Millimeter-wave MMIC Switches with pHEMT Cells Reduced Parasitic Inductance

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Abstract — **High isolation millimeter-wave switches have been successfully developed using a newly developed line unified shunt pHEMT structure, which is effective to reduce parasitic inductance of its short circuit. The developed V-band SPDT switch shows an isolation of greater than 40 dB and an insertion loss of 1.8 dB at 60 GHz, and the W-band SP3T switch shows an isolation of greater than 35 dB and an insertion loss of 2.5 dB at 77 GHz. Input and output return losses are better than 12 dB in ON-state. These performances of high isolation and low insertion loss are the best among V-band and W-band pHEMT MMIC switches. The switches consume no DC power, and require no complex off-chip bias circuitry.**

I. INTRODUCTION

Millimeter-wave switches are one of the key elements in developing transmitter/receiver modules for many mm-wave systems such as automotive applications. Most of these systems require switching to occur between an antenna and the transmit or receive circuitry.

Recently, several PIN diode switch MMICs[1-3], high isolation switches[4-5], and traveling-wave switches[6] have been reported. Passive HEMT switches offer the benefits of low power consumption, which is important for these systems and applications. However, the switches employed a shunt configuration, which degrades isolation at the mm-wave frequency range for the increase of impedance by parasitic inductance of shunt FET [7]. Thus, the reduction of parasitic inductance of the FET is of foremost importance in realizing good isolation performance.

In this paper, we propose a newly developed line unified shunt pHEMT structure which has a sufficiently low parasitic inductance of 10 pH. By incorporating this structure, a high isolation V-band SPDT MMIC switch, W-band SP3T switch, and W-band SPDT switch have been developed for mm-wave applications to demonstrate the superiority of the structure.

II. PHEMT CELL REDUCED PARASITIC INDUCTANCE

Figure 1 shows a schematic diagram of a conventional shunt FET switch. Isolation of the switch strongly depends on the parasitic inductance of shunt FET [7]. Figure 2 shows a schematic diagram of the ON-state shunt FET. In order for the switch to achieve high isolation performance in the millimeter-wave band, the impedance of the ON-state shunt FET should be low. Figure 3 shows the developed switch layouts (STEP1, 2) and conventional switch layout.

STEP1. The pHEMT is unified in the RF signal line. This structure effectively minimizes the distance between source electrode and viahole. The parasitic inductance of the distance between source electrode and viahole is estimated to be negligibly small.

STEP2. The source electrode is connected to double viaholes employed at both sides of the RF signal line.

Figure 4 shows measured isolation and insertion loss of the newly developed switch by fabricating the test layout (STEP2) compared with the developed switch (STEP1). The parasitic inductance of the developed switch is estimated to be only 10 pH, which is less than 1/2 that of the STEP1 switch. Thus, isolation and insertion loss are dramatically improved at mm-wave frequencies by adopting a double viaholes shunt FET structure. Also for the high isolation mm-wave switches, the improved pHEMT equivalent circuit model, which considers parasitic components such as electrode configuration, was used.

III. CIRCUIT DESIGN

The design target was an on/off ratio of greater than 30 dB. Figure 5 shows the measured results of isolation and

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insertion loss of the single switch circuit for the gate widths at 77 GHz.

Gate width of 160 μm was selected for shunt pHEMT to realize 30 dB isolation using two stage switch with the smallest insertion loss. For the 160 μm (40 μm x 4) pHEMT, Ron and Coff were 7 ohms and 47 fF respectively. Ron is on-resistance and Coff is off-capacitance of pHEMT.

Figure 6 shows the equivalent circuits of V-band SPDT and W-band SP3T switches. These are all two-stage structures using a 1/4-wavelength line between the feed-point and the first shunt pHEMTs.

IV. Results

Photographs of the completed MMIC switch are shown in Fig.7. Chip sizes are 1.0 mm x 2.0 mm for the V-band SPDT, 1.25 mm x 1.65 mm for the W-band SP3T, and 0.8 mm x 1.65 mm for the W-band SPDT. The substrate thickness is 100 μm. These switches operate with 0 V/-3 V bias supply.

RF performances of the fabricated MMIC switches were measured by using an on-wafer probing system.

A. V-band SPDT

Figure 8 shows measured insertion loss in the ON-state and isolation in the OFF-state. The insertion loss was less than 1.8 dB at 60 GHz. The isolation was greater than 40 dB. Figure 9 shows input and output return losses in the ON-state. The input and output return losses are higher than 12 dB.

B. W-band SP3T

Figure 10 shows measured insertion loss in the ON-state and isolation in the OFF-state. The insertion loss was less than 2.5 dB at 77 GHz. The isolation was greater than 35 dB at 77 GHz. Figure 11 shows input and output return losses in the ON-state. The input and output return losses are higher than 12 dB. Good agreement between the measured and simulated data has been achieved.

C. W-band SPDT

Figure 12 shows measured insertion loss in the ON-state and isolation in the OFF-state. The insertion loss was less than 2.5 dB at 77 GHz. The isolation was greater than 30 dB. Figure 13 shows input and output return losses in the ON-state. The input and output return losses are higher than 12 dB.

V. Conclusion

High isolation mm-wave switches have been successfully developed with GaAs pHEMT cell that employs a reduced parasitic inductance structure. The newly developed switch layout has a sufficiently low inductance of 10 pH, which is less than half that of a developed cell. By decreasing the parasitic inductance, RF performance of the switch was dramatically improved especially in the mm-wave frequency range. The developed V-Band SPDT shows an isolation of greater than 40 dB and an insertion loss of 1.8 dB at 60 GHz. A W-band SP3T switch shows an isolation of grater than 35 dB and insertion loss of 2.5 dB at 77 GHz. These performances of high isolation and low insertion loss are the best among V-band and W-band pHEMT MMIC switches.

References

[1] M. Case, M. Matloubian, H. C. Sun, D. Choudhury, and C.Ngo, "High-Performance W-Band GaAs PIN Diode Single-Pole Triple-Throw Switch CPW MMIC," *IEEE MTT-S Int. Microwave Symp. Dig.*,vol.2, pp. 1047-1050, June 1997.

[2] E. Alekseev, D..Pavlidis, J. Dickmann, and T. Hackbarth, "W-band InGaAs/InP PIN Diode Monolithic Integrated Switches," *IEEE GaAs IC Symp. Dig.*, pp. 285-288, November 1996.

[3] J. Putnam, M.Barter, K. Wood, and J. LeBlane, "A Monolithic GaAs PIN Switch Network For A 77GHz Automotive Collision Warning Radar," *IEEE MTT-S Int. Microwave Symp. Dig.*,vol.2, pp. 753-756, June 1997.

[4] T. Shimura, Y. Mimino, K. Nakamura, Y. Aoki, and S. Kuroda, "High Isolation V-Band SPDT Switch MMIC for High Power Use, " *IEEE MTT-S Int. Microwave Symp. Dig.*,vol.1, pp. 245-248, May 2001.

[5] E. Alekseev, D.Pavlidis, "77Ghz High-Isolation Coplanar Transmit-Receive Switch Using InGaAs/InP PIN Diodes," *IEEE GaAs IC Symp. Dig.*, pp. 177-180, November, 1998.

[6] H. Mizutani, Y. Takayama, "DC-110-GHz MMIC Traveling-Wave Switch, " *IEEE TRANS. on Microwave Theory and Tech.*, vol.48, No.5, pp. 840-845, May 2000.

[7] K. Nakahara, K. Miyaguchi, M. Hieda, H. Kurusu, Y. Iyama, and T. Takagi, "SWITCHES WITH CAPACITOR CANCELLED PARASITIC INDUCTANCE OF FET," *IEEE MTT-S Int. Microwave Symp. Dig.*,vol.1, pp. 249-252, May 2001.

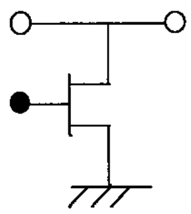


Fig.1. Schematic diagram of conventional shunt FET switch.

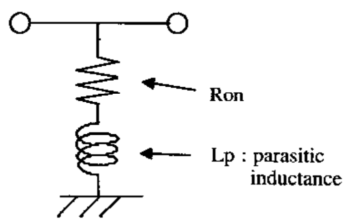


Fig.2. Schematic diagram of ON-state shunt FET as OFF-state of switch.

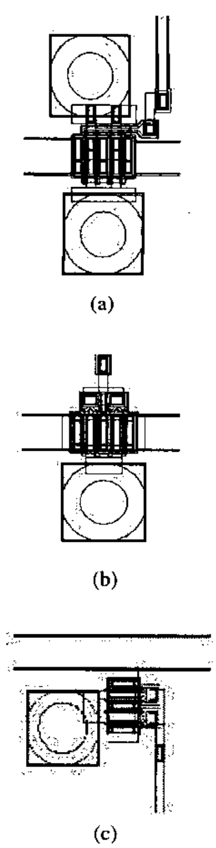


Fig.3. The shunt pHEMT cell layouts.
(a) Newly developed layout (STEP2).
(b) Developed layout (STEP1).
(c) Conventional.

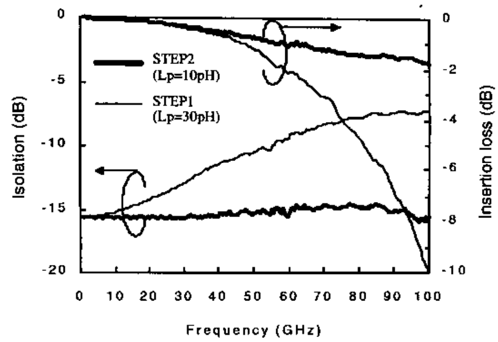


Fig.4. Measuerd data of newly developed switch (STEP2) compared with the developed switch (STEP1).

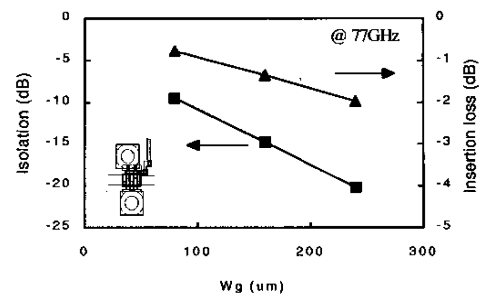


Fig.5. Measuerd data of newly developed switch (STEP2) for gate width at 77GHz.

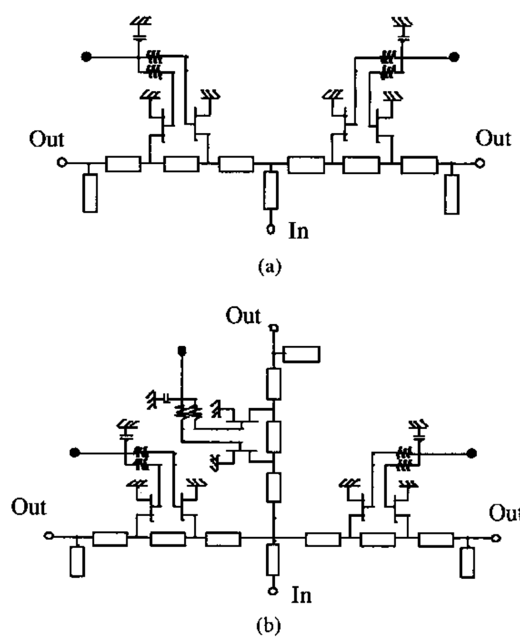
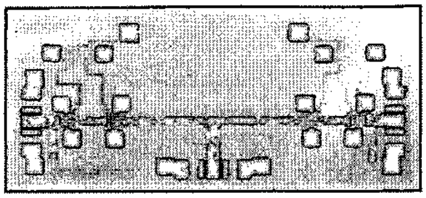
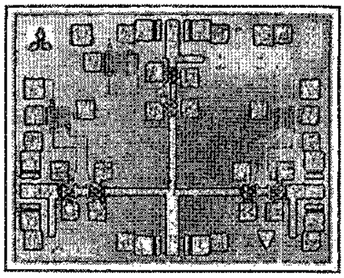


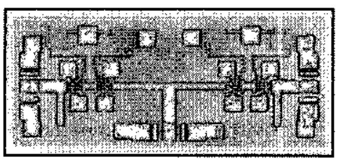
Fig.6. Equivalent circuits of (a) V-band SPDT and (b) W-band SP3T .



(a) V-band SPDT switch (1.0mm x 2.0mm).



(b) W-band SP3T switch (1.25mm x 1.65mm).



(c) W-band SPDT switch (0.80mm x 1.65mm).

Fig.7. Photograph of the MMIC switches.

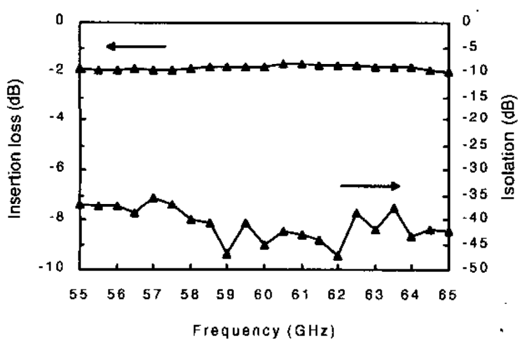


Fig.8. Insertion loss in the ON-state and isolation in the OFF-state performances of the V-band SPDT.

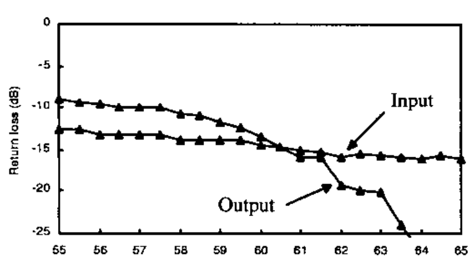


Fig.9. Input and output return losses in the ON-state performances of the V-band SPDT.

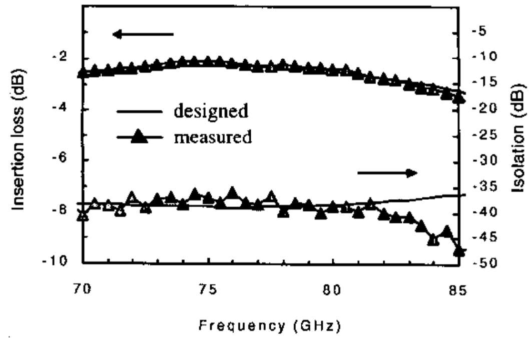


Fig.10. Insertion loss in the ON-state and isolation in the OFF-state performances of the W-band SP3T.

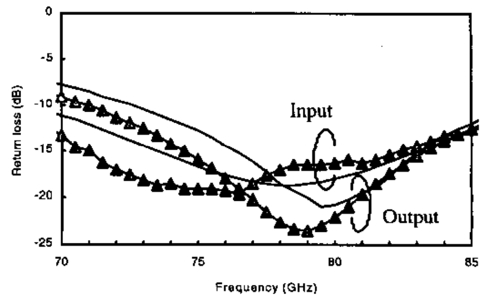


Fig.11. Input and output return losses in the ON-state performances of the W-band SP3T.

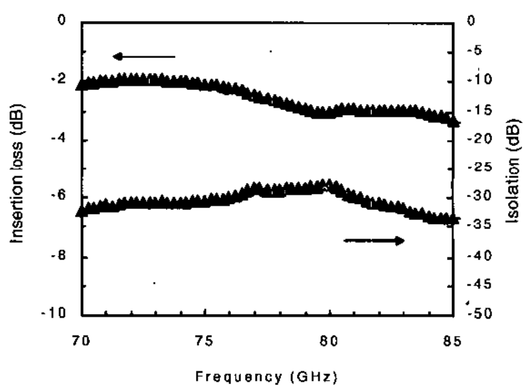


Fig.12. Insertion loss in the ON-state and isolation in the OFF-state performances of the W-band SPDT.

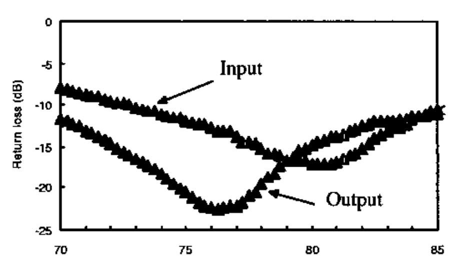


Fig.13. Input and output return losses in the ON-state performances of the W-band SPDT.