the octave range $60° < \theta < 120°$ are shown in Table I.

TABLE I

	Theoretical	Experimental
Isolation	>22 db	>18 db
Input Match	<1.5:1	<1.4:1

The performance figures observed from the four possible input terminals are similar over this frequency range.

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[2] Mullard Ltd., S. J. Robinson, and N. E. Goddard, British Patent Application no. 770317.
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Lightweight Y-Junction Strip-Line Circulator*

In a recent issue, the practical realization of a Y-junction strip-line circulator was described[1] which used disks of yttrium iron garnet located at the junction of the Y, magnetically biased above resonance at approximately 2200 gauss. By using a material with a lower saturation magnetization (magnesium, manganese, aluminum ferrite, $4\pi M_s = 600$) we have reduced the bias field required to approximately 190 gauss for frequencies in the 2-kMc range and to approximately 800° gauss for frequencies in the 1-kMc range, thus reducing considerably the weight of the circulator. If the circulator is to be operated as a switch, the reduced field requirements permit faster switching times or, for a given switching time, a considerable reduction in power supply requirements.

Fig. 1 shows the results of a circulator operating at a fixed magnetic bias of 190 gauss. Although no attempt was made to determine the optimum ferrite diameter for this frequency range, it is felt that the performance of the circulator would be improved if a more optimum diameter were used.

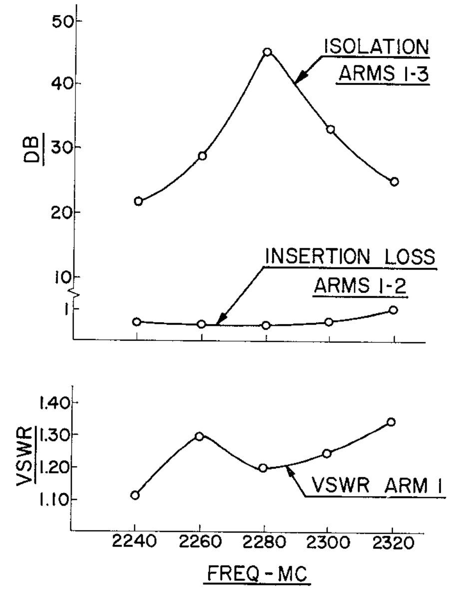

Fig. 1—Circulator characteristics with fixed dc magnetic bias; $H_{DC} = 190$ gauss.

Below 1400 Mc, the performance of the circulator was degraded at these low biasing fields, but by reversing the polarity of the magnetic field and biasing above resonance, good circulator action could again be obtained. Reversing the biasing field and biasing above resonance does not change the direction of circulation, as may be seen by referring to the equation below given by Auld[2] for the change in the ath eigenvalue (δs_a) of the scattering matrix of the symmetrical Y-junction due to the application of the magnetic biasing field. The magnetic biasing field splits the reciprocity degeneracy of the eigenvalues to give circulator action:

$$\delta s_a = -j \frac{b}{2\omega\mu_u^2} \sum_{p=-\infty}^{\infty} A_{-p}^{(-a)} A_p^{(a)} \cdot \left\{ (\mu - \mu_u) \int_0^R f_{-p}^{(-a)} \cdot f_p^{(a)} r dr + j\kappa \int_0^R k \cdot f_{-p}^{(-a)} \times f_p^{(a)} r dr \right\} a \neq 0$$

where μ and κ are the components of the peameability tensor and the other symbols are as defined by Auld.[2]

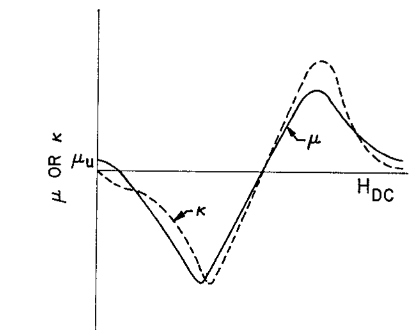

Fig. 2—Typical variations of real components of tensor permeability as a function of dc magnetic field.

A typical variation of μ and κ as a function of magnetic field is shown in Fig. 2. The magnetic biasing field is adjusted to make $\mu - \mu_u = 0$ either above or below resonance. Since κ reverses sign above resonance, there is a reversal in the direction of circulation, but by reversing the biasing field, the direction of circulation remains the same. Fig. 3 shows the characteristics of a circulator biased above resonance but still only requiring a magnetic field of 820 gauss. Here again it is felt that the performance would be improved if ferrites of optimum diameter were used. Thus by using a material with a lower saturation magnetization than yttrium iron garnet, bias field requirements are reduced with a consequent reduction in weight of the circulator.

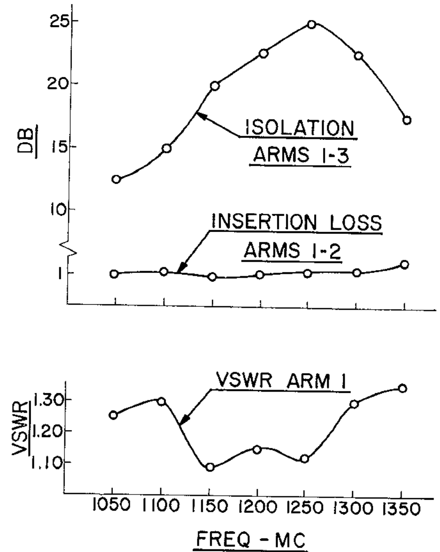

Fig. 3—Circulator characteristics with fixed dc magnetic bias; $H_{DC} = 820$ gauss.

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* Received by the PGMTT, August 15, 1960.
[1] U. Milano, J. H. Saunders, and L. Davis, Jr., "A Y-junction strip-line circulator," IRE Trans. on Microwave Theory and Techniques, vol. MTT-8, pp. 346–351; May, 1960.

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

A Novel Broad-Band Balun*

Broad-band baluns have recently become the subject of renewed interest, particularly those suitable to couple spiral or planar log periodic antennas to the commonly used coaxial lines.[1–3]

To make such a balun capable of operating over the frequency band of 1000–4000 Mc and to take advantage of the strip transmission line techniques, the broad-band

* Received by the PGMTT, September 6, 1960.
[1] R. Bawer and J. J. Wolfe, "A printed circuit balun for use with spiral antennas," IRE Trans. on Microwave Theory and Techniques, vol. MTT-8, pp. 319–325; May, 1960.

[2] E. M. T. Jones and J. K. Shimizu, "A wide-band stripline balun," IRE Trans. on Microwave Theory and Techniques, vol. MMT-7, pp. 128–134; January, 1959.

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phase difference circuit of Schiffman[4] was utilized. In this balun the 50-ohm coaxial input is transformed to strip transmission line at 50 ohms, which then splits into two 100-ohm lines in parallel. By an application of two 90° phase difference circuits (Schiffman Type A), two outputs with approximately 180° phase difference over a broad frequency band are obtained. These are connected to opposite sides of a 200-ohm twin wire balanced transmission line. Since the two 100-ohm striplines are thus effectively placed in series, a match is obtained at the junction.

The center conductor of the strip transmission line is laid out as shown in Fig. 1. The ratio Z_{oe} to Z_{oo} for the coupled sections is taken as 3 with a Z_o of 100 ohms. This gives $Z_{oe}=173\ \Omega$ and $Z_{oo}=57.7\ \Omega$. The lengths of the coupled sections and the difference in path length are made such as to give a center frequency of 2750 Mc. The photograph of Fig. 2 shows the balun assembled.

Measurements of the characteristics of the junction were made by the method described by Wentworth and Barthel.[5] The VSWR of the junction as determined by this method is shown in Fig. 3. This indicates a reasonably matched structure from 750 to 4750 Mc, a range of greater than 6 to 1.

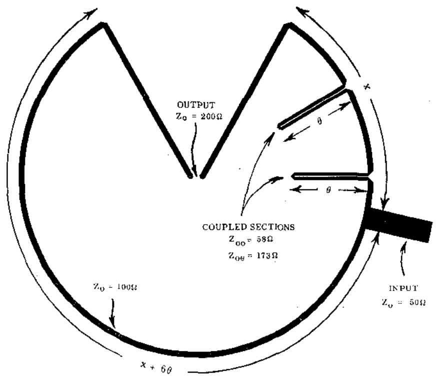

Fig. 1—Center conductor configuration of differential phase-shift balun.

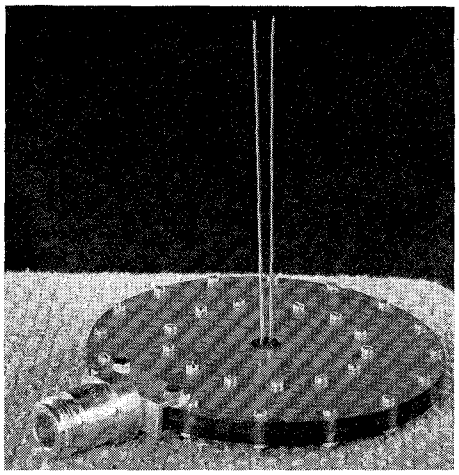

Fig. 2.

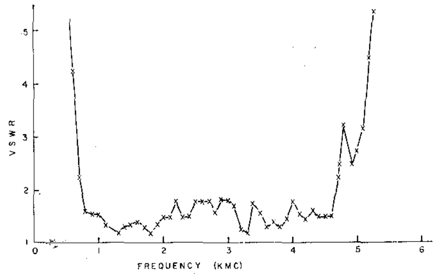

Fig. 3—Differential phase-shift balun VSWR vs frequency.

Simple tests also indicate that radiation from the balanced line only becomes apparent at the extremes of this range.

This particular configuration for a balun arose from a requirement for the balun to be mounted on the rear of the flat reflector of a broad-band antenna with a minimum rearward projection while still allowing relatively easy changes of reflector spacing.

Although this model of the balun was designed for a balanced output of 200 ohms, other output impedances could be obtained by suitable tapers either within the balun structure or on the unbalanced input line. Somewhat larger bandwidths or lower VSWR's could be obtained by taking advantage of the more complex combination of coupled sections as indicated by Schiffman. This balun uses only the simplest configuration.

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[4] B. M. Schiffman, "A new class of broad-band microwave 90° phase shifters," IRE Trans. on Microwave Theory and Techniques, vol. MTT-6, pp. 232–237; April, 1958.

[5] F. L. Wentworth and D. R. Barthel, "A simplified calibration of two-port transmission line devices," IRE Trans. on Microwave Theory and Techniques, vol. MTT-4, pp. 173–175; July, 1956.