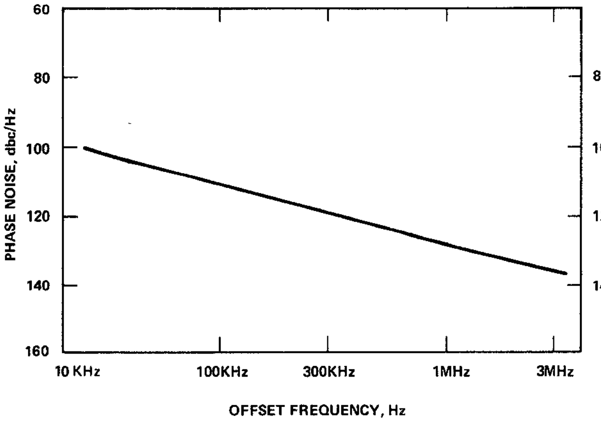

Fig. 9. FM noise versus offset frequency.

guide and the coaxial-to-waveguide transition tend to act as a band-pass filter, helping to reduce these out-of-band oscillations.

The VCO was also operated with a short in place of one of the varactors. The tuning bandwidth for this higher Q circuit was less than one-half of the two-varactor circuit due to the inherently narrow-band nature of the short behind the IMPATT diode.

The VCO noise performance ultimately determines the receiver front-end sensitivity and the amount of processing (and thus, hardware) required in the back end. The phase noise was measured in a test setup which uses klystrons as a reference and which has a sensitivity of at least 150 dBc/Hz. The noise performance is plotted in Fig. 9. This result is 8–10 dB better than previously reported for wide-band varactor-tuned VCO's, and would be considered more than adequate for most VCO applications.

IV. Conclusions

A varactor-tuned IMPATT-diode oscillator with 27-percent tuning bandwidth in X band has been achieved with inexpensive, commercially available IMPATT and varactor diodes. The equivalent-circuit model of the VCO predicts for higher power IMPATT's (i.e., larger negative conductances) and higher Q varactors, total tuning ranges in excess of 40 percent in X band. These tuning ranges have been obtained with reasonable tuning linearity and without significant sacrifice in power output or efficiency. Also the noise performance of the oscillator has not been degraded.

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X-Band Microstrip-Inserted Puck Circulator Using Arc-Plasma-Sprayed Ferrite

Y. S. WU, MEMBER, IEEE,
F. J. ROSENBAUM, SENIOR MEMBER, IEEE, AND
D. H. HARRIS, MEMBER, IEEE

***Abstract*—Experimental circulators using ferrite pucks which have been sprayed into cavities in dielectric substrates by an arc-plasma-spray (APS) process are described.**

Microwave-quality ferrite materials can be quickly and efficiently deposited using the arc-plasma-spray (APS) process [1],[2]. This short paper reports on the performance of two X-band microstrip circulators fabricated with Trans-Tech TT1-105 ferrite deposited in a circular hole of diameter 0.195 in, in a 0.035-in-thick dielectric substrate whose relative dielectric constant is $\epsilon_d = 13$. The blind holes were ultrasonically cut in the substrate to a depth of 0.025 in or less. After deposition, the samples were lapped such that the final substrate thickness was 0.025 in, and the ferrite thickness was 0.020 in. The substrate dimensions are 1 in $\times$ 0.5 in nominal. Table I compares the properties of sintered-bulk TT1-105 with those of APS TT1-105. A photograph of a representative circulator and a sample substrate is shown in Fig. 1.

TABLE I
Comparison of Bulk Properties of TT1-105 with Those of APS TT1-105

Property	Bulk*	APS**
Saturation Magnetization $4\pi M_s$	1750	1750
Coercivity, H_c (Oe)	1.16	1.1
Remanence Ratio, M_r/M_s	70%	80%
Gyromagnetic Resonance Measurements at 9.4 GHz		
Average 3 dB linewidth, ΔH (Oe)	225	112
Average g-effective	1.98	---
Permittivity Measurements at 9.4 GHz		
Average Dielectric Constant, ε'	12.2	12.2
Average Loss Tangent, $\tan\delta$	<.00025	<.0002
Density > 99% of Theoretical		

* Trans. Tech. Catalog.
** Measured.

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Y. S. Wu was with the Department of Electrical Engineering, Washington University, St. Louis, Mo. 63130. He is now with the Central Research Laboratory, Texas Instruments Incorporated, Dallas, Tex. 75222.
F. J. Rosenbaum is with the Department of Electrical Engineering, Washington University, St. Louis, Mo. 63130.
D. H. Harris is with Monsanto Research Corporation, Dayton, Ohio 45407.

Two different conductor patterns were used. Fig. 2 shows a typical [3], [4] quarter-wave transformer-matched 3-port Y-junction circulator. Connections are made through 50-Ω microstrip transmission lines and SMA connectors. In the actual device, the 50-Ω lines connected to ports 2 and 3 had 30° bends and were about $\frac{1}{2}$ in longer than line 1. Fig. 3(a) is the isolation of the circulator measured sequentially between each set of ports. Isolation in excess of 10 dB is obtained over the frequency range 8–12 GHz. The 15-dB-isolation bandwidth is about 2 GHz. The unsymmetrical isolation observed stems from mismatches in the output line impedance (50 Ω *nominal*) and lengths, the connectors, and inhomogeneities in the permanent magnets used to bias the ferrite junctions.

Two magnets were used, one on top of the junction, the other below the metallized group plane. Their diameters are 0.200 in and their heights are 0.375 in.

The insertion loss is shown in Fig. 3(b). For the two symmetrical transmission paths the losses are approximately 0.8 dB and track to within 0.2 dB. Transmission through the long path shows about 0.2-dB excess loss at midband and much more loss at the band edges.

A second design using short linear tapered transformers is shown in Fig. 4. Here again unsymmetrical isolation performance is noted in Fig. 5(a). The transformer characteristics are quite different than those of the previous case, giving rise to more nearly flat isolation (≈ 14 dB) over the band for two of the ports, and a larger isolation (> 20 dB) for the third. The staggered effect is indicative of asymmetries in the fabrication of the device. The insertion-loss characteristics are shown in Fig. 5(b). Once again, a nominal 0.8-dB loss is indicated over most of the band, except for the long transmission path between ports 2 and 3.

The APS circulator results can be contrasted with those for solid substrate and mechanically bonded inserted puck-type circulators. Hartwig *et al.* [5] show an optimized solid-substrate design using TT1-105 which yielded a 25-dB-isolation bandwidth of 59

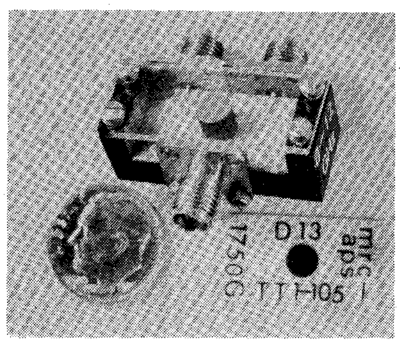

Fig. 1. X-band circulator and APS-deposited ferrite-dielectric substrate.

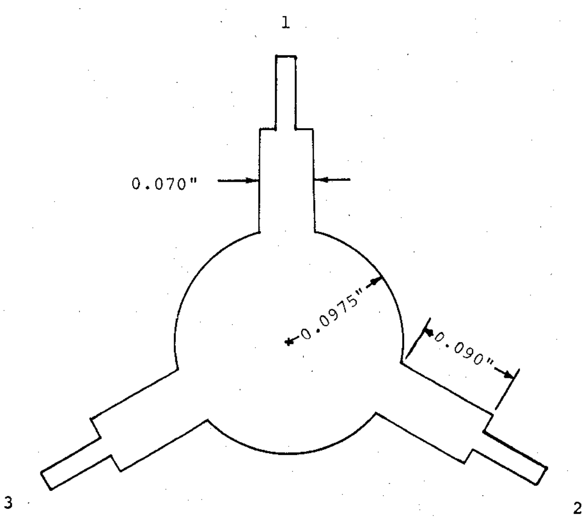

Fig. 2. Conductor pattern for APS microstrip circulator 1, quarter-wave transformer coupled.

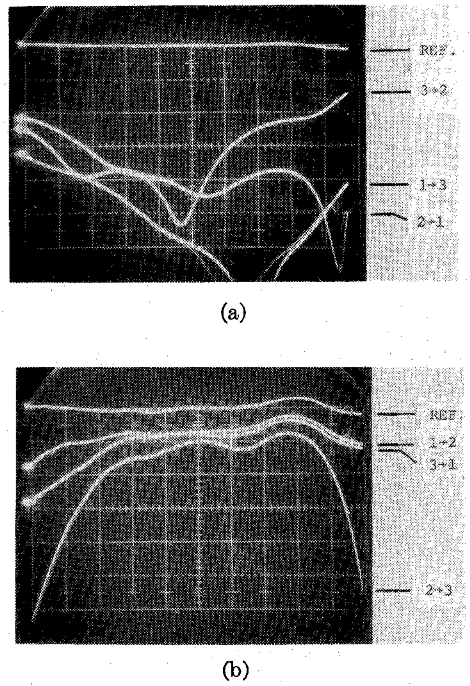

Fig. 3. Experimental performance of APS circulator 1. Horizontal scale: 8–12.4 GHz. (a) Isolation: 5 dB/div. (b) Insertion loss: 1 dB/div.

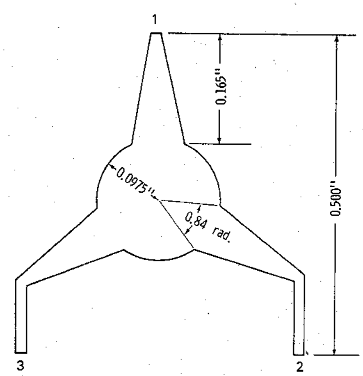

Fig. 4. Conductor pattern for APS microstrip circulator 2, linear tapered transformer coupled.

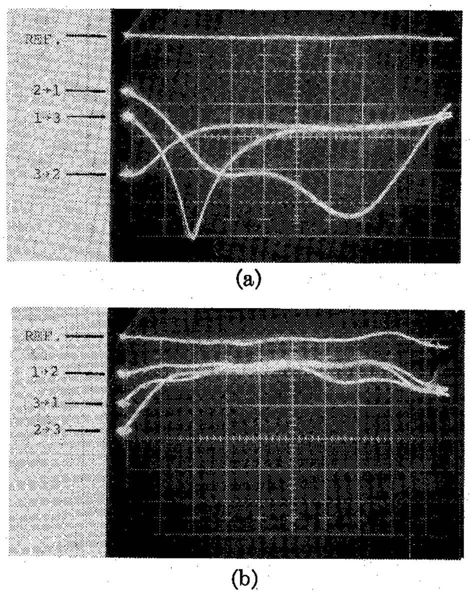

Fig. 5. Experimental performance of APS circulator 2. Horizontal scale: 8–12.4 GHz. (a) Isolation: 5 dB/div. (b) Insertion loss: 1 dB/div.

percent at X band with insertion loss less than 0.5 dB over 79 percent of that bandwidth. Massé [6] described a TT1-390 mechanically inserted puck-type X-band device which gave a 32.5 percent 20-dB bandwidth with insertion loss less than 0.5 dB over the band.

A portion of the excess insertion loss of these APS circulators is due to the length of the microstrip lines required in the packaging. However, some of the loss is likely due to a slight erosion noted at the ferrite–dielectric peripheral interface after lapping. This is caused by the thermal-expansion mismatch between the D-13 dielectric and the ferrite which results in the ferrite shrinking away from the peripheral wall, or the creation of tensile stress in the two materials at the interface. Subsequent lapping removes the stressed material in this region at a faster rate than the rest of the surface, resulting in a slight trenching effect. This caused the final chrome–gold metallization to be degraded slightly in quality in the trenched region. This effect was most pronounced in TT1-105 compared to other material systems examined and may be allieviated through appropriate selection of ferrite and substrate materials.

It is felt that the preliminary results reported here demonstrate that APS material is well suited for inserted puck-type circulators, and that with optimized layout and fabrication procedures, the performance of APS circulators can be at least as good as solid-substrate circulator designs. One advantage of the puck-type circulator is that the transformers are fabricated on a dielectric substrate rather than on ferrite and so can be accurately designed. The fringing fields from the bias magnets will have no effect on the transformer behavior in this case.

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A Millimeter-Wave Reflection-Beam Isolator

M. KANDA AND W. G. MAY, MEMBER, IEEE

***Abstract*—A new and simple type of millimeter-wave isolator using a solid-state magnetoplasma in a reflection-beam system is described. Some data are presented showing performance at 94 GHz. Practical considerations indicate that performance should be much closer to ideal at higher frequencies.**

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M. Kanda was with the Department of Electrical Engineering, University of Colorado, Boulder, Colo. 80302. He is now with the Noise and Interference Section, Electromagnetics Division, National Bureau of Standards, Boulder, Colo. 80302.

W. G. May is with the Department of Electrical Engineering, University of Colorado, Boulder, Colo. 80302.

I. INTRODUCTION

We present here a solid-state magnetoplasma isolator with simple configuration for use in a millimeter-wave reflection-beam system. The geometry of this nonreciprocal mirror is that of the Kerr transverse magnetooptic effect, wherein electromagnetic (EM) waves propagate perpendicular to a dc magnetic field and are reflected from the surface of the plasma, the wave polarized in the plane of incidence. Large nonreciprocal behavior with this geometry was explained for EM waves reflected from the ionosphere by Barber and Crombie [1].

The same configuration with the gaseous plasma replaced by a semiconductor, GaAs, has been studied in both theory and experiment for a wide range of material parameters. But the large nonreciprocity observed for the ionosphere was not found, due to the relatively large background dielectric constant K_L of the semiconductor lattice. In this short paper we extend the calculations of Wait [2] and Seaman [3] to include not only the permittivity of the semiconductor lattice, but also a dielectric half-space in which the incident and reflected waves travel. The inclusion of such a dielectric markedly improves the degree of nonreciprocity and efficiency of the device as an isolator. We also show experimental behavior of a small isolator at 94 GHZ and room temperature. This short paper presents results more complete and more nearly ideal than the preliminary report of [4].

II. THEORY

A convenient means for dealing with EM waves in a solid-state magnetoplasma is to characterize the medium as a complex dielectric tensor which we calculated for the simplest case with isotropic electron effective mass m^* and isotropic energy-independent collision time τ. Anisotropy of the conductivity arises from the presence of an applied dc magnetic field B_0 which causes the charged particles to orbit at the cyclotron frequency ω_c.

The reflection coefficient R_M for a plane boundary between a semi-infinite dielectric medium and a semi-infinite plasma can be shown to be [4]

$$R_M = \frac{\cos\Theta - \Delta_M}{\cos\Theta + \Delta_M} \tag{1}$$

where Δ_M is a function of the angle of incidence Θ (shown in Fig. 1), the semiconductor parameters m^*, τ, ω_c, and the dielectric constant K_M of the semi-infinite dielectric medium. When collisions are present (τ is finite, neither zero nor infinite), the reflection coefficient R_M

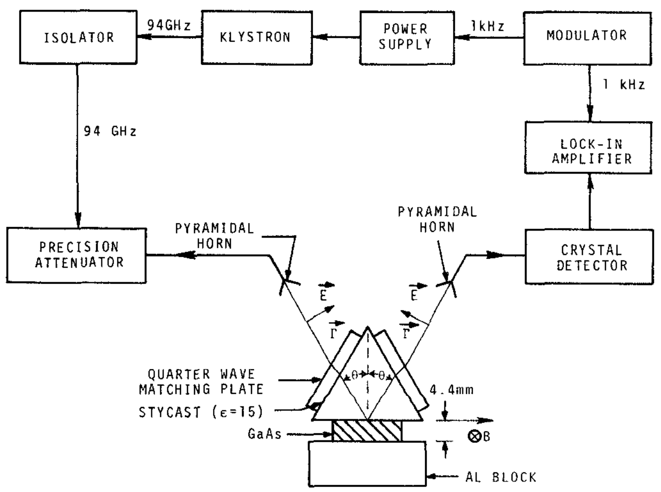

Fig. 1. Experimental setup used to measure reflection from GaAs at 94 GHz.