R. Ludwig and G. Bogdanov
"RF Circuit Design: Theory and Applications"
2nd edition

Figures for Chapter 4

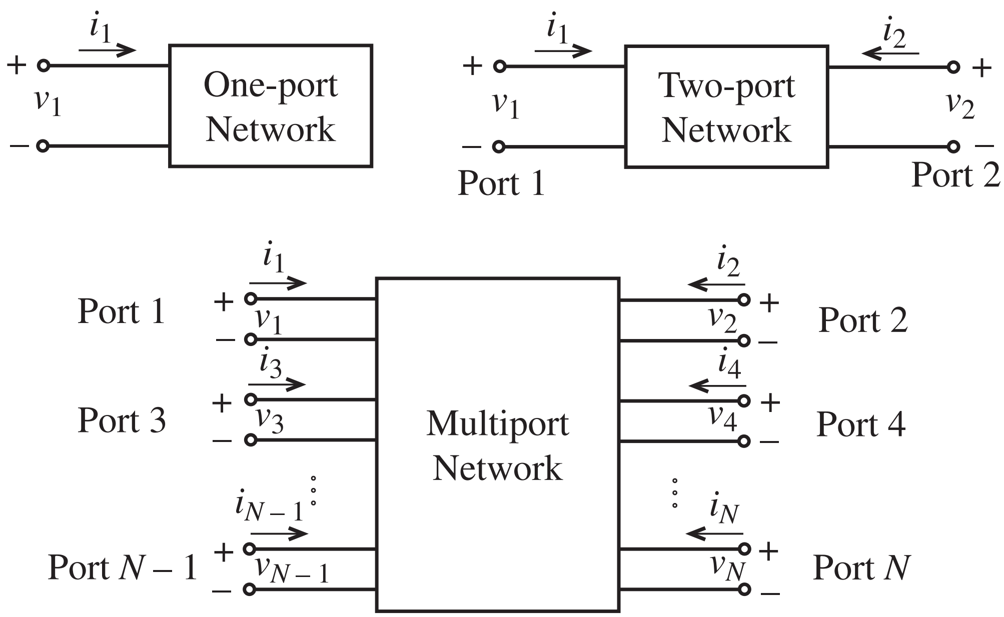


Figure 4-1 Basic voltage and current definitions for single- and multiport network.

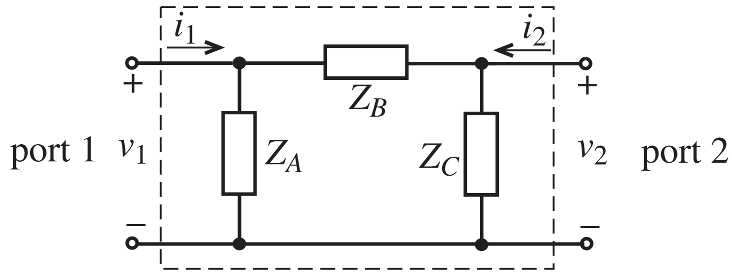


Figure 4-2 Pi-network as a two-port network.

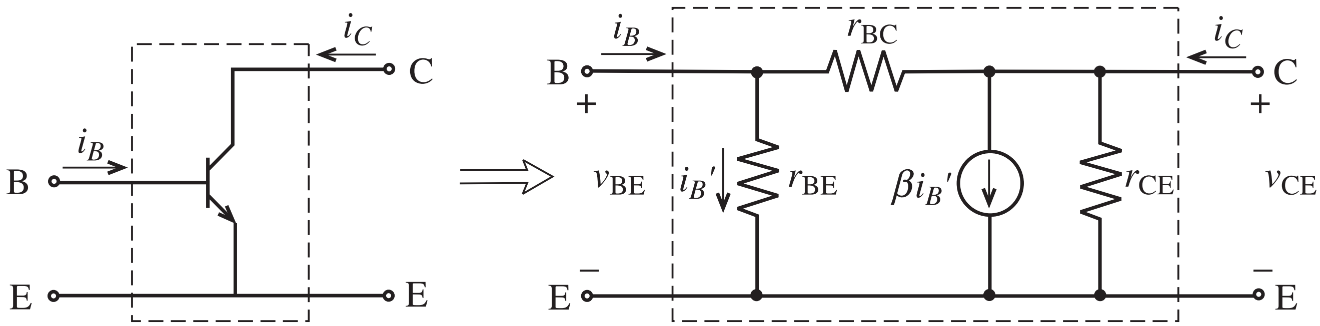


Figure 4-3 Common-emitter low-frequency, small-signal transistor model.

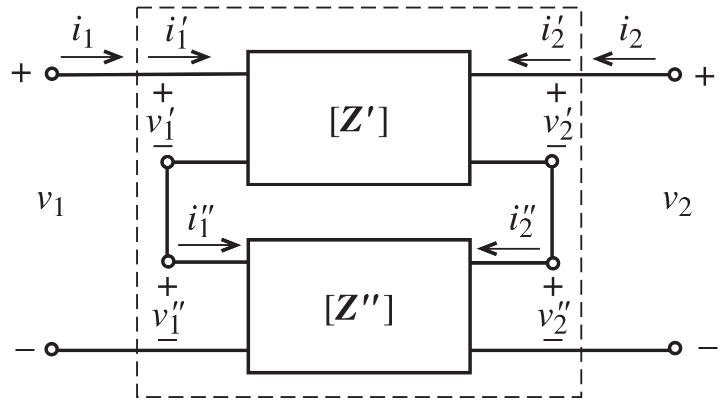


Figure 4-4   Series connection of two two-port networks.

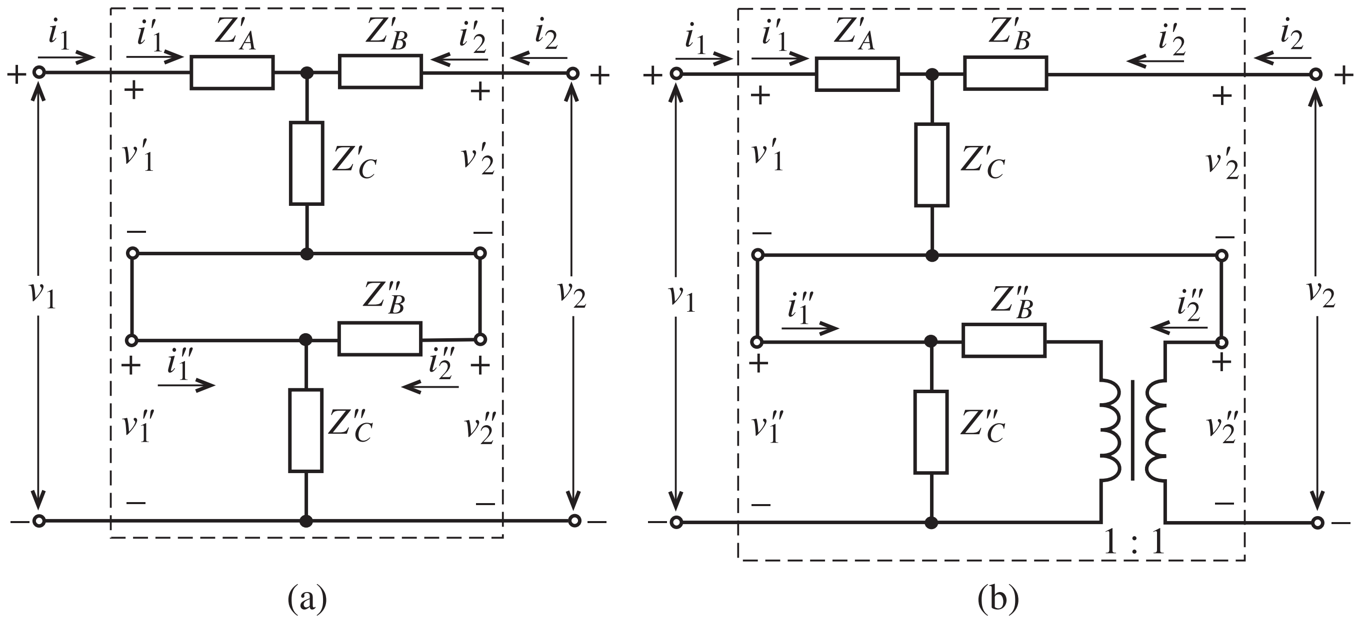


Figure 4-5 (a) Short circuit in series connection. (b) Transformer to avoid short circuit.

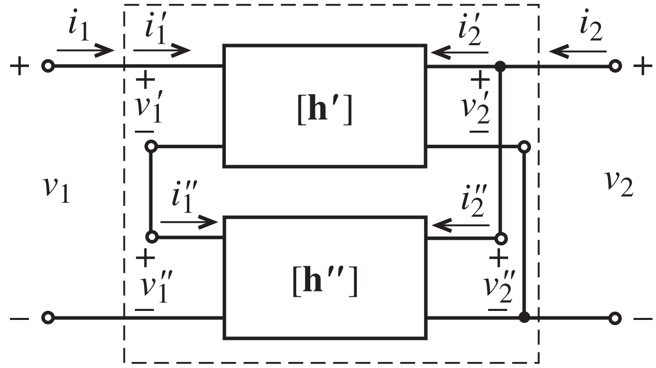


Figure 4-6 Connection of two-port networks suitable for hybrid representation.

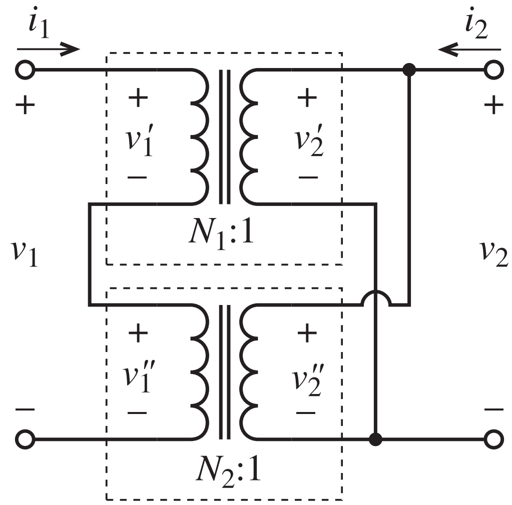


Figure 4-7 Series connection of two hybrid networks.

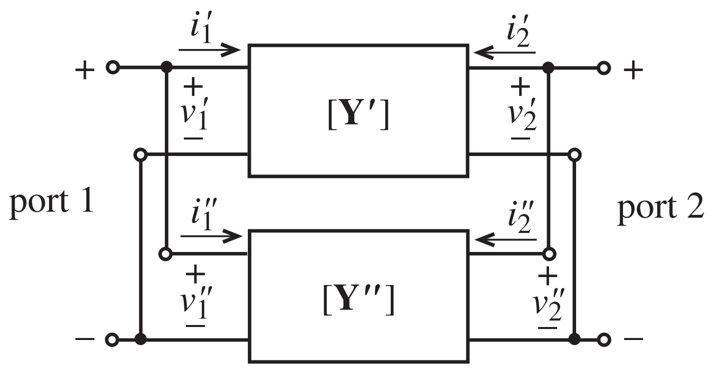


Figure 4-8   Parallel connection of two two-port networks.

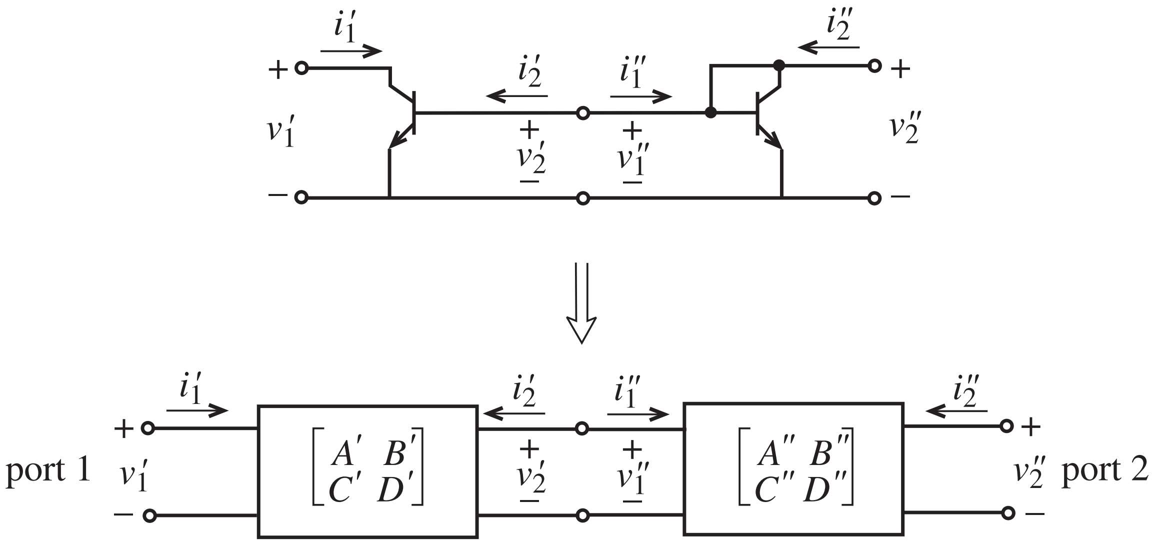


Figure 4-9 Cascading two networks.

Table 4-1 *ABCD*-parameters of several two-port circuits

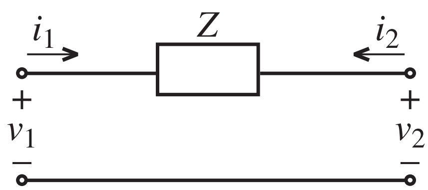
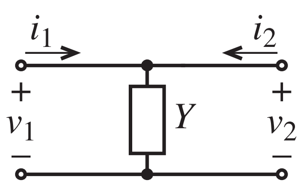
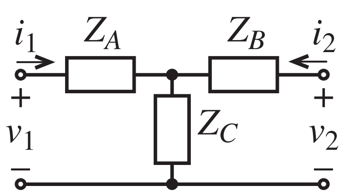
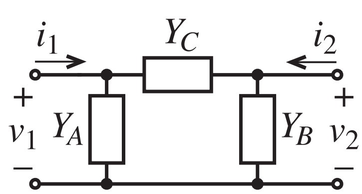
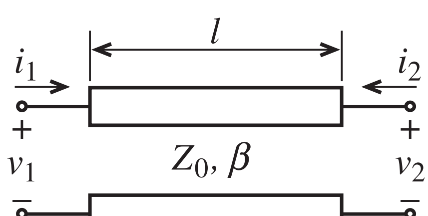
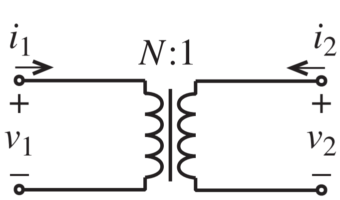
Circuit	***ABCD* Parameters**	
	$A = 1$	$B = Z$
	$C = 0$	$D = 1$
	$A = 1$	$B = 0$
	$C = Y$	$D = 1$
	$A = 1 + \frac{Z_A}{Z_C}$	$B = Z_A + Z_B + \frac{Z_A Z_B}{Z_C}$
	$C = \frac{1}{Z_C}$	$D = 1 + \frac{Z_B}{Z_C}$
	$A = 1 + \frac{Y_B}{Y_C}$	$B = \frac{1}{Y_C}$
	$C = Y_A + Y_B + \frac{Y_A Y_B}{Y_C}$	$D = 1 + \frac{Y_A}{Y_C}$
	$A = \cos(\beta l)$	$B = jZ_0 \sin(\beta l)$
	$C = \frac{j\sin(\beta l)}{Z_0}$	$D = \cos(\beta l)$
	$A = N$	$B = 0$
	$C = 0$	$D = \frac{1}{N}$

Table 4-2 Conversion between different network representations

	[Z]	**[Y]**	**[h]**	**[ABCD]**
[Z]	$\begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix}$	$\begin{bmatrix} \frac{Z_{22}}{\Delta Z} & -\frac{Z_{12}}{\Delta Z} \\ -\frac{Z_{21}}{\Delta Z} & \frac{Z_{11}}{\Delta Z} \end{bmatrix}$	$\begin{bmatrix} \frac{\Delta Z}{Z_{22}} & \frac{Z_{12}}{Z_{22}} \\ -\frac{Z_{21}}{Z_{22}} & \frac{1}{Z_{22}} \end{bmatrix}$	$\begin{bmatrix} \frac{Z_{11}}{Z_{21}} & \frac{\Delta Z}{Z_{21}} \\ \frac{1}{Z_{21}} & \frac{Z_{22}}{Z_{21}} \end{bmatrix}$
[Y]	$\begin{bmatrix} \frac{Y_{22}}{\Delta Y} & -\frac{Y_{12}}{\Delta Y} \\ -\frac{Y_{21}}{\Delta Y} & \frac{Y_{11}}{\Delta Y} \end{bmatrix}$	$\begin{bmatrix} Y_{11} & Y_{12} \\ Y_{21} & Y_{22} \end{bmatrix}$	$\begin{bmatrix} \frac{1}{Y_{11}} & -\frac{Y_{12}}{Y_{11}} \\ \frac{Y_{21}}{Y_{11}} & \frac{\Delta Y}{Y_{11}} \end{bmatrix}$	$\begin{bmatrix} -\frac{Y_{22}}{Y_{21}} & -\frac{1}{Y_{21}} \\ -\frac{\Delta Y}{Y_{21}} & -\frac{Y_{11}}{Y_{21}} \end{bmatrix}$
[h]	$\begin{bmatrix} \frac{\Delta h}{h_{22}} & \frac{h_{12}}{h_{22}} \\ -\frac{h_{21}}{h_{22}} & \frac{1}{h_{22}} \end{bmatrix}$	$\begin{bmatrix} \frac{1}{h_{11}} & -\frac{h_{12}}{h_{11}} \\ \frac{h_{21}}{h_{11}} & \frac{\Delta h}{h_{11}} \end{bmatrix}$	$\begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix}$	$\begin{bmatrix} -\frac{\Delta h}{h_{21}} & -\frac{h_{11}}{h_{21}} \\ -\frac{h_{22}}{h_{21}} & -\frac{1}{h_{21}} \end{bmatrix}$
[ABCD]	$\begin{bmatrix} \frac{A}{C} & \frac{\Delta ABCD}{C} \\ \frac{1}{C} & \frac{D}{C} \end{bmatrix}$	$\begin{bmatrix} \frac{D}{B} & -\frac{\Delta ABCD}{B} \\ -\frac{1}{B} & \frac{A}{B} \end{bmatrix}$	$\begin{bmatrix} \frac{B}{D} & \frac{\Delta ABCD}{D} \\ -\frac{1}{D} & \frac{C}{D} \end{bmatrix}$	$\begin{bmatrix} A & B \\ C & D \end{bmatrix}$

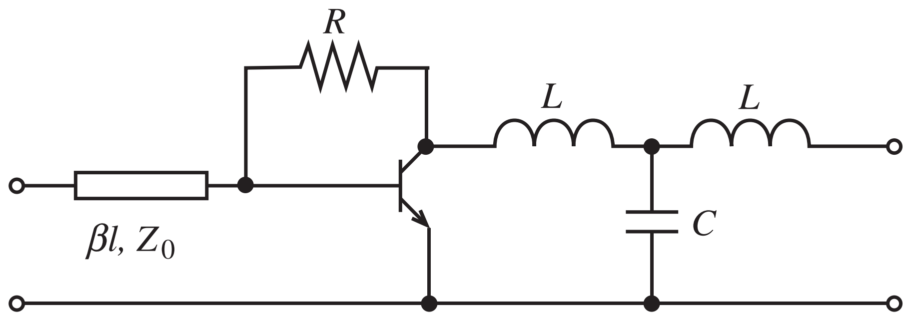


Figure 4-10　Microwave amplifier circuit diagram.

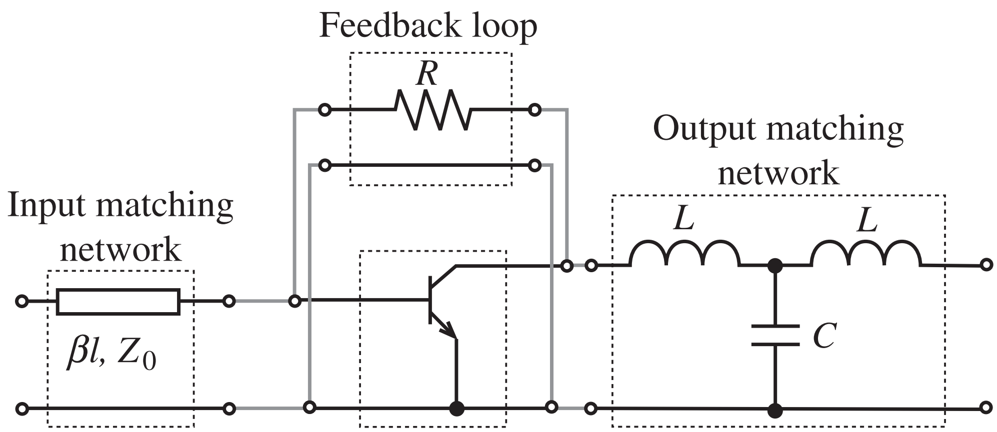


Figure 4-11 Subnetwork representation of the microwave amplifier.

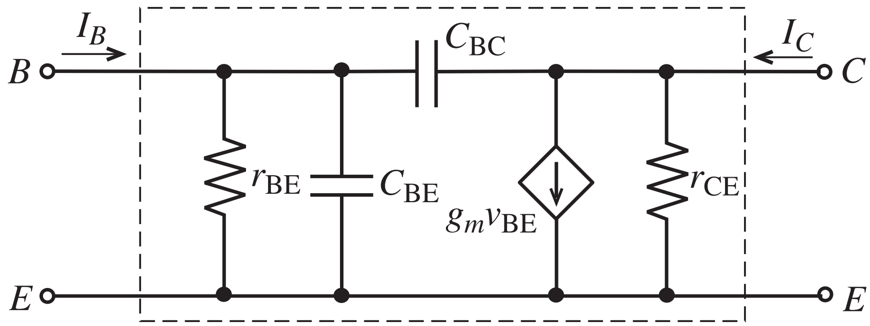


Figure 4-12 High-frequency hybrid transistor model.

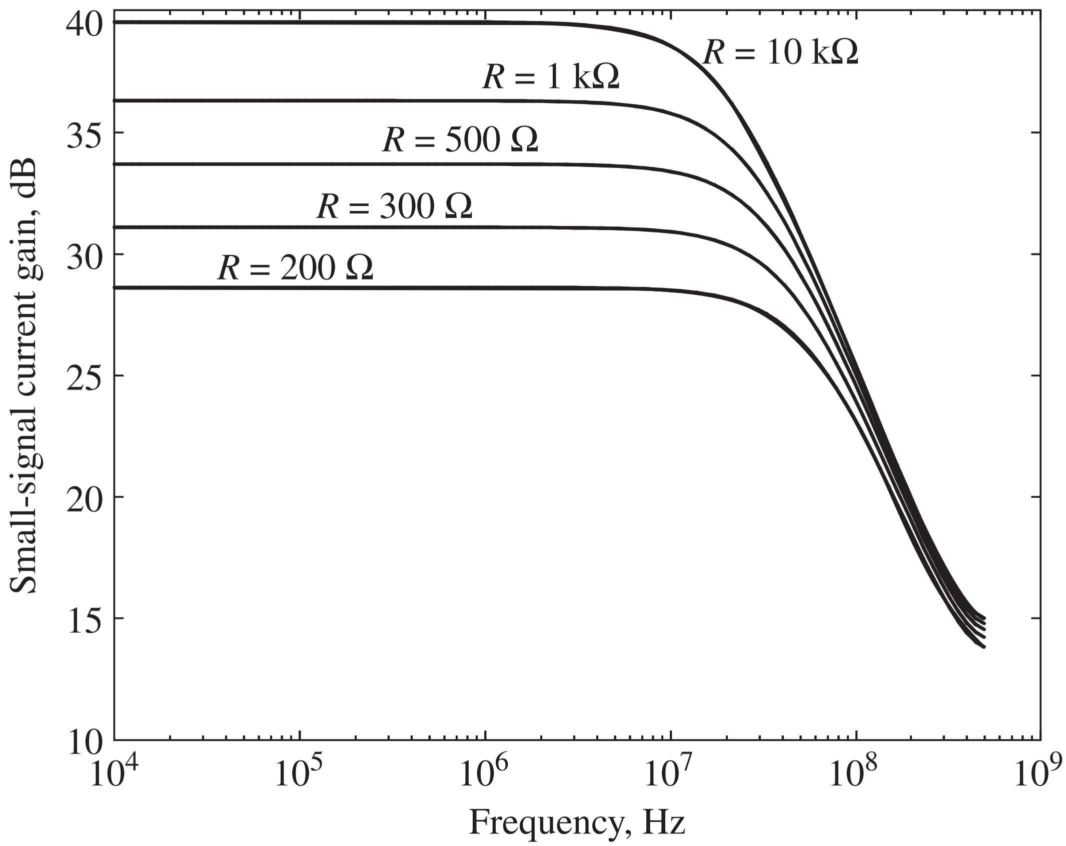


Figure 4-13 Small-signal current gain of the amplifier versus frequency for different values of the feedback resistor.

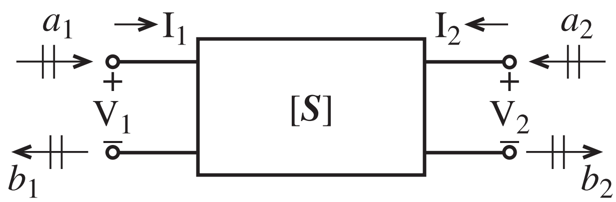


Figure 4-14 Convention used to define *S*-parameters for a two-port network.

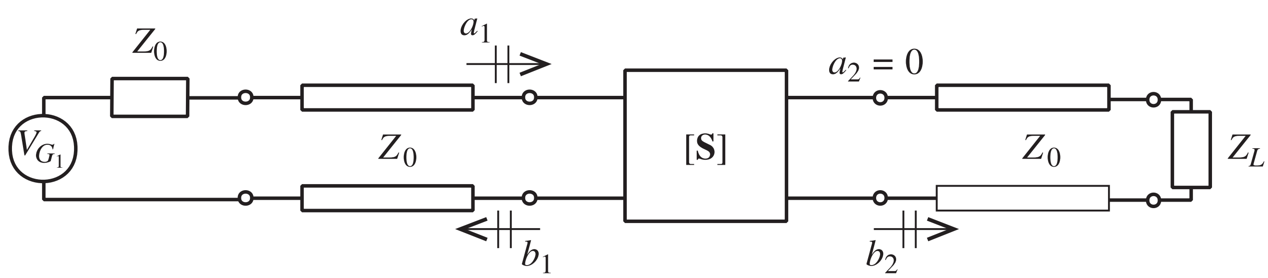


Figure 4-15 Measurement of S_{11} and S_{21} by matching the line impedance Z_0 at port 2 through a corresponding load impedance $Z_L = Z_0$.

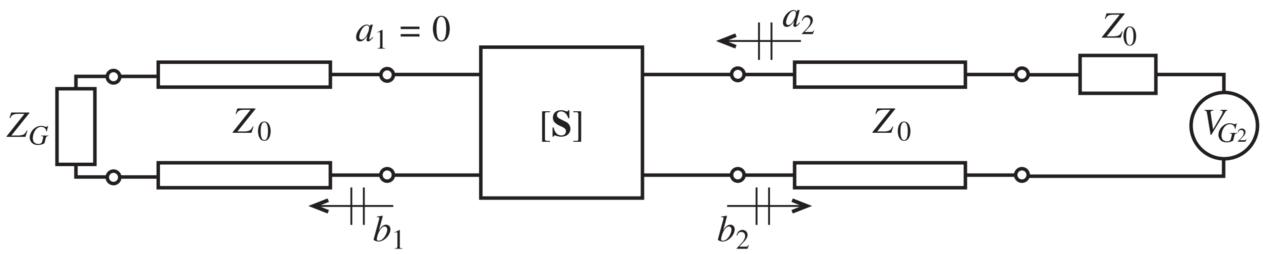


Figure 4-16 Measurement of S_{22} and S_{12} by matching the line impedance Z_0 at port 1 through a corresponding input impedance $Z_G = Z_0$.

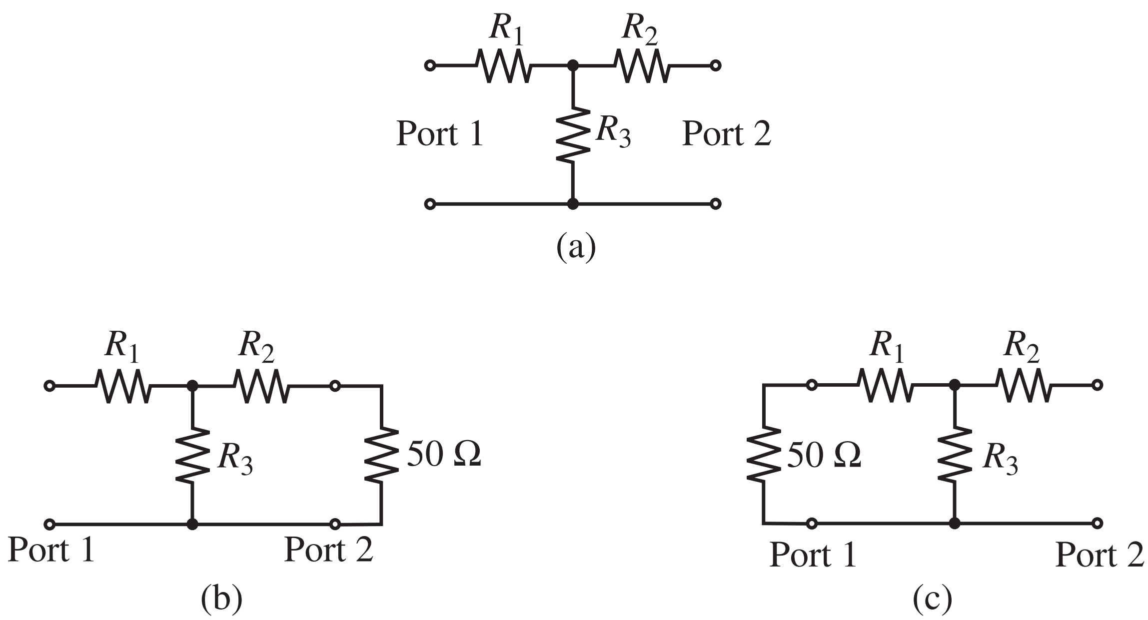


Figure 4-17 S-parameter computation for a T-network. (a) circuit diagram; (b) circuit for S_{11} and S_{21} measurements; (c) circuit for S_{12} and S_{22} measurements.

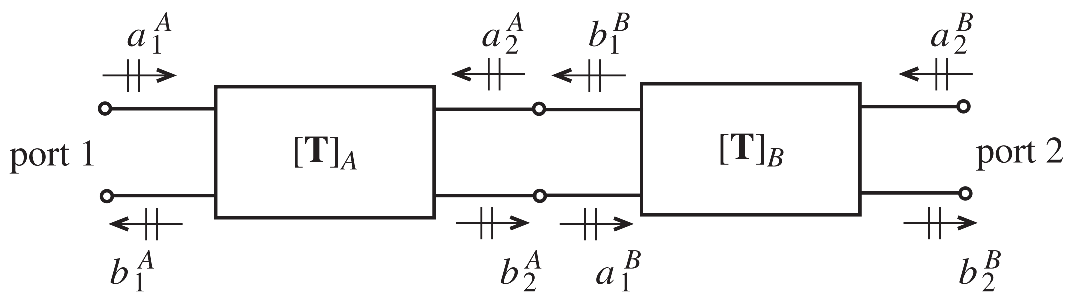


Figure 4-18 Cascading of two networks *A* and *B*.

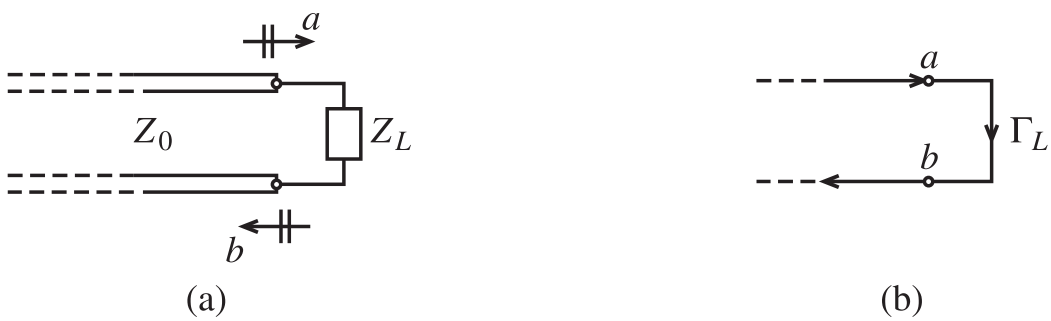


Figure 4-19 Terminated transmission line segment with incident and reflected power wave description. (a) Conventional form, and (b) Signal flow form.

(a) Source node *a*, which launches wave.

(b) Sink node *b*, which receives wave.

(c) Branch connecting source and sink.

Figure 4-20 Generic source node (a), receiver node (b), and the associated branch connection (c).

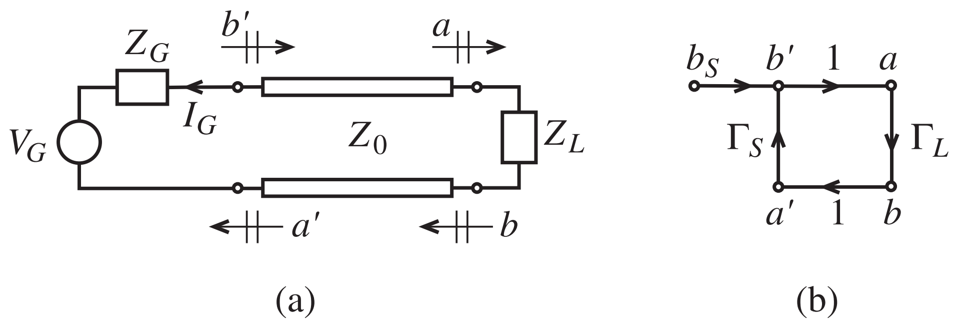


Figure 4-21 Terminated transmission line with source. (a) conventional form, (b) signal flow form, and (c) simplified signal flow form.

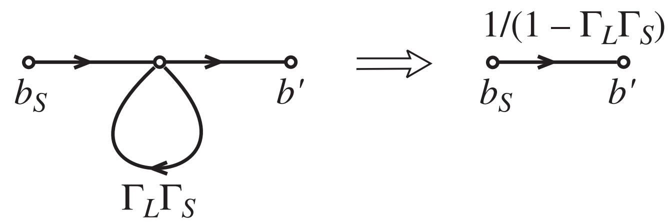
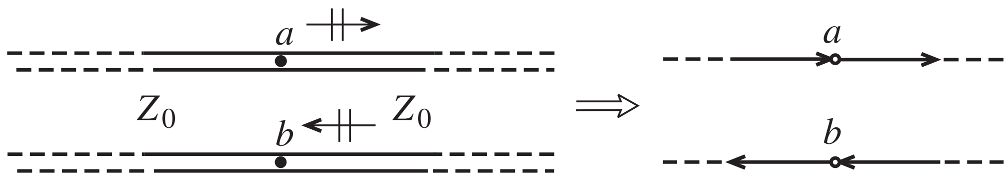
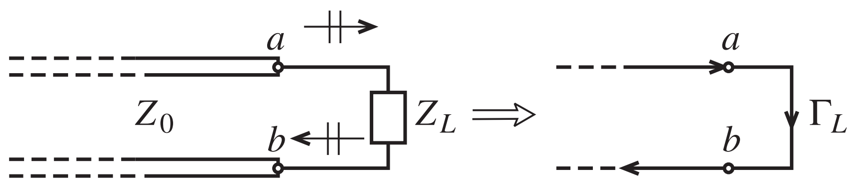
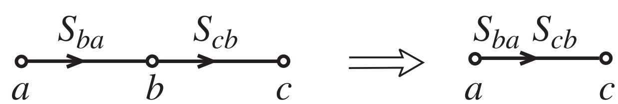
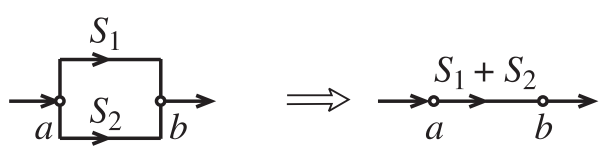
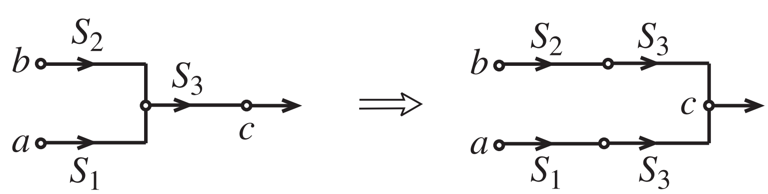
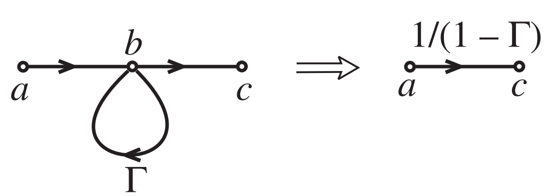
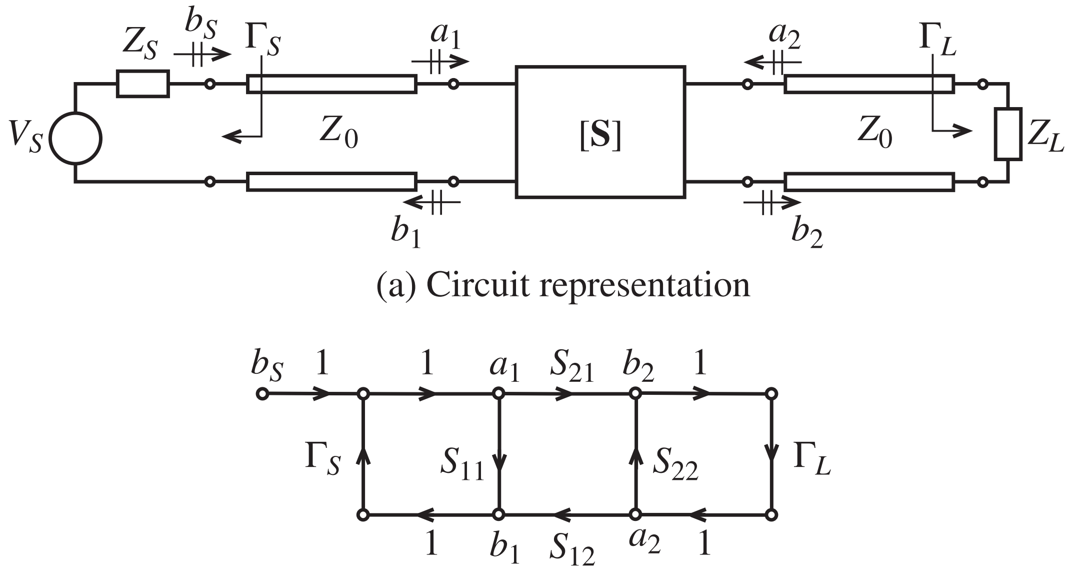


Figure 4-22 A self-loop that collapses to a single branch.

Table 4-3 Signal flowgraph building blocks.

Description	Graphical Representation
Nodal Assignment	
Branch	
Series Connection	
Parallel Connection	
Splitting of Branches	
Self-Loop	



(a) Circuit representation

(b) Signal flowgraph

Figure 4-23 Sourced and terminated two-port network.

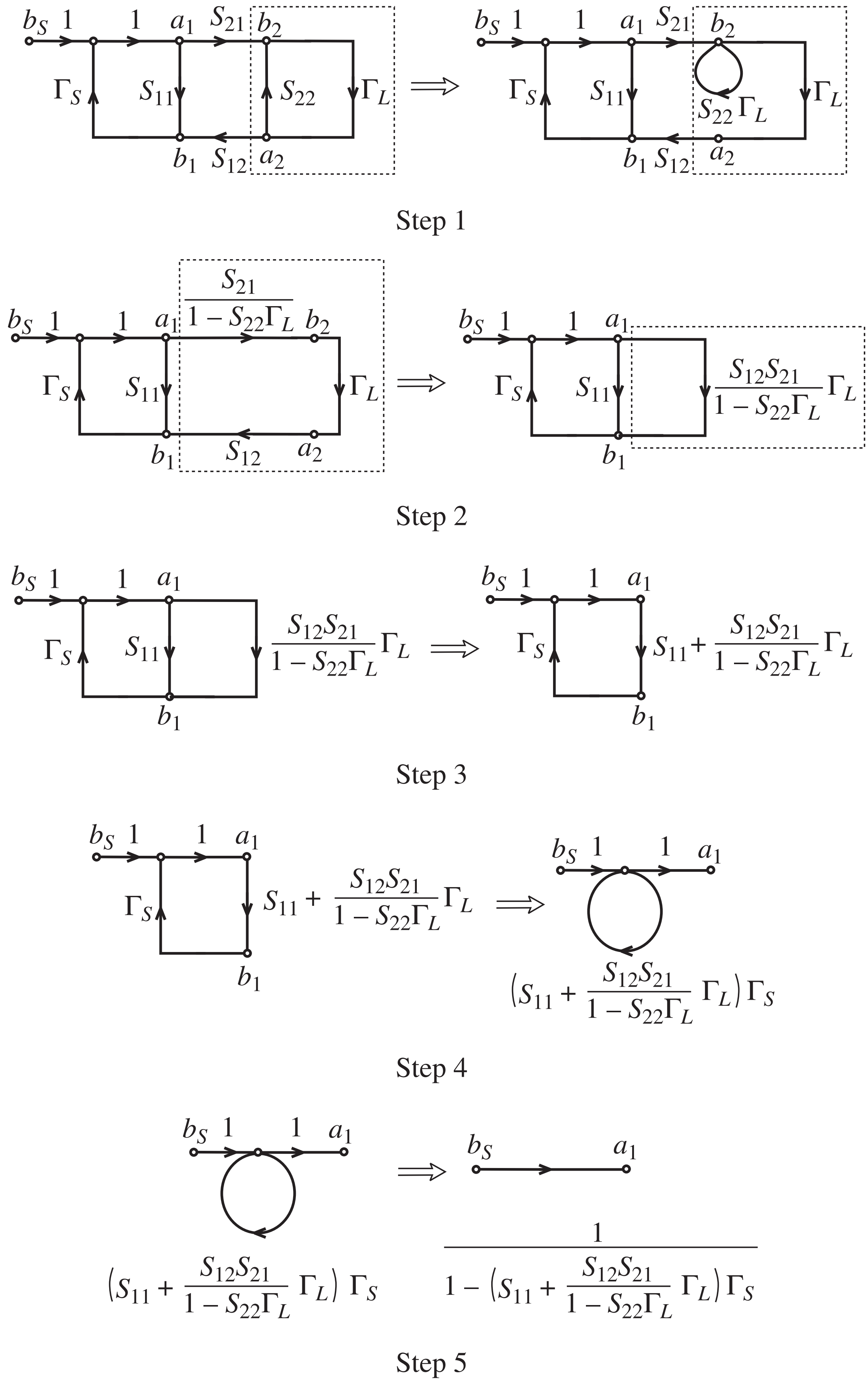


Figure 4-24 Step-by-step simplification to determine the ratio a_1/b_S.

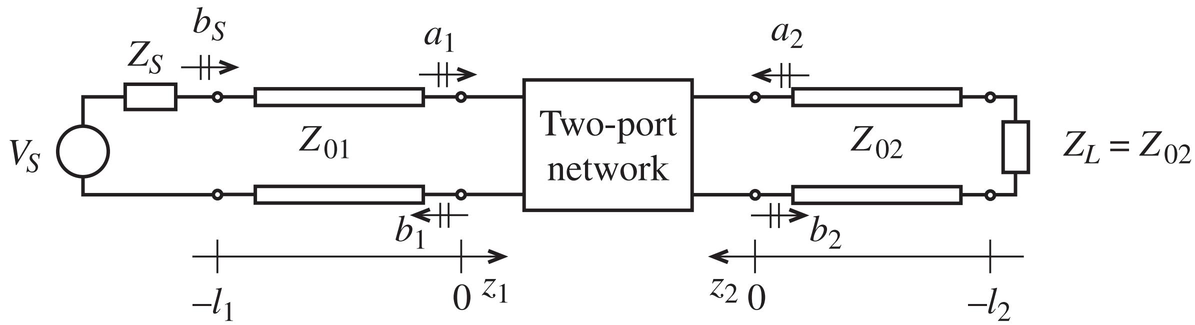


Figure 4-25 Two-port network with finite-length transmission line segments.

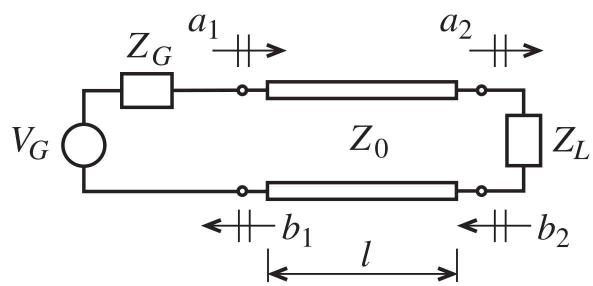


Figure 4-26 Transmission line attached to a voltage source and terminated by a load impedance.

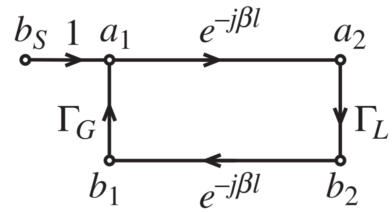


Figure 4-27 Signal flowgraph diagram for transmission line system in Figure 26.

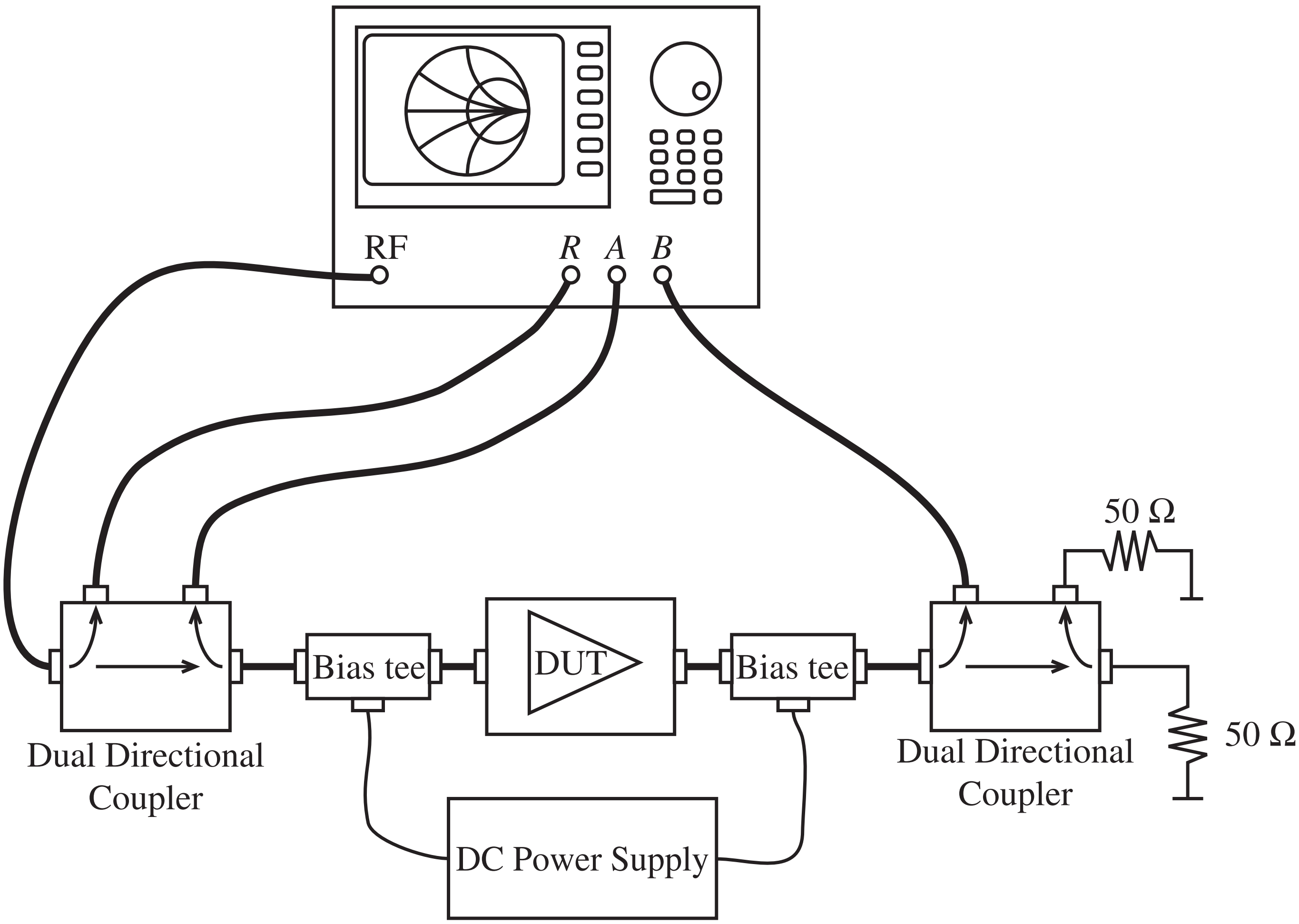


Figure 4-28 Measurement system for S_{11} and S_{21} parameters using a network analyzer.

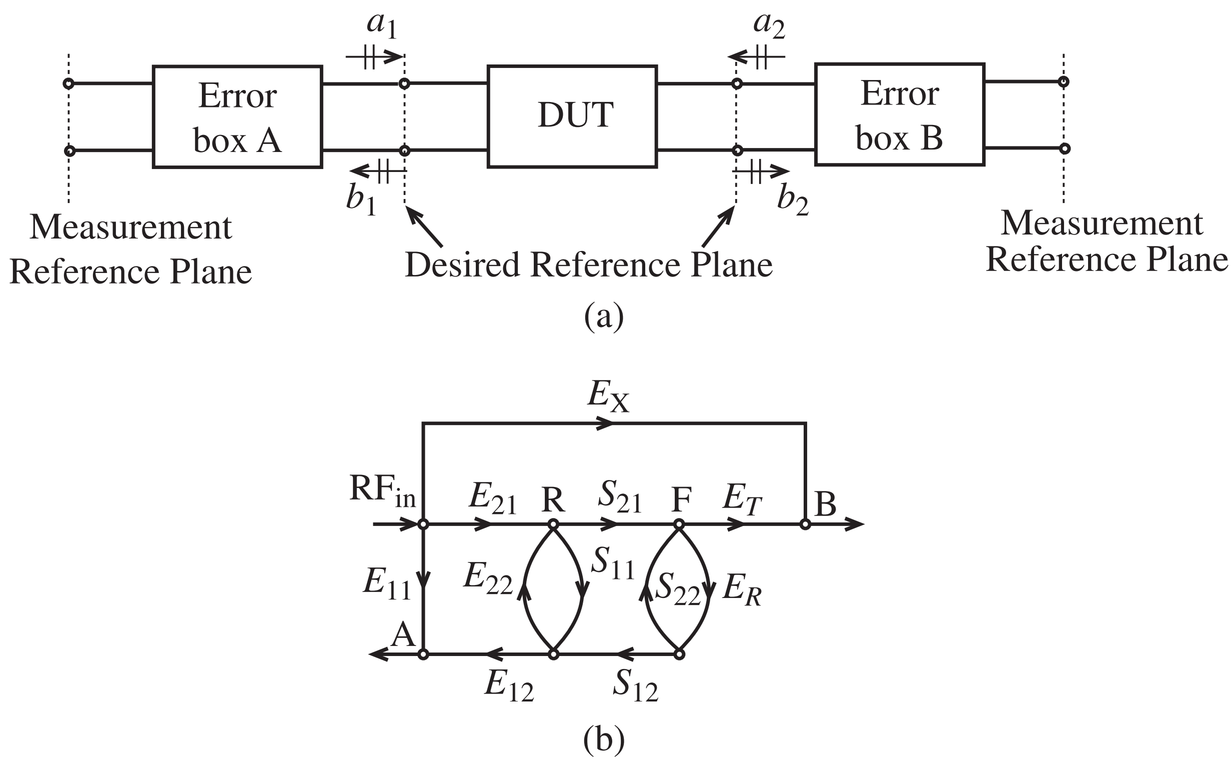


Figure 4-29 (a) Block diagram of the setup for measurement of *S*-parameters of a two-port network; (b) signal flowgraph of the measurement test setup.

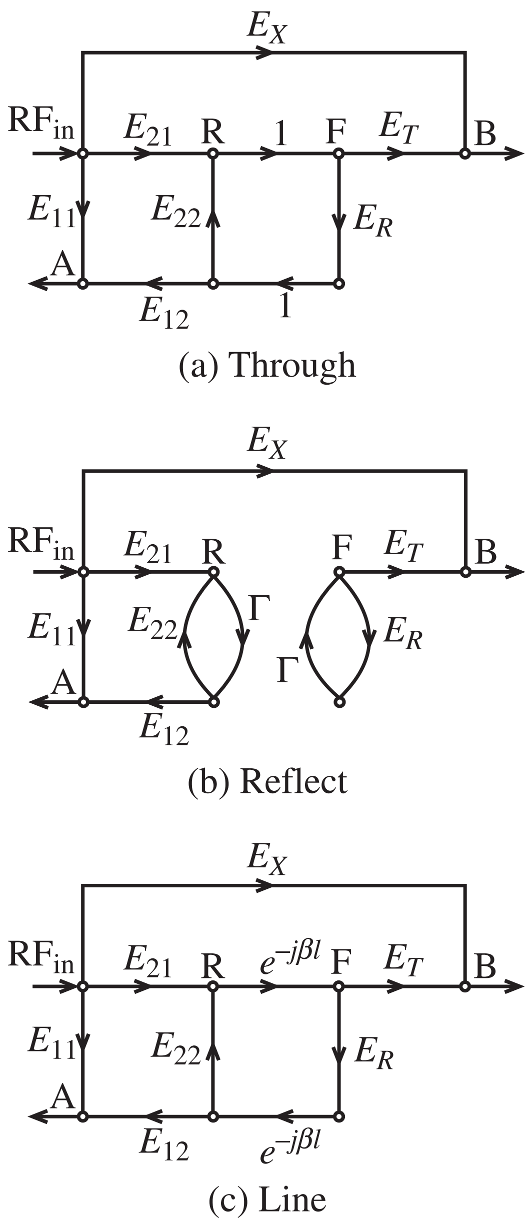


Figure 4-30 Signal flow graphs of TRL method: (a) Through, (b) Reflect, (c) Line configurations.

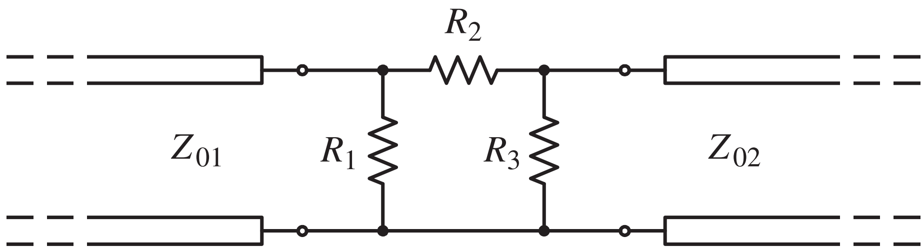


Figure 4-31 Resistive Pi-network attenuator with arbitrary characteristic impedances at the ports.

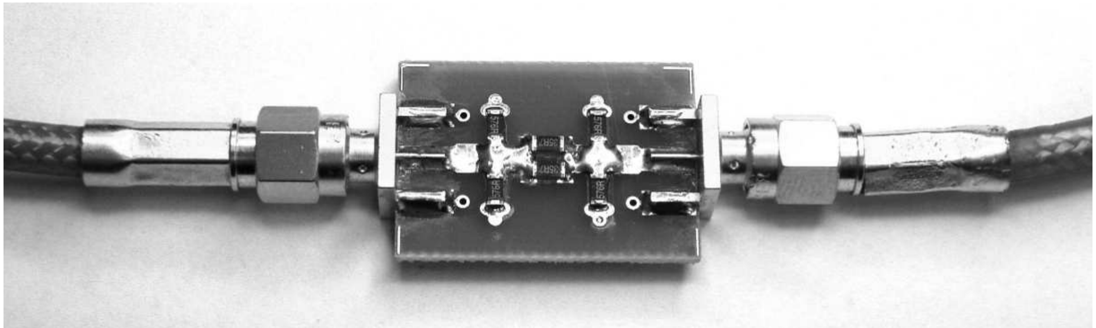


Figure 4-32   Pi-network of a 3 dB attenuator with SMA connectors.

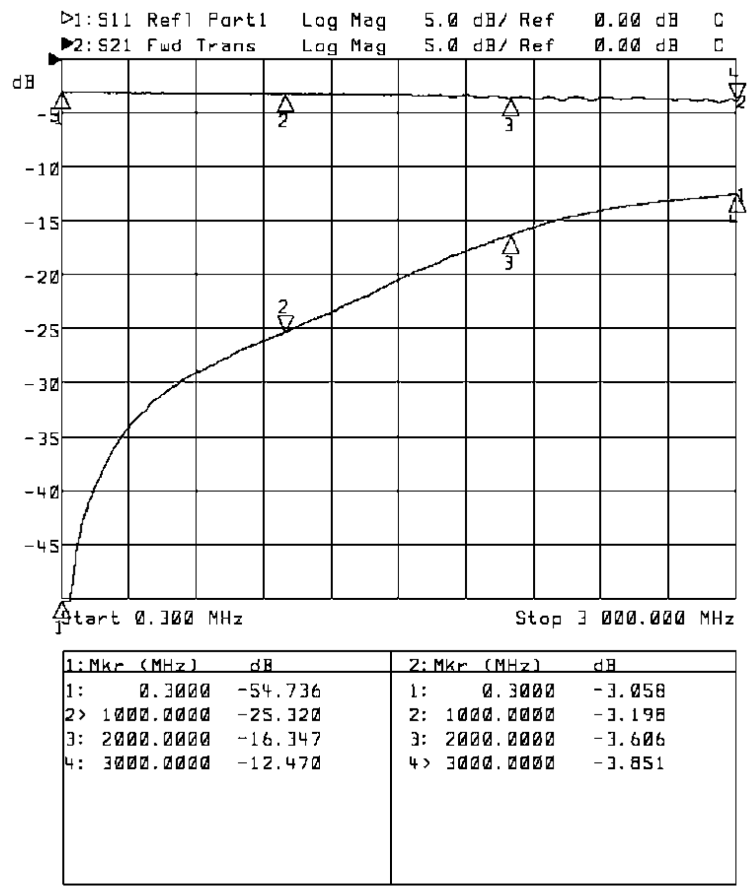


Figure 4-33 S_{11} and S_{21} recording of the attenuator.