Technical Note — Directional Couplers

Basic Theory

The function of a directional coupler to provide a preset sample of incident microwave energy to a separate output terminal (coupled port). The basic configuration is shown in Fig. 1. Most directional couplers are bi-directional 4-port devices; with the fourth port isolated from the coupling circuit

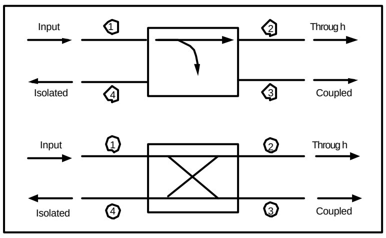


Fig. 1. Two commonly used symbols for directional couplers, and power flow conventions

The three primary terms which characterize a directional coupler are as follows:

Coupling Factor: $C = 10 \log P_1 / P_3$ Coupling factor describes the level of coupled (sampled) power at the coupled port. The coupling factor is always expressed in dB. The coupling factor is a function of proximity of the coupled transmission line to the primary transmission line. Coupling factors between 6 dB and 40 dB are commonly available.

Directivity: $D = 10 \log P_3 / P_4$ Directivity is a measure of the isolation of the forward and backward waves(energy at the coupled and isolated ports respectively). The ideal coupler will have an infinite directivity (total isolation). In practical terms, directivity in excess of 20/25dB are achievable.

Isolation: $I = 10 \log P_1 / P_4$

Airline Directional Coupler (Coaxial Coupler)

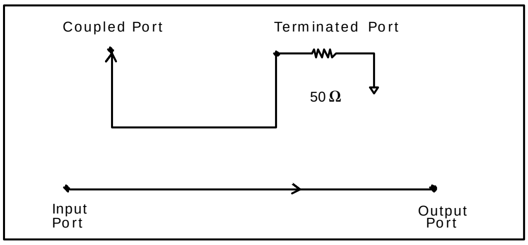
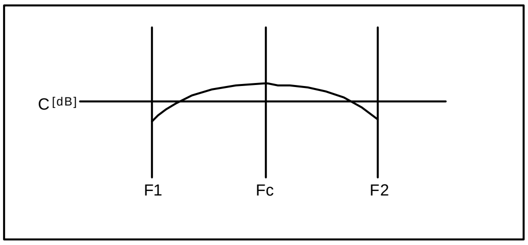


Fig. 2. (a) Schematic Diagram



(b) Coupled Port Response

Important Characteristics and Specifications

Directional couplers are important and versatile tools in micro-wave measurements. Their main purpose is to separate and isolate signals, or conversely to mix different signals. The versatility of couplers makes them useful in a variety of applications such as power monitoring, signal mixing, isolation of signal sources, swept transmission and reflection measurements and external leveling of sources. There are several coupler designs; each optimizes the coupler's performance to a specific application. Couplers can be narrow band or broadband, have high or low directivity, or have high orlow coupling coefficients. In general, coupler specifications involve an engineering trade-off such as coupling factor versus frequency range and directivity, or directivity versus cost Therefore, when choosing a coupler, make sure its performance is optimized to your application. The coaxial couplers are available in single or dual, and narrow band or broadband models.
The key specifications for a directional coupler depend on its application. In general, the important specifications are;

- Directivity
- V S W R
- Coupling coefficient
- Insertion loss

Each of these specifications must be carefully evaluated to ensure that a coupler meets the performance required for its application.

Importance of Directivity

Directivity is a measure of how well a coupler can isolate two signals. Directivity, therefore, sets the limits on how accurately a coupler can perform a specific measurement. Ideally, one would like to measure the magnitude of the reflected signal alone.
However, because of directivity, the reflected signal is combined with a small, undesired portion of the incident signal. It is important to emphasize that the magnitude of this reverse-coupled signal depends strictly on the directivity of the coupler.

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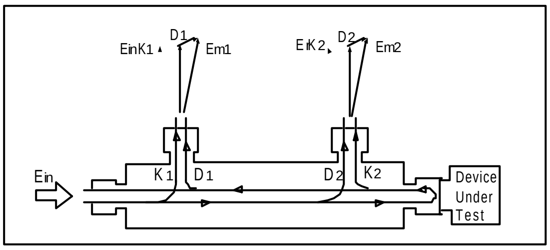
Fig. 3. shows the effect of directivity on a reflection measurement. The reverse-coupled signal is a phasor that directly adds to the measurement uncertainty. Thus, the higher the directivity, the higher the measurement accuracy. Because the reverse-coupled signal is very small, it adds negligible amount of uncertainty when measuring large reflections. But as the reflected signal becomes smaller, the reverse-coupled signal becomes more significant. When the reflected signal in dB (return loss) equals the coupler directivity, the measurement error can be -6 to +8 dB.



K1 and K2 : Coupling Coefficients (dB)
D 1and D2 : Directivities (dB)
Ein = Input Signal
Er = Reflected Signal from DUT
Em = Measured Signal (includes directivity error)

Fig. 3. Effect of directivity on reflection measurement

Importance of Low VSWR

For many applications, coupler VSWR is important to minimize low mismatch errors and to improve measurement accuracy. For example, when making swept reflection measurements, it is customary to set a full reflection (0 dB return loss) reference by connecting a short at the test port of the coupler Some of the reflected signal re-reflects due to the output port (test port) VSWR.
This re-reflected signal goes through a wide phase variation due to the width of the frequency sweep, adding to and subtracting from the reflected signal. This phase variation creates a ripple in the full-reflection (0 dB return loss) reference. The magnitude of the re-reflected signal, and thus the measurement uncertainty, can be minimized by selecting couplers with the lowest VSWR.

Importance of Coupling Coefficient

Coaxial couplers have been designed for the best directivity over a wide frequency range. This has resulted in a relatively fixed nominal coupling coefficient of 20 dB. A 20 dB coupling coefficient is also an optimum value. The magnitude of the coupled signal is large enough for most applications and only one percent of the available power is extracted. This compares to ten percent for a 10 dB coupler, which decreases the power available at the test port when using broadband sources with limited power output

Importance of Insertion Loss

Insertion loss is the total loss in the main line of a directional coupler, including insertion loss and coupling loss. The loss depends on the design and type of a directional coupler as well as the coupling coefficient; the lower the coupling coefficient, the more power that is extracted from the main line and the higher the loss. Higher loss decreases the available source power for measurement. Insertion loss is usually not important at low frequencies where most swept sources have more available power. However, insertion loss becomes significant as the frequency of interest increases. As a rule, broadband swept frequency sources have limited power output (usually no more than + 10 dBm) and their cost is significantly higher than lower frequency sources. Therefore, you want to obtain as much power from your high frequency source as possible, and lose as little as possible in the components that make up your measurement set up. In general, broadband couplers have insertion losses on the order of 1 dB. On the other hand, directional bridges have insertion losses of at least 6 dB. This 6 dB loss directly subtracts from the dynamic range available for transmission measurements.

Isolation : (As referring to Power Dividing Devices.) The amount of power reduction expressed in dB measured at any output port with respect to the power level applied to any other output port with all other ports adequately terminated.
Amplitude Balance : The maximum difference expressed in dB of output power levels measured at any given frequency in the specified operating band.
Phase Balance : The maximum difference in output port phase levels measured at any given frequency in the specified operating band.
Average Power : Maximum CW power level which may be applied at the input of a device without potentially resulting in damage to the device.
Reverse Power : Maximum CW power level which may be applied at the output of a device without potentially resulting in damage to the device.
Peak Power : Maximum peak power level which may be applied at the input of a device without potentially resulting in damage to the device.
Note : The average power level (determined by duty cycle) of a peak power signal must not exceed the "Average Power"rating