Compact W-band SPQT MMIC Switch Using Traveling Wave Concept

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Abstract — **A high performance W-band single-pole-quadruple-throw (SPQT) switch with a compact chip size using GaAs HEMT is demonstrated. This SPQT switch has a measured insertion loss of 3.9-5.5 dB and isolation higher than 30 dB from 70 to 102 GHz. A minimum insertion loss of 3.9 dB with isolation higher than 30 dB was measured at 90 GHz.**

I. Introduction

Recently with the rapid development of the millimeter-wave communication and radar systems, transmitter/receiver (T/R) switches playing an important role to control the RF signal flow. For these applications, high-performance and small-size switches for low-cost monolithic microwave integrated circuit (MMIC) production are required.

Many millimeter-wave switches have been reported [1]-[8]. Passive HEMT switches are popular because of their good performance and almost zero power consumption. SPQT switch in [3] has insertion loss less than 3 dB and the isolation in the range of 35-45 dB from 41 to 45.5 GHz with chip size of 3.6 x 5 mm^2. Although this SPQT switch performs well in desired frequency, it is for a narrow-band application and with large chip area.

Switch designs utilize traveling-wave concept have wideband characteristics [7]-[8], thus in this paper we use this concept to design a SPQT switch in W-band. And in order to reduce chip area a difference from [3] is that we use a five-way combining junction instead of directly connecting SPDT switches to form this millimeter-wave SPQT switch. This switch was used to control the signal flow to feed antennas at four different directions in transmitter end. This MMIC switch performs well in desired frequency range with broadband characteristics and has a compact chip area (2 x 1 mm^2). This switch is fabricated using standard 0.15-μm GaAs HEMT process, and therefore it is easy to integrate with RF front-end components.

II. Device Characteristic

The HEMT device used in this design is the WIN standard 0.15-μm high-linearity InGaAs/AlGaAs/GaAs pHEMT MMIC process. The HEMT device has a typical unit current gain cutoff frequency (f_T) of 85 GHz and maximum oscillation frequency (f_{MAX}) is over 200 GHz. The gate–drain breakdown voltage is 10 V, and the peak drain current at 5-V drain–source voltage is 650 mA/mm. The wafer is thinned to 4 mil for gold plating of the backside and reactive ion etching via-holes are used for dc grounding. And these HEMTs bias in their passive mode have on-state resistance R_{on} = 18 Ω and off-state capacitance C_{off} = 0.019 pF

This work is supported in part by the Defense Industry Development Foundation of Taiwan, R. O. C. and National Science Council of Taiwan, R. O. C. (NSC 93-2752-E-002-002-PAE, and NSC 92-2213-E-002-069). The MMIC chip is fabricated by WIN Semiconductors.

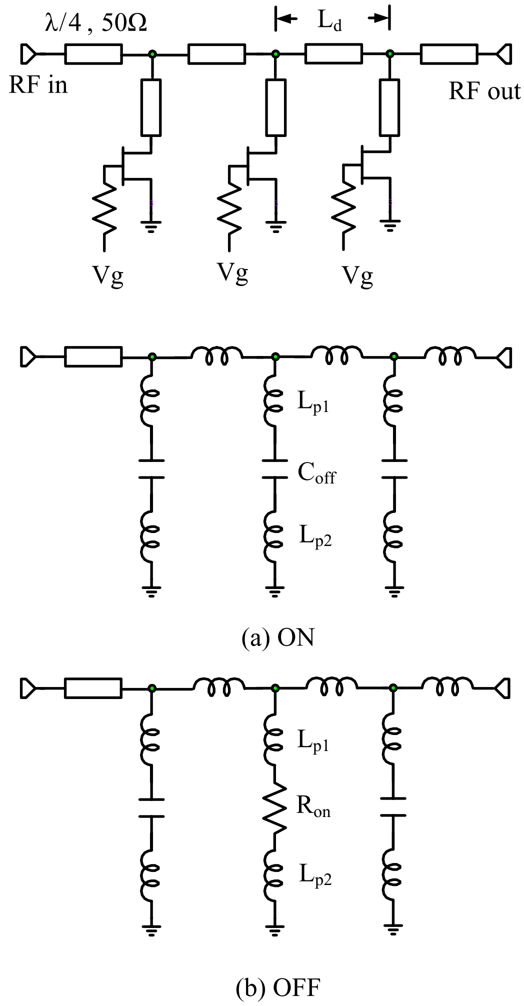
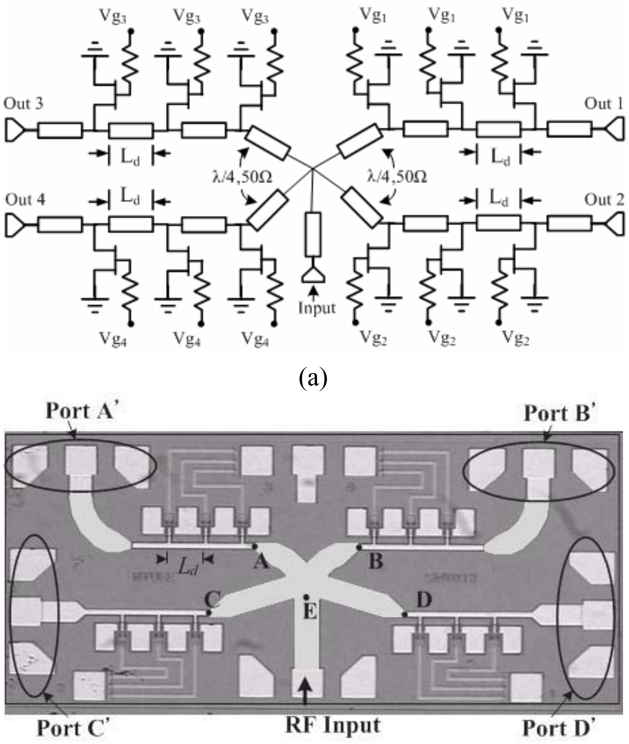


Fig. 1. Schematic of SPST switch and its simplified equivalent on&off models.



(a)

(b)

Fig. 2. (a) Circuit schematic, (b) chip photo of SPQT switch with a chip size of 2 x 1 mm^2.

III. CIRCUIT DESIGN

To accomplish this SPQT switch, we need to design a SPST switch first to form the basic block of SPQT switch. Fig. 1 shows the schematic of a SPST traveling-wave switch including parasitic inductance. The shunt transistors periodically load the inductive transmission line at an optimal distance (L_d) to form a distributed type switch. L_{p1} is the line inductance of the line connects the drain of HEMT device and the RF signal line, and L_{p2} is the via hole inductance (25 pH for each) at the source terminal. L_{p1} and L_{p2} are usually the major factors that cause the performance of traveling-wave switch to degrade at higher frequency. To reduce L_{p1} inductance we shorten the line connect the inductive transmission line and HEMT device to an optimal length that the coupling between RF signal lines and via-holes are not significant. L_{p2} inductance is unavoidable in our microstrip version design; however it can be eliminated in CPW version. When switch is off, a control voltage of 0 V is applied to the gate of the HEMTs, and high impedance will be seen at input terminal after the 50 Ω quarter-wave length transmission line; thus RF signal is blocked. When switch is on, a control voltage of -3 V is applied to gate terminals, and the three periodically shunt capacitors with inductive transmission lines form an artificial transmission line with 50 Ω characteristic impedance and thus RF signal can pass through. HEMT device of two finger 60-μm total gate periphery was chosen in this design (R_{on} = 18 Ω and C_{off} = 0.019 pF) for the consideration of lowering insertion loss at higher frequency.

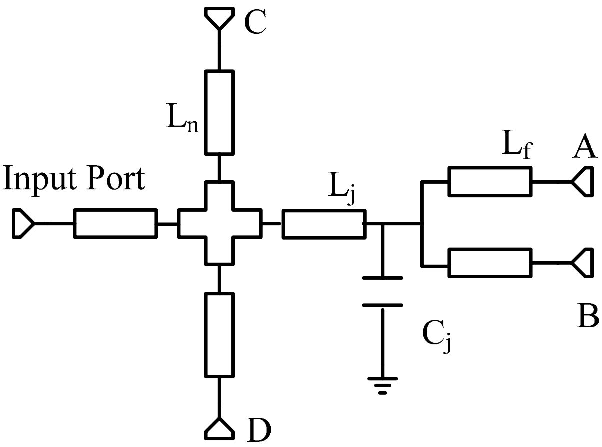


Fig. 3. Equivalent model of five-way junction

An important factor that will affect the insertion loss is the length of inductive transmission lines (L_d) that connect the shunt HEMT devices. The longer the L_d is the insertion loss of the switch will degrade more rapidly at higher frequency. Therefore, to lower the insertion loss in W-band we have to make the length as short as possible, but with the constraint of via-hole size of the transistor, the length (L_d) in layout is 108μm.

The SPQT switch is implemented on the basis of the SPST switch above. In order to minimize the chip area we use a five-way junction to combine these five arms (one input and four outputs) instead of using connected SPDT switches [3]. Fig. 2(a) and (b) show the schematic and layout of this SPQT switch; A', B', C' and D' are four RF signal output ports. And from points A, B, C and D to point E the equivalent electrical length is λ/4 at the center frequency (85 GHz). However, the area combines these five arms will unavoidably result in a junction capacitor. This junction capacitor cannot be ignored at our operating frequency that will add additional phase change from points A and B to point E. From the EM simulator Momentum, we construct the equivalent model of this five-way junction as shown in Figure 3 (C_j = 0.037 pF). To compensate the additional phase change, the physical lengths from points A and B to point E (L_j+ L_f) are shorter than that lengths from points C and D to point E (L_n).

IV. MEASUREMENT

The SPQT switch was measured via on-wafer probing. During testing only one of the outputs is on (through state) and the other three outputs are off (isolated state). Because this circuit has five ports, it is difficult for us to terminate all these ports with 50 Ω during testing. Thus, each time when testing, except one RF input port and two output ports (one through port and one isolated port) under testing are terminated with 50 Ω, the other two isolated ports are left open. If port A' is left open, the impedance looking into A to the arm with three shunt FETs at on-state is still low. And that will be transformed

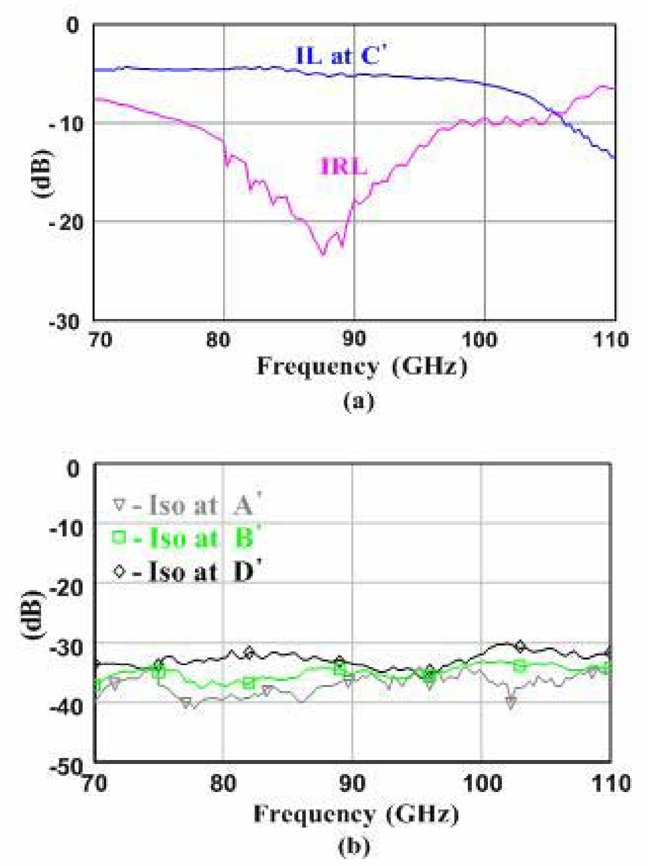


Fig. 4. (a) Measured IL at port C' and the IRL. (b) Measured isolations between input and A', B' and D' ports when C' is on.

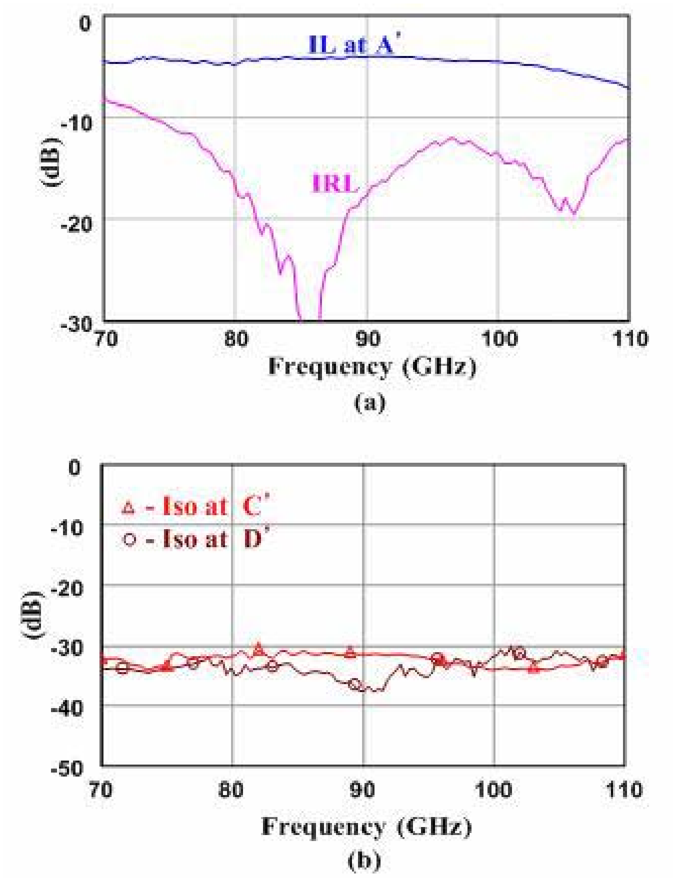


Fig. 5. (a) Measured IL at port A' and the IRL. (b) Measured isolations between input and C' and D' ports when A' is on.

into high impedance at point E after the λ/4 line, this is the same as port A' is terminated with 50 Ω. Therefore most RF signal still enter the through port, the two isolated ports that left open will have little effect to the other ports are under testing. We have also performed the simulations of the testing condition described above and obtained identical performances at the measuring ports for either all ports terminated with 50 Ω or two unmeasured isolated ports left open.

Figure 4 shows measured results when port C' (see Fig. 2(b)) is on and A', B' and D' are off. Figure 4(a) depicts the results of insertion loss between input and port C' and the input return loss; an insertion loss of 4.2-5.5 dB with input return loss better than 10 dB was measured at 77-95 GHz. The minimum insertion loss is 4.2 dB at 84 GHz. Figure 4(b) depicts the measured results of isolation between input and A', B' and D' ports when C' is on; measured isolations are all better than 30 dB from 70 to 110 GHz. Figure 5 gives measured results when port A' is on and B', C' and D' are off. In Fig. 5(a) the results of insertion loss between input and port A' was shown; an insertion loss of 3.9-5 dB with input return loss better than 10 dB was measured at 73-102 GHz. The minimum insertion loss is 3.9 dB at 90 GHz. Figure 5(b) presents the measured results of isolation between input and C' and D' ports when A' is on; measured isolations are all better than 30 dB from 70 to 110 GHz. Since A' and B' ports are on the same side of the chip, we cannot put our probes on the two ports at the same time. Thus, the isolation data from input to port B' was not measured when port A' is on (terminated with 50 Ω).

V. Conclusion

A single-pole-quadruple-throw (SPQT) switch has been realized and tested in W-band using passive HEMTs, and which has a compact chip size of 2 x 1 mm^2. An insertion loss of 3.9-5 dB with input return loss better than 10 dB was measured between 73-102 GHz at port A' and B', and an insertion loss of 4.2-5.5 dB with input return loss better than 10 dB was obtained between 77-95 GHz at port C' and D'. And all the ports in their off state have isolations better than 30 dB from 70 to 110 GHz. To the best of our knowledge, this is the first MMIC SPQT switch demonstrated in W-band.

Acknowledgement

The chip is fabricated by WIN Semiconductors through Chip Implementation Center of Taiwan. The authors would like to thank Mr. G. G. Boll of GGB Corporation for his providing the W-band RF probes.

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