A FAST SWITCHING, LOW LOSS, LOW DRIVE, 12 GHz PIN PHASE SHIFTER*

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ABSTRACT

A 4-bit PIN microstrip phase shifter switching in 1 ns/bit with only 9 mW/bit of driving power is described. The phase shifter is combined with its TTL-compatible driver in a single compact package. RF insertion loss is 1.6 dB ± 0.2 dB for the 16 phase states over the 11.7 - 12.2 GHz band. Forty-two phase shifter modules have been built. A linear phase array employing these modules has been constructed.

Introduction

Scanning spot beams are envisioned for future satellite communication systems.[1] Among the crucial components in such systems are fast switching (under 10 ns) phase shifters with minimal driving power consumption. A phase shifter has been developed in microstrip circuit at 12 GHz with a switching time and a driver power requirement which constitute an order of magnitude improvement over the best presently available phase shifters. The RF insertion loss has also been reduced by about 50 % as compared to similar phase shifters[2,3,4] in spite of using a lower biasing diode current; 2.5 mA/diode.

Circuit Description

The RF circuit, made in microstripline, consists of 4 cells in cascade as shown in Fig. 1.

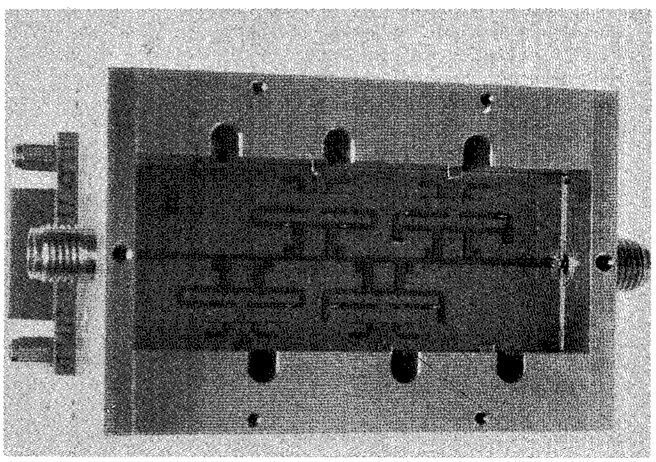

FIGURE 1: Photograph of the phase shifter showing the circuit made of 4 cells designed to provide phase shifts of 180°, 90°, 45° and 22.5° respectively.

*Preliminary results of this phase shifter have been published by B. Glance in a paper entitled, "A Fast Low-Loss Microstrip PIN Phase Shifter" in the January 1979 issue of the IEEE MTT Transactions.

The 4 cells are designed to provide phase shifts of 180°, 90°, 45° and 22.5°. Each cell is made of a 3-dB branch-line hybrid coupler whose coupling arms are connected to open sections of transmission line with a PIN diode in each line.

Confinement of 4 cells in a metallic box devoid of parasitic resonances in the operating range 11.7 - 12.2 GHz required the selection of a 3-dB branch-line hybrid coupler because of its small size and the compactness of its biasing circuit. The narrow bandwidth problem associated with this type of coupler was resolved by means of stubs positioned on each side of the coupler as shown in Fig. 1. A three-fold increase in bandwidth was thus obtained. Figure 2 shows the RF insertion loss of the RF circuit made of 4 cascaded cells without diodes from 11.3 GHz to 12.8 GHz.

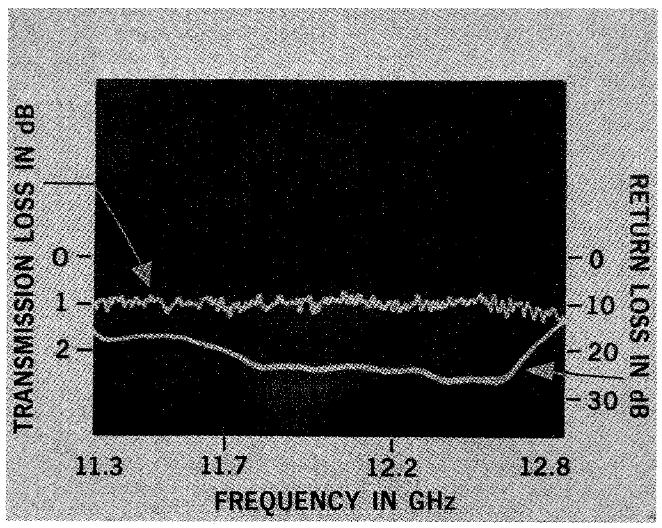

FIGURE 2: Transmission loss and return loss of the RF circuit without the diodes.

The driver circuit which interfaces the phase shifter to the phase memory of the system is low power Schottky TTL compatible. Each bit is individually driven. The driver circuit consists of a modified complementary arrangement of a PNP and NPN transistors. Fast switching of the PIN diodes was obtained by

(a) Maintaining a high ratio of peak reverse to forward current.

b) Employing inherently fast semiconductor devices and avoiding deep saturation of these devices prior to the change of state.

The low power consumption was obtained by using a low forward current for the PIN diodes and driving it from a low voltage source. Additional circuit details will be given in the presentation. The driver circuit is enclosed in the same box, on the opposite side of the RF ground plane as shown in Fig. 3. The biasing circuits are connected to the driver circuits through pins running in the sidewalls.

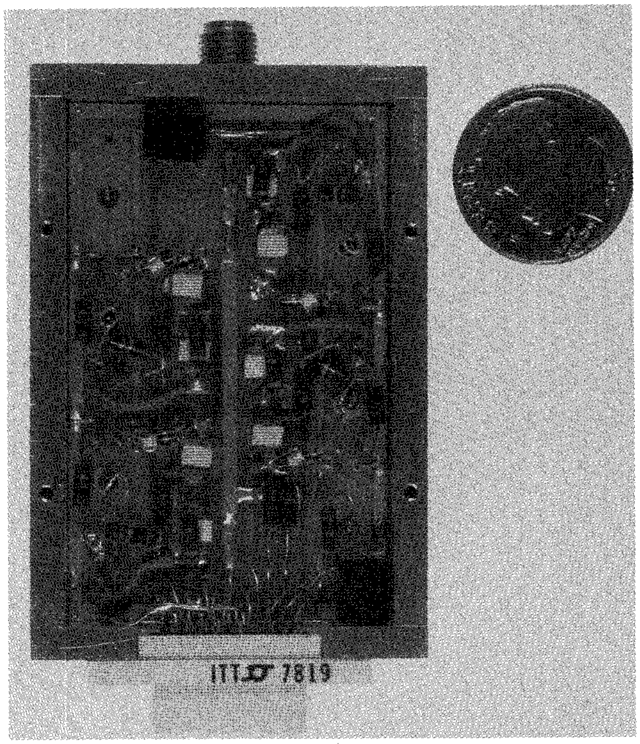

FIGURE 3: Photograph of the driver circuit enclosed in the phase shifter box on the opposite side of the RF ground plane.

Experimental Results

PIN diodes from different suppliers were tried. The best results were obtained with Hewlett-Packard beam-leaded diodes (HPND-4001). Figure 4 shows the 16 phase states measured over the 11.7 - 12.2 GHz band. The lower trace shows the corresponding transmission loss which is 1.6 dB ± 0.2 dB over most of the bandwidth for a forward current of 5 mA/cell (2.5 mA/diode) and a reverse voltage of 14V. The current can be reduced to 2 mA for the 45° cell and to 1 mA for the 22.5° cell with less than 0.1 dB degradation in the insertion loss. By increasing the current to 20 mA/cell, the insertion loss can be decreased to 1.3 dB ± 0.2 dB.

Switching time was measured with a sampling oscilloscope after phase detection. Figure 5 shows the switching time for the 180° cell, showing 1 ns for switching-on and 0.7 ns for switching-off when driven by fast risetime and falltime pulses. Similar switching times were observed for the three remaining cells. The maximum switching time for the 4 simultaneously driven cells fed by low power Schottky TTL devices is below 8 ns which is well within the 10 ns satellite system requirement. The increase in switching time is due to the different delays in each cell driver. If necessary, this switching time could be reduced by proper delay compensations. Figure 6 shows sequential switching of the 16 phase states at the output of a phase detector bridge using a balanced mixer. Additional waveforms associated with switching between the various phase states will be shown.

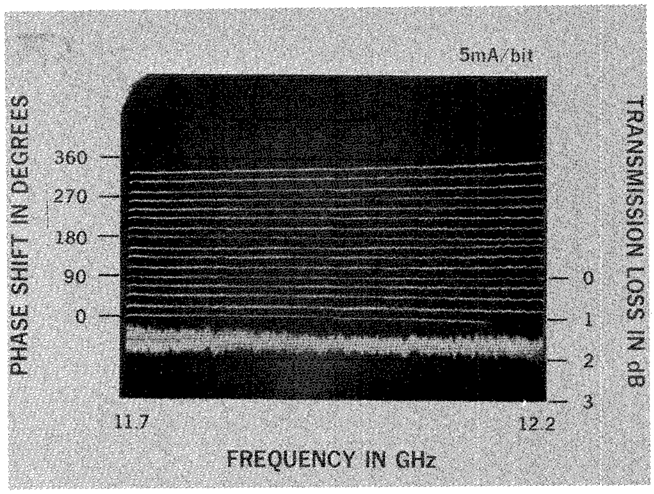

FIGURE 4: Display of the 16 phase shift states from 0° to 337.5° by increment of 22.5° over the 11.7 - 12.2 GHz bandwidth. The lower trace shows the corresponding RF insertion loss varying between 1.8 dB and 1.4 dB over most of the band.

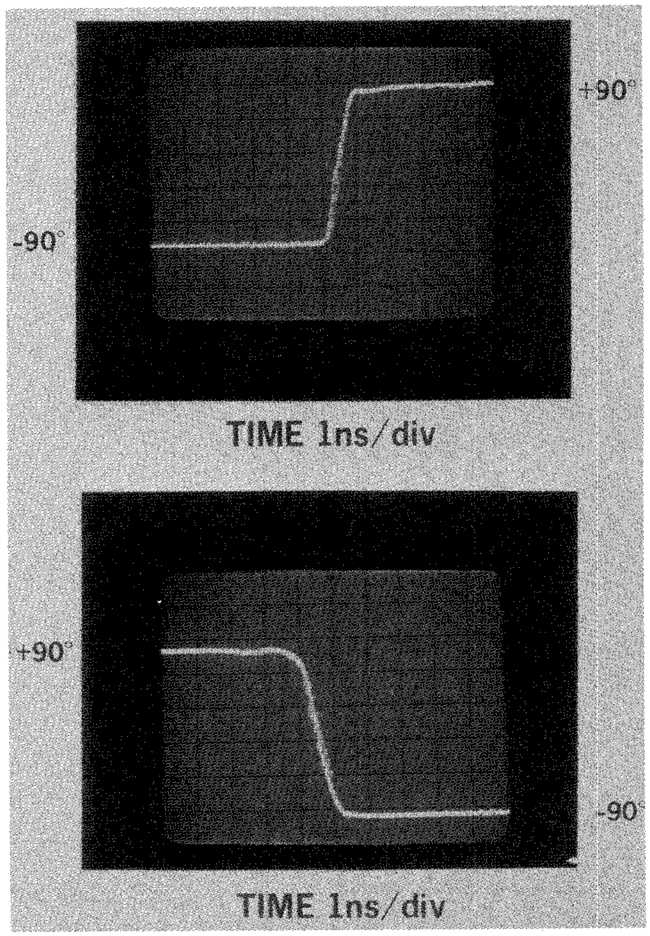

FIGURE 5: Photographs showing the switching times of the 180° cell obtained by using a fast risetime and falltime pulse generator.

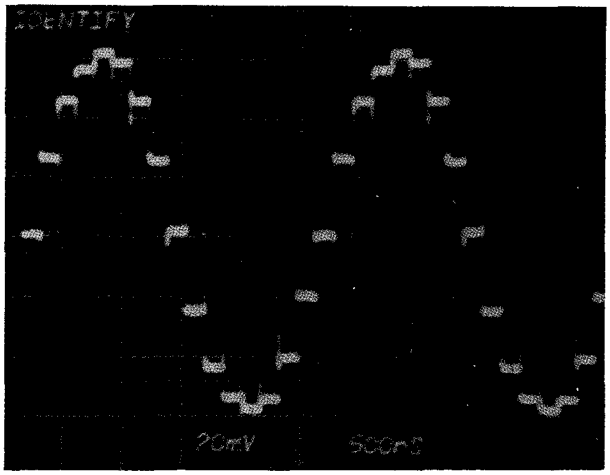

FIGURE 6: Sequential phase switching waveform of the 16 phase states as detected by a phase bridge using a balanced mixer. Driver inputs fed by low power Schottky TTL devices.

The dc power consumption of the combined driver and phase shifter was measured when the 4 cells were switched to periodically increment the phase in steps 22.5° from 0° to 337.7°. The duration of each phase step was 1 μs with a forward current of 5 mA/cell. At this current level, the total dc power required was 36 mW. RF power handling capability has been checked up to 800 mW, the limit of the available equipment. Analysis indicates that the diode employed should sustain about 1100 mW.

Forty-two phase shifters were built showing a good reprocibility of the performances. Variations between phase shifters were confined to ± 0.1 dB for the insertion loss and ± 2° for the phase at midband.

Conclusion

We have demonstrated that by combining an improved RF circuit design with the best available PIN diodes and a well designed driver circuit, the switching time and driver power requirement of PIN phase shifters can be substantially improved. A significant reduction of the RF insertion loss has also been achieved.

The performance and compactness of the combined phase shifter-TTL compatible driver made this phase shifter especially attractive for satellite and airborne applications.

Acknowledgment

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