Correspondence

Interdigitated Stripline Quadrature Hybrid

Abstract—**Interdigitated microstrip couplers consist of three or more parallel striplines with alternate lines tied together. A single ground plane, a single dielectric, and a single layer of metallization are used. Thus the approach is eminently suited for monolithic or hybrid thin-film microwave integrated circuitry. Tight coupling is achieved much more easily than with noninterdigitated edge-coupled lines. Fabrication and tolerance problems make it almost impossible to build noninterdigitated 3-dB edge couplers. Also, current crowding at the edges, which can result in high loss, is much less severe for the interdigitated coupler.**

Previously, tight coupling in directional couplers for microwave integrated circuits has been achieved by broadside coupling, reentrant sections, tandem sections, or branch-line couplers. Some of the disadvantages of these approaches are narrow bandwidth, large substrate area, and the need for multilayer circuitry.

A 3-dB directional coupler (quadrature hybrid) for *S* band has been fabricated in microstrip on 40-mil alumina. A single quarter-wave section was used.

The hybrid showed a directivity of over 27 dB, a return loss of over 25 dB, an insertion loss of less than 0.13 dB, and an imbalance of less than 0.25 dB over a 40 percent bandwidth.

Hybrids are frequently used as components in microwave systems or subsystems such as balanced mixers, balanced amplifiers, phase shifters, attenuators, modulators, discriminators, measurement bridges, etc. An ideal hybrid is a four-port junction with properties such that a wave incident in port one couples equal power into ports three and four but none into port two (see Fig. 1). Hybrids are classified according to the phase shift between the two outputs. There are two basic types: 180° hybrids and 90° (quadrature) hybrids. The latter are also called 3-dB directional couplers.

The increasing use of thin-film microwave circuitry has created a need for small, low-loss hybrids which can be easily fabricated on microstrip. This has led to the introduction of this new class of directional couplers.

Interdigitated microstrip couplers consist of three or more parallel striplines with alternate lines tied together (see Fig. 1). A single ground plane, a single dielectric, and a single layer of metallization are used. Thus the approach is eminently suited for monolithic or hybrid thin-film microwave integrated circuitry. Tight coupling is achieved much easier than with noninterdigitated edge-coupled lines. Fabrication and tolerance problems

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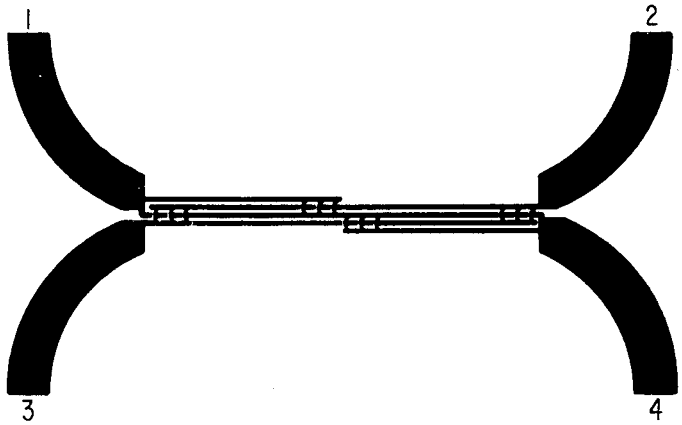

Fig. 1. Interdigitated 3-dB coupler.

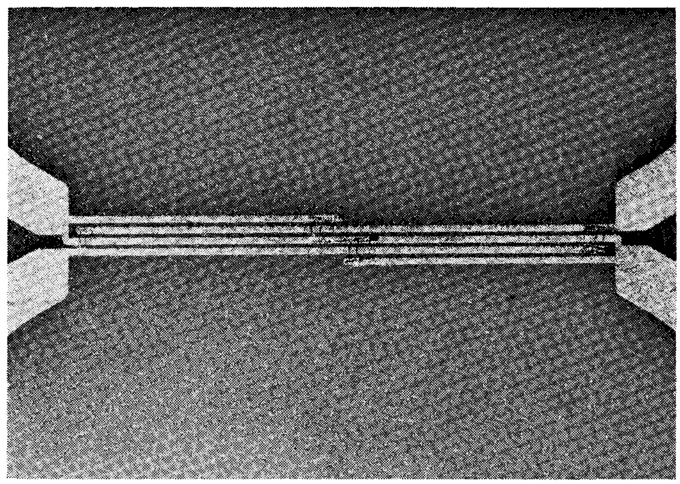

Fig. 2. Interdigitated quadrature hybrid.

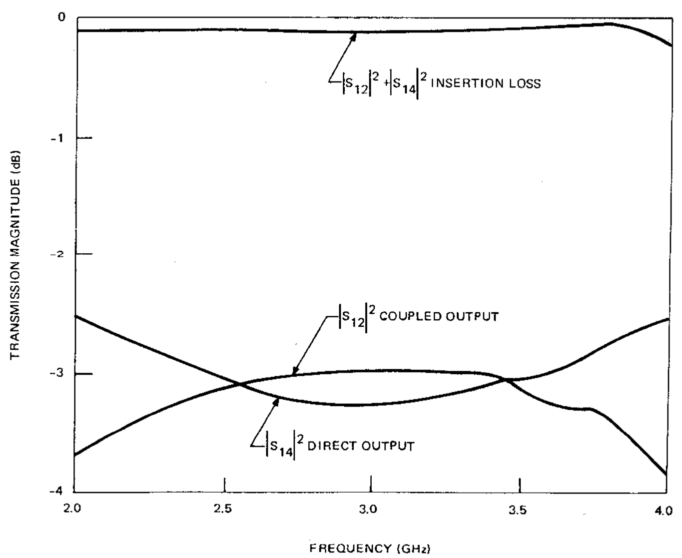

Fig. 3. Coupler response and insertion loss.

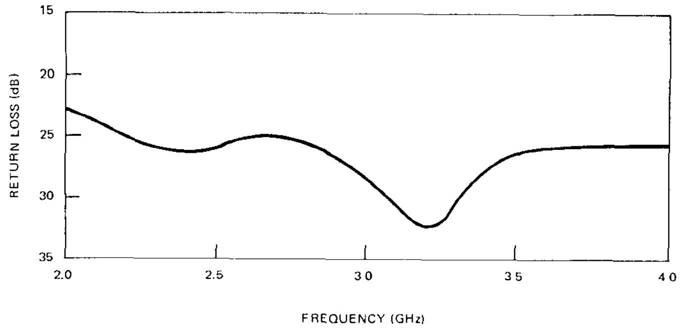

Fig. 4. Coupler return loss.

make it almost impossible to build non-interdigitated 3-dB edge-couplers. Also, current crowding at the edges, which can result in high loss, is much less severe for the interdigitated coupler.

Previously, tight coupling in directional couplers for microwave integrated circuits has been achieved by

1) broadside coupling,
2) reentrant sections,
3) tandem sections,
4) branch-line couplers.

Choices 1) and 2) require multilayer circuitry which is extremely difficult to build on ceramic or monolithic substrates. Choices 3) and 4) have a narrower bandwidth and require much larger substrate areas than single-section coupled-line couplers.

A quadrature hybrid for S band has been fabricated on a 42-mil single-layer alumina dielectric (Fig. 2). The metallization consists of thin-film gold plated up with gold. A single quarter-wave section of four lines is used. The lines are 4.5 mils wide, the spaces 3.0 mils. The crossovers were each made with three thermo-compression-bonded 0.7-mil gold wires.

In designing this coupler, special care was taken to minimize the effect of bonding-wire inductance and to maintain electrical symmetry. Good performance of a quadrature coupler, i.e., high isolation, high return loss, and exact 90° phase difference, are dependent on good symmetry, as can be shown from fundamental theoretical considerations. Therefore, some of the crossovers were made at the center of the coupled section rather than at the ends. This layout also makes possible the use of multiple crossovers, reducing bonding-wire inductance.

Extensive tests were made on the coupler. Some of the results are shown in Figs. 3 and 4. Imbalance, the ratio of outputs, was less than 0.25 dB between 2.4 and 3.6 GHz (see Fig. 3). The insertion loss referenced to a 50-ohm system was less than 0.13 dB between 2.0 and 3.9 GHz. This includes losses due to mismatch and finite directivity. The directivity was above 27 dB for the whole band. The return loss was over 25 dB between 2.2 and 4.0 GHz (see Fig. 4). Most of this mismatch was due to the transition between the stripline and the coaxial measurement system since standard commercial connectors were used. The irregularity of the curve in Fig. 3 would indicate as much. The phase difference between output ports was within 2° of 90°.

The hybrid has been used in a balanced amplifier of the type proposed by Engelbrecht.[1] Use of this technique was successful in reducing the maximum VSWR at the input and output from 2.7 to 1.2.

In conclusion, a high performance quadrature hybrid for S band has been built on alumina microstrip. Loss, isolation, VSWR, balance, and phase relationships are excellent over a 40 percent bandwidth.

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[1] R. S. Engelbrecht and K. A. Kurokawa, "A wide-band low noise L-band balanced transistor amplifier," *Proc. IEEE*, vol. 53, pp. 237–247, March 1965.

VHF- and UHF-Band Stacked-Junction Circulators

Abstract—**The stacked-junction circulator, in which two ordinary ferrite-loaded junctions are stacked and assembled in a common housing, is described. A UHF-band stripline stacked circulator and a VHF-band lumped-element stacked one have been constructed and proved to be effective in improving the cost to power performance.**

Introduction

This correspondence describes stacked-junction circulators, in which two ferrite-loaded junctions are stacked and assembled in a common housing. The input power is divided into two junctions, and CW power rating is doubled. The stacked circulator increases the freedom to choose a ferrite size, which must be optimized for a specific power level in each application because it closely affects the cost of the assembled circulator. However, a conventional stripline circulator needs a suitable diameter and thickness of ferrite, which correspond to the operating frequency. If the junction structure is specified, the ferrite size is fixed and the power rating is also determined. Therefore, it is necessary to prepare different kinds of junction structures in order to optimize the ferrite size. From this point of view, stacking proved to be very effective in improving the figure of merit of the cost to power performance. Fig. 1 shows the CW power rating of stacked circulators.

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A variety of VHF- and UHF-band circulators, from high-power composite ferrite junction [1], [2] to the miniature lumped-element type [3], have been reported. However, a VHF-band circulator appropriate for medium power of 300 watts or so has not yet been obtained because ferrite discs 300 mm in diameter and 10 mm thick are needed to fabricate a stripline circulator at 100 MHz which will be capable of handling 3 kW.

First, a high-power compact stripline stacked circulator was built. Then a VHF-band lumped-element stacked circulator, which has the same physical size and power rating as a 700-MHz conventional stripline model, was constructed.

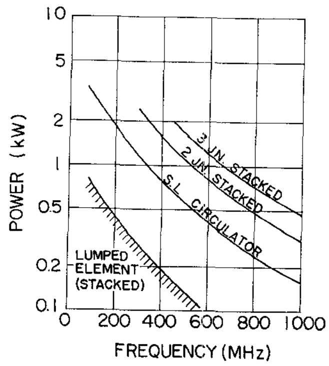

Fig. 1. CW power rating of stacked circulators.

Stripline Stacked Circulator

Although adopting a composite junction can increase the power handling capability, it decreases the bandwidth due to decreased filling factor. Stacking, on the other hand, can double or triple the power rating without degrading the bandwidth, if the corresponding number of junctions are stacked.

At the beginning, a conventional 50-ohm stripline junction is designed. The ferrite disc diameter is fixed by the signal frequency to be handled. In the choice of the ferrite thickness, two factors which must be considered are heat removal and junction impedance. The two center conductors are connected in parallel as shown in Fig. 2. This configuration reduces the junction impedance by half, and thick discs are required to form a 50-ohm stacked junction. This increases the temperature rise within the ferrite, and no attempt was made to increase the thickness. Stacking of 50-ohm junctions decreases the input impedance and an additional matching scheme is necessary. A quarter-wave transformer or a matching capacitor connected in the transmission line can be used. If we consider that the series-resonant effect of a stepdown transformer gives broader bandwidth, a low junction impedance is rather preferred.

For the ferrite material, Gd-substituted YIG discs 60 mm in diameter, 4 mm thick,