V-13. Broadband Binary 180° Diode Phase Modulator

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The recent emergence of diode phase modulators makes certain systems realizable which were previously impossible or impractical because of the high modulation power required to obtain high-speed phase control. Systems benefiting from this new diode phase shifter technology include high-speed electronic antenna scanners and phase modulation radars. It was as part of an effort to develop a video frequency phase modulated radar that the task reported here was undertaken. The system[1] requires a phase shifter that can be switched between 0° and 180° phase shift in 20 nanoseconds or less. The amplitudes in each phase state must be equal and the switching transient should be small. Additional flexibility is allowed the system if the phase shifter is broadband. Other requirements on the phase shifter such as power limitations depend on the diode, and are not considered here. The purpose of this task is to find a suitable technique to satisfy the system requirements using presently available diodes. The new technique reported here has application to variable phase control as well as binary phase control.

In the system, part of the phase modulated signal is coupled to the mixer, providing the local oscillator. The voltage of the delayed echo then adds to or subtracts from the local oscillator voltage, depending on their relative phases and produces the video output. If the two phase states have unequal amplitudes, the local oscillator generates a false signal.

Theory. The technique of switching between various lengths of transmission line to obtain phase shift was suggested by E. Rutz.[2] This basic technique was used here because it provides for easy balancing by adjusting the drive power on the diode switches. The circuit can be simplified in a 180° phase modulator in that two line lengths need only two diode switches instead of four if all four diode-to-junction dimensions are integral multiple half-wavelengths. The phase shift is made frequency-independent by putting a 180° waveguide twist in one path and making the paths of equal length.[3] Alternatively, for symmetry, 90° twists of opposite sense can be put in each arm, as shown in Fig. 1. When the lower diode switch is "off" it appears as zero impedance across the X-band waveguide. This impedance is transformed to each T junction to provide minimum loss to the power in getting through the T's and into and out of the upper arm, which would be "on." The output phase would then be "up," as shown by the encircled vector. When the lower arm is "on" and the upper arm "off," the output phase is 180° different, as shown by the encircled vector pointing "down." Because the diode switches are not perfect reflectors when they are "off," the incident power is reduced by about 1 db at each T. The diode in the "on" state also reduces the power by about 1 db. As frequency is changed, the impedance of the "off" switch as seen from each junction changes, causing power to be reflected from the T and increasing the insertion loss. Insertion

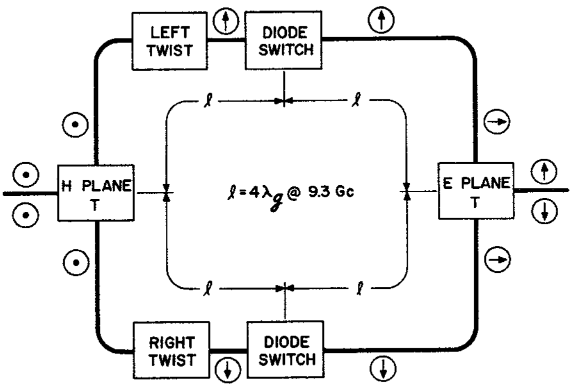

Fig. 1 Circuit diagram of the 9.3 Gc binary 180° diode phase modulator.

loss poles occur when the distance from diode to junction is an odd multiple of quarter-wavelengths. If four diodes were used, as originally suggested by E. Rutz,[2] the insertion loss would be about 1 db higher than the minimum, but no insertion loss poles would occur.

Experimental Results. The insertion loss of the device shown in Fig. 1 is given in Fig. 2. Germanium diodes were used for switches and the incident power was 50 mw peak (25 mw average). Phase shift at all data points shown was 180° ± 2°. The balance was achieved by feeding the modulation to the center of a 50 ohm potentiometer and feeding one diode from each end of it. The diodes were mounted in opposite dc polarity to put them in 180° video phase.

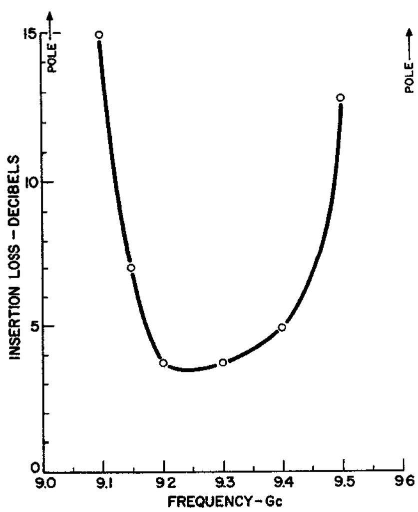

Fig. 2 Insertion loss of the binary 180° diode phase modulator represented by Fig. 1.

The device can be further simplified as shown in Fig. 3. Turning the H-plane T so that the feed is perpendicular to the plane of the assembly eliminates the twist sections and H-plane bends which take up space. In this configuration, the diodes can be mounted $\lambda_g/2$ from each T, and the bandwidth is increased by a factor of approximately 8 over that shown in Fig. 2. In this form, the entire device can be simply milled out of a block of metal and is very compact.

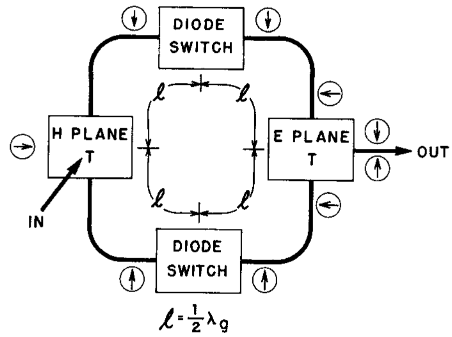

Fig. 3 Circuit diagram of the simplified waveguide broadband binary 180° diode phase modulator.

Experiments on the phase shifter of Fig. 1 have shown that between phase states the power momentarily drops to zero, making dips in the local-oscillator power in the system. The dips do not give a false signal but drive the video amplifiers out of the linear region. The dips are reduced as shown in Fig. 4. The phase shifter reflects power when it is not passing it. The reflected power is coupled to the local oscillator in phase quadrature with the two binary phase states. The result is a vector of relatively constant amplitude, traveling, during the switching transient, through 180°.

By feeding the phase shifter with a circulator and combining the transmitted and reflected waves in a 3 db coupler, the outputs could be made such that one output is 0° to +180° and the other output is 0° to −180°. However, other phase shifting techniques can do the same thing with less equipment. The device of Fig. 3 is most advantageous in applications needing a broadband balanced binary 180° phase modulator.

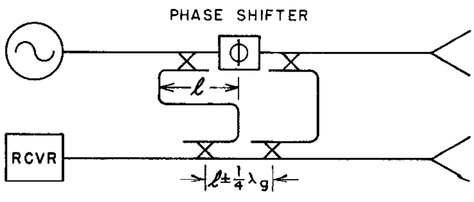

Fig. 4 Circuit diagram of the radar system using the 180° binary phase modulator, ϕ. By coupling the power reflected by the phase modulator to the receiver in the proper phase, the local oscillator amplitude dip during phase switching is reduced.

A rather interesting equivalence of Fig. 3 can be drawn in TEM transmission line as shown in Fig. 5. The "off" diode is transformed into a short at the balun input by the λ/4 line length. The power is then switched from one input to the other. Although a stripline 3 db directional coupler is not exactly a balun, its characteristics are similar enough to work over a half-octave bandwidth. Broadband baluns made using the techniques of Jones and Shimizu[4] would be more satisfactory.

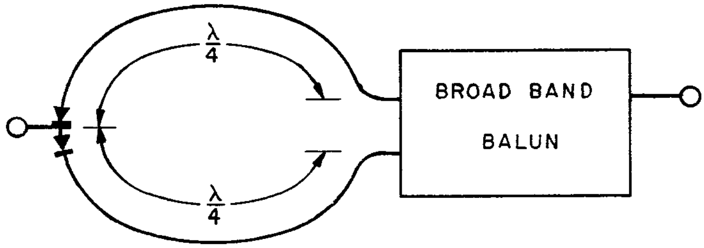

Fig. 5. Circuit diagram of the TEM transmission line equivalent of the broadband binary 180° diode phase modulator. Only the center strip of stripline is shown.

REFERENCES

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4. E. M. T. Jones and J. K. Shimizu, "A Wide-Band Stripline Balun," *IRE Trans. on Microwave Theory and Techniques*, Vol. MTT-7, pp. 128–134 (January, 1959).