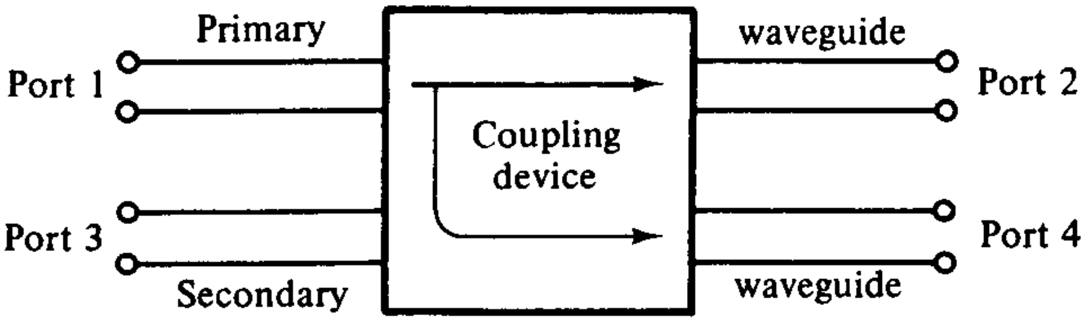
Directional Couplers:

Directional coupler is a four port waveguide as shown in the figure below. It consists of a primary waveguide 1-2 and a secondary waveguide 3-4. When all ports are terminated in their characteristics impedances, there is free transmission of power, without reflection, between port 1 and 2, and there is no transmission of power between port1 and 3 or between 2 and 4 because no coupling exists between these two pairs of ports. The degree of coupling between port1 and port 4 and between port2 and 3 depends on the structure of the coupler. Directional couplers sample the power traveling in only one direction down a transmission line. Directional coupler can also be used as an attenuator and to measure the reflected power from a mismatch.



the characteristics of the directional coupler can be expressed in terms of its coupling factor and its directivity. Assuming that the wave is propagating from port 1 to port 2 in the primary line, the coupling factor and directivity are defined, respectively by,

$$\text{Coupling factor (dB)} = 10 \log_{10} \frac{P_1}{P_4}$$

$$\text{Directivity (dB)} = 10 \log_{10} \frac{P_4}{P_3}$$

where P1= power input to port 1

P2= power input to port 2

P3= power input to port 3

P4= power input to port 4

It should be noted that port 2, and port3, and 4 are terminated in their characteristics impedances. The coupling factor is a measure of ratio of power levels in the primary and secondary lines. Hence if the coupling factor is known, a fraction of measured power at port 4 may be used to determine the power input at port 1. This significance is desirable for microwave power measurements because no disturbance, which may be caused by the power measurements occurs in the primary line.

The directivity is a measure of how well the forward travelling wave in the primary waveguide couples only to a specific port of the secondary waveguide. An ideal directional coupler should have infinite directivity. In other words, the power at port 3 must be zero because port2 and port4 are perfectly matched. Actually , well-designed directional couplers have a directivity of only 30 to 35dB.

Several types of directional couplers exist, such as a two-hole directional coupler, four-hole directional coupler, reverse coupling directional coupler (Schwinger coupler), and Bethe-hole directional coupler. Only the very commonly used is the two-hole directional coupler is described here.

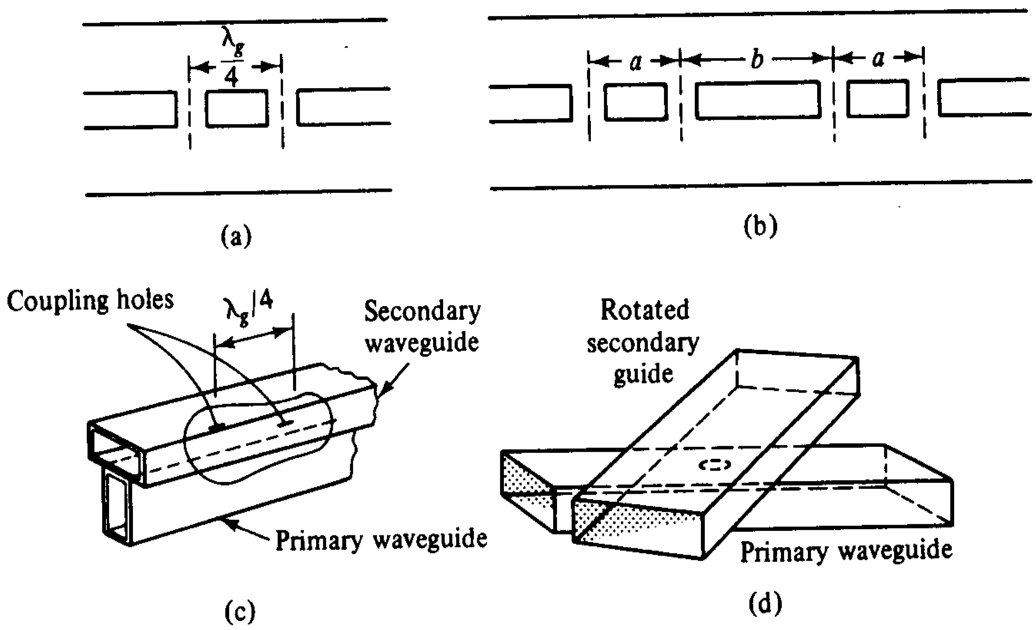


Figure 4-5-2 Different directional couplers. (a) Two-hole directional coupler. (b) Four-hole directional coupler. (c) Schwinger coupler. (d) Bethe-hole directional coupler.

Two-Hole Directional Coupler:

A two – hole directional coupler with traveling waves propagating in it is illustrated in the figure below. The spacing between the centers of two holes must be

$$L = (2n + 1)\frac{\lambda_g}{4}$$

Where n is any positive integer

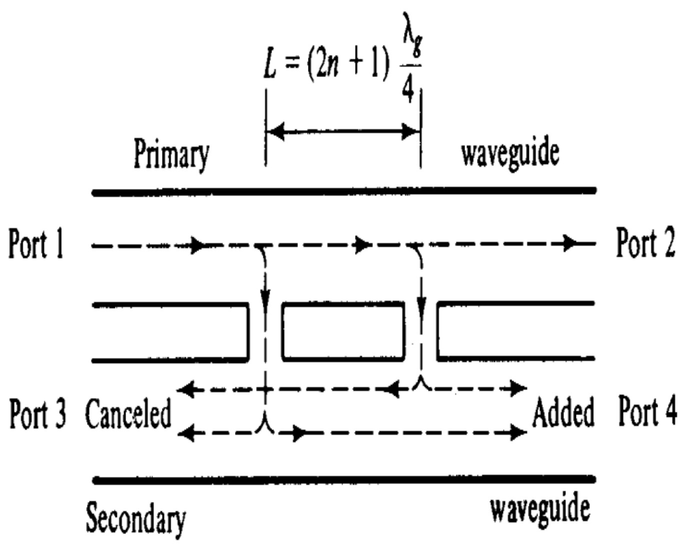


Figure 4-5-3 Two-hole directional coupler.

a fraction of wave energy entered into port 1 passes through the holes and is radiated into the secondary guide as a holes act as slot antenna. The forward waves in the secondary guide are in the same phase, regardless of the hole space, and are added at port 4. The backward in the secondary guide (waves are progressing from right to left) are out of phase by
$(2L/\lambda_g)2\pi$
and are be canceled at port3

S Matrix of a Directional Coupler:

In a directional coupler all four ports are completely matched. Thus the diagonal elements of the S matrix are zeros and,

$$S_{11} = S_{22} = S_{33} = S_{44} = 0$$

As noted, there is no coupling between port1 and port3 and between port2 and port4. Thus

$$S_{13} = S_{31} = S_{24} = S_{42} = 0$$

Consequently, the S matrix of a directional coupler becomes,

$$\mathbf{S} = \begin{bmatrix} 0 & S_{12} & 0 & S_{14} \\ S_{21} & 0 & S_{23} & 0 \\ 0 & S_{32} & 0 & S_{34} \\ S_{41} & 0 & S_{43} & 0 \end{bmatrix}$$

Because of zero property of S matrix and unity property also and many operations of matrix reduction,

$$S_{12} = S_{34} = p$$

Where p is positive and real value,

$$p(S_{23}^* + S_{41}) = 0$$

Let

$$S_{23} = S_{41} = jq$$

Where q is positive and real value, then from the equation,

$$S_{12}S_{12}^* + S_{14}S_{14}^* = 1$$

we can write the above equation as

$$p^2 + q^2 = 1$$

The **S** matrix of a directional coupler is reduced to

$$\mathbf{S} = \begin{bmatrix} 0 & p & 0 & jq \\ p & 0 & jq & 0 \\ 0 & jq & 0 & p \\ jq & 0 & p & 0 \end{bmatrix}$$

Example 4-5-1: Directional Coupler

A symmetric directional coupler with infinite directivity and a forward attenuation of 20 dB is used to monitor the power delivered to a load $\mathbf{Z}_\ell$ (see Fig. 4-5-4). Bolometer 1 introduces a VSWR of 2.0 on arm 4; bolometer 2 is matched to arm 3. If bolometer 1

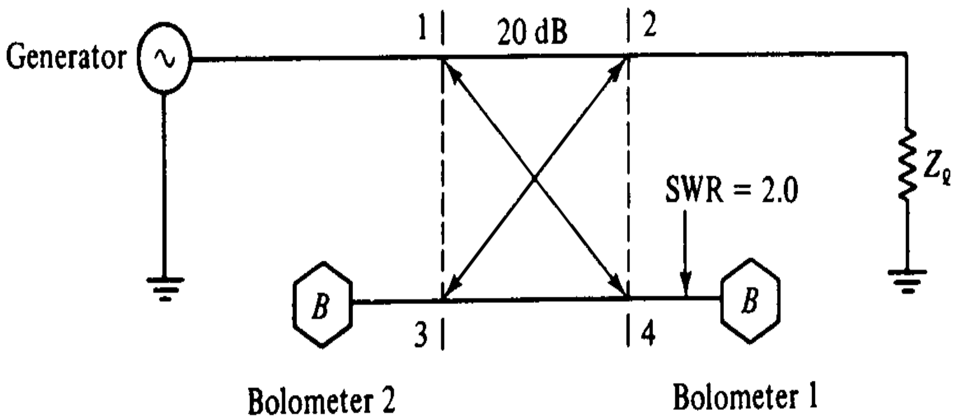


Figure 4-5-4 Power measurements by directional coupler.

reads 8 mW and bolometer 2 reads 2 mW, find: **(a)** the amount of power dissipated in the load $\mathbf{Z}_\ell$; **(b)** the VSWR on arm 2.

Solution: the wave propagation in the directional coupler is as the following figure,

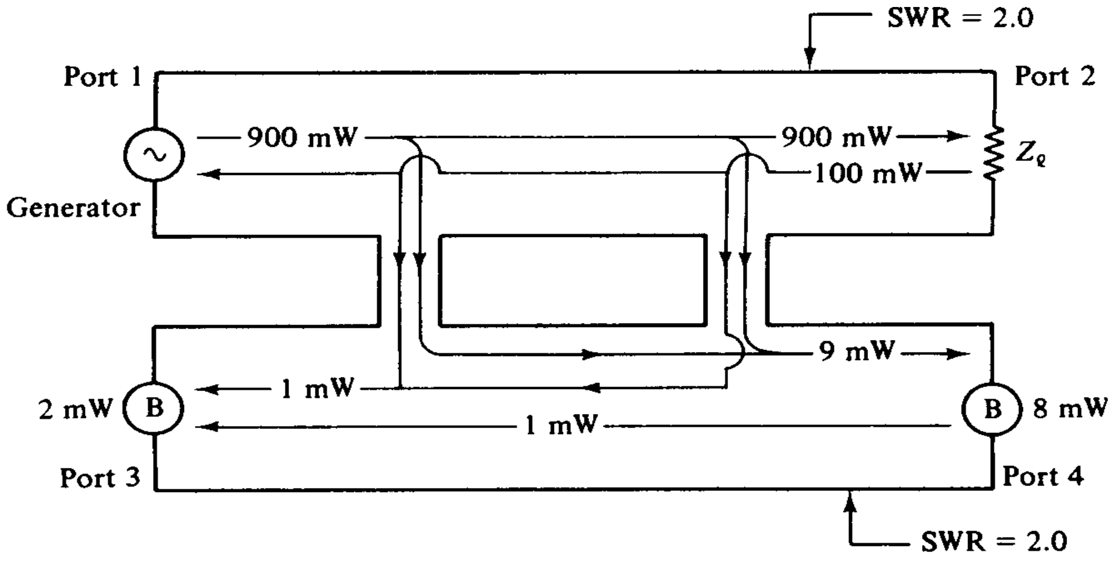


Figure 4-5-5 Wave propagation in the directional coupler.

a. Power dissipation at $\mathbf{Z}_\ell$.

1. The reflection coefficient at port 4 is

$$|\Gamma| = \frac{\rho - 1}{\rho + 1} = \frac{2 - 1}{2 + 1} = \frac{1}{3}$$

2. Since the incident power and reflected power are related by

$$P^- = P^+ |\Gamma|^2$$

where P^+ = incident power and P^- = reflected power, then

$$|\Gamma| = \frac{1}{3} = \sqrt{\frac{P^-}{P^+}} = \sqrt{\frac{P^-}{8 + P^-}}$$

The incident power to port 4 is $P_4^+ = 9$ mW, and the reflected power from port 4 is $P_4^- = 1$ mW.

3. Since port 3 is matched and the bolometer at port 3 reads 2 mW, then 1 mW must be radiated through the holes.

4. Since 20 dB is equivalent to a power ratio of 100:1, the power intput at port 1 is given by

$$P_1 = 100P_4^+ = 900 \text{ mW}$$

and the power reflected from the load is

$$P_2^- = 100 \times (1 \text{ mW}) = 100 \text{ mW}$$

5. The power dissipated in the load is

$$P_\ell = P_2^+ - P_2^- = 900 - 100 = 800 \text{ mW}$$

b. The reflection coefficient is calculated as

$$|\Gamma| = \sqrt{\frac{P^-}{P^+}} = \sqrt{\frac{100}{900}} = \frac{1}{3}$$

Then the VSWR on arm 2 is

$$\rho = \frac{1 + |\Gamma|}{1 - |\Gamma|} = \frac{1 + \frac{1}{3}}{1 - \frac{1}{3}} = 2.0$$

Phase Shifters:

A Phase Shifter is two-port device whose basic function is to provide a change in the phase of RF signal with practically negligible attenuation.

Types of Phase Shifters:

1. **Switched-Line Phase shifter:** These phase shifters are similar to their attenuator equivalent where two switches are used to switch two line lengths, one of which is X degrees longer in electrical length than the other. The circuit is shown in Figure 1.

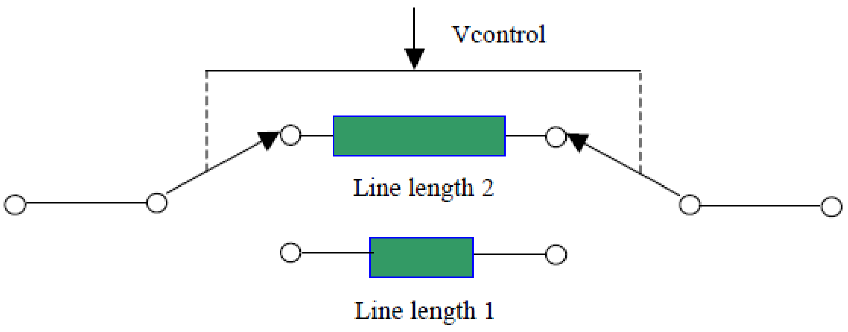


Figure 1 Switched-line phase shifter

As shown in Fig. 1 Line length 2 has a longer electrical length than line length 1 so when switched in line will cause an in-line phase shift $\Delta\varphi=\beta(l_2-l_1)$.

2. **Loaded-Line Phase shifter:** These phase shifters work by adding a shunt reactance to the micro-strip line (in the form of an inductor or capacitor) causing the incident signal to undergo a phase shift.

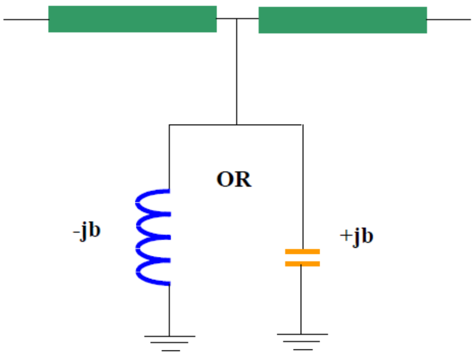


Figure 2 Switched-line phase shifter.

As shown in Fig. 2 A shunt susceptance inductive (-jB) or capacitive (+jB) is switched in across the line causing a phase shift on the incident signal.

3. **Modified loaded-line Phase shifter:** The return losses of loaded-line phase shifters can be greatly improved by having two shunt susceptances separated by 90 degrees. If these susceptances are switched in or out by Pin diodes then a switchable phase shifter can be made as below. The equivalent circuit is a transmission line with phase θe.

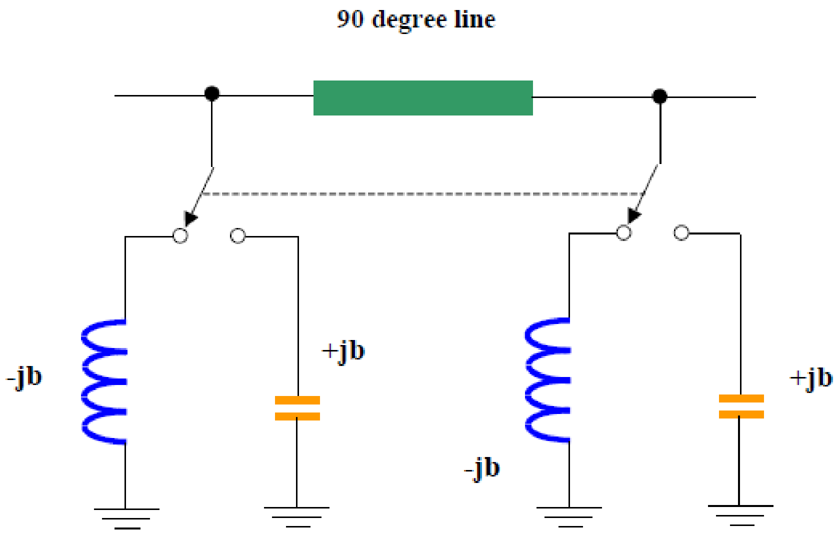


Figure 3 Improved switched-line phase shifter using two shunt susceptances and a quarter-wave length of transmission line.

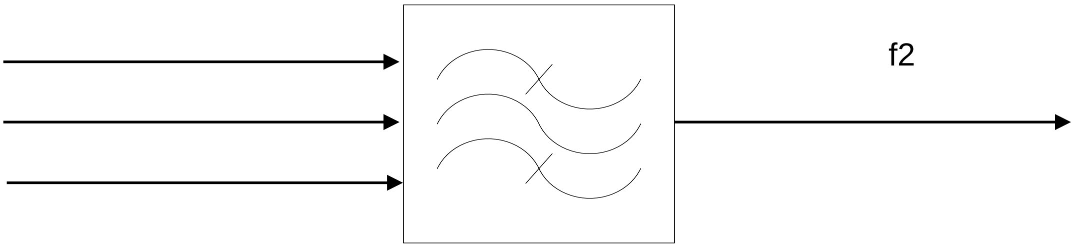
APPLICATIONS Of Phase Shifters

1. Used in a variety of communication and radar systems
2. microwave instrumentation and measurement systems
3. In industrial applications.

Microwave filter

A filter is a two-port network used to control the frequency response at a certain pointin an RF or microwave system by providing transmission at frequencies within the passband of the filter and attenuation in the stopband of the filter.

- **The goal of filter design is to approximate the ideal requirements within acceptable tolerance with circuits or systems consisting of real components.**



Commonly used block Diagram of a Filter

Why Use Filters?

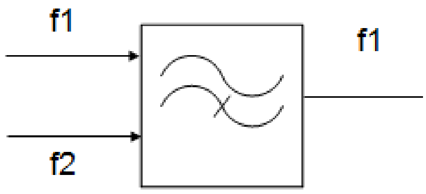
- RF signals consist of:
    1. Desired signals – at desired frequencies
    2. Unwanted Signals (Noise) – at unwanted frequencies
- That is why filters have two very important bands/regions:
    1. Pass Band – frequency range of filter where it passes all signals
    2. Stop Band – frequency range of filter where it rejects all signals

Categorization of Filters

- Low-pass filter (LPF), High-pass filter (HPF), Bandpass filter (BPF), Bandstop filter (BSF), arbitrary type etc.
- In each category, the filter can be further divided into active and passive types.
- In active filter, there can be amplification of the of the signal power in the passband region, passive filter do not provide power amplification in the passband.
- Filter used in electronics can be constructed from resistors, inductors, capacitors, transmission line sections and resonating structures (e.g. piezoelectric crystal, Surface Acoustic Wave (SAW) devices, and also mechanical resonators etc.).
- Active filter may contain transistor, FET and Op-amp.

Types of Filters

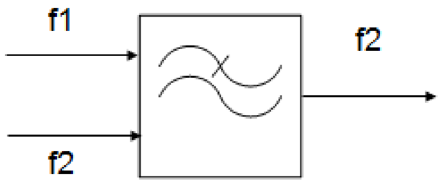
1. **Low-pass Filter**



❒ Passes low freq

❒ Rejects high freq

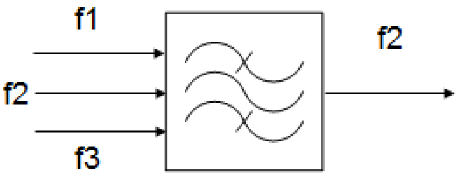
2. **High-pass Filter**



❒ Passes high freq

❒ Rejects low freq

3. **Band-pass Filter**



❒ Passes a small range of freq

❒ Rejects all other freq

4. **Band-stop Filter**

    1. **Rejects a small range of freq**
    2. **Passes all other freq**

Circulator and Isolator

- **Both use the unique properties of ferrites in a magnetic field**
- **Isolator passes signals in one direction, attenuates in the other**
- **Circulator passes input from each port to the next around the circle, not to any other port**

Circulator

Circulatoris a passive non-reciprocal three- or four-port device, in which a microwave or radio frequency signal entering any port is transmitted to the next port in rotation (only). A *port* in this context is a point where an external waveguide or transmission line (such as a microstrip line or a coaxial cable), connects to the device. For a three-port circulator, a signal applied to port 1 only comes out of port 2; a signal applied to port 2 only comes out of port 3; a signal applied to port 3 only comes out of port 1, so to within a phase-factor, the scattering matrix for an ideal three-port circulator is

$$S = \begin{pmatrix} 0 & 0 & 1 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{pmatrix}$$

Circulators fall into two main classes:

4-port waveguide circulators based on Faraday rotationof waves propagating in a magnetized material, and 3-port "Y-junction" circulators based on cancellation of waves propagating over two different paths near a magnetized material. Waveguide circulators may be of either type, while more compact devices based on strip lines are of the 3-port type. Sometimes two or more Y-junctions are combined in a single component to give four or more ports, but these differ in behavior from a true 4-port circulator.

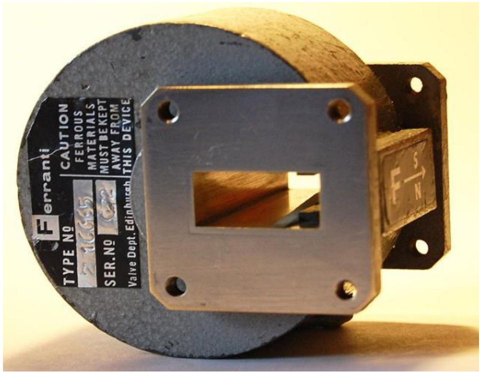
Radio frequency circulators are composed of magnetizedferritematerials. A permanent magnet produces the magnetic flux through the waveguide. Ferromagneticgarnet crystal is used in optical circulators.

Applications of Circulators

- **Isolator**

When one port of a three-port circulator is terminated in a matched load, it can be used as an *isolator*, since a signal can travel in only one direction between the remaining ports. An isolator is used to shield equipment on its input side from the effects of conditions on its output side; for example, to prevent a microwave source being detuned by a mismatched load.

Isolator is a microwave device which allows RF energy to pass through in one direction with very little loss, while RF power in the reverse direction is absorbed.

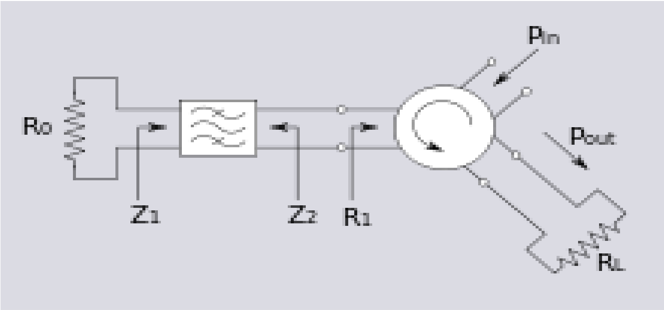


- **Duplexer**

In radar, circulators are used as a type of duplexer, to route signals from the transmitter to the antenna and from the antenna to the receiver, without allowing signals to pass directly from transmitter to receiver. The alternative type of duplexer is a *transmit-receive switch* (*TR switch*) that alternates between connecting the antenna to the transmitter and to the receiver.

- **Reflection amplifier**

A *reflection amplifier* is a type of microwave amplifier circuit utilizing negative resistance diodes such as tunnel diodes and Gunn diodes. Negative resistance diodes can amplify signals, and often perform better at microwave frequencies than two-port devices. However since the diode is a one-port (two terminal) device, a nonreciprocal component is needed to separate the outgoing amplified signal from the incoming input signal. By using a 3-port circulator with the signal input connected to one port, the biased diode connected to a second, and the output load connected to the third, the output and input can be uncoupled.



Microwave diode reflection amplifier using a circulator