A Monolithic GaAs PIN Switch Network For A 77 Ghz Automotive Collision Warning Radar

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Abstract

This paper presents the design, fabrication, and performance of a 77 Ghz monolithic GaAs PIN switch network developed for an automotive collision warning radar. The RF front end of the radar contains three control circuits which were initially realized by a hybrid approach using a duroid circuit and beam lead diodes. These three circuits were successfully integrated into a single 77 Ghz MMIC. The MMIC uses vertical GaAs PIN diodes with a switching cutoff frequency of over 3000 Ghz, attaining low insertion loss and high isolation. Insertion loss is comparable to that obtained with a hybrid circuit, while the isolation improved from a typical level of 16 dB for a single hybrid switch to over 25 dB in the MMIC. The use of GaAs PIN diodes also allowed switching speeds of less than 2ns to be attained, a key requirement for the radar.

Introduction

Millimeter wave systems for automotive applications require monolithic solutions for realization of low cost, manufacturable systems. Monolithic amplifiers, oscillators, and mixers based on three terminal GaAs devices have been reported with excellent performance characteristics at millimeter-wave frequencies. The low switching cut-off frequencies of three terminal devices has precluded their use in high performance control circuits above 50 Ghz, however. Systems at millimeter frequencies are being realized by a multichip approach, where the best available device technology is used for a specific circuit function. The switching functions required by the pulsed Doppler radar described in this paper are best realized by a monolithic GaAs PIN diode approach.

Radar Architecture

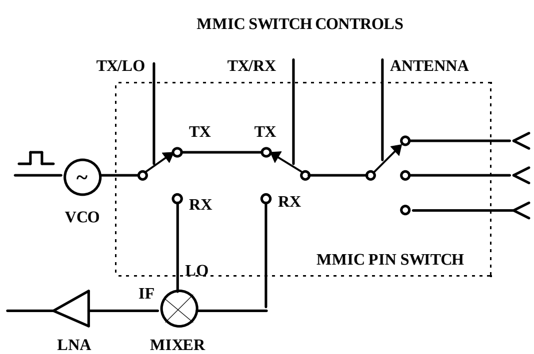

Figure 1: Three Beam Pulsed Radar Front End

Two types of front end configurations are commonly used for intelligent cruise control and collision warning radars: FMCW and pulse Doppler. The switch described in this paper was developed for use in a pulsed Doppler front end. Figure 1 shows the block diagram of the front end. A single millimeter wave source is used to provide both the transmit signal and the local oscillator signal for the receiver downconvertor. This source is switched coherently within 1 to 2 ns between the transmit and local oscillator frequencies. The transmit pulse duration is 36 ns; this 36 ns pulse is transmitted from the unit

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through one of the selected antennas, with the switches in the “TX” position. Simultaneously with the change of the transmitter source frequency at the end of the transmit pulse the switches are changed to the “RX”position. The return from the target is then coherently mixed down to a baseband signal.

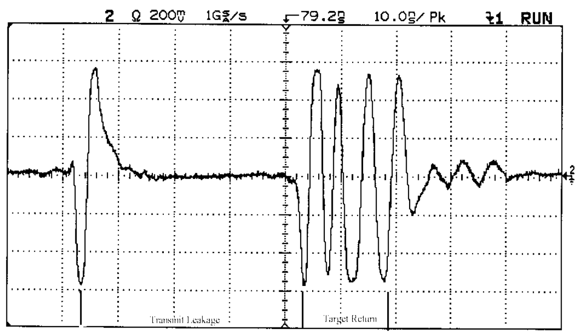

Figure 2: Front End Near Range Performance

A key element in the successful operation of this pulse Doppler front end is the ability to provide very fast switching (<2ns) between the “TX” and “RX” positions. There are two reasons for this. The first is to maintain the fidelity of the transmitted pulse, ensuring that no components of the local oscillator frequency are transmitted. The second reason for the fast switching is to ensure good near range performance of the radar front end. Figure 2 shows the received pulse from a target placed within the blind range of the radar: note the presence of the target return immediately following the end of the transmit signal.

Another requirement of the switch, which makes the PIN approach particularly attractive, is the ability to switch the relatively high power (+16dBm) of the transmitter source. Also, as the cost of the front end is of prime importance in this application another very attractive attribute of the switch described in this paper is that it can be switched at nanosecond speeds using a TTL driver which costs less than a dollar, and which operates from a single +5 volt supply.

GaAs PIN Process

The switch networks developed in this effort were fabricated on three inch diameter semi-insulating GaAs wafers with MOCVD grown P+, I, and N+ layers, as well as an undoped AlGaAs etch stop layer. The PIN diode mesas were produced with a wet etch process; contact to the P+ and N+ layers was realized through AuZn/Au and AuGe/Ni/Au ohmic contacts. Two layers of Ti-Pt-Au and a 0.3 micron thick layer of silicon nitride on the top of the wafers were used to produce microstrip transmission lines and MIM capacitors. The AlGaAs etch stop allows placement of a via hole directly underneath the PIN diode, resulting in low diode parasitics and improved switch isolation.[1]

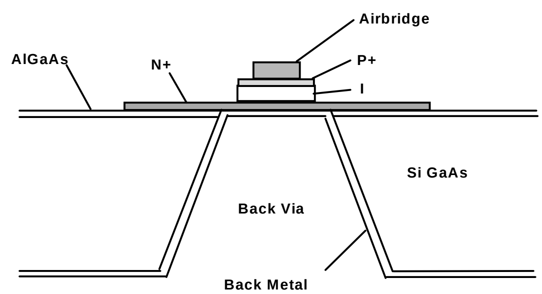

Figure 3: Vertical PIN Diode Cross Section

Figure 3 is a cross-sectional view of a vertical PIN diode, while Figure 4 is an SEM photograph of a vertical PIN, showing the PIN mesa structure and an airbridge strap contacting the top of the P+ layer.

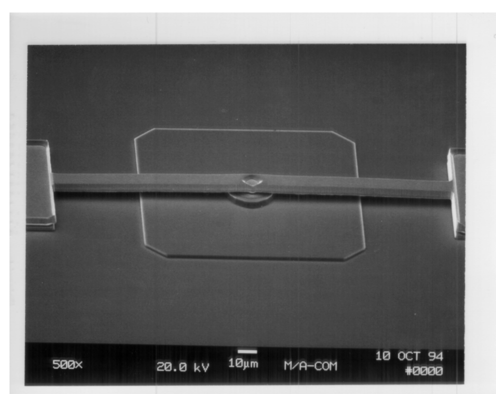

Figure 4: PIN Diode SEM

Switch Network Design

Figure 5 contains a schematic for the monolithic switch network, while Figure 6 contains a photograph of a completed chip. The PIN diode mesas are 28 um in diameter, with a zero bias junction capacitance of 0.032 pF and a forward biased resistance of 1.6 ohms at +10 mA. Each of the switches in the network is a shunt configuration; spacing of the PIN diodes is approximately one quarter wavelength from the switch junctions. Each switch has a single shunt diode in each arm, with the exception of the T/R switch, which has two shunt diodes on the transmit side.

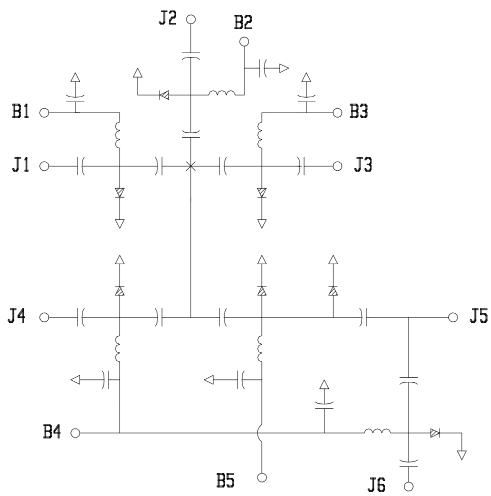

Figure 5: Monolithic Switch Network Schematic

Connection to the top P+ mesa of each PIN diode is made through an airbridge structure. The inductance of the airbridge and the capacitance of the PIN diode forms a low-pass filter structure.

The DC bias structures are resonant circuits consisting of a high impedance quarter wave line terminated by an MIM capacitor shunted to ground through a via hole. The overall chip dimensions are 1.8 mm by 2.1 mm x 0.10 mm.

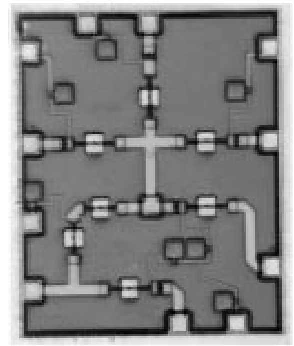

Figure 6: Photograph of Monolithic Chip

Measured RF Performance

Figure 7 contains plots of measured insertion loss from port J5 (Tx) to port J2 (antenna) and port J5 to port J6 (LO). The loss from J5 to J6, which is through the SPDT LO switch, is less than 1.5 dB from 73 to 77.5 Ghz and is 1.2 dB at 77 Ghz. This loss is comparable to that realized by a hybrid switch. The loss from J5 to J2 is through the LO and T/R SPDT switches, as well as the SP3T antenna switch. This loss is less than 4.0 dB from 73 to 80 Ghz, and is 3.5 dB at 77 Ghz. Figure 8 contains a plot of isolation between ports J5 and J2 when transmitting from port J1. Isolation is greater than 26 dB from 70 to 80 Ghz, and is 32 dB at 77 Ghz. Isolation and insertion loss levels between other pairs of ports are similar.

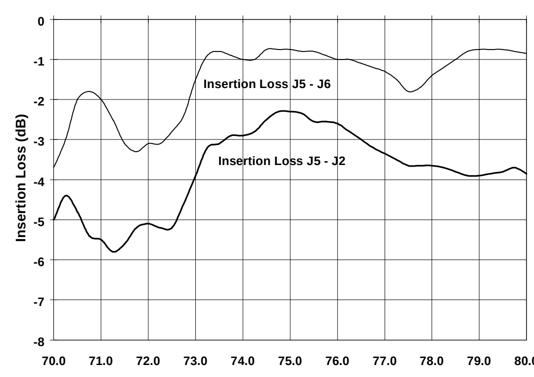

Figure 7: J5 To J6 and J5 to J2 Insertion Loss

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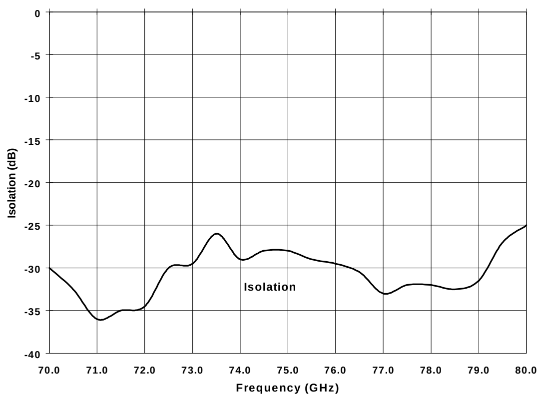

Figure 8: J5 To J2 Isolation

Levels of insertion loss vary from 1.0 dB to 4.0 dB, depending on the switch states and the selected ports, while the isolation ranges from 24 dB to over 30 dB. The improvement in isolation relative to the hybrid approach is particularly critical in the LO and T/R switches, since LO leakage through these switches will appear at the RF input port of the mixer.

Switching Performance

This MMIC switch network exhibits very fast switching, which is required to ensure proper operation of a pulsed radar front end. It is also important that the switch does not contribute to any phase change across the transmitted pulse. To test these parameters of the switch network a phase bridge which operated at 77 Ghz was used. The phase bridge has very wide bandwidth (several GHz) making it ideal for very high speed measurements. The phase bridge will also show any degradation of the phase across the switched pulse. Figure 9 shows the result of this phase bridge measurement on the switched pulse in a radar front end.

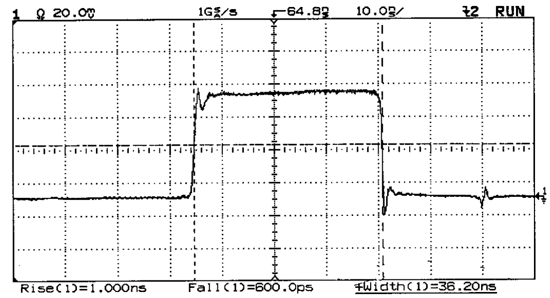

Figure 9: Phase Bridge Output Showing the MMIC Switch Network Switching Speed

Conclusion

We have described the design, fabrication, and performance of a 77 Ghz monolithic GaAs PIN switch network, which contains three switching functions. This network has low insertion loss and high isolation, and was developed for a 77 Ghz pulsed Doppler automotive radar. The performance of the switching network is a substantial improvement over the performance levels realized with a hydrid approach. Integration of three functions into a single monolithic die results in improved system performance, while lowering the complexity and difficulty of system assembly and reducing system cost.

References

1. Putnam, J., Fukuda, M., Staecker, P., and Yun, Y., "A 94 Ghz Monolithic Switch with a Vertical PIN Diode Structure", GaAs IC Symposium Digest, Oct., 1994, pp. 333-336.

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