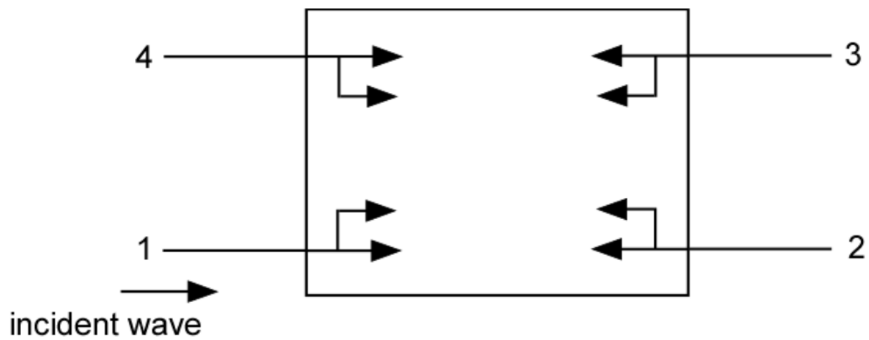
ECE 451
Advanced Microwave Measurements

Directional Couplers

Jose E. Schutt-Aine
Electrical & Computer Engineering
University of Illinois
jschutt@emlab.uiuc.edu

Directional Coupler

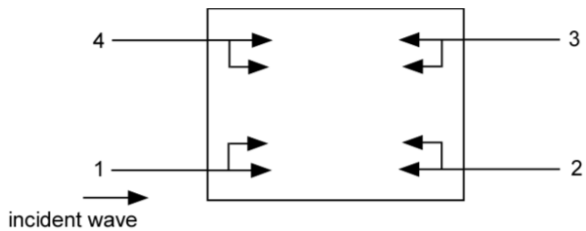


- Wave incident in port 1 couples into ports 2 & 3 but NOT in port 4 ➔ ports 1 &4 are uncoupled
- Wave incident in port 2 couples into ports 1 & 4 but NOT in port 3 ➔ ports 2 &3 are uncoupled
- In addition, all 4 ports are matched. That is if 3 ports are terminated with Z_o, the fourth port appears terminated with Z_o.

Characteristics of Directional Couplers

Coupling

Let P_i be the incident power in port 1
Let P_f be the coupled power in port 3
Define coupling in decibels (dB) as:



$$C = 10\, log\, \frac{P_i}{P_f}$$

Directivity

Ideally, power coupled into port 4, P_b should be zero, but in reality it is not which defines the directivity of the coupler

$$D = 10\, log\, \frac{P_f}{P_b}$$

Ideally, directivity should be infinite

S-Parameters of Directional Couplers

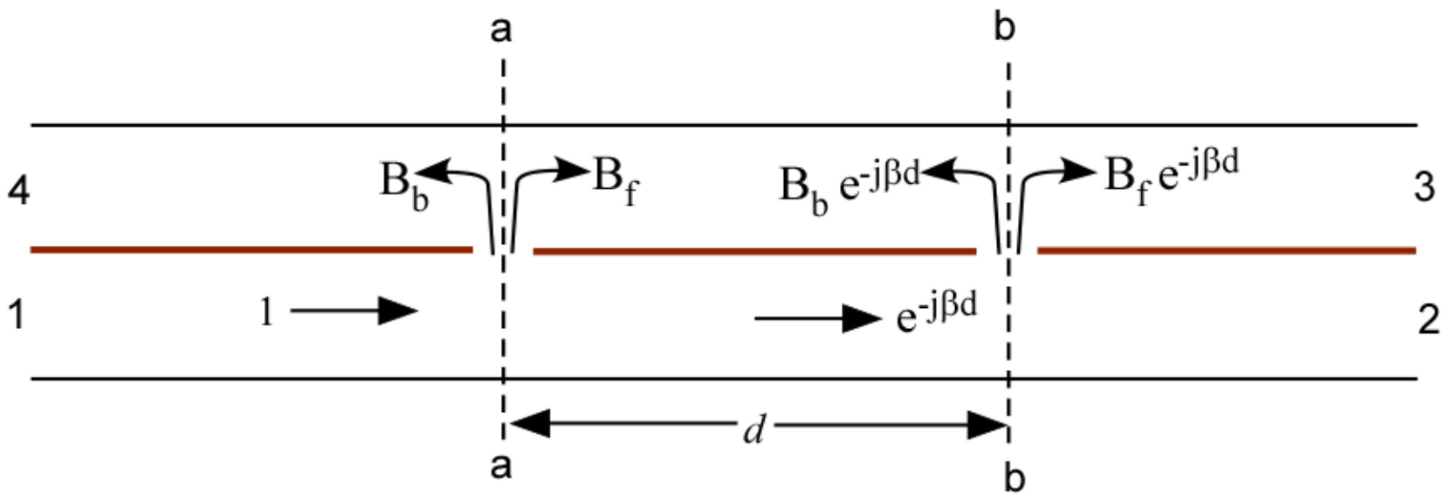
Directional coupler is described by a 4 by 4 S-parameter matrix. It is obvious that $S_{14}=S_{23}=0$ ➔ $S_{41}=S_{32}=0$. Moreover, $S_{11}=S_{22}=S_{33}=S_{44}=0$

$$\mathbf{S}=\begin{bmatrix} 0 & S_{12} & S_{13} & 0 \\ S_{21} & 0 & 0 & S_{24} \\ S_{31} & 0 & 0 & S_{34} \\ 0 & S_{42} & S_{43} & 0 \end{bmatrix}$$

By reciprocity, $S_{12}=S_{21}$, $S_{13}=S_{31}$, $S_{42}=S_{24}$ and $S_{43}=S_{34}$

Design of Directional Coupler

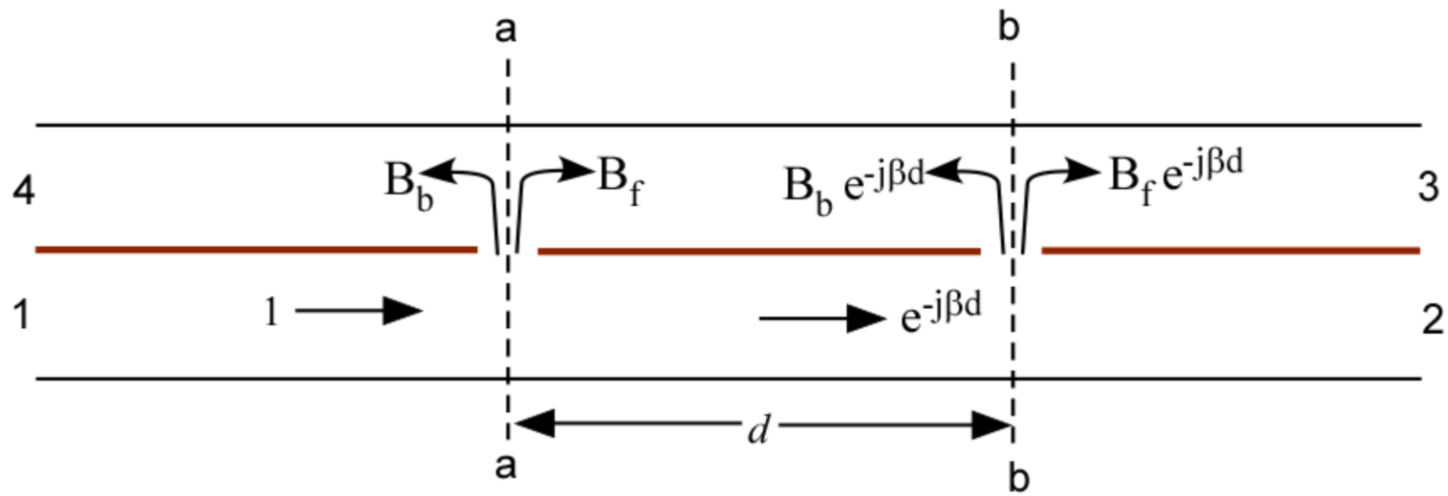
Aperture Coupling



- Incident wave in port 1 has value 1
- Forward wave coupled in second guide at first hole has value B_f.
- Backward wave coupled in second guide at first hole has value B_b.
- B_b and B_f are the aperture coupling coefficients

Design of Directional Coupler

Aperture Coupling



- At second aperture, the field is approximately of the same magnitude but the phase has changed.
- Forward: $B_f e^{-j\beta d}$ --- Backward: $B_b e^{-j\beta d}$
- Total forward wave in upper guide at plane bb is $2B_f e^{-j\beta d}$
- Total backward wave in upper guide at plane aa is given by $B_b(1+e^{-j2\beta d})$

Design of Directional Coupler

Results

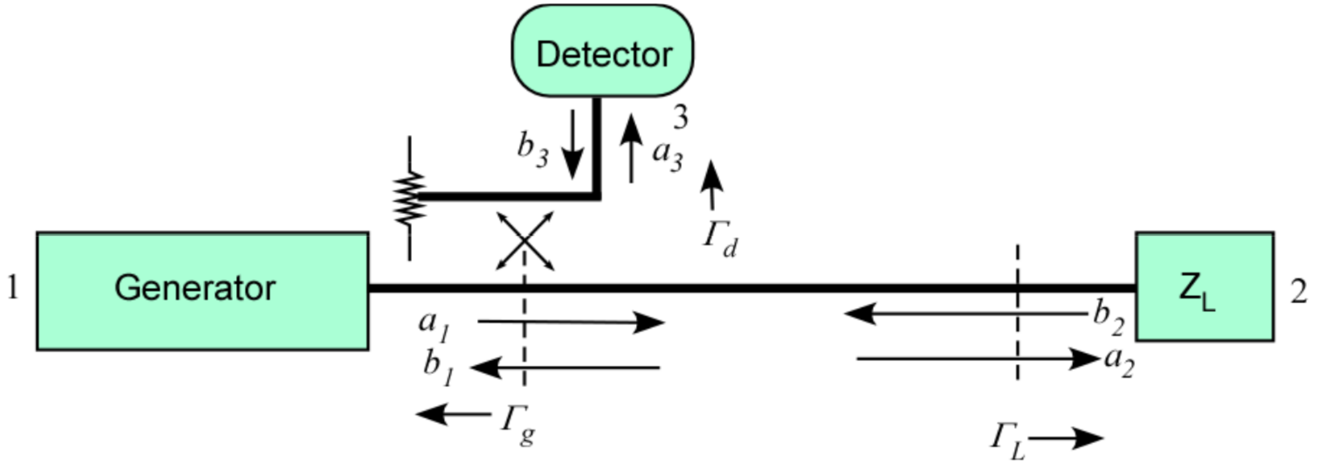
- Forward waves add in phase (same path length)
- Backward waves add out of phase if d=λ/4 or if d is an integer multiple of λ/4.

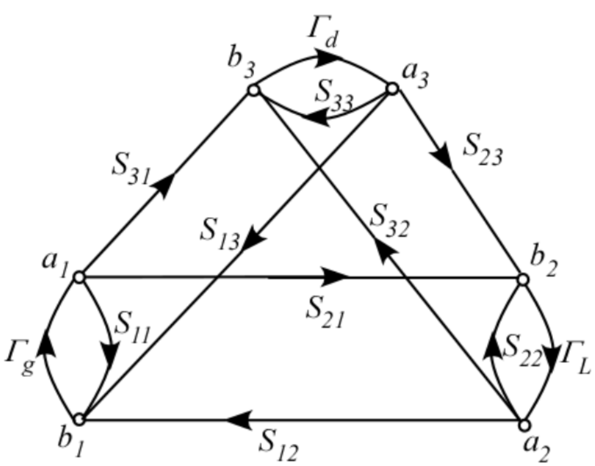
Coupling: $C = -20\,log\,2\left|B_f\right|$

Directivity: $D = 20\,log\dfrac{2\left|B_f\right|}{\left|B_b\right|\left|1+e^{-2j\beta d}\right|} = 20\,log\dfrac{2\left|B_f\right|}{\left|B_b\right|\left|cos\,\beta d\right|}$

$$D = 20\,log\frac{\left|B_f\right|}{\left|B_b\right|} + 20\,log\left|sec\,\beta d\right|$$

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:

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

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