

Motivate

- 2 ports
- Delivery to 1 port
- Transmission

Define

- wave vs port
- Linear!

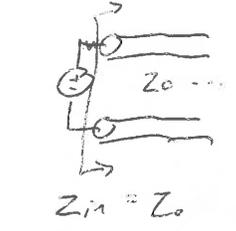
S params & Power

- point @ power details
- squaring
- conservation

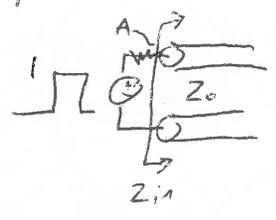
VNA

- directional coupler
- vs. freq.
- phase errors
- SOLT & why

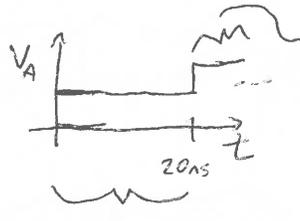
• Revisit driving point impedance



1/2 ∞ cable



$V = 0.1L/ns$



Z_{in} looks like Z_0

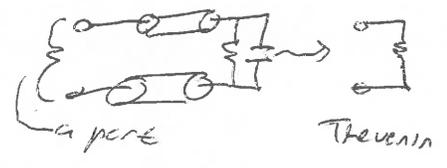
Z_{in} looks like open
 ~ reflection "sets" apparent load impedance
 ~ get information from reflection about load

• Talking about S-parameters ~ describe power Xfer in RF systems

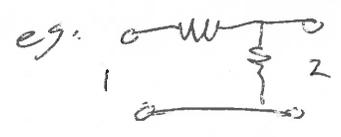
- A way of abstracting away a lumped model
- describe input-output behavior assuming linearity
- close relatives of Z & Y parameters which you may have seen

• Introducing 2 ports

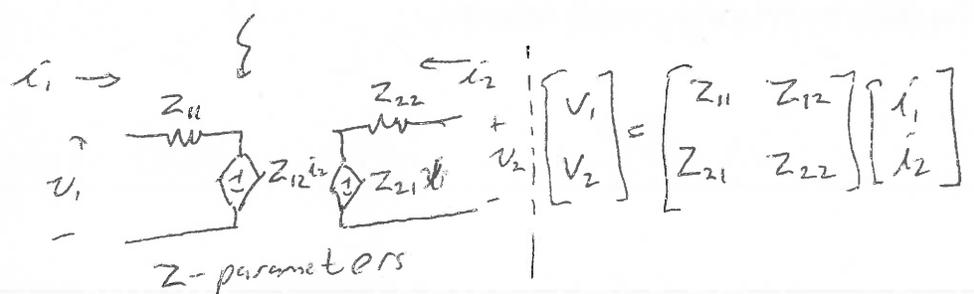
~ Thevenin used to describe systems w/ 1 port
 ↳ abstract details to an IV relationship



~ often systems we care about have 2 ports



- Thevenin @ 1 fails b/c need to know load @ 2
 - so use more complex Thevenin model



~ "matrixize" Ohm's law & Thevenin
 ~ dependent sources

- Calculate Z-params by measuring w/ loads
- ~ if i_1 or $i_2 = 0$ then easy to find

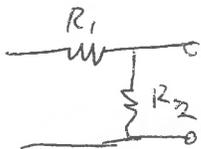
eg: $V_1 = Z_{11} i_1 + Z_{12} i_2$ so
 $= Z_{11} i_1$



$Z_{11} = V_1 / i_1$ w/ 2 open
 $Z_{21} = V_2 / i_1$ w/ 2 open

~ Just a resistor in this case

eg: for us



$Z_{11} = R_1 + R_2$

$Z_{21} = R_2$

you guys get Z_{22} & Z_{12}

$Z_{22} = R_2$

$Z_{12} = R_2$

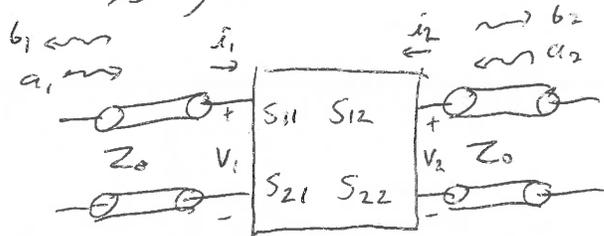
- These are fine if you can make open ckt. & i src.

↳ hard to do @ RF b/c of fringing fields & tline effects
 ↳ unstable into shorts/opens

- At RF, usually go with a different set of parameters that are easier to measure

~ S-parameters of scattering parameters sort of
 ~ Describe incident & reflected waves instead of port i & v

~ generalization of Γ to two ports



- Define a_1 in terms of fwd wave amplitude (implicitly sinusoidal)

↳ $a_1 = V_{11} / \sqrt{Z_0}$ ← convenient for power flow

$a_2 = V_{12} / \sqrt{Z_0}$ $-|a_1|^2 = V_{11}^2 / Z_0$

$b_1 = V_{r1} / \sqrt{Z_0}$ - Power in tline is $\frac{1}{2} |a_1|^2$

$b_2 = V_{r2} / \sqrt{Z_0}$

- assume Z_0 of line same on ports
- can relax that w/ more math

$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \end{bmatrix} \rightarrow b_1 = S_{11} a_1 + S_{12} a_2$$

term port 2 in Z_0 kills $S_{12} a_2$
 $b_1 = S_{11} a_1 \rightarrow S_{11} = b_1 / a_1 = \frac{V_{r1}}{V_{11}} = \Gamma_{11}$

- Really similar argument (term part 1) shows S_{22} is Γ_{22}

- S_{12} & S_{21} are same w/ appropriate terminations

$S_{21} = \frac{V_{r2}}{V_{i1}}$ w/ part 2 terminated

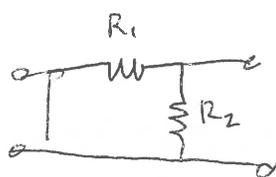
~ square this to get a type of gain called "Transducer power gain" ← more later

- Measure by terminating ports in Z_0

power flow
ports
VNA

Let's do an example:

• Find S-parameters for



$$S_{11} = \frac{R_2 \parallel Z_0 + R_1 - Z_0}{R_2 \parallel Z_0 + R_1 + Z_0}$$

$$S_{22} = \frac{R_2 \parallel (R_1 + Z_0) - Z_0}{R_2 \parallel (R_1 + Z_0) + Z_0}$$

$$S_{21} = \frac{R_2 \parallel Z_0}{R_1 + R_2 \parallel Z_0} (1 - S_{12})$$

$$S_{12} = \frac{Z_0}{R_1 + Z_0} (1 - S_{22})$$

• Power conserved in lossless 2 port $\frac{1}{2}|a|^2 = \frac{1}{2}|b|^2 + \frac{1}{2} \text{Re}\{V_1^* I_1\}$ 2 port

Complex power entering

• Can also express port voltages in terms of waves

$$V_1 = \sqrt{Z_0} (a_1 + b_1)$$

$$V_2 = \sqrt{Z_0} (a_2 + b_2)$$

$$I_1 = (a_1 - b_1) / \sqrt{Z_0}$$

$$I_2 = (a_2 - b_2) / \sqrt{Z_0}$$

• Invert these expressions to get port I V expressions for

↳ I find these confusing

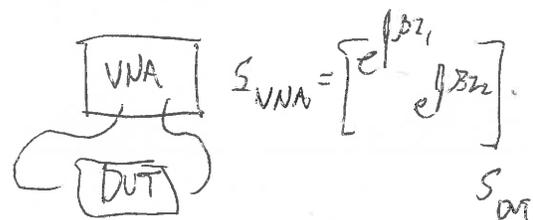
$$a_1 = \frac{V_1 + Z_0 I_1}{2\sqrt{Z_0}}$$

$$a_2 = \frac{V_2 - Z_0 I_2}{\sqrt{Z_0}}$$

$$b_1 = \frac{V_1 - Z_0 I_1}{2\sqrt{Z_0}}$$

$$b_2 = \frac{V_2 + Z_0 I_2}{\sqrt{Z_0}}$$

• VNA needs cal.



- Vector i/c mag & phase