III-5 BROADBAND LATCHING WAVE-GUIDE CIRCULATOR

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There exist two basic approaches for the construction of a latching junction circulator in rectangular waveguide. The first of these utilizes a ferrite element having a closed magnetic path contained entirely within itself (that is, the entire ferrite toroid is contained within the region of microwave interaction). Structures of this type have been used previously[1] to produce circulation over a bandwidth of approximately 15%. Devices of this type may be called internal return path circulators.

The second approach requires that the magnetic return path be outside the microwave structure and shielded from the RF energy. Devices of this type are called external return path circulators.

The internal return path configuration has several advantages over the external return path circulator, such as faster switching speed, lower switching energy, and less complicated fabrication. This type of circulator, however, has been difficult to broadband for two reasons. First, the return paths do not seem to act as part of the ferrite junction, but (having a relative dielectric constant between 12 and 16) present difficult matching problems. In addition, this extra "dielectric" material lowers the frequency at which higher order modes may exist within the junction. The external return path structure does not, of course, have either of these limitations and appears to be the best choice for a large bandwidth device.

Although the use of the external return path approach allows far greater freedom in the selection of a junction configuration than does the internal return path technique, some basic limitations must be placed on the shape of the microwave ferrite element. Most important, the ferrite element must extend fully from the top to the bottom broad wall of the waveguide junction, since any sizable gap in the magnetic path would cause intolerable reduction in the remanent magnetization. In addition, it is desirable that the ferrite element have a constant cross-sectional area in order to maintain uniform magnetization.

The major difficulty in building a waveguide circulator of this type stems from the fact that most of the conventional waveguide designs do not use ferrite elements which extend fully from the top to the bottom wall. One such structure which shows great promise has been found, however, and is shown in Figure 1. Fixed circulators using this construction have been operated over 30 to 35% bandwidths with good performance characteristics in X-band. A design of this type was originally predicted in a theoretical analysis by Parsonson and Longley[2]; their work consisting of solving on a high-speed computer the special case of the central conducting post, concentric ferrite rod, and external dielectric sleeve. Predictions were arrived at which ultimately led to a working, non-latching waveguide circulator.

In inital development work described in the present paper, the same configuration was used and was found to provide reasonably good operation over a bandwidth of about 20% when a Trans-Tech 1-390 ferrite element was employed. More recently, because of the difficulty of obtaining materials with other than integral values of relative permittivity, the modified junction configuration shown in Figure 1(b) was adopted. In this geometry, varying the thickness, t, of the teflon ring produces an effect similar to that which is obtained by varying the dielectric constant of the dielectric ring in Figure 1(b). Experimental measurements confirm that both of the structures have essentially the same properties, if a proper value of t is chosen.

Using this basic configuration in conjunction with external reactive matching elements to optimize the operating performance, broadband performance of a fixed (non-latching) device was achieved with an external applied field of approximately 350 oersteds. This junction configuration was then constructed as a latching device using the structure shown in Figures 2 and 3. Figure 2, a cut-away sketch of the latching circulator housing, illustrates the technique by which an essentially closed magnetic path is provided for the dc magnetization, while confining the RF energy to the microwave ferrite element. It is necessary that there by a conducting surface between the microwave ferrite element and the external return path in order to confine the microwave fields to the waveguide. Since the dc magnetic field passes through this conducting surface, eddy currents will be induced as the flux is reversed. Fortunately, however, the thickness of this conducting surface can be chosen to give satisfactory shielding and low insertion loss at microwave frequencies and at the same time allow the reversal of dc magnetization with little deterioration of the switching energy and switching time. This follows from the fact that the skin depth of the conducting material is inversely proportional to the square root of the frequency; thus it is possible to make the waveguide wall thick in terms of skin depths at 10 GHz and thin in terms of skin depths at the highest frequency at which the magnetization will be reversed. The wall will then appear to be infinitely thick to the microwave energy, but will suppress and quickly damp out eddy currents, assuring fast switching. It has been found experimentally that a 0.0003 inch thick sheet of metallic conductor allows the device to be switched rapidly (2 to 4 microseconds) with no noticeable effect upon the microwave performance. Another important feature of the latching circulator housing is that the housing itself does not form a closed conducting path through the composite toroid, since the resulting shorted turn would tremendously increase the switching time and energy.

The dimensions of the ferrite return path were chosen to produce the same magnetization which had been found to be optimum when the junction was tested in a non-latching configuration. To some extent, this can be done theoretically by considering the length, cross-sectional area, and magnetic properties of both the ferrite element and the return path, as well as the air gaps in the composite toroid. Once the proper return path cross-sectional dimensions were utilized, the operating characteristics were very similar to those obtained for the non-latching case, indicating that the return path does in fact provide the proper magnetization. The performance characteristics of this device in a latched condition are shown in Figure 4.

Figure 5 shows oscilloscope traces of the trigger pulse to the electronic driver and the detected RF output when the device is switched between states. Switching is accomplished in less than 4 microseconds. To obtain this trace, a 28-volt pulse was applied to the magnetizing windings, resulting in a total dc energy loss of approximately 500 microjoules (including losses in the electronic driver circuit). By using higher drive voltages and expending more switching energy, switching times as low as 2 microseconds have been obtained.

In conclusion, a new waveguide latching circulator has been described in which the ferrite return path is closed outside the waveguide, allowing the achievement of very broad operating bandwidths; the geometry is probably more suitable for higher operating power levels than is the case for internal return path circulators.

Acknowledgments

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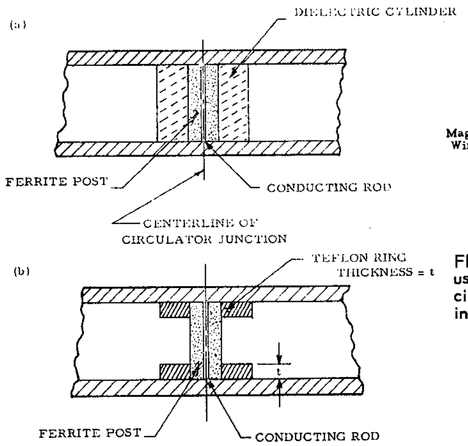

FIG. 1 - Basic Junction Configuration Investigated for the Construction of an External Return Path Latching Circulator
(a) Theoretically Predicted Structure
(b) Modified Structure

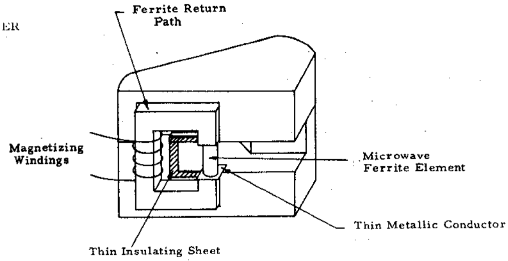

FIG. 2 - Sketch of the housing and the return path configuration used in the construction of an experimental X-band latching circulator (Part of the housing has been removed to show the internal details)

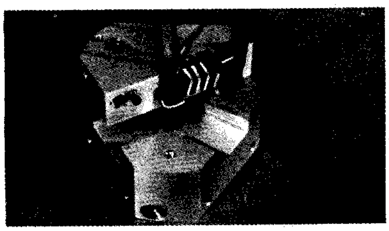

FIG. 3 - Photograph of the housing and return path configuration used in the construction of an experimental X-band latching circulator (Part of the housing has been removed to show the internal details)

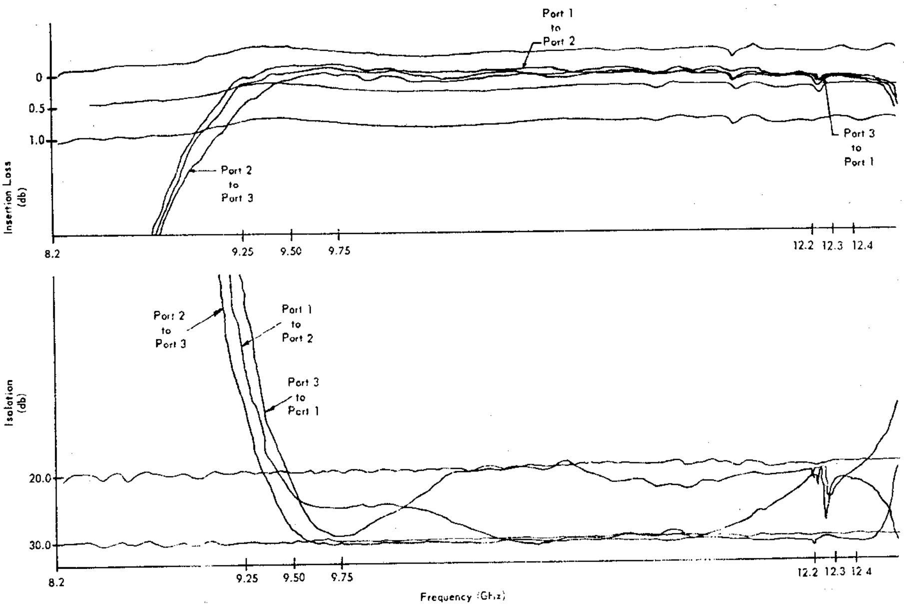

FIG. 4 - Performance characteristics of the X-band, External Return Path, Latching Circulator

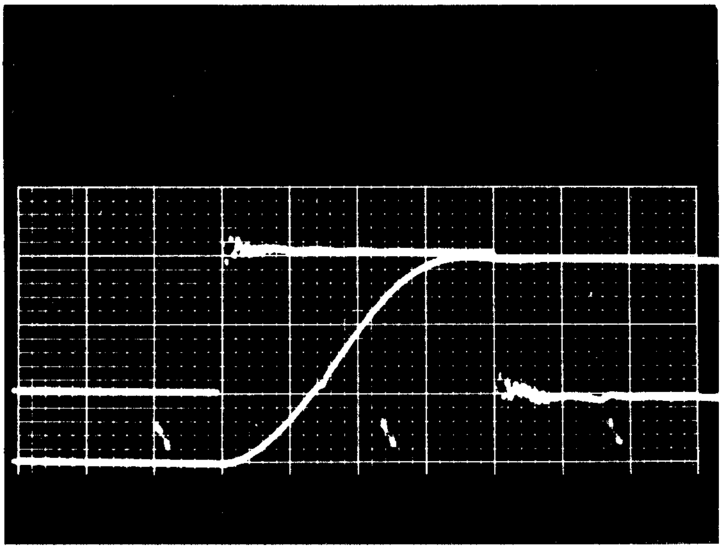

FIG. 5 - Oscilloscope Trace of the Trigger Pulse (upper trace) and Detected RF Output (lower trace) for an X-band, External Return Path, Latching Circulator (Horizontal scale -- 1 usec/cm)