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MICROWAVELENGTHS

Directional Couplers

Directional couplers are useful microwave devices, both for determining what is happening on transmission lines and as microwave circuit elements. While many surplus varieties are available, it is also possible to roll your own. We shall also see how to use some of them successfully for ham bands outside their designated operating range.

A small capacitance connected to a transmission line — a probe inserted inside a coaxial line or waveguide — can be used to detect relative voltage at that point on the line, but we would like more information. Usually, we would like to know the Virtual SWR (VSWR) on the line or the amount of power being transmitted.

If an antenna is not perfectly matched, some transmitted power will be reflected and flow back down the transmission line toward the transmitter. A directional coupler samples the power flowing in one direction while ignoring the power flowing in the other, so that we can determine the VSWR by comparing the power flowing in the two directions. The difference in dB between the reflected power and the forward (transmitted) power is called Return Loss (RL). Then the VSWR may be calculated:

$$\mathrm{VSWR} = \frac{10^{\frac{RL}{20}} + 1}{10^{\frac{RL}{20}} - 1}$$

But most microwave engineers find it easier to work directly in Return Loss instead.

How does the directional coupler perform this magical feat? One type samples the transmission line in two locations, and then connects the two samples so that the phases of the samples traveling in one direction add, while in the other direction the phases cancel. In waveguide, the sampling is done through holes between parallel guides. In coax and stripline, the most common form of directional coupler achieves the same result by adding a second conductor in parallel with the center conductor for a quarter-wavelength, as shown in Figure 1. Power may flow in both directions in the second conductor, but one end is normally terminated in a matched load to absorb the unwanted direction. The spacing between the conductors determines the coupling, the amount of power that is sampled compared to the power flowing in the transmission line. Typical couplings are −20 dB or −30 dB, but may range from −3 dB to −60 dB. For power measurement, −30 dB samples 1 mW for each watt flowing, making calculations easy for measurements — many microwave power meters have a 10 mW maximum. For higher powers, −40 dB samples one mW for each 10 W and −50 dB samples one mW for each 100 W, or 1 kW full scale. I've not had to worry about even higher powers.

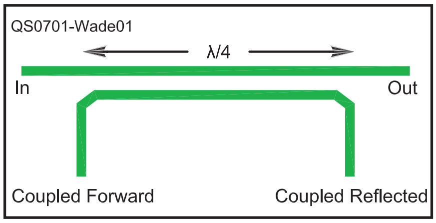

Figure 1 — A sketch of basic directional coupler.

In addition to coupling, we must consider directivity. In any real coupler, some power flowing in the undesired direction leaks through, so the separation between directions is not perfect. Directivity is the difference in dB between the desired and undesired coupling. It can be a problem when measuring Return Loss — for example, if the directivity were only 15 dB, then the indicated Return Loss would be only 15 dB (VSWR=1.43), even with a perfectly matched load or antenna. Good directional couplers have directivity well over 20 dB.

To measure Return Loss, the coupler may be reversed, or a dual directional coupler may be used, one that has a third quarter-wave long conductor so that both directions may be sampled simultaneously. Since the direction of the single coupler matters, it is important to get the direction right; to confuse matters, waveguide and coax couplers work in opposite directions, as illustrated in Figure 2.

Homebrewing a Directional Coupler

The basic form of the directional coupler is as shown in Figure 1. Physically, a good way to make one would be in Tri-plate stripline, with round or rectangular conductors centered vertically between two flat plates like the ones in Figure 3. The spacing between the plates may be calculated to make the characteristic impedance of the transmission line near 50 . The exact characteristic impedance needed is a function of coupling, but for coupling levels of −30 dB or weaker, it is very close to 50 (in a 50 transmission line, of course). The best dielectric surrounding the conductor is air, but other good

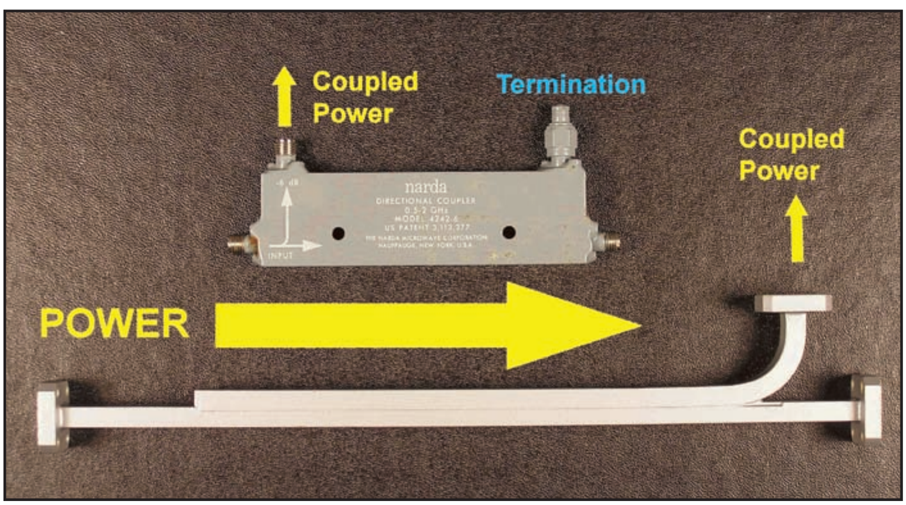

Figure 2 — Coupling direction: in coaxial couplers, the coupled port is closer to the input port, while in waveguide couplers, the coupled port is closer to the output port.

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Figure 3 — Common cross-section geometries for directional couplers.

dielectrics may be used as long as they surround the conductors uniformly. To provide support and hold the conductors in place, Styrofoam may be used — at microwave frequencies, it acts just like air.

Calculating the spacing is a bit more complicated. The coupled lines have two characteristic impedances, the even mode, Zoe, when they are excited in parallel, and the odd mode, Zoo, when they excited in opposite phases, both of which depend on the spacing.

Then the coupling may be calculated[1]

$$\text{Coupling} = -20\log\left[\frac{\text{Zoe}/\text{Zoo} - 1}{\text{Zoe}/\text{Zoo} + 1}\right]$$

To be matched to the characteristic impedance Zo, usually 50 ,

$$\text{Zo} = \sqrt{\text{Zoe}*\text{Zoo}}$$

must be true as well.

I calculate Zoe and Zoo, coupling, and corresponding physical dimensions for rectangular conductors, with the free *Ansoft Designer SV* software,[2] using the TRL wizard. For instance, if Zoe=51 and Zoo=49, then Zo=50 and Coupling= −34 dB. For round conductors, formulas are given in Note 1.

It would be convenient to make directional couplers in microstrip lines, on printed-circuit boards with dielectric below and air above, but microstrip couplers have very poor directivity. The problem is that electromagnetic waves propagate at different speeds in air and dielectric, so it is difficult to achieve phase cancellation for the undesired direction. I simulated some microstrip couplers using the *Ansoft Designer SV* software and the calculated directivity was only around 10 dB.

At UHF frequencies, a simple way to make a coupler is to slip a thin wire under the braid of a section of coax, with the length under the braid about ¼ λ times the velocity factor of the coax. I did this by carefully slitting the outer jacket of some RG-58 coax, removing the jacket, then pushing the braid from both ends to make it fatter (like the "Chinese handcuffs" toy). After slipping some thin hookup wire through, the braid is pulled tight again, and SMA connectors

[1]G. L. Matthaei, L. Young, E. M. T. Jones, *Microwave Filters, Impedance-matching Networks, and Coupling Structures*, Artech House, 1980, pp 775-780.

[2]**www.ansoft.com**

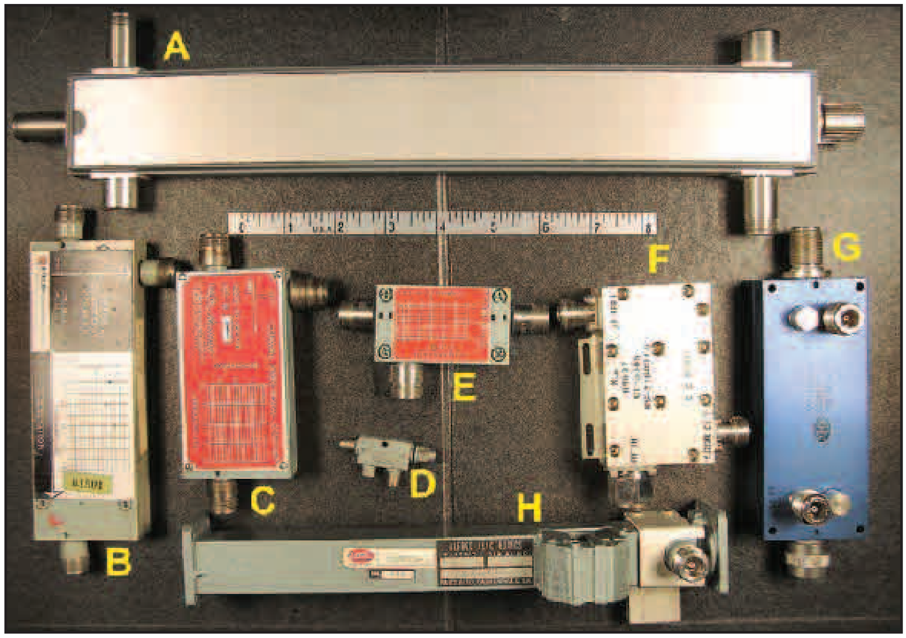

Figure 4 — Directional coupler surplus potpourri: A — from HP instrumentation, dual −20 dB, ~100 to 1500 MHz; B — PRD −20 dB, 4 to 8 GHz; C — Narda, −30 dB, 0.95 to 2 GHz; D — Omni-Spectra, −30 dB, 7 to 12.4 GHz; E — Narda, −20 dB, 7 to 13 GHz; F — from cell site, −50 dB, ~700 to 1300 MHz; G — Meca, dual −50 and −40 dB, ~700 to 1300 MHz; H — Alfred, −10 dB, WR-90 waveguide (8 to 12.4 GHz).

soldered to one end of the hookup wire and braid for the coupled power. The other end of the wire is terminated to the braid with a 51 resistor. I measured about −22 dB coupling with 20 dB or so directivity — good enough for a QRP rig.

Dick Turrin, W2IMU (SK), made some directional couplers with semi-rigid coax by cutting away a section of the outer jacket on one side of two pieces, flattening the open sides, and soldering the two pieces together[3].

Surplus Directional Couplers

A selection of couplers from my junk box, acquired at various hamfests, is shown in Figure 4. Many are marked with coupling and frequency range, while the frequency range of others may be estimated by size comparison. Some even have individual calibration charts attached. The couplers on the right (items F and G) are probably from cell towers operating around 900 MHz, and have excellent performance at 902 and 1296 MHz. Couplers like the one at the top (item A) were removed from HP test equipment and are excellent performers over a wide frequency range — this one covers from below 2 meters to >1300 MHz with 40 dB directivity. Some similar models cover 2-18 GHz. Typical coupling for these is around −22 dB.

Most commercial directional couplers have pretty good directivity over the specified operating range and can be used for checking Return Loss, even if the coupling is not known. Even better, at frequencies below the operating range, the coupling decreases but the directivity is usually still good, so the coupler can be very useful. For instance, I have a coupler (item C) specified for a nominal −30 dB over 1 to 2 GHz, but the coupling measures −41.8 dB at 222 MHz and −46.5 dB at 144 MHz. Similarly, a small −30 dB X-band coaxial unit (item D) is useful at all lower microwave bands, with the coupling falling off to around −40 dB at 1 GHz.

For accurate power measurement with a directional coupler, good calibration is necessary. This can be done with a known power flowing through the coupler, or with a network analyzer. These expensive instruments are often available to make measurements at VHF conferences and microwave meetings, but not many hams take advantage to calibrate things like directional couplers and attenuators. There isn't much to drift in a directional coupler, so once calibrated, they may be used for reasonably accurate measurements back home. We will discuss power measurement in the next column.

3 dB Couplers

With coupling of −3 dB, half the power is extracted through the coupled port, leaving the other half to continue straight through. One obvious use is as a power splitter; turned around, it becomes a power combiner. Another common use is in balanced mixers and balanced amplifiers. A future column will look at various types of mixers, another essential part of a transverter. QST

[3]R. Turrin, W2IMU, "UHF Directional Couplers," *QST*, Sep 1970, p 26.