AN IMPROVED CIRCUIT FOR IMPLEMENTING THE SIX-PORT TECHNIQUE OF MICROWAVE MEASUREMENTS*

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Abstract

In a companion paper, circuit design criteria have been developed which will lead to optimal results in applying the six-port technique to the measurement of microwave parameters. This paper will describe what promises, in many situations, to become the "preferred" six-port circuit.

The response of a six-port measuring system is contained in the reading of four power meters $P_3 \cdots P_6$, which may be written,

$$P_3 = |A|^2\ |b|^2\ |\Gamma_\ell - q_3|^2 \quad (1)$$

$$P_4 = |D|^2\ |b|^2\ |1-\Gamma_\ell \Gamma_g|^2 \quad (2)$$

$$P_5 = |E|^2\ |b|^2\ |\Gamma_\ell - q_5|^2 \quad (3)$$

$$P_6 = |G|^2\ |b|^2\ |\Gamma_\ell - q_6|^2 \quad (4)$$

where $|b|^2$, Γ_ℓ represent the measurands of interest and the remaining parameters are determined by the properties of the six-port.

In a companion paper[1] the following design criteria were developed: $\Gamma_g = 0$, $|q_6| = |q_5| = |q_3|$ while the arguments of these last three terms differ by ± 120°. The optimum choice of $|q_3|$ may be expected to lie in the range 0.5-1.5, while $|A|$, $|D|$, $|E|$, and $|G|$ are scale factors which determine the power levels at the respective power detectors.

As a means of illustration, it is convenient to consider a specific problem. Let it be required to design a six-port circuit for calibrating bolometer mounts and measuring reflection coefficient, where the detectors $P_3 \cdots P_6$ are also of the bolometric type. Moreover, let it be further stipulated that the circuit is to be broadband and, in order to reduce the power requirements at the input, inherently lossless.

In today's art the broadest frquency coverage is afforded by stripline components. Here bandwidths of 10:1 are not uncommon. The basic circuits thus available include quadrature hybrids, 180° hybrids, and directional couplers. In waveguide parlance a quadrature hybrid is a 3-dB directional coupler, while an 180° hybrid is an E-H tee. These two hybrids and the relationships which exist among the incident and emergent wave amplitudes are as shown in Fig. 1. Ideally these devices are lossless and matched at all ports.

In the existing art, a broadband circuit which yields a 120° phase shift is unknown (to the author at least!). However, one is able to achieve a broadband 90° phase shift by means of a quadrature hybrid. This suggests some compromises in the design goals outlined in the preceding paragraph.

The basic configuration of the proposed six-port circuit is shown in Fig. 2. Here ideal components have been assumed while the emergent and incoming wave amplitudes are designated by b and a, respectively. The wave amplitudes at other selected positions in the circuit are also shown. These may be confirmed by comparison with Fig. 1. Note, however, that no attempt has been made to keep track of the phase of a or b or even their phase difference in an absolute sense. The only question of importance in this context is: How does the phase difference between a and b at port 3 compare with that which exists at ports 5 and 6?

Comparing this circuit with the design goals, one first notes that although resistive terminations are shown at two different locations, ideally none of the signal power reaches these, so the circuit is inherently lossless.

If one assumes 20 mW of power at the input, 5 mW or 1/4 of this reaches the measurement port. If the termination at the measurement port is a matched load, this power will be absorbed, and the remaining 3/4 is divided equally among the detectors $P_3 \cdots P_6$, which results in a power level of 3.75 mW at each detector. If now P_4 is stabilized at this value, and a sliding short is connected to the measurement port, the value of P_3 will reach approximately 11 mW for certain short positions, while the maximums at P_5 and P_6 will be approximately 8.5 mW. The maximum dynamic range excursion at any detector is a nominal 15 dB which occurs at P_3.

Finally, it may be noted that $\Gamma_g = 0$ for this circuit, while the values of q_3, q_5, and q_6 are as shown in Fig. 3. Although this result falls somewhat short of the design objectives, these goals are more nearly achieved by this circuit than by any other which has been devised to date. Moreover, it appears that the theoretical loss in performance between this circuit and an "ideal" one may be insignificant in comparison with the performance degradation allowed by tolerances on existing components.

Perhaps the most distinctive feature of this circuit is in the ratios q_5/q_3 and q_6/q_3 which it yields. These ratios are determined by that part of the circuit contained within the dotted line in Fig. 2. Taken alone, this part of the circuit may be considered a "vector voltmeter" which has been the subject of an earlier paper.[2] As a vector voltmeter, this circuit has certain properties not provided by other designs.

As a variant to Fig. 2, one may wish to replace the 6-dB directional coupler by a 3-dB one. If this is done, the power level at the measurement port is doubled, but at the expense of the power levels at $P_3 \cdots P_6$. In addition the $|q's|$ are multiplied by $\sqrt{2}/2$. Because 3-dB couplers are more readily available than 6-dB couplers, this alternative warrants careful consideration.

If one removes the restriction on the power level at the measurement port, and assumes a surplus of power from the signal generator, the number of additional alternatives increases rapidly, and no attempt will be made to discuss these in detail. The nature of the tradeoffs, however, may be simply stated. Returning again to Fig. 2, one notes that the input levels to the "vector voltmeter" (i.e., that portion of the circuit enclosed in dotted lines) are $\sqrt{3}b$ and $\frac{\sqrt{3}a}{2}$. Basically, the parameters at one's disposal are the coefficients in these terms. Let these be designated by β and α so that in Fig. 2, $\beta = \sqrt{3}$ and $\alpha = \sqrt{3}/2$. In general it is a simple matter to make α and β small; this can be achieved by inserting attenuators in the associated lines. A preferred procedure, in most cases however, would be to interchange the generator and reflected wave connections at the left side of the coupler in Fig. 2 and then change the coupling value to 10 dB, 20 dB, or larger as required. With the connections as shown, β can be made large by using a 10- or 20-dB coupler in place of the 6-dB one. For a passive circuit, however, $\alpha < 1$. In order to increase the power levels at $P_3 \cdots P_6$ it is usually desirable to increase both α and β. If β is increased while α remains constant, the power levels increase as well as the $|q's|$. Returning to Fig. 2 once more, if one wishes to bring the $|q's|$ inside the unit circle, this can be done by adding attenuation in the line which feeds the "H" hybrid. This, however, will also result in a signal loss at $P_3 \cdots P_6$ unless compensated for by an increase in input power and an accompanying level change at the measurement port.

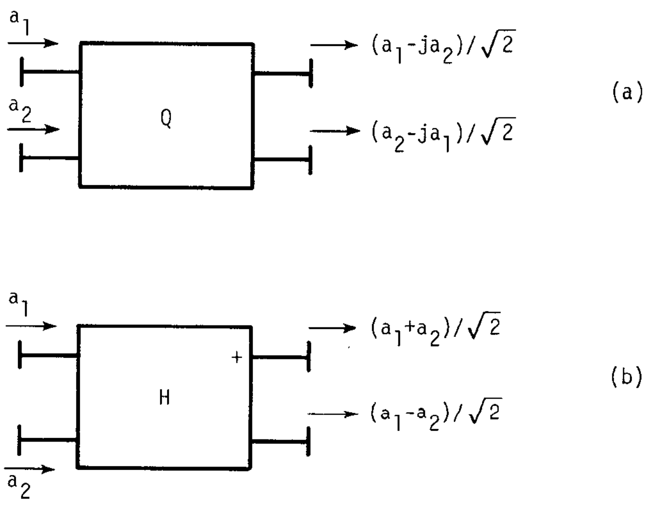

Fig. 1-Basic modules for six-port circuit.

There are also a number of variants to the "vector voltmeter" part of the circuit; some of these include:

1. Change the hybrids at positions 2 and 3 from Q to H types.
2. Interchange the Q and H hybrids at positions 1 and 4.
3. Interchange the connections at the inputs or outputs of both hybrids at positions 2 and 3.

Another variant is shown in Fig. 4. Here all hybrids are of the quadrature type. A variant of the circuit of Fig. 4 is shown in Fig. 5.

Although only a limited amount of practical experience has been obtained to date, a number of these circuits have been assembled and the predicted performance realized.[3,4]

References

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3. M. P. Weidman, "A Semi-Automated Six-Port for Measuring Millimeter Wave Power and Reflection Coefficient," 1977 IEEE Microwave Symposium Digest.

4. E. L. Komarek, "An Application of the Six-Port Reflectometer to Precision Measurement of Microwave One-Port Parameters," 1977 Microwave Symposium Digest.

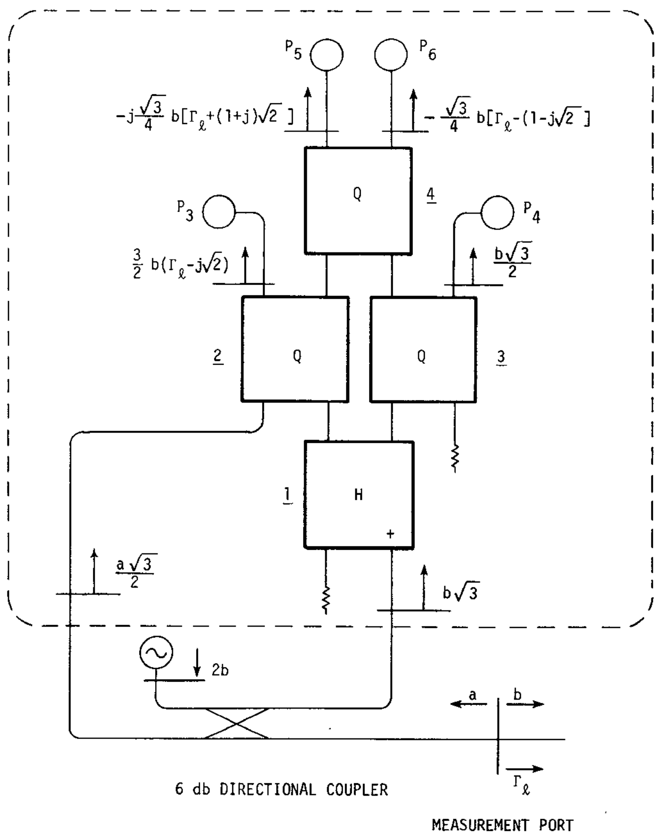

Fig. 2-A proposed six-port circuit.

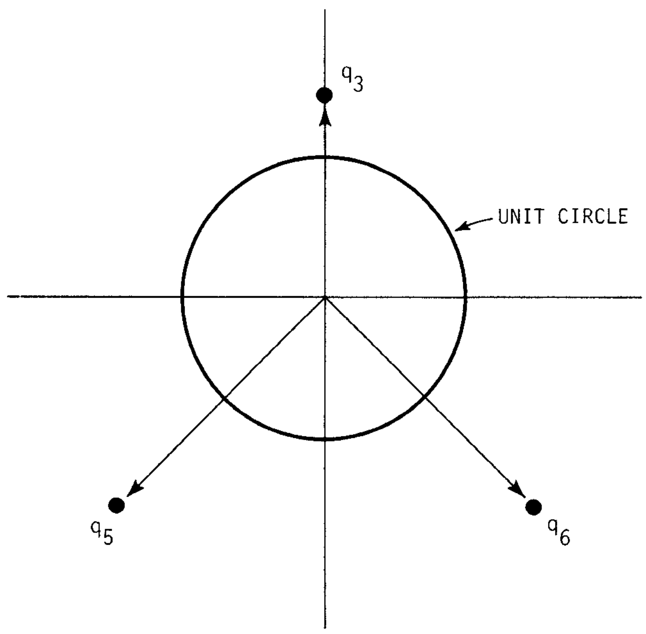

Fig. 3-Illustrating q_3, q_5, q_6 for the circuit of Fig. 7.

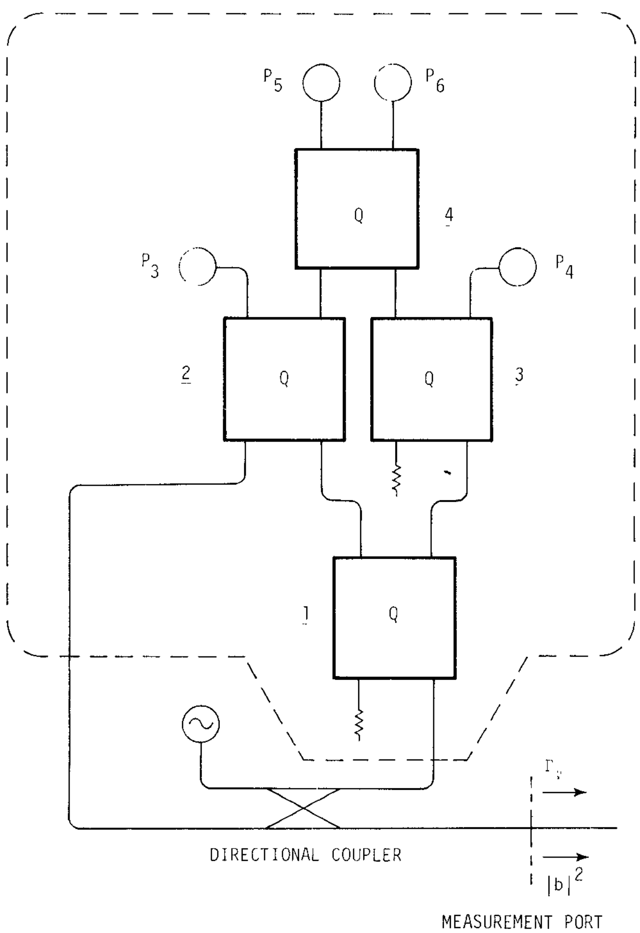

Fig. 4-A six-port circuit using only quadrature hybrids.

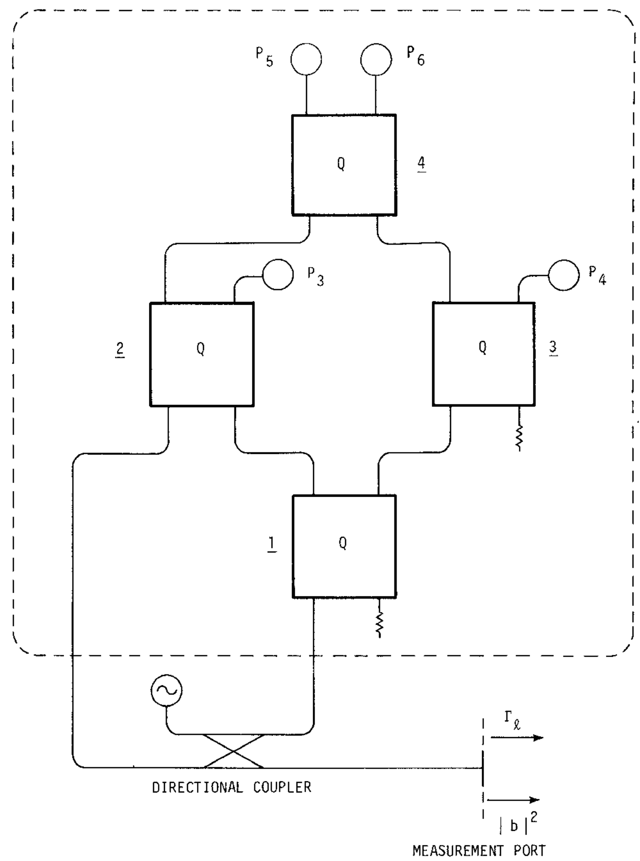

Fig. 5-An alternative to the circuit of Fig. 9.