THE HIGH POWER PERFORMANCE OF A 5 KW MIC DIODE PHASE SHIFTER

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ABSTRACT

This paper describes the diode selection and the design of a three-bit microwave integrated circuit (MIC) phase shifter for high peak-power operation under various bias conditions (including zero bias). Insertion loss, phase accuracy, distortion and leakage current readings are given for both low- and high-power operation. The average insertion loss recorded was 1.1 dB, with a bit inaccuracy of 6 degrees RMS. The MIC phase shifter was designed for phased array radar operation in environmental extremes, including survival in neutron radiation.

Application Requirements

The requirements for this diode phase shifter are derived from an F-band common-aperture phased array application. The power handling requirement is 5 KW peak for a 50 microsecond pulse width and a duty cycle of 1%. Further requirements include small size and light weight (hence a microwave integrated circuit approach), bit accuracy of 8° RMS, a 1 dB average insertion loss, and an average VSWR of 1.25:1. The system also demands high reliability and survival under adverse conditions such as a short circuit load-pull, hot switching, zero bias operation, and neutron radiation.

Circuits and Diodes

The selection of diodes for these requirements depends to some degree on the phase shifter circuitry. The zero bias survival condition, however, dominates the power handling requirements for the diodes.

At zero bias a large percentage of the incident power to the phase shifter is absorbed by the diodes. Figure 1 is a plot of diode power absorption versus all possible adverse system operating conditions. The plot takes into account the load-pull and stored energy build-up in the common-aperture portion of the system, as well as zero bias diode loss characteristics. The figure shows that 50% of the incident power can be dissipated per diode in the first bit of the phase shifter for the worst-case operating conditions.

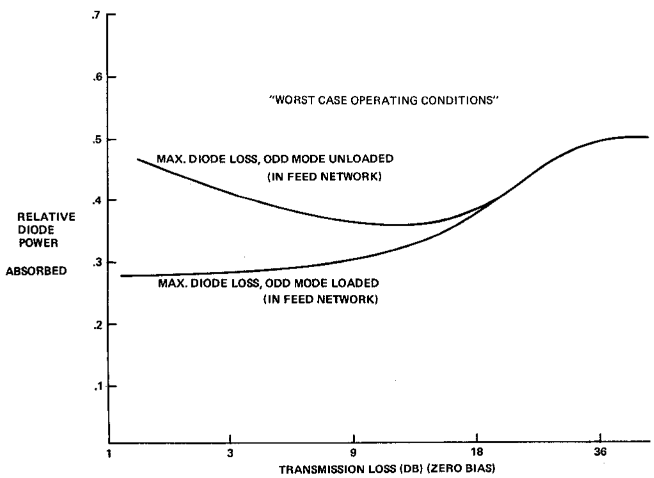

Figure 1. 3-Bit Diode Phaser in Common Aperture Phase Array Application

In order to hold the maximum junction temperature below 150°C, a PIN diode with large heat capacitance (transient thermal resistance of 0.1°C/W) must be selected. A diode with large heat capacitance also exhibits large junction capacitance. A device with a figure of merit of greater than 100 and the required thermal and power-handling properties will have a junction capacitance of 2 PF and an intrinsic layer thickness of 75 microns (of the meter).

To produce a large phase change from a pair of large junction diodes,[1] the hybrid coupled phase shifter is employed. The hybrid coupled approach also offers low loss and high power-handling capability.[2] The three-bit phase shifter is shown in Figure 2. Each bit is a hybrid coupled diode phaser. The hybrids are a mixture in design, each emphasizing a particular solution. The 45° bit uses a transforming two-branch hybrid, primarily to save space. The 90° bit is designed with a 2:1 transforming hybrid, whereas the 180° bit transforms externally by a ratio of 4:1. The surface area occupied by the MIC phaser is less than 2 square inches.

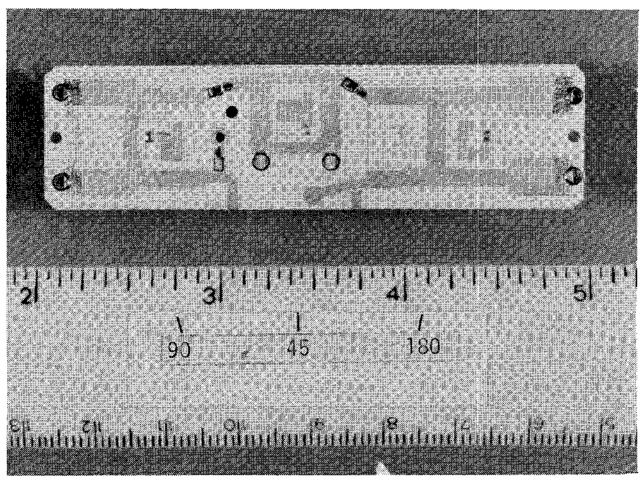

Figure 2. 3-Bit Diode Phase Shifter

Performance

The low-power data is summarized in Table I. The data represents the average over a 13% bandwidth for all eight possible phase shift states and for all units.

TABLE I

LOW POWER PERFORMANCE OF MIC 3-BIT DIODE PHASE SHIFTER	
Bit Accuracy (RMS)	6.2 Deg.
Insertion Phase Variation (RMS)	5.7 Deg.
Insertion Loss, Average (dB)	1.1
Insertion Loss Variance (dB)	0.25
VSWR, Average	1.2
VSWR, Maximum	1.5
Insertion Phase Linear per 50 MHz	± 1 Deg.
Forward Bias at 50 ma/Diode	
Bias Current Loss Sensitivity	-0.3 dB/50 ma
Bias Current Phase Sensitivity	0.35 Deg/50 ma
Reverse Bias at -40 V	
Bias Voltage Loss Sensitivity	0.1 dB/40 V
Bias Voltage Phase Sensitivity	-0.4 Deg/40 V

The high-power performance is summarized in Table II. Not all units were subjected to all high-power tests, but sufficient data was taken to confirm performance.

TABLE II

HIGH POWER PERFORMANCE OF MIC 3-BIT DIODE PHASE SHIFTER	
Hot Switching to 6.5 KW	No Burnout
Hot Switching Insertion Loss/Bit	0.8 dB
Zero Bias Operation to 5 KW	No Burnout
Zero Bias Insertion Loss	5 dB
Leakage Current at 1.5 KW	< 0.1 ma
Leakage Current at 5 KW	0.1 ma
Increased Insertion Loss at 1.5 KW	< 0.1 dB
Forward Bias Peak Power Phase Sensitivity	1.3^{o}/dB
Reverse Bias Peak Power Phase Sensitivity	1^{o}/dB
Switching Time Including Driver	3 Microsec
Delay Time Including Driver	0.5 Microsec
High Power Pulse Settling Time	
Amplitude	0.4 Microsec
Phase	1 Microsec
Pulse to Pulse Amplitude Variation	$\leq$0.05 dB
Pulse to Pulse Phase Variation	< 0.5 Deg.
Increased Loss at 0.42 n/cm^2	0.58 dB
Harmonic Distortion Down from 1 KW	65 dB

The zero bias operating condition is the most critical high-power test because it can produce a thermal runaway with excessive incident power. Curve A of Figure 3 illustrates the normal incident-power operating condition of the phase shifter at zero bias. Curve C gives the forward current at zero bias for three times the incident power level. Compared with Curve B (twice the incident power level) Curve C shows the onset of thermal runaway at about 25 microseconds into the applied RF pulse. This sharp decrease in forward current is due to an increase in leakage current when the junction temperature goes beyond 175°C. Diodes showing thermal onset at a lower power level should be derated proportionally.

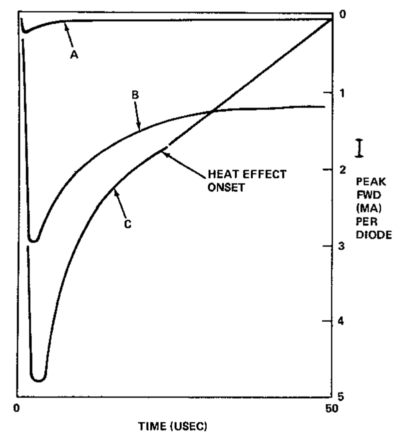

Figure 3. Zero Bias Forward Current with Power as the Parameter

The effects of neutron radiation on the diode phaser were measured: average insertion loss increase at 0.42 x 10^{13} n/cm^2 exposure was 0.58 dB. Considering the over-design for survival at zero bias, the phase shifter exposed to this level of radiation will continue to perform, but at reduced efficiency and reliability.

Conclusion

High power microwave integrated circuit diode phase shifters offer comparable performance to stripline and waveguide forms at F Band, but with the added advantage of very small size. This size advantage is becoming increasingly important in integrating the phase shifter with the radiating element in advanced phased array radar designs.

Acknowledgment

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References

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2. R. W. Burns, L. Stark, "PIN Diodes Advance High Power Phase Shifting," Microwaves, Nov. 1965, pg. 38.