Symmetry in a High Power Circulator for 35 GHz

A ferrite loaded junction circulates at many values of frequency and applied magnetic field, sometimes giving circulation over a useful bandwidth. In the empirical design of a circulator, the various combinations of field and frequency must be found and modified to give circulation at the required frequency. An *E*-plane junction[1,2] with a ferrite disk on each narrow wall was selected for high power operation. (Figure 1 shows the final circulator with a permanent magnet.) The best conditions for circulation were found, but results from the three-ports differed substantially with the circulation bands for the three-ports in some cases not overlapping. This asymmetry was independent of mechanical tolerances in waveguide manufacture and cleanliness of ferrite. It was presumably due to differential scatter caused by inhomogeneity of the ferrite material of the linear effects of surface grinding. As it was easier to investigate surface finish effects, three forms of improved finish were devised and tested.

In the first experiment ferrite disks were polished with 6_μ grit and showed no improvement over normal samples. It was later concluded that this grit was too fine to have appreciable effect. The next disks were lapped with 26_μ grit. The resulting circulator had a bandwidth for 20 dB isolation of 3.2 GHz and an asymmetry spread between ports of 0.1 GHz (see Table I). The third pair of experimental disks were finished by grinding, at a constant level setting, in three directions 120° apart. The symmetrical bandwidth is 3.1 GHz (32.7–35.8 GHz), and one-port gave 3.6 GHz (32.3–35.9 GHz); the difference of 0.4 GHz at the low-frequency end is a measure of the asymmetry.

Of these three methods, the latter two gave improved symmetry. The last process was the best mechanically and was selected for further work. Some more samples were made from the next batch of ferrite materials, but, on inspection, the surfaces appeared coarsely ground and the effects of grinding in three directions were not visible. The results are given in Table I (line 4). The circulator bandwidth is reduced because of a change in the ferrite batch, but the symmetry is reasonable. The next samples were made by reducing the disk height in 0.0001 inch steps and then grinding in three directions 120° apart. Two pairs of disks were also made by this method for an application at 33 GHz.

The results showed improved symmetry, but the grinding method was tedious and attempts were made to simplify it. To verify the need for small cuts during the grinding operation, this procedure was omitted. The final cut was 0.0005 inch and then the disks were ground in the usual three directions. In the next sample, the disk height was finally reduced by five cuts of 0.0001 inch and the grinding in three directions was omitted. In the last experiment all attempts at a good surface finish were omitted and the grinding finished with a cut of 0.0005 inch.

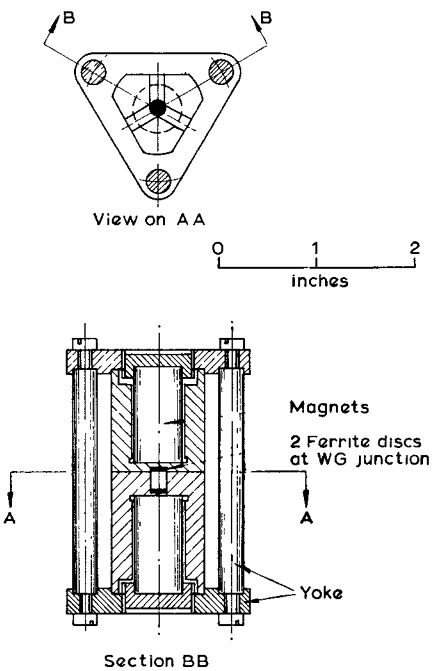

Fig. 1. Circulator with permanent magnet.

TABLE I

	20 dB Band-width GHz	Asym-metry GHz
26^μ grit	3.2	0.1
*	3.1	0.4
(Rotate disk	2.6	0.8)
New samples* seemed coarse 1)	1.7	0.2
2)	1.8	0.3
New sample fine cut*	1.5	0.3
fine cut* 33 GHz 1)	1.6	0.2
2)	1.4	0.1
New sample coarse cut*	0.8	0.6
New sample fine cut 1)	1.4	0.1
2)	1.5	0.1
New sample coarse cut	0.8	0.6

* Ground in three directions, 120° apart.

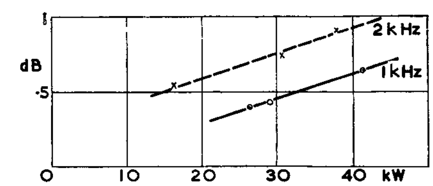

Fig. 2. Insertion loss against peak power for pulse repitition rate, 1 kHz and 2 kHz.

The above experiments demonstrated the effect of ferrite surface finish on circulation. As the asymmetry could be reduced to a negligible value, the possible material inhomogeneity was considered unimportant.

The size of the ferrite disks was optimized for circulation at the required frequency and gave 20-dB isolation over a 1.5-GHz band. The effect of a reduction in waveguide width and also the addition of dielectric loading were investigated but gave no improvement in bandwidth. The simple circulator of Fig. 1 was therefore selected.

To improve the high power operation of the circulator, the ferrite disks were reduced in diameter and surrounded by polytetrafluoroethylene rings 0.005 inch thick. This modification prevented breakdown at powers up to the maximum available (41 kW peak). The insertion loss of the circulator was measured at several power levels up to 40 kW peak (8 or 16 watts mean) using a pulse length 0.2 μs, and repetition rate 1 or 2 kHz. The results are presented in Fig. 2. There was no measurable change in isolation. The circulator was also assessed for another application and operated satisfactorily at 2.5 watts mean, 25 kW peak between −10 and +40°C.

A. P. Darwent
Mullard Research Labs.
Redhill, Surrey
England

Manuscript received May 23, 1966; revised August 8, 1966.

[1] S. Yoshida, "An *E*-type *T* circulator," *Proc. IRE (Correspondence)*, vol. 47, p. 2018, November 1959.

[2] L. E. Davies and S. R. Longley, "*E*-plane 3-port *X*-band waveguide circulators," *IEEE Trans. on Microwave Theory and Techniques*, vol. MTT-11, pp. 443–445, September 1963.

The Directional Coupler—1966

I Introduction

The directional coupler is a well-known device used as an attenuator, power splitter, hybrid junction, local oscillator injection device, and, most commonly, a sampling device for measuring separately the forward and backward waves on a transmission line. Over a period of twenty-five years many papers have appeared dealing with analysis, design, and application of the device.

In 1954, R. F. Schwartz prepared a bibliography of 91 papers which had appeared up to that time relating to the directional coupler field and, in 1955, Schwartz and Medhurst prepared a supplement of 41 additional papers. The present correspondence focuses attention on those problems which were treated up to 1954–55, highlights the significant advances to date, and points out some of the fruitful areas for further work.

While a considerable number of bibliographical entries are presented here, it is almost impossible to be exhaustive. Some restricted circulation reports and theses have been noted, for they help to indicate certain areas of interest as well as organizations and people involved. It is recognized, however, that there are probably many more entries that could be added.

II. Pre-1955 Directional Couplers

The directional coupler became a common transmission line and microwave device during World War II. It was early appreciated that two distinct mechanisms could be exploited: 1) the constructive and destructive interference of waves coupled by two superimposed, but different type, couplings as in the Bethe-hole and loop-type directional couplers, and 2) the constructive and destructive interference produced by waves arriving

Manuscript received May 23, 1966; revised September 12, 1966.