A Wide-Band Quadrature Hybrid Coupler

***Abstract*—Wide-band quadrature hybrid proximity couplers consist of a conductor fabricated by thin-film techniques in microstrip on the conductor side and a slot in the ground plane side. A 4 to 1 bandwidth was achieved using an alumina substrate of 99.6-percent purity with a surface finish of 10 μin. A single-section quadrature hybrid has been fabricated and operates over a 2.5- to 10-GHz frequency range with a maximum VSWR of 1.43:1, a 20-dB typical isolation, and a phase difference between outputs of 90° ± 3°.**

Quadrature hybrid couplers are commonly used as integral components in microwave integrated circuits. Multioctave bandwidths are normally achieved through the use of a multisection coupler. Recent work conducted by the author has resulted in a single-section quadrature hybrid having a 4 to 1 bandwidth.

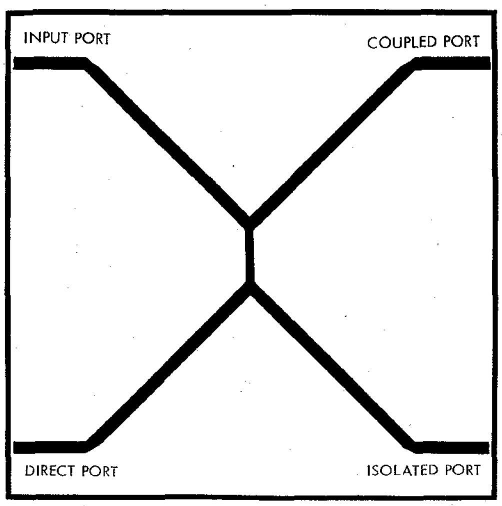

Fig. 1. Microstrip conductor side of substrate.

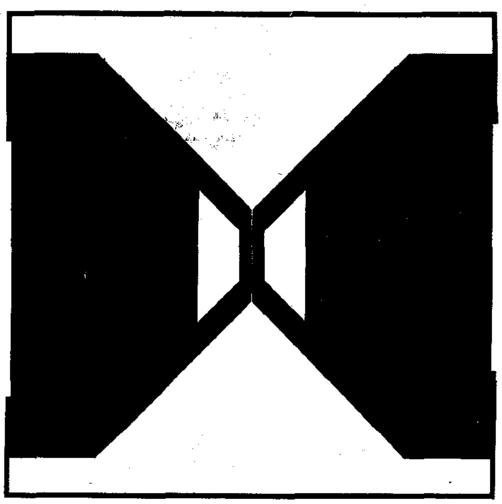

Fig. 2. Microstrip ground plane–slot-line side of substrate.

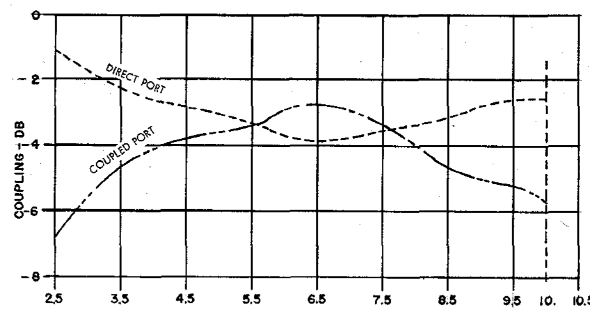

Fig. 3. Coupling

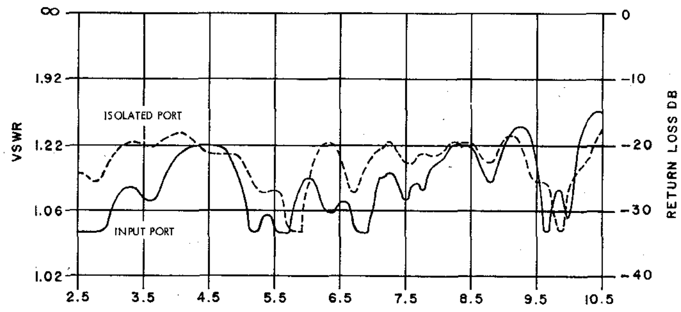

Fig. 4. VSWR.

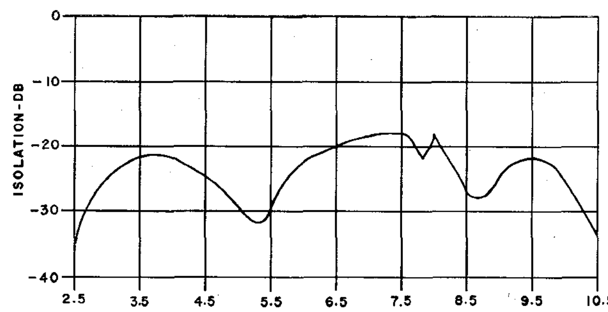

Fig. 5. Isolation.

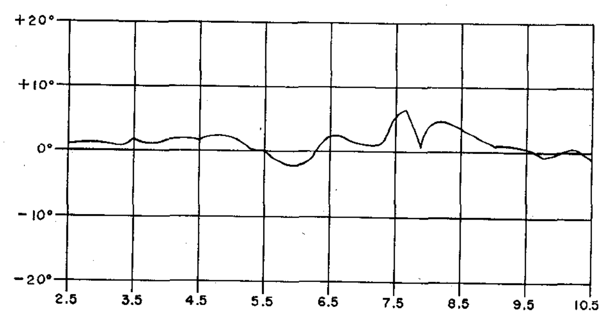

Fig. 6. Deviation from true quadrature (90°) coupling.

The coupler was developed as an effort to obtain a relatively smaller component for a multioctave (2.5– to 10-GHz) bandwidth mixer application and was based on the directional coupler described by deRonde [1] of The Netherlands. DeRonde's directional coupler uses microstrip and slot-line construction and covers a bandwidth of 4 to 1. The coupler described here is similar in construction using microstrip and slot-line sections but differs in that additional openings in the ground plane are used to tune the circuit, and an overlay capacitor is not required.

The hybrid was empirically developed and required several attempts before multioctave bandwidth performance was achieved. The hybrid is fabricated on a $1 \times 1 \times 0.025$ alumina substrate using thin-film techniques. The substrate has a purity of 99.6 percent and is coated with 200 Å of chromium and 300 μin of gold. The hybrid circuit is shown in Figs. 1 and 2 and consists of a 0.014-in wide and 0.112-in long conductor on the circuit side and 0.0008-in wide slot

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on the ground plane side directly opposite the conductor. The slot on the ground plane side is 0.21 in long and is directly underneath the conductor.

Several experiments were required with circuits having different combinations of conductor and slot length and width before the optimum dimensions were found. Figs. 3–6 show the coupling, VSWR, isolation, and phase difference between outputs that were achieved over the bandwidth with the resulting hybrid circuit.

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References

[1] F. C. deRonde, "A new class of microstrip directional coupler," in *1970 IEEE Int. Microwave Symp. Dig.*, May 1970, pp. 184–186.

An Integrated Microstrip Circulator

Abstract—**Ferrite circulators, incorporated as integral parts of a microstrip circuit on a copper-clad dielectric substrate, have been developed and tested. These circulators do not require the machining of a hole in the dielectric substrate or etching of the ferrite metalization. 20-dB isolation bandwidths of 3.5 to 4 percent in the frequency range 1.75 to 2.23 GHz were measured.**

Existing techniques [1]–[3] for incorporating circulators in microstrip circuits etched on nonferrite metallized dielectric substrates consist of either 1) attaching circulators fabricated as separate entities to the circuit, or 2) mounting ferrite disks through holes in the substrate, metallizing the ferrite surfaces and etching the circulator circuit in conjunction with others in the system. Techniques [4] for incorporating circulators on ferrite substrates consist of etching the microstrip circuits directly on the metallized surface of the ferrite substrate. This correspondence describes a modified version of the technique described in [1] in which a circulator is attached to the surface of a nonferrite substrate and capacitively coupled from the top of the circulator through the ferrite to the microstrip circuits. In the modified version, however, the ferrite, in the form of a slab or disk, is mounted below the circuit ground plane and capacitively coupled through the substrate to the microstrip circuits. With this configuration the actual shape of the slab has little effect on the performance of the circulator, and therefore accurate machining of the ferrite to obtain a circular or any other shape is not required.

Top and ground plane views of a test circulator that uses this technique are shown in Fig. 1. The circulator involves circuitry on both surfaces of the substrate with a biasing magnet attached to the top surface and a ferrite to the ground plane. The equivalent circuit is shown in Fig. 2. Three capacitive pads (C_p), interconnected by inductive sections of transmission line (L_p) etched into the circuit ground plane, form a resonant pi network in contact with the surface of the ferrite. The pads mate with similar pads on the top surface, thus providing capacitive coupling (C_s) through the substrate. Inductive sections of transmission line (L_s) are series resonant with the coupling capacitors at the required center frequency. Quarter-wave transformers (T) match the impedance of the circulator to 50 Ω. The exposed surfaces of the ferrite are coated with conductive paint to complete the circuit groundplane.

The inductance of the transmission lines L_p in the resonant pi network, and thus the resonant frequency of the network, can be controlled by varying the applied magnetic biasing field, since the permeability of the ferrite is a function of the field. The field also determines the gyromagnetic characteristics of the ferrite. Thus the center frequency, bandwidth, and isolation of the circulator are functions of the circuit geometry, type of ferrite, and magnetic biasing field.

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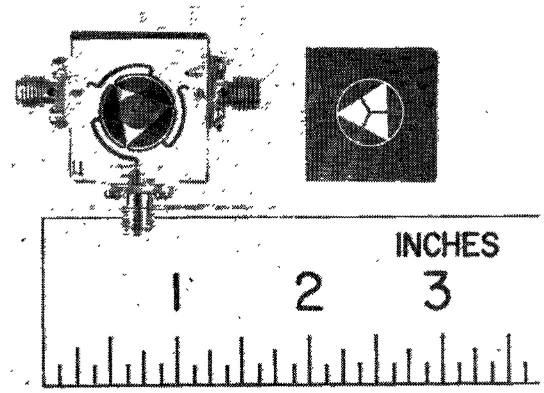

(a) (b)

Fig. 1. Test circulator. (a) Top view of test circulator mounted in test jig with 0.25-in magnet positioned over the circuit. (b) Bottom view of circuit board showing capacitive pads and inductive lines etched into the circuit ground plane.

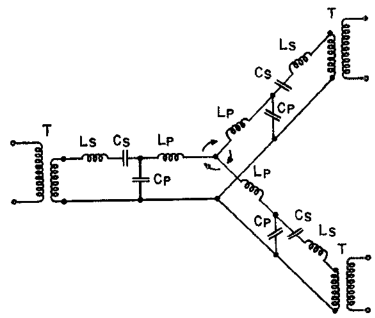

Fig. 2. Equivalent circuit.

TABLE I

Dielectric	
material	custom high-K 707-10
dielectric constant	10
thickness	0.02 in
copper thickness	0.00137 in both sides
Ferrite	
dielectric constant	14.2
saturation magnetization	400 G
thickness	0.1 in
diameter of disk	5/8 in
Magnet	
material	Alnico 8
magnetization	fully magnetized
dimensions	see text

Two circulators having slightly different geometries were tested in order to demonstrate the utility of the technique. Plots of the results obtained are given in Figs. 3 and 4. The characteristics of the substrate, ferrite, and magnet materials that were used in the tests are given in Table I.

The configuration of the circulators is shown in Fig. 1. The diameter of the circuit to the outer edges of the capacitive pads is 0.5 in. In circulator no. 1 the ferrite was bonded to the ground plane with an adhesive having a dielectric constant of 10. The adhesive filled the gap (0.009 in) between the pads and the circuit ground plane, thus increasing the capacity between the pads and the ground plane and lowering the resonant frequency of the pi network. Two magnet sizes were tested in order to determine the effect of magnet diameter on circulator performance. The first, with a 1-in diameter and 0.1-in thickness, produced circulation at 1.82 GHz (Fig. 3). The second, with a 0.25-in diameter and a 0.1-in thickness, produced circulation at 1.75 GHz. It is evident therefore that although circulator performance is not a sensitive function of magnet geometry, some control