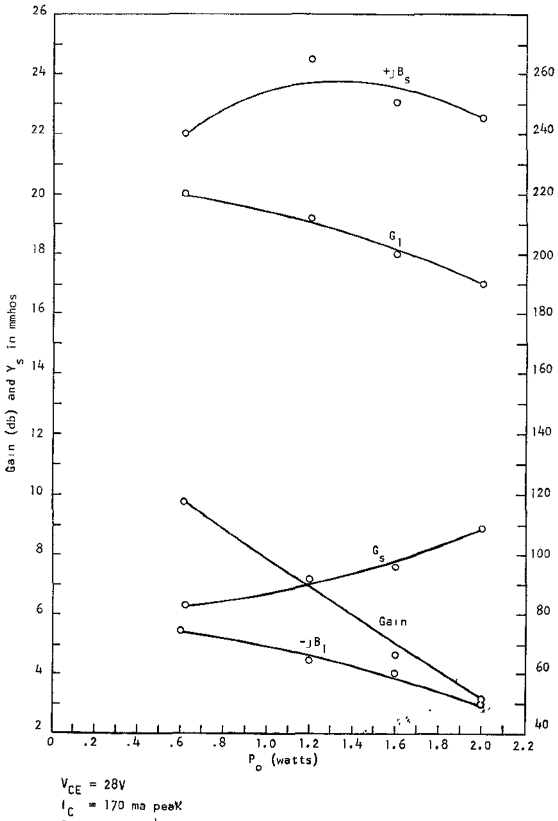


Fig. 3. Gain, $Y_S$, and $Y_1$ vs. peak output power (20 $\mu$s, 5 kc pulsed) for A63-B No. 10 silicon transistor.

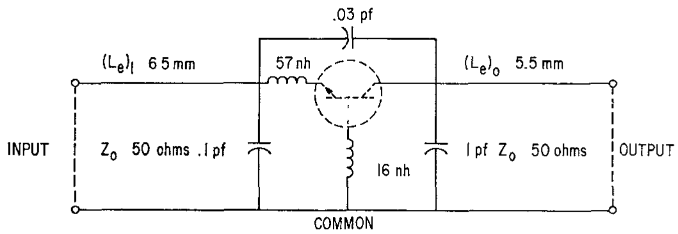


Fig. 4. Approximate equivalent circuit of T1-line package.

while maintaining a minimum of reflected power in the input, reasonably good input to output isolation was obtained and admittance measurements made at low power levels (small-signal) correlated closely with values calculated from small-signal $Y$ parameters.

The measured source and load admittance in Figs. 2 and 3 are references of the terminals of the stripline package in which the transistors were packaged. The approximate equivalent circuit of this package is shown in Fig. 4 with the common-base configuration indicated. The internal inductances are somewhat lower than shown for the higher power transistor of Fig. 3 because of the method of lead bonding. The package reactances of this, or other typical microwave packages, can cause a considerable transformation between the admittance presented at the terminals of the transistor package and that seen from the transistor chip itself. For this reason, it is especially important with power transistors in the microwave range either to characterize the transistors in the packaging configuration in which they will be utilized in the circuit application, or to accurately know the package parameters so that suitable corrections can be made if the transistors are mounted in a different environment.

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# A Four-Bit Latching Ferrite Switch

## Introduction

Latching ferrites [1], [2] are rapidly advancing a new era of solid-state devices [3], [4]. These new devices require neither external magnets nor continuous drive current, and, in many applications, are far superior to those which utilize conventional biasing techniques. The resultant economy of weight and power supply requirements suggests the possibility of uses in a variety of microwave components such as circulators, switches, isolators, and digital phase shifters. Their fast-switching lightweight characteristics make them particularly suited to phased array and other systems.

This correspondence deals with a novel approach for combining polarized input signals through the use of latching ferrites. Vertical, horizontal, left-hand circular and right-hand circular polarized input waves are combined at a common output as shown in Fig. 1.[1] This is accomplished by proper selection of the bit states of a fast-switching, lightweight four-bit latching ferrite switch, the term bit being used to describe a single (90°) differential phase shift section. A transistorized power supply, and associated electronic driver, is used to select and transmit the commands necessary for the desired mode of operation.

## Development of a 90° Bit

An experimental model of a 90° bit is shown in Fig. 2. It consists of a straight section of waveguide, with the toroid placed directly in the center and with the waveguide width reduced in the vicinity of the ferrite. The selection of material for the toroid can be obtained from the graph of Fig. 3. These data have been collected from previous empirical work with broadband ferrite circulators [5] and have been found to be applicable to phase shifters. One-piece toroids were formed by pressing the material around a mandrel. This technique has been found to be far less costly than the ultrasonic cutting method by which the final toroid was built up from shorter toroidal elements cemented together. Dielectric-stepped transformers of $K=10$ were designed, using techniques previously outlined by Cohn [6] and Vartanian [7], to match out the impedance of the air-filled waveguide to that of the loaded section which has a dielectric constant of $K=16$. A 0.010-inch diameter beryllium copper wire was used to pass the current pulse down the center of the toroid. To minimize RF magnetic coupling effects, it is essential that the wire travel a path parallel to the H plane from the toroid to the waveguide wall from which it emerges.

Initial test data indicated the presence of a sharp "spike" in both the VSWR and insertion loss characteristics. However these spikes were effectively suppressed through the use of cylindrical sleeves, made from a lossy material, and inserted into the waveguide walls through which the charging wires entered and emerged.

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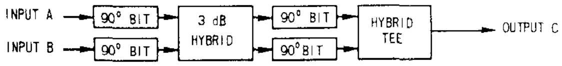
[1] Since the waveguide supports only one mode, it should be understood that the actual conversion of the other various polarizations, to that one supported by the waveguide, takes place before they reach the switch.




| LATCHING MODE | TRANSMISSION |
|---|---|
| I | Port A to Port C - Linear |
| II | Port B to Port C - Linear |
| III | Ports A & B to Port C - A leads B by 90° |
| IV | Ports A & B to Port C - B leads A by 90° |

Block Diagram of Four-Bit Switch

Fig. 1. Block diagram of four-bit switch.

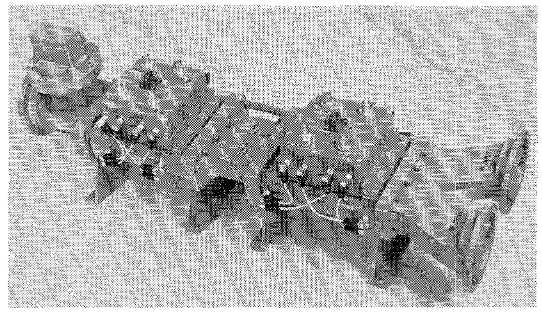


Fig. 5. Final switch assembly.

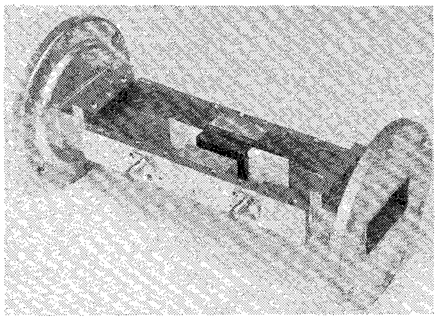


Fig. 2. Experimental model of 90° latching bit.

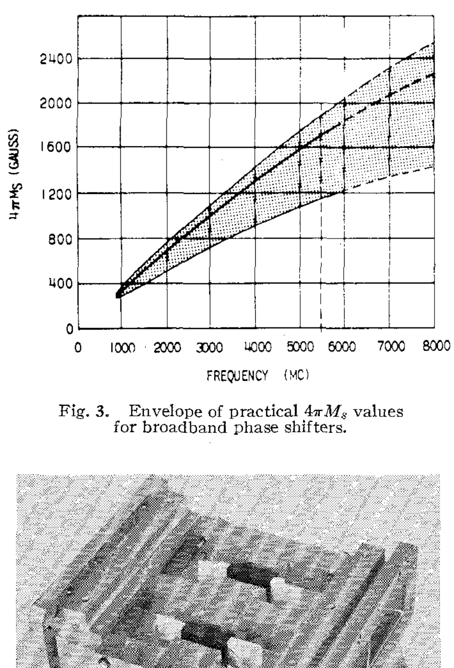



Fig. 3. Envelope of practical $4\pi M_s$ values for broadband phase shifters.

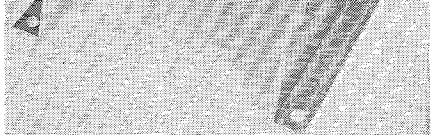


Fig. 4. Dual 90° latching bits.

Since the performance characteristics of the final switch assembly depends upon the differential phase shift obtained from four separate and distinct 90° bits, it is essential that close control of these bits be maintained. Buildup of mechanical tolerances, combined with physical and electrical variations within the material itself, can produce a wide variation in resultant phase shift through each bit. Precise control of the phase shift, through each section, was very accurately controlled through the use of a variable resistance placed in series with the electronic driver circuit. This enabled the driver current (i.e., the current pulse) to be varied, thereby allowing operation of the device on a lower portion of the hysteresis curve. In this manner, each individual bit was preset to the desired amount of phase shift, regardless of variations in physical or electrical tolerances of the materials and structures. This technique was found to be of great value in achieving the overall performance of the four-bit switch.

Using the experimental results obtained from the model previously described, two dual-section waveguide assemblies, similar to that shown in Fig. 4, were constructed. Each of the 90° nonreciprocal phase shift sections is constructed in reduced height and width waveguides, and are impedance matched through the use of appropriate step transitions. The intimate close contact, required between the ferromagnetic toroids and waveguide walls to prevent VSWR and insertion loss "blip," is assured by the monitoring of close tolerances and the design of "positive" pressure top waveguide walls.

Each of these sections is adjusted to give $90° \pm 2°$ of nonreciprocal phase shift. An input VSWR of less than 1.08 is maintained over the frequency band using dielectric stepped transformers on the toroid plus, of course, appropriate matching sections on the waveguide wall. Low dielectric and magnetic losses in the ferromagnetic toroid assure insertion losses of less than 0.20 dB per section.

Using these dual sections, in conjunction with appropriate associated hybrids, the final switch assembly of Fig. 5 is derived. This unit is designed to operate from 5.4–5.9 Gc/s at a maximum power level of 10-watts peak power. Temperature compensation problems were essentially removed from consideration through the utilization of system coolant, which is maintained at a temperature of $125 \pm 10°$F.

Final operating characteristics of the device are shown in the following.

| | |
|---|---|
| Frequency | 5.4–5.9 Gc/s |
| Insertion Loss | 0.60 dB max |
| VSWR | 1.20 max |
| Switching Time | less than 1.0 $\mu$s |
| Switching Energy | 150 micro joules |
| Power | 10.0-watts peak |

Of further significance is the differential electrical length between adjacent ports or between two legs of separate switches. Here identical phase lengths are maintained to a $\pm 4°$ tolerance. Maximum phase ripple (i.e., variation of phase response with frequency) is less than $\pm 1°$.

## Conclusions

The development of a very fast switching, low-loss, all solid-state, phase stable, latching switch has been outlined. This device provides a means of combining waves of various polarizations, from two inputs, at a common output.

Fabrication of toroidal elements, as single entities, along with the utilization of new techniques in the field of latching ferrites, namely, the precise control of differential phase shift and the suppression of spikes, provides the device with a high degree of reliability and long life performance at a minimum of size, weight, and cost.

## Acknowledgment

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