A 38/77 GHz MMIC Transmitter Chip Set for Automotive Applications

J. Udomoto, T. Matsuzuka, S. Chaki, K. Kanaya, T. Katoh, Y. Notani, T. Hisaka, T. Oku, T. Ishikawa, M. Komaru, and Y. Matsuda

High Frequency & Optical Semiconductor Div., Mitsubishi Electric Corporation
4-1 Mizuhara, Itami, Hyogo, 664-8641 Japan

Abstract — **This paper describes the successful development of 38/77 GHz transmit MMICs for automotive applications. They consist of a 38 GHz amplifier, a frequency doubler, and a 77 GHz power amplifier. These amplifiers achieve output powers of 16 dBm at 38 GHz and 15 dBm at 76.5 GHz at 1 dB gain compression point. The output power of the 77 GHz amplifier is one of the highest delivered by a single chip MMIC at 76.5 GHz. The frequency doubler delivers an output power of 5.7 dBm at 76.5 GHz. These results are promising for automotive applications in the W-band.**

I. Introduction

Millimeter automotive radar systems are key technology for future adaptive cruise control systems. They are now booming after more than 20 years of research and development around the globe. Thus, demand for low-cost W-band MMICs has continued to increase, leading to commercial success of car radar systems. This increasing demand has resulted in rapid advances in development of millimeter wave FET MMICs.

There have been many reports on MMIC chip sets for automotive radar systems [1]-[5]. The recent interest has been focused on the cost and reliability of radar systems. To realize low cost and highly reliable radar systems, a full MMIC solution must be used, and the development of compact and highly reliable MMICs is crucial.

We developed an MMIC chip set with a high performance and a compact chip size. The MMIC chips are fabricated using 0.2 μm AlGaAs/InGaAs/GaAs pseudomorphic T-gate power HEMT (pHEMT) MMIC technology on a 100 μm GaAs substrate.

This paper describes the successful development of 38/77 GHz transmit MMICs for automotive applications. They consist of a 38 GHz amplifier, a frequency doubler and a 77 GHz output amplifier. Figure 1 shows a block diagram example of the radar system.

II. Device Description

A transistor used in this work is a pHEMT fabricated using T-shaped Al gate process with a 0.2 μm gate length. Figure 2 shows a schematic cross section of the pHEMT. The device structure is a double heterojunction structure which is optimized for power performance. It is formed by molecular beam epitaxy. The substrate thickness is 100 μm and then plated with 3 μm gold. This pHEMT has a gate-to-drain breakdown voltage of 10 V typically, a maximum drain current of 600 mA/mm and transconductance of 420 mS/mm.

III. MMIC Amplifiers

Figure 3 shows circuit diagrams of the amplifiers. The 38 GHz driver amplifier is a 2-stage configuration consisting of the first stage with a 160 μm HEMT and the second stage with a 200 μm HEMT. Unit gate finger widths are 40 μm and 50 μm, respectively.

The 77 GHz amplifier is a 4-stage configuration consisting of the first and second stages with an 80 μm HEMT, the third stage of a 160 μm HEMT and the fourth stage of a 320 μm HEMT. Unit gate finger widths are all 40 μm.

A small signal FET model was derived from S-parameters estimated by on-wafer measurements for the single gate HEMTs. Curtice cubic model was selected to simulate large signal characteristics.

Small metal insulator metal (MIM) capacitors and short stubs using high impedance lines are employed as matching elements in these amplifiers to assure compact chip sizes. The matching

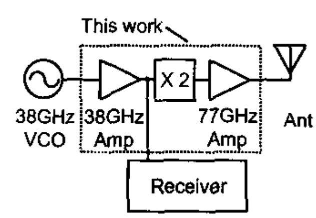


Fig. 1 Block diagram example of the radar system.

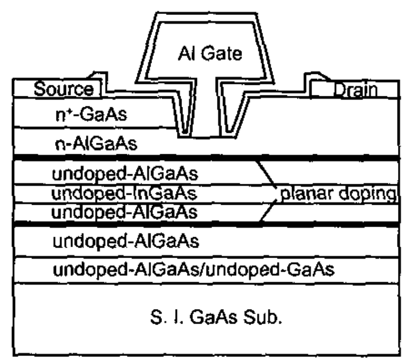


Fig. 2 Schematic cross section of the pHEMT.

circuits of the amplifiers were first designed with small signal S-parameters providing acceptable return loss and gain.

In designing these amplifiers, a high-pass filter configuration is used for an input matching circuit in each stage. This type of matching is effective for compact circuit layout in this frequency range. In addition, this has the effect of making circuits unconditionally stable by rejecting out-of-band gain. Since the bandwidth having unwanted gain is broad when a designer designs amplifiers for the millimeter wave band, this type of matching is particularly effective in this frequency range.

To achieve a compact chip size, moreover, it is necessary to consider coupling effects between lines to adjust performance from the layout to target performance. It is more important in designing W-band MMICs compared with MMICs at lower frequency bands. The circuit layouts were, therefore, optimized using EM analysis [6].

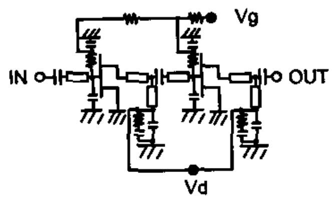
Figure 4 shows a chip photograph of the 38 GHz driver amplifier. The chip area is only 1.0 mm x 1.2 mm. Figure 5 shows the measured small signal performance at a drain voltage of 4 V. A small signal gain of 16 dB has been obtained with an input return loss of 12 dB and an output return loss of 22 dB at 38.25 GHz. The small signal gain of this amplifier is less than 0 dB in the frequency range below 29 GHz owing to matching circuits using high-pass filters. Figure 6 shows the measured power performance at 38.25 GHz. An output power of 16 dBm was achieved at 1 dB gain compression point.

Figure 7 shows a chip photograph of the 77 GHz output amplifier. The chip area is 1.2 mm x 2.9 mm. Figure 8 shows the measured small signal performance at a drain voltage of 4 V. A small signal gain of 16 dB was obtained with an input return loss of 15 dB and an output return loss of 12 dB at 76.5 GHz. As well as the 38 GHz driver amplifier, the small signal gain of this amplifier is less than 0 dB in the frequency range below 65 GHz owing to matching circuits using high-pass filters. Figure 9 shows the measured power performance at 76.5 GHz. An output power of 15 dBm was achieved at 1 dB gain compression point. This output power is one of the highest delivered by a single chip MMIC at 76.5 GHz.

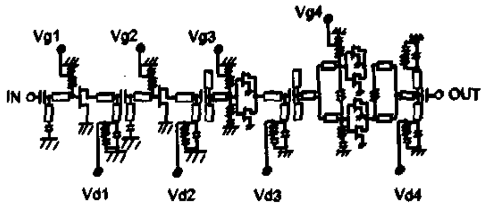
IV. Frequency Doubler

Figure 10 shows the circuit diagram of the frequency doubler. The configuration consists of a 320 μm HEMT. Unit gate finger width is 40 μm. We decided the gate width of pHEMT in order to accept an input power of more than 10 dBm. We designed an input circuit and an output circuit to match at 38.25 GHz and 76.5 GHz, respectively. In designing matching circuits, we used open stubs having λ/4 length at these frequencies. The operating conditions are near the pinch off region so that high even harmonic power levels are generated.

Figure 11 shows a chip photograph of the frequency doubler. The chip area is 1.0 mm x 1.25 mm. Figure 12 shows the measured power performance at a drain voltage of 3 V. An output power of 5.7 dBm was achieved with a conversion gain of −11.3 dB for an input power of 17 dBm and a 38.25 GHz input frequency. This frequency doubler is used at an input power of less than 17 dBm.



(a) 38 GHz amplifier



(b) 77 GHz amplifier

Fig. 3 Circuit diagrams of the amplifiers.

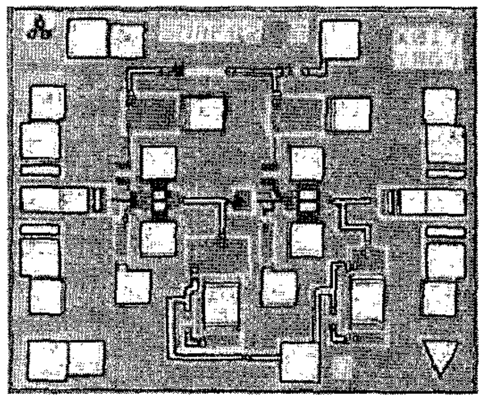


Fig. 4 Photograph of the 38 GHz driver amplifier.

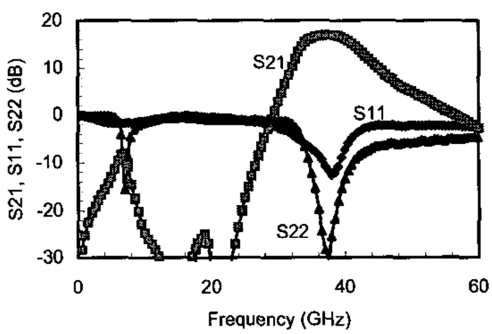


Fig. 5 Small signal performance of the 38 GHz amplifier.

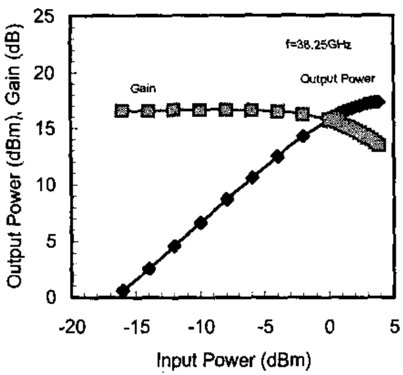


Fig. 6 Power performance of the 38 GHz amplifier.

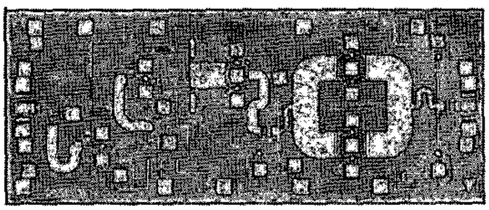


Fig. 7 Photograph of the 77 GHz output amplifier.

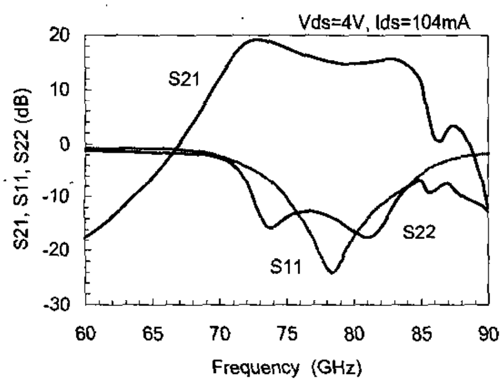


Fig. 8 Small signal performance of the 77 GHz amplifier.

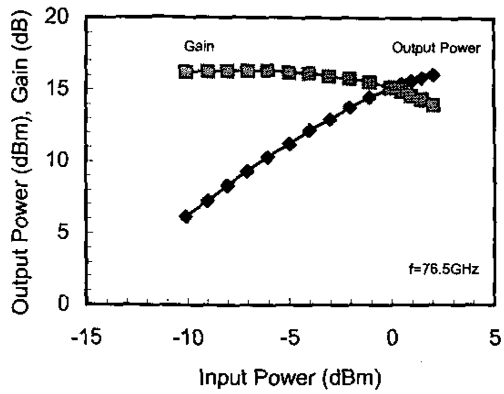


Fig. 9 Power performance of the 77 GHz amplifier.

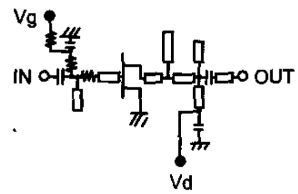


Fig. 10 Circuit diagram of the frequency doubler.

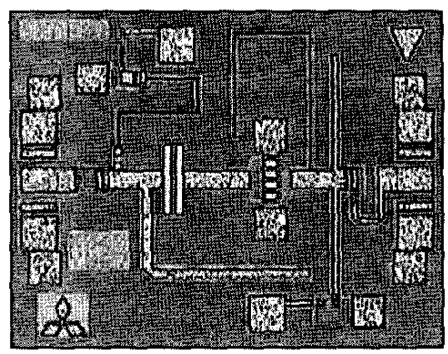


Fig. 11 Photograph of the frequency doubler.

V. CONCLUSION

We developed an MMIC chip set with a high performance and a compact chip size. They consist of a 38 GHz amplifier, a frequency doubler and a 77 GHz output amplifier. These amplifiers achieve output powers of 16 dBm at 38 GHz and 15 dBm at 76.5 GHz, respectively. The frequency doubler delivers an output power of 5.7 dBm with a conversion gain of –11.3 dB at 76.5 GHz. We believe that these results are promising for automotive applications.

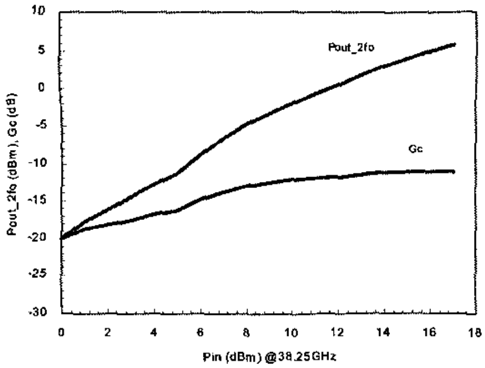


Fig. 12 *Power performance of the frequency doubler.*

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