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THE EQUAD:* A FLAT AMPLITUDE, OCTAVE BANDWIDTH PLANAR QUADRATURE NETWORK

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ABSTRACT

This paper will describe a hybrid structure with quadrature properties. The technique to be described adds bandpass - bandstop networks to the outputs of in-phase N-way power dividers resulting in circuits possessing hybrid properties with output port phases in quadrature. Output amplitude characteristics may be made equal or may differ by offset values, depending on the power split properties of the power divider chosen. Applications to amplifier arrays and antenna feeds are discussed.

Introduction

We have developed a quadrature power divider with a hitherto unavailable property: The new broadband power divider provides two or three outputs, with each output equal in amplitude to any other and with the phase of each output differing from that of any other by 90 degrees. The equal-split, 90 degree properties are maintained over an octave bandwidth. Each output is isolated from any other, theoretically by 33 db minimum and practically by not less than 15 db. The devices are all planar and do not utilize coupled lines or complicated bridges as are required by overlap or Lange couplers, respectively.

Principle of Operation

The fundamental principle of the device can readily be understood by considering Fig. 1A. We start with a conventional two section in phase power divider. Attached to each power divider output are networks which provide a broadband 90^o differential phase shift. On one output is a Z_O 3/4 wavelength line. The 3/4 wavelength applies at center frequency. Attached to the other output is a network consisting of a low impedance 1/4 wavelength line bisected by an 1/8 wavelength open circuited stub and short circuited stub. This combination is followed by another low impedance Z_O line. At center frequency, therefore, the output phase difference is merely that of the difference between the 3/4 wavelength line and the 1/2 wavelength line: 90^o. If the open and short circuited stubs were not present, one would find that the phase slope of the 3/4 wavelength line is intrinsically steeper than that of the 1/2 wavelength line. Therefore, the outputs would not have the broadband 90^o differential. However, addition of the stub network skews the phase slope such that it matches the slope of the 3/4 wavelength arm - but is offset by the 90^o. Although the stub network is not all-pass, its zeroes may be selected in a Chebychev manner such that no more than a one degree phase error theoretically exists over an octave. Judicious synthesis of stub impedances results in a matched network such that the composite structure is low VSWR with respect to Zo. The hybrid properties of the device are based upon the even and odd mode equivalent circuits as presented in references 1 and 2. Internal termination of symmetrical reflections (quadrature hybrid property) is shown for the mid-band case, in Fig. 1B. The even mode equivalent circuit is used to compute line admittances while the odd mode network is used to determine the conductances necessary for isolation. The total scattering matrix is derived from a conventional cascade of the entire structure and fundamentally differs by a fixed phase shift from that of the in phase divider. This may be understood easily, as it is only the even mode network which is affected by cascading non-coupled lines on to the power divider outputs. A computer optimization program is used to adjust the line impedances slightly. This procedure results in the best compromise between isolation and VSWR. Isolation and VSWR are computed using equations (4) and (5) of reference 1. The three-way device is an extension of the two-way. On the first arm, the output is preceded by a Z_O line length of 1.5 wavelengths. The second arm consists of a stub network identical to that on the two-way, connected to a 3/4 wavelength Z_O line. The third arm contains a two pair stub network, i.e. two open circuited and two short circuited stubs. The three lines are driven by an in phase three-way splitter which provides the fundamental hybrid isolation in similar fashion to the two-way device. The entire structure is illustrated in Fig. 2. Installation of the unit into a microstrip mother board is shown in Fig. 7.

Applications

What are some of the limitations of modern quadrature combined amplifier structures? For broadband, (i.e. more than 25% bandwidth) the splitting of driver power is normally accomplished through the use of a quadrature hybrid. Coupling characteristics of conventional coupled line quadrature hybrids are theoretically complimentary. That is, one output has an amplitude characteristic which is concave with frequency while the other is convex. The sum of the two outputs, if dissipative losses are not considered, would add up to unity. However, across an octave, the amplitude difference between the two outputs will be as much as 1 db for a single pair of outputs. If a concatenation of such structures are configured, the path which traces its origin to the coupled port of the first splitter will deviate in an increasing

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fashion with each successive power split. For example, if the amplifier module comprises a single splitter, two amplifiers and a recombiner, use of a quadrature splitter-fed pair of such modules will result in the input of an output stage being as much as 2 db different in drive from one of the other three output stages. This is shown in Fig. 3. This split "treeing" effect increases as the number of modules cascaded. This clearly results in stages approaching saturation at different rates, thus destroying the intrinsic symmetry and spurious product reduction which normally results from the symmetry. The classic problem of "fan-out" can be solved through the use of couplers with nominal values other than 3 db. This approach, which has been known for at least 13 years, was developed at Bell Labs by H. Seidel (Ref. 3). However, the coupler structures necessary for application of the technique are complicated and the over all approach is expensive, due to the large number of different coupler values required. A simpler solution is provided by our new approach, in that each splitter output is almost identical in amplitude to that of any other output. Thus, the entire "fan-out" problem is eliminated. It should be mentioned in passing, that many other differential phase shift combinations are available with this approach. For example, the outputs could differ by 120 degrees or 32 degrees or whatever - on a one octave constant phase basis. This may well have applications to antenna feeds or devices wherein a specifically weighted phase front is required. It would seem as though the fundamental application of the new device would be in frequency ranges above 500 MHz (due to the board area required for the network) and for broad bandwidths. The latter stipulation is due to the availability or simpler techniques for the narrow band case. One of the simpler techniques could be considered a predecessor of this device and is achieved by simply connecting a 90 degree line length on one output of a two-way splitter.

In addition, it would seem that the three-way 0 degree, 90 degree, or 180 degree network would offer a unique new possibility: the ability to use a fundamental gain module comprised of three solid state devices rather than two, with each device isolated from any other and with the entire module possessing the low VSWR properties typical of the quadrature coupled devices. This is illustrated in Fig. 4.

In considering potential application for the device, the limitations of present solid state technology must be taken into account. For octave bandwidth, known solid state devices do not provide gain and output power sufficiently high to require more than 15 or 20 Watt internal terminations. Resistors in either case may be low power or high power resistors, depending upon the proposed application. Installation of a high power resistor is shown in Fig. 5. Typical performance is shown in Fig. 6.

Conclusion

The new devices have application to arrays of various kinds - amplifier, antenna feed, etc. The amplitude weighting factors are primarily a function of the in-phase divider chosen with a small contribution from the loss of the extra lines "added-on", while the phase characteristics are set by the stub networks. When the phases are quadrature related, the device is a true planar hybrid, isolated, low input VSWR device.

References

1. NAGAI ET AL, "New N-Way Hybrid Power Dividers", Trans. MTT-S, December 1977

2. YEE ET AL, "N-Way Tem Mode Broad Band Power Dividers", Trans. MTT-S, October 1970

3. H. Seidel, Private Communication (1968)

* Patent applied for

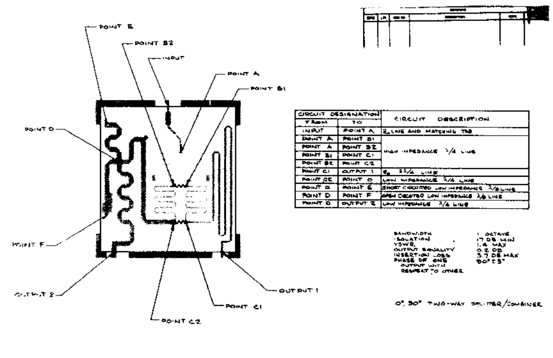
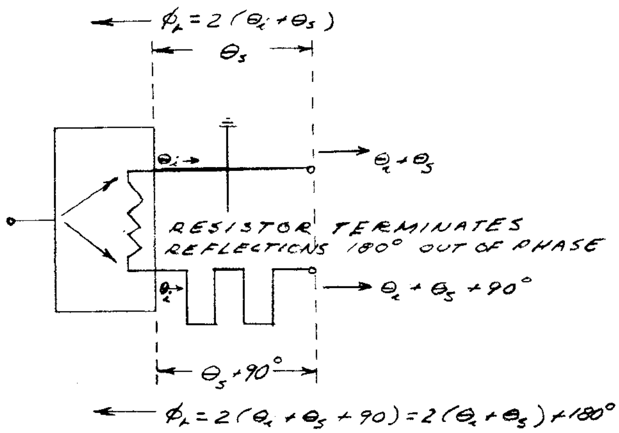
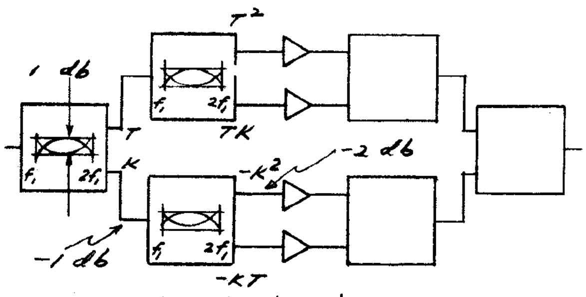


FIG. 1A



QUADRATURE HYBRID PROPERTY

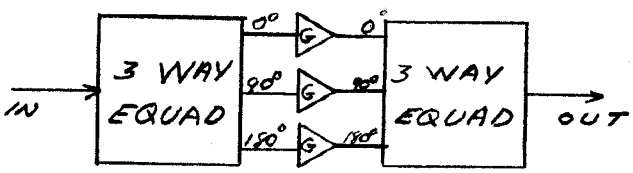
FIG. 1B



$|T^2| - |K^2| = 2\ db\ @\ f_0$

FAN OUT PROBLEM CAUSED BY CONVENTIONAL COUPLED LINE QUADRATURE HYBRIDS

FIG-3



N=3 WAY

BASIC GAIN MODULE

SYMMETRICAL REFLECTIONS TERMINATED INTERNALLY

FIG. 4