S-parameters

MUSE

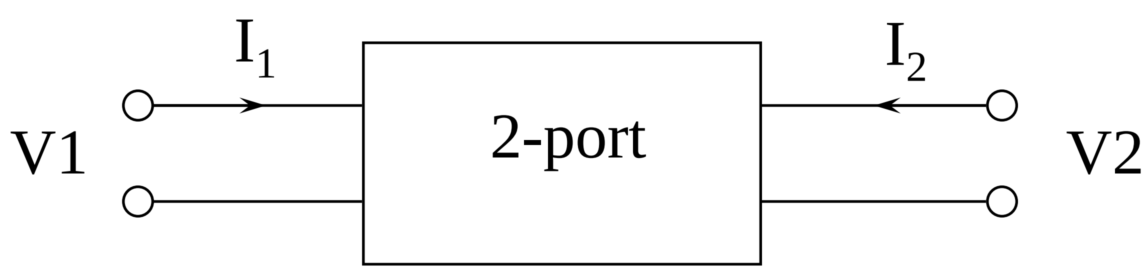
Material developed by Prof. L. Dunleavy, USF

2-Port Parameters

- Recall Z-Parameters:

$$V_1 = Z_{11} I_1 + Z_{12} I_2$$
$$V_2 = Z_{21} I_1 + Z_{22} I_2$$

$$\Longrightarrow \begin{bmatrix} \mathbf{V}_1 \\ \mathbf{V}_2 \end{bmatrix} = \begin{bmatrix} \mathbf{Z}_{11} & \mathbf{Z}_{12} \\ \mathbf{Z}_{21} & \mathbf{Z}_{22} \end{bmatrix} \begin{bmatrix} \mathbf{I}_1 \\ \mathbf{I}_2 \end{bmatrix}$$



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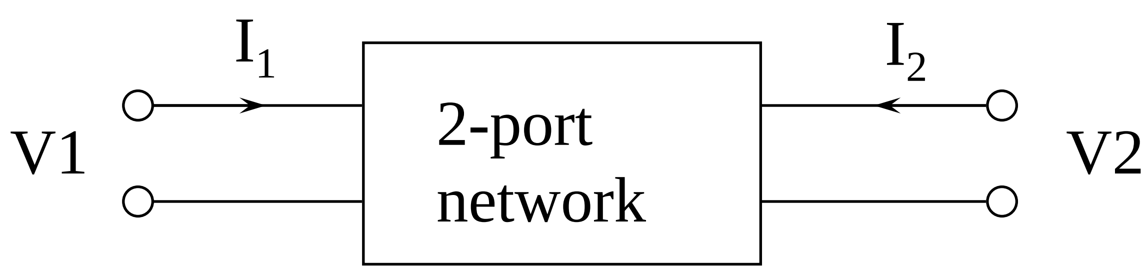


2-PORT Parameters (cont'd)

- Y-Parameters:

$$I_1 = Y_{11}V_1 + Y_{12}V_2$$
$$I_2 = Y_{21}V_1 + Y_{22}V_2$$

$$==> \begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} Y_{11} & Y_{12} \\ Y_{21} & Y_{22} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix}$$

- h-Parameters:

$$V_1 = h_{11}I_1 + h_{12}V_2$$
$$I_2 = h_{21}I_1 + h_{22}V_2$$

$$==> \begin{bmatrix} V_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} I_1 \\ V_2 \end{bmatrix}$$

2-Port Parameters (cont'd)

- 2-port Parameter Determination:

$$h_{11} = \frac{V_1}{I_1}\Big|_{V_2 = 0}$$

$$h_{21} = \frac{I_2}{I_1}\Big|_{V_2 = 0}$$

(Put a Short Circuit at Port #2)

$$h_{12} = \frac{V_1}{V_2}\Big|_{I_1 = 0}$$

$$h_{22} = \frac{I_2}{V_2}\Big|_{I_1 = 0}$$

(Put an Open Circuit at Port # 1)

S-Parameters

At high RF and Microwave frequencies direct measurement of Y- , Z-, or H- parameters is difficult due to:

- Unavailability of equipment to measure RF/MW total current and voltage.
- Difficulty of obtaining perfect opens/shorts
- Active devices may be unstable under open/short conditions.

S-Parameters

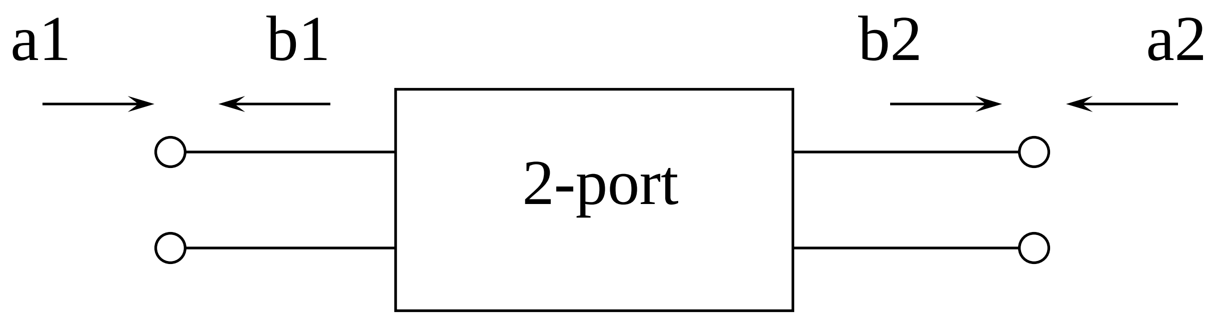
- For a two-port device there are four S-parameters S_{11}, S_{21}, S_{12}, and S_{22}
- S_{11}, and S_{22} are simply the forward and reverse reflection coefficients, <u>with the opposite port terminated in Z_0</u> (usually 50 ohms.)
- S_{21} and S_{12} are simply the forward and reverse gains <u>assuming a Z_0 source and load</u> (again usually 50 ohms).

S-Parameters (cont'd)

- S-Parameters:

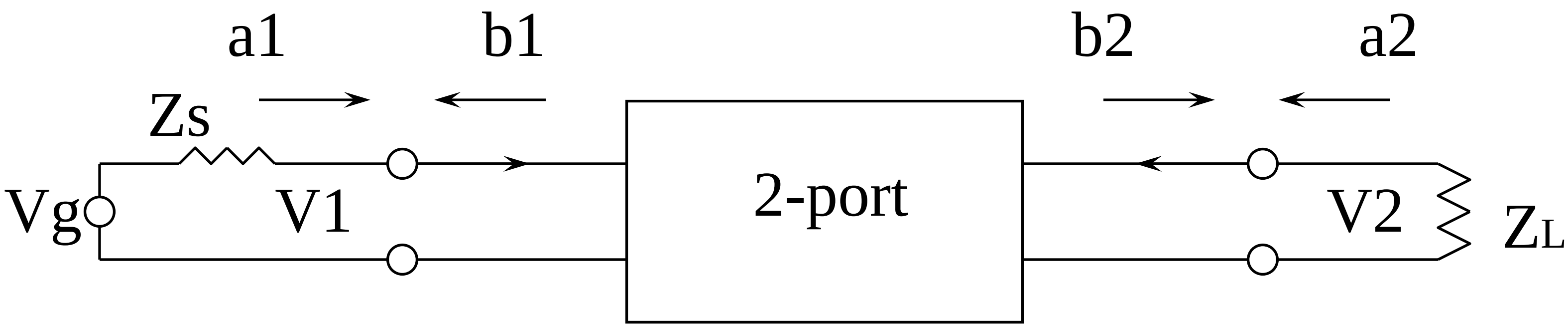
$$\mathbf{b}_1 = \mathbf{S}_{11}\mathbf{a}_1 + \mathbf{s}_{12}\mathbf{a}_2$$
$$\mathbf{b}_2 = \mathbf{S}_{21}\mathbf{a}_1 + \mathbf{S}_{22}\mathbf{a}_2$$

$$\Longrightarrow \begin{bmatrix} \mathbf{b}_1 \\ \mathbf{b}_2 \end{bmatrix} = \begin{bmatrix} \mathbf{S}_{11} & \mathbf{S}_{12} \\ \mathbf{S}_{21} & \mathbf{S}_{22} \end{bmatrix} \begin{bmatrix} \mathbf{a}_1 \\ \mathbf{a}_2 \end{bmatrix}$$



S-Parameters (cont'd)

- Q. So what's the deal with the a's and b's?



- A. a1 and a2 are incident waves; b1 and b2 are reflected waves

Incident & Reflected Waves:
Simplified Case: Z1=Zs=Z2=ZL=Zo (real)

$$a_1 = \frac{V_1 + Z_0 I_1}{2\sqrt{Z_0}} = \frac{\text{Incident port 1 voltage}}{\sqrt{Z_0}} = \frac{E_{i1}}{\sqrt{Z_0}}$$

$$a_2 = \frac{V_2 + Z_0 I_2}{2\sqrt{Z_0}} = \frac{\text{Incident port 2 voltage}}{\sqrt{Z_0}} = \frac{E_{i2}}{\sqrt{Z_0}}$$

$$b_1 = \frac{V_1 - Z_0 I_1}{2\sqrt{Z_0}} = \frac{\text{reflected port 1 voltage}}{\sqrt{Z_0}} = \frac{E_{r1}}{\sqrt{Z_0}}$$

$$b_2 = \frac{V_2 - Z_0 I_2}{2\sqrt{Z_0}} = \frac{\text{reflected port 2 voltage}}{\sqrt{Z_0}} = \frac{E_{r2}}{\sqrt{Z_0}}$$

S-Parameter Determination

$$s_{11} = \frac{b_1}{a_1}\Big|_{a_2 = 0}$$

= Input reflection coefficient Γin
for case of $Z_L=Z_0$

$$s_{21} = \frac{b_2}{a_1}\Big|_{a_2 = 0}$$

= Forward transmission (insertion) gain
for case of $Z_L=Z_0$

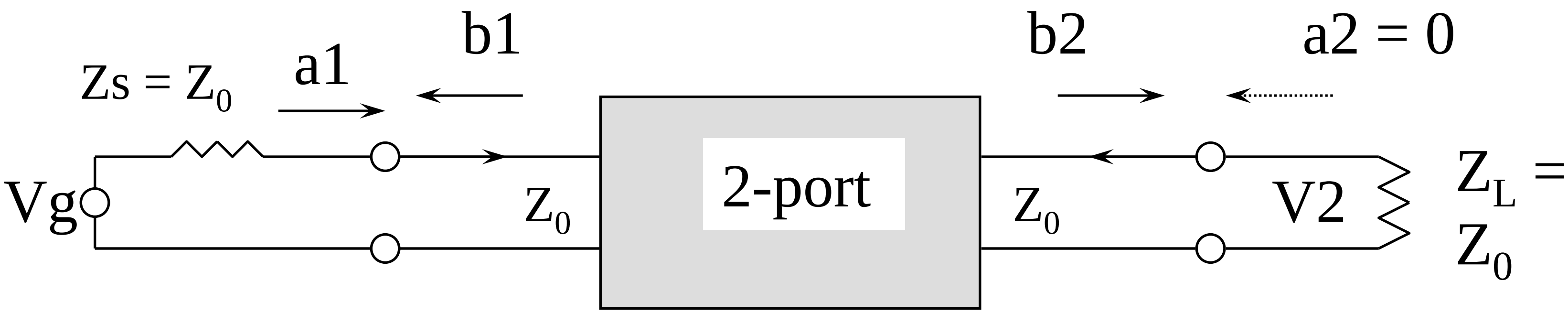
$$s_{12} = \frac{b_1}{a_2}\Big|_{a_1 = 0}$$

= Reverse transmission (insertion) gain
for case of $Z_s=Z_0$

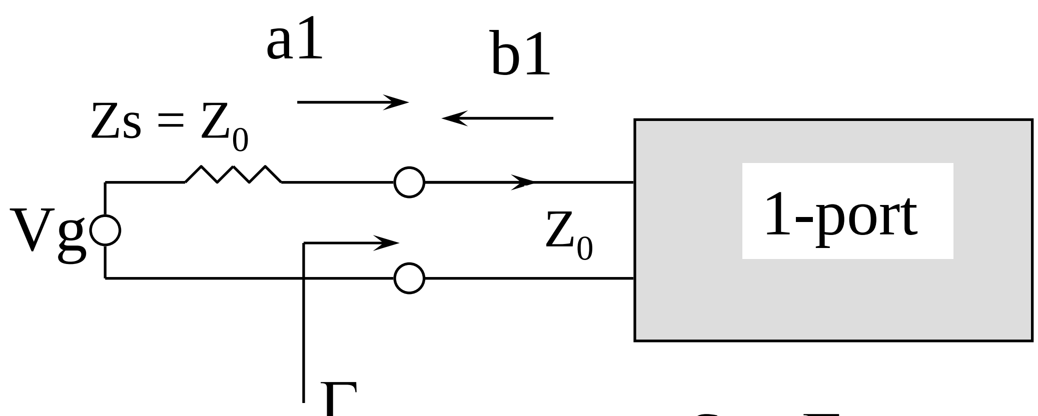
$$s_{22} = \frac{b_2}{a_2}\Big|_{a_1 = 0}$$

= Output reflection coefficient Γout
for case of $Z_s=Z_0$

Desired Measurement Conditions

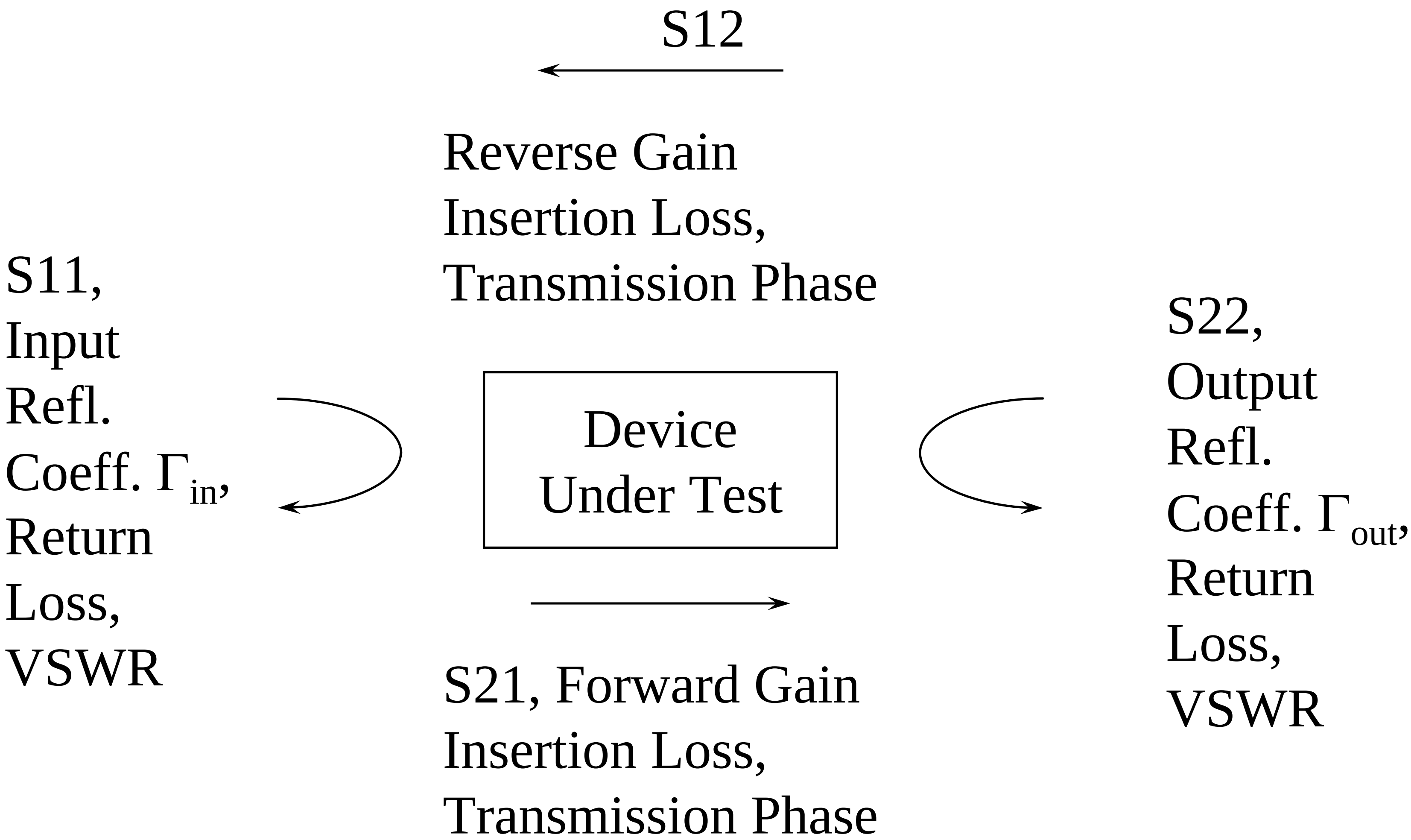


Note…the input and output are terminated in Z_0



$S_{11}=\Gamma$

GRAPHICAL VIEW OF S-PARAMETERS

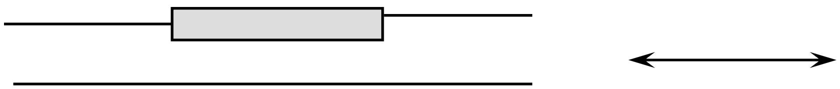


S-Parameters in Decibels

	dB	Meaning or interpretation
S_{11}	$20 \log_{10} \lvert S_{11} \rvert$	Corresponds to the algebraic negative of the input return loss of a 2-port with an R_0 termination on the opposite port.
S_{12}	$20 \log_{10} \lvert S_{12} \rvert$	Reverse isolation (active device or amplifier), or algebraic negative of the insertion loss (I.L.) for a passive device, with R_0 at ports 1 and 2.
S_{21}	$20 \log_{10} \lvert S_{21} \rvert$	Power gain (active device or amplifier), or algebraic negative of the insertion loss (I.L.) for a passive device, under matched R_0 at ports 1 and 2.
S_{22}	$20 \log_{10} \lvert S_{22} \rvert$	Corresponds to the algebraic negative of the output return loss of a 2-port with an R_0 termination on the opposite port.

WHAT TO EXPECT

Ideal Lossless T-line

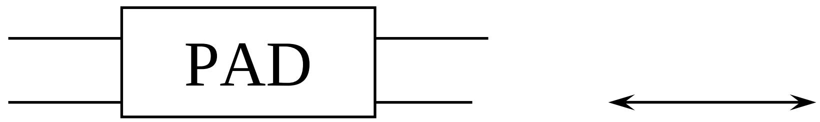


$S11=S22=0$

$S21=S12=1e^{-j\theta}$

$S21DB=0$

<u>Ideal</u> "**X**" dB Attenuator



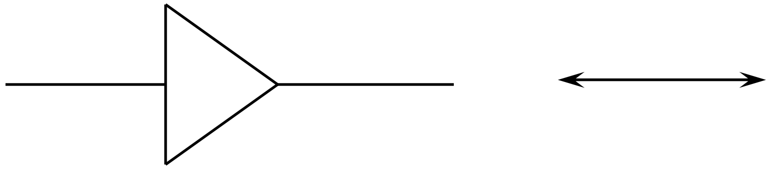
$S11=S22=0$

$S21=S12=xe^{-j\theta pad}$

$S21DB= \mathbf{X}=20\log(|S21|)$

$x =10^{-\mathbf{X}/20}$

<u>Ideal</u> "G" dB Gain Amp



$S11 = S22 = 0 = S12$

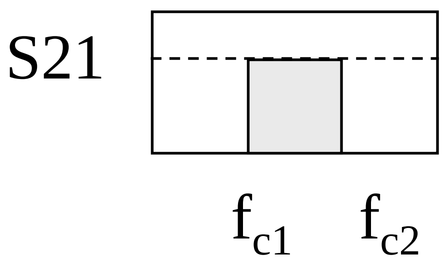
$S21 = g_v e^{-j\theta amp}$

$S21DB= G=20\log(S21)$

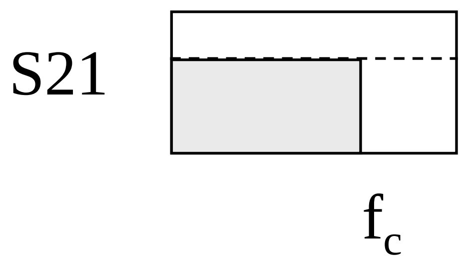
$$g_V = 10^{\frac{G}{20}}$$

WHAT TO EXPECT: Ideal Filters

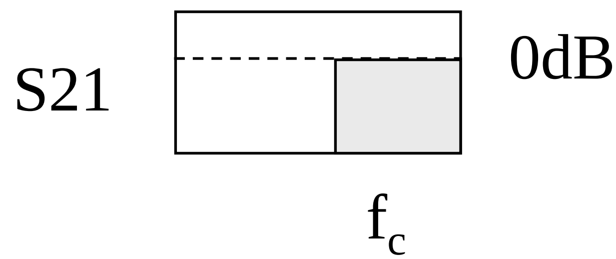
Ideal Band Pass



Ideal Low Pass



Ideal High Pass



GENERAL “IN-BAND”

$S_{11}=S_{22}=0$
$S_{21}=S_{12}=1e^{-j\theta(f)}$
$S_{21}(dB)=S_{12}(dB)=0dB$

GENERAL “OUT-OF-BAND”

$|S_{11}|=|S_{22}|=1$
$S_{21}=S_{12}=0$
$S_{11}(dB)=S_{22}(dB)=0dB$