2}{h}\right)^2}\right)$$

$\Rightarrow \pm 0.1\%$ error, $0.1 \le w/h \le 6$; $\Rightarrow \pm 0.2\%$ error, $6 \le w/h \le 10$

[1] B. C. Wadell, “Transmission Line Design Handbook”, Artech House, London, 1991.

Covered microstrip line

➢Effective dielectric constant ε_{eff} :

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2}+\alpha\frac{\varepsilon_r-1}{2}$$

–It depends on the superior metallic plane distance, and the line width:

$$\alpha = \tanh\left(1.043+0.121\frac{h_2}{h}-\frac{1.164h}{h_2}\right)\left(\left(1+\frac{10h}{w}\right)^{ab}-\left(\frac{2t\ln(2)}{\pi h\sqrt{\frac{w}{h}}}\right)\right)$$

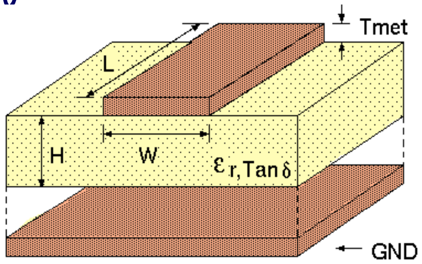
where:

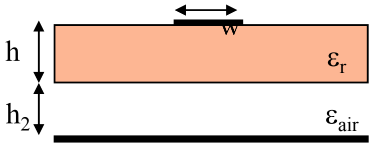
$$a = 1+\frac{1}{49}\ln\left(\frac{\left(\frac{w}{h}\right)^2\left[\left(\frac{w}{h}\right)^2+\left(\frac{1}{52}\right)^2\right]}{\left(\frac{w}{h}\right)^4+0.432}+\frac{1}{18.7}\ln\left(1+\left(\frac{w}{18.1h}\right)^3\right)\right) \qquad b = -0.564\left(\frac{\varepsilon_r-0.9}{\varepsilon_r+3}\right)^{0.053}$$

$\Rightarrow \pm 0.2\%$ error , $0.01 \le w/h \le 100$ y $1 \le \varepsilon_r \le 100$;

[1] B. C. Wadell, “Transmission Line Design Handbook”, Artech House, London, 1991.

Suspended microstrip line





- The suspended microstrip line is used when low losses are needed.
- The effective dielectric constant ε_{eff} is reduced. For the same width (as in microstrip line) ⇒ Z is higher.
- For the same impedance (as in microstrip line) ⇒ the line is wider.

- When $h_2 \searrow \Rightarrow$ microstrip line
- When $h_2 \nearrow \Rightarrow Z \nearrow$ y $\varepsilon_{eff} \searrow$

[1] B. C. Wadell, “Transmission Line Design Handbook”, Artech House, London, 1991.

Suspended microstrip line

- **Features:**
  - ➢Characteristic impedance Z : ⇒ ± 0.2% error, $\varepsilon_r \le 20$

$$Z = \overset{\substack{\text{Layer}\\ \text{impedance}\\ \downarrow}}{\frac{\eta_0}{\sqrt{\varepsilon_{eff}}}}\ \overset{\substack{\text{Geometric}\\ \text{constant}\\ \downarrow}}{K_g} = \frac{\sqrt{\frac{\mu_0}{\varepsilon_0}}}{2\pi\sqrt{\varepsilon_{eff}}}\ln\left(\frac{6+(2\pi-6)\cdot e^{\left(-\left(\frac{30.666}{u}\right)^{0.7528}\right)}}{u}+\sqrt{1+\frac{4}{u^2}}\right) \qquad u=\frac{w}{h+h_2}$$

Effective dielectric constant ε_{eff} : ⇒ ± 0.2% error, $\varepsilon_r \le 20$

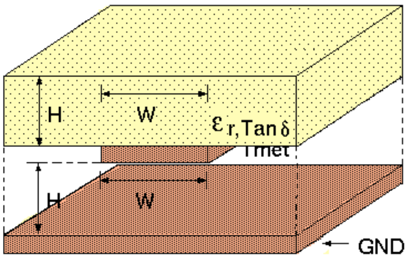
$$\varepsilon_{eff} = \frac{1}{\left[1+\frac{h}{h_2}\left(h' - h''\ln\left(\frac{w}{h_2}\right)\right)\left(\frac{1}{\sqrt{\varepsilon_r}}-1\right)\right]^2}$$

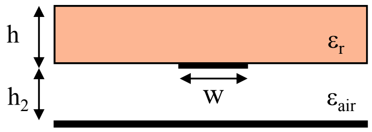
$$h' = \left(0.8621-0.1251\ln\left(\frac{h}{h_2}\right)\right)^4$$

$$h'' = \left(0.4986-0.1397\ln\left(\frac{h}{h_2}\right)\right)^4$$

[1] B. C. Wadell, “Transmission Line Design Handbook”, Artech House, London, 1991.

Inverted microstrip line





- The inverted microstrip line is also used when low losses are desired.
- Effective dielectric constant ε_{eff} is reduced. For the same width (as in conventional microstrip line) $\Rightarrow$ Z is higher.
- For the same impedance Z (as in conventional microstrip) $\Rightarrow$ the line is wider.
- When $h_2 \searrow \Rightarrow$ microstrip line
- When $h_2 \nearrow \Rightarrow Z \nearrow$ y $\varepsilon_{eff} \searrow$ ($\varepsilon_{eff} \approx 1$, Air)

[1] B. C. Wadell, "Transmission Line Design Handbook", Artech House, London, 1991.

Inverted microstrip line

- **Features:**
  - ➢Characteristic impedance Z : $\Rightarrow \pm 1\%$ error, $\varepsilon_r \leq 20$

$$Z = \overset{\text{Layer impedance}}{\frac{\eta_0}{\sqrt{\varepsilon_{eff}}}}\overset{\text{Geometric constant}}{K_g} = \frac{\sqrt{\frac{\mu_0}{\varepsilon_0}}}{2\pi\sqrt{\varepsilon_{eff}}}\ln\left(\frac{6+(2\pi-6)\cdot e^{\left(-\left(\frac{30.666}{u}\right)^{0.7528}\right)}}{u}+\sqrt{1+\frac{4}{u^2}}\right) \qquad u = \frac{w}{h_2}$$

  - ➢Effective dielectric constant ε_{eff} : $\Rightarrow < 0.6\%$ error, $\varepsilon_r \leq 20$; $0.5 \leq w/h_2 \leq 10$ y $0.06 \leq h/h_2 \leq 1.5$

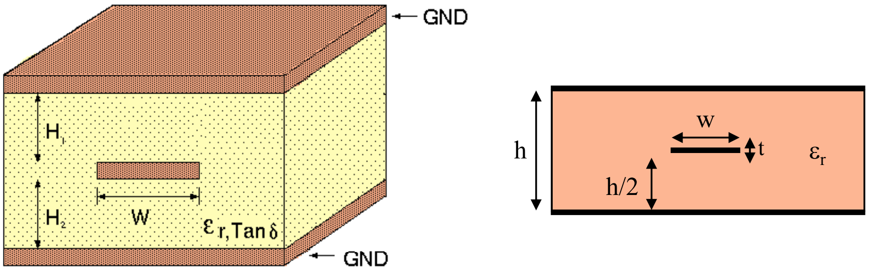
$$\varepsilon_{eff} = \left[1+\frac{h}{h_2}\left(h' - h''\ln\left(\frac{w}{h_2}\right)\right)\left(\sqrt{\varepsilon_r}-1\right)\right]^2$$

$$h' = \left(0.5173 - 0.1515\ln\left(\frac{h}{h_2}\right)\right)^2$$

$$h'' = \left(0.3092 - 0.1047\ln\left(\frac{h}{h_2}\right)\right)^2$$

[1] B. C. Wadell, "Transmission Line Design Handbook", Artech House, London, 1991.

Stripline line



- For the same width, ε_r and $h/2 = h_{microstrip}$ as in conventional microstrip line ⇒ Z is lower.
- For the same impedance as in conventional microstrip line (same ε_r and $h/2 = h_{microstrip}$) ⇒ the line is narrower.

Symmetric stripline

- **Features:**
  - ➢Characteristic impedance Z : ⇒ 0.5% error, $\varepsilon_r \leq 20$ y $w/h > 0.1$

$$Z = \overset{\substack{\text{Layer}\\\text{impedance}\\\downarrow}}{\frac{\eta_0}{\sqrt{\varepsilon_{eff}}}}\overset{\substack{\text{Geometric}\\\text{constant}\\\downarrow}}{K_g} = \frac{\sqrt{\frac{\mu_0}{\varepsilon_0}}}{2\pi\sqrt{\varepsilon_r}}\ln\left(1+0.5\frac{8h}{\pi w'}\left[\frac{8h}{\pi w'}+\sqrt{\left(\frac{8h}{\pi w'}\right)^2+6.27}\right]\right)$$

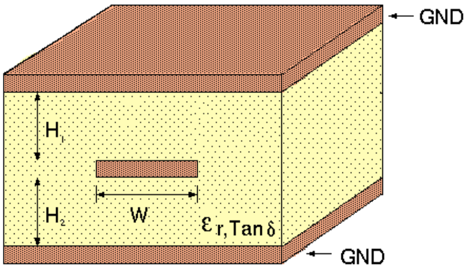
$$w' = w + \frac{\Delta w}{t}t \qquad \frac{\Delta w}{t} = \frac{\ln\left(\frac{5h}{t}\right)}{3.2}$$

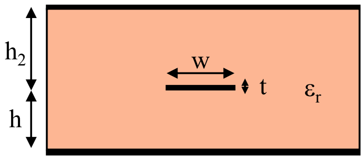
  - ➢Effective dielectric impedance ε_{eff} :

$$\varepsilon_{eff} = \varepsilon_r$$

[1] B. C. Wadell, “Transmission Line Design Handbook”, Artech House, London, 1991.

Asymmetric stripline





- For the same dimensions (as symmetric stripline) ⇒ Z is lower.
- For the same impedance ⇒ the width is lower.

[1] B. C. Wadell, "Transmission Line Design Handbook", Artech House, London, 1991.

Asymmetric stripline

- **Features:**
  - Characteristic impedance Z : ⇒ 0.5% error, $\varepsilon_r \leq 20$ y w'/h > 0.1

$$Z = \frac{\overset{\text{Layer impedance}}{\downarrow}\atop{\eta_0}}{\sqrt{\varepsilon_{eff}}}\overset{\text{Geometric constant}}{\overset{\downarrow}{K_g}} = \frac{1}{\sqrt{\varepsilon_r}}\left(\underbrace{\frac{\sqrt{\frac{\mu_0}{\varepsilon_0}}}{2\pi\sqrt{\varepsilon_r}}\ln\left(1+0.5\frac{8h}{\pi w'}\left[\frac{8h}{\pi w'}+\sqrt{\left(\frac{8h}{\pi w'}\right)^2+6.27}\right]\right)}_{Z_{symmtric}(\varepsilon_r,w,h,t)} - \Delta Z\right)$$

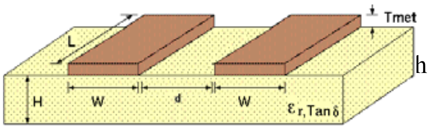
$$\Delta Z = \frac{0.26\pi}{8}Z''^2\left(0.5-\frac{h_2+\frac{t}{2}}{h_2+h+t}\right)^{2.2}\left(\frac{t+w}{h_2+h+t}\right)^{2.9} \qquad Z'' = 2\left[\frac{Z_{symmetric}(\varepsilon_r,w,h_2,t)Z_{symmetric}(\varepsilon_r,w,h,t)}{Z_{symmetric}(\varepsilon_r,w,h_2,t)+Z_{symmetric}(\varepsilon_r,w,h,t)}\right]$$

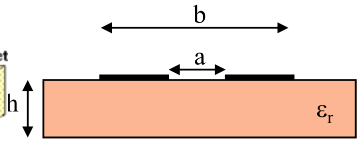
  - Effective dielectric constant ε_{eff}:

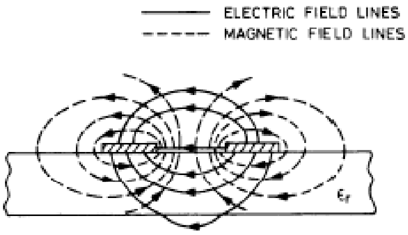
$$\varepsilon_{eff} = \varepsilon_r$$

[1] B. C. Wadell, "Transmission Line Design Handbook", Artech House, London, 1991.

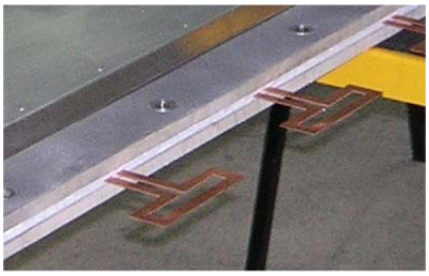
Coplanar

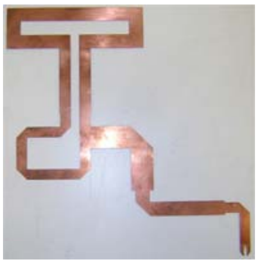






- There is no ground plane.
- In order to prevent superior mode propagation: $b < \lambda_g$
- Practical example: couplers, dipole feeding…





[1] B. C. Wadell, “Transmission Line Design Handbook”, Artech House, London, 1991.

Coplanar line

- **Features:**
  - Characteristic impedance Z : 2% error,

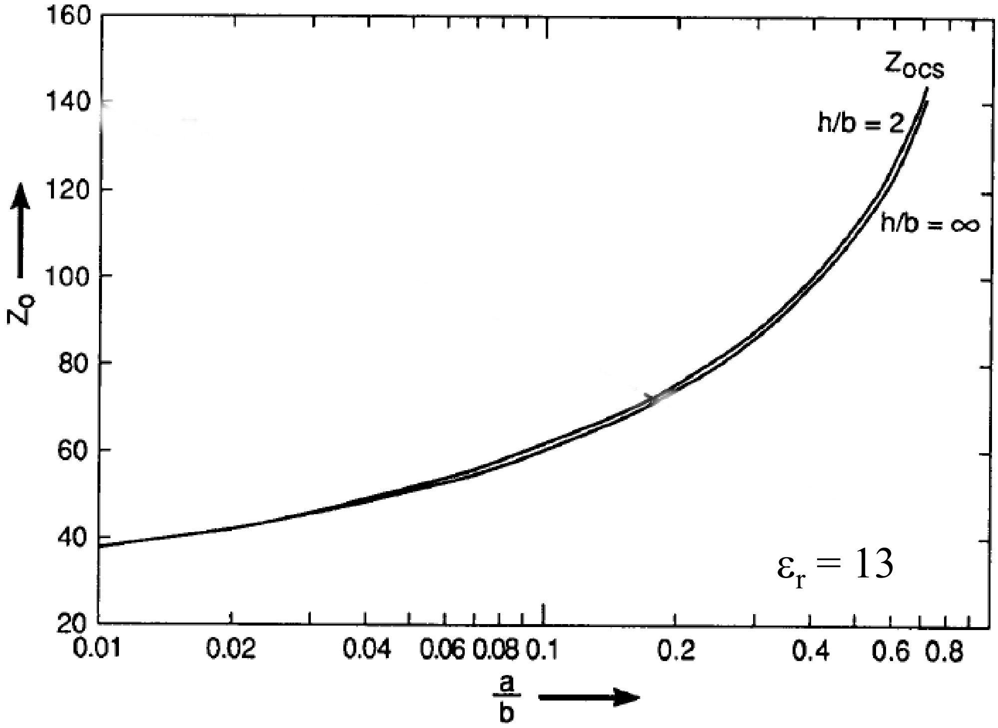
$$Z = \overset{\substack{\text{Layer}\\\text{impedance}\\\downarrow}}{\frac{\eta_0}{\sqrt{\varepsilon_{eff}}}}\ \overset{\substack{\text{Geometric}\\\text{constant}\\\downarrow}}{K_g} = \frac{\sqrt{\dfrac{\mu_0}{\varepsilon_0}}}{\sqrt{\varepsilon_{eff}}}\frac{1}{2\pi}\ln\left(2\frac{\sqrt{1+\dfrac{a}{b}}+\sqrt[4]{4\dfrac{a}{b}}}{\sqrt{1+\dfrac{a}{b}}-\sqrt[4]{4\dfrac{a}{b}}}\right)$$

  - Effective dielectrc constant ε_{eff} : 1% error

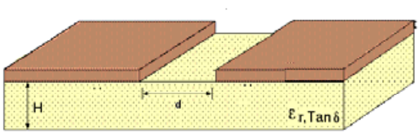
$$\varepsilon_{eff} = 1 + \frac{\varepsilon_r - 1}{2}\ln\left(2\left(\frac{\sqrt{1+k_1}+\sqrt[4]{4k_1}}{\sqrt{1+k_1}-\sqrt[4]{4k_1}} - \frac{\sqrt{1+\dfrac{a}{b}}+\sqrt[4]{4\dfrac{a}{b}}}{\sqrt{1+\dfrac{a}{b}}-\sqrt[4]{4\dfrac{a}{b}}}\right)\right) \qquad k_1 = \frac{\sinh\left(\dfrac{\pi a}{4h}\right)}{\sinh\left(\dfrac{\pi b}{4h}\right)}$$

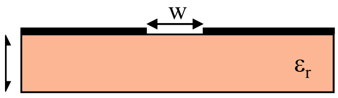
[1] B. C. Wadell, “Transmission Line Design Handbook”, Artech House, London, 1991.

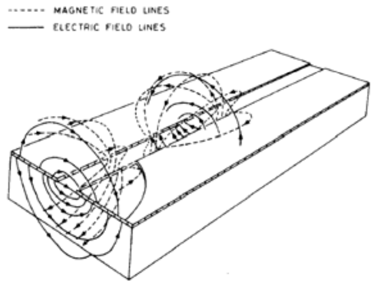
Coplanar line



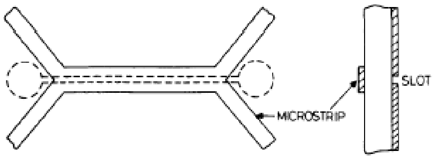
Slot line







- The slot line is a TE structure, not a TEM one.
- This structure needs a substrate with a high dielectric constant value ε_r ($\varepsilon_r \geq 10$) ⇒ on behalf to concentrate propagating fields and decrease radiation.
- The slot line is combined with microstrip in designing directional couplers, branchlines...



[1] B. C. Wadell, “Transmission Line Design Handbook”, Artech House, London, 1991.

Slot line

- **Features:**
  - ➢Characteristic impedance Z : ⇒ 2% error, $0.02 \le w/h \le 1$

$$Z = 72.62 - 81.028\ln(\varepsilon_r) + \frac{50\left(\frac{w}{h} - 0.02\right)\left(\frac{w}{h} - 0.1\right)}{\frac{w}{h}} + 2.3026\ln\left(\frac{w}{h}100\right)(44.28 - 45.0849\ln(\varepsilon_r))$$
$$-\left[0.7368\ln(\varepsilon_r) - 0.11 + \frac{w}{h}(2.4638\ln(\varepsilon_r) + 1.44)\right]\cdot\left(11.4 - 13.9768\ln(\varepsilon_r) - \frac{h}{\lambda_g 100}\right)^2$$

  - ➢Effective dielectric constant ε_{eff} : ⇒ 2% error, $0.02 \le w/h \le 1$

$$\varepsilon_{eff} = \left[0.923 - 1.0316\ln(\varepsilon_r) + 0.2\frac{w}{h} - \left(0.6678\frac{w}{h} + 0.1082\right)\ln\left(\frac{h}{\lambda_0 100}\right)\right]^{-2}$$

[1] B. C. Wadell, “Transmission Line Design Handbook”, Artech House, London, 1991.

Typical losses for different lines

Typical losses with those structures when applying high frequency (10 GHz)	
Network	**Losses (dB/m)**
Waveguide	0.2
Suspended line	1.8 – 3.0
Stripline	2.7 – 5.6
Microstrip line	4 - 6

Substrates

Printed lines at high frequency need quality materials⇒ loss tangent : tan(δ) < 0.002

Features of substrates for printed lines at 10 GHz		
	Dielectric constant: ε_r	losses: tan(δ)
Epoxy fiberglass FR-4	4.4	0.01
Laminex	4.8	0.03
Taconic	2.33	0.0009
Kapton	3.5	0.002
CuClad	2.17	0.0009
RT Duroid 5880 (teflon + glass fiber)	2.2	0.0009
Alumina (Ceramic form of Al_2O_4)	9.9	0.0003
RT Duroid 6010 (PTFE[1] ceramic)	10.5	0.002
GaAs (Gallium Arsenide) (Semiconductor dielectric)	12.8	0.0006

[1] Polytetrafluoroethylene (Teflon)

Substrate selection

	Substrate thickness	**ε_r**
Reduction in line radiation	Quite little	high
Small dimensions	little	high
Low Losses	little	low
Reduction in losses due to surface currents	little	low
Increase in band width	big	low

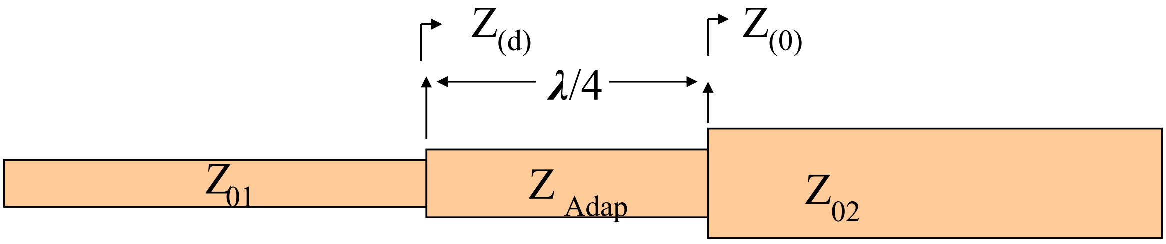
- Thin substrates with high ε_r are used in microwave circuitry, as feeding network:
  - Advantages:
    - Lower line width.
    - Reduction in radiation and coupling effects, although they should not be neglected.
  - Disadvantaged:
    - Higher losses.
    - Lower efficiency.
    - Lower bandwidth.

Introduction

Transmission Lines Architecture

Some Feeding Devices

λ/4 Adaptator



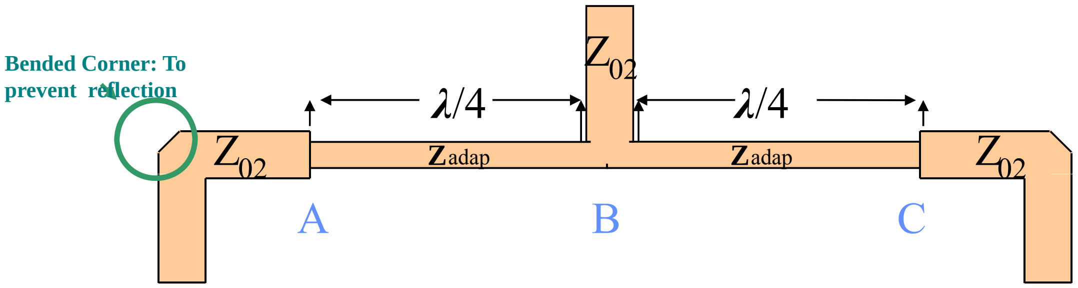
Transformation (considering no losses):

$$Z(d) = Z_{adap} \frac{Z(0)\cos\beta d + Z_{adap}\, jsen\beta d}{Z_{adap}\cos\beta d + Z(0)\, jsen\beta d}$$

$\downarrow$ λ/4 case

$$Z(d) = Z_{adap} \frac{Z(0)\cos\frac{\pi}{2} + Z_{adap}\, jsen\frac{\pi}{2}}{Z_{adap}\cos\frac{\pi}{2} + Z(0)\, jsen\frac{\pi}{2}} = Z_{adap}\frac{Z_{adap}}{Z(0)} \longrightarrow \boxed{Z_{adap} = \sqrt{Z(0)Z(d)}} \longleftarrow \begin{cases} Z(0) = Z_{02} \\ Z(d) = Z_{01}^{*} = Z_{01} \end{cases}$$

Power Divider



Point A: $Z(A) = Z_{02}$

Point C: $Z(C) = Z_{02}$

Point B:

$$Z(B) = Z(B_{izq}) // Z(B_{der}) = \frac{Z(B_{izq})\cdot Z(B_{der})}{Z(B_{izq}) + Z(B_{der})}$$

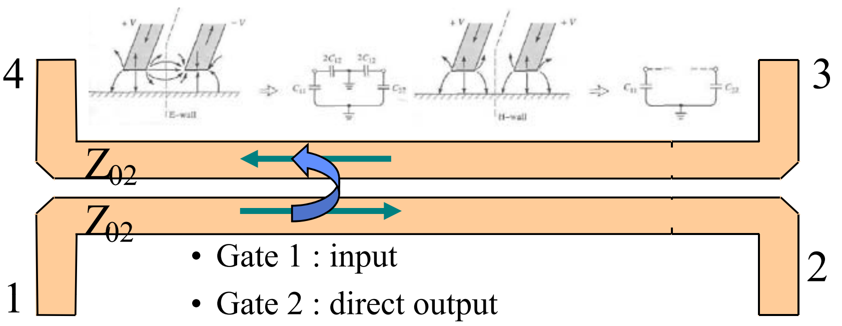
$$Z(B) = Z_{02}$$

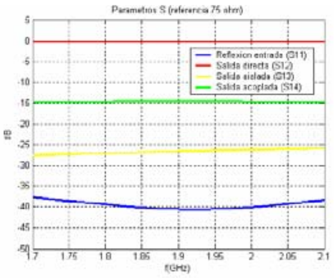
$$Z(B_{izq}) = Z(B_{izq}) = \frac{Z_{adap}{}^2}{Z_{02}}$$

$$Z_{02} = \frac{\frac{Z_{adap}{}^2}{Z_{02}} \cdot \frac{Z_{adap}{}^2}{Z_{02}}}{\frac{Z_{adap}{}^2}{Z_{02}} + \frac{Z_{adap}{}^2}{Z_{02}}} = \frac{Z_{adap}{}^2}{2Z_{02}}$$

$$\boxed{Z_{adap} = \sqrt{2}Z_{02}}$$

Directional Coupler





- Gate 1 : input
- Gate 2 : direct output
- Gate 3 : isolated output
- Gate 4 : coupled output

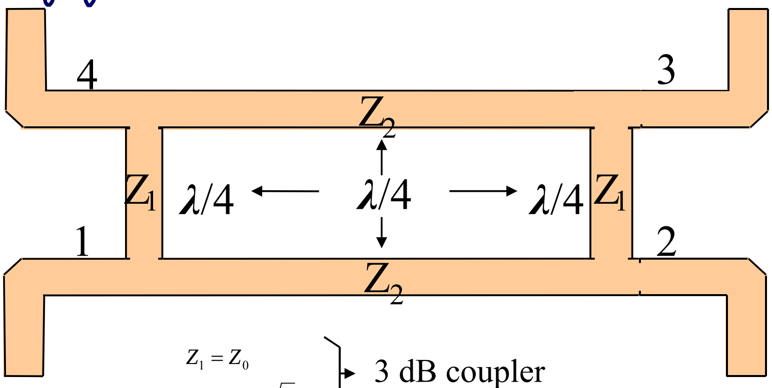
➢A portion of the injected power (**input**) yields coupling in the alongside line (**coupled output**), the rest flows through the **coupled output**.

➢Power relation between direct and coupled output is a designer choice.

➢Direct and coupled outputs have a signal phase delay (90º).

➢Ideally, there is no power at the isolated gate.

Hibrid Coupler 90º



- Gate 1 : input
- Gate 2 : -90º output
- Gate 3 : -180º output
- Gate 4 : isolated port

$Z_1 = Z_0$

$Z_2 = Z_0 / \sqrt{2}$

} → 3 dB coupler

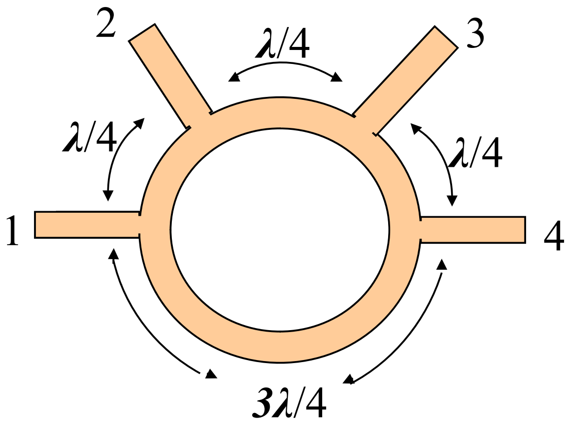
$$S = \frac{1}{\sqrt{2}} \begin{bmatrix} 0 & -j & -1 & 0 \\ -j & 0 & 0 & -1 \\ -1 & 0 & 0 & -j \\ 0 & -1 & -j & 0 \end{bmatrix}$$

➢A portion of the injected power (**1**) reaches **3** with -180º phase delay), the rest flows through the -90º output (**2**).

➢The output signals at 2 and 3 have a 90º phase delay, refered one to the other.

➢Ideally, there is no power at the isolated gate (4).

Circular Coupler (Rat Race)



- Gate 1 : input
- Gate 2 : output -90º
- Gate 3 : isolated port
- Gate 4 : output -270º

$$S = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 & -j & 0 & j \\ -j & 0 & -j & 0 \\ 0 & -j & 0 & -j \\ j & 0 & -j & 0 \end{pmatrix}$$

➢The injected power at **1** reaches **2** and **4** with a phase delay of -/+90**º** respectively.

➢The output signals at **2** and **4** have a 180º phase delay, referred one to the other.

➢Ideally, there is no power at the isolated gate (**3**).

References

[1] B. C. Wadell, “Transmission Line Design Handbook”, Ed. Artech House, London, 1991.

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[3] S. J. Orfanidis, “Electromagnetic Waves & Antennas”, 2004.

[4] H. Howe, “Stripline Circuit Design”, Ed. Artech House, London, 1982.

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[6] K.C. Gupta, R. Garg, I. Bahl and P. Bhartia, “Microstrip Lines and Slotlines”, Artech House, London, 1996.

[7] P. Barthia & al., “Milimeter wave microstrip and printed circuit antennas”, Norwood, Mass, Ed. Artech House,1991.

[8] Ansoft Ensemble, “Ansoft Ensemble: Getting Started and Tutorials”, Versión 8.0 Copyright 1984-1999, Ansoft Coporation, 1999.