A HIGH POWER UHF MICROSTRIP DIODE PHASE SHIFTER

R. L. Holden
R. W. Burns

Hughes Aircraft Company
Ground Systems Group
Fullerton, California 92634

Abstract

A four-bit high power UHF diode phase shifter is described. This device, using eight PIN diodes mounted in a low dielectric constant microstrip circuit, has operated at an 8 KW peak, 240 watt average power level with an average insertion loss of 0.75 dB.

Introduction

High power PIN diode phase shifters have used large numbers of diodes in order to achieve high power capacity.[1,2,3] Circuits in the past have generally used coaxial transmission lines which require many expensive machined parts. This paper describes the design of a four-bit high power UHF diode phase shifter which has been optimized for low loss at high power levels. In order to minimize production costs, the phase shifter uses only eight diodes mounted in a relatively simple microstrip circuit.

The design goals for this phase shifter are as follows:

Center Frequency	400 MHz
Bandwidth	5%
Maximum Loss	1.0 dB
Phase Shift Accuracy	±11 degrees
VSWR	1.3 maximum
Peak Power	4 KW
Duty Factor	3%
Pulse Length	300 µsec
Bias per Bit	200 mA forward, -100 volts reverse

Design

A schematic circuit diagram of the phase shifter is shown in Figure 1. The phase shifter incorporates a combination of bit designs. The 90° and 180° bits are hybrid coupled circuits and the 22.5° and 45° bits are periodic loaded line sections. Each bit uses two PIN diodes made by Unitrode Corporation. The diodes, type No. UM 4000, have a forward bias series resistance of less than 0.3 ohms at 100 mA and a reverse bias series resistance of less than 0.6 ohm at -100 volts. The capacitance is approximately 2.0 picofarad and the DC breakdown voltage is 800 volts.

The most stringent design goal for this phase shifter was to maintain low insertion loss at a peak power level of 4 kilowatts with only -100 volts of reverse bias. The diodes in the 180° bit are mounted at a 25 ohm impedance level. At a power level of 4 kilowatts the maximum RF voltage across these reversed biased diodes is about 630 volts.

Ideally, a diode switch is reverse biased to a voltage level that is at least equal to the peak forward excursion of the applied RF voltage, 630 volts in this case. This is done in order to avoid operating the diode in the high resistance region near zero bias. When the peak excursion of the RF voltage swings into this region, with the diode in reverse bias, high level limiting occurs and the loss increases.[2,4] As the operating frequency is decreased to the UHF region, this limiting effect becomes more pronounced since the diode series resistance, near zero bias, varies inversely as the square of the frequency.[5] In this design, high level limiting is minimized by shunting the 2 picofarad diode, C_d, with an external 14 picofarad high Q capacitor, C_E, as shown in Figure 2. This combination effectively lowers the equivalent reverse bias series resistance by a factor of $(1 + C_E/C_d)^2$ or about 64. This reduction of series resistance improves the high level limiting characteristic of the diode.

The 25 ohm capacitive reactance of the diode and shunt capacitor combination, X_{C_T}, is series resonated with the inductive reactance, X_L, to produce a short circuit condition in the reverse bias state (Figure 2). An open circuit condition is obtained in forward bias by parallel resonating X_L with X_{C_p}.

Figure 3 shows a photograph of the microstrip phase shifter circuit. The 3 dB two branch hybrids used in the 90° and 180° bits, incorporate transformers which lowers the 50 ohm main transmission line impedance to 25 ohms at the diode switches. The switches are mounted directly on the coupled ports of the hybrids in order to conserve space.

Loaded line sections are used for the two smaller bits in order to keep the circuit area to a minimum. The switches for these bits are coupled to the main line through quarter wavelength lines. The impedance level of these lines is adjusted to yield shunting susceptance of ±J.2 and ±J.414 for the 22.5° and 45° bits respectively. Each pair of susceptances are quarter wave length spaced along the transmission line which is adjusted for low VSWR across the band.

The circuit was fabricated on a 1/8 inch thick polyphenelene-oxide (PPO) laminate using conventional print and etch techniques. This board has a dielectric constant of 2.55 and a loss tangent of .0006 at UHF. The circuit board is mounted in a watertight die cast housing which also serves as a finned heat sink for the diodes. In order to obtain good heat transfer to the heat sink, each diode is mounted on a large copper stud which is threaded into the housing. The base of the stud makes contact with the circuit ground plane while the diode extends through the board to make contact with the etched circuit. The four bits are DC isolated from one another by 100 picofarad button mica blocking capacitors. The total loss contributed by the five capacitors was less than 0.1 dB. Mica feed-through capacitors are used to bypass the bias control lines. A photograph showing the exterior of the completed phase shifter is shown in Figure 4.

Performance

Figure 5 shows the measured performance of the completed phase shifter. The maximum insertion loss is under 1 dB, with the average loss about 0.75 dB over the band for all phase steps. The measured insertion loss for the phase shifter with all of the diodes removed was about 0.5 dB, hence the loss contributed by the diodes varies from 0.1 dB with all diodes reverse biased to about 0.5 dB with all diodes forward biased. A flat phase shift characteristic over the operating frequency range was required. This requirement was met with the measured phase deviation being only ±8° for all 16 phase steps, from 390 MHz to 410 MHz. Input VSWR is less than 1.3 over the same frequency range. Although the peak power requirement was 4 kilowatts, the phase shifter was tested to a peak power level of 8 kilowatts with a 3% duty factor and a 300 μsec pulse length. As the power was increased from a low level to the 8 kilowatt level, the measured increase in insertion loss was less than 0.1 dB for all phase steps.

Following the design phase of this program, 800 phase shifters were constructed and tested. The distribution spread of the measured parameters was quite narrow. Insertion phase from unit to unit was within 5°. The differential phase for 16 steps was $\pm 3^\circ$ for all 800 phase shifters. Loss for all units was less than 1 dB and input VSWR less than 1.3.

Acknowledgement

The authors express appreciation for the support of Mr. Ron Presnell of Stanford Research Institute, Menlo Park, California.

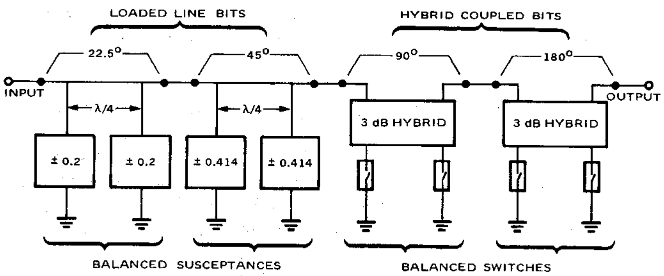

Figure 1. Four Bit UHF Diode Phase Shifter

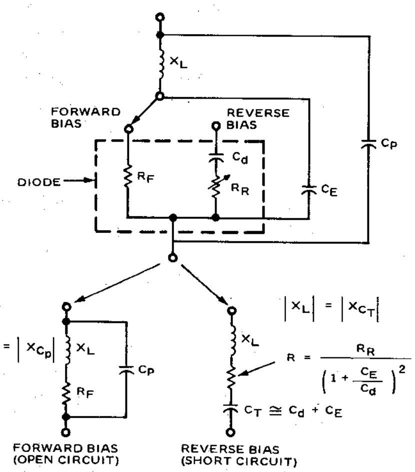

Figure 2. Equivalent Circuit of UHF 180° Switch

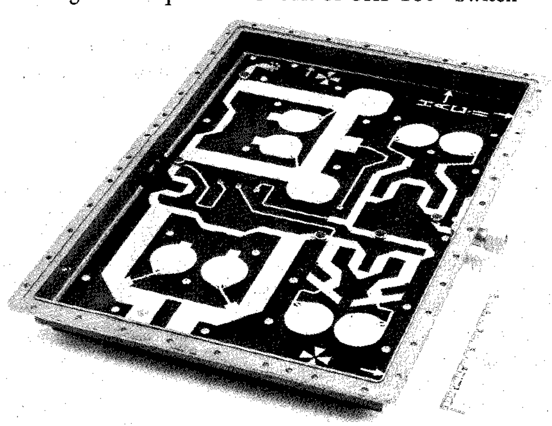

Figure 3. UHF Diode Phase Shifter with Cover Removed

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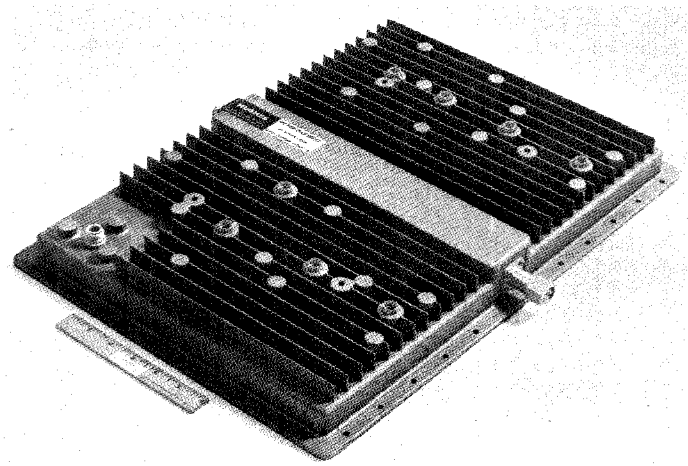

Figure 4. Exterior View of UHF Phase Shifter

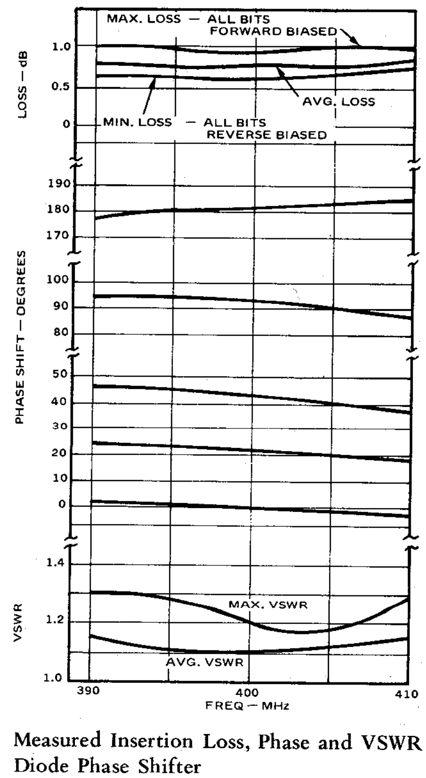

Figure 5. Measured Insertion Loss, Phase and VSWR for UHF Diode Phase Shifter