IV-5. A LATCHING FERRITE JUNCTION CIRCULATOR FOR PHASED ARRAY SWITCHING APPLICATIONS

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This paper describes an X-band latching three-port junction circulator with switching time less than one microsecond, wide bandwidth, and small size. It is particularly well suited for use as the switching element in differential time delay networks and other switching networks required in phased array antennas.

Previous switching circulators have been either too slow or too bulky to be suitable for many proposed r-f switching applications. Compact junction devices have been built in TEM structures with switching times in the 10 to 50 microsecond range; also latching differential phase shifters and hybrid junctions have been interconnected to form fast but bulky four-port circulator switches (References 1, 2, and 3).

High-speed switching and small size are combined in the latching junction circulator shown in Figure 1 by use of a novel configuration of the ferrimagnetic member and the bias coil. The ferrimagnetic member is designed to provide a closed magnetic path entirely within the material, and thus entirely within the waveguide walls. The remanent magnetization of the material provides the necessary magnetic bias in the ferrite. The sense of magnetization of the material and thus the sense of circulation in the device may be rapidly reversed by passing a current pulse through a bias wire properly located with the junction.

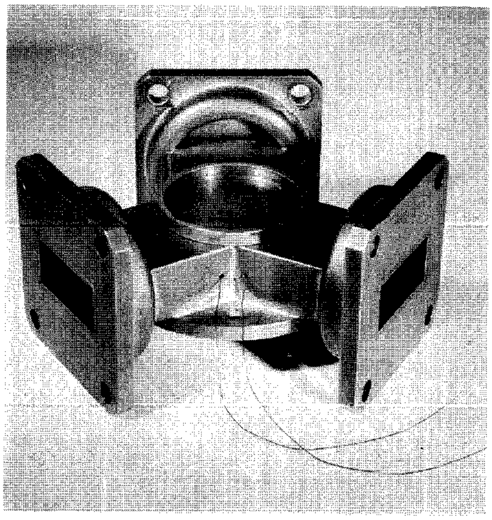


Figure 1. X-Band Latching Junction Circulator

Principles of Operation. Non-reciprocal action in the three-port junction is achieved by choosing a ferrite geometry which placed much of the ferrite material in regions of circular polarization of the r-f magnetic fields. The geometry must be such that a large component of the remanent magnetization in the ferrite is perpendicular to the plane of this circularly polarized r-f field. Electrical symmetry of the junction is insured by complete geometrical symmetry (three-fold rotational symmetry) of the ferrite member and the bias wire. Any dielectric introduced for tuning purposes must also be symmetrically arranged.

After achieving a symmetrical non-reciprocal junction, it is further necessary to match the junction to obtain circulator performance. It has been shown by Auld (Reference 4) that a symmetrical, non-reciprocal, lossless three-port junction can be matched at a specified frequency (and thus will operate as a circulator at that frequency) by the proper adjustment of two physical junction parameters. In a simple waveguide junction with a round ferrite post, the two parameters might be the post diameter and the magnetic bias field. This principle can be demonstrated experimentally with a large variety of physical junctions, but the resulting circulator is often quite frequency sensitive and lossy. To obtain a practical device with wide bandwidth and low insertion loss, it is usually necessary to optimize several physical junction parameters.

The procedure used in tuning this latching junction circulator was quite similar to that used with externally biased circulators. Several different ferrite configurations were selected which were expected to operate well at X-band on the basis of experience with normal junction circulators. The bias field would provide an additional variable in an externally biased device, but in the latching device the ferrite must be switched only on the major hysteresis loop to eliminate sensitivity to switching current variations. Thus the magnetic field can be varied only by using various ferrimagnetic materials with different remanent magnetizations. Several configurations were assembled with different materials and the input impedance of each was plotted over the X-band frequency range. The criterion used in choosing the final configuration was that the junction reflection coefficient be small and have a smooth frequency variation over a 15 to 20 percent frequency band.

Final matching of the junction is accomplished with the aid of reactive networks at each port (Reference 5). If this network is considered as part of the junction, then the magnitude and phase of the reflection coefficient of this network are the two physical parameters which must be varied to match the junction. Simple capacitive dielectric posts were used to obtain a broadband input match in the 10 to 11 gigacycle range, or a more frequency sensitive match at other frequencies. A slight change in ferrite dimensions will allow broadband matching at other frequencies.

Experimental Results. The principles outlined above were employed in building the circulator shown in Figure 1. Performance characteristics are shown in Figures 2 and 3. The 15 percent band of operation is centered at 10.5 gigacycles. Isolation is greater than 20 db, VSWR is less than 1.2:1, and insertion loss is less than 0.2 db. Switching time is less than 1.0 microsecond with 75 microjoules total switching energy (energy stored in a capacitor which is discharged through the bias coil by a silicon controlled rectifier).

The same design techniques were used in building a waveguide four-port latching circulator in the K_u-band region. The same general principles that were applied to design of waveguide junctions have been used to achieve latching junction circulators in TEM line structures at frequencies from 3 to 10 gc.

Experimental results to date and theoretical design considerations indicate that fast switching, latching junction circulators may be built in both waveguide and TEM line, with performance equal to that obtained in externally biased junction devices.

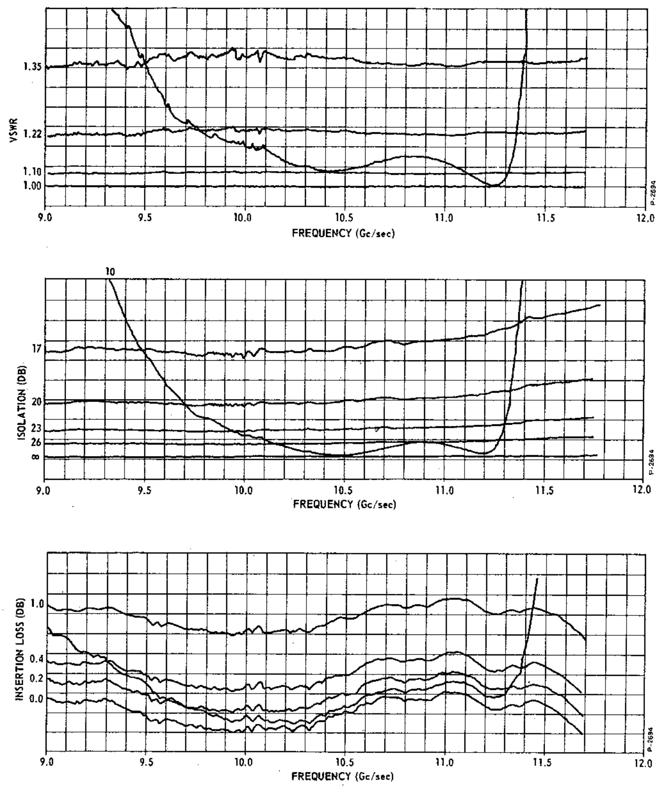
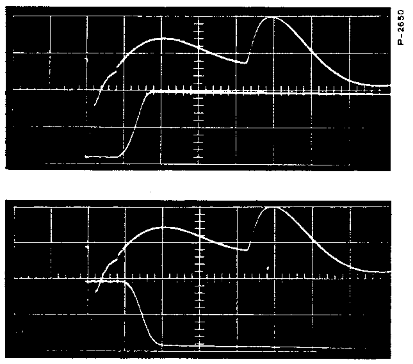
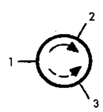


Figure 2. Performance Characteristics of X-Band Latching Junction Circulator





HORIZONTAL SCALE: 0.5 μ s / LARGE DIVISION
VERTICAL SCALE: ARBITRARY UNITS

UPPER TRACE IN EACH PHOTO IS THE TRIGGER VOLTAGE WAVEFORM IN THE DRIVER.

LOWER TRACES ARE DETECTED CW MICROWAVE SIGNALS AT PORTS 2 AND 3 SHOWING APPROX. 0.5 MICROSECOND DELAY TIME AND 0.5 MICRO-SECOND SWITCHING TIME.

Figure 3. Switching Characteristics of the X-Band Latching Circulator

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