ECE 451
Advanced Microwave Measurements

Flow Graphs

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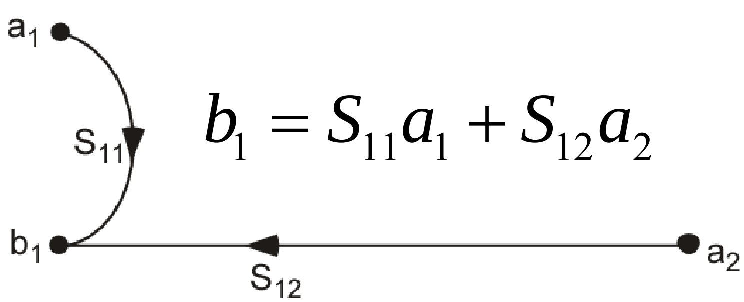
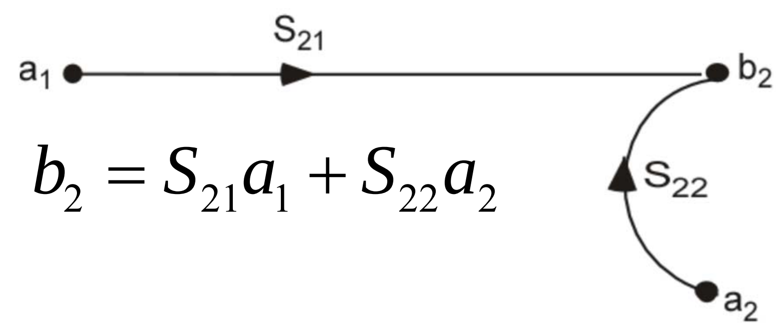
Flow Graph Definitions

- Voltage waves designated as nodes.
- S parameters designated as branches
- Branches enter dependent nodes and emanate from independent nodes

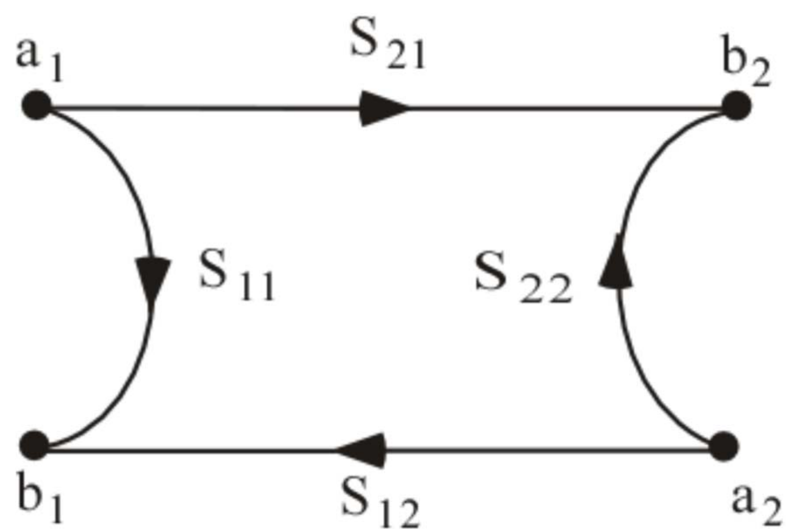


$$b_1 = S_{11}a_1 + S_{12}a_2$$

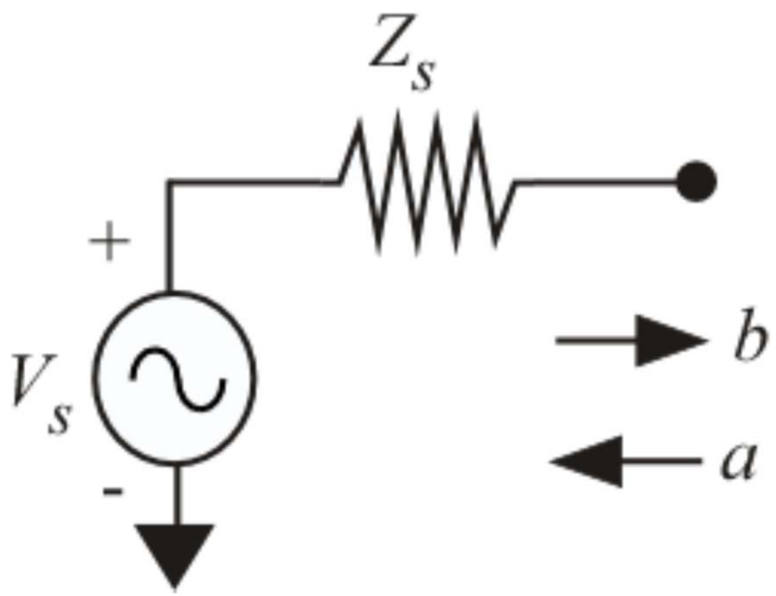


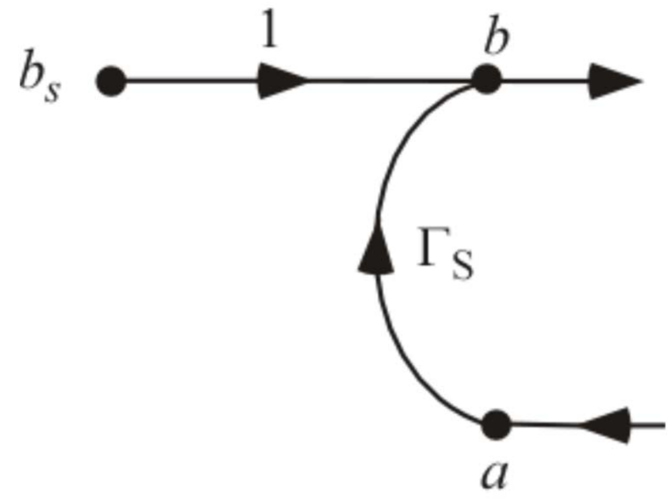
$$b_2 = S_{21}a_1 + S_{22}a_2$$

Two-Port Flow Graph



Flow Graph for Source



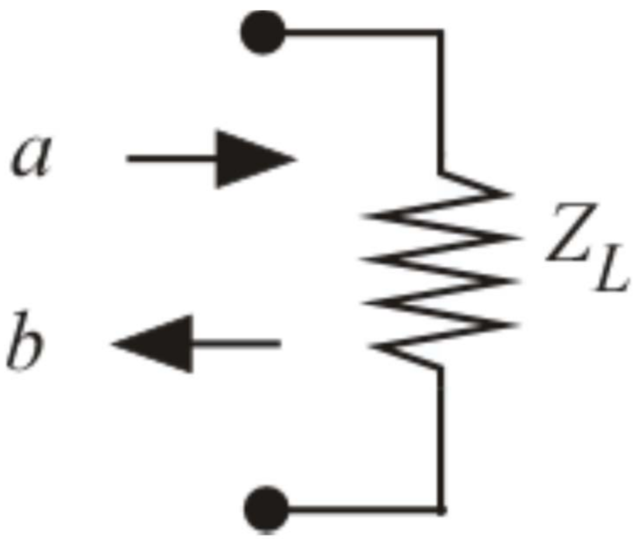


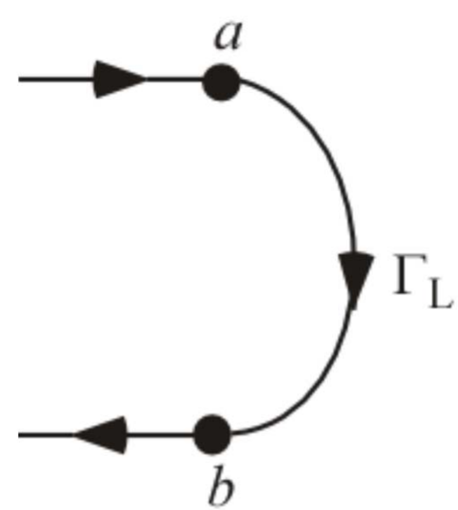
$$b_S = \frac{V_S\sqrt{Z_o}}{Z_S + Z_o}$$

$$\Gamma_S = \frac{Z_S - Z_o}{Z_S + Z_o}$$

b_s is power wave associated with power dissipated in a load of value Z_o connected to the source.

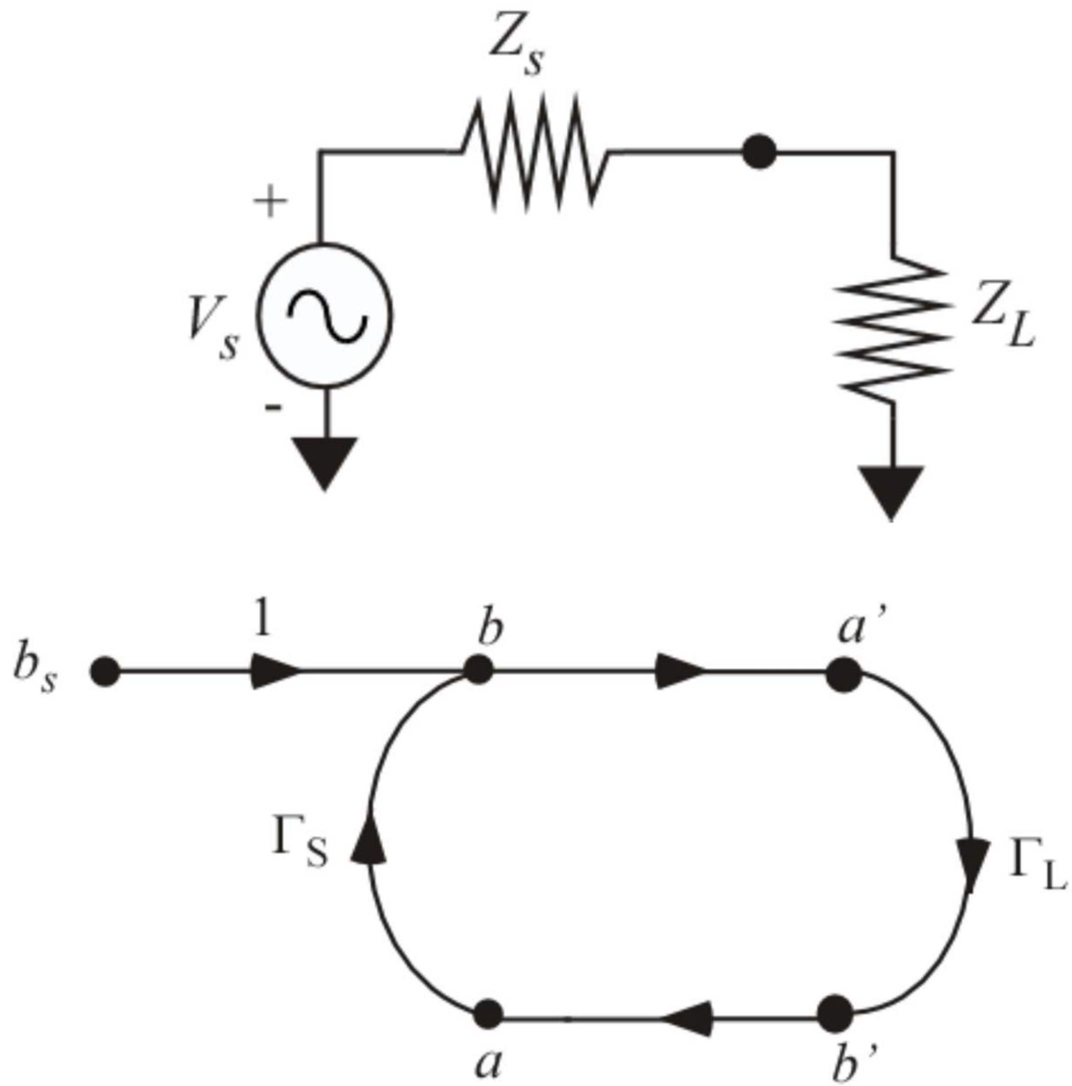
Flow Graph for Load



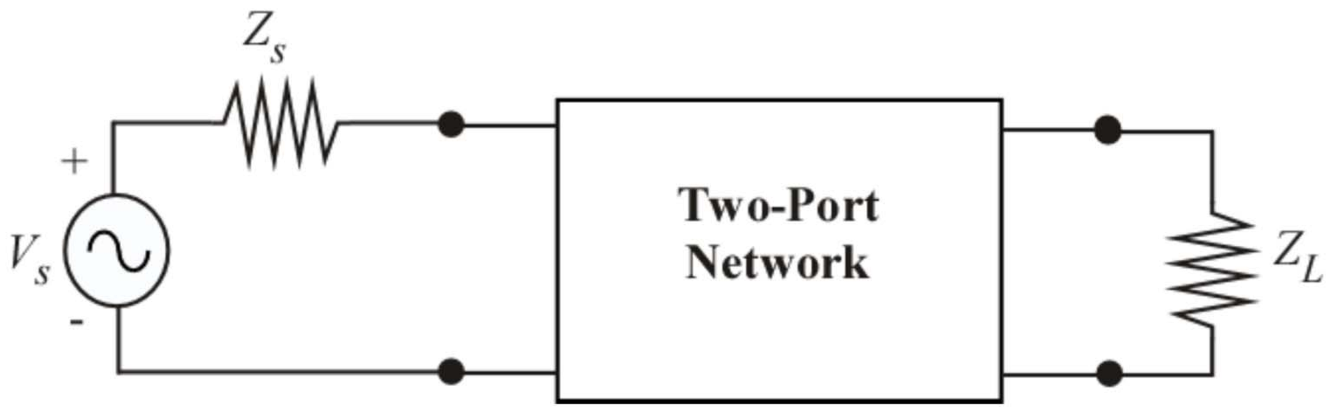


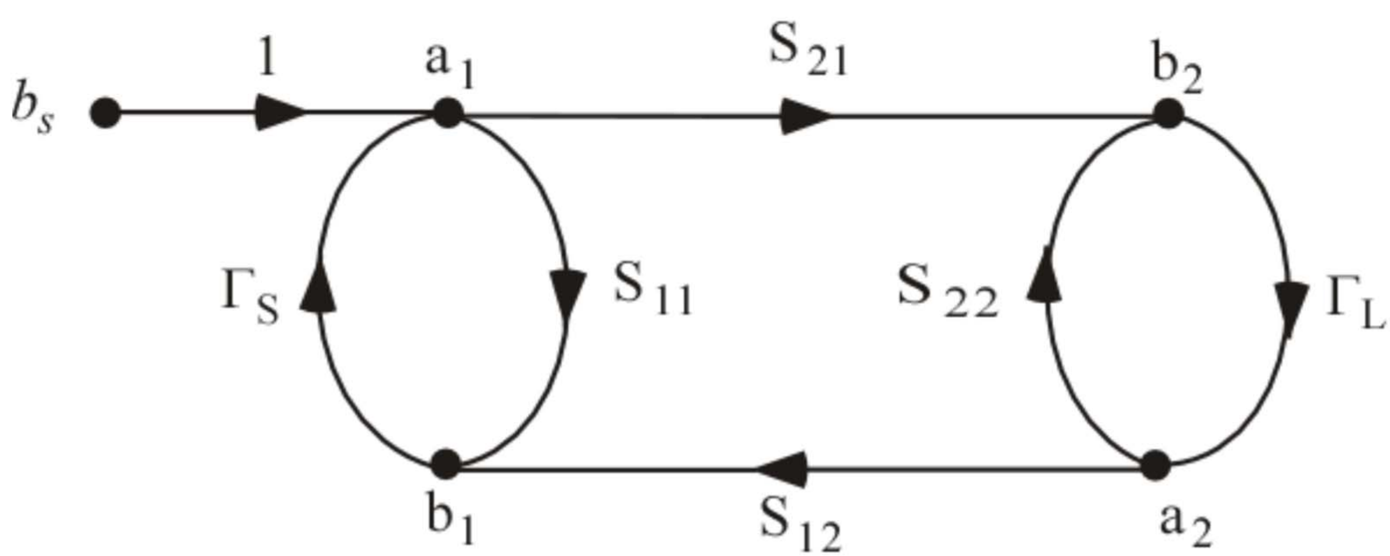
$$\Gamma_L = \frac{Z_L - Z_o}{Z_L + Z_o}$$

Flow Graph for Composite Circuit



Flow Graph of Complete Two-Port





Loop Definitions

- A first order loop is defined as the product of the branches encountered in a journey starting from anode and moving in the direction of the arrows back to that original node

- A second order loop is defined as the product of any two non-touching first order loops.

- A third order loop is defined as the product of any three non-touching first order loops.

Mason's Non-Touching Loop Rule

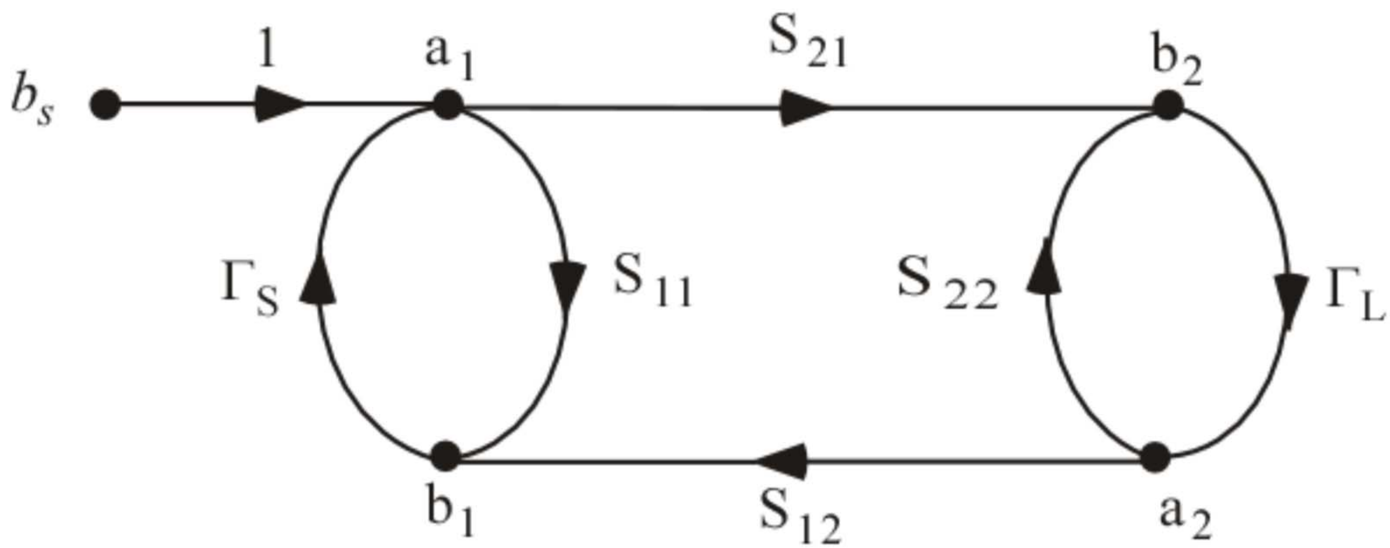
$$T = \frac{P_1\left[1-\sum L(1)^{(1)}+\sum L(2)^{(1)}-\ldots\right]+P_2\left[1-\sum L(1)^{(2)}+\ldots\right]+\ldots}{1-\sum L(1)+\sum L(2)-\sum L(3)+\ldots}$$

T: ratio of dependent variable over independent variable

P_k's: are the various paths connecting the two variables of interest

$L(j)^{(k)}$ is a loop of order j that does not touch path k

Example: Find b_2/b_s



First Order Loops: $S_{11}\Gamma_S$, $S_{22}\Gamma_L$, $S_{21}S_{12}\Gamma_L\Gamma_S$

Second Order Loops: $S_{11}\Gamma_S S_{22}\Gamma_L$

Paths: S_{21}

$$\frac{b_2}{b_s} = \frac{S_{21}}{1 - S_{11}\Gamma_S - S_{22}\Gamma_L - S_{21}S_{12}\Gamma_L\Gamma_S + S_{11}\Gamma_S S_{22}\Gamma_L}$$

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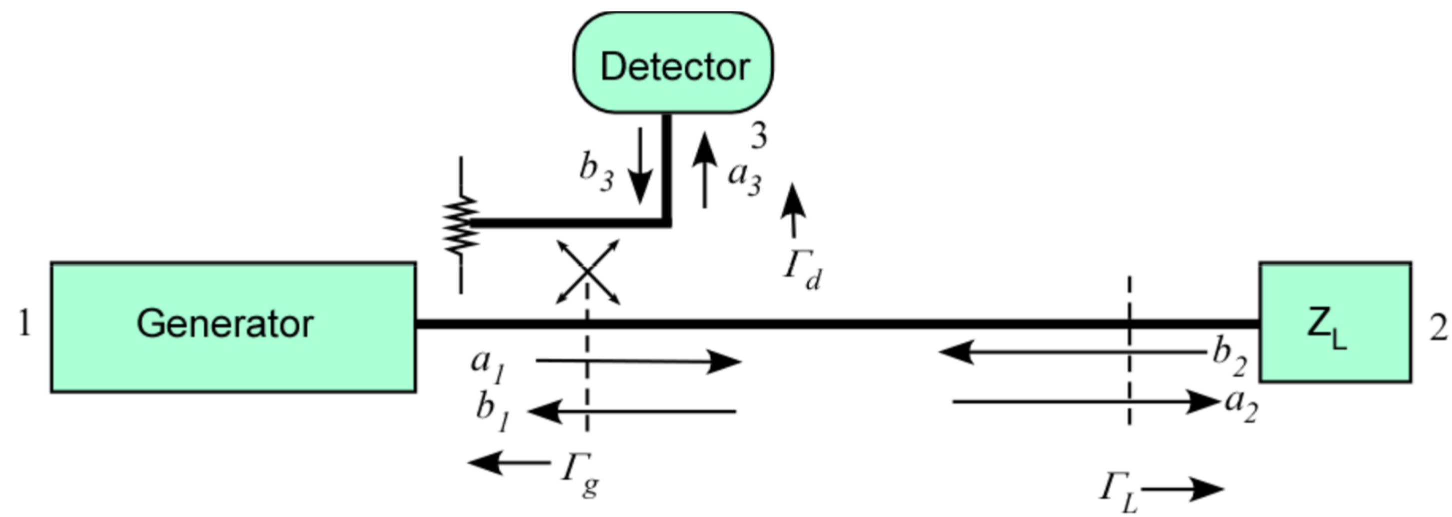
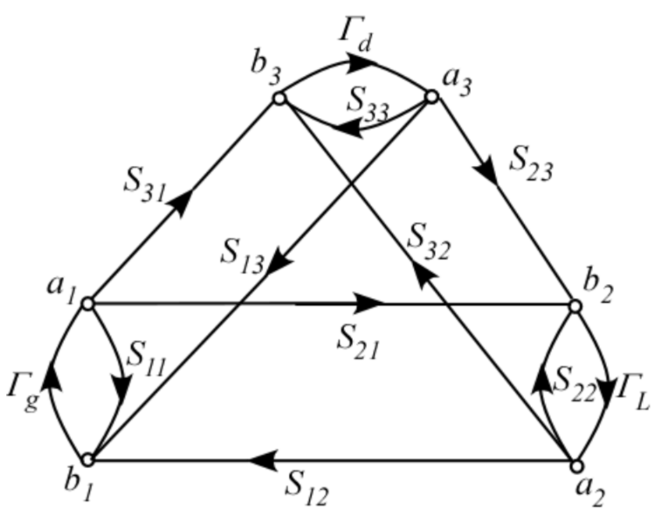
Flow Graph for Directional Coupler





Assume load is matched $\Gamma_L=0$

First order loops:

$$\Gamma_g S_{11},\ \Gamma_g S_{31}\Gamma_d S_{13},\ \ \Gamma_d S_{33}$$

Second order loop:

$$\Gamma_g S_{11}\Gamma_d S_{33}$$

$$\Delta = 1-\Gamma_g S_{11}-\Gamma_d S_{33}-\Gamma_g S_{31}\Gamma_d S_{13}+\Gamma_g S_{11}\Gamma_d S_{33}$$