Lec 11 - VNA & S-params in ckt.

*Port S&V
  - Power flow
  - Complex power
  - 2 port resistor
  - 2 port

Talking about S-parameters

- Type of 2 port parameters - expression how waves bounce off black box.

- Contrast V/2-params - talk about voltages induced by currents

\[
\begin{bmatrix}
V_1 \\
V_2
\end{bmatrix} = Z \begin{bmatrix}
I_1 \\
I_2
\end{bmatrix} \text{ (Vs)} \quad \begin{bmatrix}
b_1 \\
b_2
\end{bmatrix} = S \begin{bmatrix}
a_1 \\
a_2
\end{bmatrix}
\]

- Measure by setting \( I_1, I_2 = 0 \)
- Measure by terminating (terminate V/open)
- \( V/2 \) to kill \( b_1 \) or \( b_2 \)

- Want to: Figure out measurement techniques & interpretation
  - Relate to circuit calculations we already knew
  - Relate to power delivery

To measure S-params we use a Vector Network Analyzer

- Relies on directional couplers
  - Split waves into fwd & rev components & more later
  - Observe reflected waves on one & fwd. waves on other for direct S-param measure
- VNA only takes good measurements when calibrated.
  
  To calibrate with eat. standards short, open, load, thru.

- Short to find ref. plane.

\[
S_{\text{VNA}} = \begin{bmatrix}
e^{jBz_1} \\
e^{jBz_2}
\end{bmatrix} S_{\text{OUT}}
\]

- Need to define where \( z = 0 \) is, i.e.: measure \( E_1, \phi_z \).

- Or we have a lot of excess phase: \( \phi = Bz_1 = \frac{2\pi}{\lambda} z_1 = \omega \frac{z_1}{v} \).

We will see phase plot:

\[ \begin{array}{c}
\pi \\
- \pi \\
\end{array} \]

You guys — what will Smith chart look like?

- Why not open? Capacitance + radiation lead to worse results.

- Going on to PCB.

\[
\begin{array}{c}
\text{Optics: cal. in place} \\
\text{Short sets zero here}
\end{array}
\]

- Open + Load

- Source mismatch + directivity errors

- Open is an independent reflection, load should be no reflection

- thru

- Frequency response of fixtureing
- post cal checks
  - short 511 or 522
  - open 511 or 522
  - thru
    - Not as good if short cap

- control 1 & part 2 connector protector
- only screw in turtle-neck so you don't break internal pins
- debugging ~ check cables or connectors. Wibble to find bad ones
  - sanity check ... am I seeing a signal?
- when to recalibrate ~ change in sweep or cal
  - change in fixtureing

Notes on PCB parasitics - via has inductance ~ in series to ground
- pad has cap
- in short to ground.

Extract of SWA by making resonant
- @ resonance series ~ short 511, 522 ~ open
- big phase change, magnitude changes, but reflects @ 10^5 and 10^6 ohms

Can express port I & V in terms of 5 parameters
- \( V_I = V_{i1} + V_{i2} \)
- \( I_I = (V_{ii} - V_{i1})/2o \)

\[ V_I = \sqrt{2o}(a_1 + bi) \]
\[ a_1 = \frac{V_I + 2aI}{\sqrt{2o}} \]
\[ b_1 = \frac{V_I - 2aI}{\sqrt{2o}} \]
- **Analytic power**

  - Relating $S$-params to ckt+
    - $S_{11} + S_{22}$ easy enough to calculate — reflection coefficients of load or port

    \[
    S_{11} = \frac{R_1 + R_2 + 2Z_0}{R_1 + R_2 + 2Z_0} - \frac{Z_0}{R_1 + R_2 + 2Z_0} \\
    S_{22} = \frac{R_2 + R_1 + 2Z_0}{R_2 + R_1 + 2Z_0} - \frac{Z_0}{R_2 + R_1 + 2Z_0}
    \]

    - Get $S_{21}$ & $S_{12}$ from port voltage 
      \[
      Z = (Z - 2Z_0)(Z + 2Z_0)^{-1} \\
      Z = (Z - 2Z_0)(Z + 2Z_0)^{-1}
      \]

    - Formulas for $S_{21} = \frac{2Z_0 Z_{11}}{(Z_{11} + 2Z_0)(Z_{22} + 2Z_0) - Z_{22} Z_{11}}$ \\
    \[
    S_{12} = \frac{2Z_0 Z_{21}}{(Z_{11} + 2Z_0)(Z_{22} + 2Z_0) - Z_{22} Z_{11}}
    \]

  - Complex power

    \[
    P = \Re \{ I^* V \} = \frac{1}{2} |I|^2 \\
    \]

    - Need voltage & current in phase to have power e.g., imped. fdl.

    - Power in wave is $\frac{1}{2} |a|^2$ & power into 2 port is $\frac{1}{2} |a|^2 - \frac{1}{2} |I|^2 = \Re \{ V^* I \}$

    \[
    \frac{|V_{II}|}{Z_0}
    \]

  - Lossy 2 ports won't send all their power out in $Z_0$ as Hermitian matrices

  \[
  \]

  - E.g., 1 port

    \[
    \]

    - Predicted $\Rightarrow$ $\Pi_{Pin}$

    - Power $\Rightarrow$ $(1 - \Pi_{Pin})^2$

    - More to come re: $S_{11}$

  \[
  \]

  - Filters next time b/c led ?

- $E_{R\Omega} 518$

  Lec II - VNA + $S$-params in ckt.