III-3 S-BAND LATCHING CIRCULATOR WITH 10-NANOSECOND SWITCHING SPEED

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This paper discusses the development of an S-band latching circulator capable of being switched in 10 nanoseconds. The switch operates with good isolation and insertion loss characteristics and requires relatively low switching energy.

BASIC DESIGN APPROACH

Design of the high-speed ferrite switch is based on efficient use of the ferrimagnetic material in order to minimize volume. This was accomplished by using large variations in tensor permeability which result from complete reversal of magnetization in the material.

A further premise was that the ferrimagnetic material should be arranged in a toroidal configuration with the drive coil wound directly on the toroid. Also, a microwave structure should be used in which all portions of the toroid contribute equally to the non-reciprocal operation of the device.

JUNCTION CIRCULATOR

An internally latched stripline junction circulator was designed for operation at the desired frequency. The ferrite members were similar to those used in latching waveguide circulators described previously by this author [1] and by Passaro [2]. This circulator was matched over a 10-percent bandwidth with highly resonant tuning elements. The subject application required wider bandwidth, however, so this structure could not be used.

COUPLED-LINE CIRCULATOR

A coupled-line circulator was designed which was based on a geometry described by Jones, et al [3] and by Boyd [4]. Boyd has discussed [5] the non-reciprocal coupling which takes place between two parallel strip transmission lines when a longitudinally magnetized ferrite is placed in the region between the two lines. Propagation on such a structure may be described in terms of two circularly-polarized normal modes excited by time quadrature inputs on the two lines. The velocities of the two modes are different and may be interchanged by reversing the sense of magnetization of the two rods. If the two lines are excited in phase,both normal modes are excited. If the differential phase shift of the two modes is 90 degrees, all energy will be transferred to one of the lines for one sense of magnetization and to the other for the opposite sense. A configuration utilizing this effect to achieve the desired switching action is shown in Figure 1. A simple power divider is used to excite the two lines in phase.

The structural form of the circulator switch is shown in Figure 2. The input power divider incorporates a 100-ohm resistor which terminates any out-of-phase (odd mode) signals on the lines. Thus the switch is a four-port circulator with an internally terminated port. This provides isolation between the output ports even when operating into poorly matched external loads.

It was necessary to wind the drive coil along the entire length of the ferrimagnetic material in order to obtain full magnetization. A completely closed toroid was not required however, since the proximity of two parallel, oppositely magnetized rods provided a very low reluctance path and high remanence ratio.

The proper operation of the switch depends on matched even and odd mode velocities on the coupled lines. The cross-section arrangement of the ferrite and other dielectrics greatly influenced the balance of these velocities. The cross-section geometry used in the switch is shown in Figure 3.

The coupled-line region was 11 inches long to provide 90-degree differential phase shift of the oppositely polarized normal modes on the lines. The ferrimagnetic material used was Trans-Tech G-600 garnet which provides temperature stability with good activity in the S-band region.

The performance characteristics of the latched switch are shown in Figure 4. Isolation and insertion loss are, respectively, about 23 db and 1.0 db over a 1.0-GHz bandwidth. VSWR is less than 1.3 at all ports over most of this band.

HIGH-SPEED SWITCHING OPERATION

High-speed repetitive reversal of the switch was accomplished by driving it with a 20-MHz sine-wave source. A driver, which was specifically designed for this application, and the switch are shown in Figure 5. The driver unti consists of a grid-pulsed 20-MHz oscillator driving a 6-tube class-C parallel push-pull power amplifier. All seven tubes were 8236 beam-pentodes. The driver furnished 10-kilowatt, one-microsecond pulses with a 0.002 duty cycle.

The driver was coupled to the switch by a reactive network. Adjustment of this network allowed the 60-MHz signal generated by the non-linear ferrite load to be shifted in phase so as to optimize switching speed and produce a "flat-topped" microwave output waveform. A 4-GHz sampling oscilloscope was used to observe the RF voltage waveforms at the switch output as shown in Figure 6. Switching time between points of 20-db isolation was about 13 nanoseconds.

Avalanche transistor and mercury-wetted mechanical switches have also been used to provide switching times of 20-50 nanoseconds.

SWITCHING ENERGY

A simple theory is proposed to predict the energy required for high-speed switching. Typical material switching parameters (threshold field H_o and switching coefficient S_w) for flux reversals occurring due to domain wall motion and domain rotation are determined from experimental results of Shevel [6]. Switching energy is determined as a function of switching speed by use of these material parameters and the relation [7,8] $E = 0.016\ V(4\pi M)\left[\frac{S_w}{t_s} + H_o\right]$ microjoules, where V is material volume in cm^3 and t_s is witching time in microseconds.

The energy required to reverse the circulator switch in 13 nanoseconds is predicted to be 322 microjoules by using the parameters $V = 3.8\ cm^3$, $4\pi M = 425$ gauss, and $\left[\frac{S_w}{t_s} + H_o\right] = 12.5$ oersteds in the above equation.

A simple calculation based on the peak power and half-period of the driver gives an actual value of 238 microjoules per switch reversal which correlates well with the predicted value.

CONCLUSIONS

A microwave ferrite device with useful performance characteristics has been switched at 10 nanosecond speeds with a driver of reasonable size. This was possible because the device was optimized with a minimum volume of ferrite material and the driver was operated in a repetitive switching mode and was optimally coupled to the device.

ACKNOWLEDGMENT

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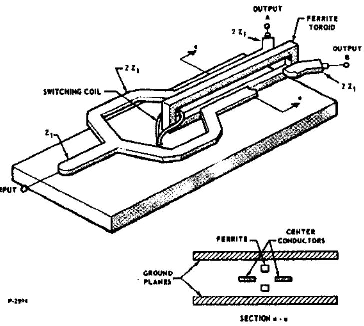

FIG. 1 - Pictorial Diagram of Latching Coupled-Line Circulator

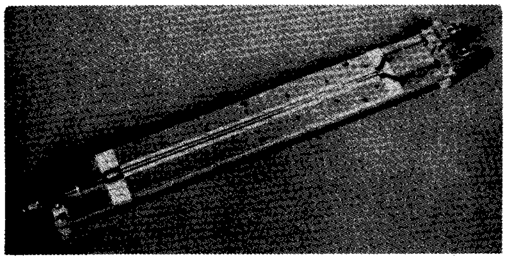

FIG. 2 - Internal View of Circulator

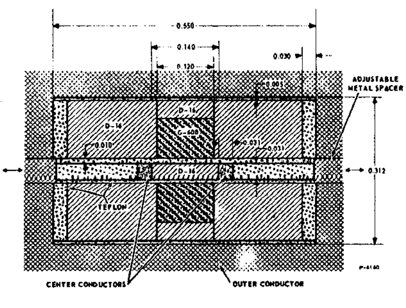

FIG. 3 - Cross-Section Configuration Used in Circulator

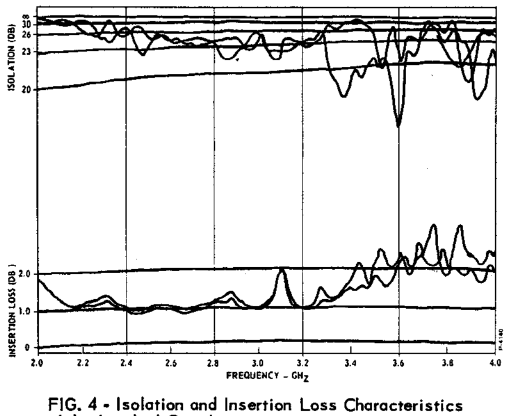

FIG. 4 - Isolation and Insertion Loss Characteristics of the Latched Circulator

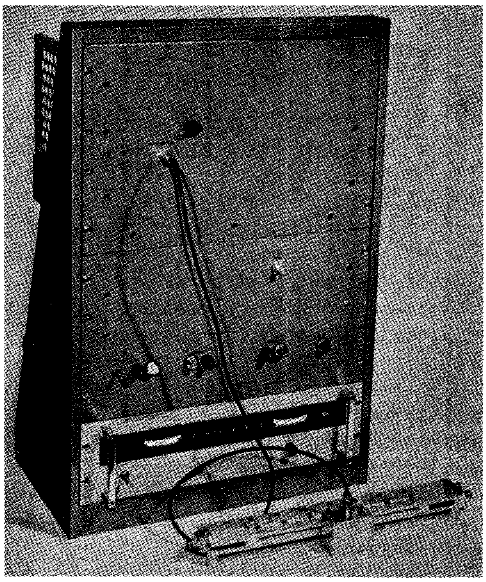

FIG. 5 - Circulator Switch with 10 KW, 20 MHz Driver

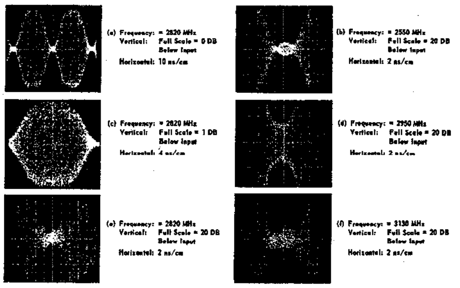

FIG. 6 - High Speed Switching Waveforms and Isolation Characteristics in the 2.6 to 3.1 GHz Region

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