A GaAs SP8T Switch Design for E-Band Automotive Radar

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Abstract

A GaAs Single Pole Eight Throw (SP8T) switch design and measured performance in a frequency range of 76–81 GHz on a commercial 1µm Schottky device process for application in the development of RF-frontend of an E-band FMCW automotive radar system is presented. Such a radar system requires minimum loss contribution from individual components. The design technique used in this work ensured minimum Insertion Loss (IL) from the SP8T switch. On-wafer measured IL is 4.7 ± 1.0 dB and port-to-port isolation is greater than 20.0 dB of the SP8T in the frequency band of 76–81 GHz. The input and output return losses are better than 9.5 and 13.0 dB respectively both in OPEN and CLOSED condition. In systems that consist of complex switching and feeding networks to large antenna arrays, use of a single SP8T when compared to a combined network of SPDT (typical IL $\sim$ 2.0 dB) and SP4T (typical IL $\sim$ 4.0 dB) switches considerably reduces transition loss, component loss and complexity, especially at such high frequencies. Thus, use of the presented SP8T switch will reduce switching network losses by $\sim 50\%$ in such systems, thereby, greatly improving the overall system performance and reducing assembly related costs. To our knowledge, this is the first commercially available GaAs SP8T switch at E-band with low IL of 4.7 ± 1.0 dB across a 5 GHz bandwidth.

INTRODUCTION

Control circuits form an integral part and important building block of any RF and microwave Transmit/Receive (T/R) module. III-V semiconductor Monolithic Microwave Integrated Circuits (MMICs) are usually the most suitable choice for the design of control circuits such as switches for high frequency applications. The main reasons for that are their compact size, faster switching speeds and better integration as compared to bulky coaxial switches.

Multi-throw switches are specifically beneficial to use in beam switching and antenna feeding networks of T/R modules, switch matrices, instrumentation, etc. Their usefulness as highlighted in [1] demonstrates that using a multi-throw switch with low insertion loss in monopulse front end modules reduces system noise figure at the receiver end, improves overall loss contribution, simplifies system architecture and reduces costs due to lesser number of system components and simpler assembly. This requirement becomes more critical as frequency of operation increases.

To address this need, the design of a GaAs SP8T MMIC switch is discussed in the following sections for its intended application in Frequency Modulated Continuous Wave (FMCW) automotive radar systems working in 76–81 GHz frequency band. Design methodology, process technology, device selection, high frequency design limitations and on-wafer measured small signal parameters are shown. GaAs and InP based SP8T MMICs have been reported earlier, but, operating in the lower end of the RF frequency spec-

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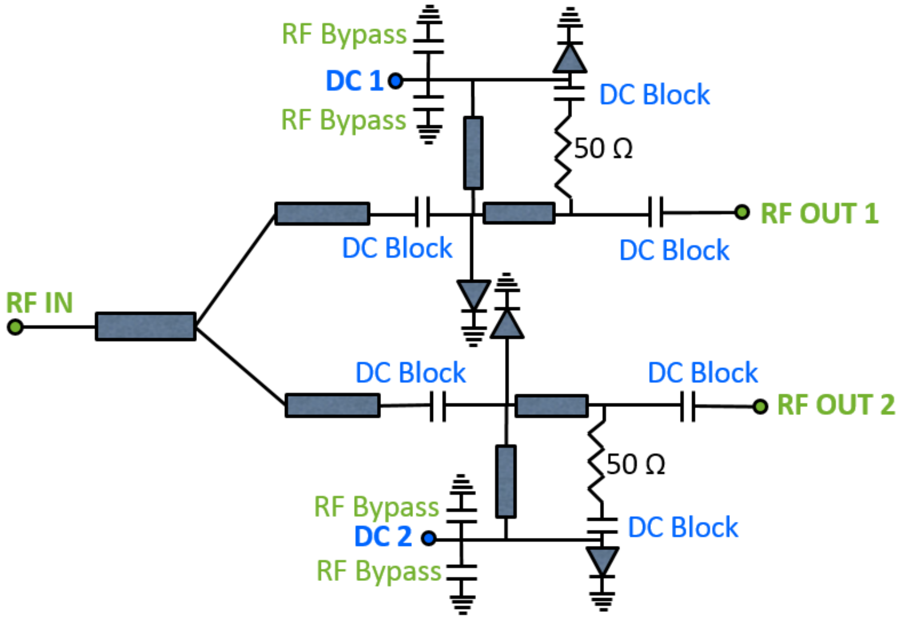


Figure 1: Schematic Design of a Single Pole Double Throw (SPDT) Switch Shunt Topology used as building block of SP8T

trum up to X-Band [2–4]. CMOS and CMOS–SOI based wideband and high performance SP8T switches are reported in [5–7] that aim at more integrated mixed signal chipsets. However, they operate up to 15 GHz only indicating a market requirement of high frequency low loss multi-throw MMIC switches.

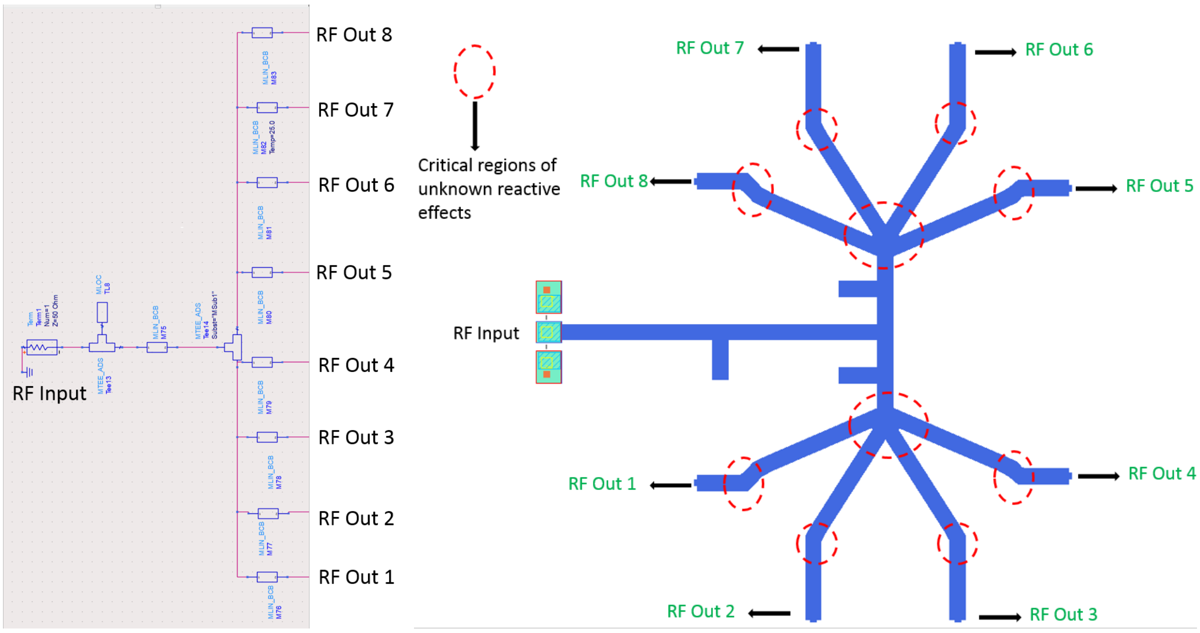
The presented GaAs SP8T switch satisfies this market need and, to the authors' best knowledge, it is the first commercially available chip operating from 76–81 GHz with IL of 4.7 ± 1.0 dB and isolation better than 20.0 dB.

DESIGN, SIMULATION AND PROCESS TECHNOLOGY

Design and Simulation Methodology

The critical parameters in the design of this SP8T switch for automotive radar application are low ON state insertion loss, high OFF state isolation and good 50Ω output port match in both OFF and ON state.

Various design topologies exist for the design of MMIC multi-throw switches depending on the critical parameter requirement [8, 9]. The switching device used could either be a diode or a Field Effect Transistor (FET). For the present design and application, achieving lowest possible insertion loss in the ON state of SP8T is the most critical parameter. Keeping that in mind a Schottky diode based shunt circuit design topology is used as shown in Figure 1. Diode is preferred over FET as the switching device because it exhibits lower IL and has a cut-off frequency in THz region due to low junction capacitance. Shunt topology is adopted as it ensures lowest insertion loss since there is no series device adding its resistance in the signal path in ON state. The Single Pole Double Throw (SPDT) schematic design shown in Figure 1 is used as a building block for the design of SP8T. DC blocking capacitors are used in RF path



(a) (b)

Figure 2: (a) SP8T Input Network Based on PDK Models (b) EM Based Input Network of SP8T highlighting critical regions

and any RF leaked in the DC line is bypassed using on-chip Metal-Insulator-Metal (MIM) capacitors.

Another important consideration during the design of the SP8T switch is a good 50Ω match at the output ports specifically in the OFF (or OPEN) state. This is important from a system integration point of view to minimise the reflections at the input of the successive components. To ensure this, each branch of the switch is terminated in 50Ω at its output. It can be seen from Figure 5b that an output return loss of better than 13.0 dB is achieved. Microstrip $\frac{\lambda}{4}$ transmission lines are used at the input of the diodes to ensure correct impedance being presented to the RF signal in the ON and OFF states.

Schematic simulation based on Process Design Kit (PDK) models followed by Electromagnetic (EM) Simulation was performed in Keysight Technologies' Advanced Design System (ADS) 2015.01.

In the design of a SPNT (where N $= 1, 2, 3, 4\ldots$) switch, N being the number of output branches, the complexity increases with increase in N. One of the main challenges was designing the input network of the switch. The SP8T forms a complex network of the common branch, common junction and eight individual signal branches connecting to the common junction at its input. For a shunt only topology it is important to have low contribution of the capacitance and least disturbance in EM field distribution from this network [10]. However, there are layout and overall chip size constraints that limit the flexibility of design of this network. Figure 2 shows regions of unknown reactive components occurring due to the junctions and bends in the input network. These cause imbalance in EM field distribution resulting in added capacitance which limits high frequency response and worsens the port-to-port isolation. These effects cannot be entirely avoided due to layout constraints, but, can be minimised by performing thorough EM analysis of this network. PDK model based simulations do not account for junction, layout geometry and proximity (crosstalk) effects (Figure 2a), thus, this network was designed using EM simulation and analysis in ADS MOMENTUM (Figure 2b).

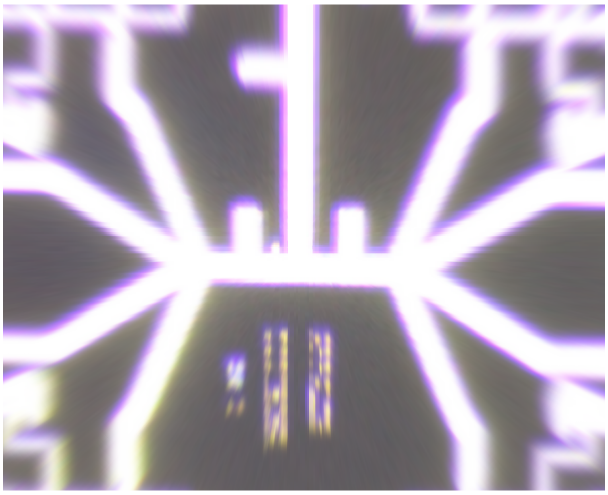


Figure 3: The Fabricated SP8T MMIC. Die Dimension: 3.38 mm $\times$ 4.2 mm

Layout of the input network and the full SP8T is done such that a compact chip size and symmetry is ensured. The RF outputs 1 and 8, 2 and 7, 3 and 6 and 4 and 5 are symmetrical. Bond wire effects are included at the simulation stage and circuit design is optimised based on full EM simulation.

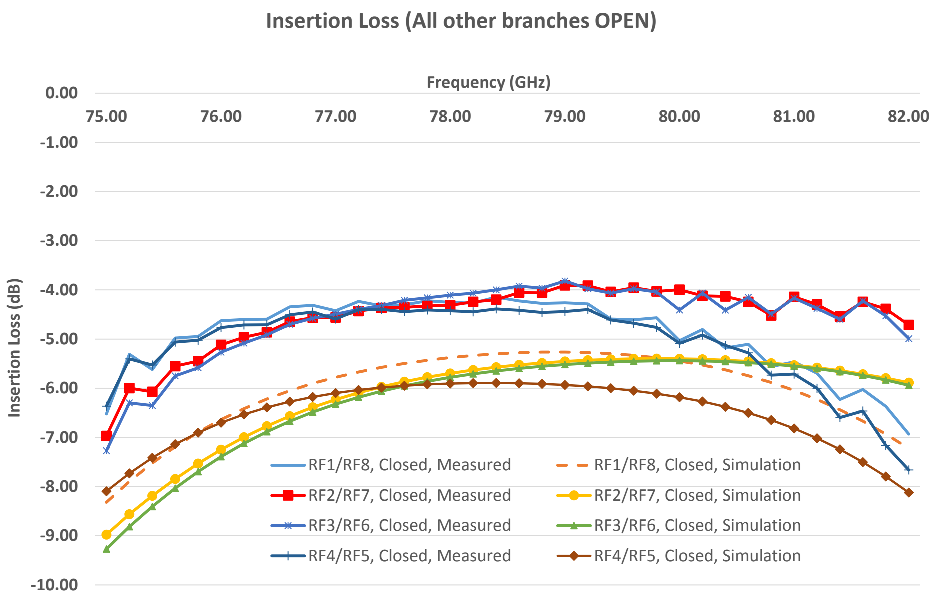
Process Technology

United Monolithic Semiconductors (UMS) BES process is used for the design and fabrication of the SP8T switch. It is the 100 μm substrate thickness GaAs Schottky Diode Technology process that has diodes operating up to 3 THz [11]. The minimum and maximum anode widths that can be used are 3 μm and 10 μm. The diode used exhibits low junction capacitance and series resistance. The maximum negative anode-cathode voltage is -3.5 V and maximum forward current/finger is 2.5 mA. The DC operating point for the diode was selected based on these limits. The PDK consisting of active and passive component models was used for the electrical design and layout of the SP8T. The circuit was fabricated at UMS and has a dimension of 3.38 mm $\times$ 4.2 mm (Figure 3). The circuit draws a maximum of 10 mA current in ON state and has a maximum input power handling capability of 22.0 dBm.

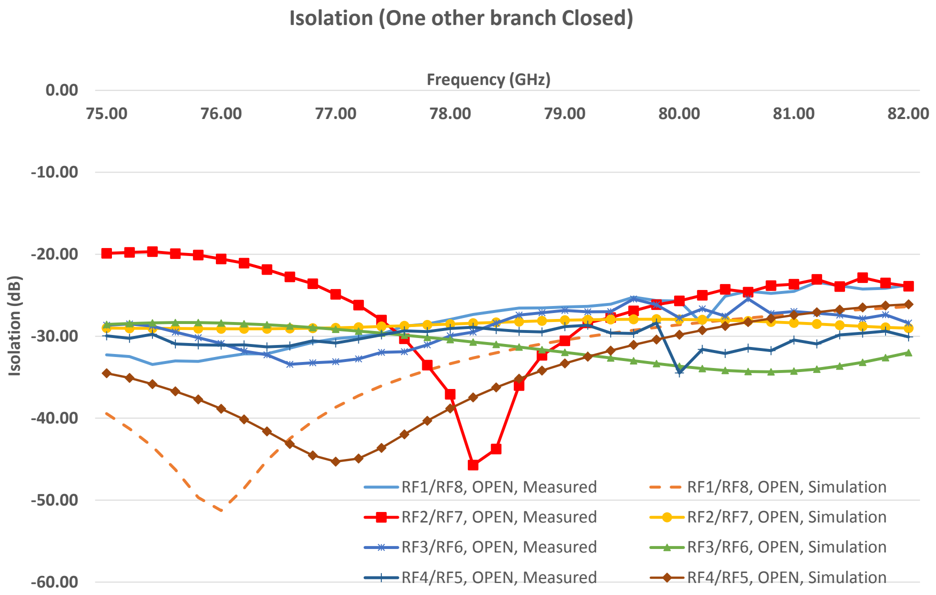
SIMULATION AND ON-WAFER MEASUREMENT RESULTS

On-wafer two-port S-parameter measurements of the SP8T MMIC were performed as a foundry service. Probe-tip on-wafer calibration was applied before performing the measurements. Since the circuit design is symmetrical, output ports 1 to 4 were measured individually by keeping all the other ports OPEN. Comparison of various small signal measurements of the fabricated chip with EM simulation of the design are shown in Figures 4 and 5.

Figure 4a shows the insertion loss, Figure 4b shows the port-to-port isolation of the circuit and Figure 5a shows the input return loss of the circuit. One of the important requirement of the system application of a multi-throw switch is to provide a good match at the OPEN branches, i.e., when they are not conducting. As shown in Figure 5b, the achieved measured isolated port return loss is $\geq$ 13.0 dB highlighting that the designed MMIC SP8T switch performs well in this aspect.

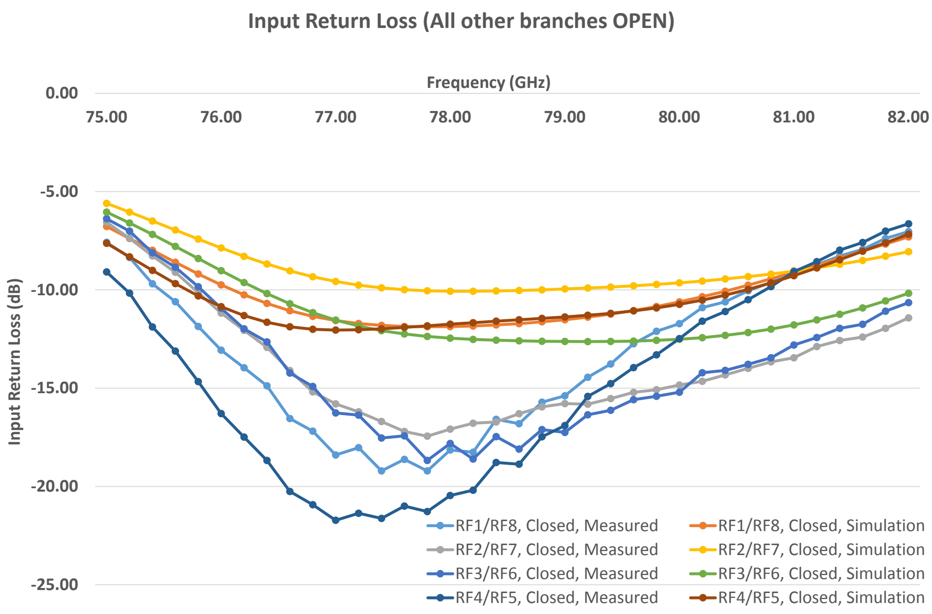


(a)

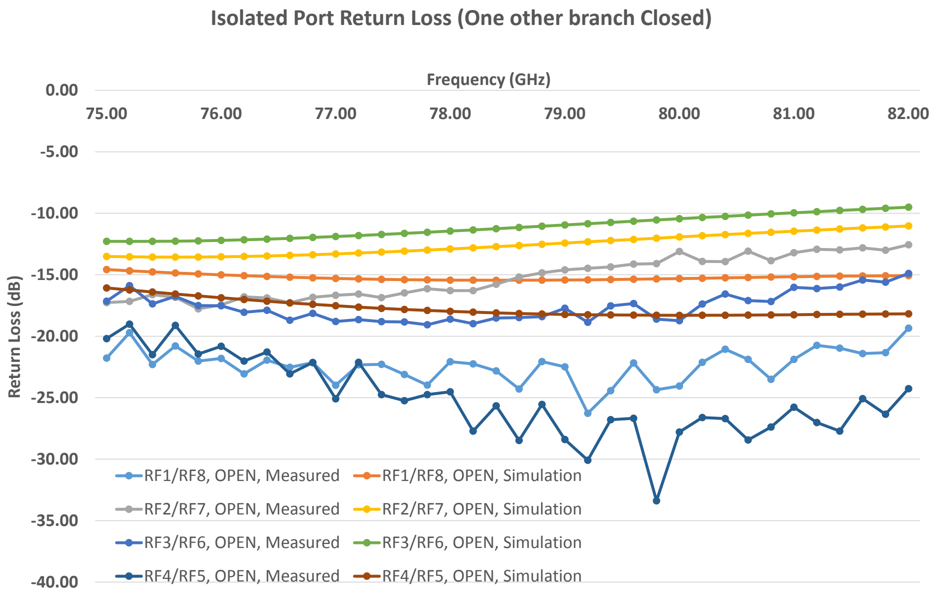


(b)

Figure 4: Comparison of Simulated and Measured (a) Insertion Loss (dB) and (b) Isolation (dB) of SP8T MMIC in the frequency band of 76–81 GHz. The measured IL is 4.7 ± 1.0 dB, while the simulated is 6.3 ± 1.0 dB showing an improvement of 1.6 dB. Simulated isolation is ≥ 24.5 dB while measured is ≥ 20.0 dB in 76–81 GHz band. The measured isolation, although 5.0 dB lower than simulated, still satisfies required specification.



(a)



(b)

Figure 5: Comparison of Simulated and Measured (a) Input Return Loss (dB) and (b) Isolated Port Return Loss (dB) of SP8T MMIC in the frequency band of 76–81 GHz. The measured input return loss of the fabricated chip is $\geq$ 9.3 dB, while simulated input return loss is $\geq$ 7.6 dB exhibiting an improvement by 1.7 dB in the input match. The measured isolated port return loss is $\geq$ 13.0 dB, while, simulated is $\geq$ 10.0 dB, hence, exhibiting an improvement of 3.0 dB.

CONCLUSION

The design, simulation and on-wafer measured results of a GaAs SP8T switch MMIC have been discussed in this work. The switch provides low insertion loss of 4.7 $\pm$ 1.0 dB with isolation better than 20.0 dB and input and output return losses better than 9.5 dB and 13.0 dB respectively in the frequency range of 76–81 GHz. The power handling capability of the switch is 22.0 dBm and it draws a maximum of 10 mA current in the ON state. The fabricated chip has a dimension of 3.38 mm $\times$ 4.2 mm. This SP8T switch MMIC is the only commercially available chip with such a low insertion loss in the frequency range of 76–81 GHz.

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