



Microwave & Wireless Measurements

- ▷ Network Analyzers
- ▷ Spectrum Analyzers
- ▷ Nonlinear & Noise
- ▷ Communications
- ▷ Antennas
- ▷ Radar
- ▷ Advanced techniques

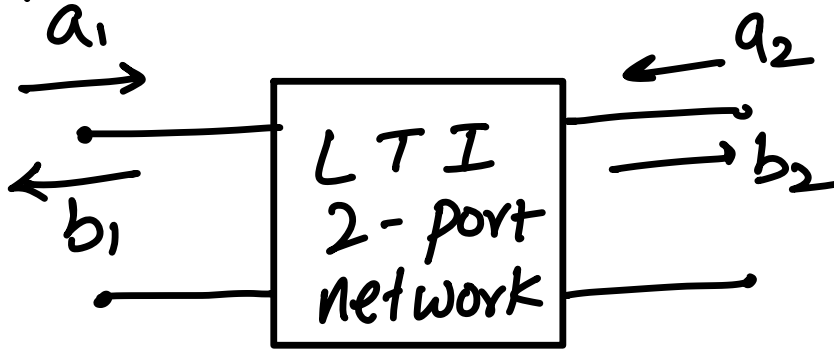
- ▷ Amplifiers
- ▷ Mixers
- ▷ PLLs
- ▷ ...

[X-parameters
Spherical Near-Field ...]

- ▷ Systems + Measurements.

Pre-req.: Linear systems, Fourier Tr.,
Transmission-lines & Smith Charts,
S-parameters, Intro EM, Planewaves,
Waveguides, Antennas.

S-parameters



$$b_1 = S_{11} a_1 + S_{12} a_2$$

$$b_2 = S_{21} a_1 + S_{22} a_2$$

$$S_{ij} = \frac{b_i}{a_j} \Big|_{a_k=0 \forall k \neq j}$$

$$a \triangleq \frac{V^+}{\sqrt{Z_0}}$$

$$b \triangleq \frac{V^-}{\sqrt{Z_0}}$$

$$\vec{b} = \vec{S} \vec{a}$$

$\hookrightarrow \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix}$

Reciprocal $\Rightarrow S_{ij} = S_{ji}$

{

Resistors,
Capacitors,
Inductors,
T-lines...

}

Time reversal symmetry $\Rightarrow S^H S = I$.

{

Inductors
Capacitors
Lossless T-lines...

}

RF Components

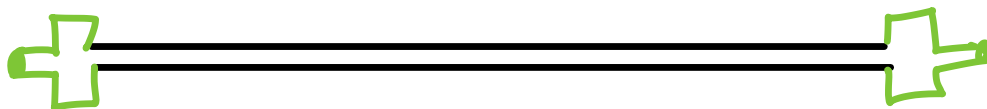
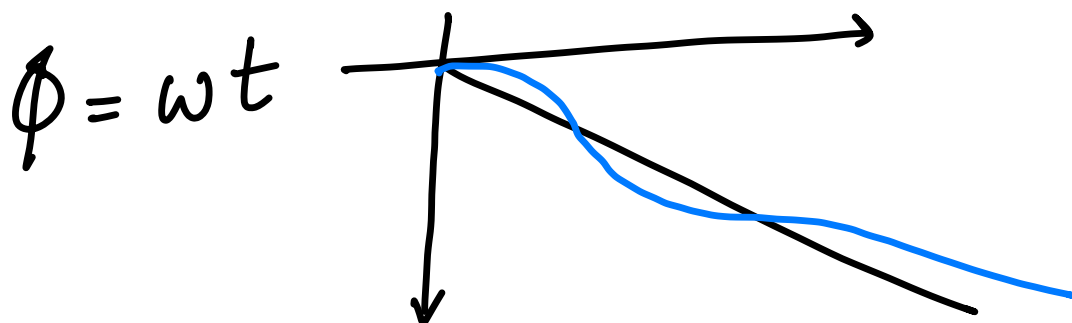
I Passives

① Cables (Transmission lines)

> Flexible, Semirigid, Rigid, Phase Stable.

Specifications

- 1) Z_0
- 2) Insertion loss $(-20 \log_{10} |S_{21}|)$
- 3) Velocity factor: $\frac{v_p}{c} = \frac{1}{\sqrt{\epsilon_r^{\text{eff}}}} \left(\begin{matrix} \text{PTFE} \\ = 0.7 \end{matrix} \right)$
- 4) Group delay: $\tau_g = -\frac{d\phi(s_{21})}{d\omega}$



② Connectors.

▷ BNC (DC - 4 GHz) → Easy to use.

▷ N-type (DC - 18 GHz) → Rugged.

▷ SMA (DC - 18 GHz) → Teflon

▷ 3.5 mm (DC - 26.5 GHz) → Air

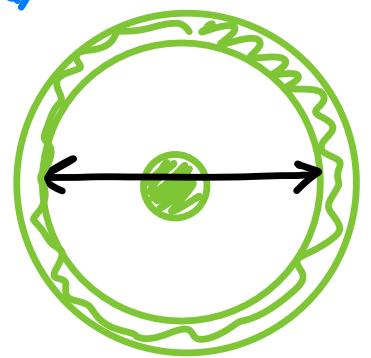
▷ 2.92 mm (DC - 40 GHz)

▷ 2.4 mm (DC - 50 GHz)

▷ 1.85 mm (DC - 67 GHz)

▷ 1.0 mm (DC - 110 GHz)

▷ 0.5 mm (DC - 250 GHz)

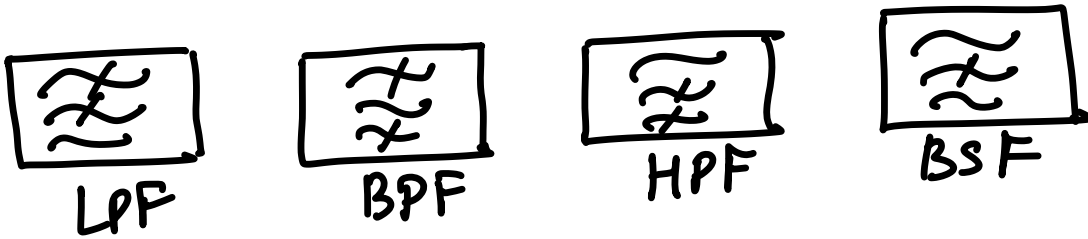
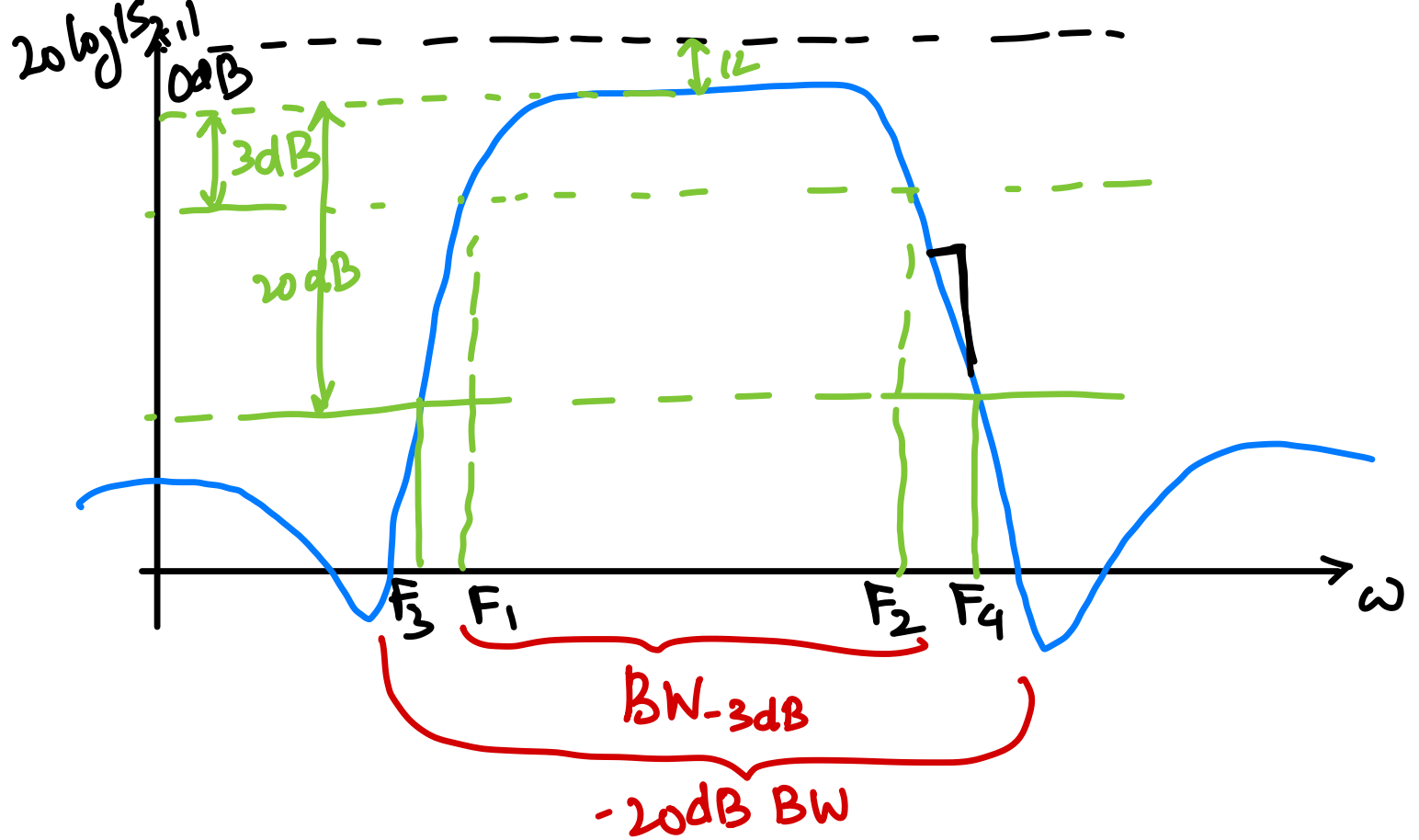


③ Filters S_{21} is a fn. of freq.

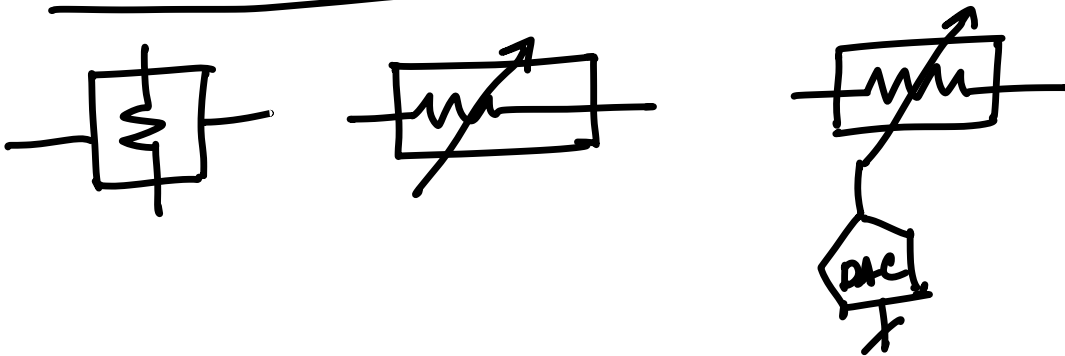
> LPF, HPF, BPF, BSF.

Specifications

- 1) IL
- 2) RL $-20 \log_{10} |S_{11}|$
- 3) BW
- 4) Stop-band rejection
- 5) Roll-off
- 6) Pass-band ripple
- 7) Group delay.

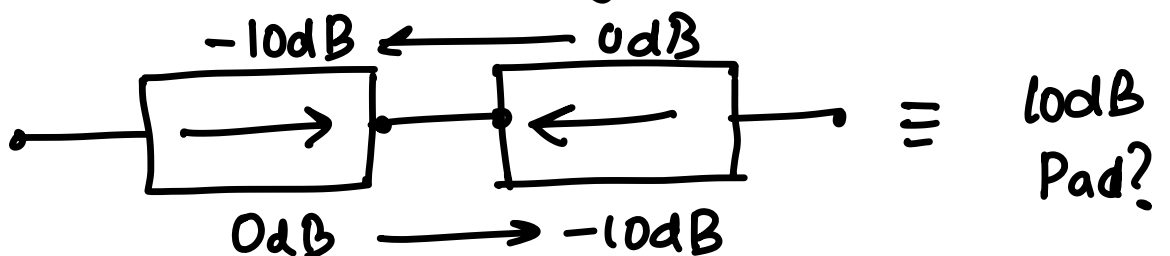


④ Attenuators (Pad)

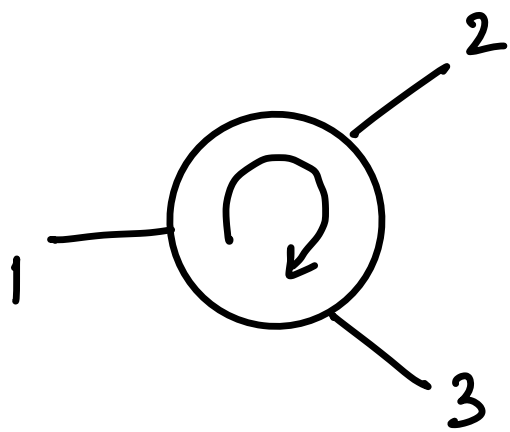


⑤ Isolators (2-port non reciprocal)

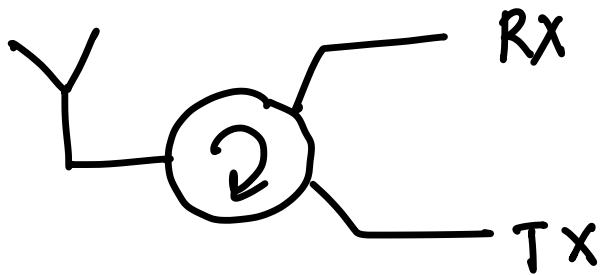
▷ IL ▷ Isolation $-20 \log |S_{12}|$ ▷ BW...



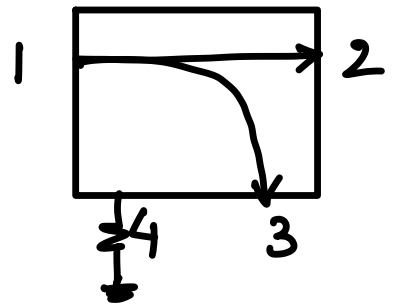
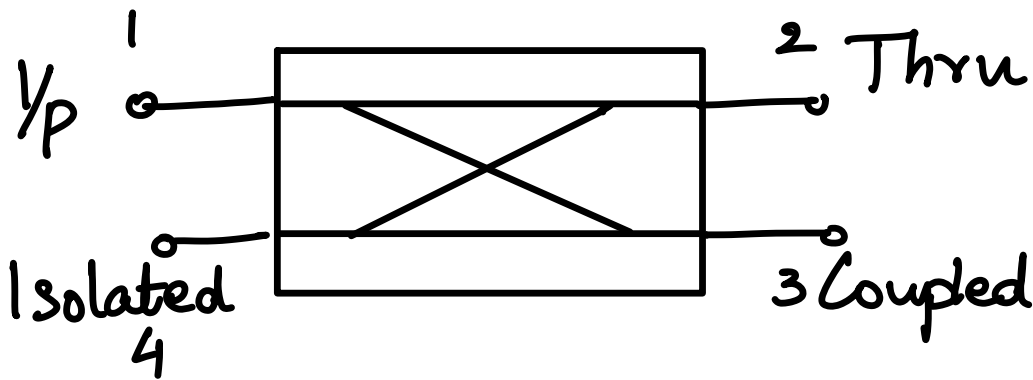
⑥ Circulators (3-port nonreciprocal)



$> IL$ $> Isolation$
 $-20 \log |S_{31}|$
 $> BW \dots$
 $\begin{matrix} 23 \\ 12 \end{matrix}$



⑦ Directional Couplers



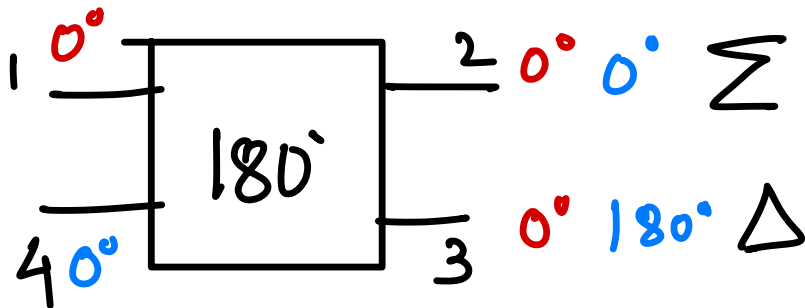
$$S = \begin{bmatrix} 0 & \alpha & j\beta & 0 \\ \alpha & 0 & 0 & j\beta \\ j\beta & 0 & 0 & \alpha \\ 0 & j\beta & \alpha & 0 \end{bmatrix}$$

$$\alpha^2 + \beta^2 = 1$$

90°: $\alpha = \beta = \frac{1}{\sqrt{2}} \quad [1 \otimes \text{mod/dem}]$

180°

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



Specifications

- > $IL > RL > BW$
- > Coupling $-20 \log |S_{31}|$
- > Isolation $-20 \log |S_{41}|$
- > Directivity $20 \log \frac{|S_{31}|}{|S_{41}|}$
- > Amp & Phase imbalance.