STEPPED GROUND PLANE CIRCULATOR*

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ABSTRACT

A microstrip circulator employing a stepped ground plane is described. It has the advantages of giving good bandwidth, low forward loss, high peak power handling capability, and a reduction in size over conventional below-resonance devices.

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I. Introduction

Distributed element microstrip circulators operating below resonance are inconveniently large in the lower microwave frequency range (< 2GHz). This has prompted most designers to build either distributed element circulators operated above resonance or lumped element circulators. Both of these alternatives result in relatively narrow bandwidth and high forward loss As far as bandwidth is concerned, Bosma[1] has shown theoretically that the distributed element circulator is superior to the lumped element version. In addition, the above-resonance device requires high bias fields and therefore cannot be operated in the remanent state. This paper describes a microstrip circulator which combines the advantages of the conventional distributed element and lumped element devices to produce a large isolation bandwidth, low forward loss, and a reasonably small size. Preliminary data on similar structures indicates that this device has the added advantage of handling higher peak power than either of the above devices. The circulator consists of a disc resonator junction with the matching network being a step in the ground plane separated from the disc by a section of transmission line less than one-eighth of a wavelength long. Figure 1 shows a sketch of the device along with an approximate equivalent circuit. Although the work described here involves only microstrip devices, the technique applies equally well to stripline circulators.

II. Theory of Operation

The stripline circulator formulas of Fay and Comstock[2] as modified for microstrip by Massé[3] were found to predict the center frequency and input conductance of a microstrip circulator reasonably well. Matching the device to the external load impedance Z_o over a broad bandwidth can be accomplished by means of a shunt capacitor separated from the disc junction by a length ℓ of microstrip line. A capacitor in the form of an abrupt increase in the substrate thickness h near the circulator junction is most desirable because of: 1) increased power handling capability, since the threshold power level due to spin wave instability[4] is proportional to h^2; 2) lower insertion loss, since this quantity varies roughly as the inverse 1/h of substrate thickness[5,6]; and 3) broader bandwidth since the loaded Q of the disc junction is also inversely proportional to the thickness[2] and, therefore, the frequency variation of the circulator's intrinsic input impedance becomes less as h is increased. In practice, there is an additional small series inductor associated with bridging the air gap between the surrounding ceramic substrate and the thicker ferrite substrate. Therefore, the total equivalent circuit at the ground plane step is an "ell" network as shown in Figure 1. The microstrip line interconnecting the terminated "ell" network and the circulator junction must have a characteristic impedance Z_{line} that will cause the normalized impedances Z_{ell}/Z_{line} and Z_c/Z_{line} to lie on the same VSWR circle of the Smith Chart. Both line parameters, Z_{line} and ℓ, which are required for a conjugate match at the edge of the circulator disc can be obtained by standard transmission line theory.

The recommended design procedure is to select a ground plane step such that the surrounding substrate is compatible with the external circuit and the internal ferrite substrate will handle the desired amount of power. This establishes the "ell" network parameters of C and L. Since no theory is yet available for determining these parameters as a function of step size or air gap, the impedance Z_{ell} must be measured directly. After finding the required disc diameter and the input conductance from Massé's adaptation[3] of the Fay and Comstock formulas, the required interconnecting line parameters can be found as described above.

III. Experimental Results

Extensive experimental measurements were made on an L-band stepped ground plane circulator to demonstrate the above theory. The parameters of this device are given in Table 1. For the substrate thicknesses indicated in the Table, it was possible to closely match the center conductor-to-ground plane spacing of available connectors and this facilitated measurements of the intrinsic input impedance of the circulator disc and the impedance of the ground plane step with an HP automatic network analyzer. Precise values of phase change $\beta\ell$ along the thick microstrip line were determined by measuring the phase velocity on a separate test structure.

The performance of the circulator with the parameters listed in Table I is shown in Figure 2. Because radiation from a disc resonator increases rapidly with substrate thickness, it was necessary to enclose the device in a metal box. The cover, which constitutes an upper ground plane, must be located at least a distance h above the top surface of the ferrite substrate in order to avoid undue distortion of the microstrip fields. The 20 dB isolation bandwidth of 33% was only eight percent less than the theoretically predicted maximum bandwidth achievable with a quarter wave transformer.[2] An even larger bandwidth of 44% was obtained by slightly increasing the equivalent shunt capacitance to about 1.1pf with an open circuit microstrip stub located very close to the ground plane step.

IV. Conclusion

We have described a new way of matching a microstrip circulator which can just as well be applied to a stripline device. The results are broad bandwidth, low forward loss, higher peak power handling capability, and a reasonable size. Furthermore, the device can easily be mated to a thin substrate in a microwave integrated circuit package. Extensive impedance measurements verified the proposed equivalent circuit of the device. The design procedure would be greatly facilitated if analytical information were available on the admittance of the ground plane step and the resonance properties of the thick disc resonator.

References

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TABLE I

Physical Parameters	
Dielectric Constant	16
Ferrite Magnetization	400 gauss
+ d	0.040
+ h	0.187
+ D_c	1.125
+ D_{Fe}	1.600

\+ Dimensions in inches; see Figure 1.

Electrical Parameters	
Center Frequency (GHz)	1.89
Input Conductance (mhos)	0.040
H_{app} (gauss)	390
Z_{line} (ohms)	38
$\beta \ell$ (degrees)	36
Z_{ell} (ohms)	40-j 12.5
L (nh)	0.5
C (pf)	0.9
20 dB Isolation Bandwidth (%)	33

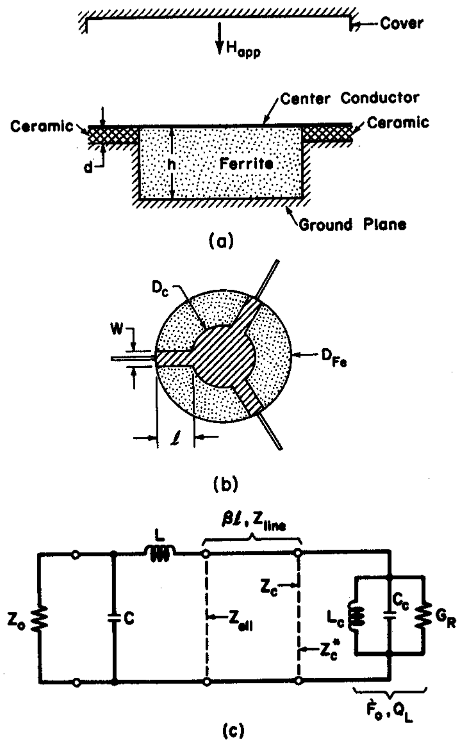

Figure 1. Circulator with Ground Plane Step
a. Cross Section
b. Top View
c. Equivalent Circuit at Input Port

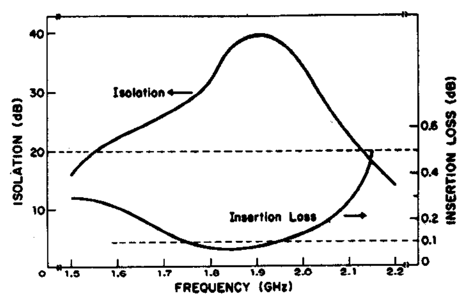

Figure 2. Performance Characteristics of L-Band Stepped Ground Plane Circulator