X-6. THE FOUR-PORT SINGLE JUNCTION CIRCULATOR IN STRIP LINE

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The four-port single junction circulator in strip line offers the possibility of a more compact and less expensive structure than the heretofore required dual three-port units in tandem. One such four-port circulator has been described previously,[1] although very little material has appeared in the literature on the theory of the device. Auld[2] points out that an additional parameter is required for the four-port circulator compared to the three-port. Davies and Cohen[3] have extended Bosma's[4,5] circulation equations to the four-port case and have included the scattering matrix analysis. Fay and Comstock[6] have indicated a possible combination of modes of a disc structure which could provide a four-port circulator.

This paper will deal with a phenomenological description of a four-port circulator similar to that done for the three-port device in Ref. 6, give some experimental results on a four-port circulator at L-band, and discuss some design considerations.

It was shown[6] that with a disc center structure, a combination of an $n = 0$ mode and an $n = 1$ mode rotated 45° would provide the necessary conditions for a four-port circulator, where n refers to the circumferential periodicity of the mode. A circulator has been made using these modes, but the extreme capacitive center-loading of the disc necessary to tune the $n = 0$ mode to the operating frequency was a major difficulty and the circulator was not very useful. The $n = 2$ mode is closest to the $n = 1$ in frequency in a disc structure. If these two modes could be brought to the same frequency and the standing wave patterns shown in Figure 1 superimposed with equal amplitudes of the E-fields at the input port, a circulator would result. The fields of the two modes would be active at ports 1 and 2 and would cancel at the other two ports. The phenomenon of the rotation of the standing wave pattern for the $n = 1$ mode was described in Ref. 6.

Some modifications of the structure have been found to bring the two modes to nearly the same frequency and apparently to inhibit the splitting of the $n = 2$ mode while permitting the $n = 1$ mode to split and rotate its standing wave pattern. A mode chart of an L-band circulator employing these principles is shown in Figure 2. This circulator was very lightly coupled to the connecting strip lines by means of high impedance quarter-wave sections in order that the mode resonances would be sharp and easy to follow. The minimum frequency points of the modes represent saturation of the ferrite which is a desirable operating point. Here it is seen that the $n = 1$ mode splits and the $n = 2$ mode comes between the $n = 1$ components.

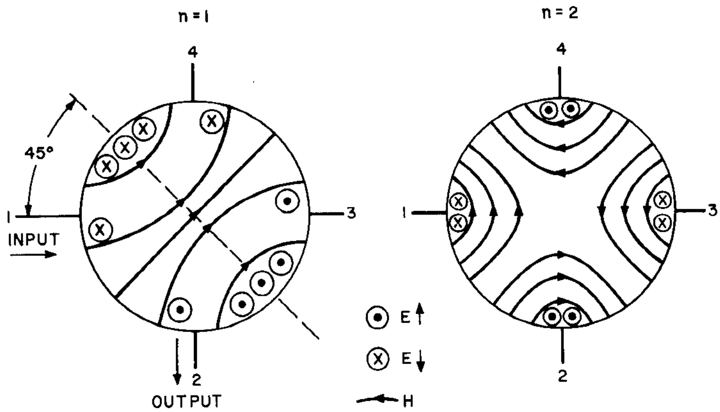

Figure 1. n = 1 and n = 2 Modes of a Disc Structure Aligned for a Circulator

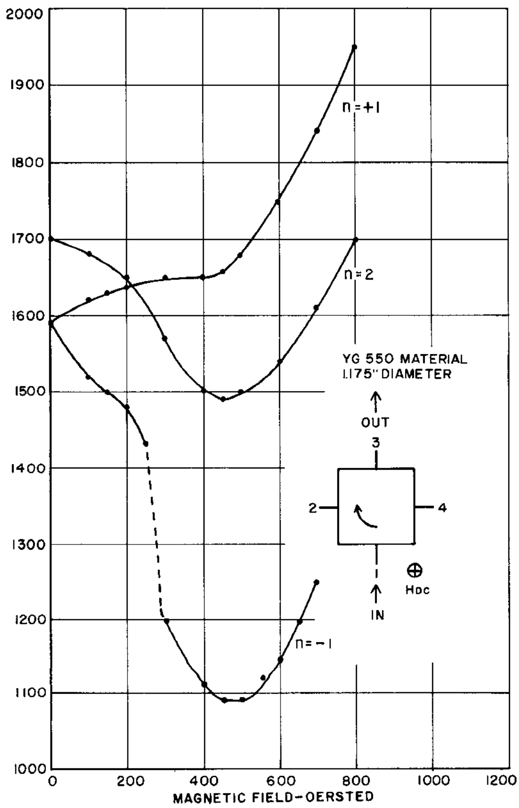

Figure 2. Mode Chart of a Four-Port Strip Line Circulator

An experimental circulator having an approximately 20% bandwidth gave the performance shown in Figure 3. This circulator had the resonator matched to the 50-ohm strip lines by means of $\lambda / 4$ strip line transformers. The performance of these four-port single-junction circulators seems to be comparable to three-port circulators except that the isolation between ports 1 and 4 is relatively low. When high isolation at port 3 is obtained, the isolation at port 4 is typically 15 - 20 dB. This isolation is dependent to some extent on the match at port 3, but seems principally to be a leakage of power directly from port 1. Isolation of 15 dB at port 4 accounts for 0.14 dB of the insertion loss from port 1 to port 2.

Since 45° rotation of the $n = 1$ mode standing wave pattern is required for the four-port circulator compared to 30° for the three-port circulator,[6] a larger value of the ratio of the Polder tensor components, κ/μ, of the ferrite permeability is required. From Ref. 6 we find that for 45° rotation of the $n = 1$ mode standing wave pattern, $\kappa/\mu \approx 1.23/Q_L$ where Q_L is the loaded Q of the disc resonator. Q_L is determined by the bandwidth and permissible VSWR, S. The rotation is[7]

$$Q_L \approx \frac{1.4\,(S-1)^{\frac{1}{2}}}{BW}$$

where BW is the fractional bandwidth. Knowing κ/μ we can determine the saturation value of the ferrite, p, from Figure 4. Also in Figure 4 we can see that large values of κ/μ are best obtained near $\sigma = 0$, implying below-resonance operation with the ferrite just saturated. For above-resonance operation, ($\sigma > 1$) it is impossible to obtain large values of κ/μ except very near resonance ($\sigma = 1$) and hence with considerable loss. Therefore wideband operation of four-port single junction circulators is confined to the below-resonance region for practical reasons.

References.

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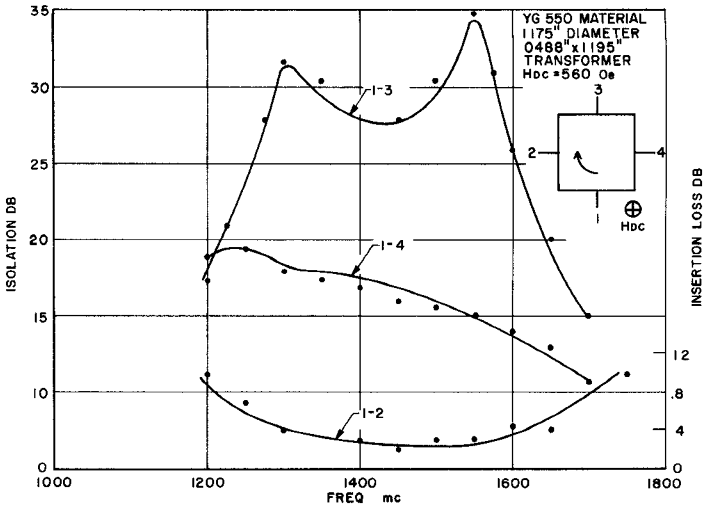

Figure 3. Performance of a Four-Port L-Band Strip Line Circulator

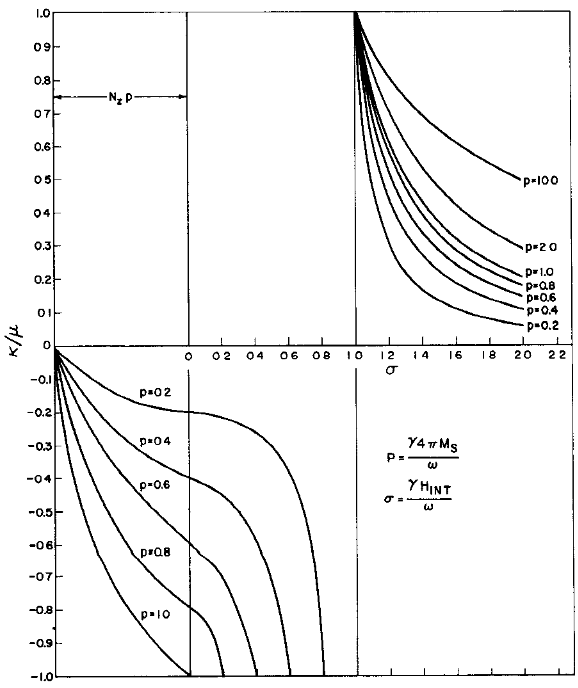

Figure 4. κ/μ vs. σ for a Thin Ferrite Disc