TECHNICAL REPORT # 2 *2

From: The Crawford Hill VHF Club, W2NFA
Date: 1963 (revised January 1987)

Subject: quadrature Hybrid

In Technical Report * 1 on the need for circular polarization for **all** EME communication to avoid Faraday rotation fading and linear polarization rotation, this report describes a quadrature hybrid device which may be used to implement one method of achieving circular polarization. There are other methods which may be implemented (one such method is described in Technical Report * 9) which will not be described here.

Circular Polarization

A circularly polarized propagating radio wave is one in which the electric field, which defines the polarization is rotating (twisting) as it propagates forward. The angular (rotational) rate of rotation is simply 2 f. Where f is the frequency of the radio wave. This means that the field has rotated one complete revolution at the r.f. rate in one wavelength of propagating distance. Although the wave polarization is linear at any instant in time, viewed over any reasonable period of time such as one or more r.f. periods, the wave appears to have any polarization orientation. For communication purposes then, the radio wave is twisting so fast that it may be considered having all polarizations, i.e., circular polarization.

In actuality, if the r.f. wave is improperly launched or suffers distortion in propagation, the circularity may become modified into an elliptically polarized wave. Radio frequency waves may therefore propagate as pure linear polarized, pure circular polarized, or any form of elliptic polarized wave.

The method suggested in this report to obtain circular polarization employs two linearly polarized antennas arranged with their polarizations at right angles to each other (orthogonal), and their phase centers coincident. That is, the radiating elements lie in the same physical plane. Examples are crossed dipoles or nested crossed Yagis. It is also a fact of nature that linearly polarized antennas or fields that are at right angles to each other, are independent and do not couple to each other. A fortunate situation, for it means that each linearly polarized antenna may be adjusted, tuned and impedance matched independently of the other.

If then, each linearly polarized radiator is fed equal amplitude (power) but with a 90 degree difference in phase, the vector addition of the two radiated wave fields will always be equal in total amplitude but the rotational orientation will change at a rate comparable with the angular frequency = 2 f. This then is the need for a quadrature hybrid to feed the two orthogonal linearly polarized radiating antennas to produce a circularly polarized radaited wave. quadrature implies a 90 degree differential between output ports, and hybrid means an equal power split between output ports. In this report only a 4-port quadrature hybrid will be described.*

To repeat, there are other methods of launching a circularly polarized radio wave. The methods suggested here has the feature of permitting both Left and Right circular polarization rotation to be implemented without physical changes or switching in the system.

By IEEE definition, a wave receding away from the antenna (transmit mode) which is rotating clockwise, is RIGHT CIRCULARLY polarized. While a wave receding away from the antenna which is rotating counterclockwise, is LEFT CIRCULARLY polarized.

It is also a fact of nature that a circularly polarized wave which is reflected by a conductive sheet will reverse its sense of rotation. This fact is of particular interest in parabolic (or any single reflecting) antenna system where the feed antenna must have the opposite rotational sense from the final radiated wave sense. More simply, if the feed antenna is arranged for RIGHT circular polarization, then the reflector radiated wave will be LEFT circularly polarized!

The Ouadrature Hybrid

The device described here is a four port (port in this particular case meaning coaxial connections) matched network which performs the function of power splitting (3 db coupler, or hybrid) with a phase differential between output ports of exactly 90 degrees. The form of this hybrid uses closely coupled transmission lines. The operation of a matched (impedance matched) 4-port quadrature hybrid may be explained with the diagram below.

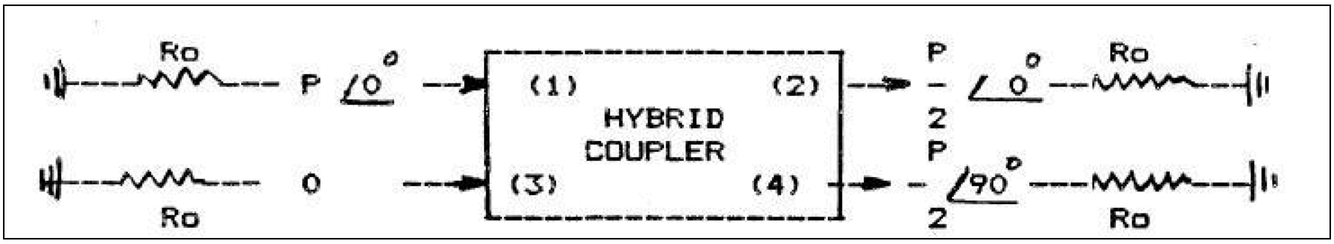
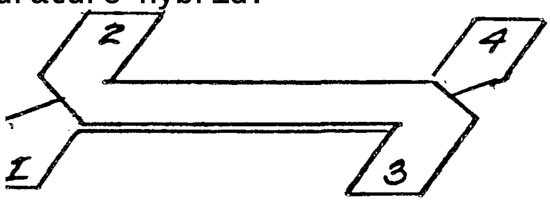


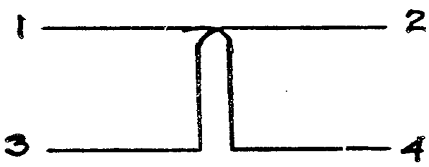
Figure 1

Ideally, if power enters port (1) as shown above, half the will appear at each of the two ports (2) and (4), and port (3) will receive no power (a null port). Note however, that the phase at ports (2) and (4) will have a 90 degree difference. In addition, because this network is a lossless, reciprocal, matched 4-port, it is also symmetric. That is to say, if power enters any one port there will always be a null port and the other two remaining ports will receive half the input power and with a 90 degree phase differential.

In particular we are interested in what happens when power enters port (3). In this case port (1) becomes the null port and ports (2) and (4) receive equal half power levels, but one with one very significance difference, the output port phases are reversed. Port (3) will now lag port (4) by 90 degrees. This property of output phase reversal, dependent on which input port is driven, is what makes the quadrature hybrid useful to implement independent LEFT and RIGHT circular polarization. The fact that the input ports are essentially isolated under impedance matched conditions performs the function of a T/R switch automatically. In practice, the isolation is difficult to obtain comparable with a good T/R relay, however, sufficient isolation < -20 dB is easily achieved permitting the transmitter to be permanently connected to one port, while the receiver preamp (connected to the other input port) will require a protective relay or 'crowbar' to prevent burn-out of the preamplifier. q

The physical ordering of the port numbers is determined by its construction and cannot be assumed from external appearance. The ordering used and shown for this hybrid is the usual arrangement encountered and is also the most desirable since it permits, the ports to be paired on opposite sides of the coupler.
To obtain this ordering of the ports, the coupled line structure is as shown below together with the symbolic designation of a quadrature hybrid.





Another feature of the coupled line hybrid is that the phase differential between output ports is by definition 90 degrees, but the power output balance must be trimmed (adjusted) to obtain a good - 3 dB split. In addition, the isolation between input ports is also dependent, not only on the impedance match at the output ports but also the electrical balance of the coupled lines. Adjustment procedures are described in the section on construction notes.

<u>Hybrid construction</u>

The drawings at the end of this report contain sufficient information for the construction of three different coupled line quadrature hybrids. The choice of which one to build is left to the reader and materials available. The first two designs, I and II are symmetrical in physical construction and complete dimensions are not always shown. The striplines are always centered between the ground planes. No critical machine work is required and the dimensions which are important are the spacing between the coupled lines and the line section lengths themselves. N-type panel receptacles are used for all ports.

<u>Pesion No. I</u>

This design is very rugged mechanically and provides edge mounting of the N-type receptacles, which is desirable for good impedance transition. When completed, the unit does not include sidepanel shields which may be added. Nylon screws are used to hold the strips centered. A good substitute can be made from strips of low density expanded foam commonly found in commercial packaging. The small capacitor tabs on this unit are soldered to the strip lines and can be adjusted for best directivity (null between input ports) and best balance between output ports. In general directivity of less than - 20 dB is desirable, while balancing of the output ports is of secondary portance.

Design No. 1

This unit is built around commonly available copper clad printed circuit board. It is available from many sources and is not necessary to get high quality, low loss material, since the functional part is only the copper inner surface. Many sources of 'mud' PC boards are available. A thicker board can provide better mechanical stability to the unit.

The boards are conveniently held apart by 20 - 2/4 inch diameter by 1/2 inch long commonly available spacers. They may be mounted with screws extending through the center hole or tapped at both ends for short screws.

The stripline sections are best cut as a pair with a nibbling tool or other cutting device which does not warp or distort the edges. Hand shears tesd to warp the sheet as it is cut, requiring extensive work to flatten the material.

Drill the copper clad PC boards as a pair for good registration. The N-type receptacle is soldered directly to the copper cladding around its inside shoulder, as indicated, to provide food electrical continuity with the ground plane (inside plane). The small copper tabs soldered to the ends of the strip lines for adjustment may be adjusted empirically with a non-metalic tool, reaching through the spacers. The adjustment procedure is the same as with the first design No. I. This unit provides all the ports on one side of the unit, although they may be arranged in other fashion on either side of the unit for convenience in application, to shorten inter-connect leads. The unit may also be enclosed on the sides for environmental protection.

Measuring and Tuning

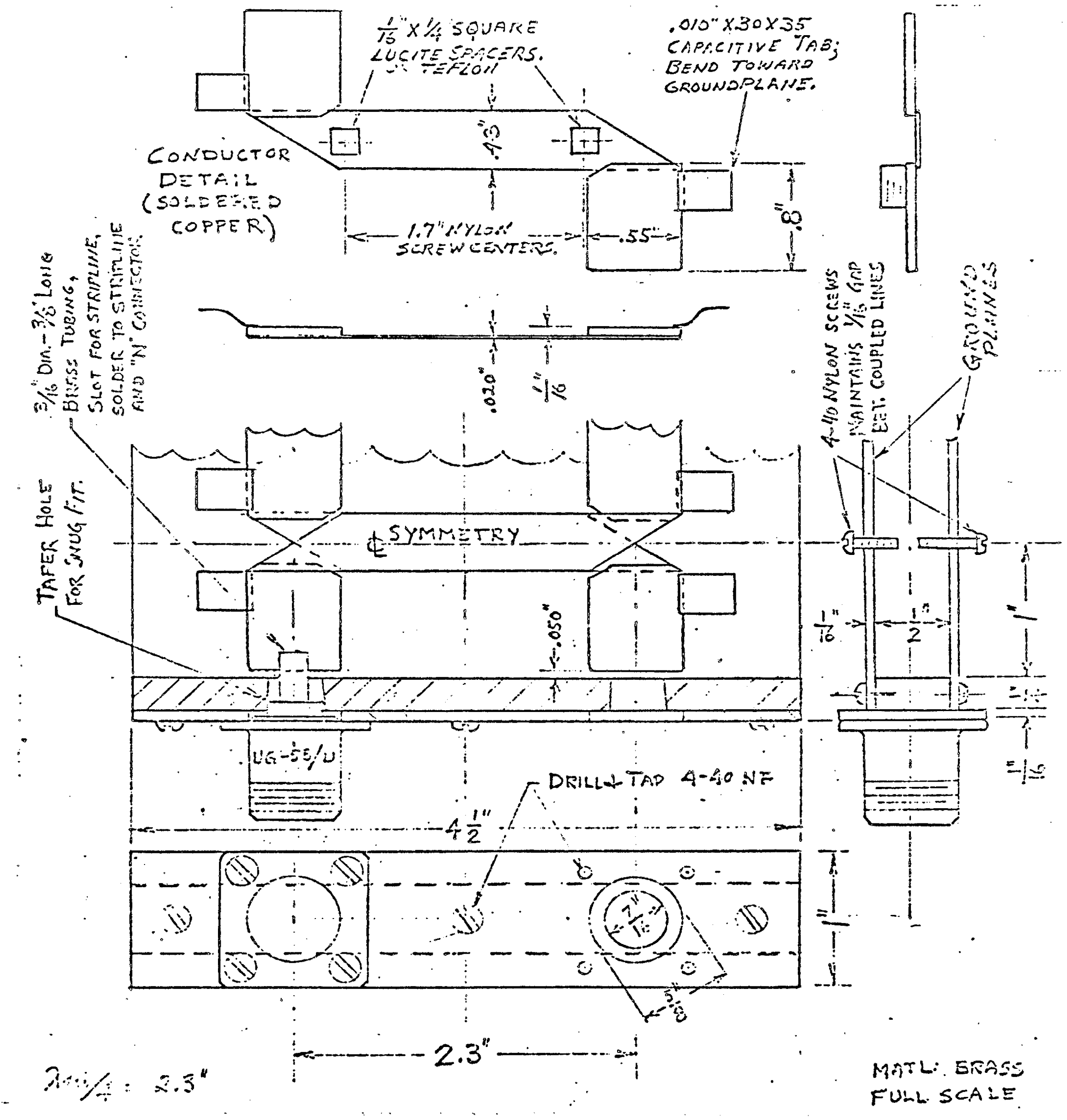
Upon completion of the coupler hybrid, it is highly desirable to make sure that the device is working properly by making some measurements and adjustments. The by-word or credo of all home made hardware (and even bought or borrowed hardware) is, DO NOT trust anyone elses word, measure it to your own satisfaction. Many well designed electronic systems have been reduced to utter disaster by interfacing hardware which was erroneously specified. In order to make measurements on your hybrid, it will be necessary to have some equipment. A low r-f power source (a watt or less) at 1296 mc/s, a pair of matched terminations, see Report # 14, and a suitable r-f detector which can, in conjunction with your r-f source, measure at least a 20 dB range. A set of calibrated attenuators would be nice but are not necessary. Any 50 ohm attenuator with at least 10 dB loss is also required.

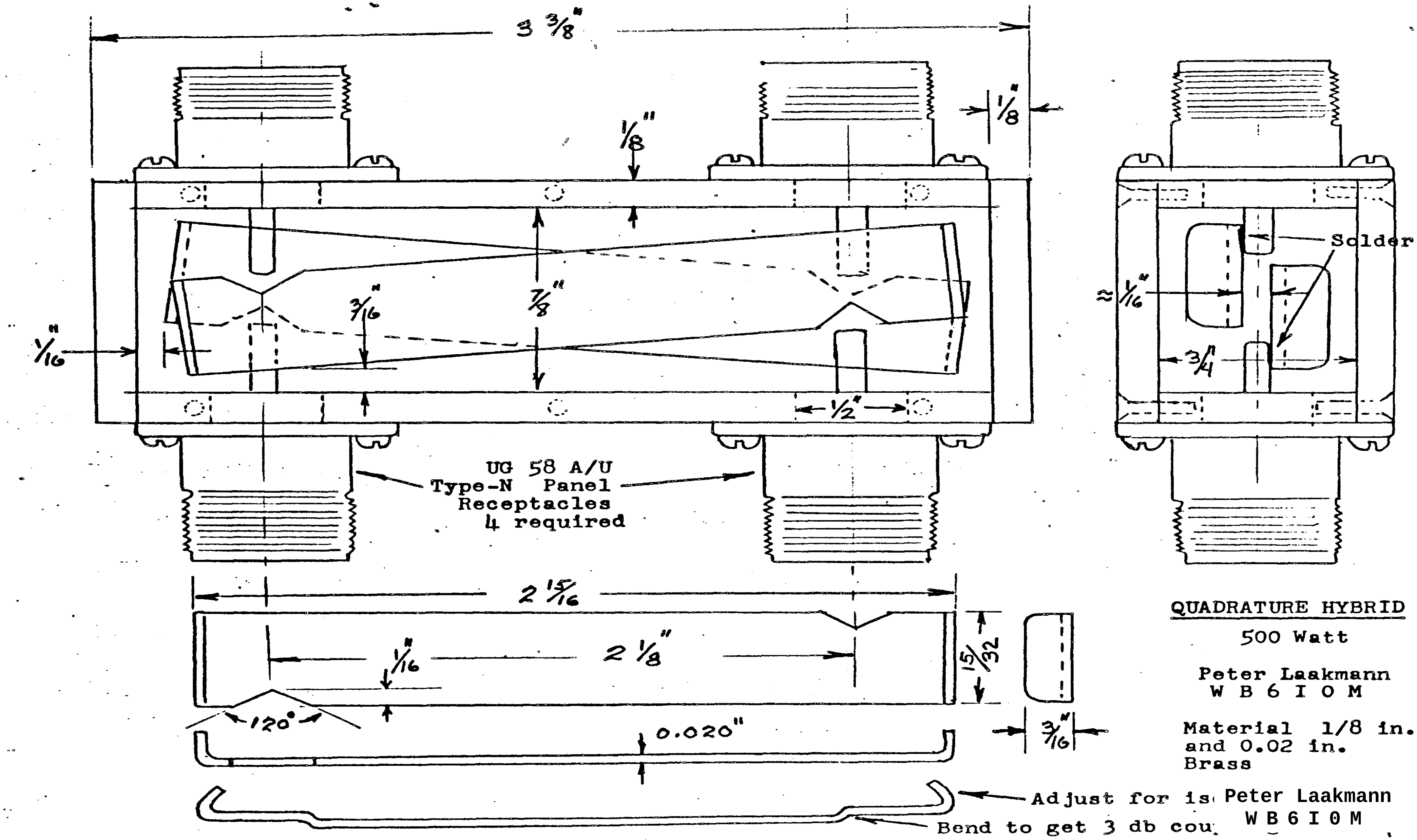
Such an attenuator may be made of a long section of RG 8 coaxial cable, but is expensive.
The measurement procedure is to connect the source to port (1), a 50 termination to the null port (3), and a matched 50 ohm termination to one output port, say port (2). The 10 dB attenuator and detector are then connected to the other output port (4). Making sure that the measuring system is not saturated, read the output r-f level at port (4).
Next switch the output ports, and note the r-f reading again. If these readings are within less than 0.5 db, the output balance is for most purposes satisfactory.
If you have no calibrated attenuator or method to measure differences less than 1 dB, sections of RG B or better still RG 214 coaxial cable may be used as fixed attenuators. Consult handbook tables of cable loss per hundred feed as a guide.
The output port balance may be adjusted by changing the spacing between the coupled line sections. Make every attempt to keep the spacing uniform along the coupled section.
When the output balance is within a few tenths of a decibel, the idrectivity or null port may be checked by first placing both matched terminations on the two output ports and the r-f detector (with of without the attenuator) on the null port (3).
It should now be possible to adjust (bend) the capacitive tabs at the ends of the coupled line sections until a good null is obtained on the r-f detector at port (3).
A measure of the actual coupler directivity may be made if r-f calibrated attenuators are available. The procedure is to first obtain a measure of the r-f source power output with at least a 30 dB attenuator (pad) between source and detector. Then connect the source directly to port (1). Now connect the detector with appropriate attenuators to measure the ratio between the total input power to the actual power at the null port (3).

If the ratio of these two levels is greater than 20dB, the directivity can be considered satisfactory for most purposes.
Careful adjustments can result is much better directivity. If all active parts are carefully smoothed and free of sharp burrs and corners, this coupler should perform satisfactorily at power levels at least through 500 watts.
These couplers tend to be correct at one frequency but are not particularly critical or very narrow band.

Reed Fisher, W2COH has developed similar coupled line transformers for lower power using tightly twisted insulated wire augmented with capacitors, which give excellent results up to the UHF range.
Similar quadrature hybrids can also be built using similar techniques wound on Ferrite toroidal cores which also give excellent results through any region of the radio frequency spectrum.

QUADRATURE COUPLER 1296 mc
3db - 90° - HYBRID - 50 OHM





QUADRATURE HYBRID

500 Watt

Peter Laakmann
W B 6 I O M

Material 1/8 in.
and 0.02 in.
Brass

Peter Laakmann
W B 6 I O M

QUADRATURE COUPLER 1296mc

3db - 90° - HYBRID - 50 OHM