Design Techniques of Reducing Chip Area and Highly Integrated MMIC for W-Band Application

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***Abstract* — In this paper, several novel techniques for minimizing chip area are presented. In order to demonstrate these features, we have developed a three stage W-band amplifier. This MMIC exhibits more than 15-dB gain from 75 GHz to 90 GHz, and size of this MMIC is less than 0.5 mm^2.**

We have also designed and fabricated a single chip 77 GHz T/R MMIC for automotive radar. This MMIC includes 25 active circuits in one chip, and size of this MMIC is less than 8.5 mm^2.

I. INTRODUCTION

The reduction of die size is one of the most important subjects in commercial MMIC design, because the die size is directly related to MMIC cost issue. Passive circuits are constructed with use of distributed transmission lines usual with millimeter wave MMIC, achieving the target performance, however, are not compatible with circuit area reduction.

As for to millimeter wave application, several functions have to be integrated into one MMIC chip, because parasitic inductance of connecting wire degrades the performance of the MMIC. For highly integrated MMIC, the circuit area of each function has to be as small as possible.

In this paper, we introduce several techniques how to reduce die size of MMIC.

II. TECHNIQUES TO REDUCE AREA OF CIRCUIT

The followings are several approaches to shrink die size, which are adapted to our MMICs.

1) Thickness of the substrate

For the microstrip circuits, thickness of substrate defines impedance of lines. Microstrip line widths can be made narrow using thin substrate. This time we used 28 µm thickness GaAs substrate instead of 75 µm often used before. Line width, which has 50-ohm characteristic impedance, reduced from 52 µm to 18 µm by using 28 µm-thick GaAs substrate. Although insertion loss of microstrip line increases, it can be neglected by management of circuit topology. Line to line spacing, without undesired coupling, is also to be narrowed.

Because the thinner substrate has advantage of lower thermal resistance of FETs, possession of FET area can be made smaller by using thinner substrate.

2) Self-biasing circuit topology

In millimeter-wave MMIC, biasing circuit utilizes λ/4 length line as usual. Even in millimeter wave region, this line occupies a large area of the MMIC. And connecting biasing circuit becomes too difficult for highly integrated circuit.

We adapted self-bias scheme to remove gate-biasing circuit by adding resistance and capacitance between FET source to ground.

3) Optimizing gate width of FET

Matching circuit topology is strongly dependent on FET's impedance or admittance. As figure 1 shows, if the admittance of FET is on the circle which normalized conductance is equals to one, matching circuit is made easily and compactly. As for to MMIC, gate width of FET can be selected to optimize the impedance.

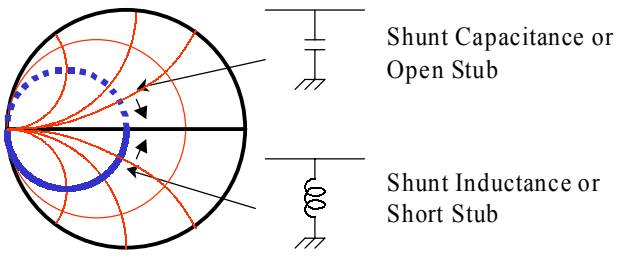

Figure 1 This admittance chart shows the matching circuit topology which can be made easily and compactly

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III. W-BAND AMPLIFIER

We have developed three-stage W-band MMIC amplifier by using the techniques mentioned above. Figure 2 shows the microphotograph and schematic circuit diagram of the MMIC, the area of the amplifier is 0.8 x 0.4 mm^2. The LNA MMIC consists of InGaP/InGaAs pseudomorphic HEMT (p-HEMT), which is fabricated on a 4-inch semi-insulated GaAs substrate with a 0.15-µm-long T-shaped gate electrode. [1], [2], [3] The gate width of each stage is 80 µm, and the unit gate width is 40 µm.

Substrate thickness of this MMIC is thinned to 28 µm by using mechanical and chemical etching. Source electrode is connected to ground by dry-etched via holes.

Each of the stage p-HEMT is self-biased with resistor and MIM (Metal-Insulator-Metal) capacitor. Degradation of the gain, which is caused by the resistor, can be neglected by using MIM capacitor.

Circuit models in the Agilent Technology's ADS library was used and were confirmed in its frequency characteristics up to 90 GHz by a 3-D electro-magnetic simulation with Ansoft HFSS.

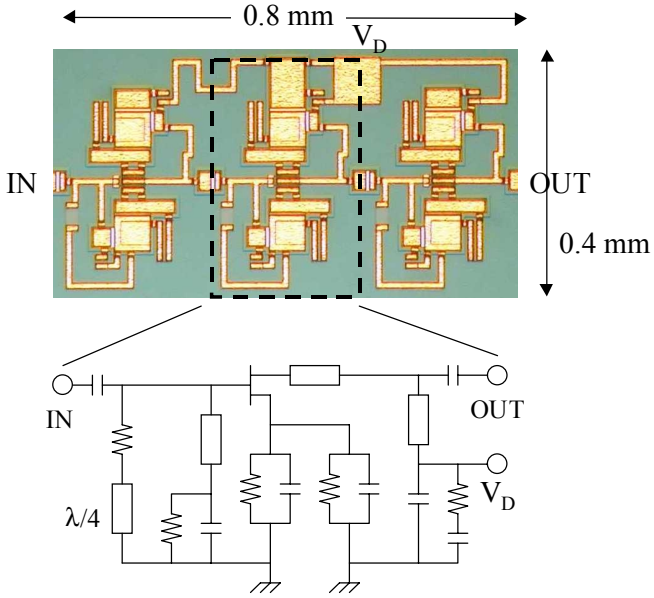

Figure 2 Microphotograph of three stages W-Band p-HEMT MMIC, and circuit schematic of a stage.

According to optimized gate width of the p-HEMT, input matching circuit is consisted of only one short stub, the width of which is 10 µm. The series-connected resistor and λ/4 microstrip line prevents lower frequency oscillation.

Frequency responses of the W-Band p-HEMT MMIC are shown in Figure 3 and Figure 4 in the frequency range from 2 GHz to 110 GHz. Figure 3 shows gain characteristic (s_{21}) of the MMIC. Figure 4 shows input and output return loss (s_{11}, s_{22}). Drain bias voltage is 3V and total drain current is 29 mA. Measurement was done by using Cascade 125-µm pitch on-wafer RF probe and Agilent 8510XF automatic network analyzer.

The gain is more than 15 dB from 75 GHz to 90 GHz, and maximum gain is 20 dB at 79 GHz. The input and out put return losses are better than 8 dB from 75 GHz to 85GHz.

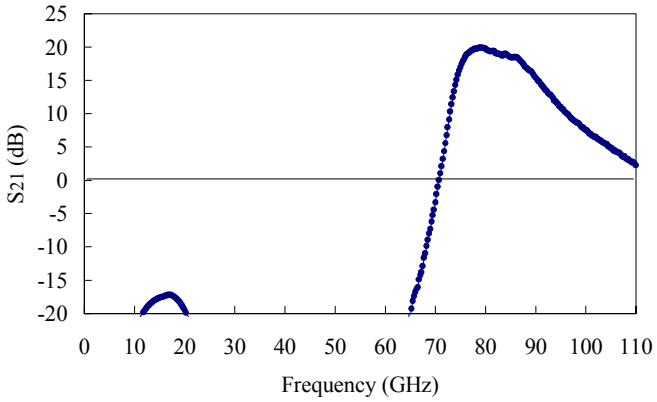

Figure 3 Frequency response of the MMIC gain (s_{21}). V_D = 3 V, I_D = 29 mA

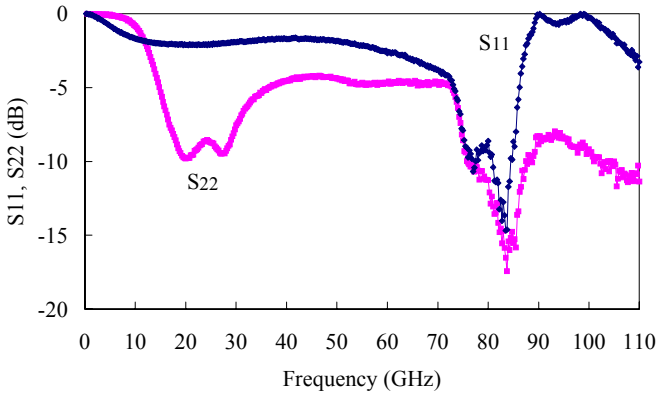

Figure 4 Frequency response of the MMIC input and output return loss (s_{11}, s_{22})

The measured noise figure of the miniature 3-stage amplifier is shown in Figure 5. Noise figure of the MMIC is about 6.5 dB in the 76-77 GHz region.

Figure 6 shows the output power characteristic of this MMIC, saturated output power of which was measured 5 dBm at 77 GHz.

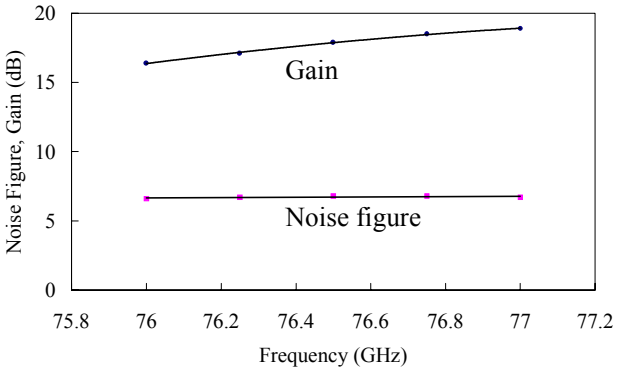

Figure 5 Frequency response of the MMIC noise figure and gain, V_D = 3V, I_D = 29 mA

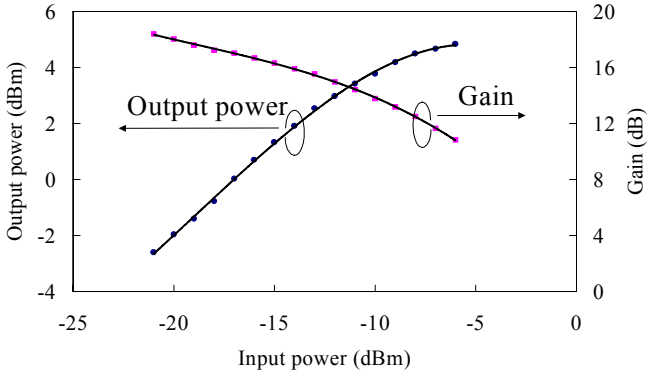

Figure 6 Measured output power and gain Frequency = 77 GHz, VD = 3 V

IV. W-BAND T/R MMIC

To demonstrate the effect of our techniques for minimizing die size, we have designed and fabricated a single chip 77 GHz T/R MMIC for automotive radar. [4] A microphotograph of the T/R MMIC 2.98 x 2.83 mm^2 in size is shown in Figure 7 and the schematic diagram is shown in Figure 8. This MMIC includes nine single ended 77 GHz small signal amplifiers, a 3-stage power amplifier, three 38.5 GHz driver amplifiers, a 9.625 GHz buffer amplifier, a times-four multiplier (9.625 GHz to 38.5 GHz), two frequency doublers (38.5 GHz to 77 GHz) and a mixer.

All of the components do not require negative voltage, and supply voltage is 3V. The three-stage W-Band amplifier is used in the input stage of the T/R MMIC.

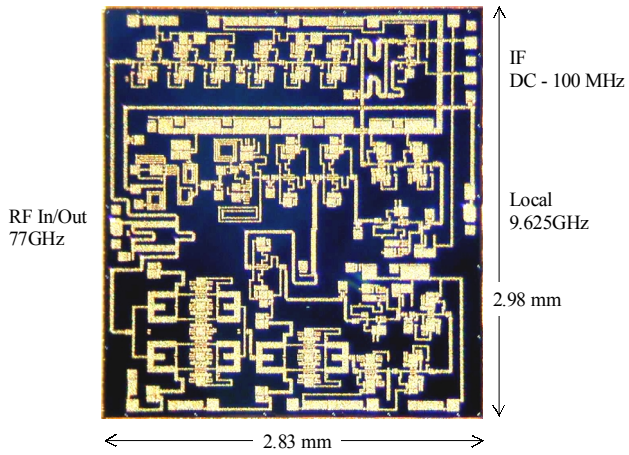

Figure 7 Microphotograph of the a single chip 77 GHz T/R MMIC for automotive radar

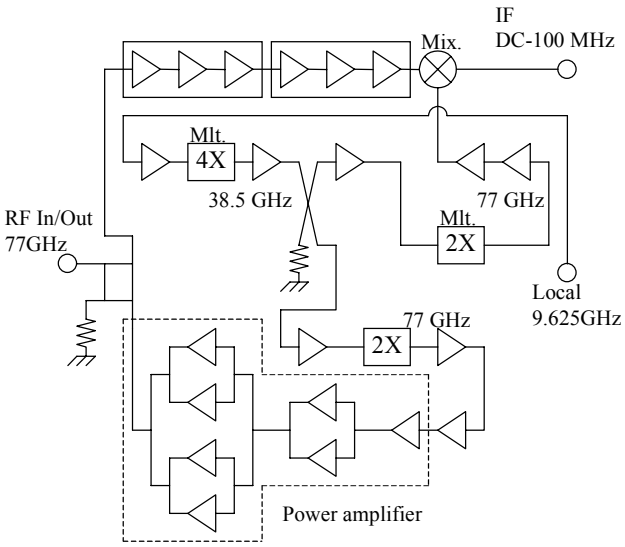

Figure 8 Schematic diagram of the 77 GHz T/R MMIC for automotive radar

Measured results of components are summarized in Table 1. As shown in this table, measured data of the

multipliers and the mixer does not agree with predicted performance in the circuit simulation. The reason of the differences are that the threshold voltage of FET's was shifted to a deep value and operation current became to high for multipliers and mixer operation.

Frequency range of the power amplifier was shifted to lower region, the maximum gain of the power amplifier is 20.7 dB at 63 GHz. Insufficient accuracy of large gate-width FET's model caused the frequency shift in the power amplifiers.

V. CONCLUSION

We have developed a miniature and broadband W-Band three-stage amplifier MMIC. Gate width optimization, 28-μm thickness substrate and self-bias scheme minimized the size of amplifier MMIC. The size of the MMIC is 0.8 x 0.4 mm^2.

We have also designed and fabricated a T/R MMIC for 77 GHz automotive radar. The die size of the T/R MMIC is 2.98 x 2.83 mm^2. The T/R MMIC includes 25 active circuit elements in single chip. Using the techniques, mentioned in this paper, minimizes the area of mm-wave MMIC's.

REFERENCES

[1] T. Saito et al, "60GHZ MMIC Image-rejection downconverter using InGaP/InGaAs HEMT" IEEE GaAs IC Symposium Digest, pp. 222-225, 1995

[2] T. Hirose et al, "A Flip-Chip MMIC Design with Coplanar Waveguide Transmission Line" IEEE Trans. Microwave Theory and Tech., Vol. MTT-46, No.12, pp. 2276-2282, DECEMBER 1998

[3] Yutaka Mimino et al, " HIGH GAIN-DENSITY K-BAND P-HEMT LNA MMIC FOR LMDS AND SATELLITE COMMUNICATION" 2000 MTT-S Digest, pp. 17-20

[4] Pchilippe Marchand, Philippe Gouessant, "Single Chip 58 GHz Radio Relay Front End" EuMC 2000 proc., vol.1 pp.425-428, October 2000.

Amplifiers	Measured		Simulation		
	Gain	Psat	Gain	Psat	Frequency
	dB	dBm	dB	dBm	GHz
Three stage 77 GHz amplifier	18	5	20	5	77
Three stage 77 GHz power amplifer	7.4	-	18	16	77
	20.7	16	-	-	63
9.6 GHz Buffer Amplifer	7.8	12.8	10	14	9.6
38.5 GHz Buffer Amplifer	7.6	8	7	8	38.5

Multipliers and mixer	Measured	Simulation	
	Conversion gain	Conversion gain	Frequency
	dB	dB	GHz
9.625 to 38.5 GHz Frequency Multiplier	-30	-16	38.5 *1
38.5 to 77 GHz Frequency Multiplier	-31	-20	77 *1
MIXER (Down convertor)	-25	-10	77 *2

Table 1 This table summarizes the performances of components in 77 GHz T/R MIC
***1 Output frequency**
***2 Local frequency = 77 GHz**
IF frequency = 100 MHz
RF > LO