Harald Braubach, DL 1 GBH

Directional Couplers – Made to Measure

It was always difficult for radio amateurs to construct wideband directional couplers having a low coupling attenuation. Microstrip couplers are easy to manufacture for those that have such capabilities. However, the minimum coupling attenuation that can be obtained with a reasonable directional characteristic is in the order of 10 dB. On the other hand. it is virtually impossible, using microstrip technology, to design 3 dB power dividers, such as are required when constructing push-pull mixers, or for feeding circular-polarized antennas. It is possible, of course, when using triplate circuits for these values to be achieved, however, the conductor lanes are then so thin that it is hardly possible to use them in conjunction with higher power levels. Most radio amateurs do not have the necessary machines to construct conventional directional couplers mechanically, and do not have enough room for accommodating such large couplers.

A good solution for solving the problem of home-made directional couplers is offered by a product manufactured by Sage Laboratories Inc.: "Wireline" and "Wirepac". It is possible using both these systems to construct directional couplers in the range of 3 to 20 dB coupling attenuation in a frequency range from 50 MHz to 2.4 GHz. Wireline is the cheaper of the two and has a directivity of 20 dB. Wirepac has a directivity of 30 dB, but is considerably more expensive, and is therefore not to be discussed here.

1. FUNDAMENTALS

The Wireline type to be described is a line directional coupler and comprises two coupled lines as shown in **Figure 1**. The coupling attenuation is dependent on frequency and achieves its minimum value at a coupling length of $\lambda/4$ (see **Figure 2**).

Under matched conditions (**Figure 3**), the following is valid:
If a signal with a power P_1 is fed to the input, a power of $P_2 = P_1 - P_1 \times c$ will be present at R_2, and a power of $P_3 = P_1 \times c$ at R_3; where c = coupling factor.

In the case of an ideal directional coupler, R_4 will be powerless, since the diagonally opposite inputs are decoupled from another. In practice, a power will be present that is reduced to the value of the directivity d.

$P_4 = P_1 \times c \times d$ (d = directivity)

accordingly

$P_3 = P_1 \times c - P_1 \times c \times d$

A further characteristic of directional couplers is that the signals of the coupled outputs will have a frequency-independent phase difference of 90°.

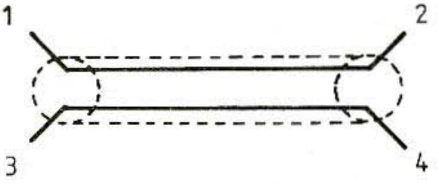

Fig. 1: Directional coupler

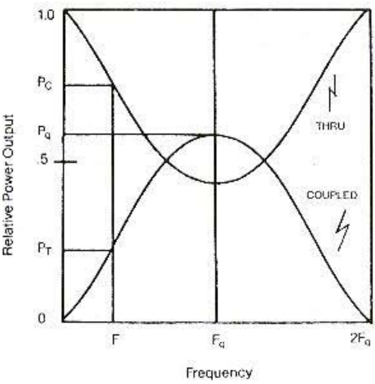

Fig. 2: Coupling attenuation and insertion loss as a function of frequency

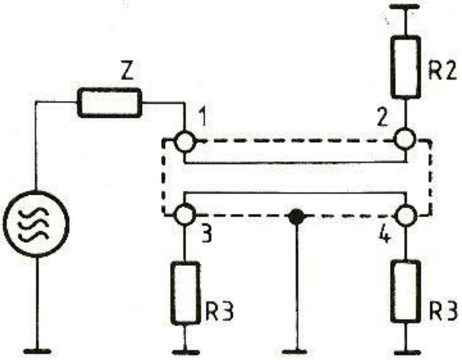

Fig. 3: Matched directional coupler

2. CONSTRUCTION OF WIRELINE

There are five different versions which differ in the type of screening and the maximum power ratings. The internal construction is shown in **Figure 4**. The following **Table 1** shows the most important differences between the individual types.

Due to the coaxial type construction of the coupler, it is possible for the two coupled outputs to be provided on one side as shown in **Figure 5**. This offers several advantages for practical construction.

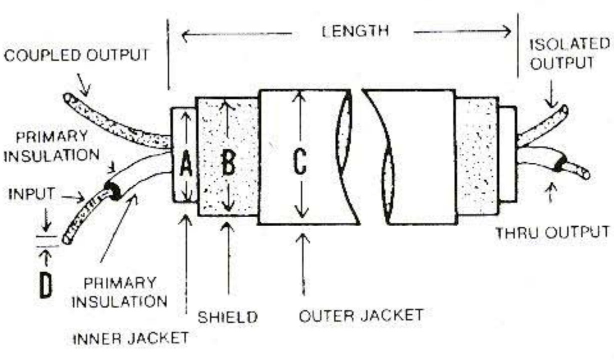

Fig. 4: Construction of Wireline

Typ	H	HB	HC	JB	JC
Schirm	Doublefoil screen	Copper mesh	Copper tube	Copper mesh	Copper tube
P_m/W	100	100	100	200	200
P_s/W	2000	2000	2000	2000	2000

Table 1: Wireline designs
P_m = mean power
P_p = peak value of the power rating

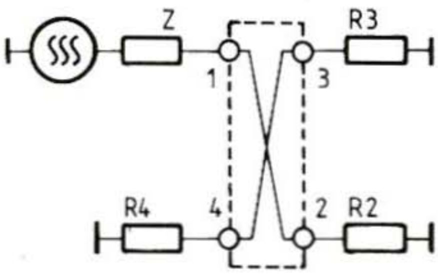

Fig. 5: Coupler showing the coupled outputs on one side

3. CALCULATION OF THE COUPLERS

3.1. Calculation of a Coupler with a certain Coupling Attenuation at a certain Operating Frequency

The following data is required for the calculation:
- Required center frequency f_{op} (e.g. 435 MHz)
- Required coupling attenuation a_c (e.g. 10 dB).

It is firstly necessary to convert the logarithmic value of the coupling attenuation a_c into the linear coupling factor c.

$$c = 10^{-a_c/10} \quad (1)$$

In the case of a 10 dB-coupler, the following results:

$$c_{10dB} = 10^{-10/10} = 10^{-1} = 0.1$$

This is followed by calculating the frequency at which a 3 dB coupling is achieved from the operating frequency f_{op} and the coupling factor of the frequency f_c.

$$f_c = \frac{90 \, f_{op}}{\arcsin \sqrt{-\left(\frac{c}{c-1}\right)}} \quad (2)$$

The following will result at the values of $f_{op} = 435$ MHz and $c = 0.1$:

$$f_{c(10\,dB/435)} = \frac{90 \cdot 435 \text{ MHz}}{\arcsin \sqrt{-\left(\frac{0.1}{0.1-1}\right)}} = 2010.66 \text{ MHz}$$

From this quarterwave frequency (f_c) one then calculates the length l of the coupler as follows:

$$l = \frac{4700 \text{ MHz} \cdot \text{cm}}{f_c \text{ (MHz)}} \quad (3)$$

This results in the following coupler length in our example:

$$l_{(10\,dB/435)} = \frac{4700 \text{ cm}}{2010,66} = 2,338 \text{ cm}$$

A 10 dB coupler at 435 MHz would therefore have a length of 23.38 mm.

3.2. Calculation of the Coupling Attenuation of any required Coupler

The following data is required for calculation:
- Length (1) of the coupler in cm (e.g. 10 cm)
- Frequency (f) at which the coupling attenuation is to be calculated (e.g. 435 MHz)

Firstly find the quarterwave frequency (f_c) of the coupler:

$$f_c = \frac{4700 \text{ MHz} \cdot \text{cm}}{l \text{ (cm)}} \quad (4)$$

In our example:

$$f_{c\,(10\,cm)} = \frac{4700 \text{ MHz}}{10} = 470 \text{ MHz}$$

This is followed by calculating the coupling factor (c):

$$c = \frac{\sin^2\left(90 \frac{f}{f_c}\right)}{\sin^2\left(90 \frac{f}{f_c}\right) + 1} \quad (5)$$

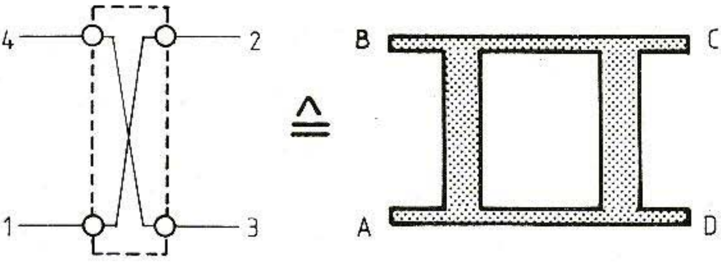

Fig. 6: Comparison between a Wireline coupler and a 4/4 λ hybrid

In our example:

$$c_{(10\,cm\,435)} = \frac{\sin^2\left(90\frac{435}{470}\right)}{\sin^2\left(90\frac{435}{470}\right) + 1} = 0.4966$$

The coupling attenuation (a_c) is now calculated from the coupling factor:

$$a_c = -10 \log c \quad (6)$$

The following will result in our example:

$$a_{c(10cm435)} = -10 \log 0.4966 = -3.04 \text{ dB}$$

4. PRACTICAL APPLICATIONS OF WIRELINE

4.1. Use as a Directional Coupler

Of course, the primary use of Wireline couplers is for determining the VSWR of antennas and other consumers. The construction of VSWR bridges is not to be discussed, since it is well known. **Table 2**, however, provides an aid for designing a directional coupler for frequencies up to 435 MHz.

Table 2: Directional coupler, length l = 50 mm, coupling attenuation as a function of frequency:

$f/_{MHz}$	$a_{c/dB}$
3.5	44.66
7.0	38.64
14.0	32.62
21.0	29.10
28.0	26.61
145.0	12.64
435.0	5.13

4.2. Use as a 3 dB Coupler

This results in a multitude of applications of which the most important are to be mentioned.

4.2.1. Feeding of Circular-Polarized Antennas

Since the coupled outputs always possess a phase shift of 90° (± 1°) to another, it is easily possible to construct a low-loss, wideband feed for circular-polarized antennas (see **Figure 7**).

Directional couplers as shown in Figure 5 have a behaviour as a 4/4 λ hybrid (see **Figure 6**). A RF-voltage fed to 1, or A, will be distributed equally to 2 and 3, or C and D. Connection 4, or B, remains decoupled. A RF-voltage fed to 4, or B, will be distributed equally to 2 and 3, or C and D. In this case, 1, or A will remain decoupled.

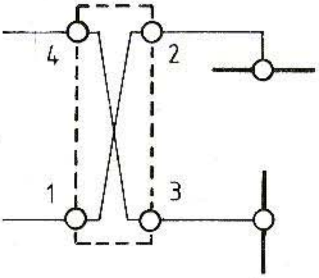

Fig. 7: Directional coupler for feeding circular-polarized antennas

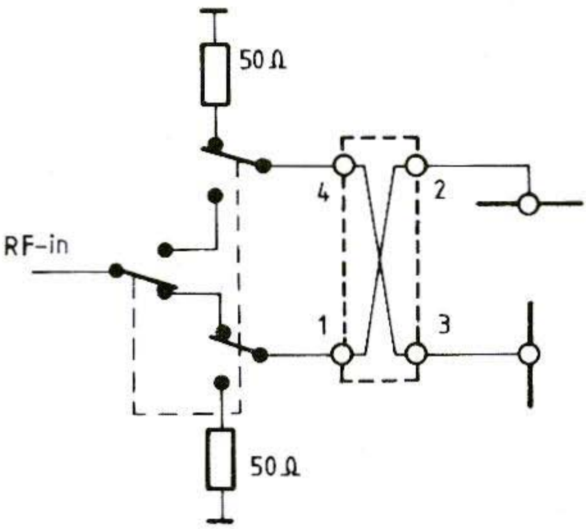

Fig. 8:
Circuit for switching the polarization of circular antennas

Connection 2 and 3, or C and D, have a phase shift of 90° to another (this will only be the case at the center frequency of a 4/4 λ hybrid).

If, for instance, an RF-signal is fed to 1, and 4 is terminated with 50 Ω, anticlockwise, circular polarization will result. If, on the other hand, 4 is fed with the RF-voltage, and 1 is terminated with 50 Ω, clockwise, circular polarization will result. Of course, the actual polarization will also be determined by the phase position of the individual antenna. An anticlockwise circular polarization will be changed to clockwise polarization on rotating the phase position of one of the antennas by 180°.

As can be seen, the polarization switching is nowhere near as critical as when using conventional coaxial delay line methods, and where the switching relay must be taken into consideration in the phase-shift calculation. In the case of the described type of feeding, the relay is placed in front of the phase-shift 3 dB coupler (**Figure 8**). Attention must only be paid that the lengths of the antenna feeders are identical. The terminating resistors should have a rating of one 100th of the transmit power if the antenna matching is good.

4.2.2. Construction of Push-Pull Mixers

A further application of Wireline 3 dB couplers is given in the constuction of push-pull mixers (**Figure 9**). A mixer constructed in this manner will have a bandwidth of one octave (frequency ratio 1:2).

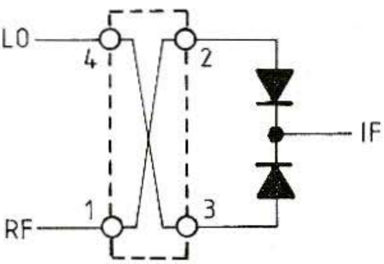

Fig. 9: Push-pull mixer with 3 dB coupler

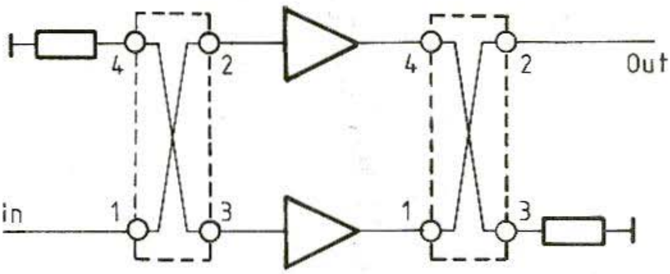

Fig. 10:
Wideband amplifier with directional coupler

4.2.3. Construction of Wideband Power Amplifiers

At higher frequencies, it is difficult to connect wideband amplifiers in parallel to achieve higher power levels. In most cases, 4/4 λ hybrids are used. This means that it is possible to use Wireline 3 dB-couplers here, which also have the advantage of being much smaller (**Figure 10**).

4.3. Table of the Most Common Couplers

Table 3:
Coupling length as a function of coupling attenuation and frequency

f/MHz	3 dB	6 dB	10 dB	20 dB
3.5	too long	too long	too long	860 mm
7.0	too long	too long	too long	430 mm
14.0	too long	too long	726 mm	215 mm
21.0	too long	880 mm	484 mm	143 mm
28.0	too long	660 mm	363 mm	107.5 mm
145.0	324 mm	127.5 mm	70.1 mm	20.7 mm
435.0	108 mm	42.5 mm	23.4 mm	too short
1275.0	36.9 mm	too short	too short	too short
2350.0	20.0 mm	too short	too short	too short

5. MANUFACTURER-AVAILABILITY OF WIRELINE AND DESIGN PROGRAMS

Wireline is available from Sage Laboratories Inc. or from Wacker at the address given below.

Since the manufacturers will probably not supply the short lengths required by radio amateurs, the publishers will consider stocking a certain quantity of such Wireline if sufficient interest is shown.

Please, inform us if you would like to purchase such Wireline; the prices are given in the kit price-list.

5.1. Program

A German company has a basic program for the TRS-80 M III for the design of such couplers. We would like to suggest that interested readers contact this company directly. The address is as follows:

Firma Wacker GmbH, Grüneburgweg 85, D 6000 Frankfurt 1/West Germany.