to quantitative terms. Table I shows a remarkable agreement between the true quarter wavelength in each ridge-guide section and the sum of the length of that section and half the height of the previous step.

TABLE I

Section No.	1	2	3
λ_c	5.15 cm	7.9	12.6
$\lambda/4$ at 9 kMc	1.091 cm	0.915	0.863
Actual length +half step height	1.092 cm	0.938	0.863

The agreement seems too good to be fortuitous and it would be interesting to find out for what range of ridge width and height it holds.

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Pulse-Operated Circulator Switch*

One of the major disadvantages of employing a ferrite circulator as a microwave switch is the holding current required to maintain the circulator in the switched position. One solution to this problem, reported by Levey and Silber,[1] is the utilization of ferrite tubes as the differential phase shift element in a circulator. Switching is accomplished with a single pulse of current which reverses the magnetization in the closed ferrite tubes, and by virtue of the closed magnetic path, remains permanently magnetized in this new state. Using this technique, microsecond switching speeds have been obtained. This approach requires a ferrite that has both the requisite microwave and dc magnetic characteristics which all too often are unattainable in a commercially available material and necessitates the development of a special material.

For many applications in which microsecond switching speeds are of no consequence, but it is mandatory that the holding current be eliminated, another approach may be followed; the best microwave material for the frequency and application of interest is used in the microwave circuit and a switchable magnetic material, external to the microwave circuit, is used to supply the bias field requirements. This arrangement provides greater flexibility in the realization of pulse actuated ferrite switches. The coercive force of the switchable magnetic material must be such that the remanent magnetization may be reversed with a current pulse of reasonable magnitude and yet retain the proper amount of magnetization at the conclusion of the current pulse. The coercive force required depends on the magnetic circuit, a greater coercive force being required when air gaps are introduced.

Using this technique, a stripline symmetrical junction circulator was converted to a pulse-operated switch. The low bias field requirement of 200 gauss[2] was obtained from a commercial steel (SAE 4130) whose composition is similar to that of a chromium permanent magnet steel. This material was used as the core of an electromagnet consisting of 30 turns of wire, located in each ground plane over the ferrite loaded junction; a soft iron, U-shaped bracket completed the magnetic circuit. Fig. 1 is a photograph of the switch.

Fig. 2 is a photograph of an oscilloscope trace showing the pulse actuated switching action. The top trace shows the train of dc current pulses of opposite polarity that causes reversal of the magnetic bias; the bottom trace is the rectified output of one port showing the switching action. The output drops from 0.5-db insertion loss to 20 db down at an operating frequency of 2050 Mc. In this configuration, 5-ampere current pulses are required to reverse the magnetization and place the "open circuit" magnetic field at 200 gauss. Pulse widths of 140 msec were used because they were readily available in the laboratory, but since the switching time is approximately 5 msec, pulse widths of 10 msec should suffice to produce the switching action for this unit.

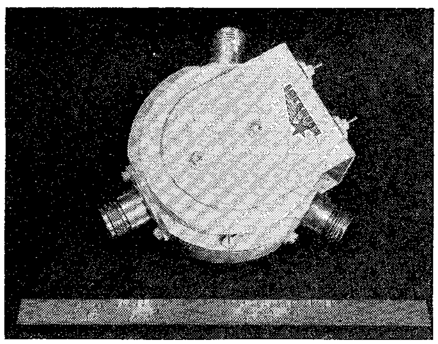

Fig. 1—Model of pulse-actuated ferrite switch.

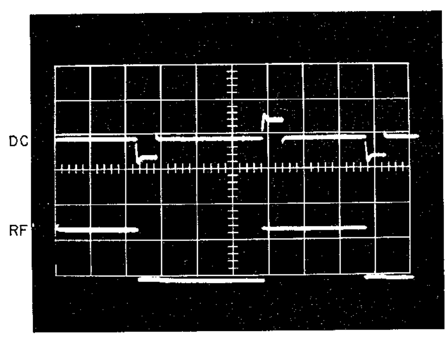

Fig. 2—Oscillograph showing pulse-actuated switching action, 200 msec/cm.

Faster switching times could be obtained by reducing the number of turns in the electromagnet. Fig. 3 shows the characteristics of the circulator-switch biased only by the remanent magnetization of the steel; after 24 hours at room temperature in this state, no changes in these characteristics were noted.

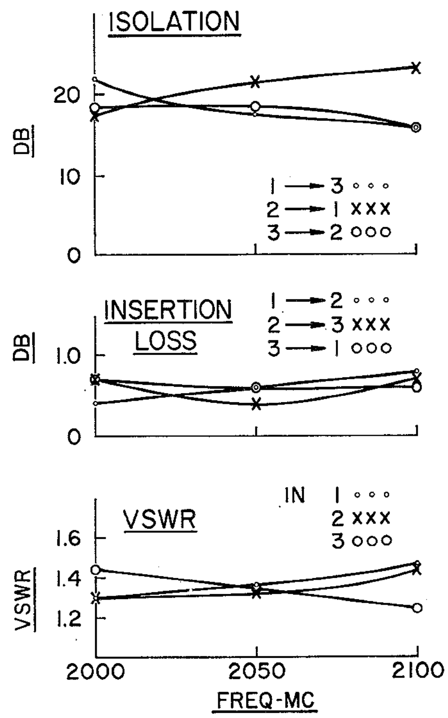

Fig. 3—Characteristics of ferrite circulator-switch.

The author wishes to acknowledge the valuable assistance of J. R. Poulson in taking the photographs and making the laboratory measurements.

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* Received by the PGMTT, February 21, 1961.

[1] L. Levey and L. M. Silber, "A fast-switching X-band circulator utilizing ferrite toroids," 1960 IRE WESCON Convention Record, pt. 1, pp. 11–20.

[2] L. Freiberg, "Lightweight Y-junction strip-line circulator," IRE Trans. on Microwave Theory and Techniques, vol. MTT-8, (Correspondence), p. 672; November, 1960.

Polishing Technique for Garnet Spheres*

A new technique using a motor-driven polishing head intended primarily for the final stages of polishing yttrium-iron-garnet spheres has been developed. This method has produced several fractional oersted linewidth crystals including a matched pair of 0.060-inch diameter spheres ground simultaneously.

The polishing device shown in Fig. 1 uses a 200-rpm motor with a $\frac{5}{8}$-inch-diameter

* Received by the PGMTT, March 1, 1961.

circular pad of metallurgical polishing cloth attached to the end of the shaft. The shallow mortar dish, also lined with metallurgical polishing cloth, contains the sphere. The polishing cloths are impregnated with the appropriate polishing compound. The rotating pad is simply lowered into the dish far enough to make contact with the sphere. A horseshoe-type magnet placed directly under the bowl pulls the steel shaft (which has a short axial travel) firmly against the garnet sphere. It is thought the inhomogeneity of the magnets field causes the sphere to constantly change direction searching for an easy crystal axis of alignment. This action, together with the circular motion of the shaft, produces an unstable orbit and a uniform surface finish. With the arrangement properly adjusted, the sphere leaves a track near the outside edge of the pad.

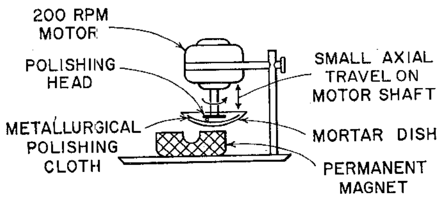

Fig. 1

Samples to be polished should be good spheres with a surface finish comparable to that obtained with no. 0 emery polishing paper. The first stage uses 25-micron diamond paste followed by an 8-micron grit. Time required in each stage depends primarily on the pressure applied to the sphere. If pressure is too great, the sphere does not rotate properly and flat spots occasionally develop. The final polishing procedure is done using $\frac{1}{4}$-micron diamond paste. Microscopic examination is desirable to check on cutting progress in all stages. Generally speaking, 4 to 6 hours in each stage produces a high surface polish.

The unloaded Q's of the finished spheres were measured at a frequency of 4 kMc using the impedance method described by Ginzton.[1] The spheres were mounted loosely in a thin sheet of polyfoam causing the spheres to be aligned along an easy axis of magnetization when placed in the dc magnetic field. The sphere is placed one-half guide wavelength away from the end of a short-circuited section of G-band waveguide. The results of the measurements on the garnet spheres were as follows:

TABLE I

Summary of Measurements of Q_u at 4000 Mc

Sphere Diameter-Inches	Unloaded Q, Q_u at 4000 Mc	Linewidth, $\Delta H = \frac{4000}{Q_u \times 2.8}$ -Oersteds
0.056	2700	0.53
0.060	2670	0.54
0.060	2850	0.50
0.095	2760	0.52

[1] E. L. Ginzton, "Microwave Measurements," McGraw-Hill Book Co., Inc., New York, N. Y., ch. 9, pp. 405–417; 1957.

This method of polishing the garnet spheres using a motor driven polishing head has the advantage, over the commonly employed tumbling technique,[2] that no spheres are now damaged due to chipping, which occurred when the spheres bounced off the wall of the tumbling dish.

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[2] W. L. Bond, "Making small spheres," *Rev. Sci. Instr.*, vol. 22, p. 344; May, 1951.

Miniaturized, Temperature Stable, Coaxial Y-Junction Circulators*

Introduction

The problem of designing a circulator that is extremely small, durable, and lightweight immediately suggests the Y- or T-junction approach. For use with coaxial connectors, the strip transmission line Y-junction suggested by Auld[1] and subsequently demonstrated by Milano, Davis and Saunders,[2] has obvious advantages. A systematic approach to developing such a device calls for the symmetrical alteration of at least two physical characteristics of the junction.[1] The obvious choice for one of these characteristics is the magnitude of the biasing magnetic field. The choice for the complementary characteristics can include any symmetrical change in the geometry of the junction (the adjustable ground plane of Fig. 1 is an example) and the symmetrical placing of isotropic and anisotropic material in the junction. The choice of this complementary characteristic most frequently mentioned in the literature is the diameter of the ferrite post. An alteration of the ferrite post height will also provide adjustment. The use of a metal pin along the axis of symmetry has also been suggested for this purpose.[3] Thaxter and Heller have also reported on the use of a copper sleeve around the ferrite post for operation at 70 and 140 kMc.[4]

The method to be described here involves the magnitude of the biasing field and the use of a dielectric-loading technique that is well suited to the design of very small and rugged devices.

In addition, the problem of temperature stability, high-power behavior, and the crucial role of low field losses in these devices will be treated. In C band, in particular, the use of high-gadolinium content YIG will be shown to offer an attractive solution to temperature problems and high-power problems associated with temperature changes.

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[1] B. A. Auld, "The synthesis of symmetrical waveguide circulators," IRE Trans. on Microwave Theory and Technique, vol. MTT-7, pp. 238–246; April, 1959.

[2] L. Davis, Jr., V. Milano, and J. Saunders, "A strip-line L-band compact circulator," Proc. IRE (Correspondence), vol. 48, pp. 115–116; January, 1960.

[3] C. Montgomery, R. H. Dicke, and E. M. Purcell, "Principles of Microwave Circuits," McGraw-Hill Book Co., Inc., New York, N. Y., ch. 12; 1948.

[4] J. B. Thaxter and G. S. Heller, "Circulators at 70 and 140 kmc," Proc. IRE (Correspondence), vol. 48, p. 110; January, 1960.

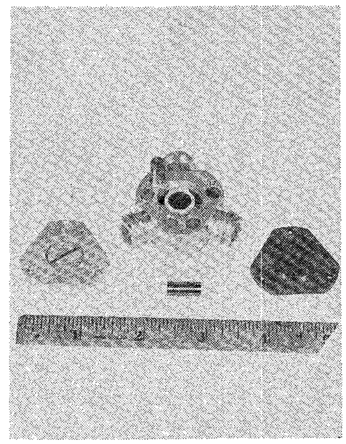

Fig. 1—The C-band circulator.

The C-Band Circulator

Physical Description

The structure of the C-band circulator is shown in Fig. 1. The housing is made of a nonmagnetic material, and the cover plates, which complete the magnetic path through the solid state material, are made of magnetic steel. Exclusive of connectors the device is 1.5 inches in diameter and 0.75 inches in height. The weight is approximately 3.75 ounces. This structure has a slight sensitivity to the proximity of magnetic material. This effect has been shown to be negligible except at the center of band frequencies where isolation between arms may exceed 35 db.

An alternate design can be used to overcome even this slight sensitivity. The exterior of this alternate design is composed entirely of magnetic steel. When fully temperature compensated, this shielded circulator constitutes an exceptionally durable and dependable solid-state device.

Electrical Characteristics

The characteristics of the C-band circulator adjusted for use in the 5.4- to 5.9-kMc range are shown in Fig. 2. These results are typical; slight asymmetries in the structure will generally cause variation in the characteristics from arm to arm. The synthesis procedure provides for design at a single frequency only; the bandwidth is consequently a characteristic of each individul circulator that must be adjusted experimentally.

The Design Technique

The synthesis procedure calls for the alteration of two physical characteristics in order to make the junction a circulator at a