A Monolithic 2-20 GHz GaAs PIN Diode SP16T Switch

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ABSTRACT

A Broadband Monolithic Single-Pole Sixteen-Throw (SP16T) Switch has been fabricated using GaAs Vertical PIN Diodes. The SP16T switch features < 4.5 dB Insertion Loss with >35 dB Isolation across the 2-20 GHz band. A novel de-embedding scheme used for switch characterization is also introduced.

INTRODUCTION

Many Electronic Warfare (EW) applications require a decade of bandwidth at microwave frequencies. Many of these systems are mounted on aircraft. As a result, low insertion loss is crucial to the feasibility of these systems. Critical elements in these systems are Multi-Pole Multi-Throw (MPMT) switches.

As a result of the size and insertion loss issues associated with broadband switches, monolithic integration is desired. Field Effect Transistors (FETs) were initially considered because of their ease of fabrication in monolithic circuits.

GaAs Vertical PIN (VPIN) diodes demonstrate more than three times the Figure of Merit of ion-implanted FETs. As a result VPINs are preferred for broadband control element applications.

A 2-20 GHz SP16T switch was used to demonstrate the feasibility of integrating VPINs into single chip MPMT broadband switches. A novel de-embedding scheme used for characterization of the SP16T switches is also described.

PIN DIODE MODELING

In broadband, low loss switching applications GaAs PIN diodes provide the optimum performance of existing control elements integrated into monolithic microwave integrated circuits, MMICs. This optimum performance is demonstrated by their superior figure of merit (FM). Existing VPIN diodes have demonstrated FM > 900 GHz as compared to 300 GHz for present ion-implanted FETs.

The design described herein integrates VPINs monolithically as broadband control elements. A Scanning Electron Microscope (SEM) photograph of a typical GaAs VPIN is shown in Figure 1.

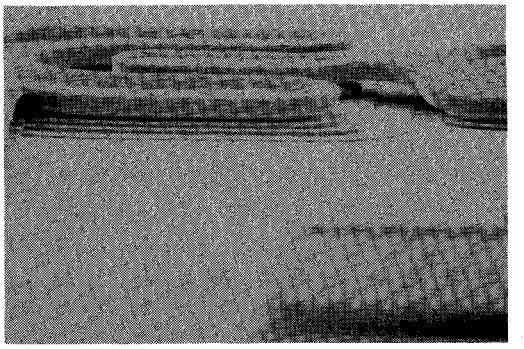

Figure 1. Typical GaAs Vertical PIN Diode SEM Photograph.

The intrinsic region length of the diodes discussed here is $L_i \approx 1.2$ microns. In GaAs 1.2-micron diodes, the intrinsic region is fully depleted of charge carriers with zero applied bias. This zero bias depletion is due to the built-in potential of the P and N junctions. As a result, reverse bias in the control element "off-state" is not required.

The zero-volt capacitance of the 1.2-micron VPIN diodes developed for this application is defined as the "off-state" capacitance, C_{off}, and has a measured value of $C_{off} \approx 35fF$. These diodes are biased at 30 mA for low "on-state" resistance, R_{on}, and power handling ability. At this bias current the diodes demonstrate $R_{on} \approx 5\Omega$.

The parameters C_{off} and R_{on} are used in the simple diode (control element) equivalent model illustrated in Figure 2. These parameters equate to a FM ≈ 900GHz.

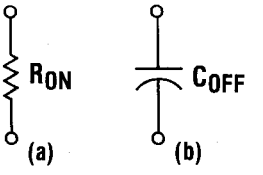

Figure 2. GaAs VPIN Diode Model.

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SP16T SWITCH CIRCUIT DESIGN

The SP16T switch circuit described herein can be thought of as a SP4T cell followed by four SP4T cells. A schematic of the switch input SP4T cell is illustrated in Figure 3. This SP4T cell can be further divided into three SPDT sub-cells.

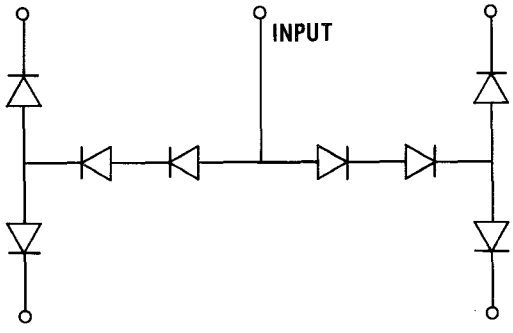

Figure 3. Schematic of the Input SP4T Cell used in the SP16T Switch.

The SPDT sub-cell located at the input of the switch utilizes two diodes in series to mimimize the capacitive loading of the input match. The other SPDT sub-cells utilitize a single series-diode since no rf constraint applies to these sub-cells other than minimum insertion loss.

Each of the SP4T cells at the output of the SP16T switch utilize the series-series-shunt topology because of its good isolation characteristic, low capacitive loading of the switch input, and power handling ability. Each of four throws are connected directly together without additional control elements. The impedance mismatch generated by the capacitive loading of the three throws in the "off-state" is matched to the output impedance of each throw of the input SP4T cell by distributed techniques.

Gateless FETs were used in the switch design as bias chokes. These gateless FETs provide the necessary 30 mA bias current while presenting the rf signal with a high impedance path due to their saturated current characteristic. Voltage sources can be used for external bias supplies as a result of the current saturation characteristic of the gateless FETs.

SWITCH CHARACTERIZATION

An APC-7 3-port test fixture was developed for characterization of the SP16T switches. This fixture is illustrated in Figure 4. The fixture utilizes a three-section stepped coaxial line transformer to transition between the 7mm Coaxial connector and the microstrip environments.

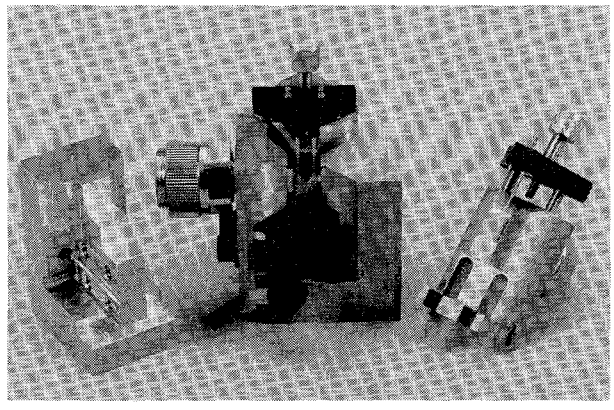

Figure 4. APC-7mm 3-Port Test Fixture.

This fixture has demonstrated >20 dB return loss with 0.15 dB insertion loss per connector through 20 GHz. Isolation with a 60 mil microstrip gap is typically >30 dB through 20 GHz.

Characterization of the full SP16T switch is difficult due to the proximity of adjacent ports. For simplicity fourteen of the sixteen throws were terminated into a broadband 50Ω load. However, due to the proximity of adjacent rf ports, the broadband 50Ω terminations could not be realized on an alumina thin-film-network (TFN) substrate >5 mils thick.

An acceptable coax-to-microstrip launch could not be achieved on a substrate less than 15 mils thick with the fixture illustrated in Figure 4. As a result, the SP16T carrier plate assembly required both 5 mil and 15 mil TFNs for characterization. This carrier plate assembly is illustrated in Figure 5.

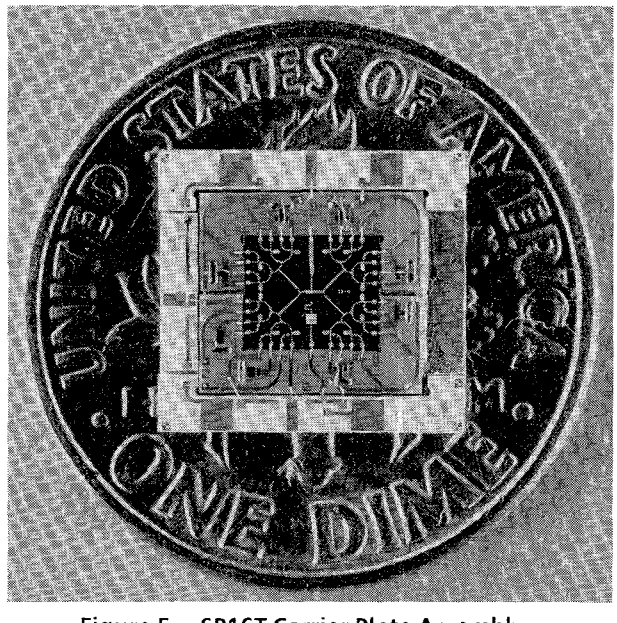

Figure 5. SP16T Carrier Plate Assembly.

Consideration of the impedance mismatch generated by the two bond wires required to connect the GaAs Switch, the 5 mil TFN and the 15 mil TFN was also required.

A "semi-distributed" 50Ω transmission line was synthesized by choosing the correct impedance for the microstrip line on the 5 mil substrate. This concept is illustrated in Figure 6. The lumped element equivalent circuit illustrates the synthesized filter affect.

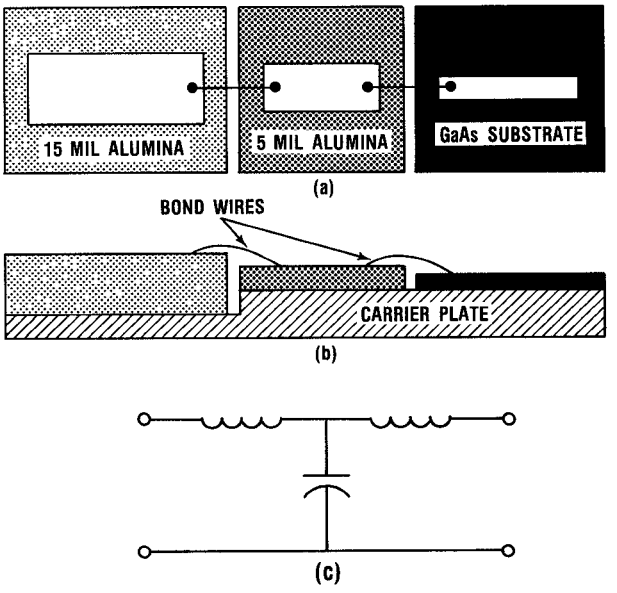

Figure 6. Lumped Element Circuit Equivalent Circuit for the Semi-Distributed Synthesized 50Ω Transmission Line.

The bond wires are represented by the inductors. A short length of low-impedance (<50Ω) transmission line approximates the shunt capacitor. Bond wire inductances were estimated and the width of the microstrip line optimized to approximate a 50Ω environment.

In addition, Thru, Short and Delay (TSD) de-embedding standards, employing the "semi-distributed" synthesized 50Ω transmission line technique, were fabricated. These standards were used in conjunction with an internal TSD de-embedding software program.

After application of the TSD corrections, measurements of the test fixture using the "Thru" (synthesized 50Ω transmission line) de-embedding standard indicate >18 dB return loss through 20 GHz at all ports

MEASURED SWITCH PERFORMANCE

After processing of the monolithic switches was completed, the individual circuits were diced Each switch was dc probed for functional PIN diodes and gateless FETs. Nearly all gateless FETs were not functional. This was caused by variations in material growth and etch rates across the slice.

Due to the low-yield of the gateless FETs, the bias stubs containing these devices were scribed out of the circuit. The bias was applied to the switches using external coaxial bias tees.

The insertion loss and isolation performance of a typical SP16T switch is shown in Figure 7 The return loss of the SP16T circuit is typically 10 dB. This was attributed to the absence of the gateless FET bias lines from the matching circuitry. The insertion loss is <4.5 dB and the isolation >36 dB through 20 GHz

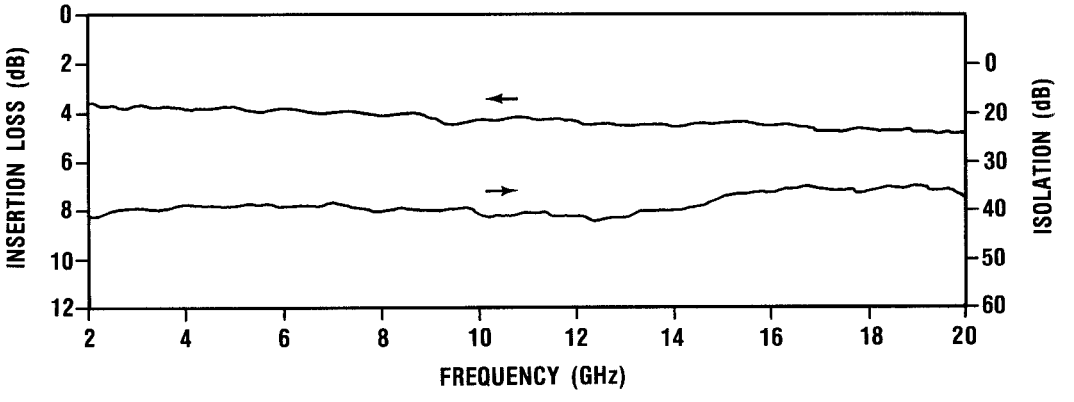

Figure 7. SP16T Measured Insertion Loss and Isolation.

The switching speed of the SP16T switch was also measured. The actual switching speed of the circuit was < 2 nsec, Figure 8. However, the ringing associated with the bias tees lasted for more than 18 nsec.

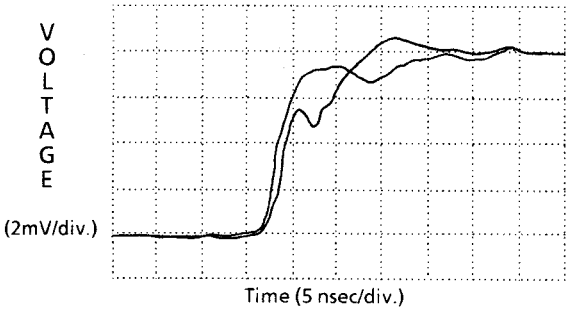

Figure 8. SP16T Measured Switching Speed.

SUMMARY

GaAs Vertical PIN diodes have demonstrated a FM>900 GHz. The devices were integrated into a SP16T 2-20 GHz monolithic switch. This SP16T circuit achieved <4.5 dB insertion loss with >38 dB isolation through 20 GHz.

An APC-7 3-port test fixture was developed for characterization of these switches. In addition a "synthesized 50Ω transmission line" de-embedding scheme was developed.

ACKNOWLEDGEMENTS

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