A 1chip RF Transceiver MMIC for ETC with Surface Via-Hole Isolation Technique

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Abstract **— An RF Transmitter Receiver MMIC (TX-RX MMIC) with 16-pins plastic package has been firstly developed for 5.8GHz Japanese Electronic Toll Collection system (ETC). The MMIC contains following RF blocks; local buffer amplifier, variable attenuator, ASK modulator, power amplifier, low-noise amplifier, down-converter, local switch and antenna switch. We have developed the new Surface Via-Hole (SVH) isolation technique to integrate all RF circuits into single chip. The double hetero-junction modulation doped FETs (MODFETs) and $SrTiO_3$ (STO) MIM capacitors are also developed to realize a single voltage operation and small chip size. By using SVH isolation technique, low carrier leakage of –43dBm, high on/off ratio of 39.6dB at 5.84GHz and low total current of 150mA are achieved, and the practical small chip size (2.25 x 1.25mm^2) is realized.**

I. Introduction

ETC allows car drivers to go through a tollgate without stopping by the two-way wireless communication at 5.8GHz between a tollgate and a car. The test operation has already begun on the Odawara-Atsugi highway in Japan on March 31 2000. ETC is expected to relieve congestion at tollgates on toll roads.

Although there are strong demands of 1chip TX-RX MMIC with single voltage operation to realize compact and low-cost on-board equipments, no 1chip TX-RX MMIC for ETC has been reported because of the degradation of the RF block isolation [1],[2]. We have successfully developed 1chip TX-RX MMIC for ETC by integrating each RF block without the degradation of isolation due to Surface Via-Hole (SVH) isolation technique.

II. DESIGN

Figure 1 shows the block diagram of the TX-RX MMIC. The MMIC integrates following RF blocks; Local Buffer Amplifier (LBA), Variable Attenuator (VA), Amplitude Shift Keying (ASK) modulator, Power Amplifier (PA), Low-Noise Amplifier (LNA), down-converter, local switch (LO-SW) and antenna switch (ANT-SW). LBA, PA and LNA are all 2-stage amplifiers. LO-SW and ANT-SW are SPDT-switches, and ASK modulator is an SPST-switch. Down converter is a passive Resistive mixer (R-mixer).

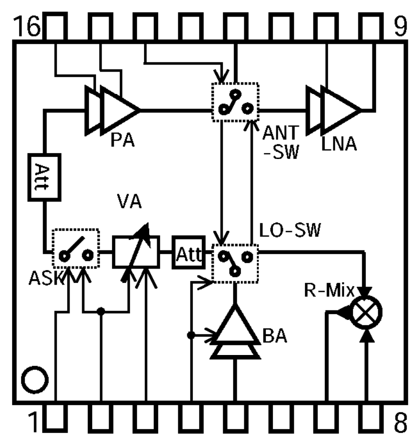

Figure 1 Block diagram of the TX-RX MMIC

In order to integrate all RF blocks in an MMIC with small chip size, SVH isolation technique has been developed. The SVH can be formed with very small diameter and placed everywhere on the MMIC. Figure 2 shows the cross-sectional view of the SVH. The diameter of SVH is 70 um, and the thickness of the GaAs wafer is 100um. The Au metal of about 4um thickness is plated.

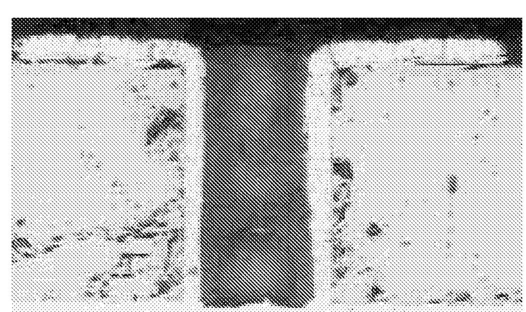

Figure 2 Cross-sectional view of the SVH

We calculated the relation of SVH spacing and isolation using electro-magnetic simulator. Figure 3 and Figure 4 show the simulation model and the results of the simulation respectively.

It is shown from Figure 4 that the isolation of 60dB is obtained by 150 um SVH spacing, while the isolation of 43dB is obtained without SVHs. Since our MMIC needs about 5dBm of LBA output, and carrier leakage must be less than –30dBm, we supposed that the minimum isolation of 45dB is required to prevent parasitic interference between RF blocks. We determined the maximum spacing of SVHs for isolation to be 400um from Figure 4.

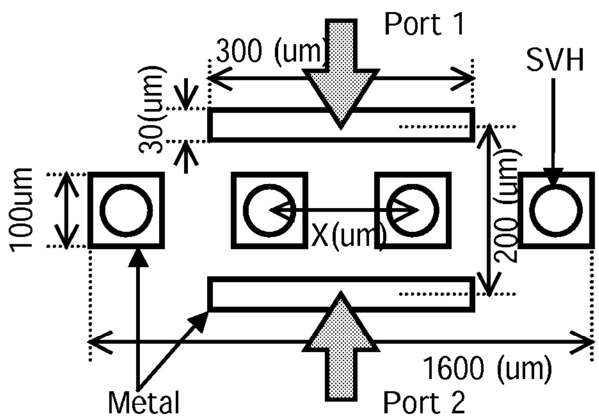

Figure 3 Simulation model on isolation with SVHs

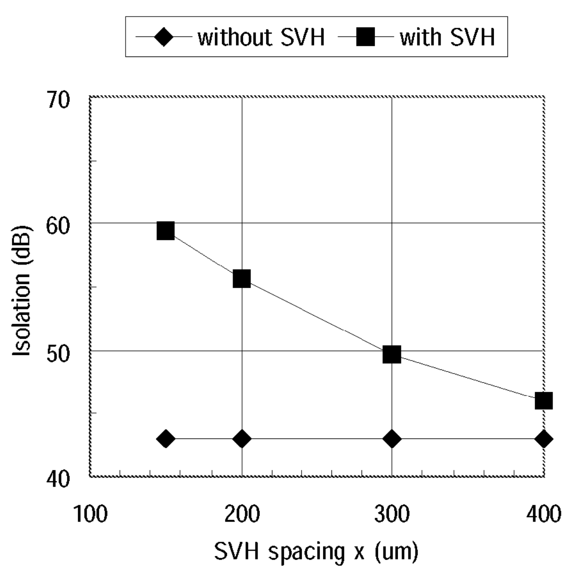

Figure 4 Results of electro-magnetic simulation

To realize the single voltage operation, shallow threshold voltage (Vth) and high maximum drain current is necessary, therefore, we have employed double hetero-junction modulation doped FETs (MODFETs) for the MMIC. The Vth is about –0.4V.

For the low-cost matching circuits, we have successfully developed high dielectric constant $SrTiO_3$ Metal-Insulator-Metal (STO MIM) capacitors on the epitaxial GaAs wafer. STO is formed by the low-temperature RF sputtering technique without degradation of hetero-junction. The relative dielectric constant of STO film is about 20 times larger than SiN, therefore, the STO MIM capacitors contribute to shrink the area of by-pass capacitors.

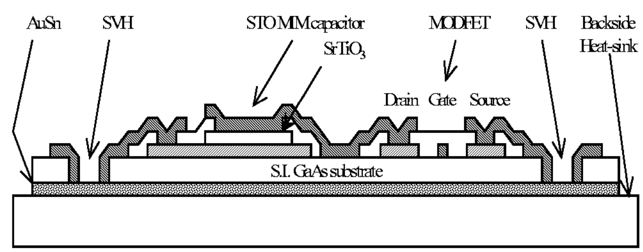

Figure 5 Schematic cross-sectional view of the MMIC

More than 20dB on/off ratio at 5.8GHz is required for the ASK modulator in ETC system. We designed the SPST type ASK modulator to realize the high on/off ratio. The ASK modulator is shown in Figure 6. To realize high on/off ratio, two through FETs and two shunt FETs with SVHs are connected as shown in Figure 6.

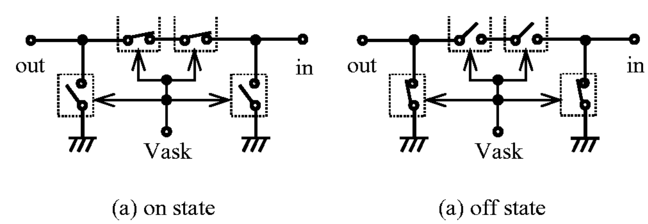

Figure 6 Circuit schematic of the ASK modulator

Since low distortion of half IF (20MHz) was required, we employed a passive R-mixer as down converter. Figure 7 is a circuit schematic of the R-mixer. LO matching circuit, High Pass Filter (HPF), Low Pass Filter (LPF) and bias circuit are integrated on the same MMIC. LO (5.84GHz) and RF (5.80GHz) are applied respectively to the gate and drain, and IF (40MHz) is extracted from the drain.

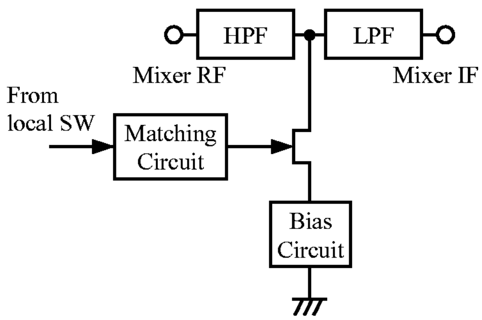

Figure 7 Circuit schematic of the resistive mixer

III. RESULTS

Figure 8 is the photograph of the MMIC chip. By using SVH isolation technique, the practical small chip size (2.25 x 1.25mm^2) is realized. Every RF block is isolated by SVHs.

Figure 9 is the photograph of the package (TSSOP-16D). We employed the 16-pins plastic package that has the backside heat-sink which connects the MMIC ground with the substrate ground directly to realize both low cost and high performance.

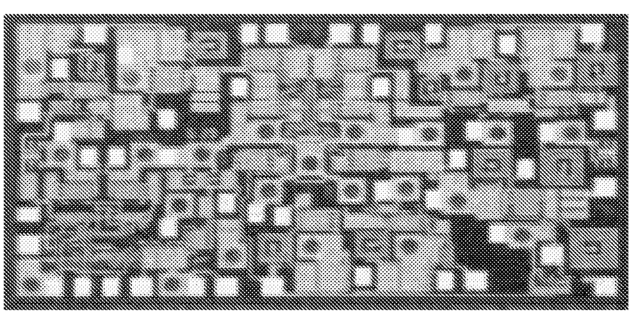

Figure 8 Photograph of the TX-RX MMIC chip. (2.25 x 1.25 mm^2)

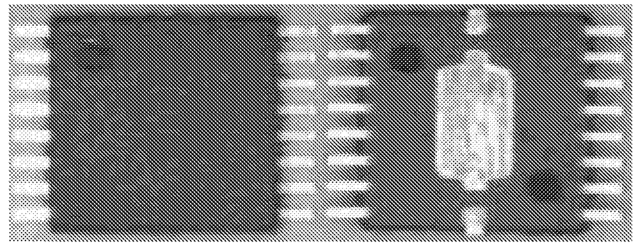

Figure 9 Photograph of the package. (TSSOP-16D, front view and back view)

Figure 10 shows ASK voltage vs. ASK loss of the MMIC. As the loss of on state (Vask=2.0V) is 0dB, and the off state (Vask=0V) is –39.6dB, high on/off ratio of 39.6dB is realized. This result is enough for the ETC system.

Table 1 summarizes RF characteristics of the TX-RX MMIC. The MMIC can operate with a single 3.0V supply. The R-mixer exhibits low conversion loss of 10dB at 5.8GHz at low LBA input (-10dBm). By using SVH isolation technique, low carrier leakage of –43dBm is realized. TX total gain of 20.0dB, TX VA reduction of 11.0dB, TX P1dB of 7.8dBm, RX total gain of 5.0dB are realized, and low total current of 150mA is achieved

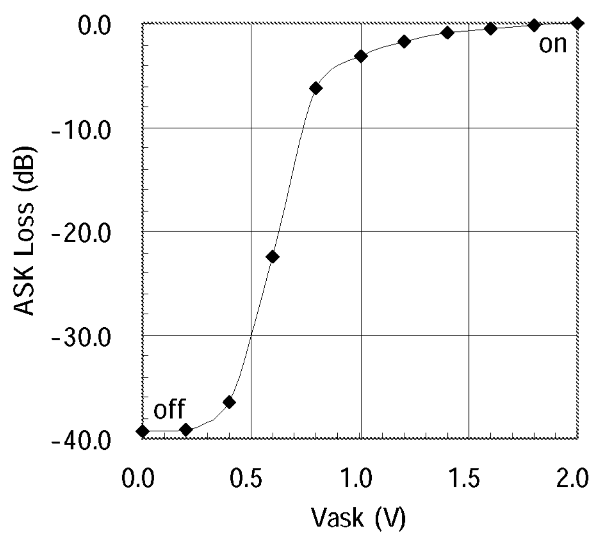

Figure 10 ASK voltage vs. ASK loss of the MMIC (Measured at Vdd=3.0V, f_{TX}=5.84GHz)

Table 1 RF Characteristics of the TX-RX MMIC (Measured at Vdd=3.0V, f_{TX}=5.84GHz, f_{RX}=5.80GHz, f_{IF}=40MHz)

Parameter	**Performance**
TX total Gain	20.0dB
TX on/off ratio	39.6dB
TX VA reduction	11.0dB
TX P1dB	7.8dBm
TX total current	100mA
RX total Gain	5.0dB
RX total current	20mA
R-mixer C. Loss	10.0dB
R-mixer NF	14.0dB
Buffer Amp. current	30mA
Carrier leakage (@LBA input=-10dBm)	-43dBm
Total current	150mA

IV. CONCLUSION

We have successfully developed a 1chip RF TX-RX MMIC for ETC with SVH isolation technique. By using this technique, the MMIC achieves low carrier leakage, high on/off ratio and practical small chip size. We believe that the newly developed TX-RX MMIC will realize compact and low-cost on-board equipments.

REFERENCES

[1] Eng Chuan Low, Hiroshi Nakamura et al. , "A PLASTIC PACKAGE GaAs MESFET 5.8GHZ RECEIVER FRONT-END WITH ON-CHIP MATCHING FOR ETC SYSTEM," IEEE RFIC Symposium Dig., pp.43-46, 1999.

[2] Z. Wen et al. , "A 5.8GHz Transmitter MMIC for Electronic Toll Collection System," IEEE GaAs IC Symposium Dig., pp.173-176, 1998.