# 4-PORT CROSSED-JUNCTION WAVEGUIDE CIRCULATORS

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Circulator action can be obtained with a symmetrical 4-port H-plane waveguide junction containing a central composite post of ferrite and a conducting material, e.g. brass, and this paper gives some details of the experimental investigation which has led to completed devices in three frequency ranges, 3 Gc/s, 9 Gc/s and 20 Gc/s.

In a 4-port device three variables are required. In our experiments we have chosen to vary one dimension of the ferrite, one dimension of the brass, and the applied magnetic field; and the greater part of the work has been on the so-called "half-height" cylindrical configuration (Fig.1). When the static magnetic field is applied perpendicular to the broad faces of the waveguide, the junction becomes asymmetrical and circulator action occurs. Several modes of circulation, numbered 1 - 8, are possible in a waveguide pass-band, as shown in Fig.1. Circulation in one direction is given an even number, and in the opposite direction an odd number. It can be seen that with a constant value of applied magnetic field ($\pm H_1$) circulation can be obtained in opposite directions at two different frequencies ($f_1$, $f_2$). This is not the diplexing action which can result from a circulator being below resonance at one frequency and above resonance at the other. With this structure, opposite directions of circulation at two frequencies can occur with the magnetic field not only below resonance but also below saturation. It is also clear from Fig.1 that two values of applied magnetic field ($H_1$ and $H_2$) can give circulation in the same direction. The best performance is usually obtained in the modes 1 and 1a, and the fixed-field performance is about 3%. The performance of a device centred on 3 Gc/s in waveguide RG-48U is shown in Fig.2. Another interesting feature of the mode chart is the demonstration of higher-order modes of circulation as shown by the repetition of modes 1 - 4 at the higher frequencies. If the diameter of the ferrite or the conducting post is changed, the operating frequency of the circulator is altered. Decreasing the diameter, increases the frequency; increasing the diameter, decreases the frequency. Thus, the mode chart may be shifted along the frequency axis. When operating in mode 1 the approximate frequency shift per 0.001" change in diameter at 3, 9 and 20 Gc/s is respectively, -2, -20, -160 Mc/s, for the ferrite, and -0.5, -5 and -30 Mc/s for the brass. Using this technique to obtain the desired centre frequency in mode 1 or 1a, 4-port circulators have been completed at frequencies from 2.6 Gc/s to 22 Gc/s.

A circulator centred near 9.0 Gc/s, complete with ceramic magnets, has operated at temperatures up to 100$^{\circ}$C without a significant deterioration in performance. Also, at room temperature, the configuration does not break down at a peak power level of 45 kW with a reduced air pressure equivalent to 20,000ft. or with 20 kW at 40,000ft. A similar device using polycrystalline yttrium iron garnet can successfully be operated in liquid nitrogen. The insertion loss at 77$^{\circ}$K is not significantly different from that at 293$^{\circ}$K, provided that the magnetic field is readjusted. The magnitude of the insertion loss depends upon the mode of operation. Modes 1 and 2 appear to be promising as losses of less than 0.4 dB have been achieved, i.e. a noise contribution of less than 10$^{\circ}$K.

A broadband 4-port junction circulator is possible only if a central configuration can be found which gives a broadband isolation characteristic.

The "full-height" cylindrical geometry shown in Fig.3 gives bandwidths of 4 - 10%, and also has the advantage that it is amenable to theoretical solution. The mode pattern, and its shift along the frequency axis as the ferrite diameter is changed, is also shown in Fig.3. As the ferrite is made larger, modes 5 and 3 shift to lower frequencies and mode 1 moves to the centre of the pass-band. Circulation can then be found in this mode from 8 - 11 Gc/s. As the ferrite diameter is increased, the operating frequency is lowered by 20 Mc/s per 0.001" change in diameter. But, as the brass diameter is increased the operating frequency increases. The effect of surrounding the central post with a full-height dielectric annular ring is shown in Fig.4. It can be seen that increasing the dielectric constant from 1 to 4 has three effects: the operating frequency is lowered, the bandwidth is decreased, and the insertion loss is increased. With a configuration without dielectric, a bandwidth of 9% has been achieved with the following performance: isolation $> 20$ dB, insertion loss $< 1.0$ dB, VSWR $< 1.2$, but the maximum bandwidths obtainable by this method are not yet known.

To conclude, the modes of circulation with two configurations in 4-port waveguide junction circulators have been carefully defined. It has been stressed that the operation of these devices can only be optimised if this is done. For some applications, which will depend upon the bandwidth required, a 4-port circulator offers a more compact solution to problems where two 3-port devices would otherwise be required.

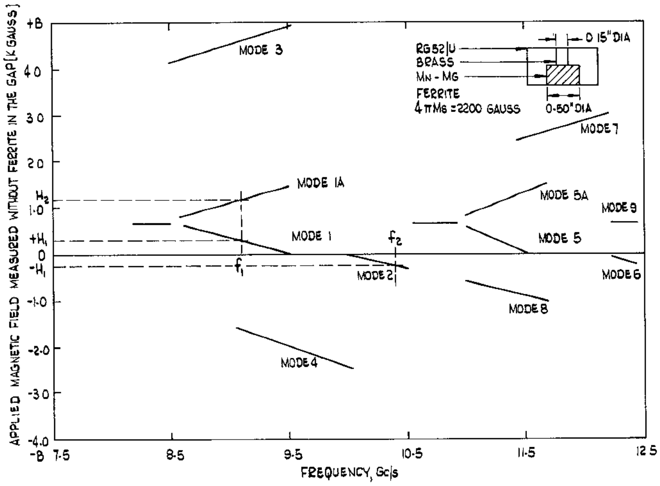


FIG 1 A SIMPLIFIED MAGNETIC FIELD/FREQUENCY CHARACTERISTIC, SHOWING MODES 1 TO 8

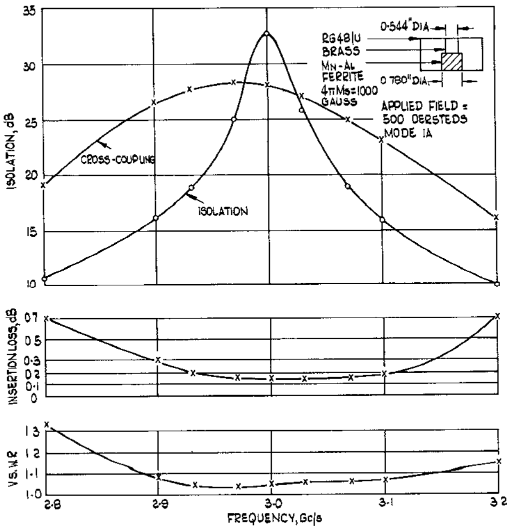


FIG 2 PERFORMANCE OF 4-PORT CIRCULATOR CENTRED ON 3Gc/s

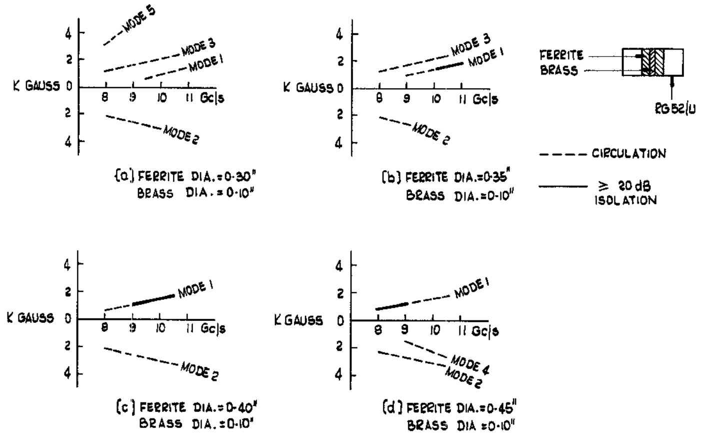


FIG. 3 SIMPLIFIED MAGNETIC FIELD/FREQUENCY CHARACTERISTICS

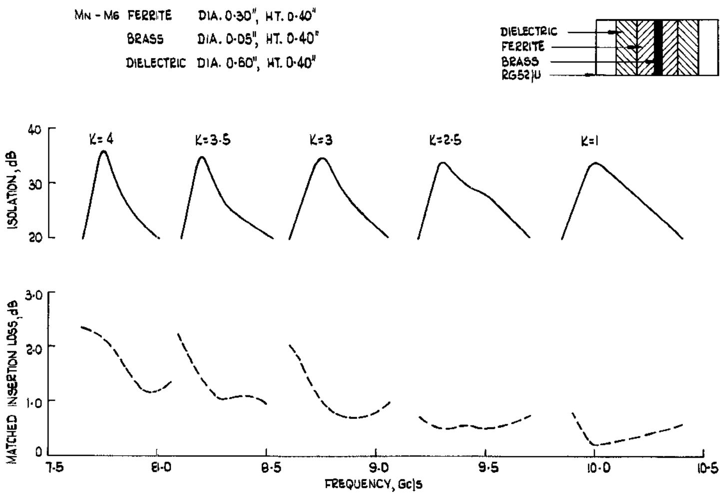


FIG 4 EFFECT OF VARYING THE DIELECTRIC CONSTANT K

# NOTES