High Isolation V-Band SPDT Switch MMIC for High Power Use

Tadayuki SHIMURA, Yutaka MIMINO, Kannichi NAKAMURA

Yoshio AOKI and Shigeru KURODA

FUJITSU QUANTUM DEVICES LIMITED

Hachiohji Daiichi-Seimei Bldg., 11F 3-20-6 Myoujin-cho, Hachiohji-shi Tokyo 192-0046, JAPAN

***Abstract* — This paper presents design and performance of a V-band SPDT switch MMIC for high power use. The switch design utilizes distributed 5-shunt diodes. The developed SPDT switch shows an isolation of greater than 32dB and an insertion loss of less than 1.8dB in a broadband frequency range from 50GHz to 70GHz. Input and output return losses are better than 9dB in ON-state. The chip size is 2.65mm x 1.33mm. The power-handling capability was confirmed to be higher than 10dBm of input power at 60GHz. To our knowledge, this total broadband performance of high isolation and low insertion loss, as well as the high power-handling capability is the best one among V-band SPDT switch MMICs so far.**

I. Introduction

Transmitter/receiver switch is a very important function for many mm-wave communication systems including the 60GHz P to P system. Required is a V-band switch with low insertion loss, high isolation, broadband frequency range and high power-handling capability [1]-[3]. For these requirements, it is necessary for active devices to have low on-resistance and low off-capacitance characteristics.

This paper describes the design and evaluation of a V-band SPDT switch MMIC using our current process technology for millimeter wave MMIC [6]. It is easy to combine the switch with other functions in one MMIC. The diode is fabricated by source-drain shorted HEMT. The advantage of this diode is its low off-capacitance and enables high isolation performance at mm-wave frequencies. We applied a novel parallel connection of shunt diode circuit structures to reduce the total on-resistance, and optimized the distributed transmission lines connecting the diodes.

Fig. 1 shows the insertion loss and isolation data of V-band and W-band SPDT switch MMICs [1]-[5]. Our SPDT switch MMIC exhibits both high isolation and an associated low insertion loss. Obtained performance of the distributed 5-shunt diodes circuit shows excellent high isolation, low insertion in broadband and high power-handling capability.

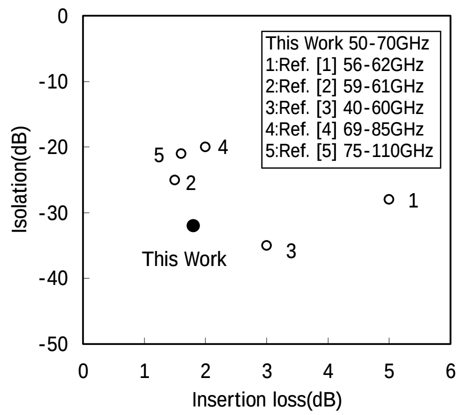

Fig. 1. Comparison of Insertion loss and isolation of V-band and W-band SPDT switch MMICs.

II. CIRCUIT DESIGN

We used a 0.15μm gate-length HEMT as diode. The process technology is the same as our millimeter-wave MMIC process [6]. Our mm-wave HEMT has low off-capacitance because it has very low Schottky capacitance, which is adequate for mm-wave use. The diode is fabricated by source-drain shorted HEMT. The on-resistance of diode is lower than that of HEMT for use as switch device. Though the HEMT based diode has higher on-resistance than PIN diode [4]-[5], the advantage of the diode is the ease to combine with other function in one MMIC.

There are two fundamental switch configurations, which are series and shunt. The series-shunt structure are usually used. Fig. 2 shows a schematic circuit diagram of the SPDT switch we developed. This SPDT is diode based reflective switch. It has shunt configurations connected with quarter wavelength transformers. A high on-resistance causes serious decrease in isolation by the shunt switch. For high isolation, we used parallel shunt diodes. The finger size of each diode is 40μm x 2. Fig 3 shows the equivalent circuit of our SPDT switch for the case of OUT1 is in the OFF-state and OUT2 is in the ON-state. Ron is on-resistance of the diode and Coff is off-capacitance of the diode. For the 40μm x 2 finger diode, Ron and Coff were measured 9ohm and 35fF. The total impedance of a path decreases as the number of the shunt diode increases and also isolation improves. Fig. 4 shows the simulation results for isolation against the number of diodes. The 5 shunt diodes scheme exhibits an isolation of greater than 30dB at V-band. Total gate width of the 5 shunt diodes is enough for 20dBm power-handling capability.

However, the insertion loss increases because the parallel shunt diodes increase the off-capacitance. In order to get a lower insertion loss without reducing the total gate width, we used distributed circuit topology. We connected the shunt diodes distributively. Transmission line length L2 between shunt diodes was optimized to obtain an insertion loss as low as 2dB. Fig. 5 shows the simulation results on insertion loss against L2. We chose L2 = 200μm to achieve the insertion loss in the V-band.

For reduction of chip size, transmission line length L1 of input side is set shorter than quarter wavelength by using an open stub.

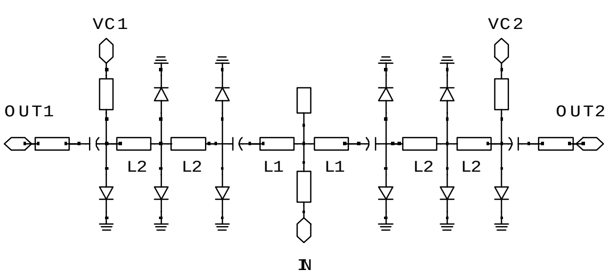

Fig. 2. Schematic circuit diagram of the SPDT switch.

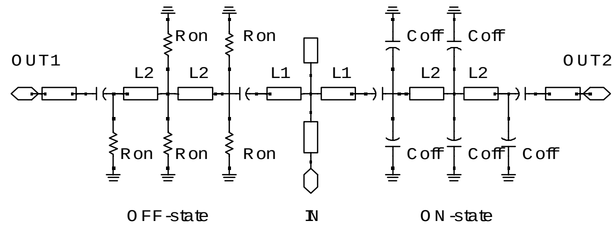

Fig. 3. The equivalent circuit of the SPDT switch for the case of OUT1 is in the OFF-state and OUT2 is in the ON-state.

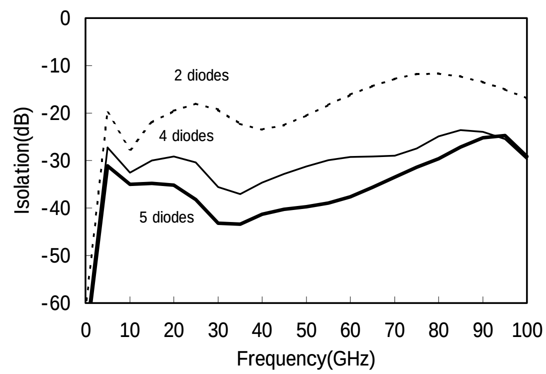

Fig. 4. Simulated isolation vs. frequency for several the number of diodes.

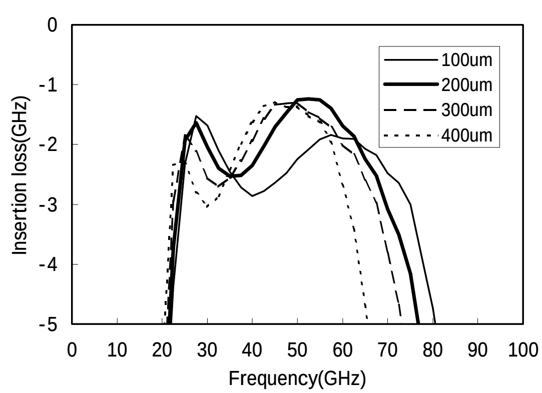

Fig. 5. Simulated insertion loss vs. frequency for L2.

III. PERFORMANCE

The SPDT was fabricated using the 0.15μm gate-length HEMT millimeter-wave MMIC process. Fig. 6 shows the photograph of the developed V-band SPDT MMIC switch chip. Chip size is 2.65mm x 1.33mm. The substrate thickness is 75μm.

RF performances of the fabricated MMIC switch were measured from DC to 100GHz by using an on-wafer probing system. One output port was terminated with 50ohm. Fig. 7 shows small signal performances of the insertion loss in the ON-state and the isolation in the OFF-state. The bias at ON-state is -2.0V and the bias at OFF-state is 1.0V. The measured insertion loss was less than 1.8dB from 50 to 70GHz. The minimum insertion loss is 1.3dB at 66.5GHz. The measured isolation was greater than 32dB from 11.5 to 73GHz. The maximum isolation in V-band was 41.3dB at 68.5GHz. Fig. 8 shows input and output return losses in the ON-state. The measured input and output return losses are higher than 9dB from 50 to 76GHz. We obtained an extremely low insertion loss and high isolation in the broadband frequency range from 50 to 70GHz. The small signal simulation indicates close agreement with the measured data.

Fig 9 shows the large signal performance at 60GHz for both ON and OFF states. One output port was terminated with 50ohm. Any degradation in the insertion loss and the isolation was not observed up to 10dBm CW input power, which is the limitation of our measurement equipment. Potential maximum input power at 60GHz is more than 10dBm. A non linear simulation indicated good agreement with the measured data. In our simulation, the 1dB compression point for an input power is measured 20dBm.

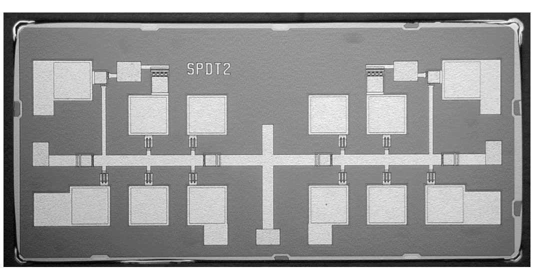

Fig. 6. Photograph of the SPDT switch MMIC. Chip size is 2.65mm x 1.33mm. Substrate thickness is 75μm.

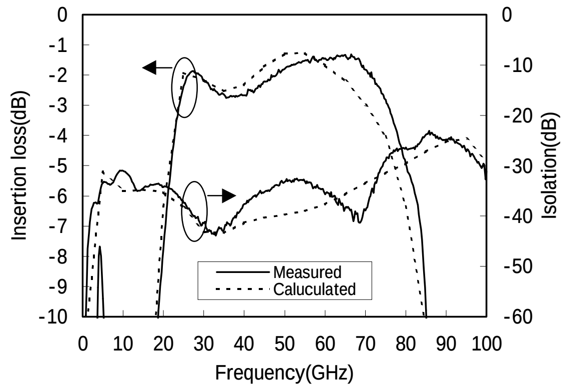

Fig. 7. Insertion loss in the ON-state and isolation in the OFF-state characteristics of the SPDT switch.

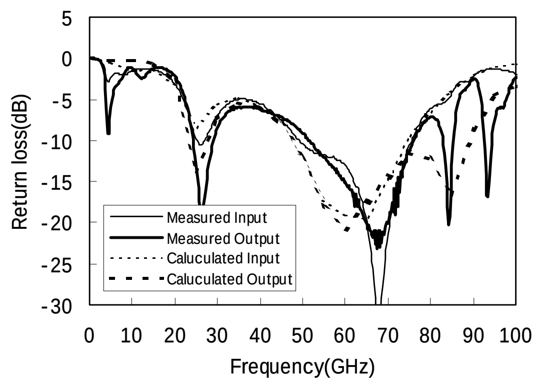

Fig. 8. Input and Output return losses in the ON-state characteristics of the SPDT switch.

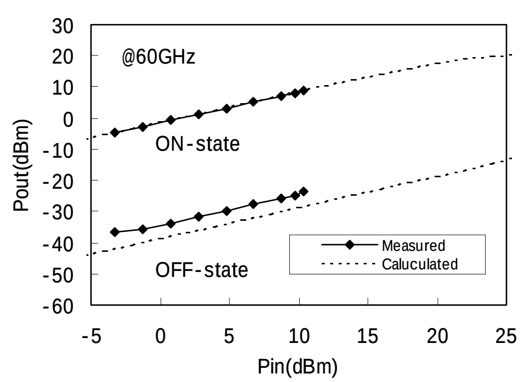

Fig. 9. Power characteristics of the SPDT switch.

IV. CONCLUSION

We have demonstrated a V-band SPDT switch MMIC using our current process technology. For high isolation, we used parallel 5-shunt diodes in circuit. For low insertion loss, we used distributed circuit technique.

This V-band SPDT switch MMIC has a high isolation of greater than 32dB and a low insertion loss of 1.8dB at frequencies from 50GHz to 70GHz. The power-handling capability was confirmed up to 10dBm of input power.

This broadband performance and high power-handling capability are valuable for the emerging millimeter-wave applications.

ACKNOWLEDGEMENT

The authors would like to thank Dr.T.Tokumitsu and Mr.K.Sakamoto for continuous encouragement throughout this work.

REFERENCES

[1] M. Madihian, L. Desclos, K. Maruhashi, K.Onda, and M. Kuzuhara, "A Sub-Nanosecond Resonant-Type Monolithic T/R Switch for Millimeter-Wave Systems Applications," *IEEE Trans. Microwave Theory and Tech.*, vol46, no. 7, pp. 1016-1019, July 1998.

[2] G. L. Lan, D. L. Dunn, J. C. Chen, C. K. Pao, and D. C. Wang, "A HIGH PERFORMANCE V-BAND MONOLITHIC FET TRANSMIT-RECEIVE SWITCH," *IEEE Microwave and Millimeter-Wave Monolithic Circuits Symposium.*, vol46, no. 11, pp. 99-101, May 1998.

[3] S. Nam, D. L. Raynes, and I. D. Robertson, "A PROGRAMMABLE HIGH ISOLATION MONOLITHIC MILLIMETER-WAVE SPST SWITCH," *IEEE MTT-S Digest.*, pp. 501-504, 2000.

[4] A. Klaassen, and J. -M. Dieudonné, "77GHz Monolithic MMIC Schottky- and PIN-Diode Switches Based on GaAs MESFET and Silicon SIMMWIC Technology," *IEEE MTT-S Digest.*, pp. 1631-1634, 1995.

[5] F. Steinhagen, H. Massler, W. H. Haydl, A. Hülsmann, and K. Köhler, "Coplanar W-Band SPDT and SPTT Resonated PIN Diode Switches," European Microwave Conference *Digest.*, pp. 53-56, 1999.

[6] Y. Mimino, M. Hirata, K. Nakamura, K. Sakamoto, Y.Aoki, and S. Kuroda, "HIGH GAIN-DENSITY K-BAND P-HEMT LNA MMIC FOR LMDS AND SATELLITE COMMUNICATION," *IEEE MTT-S Digest.*, pp. 17-20, 2000.