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Invited

Millimeter-Wave MMIC Technology

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1. Introduction

This paper presents our current design and development results on millimeter-wave MMIC technology, addressing the circuit design, fabrication, and performance of Ka-, V-, and W-bands AlGaAs/InGaAs PHEMT low-noise MMIC amplifiers.

With the recent advances of GaAs and InP based HEMT technology, millimeter-wave MMIC amplifiers have been developed using PHEMTs for use in the space and commercial applications including wireless LAN, anti-collision radar, and telecommunications. Especially in an application to the active phased array receiver modules for use in the satellite communication systems, low cost, small size, high performance, mass production, good uniformity, and high repeatability are required, which are significant advantages of MMICs over HMICs (Hybrid MICs). In this paper, our current results of Ka-, V- and W-bands low-noise MMIC amplifiers are introduced [1-3], focusing mainly on the circuit design and fabrication techniques.

2. Device Performance

Millimeter-wave low-noise MMIC amplifiers described in this paper employs $0.15 \times 120\ \mu m^2$ AlGaAs/InGaAs PHEMTs for Ka-band and $0.15 \times 60\ \mu m^2$ AlGaAs/InGaAs PHEMTs for V- and W-bands. These PHEMTs were mounted on a carrier-type fixture and evaluated by I-V measurements, S-parameter measurements up to 50 GHz, and noise measurements at 30, 60 and 90 GHz. The noise parameter measurements are based on a microstrip-type tuner whose impedance has been already measured. The load impedance is varied by tuning open-circuited stubs. The $0.15 \times 120\ \mu m^2$ PHEMT showed a d.c. transconductance of 540 mS/mm, an f_t of 82 GHz, and an f_{max} of 173 GHz for $V_d = 2$ V and $I_d = 10$ mA. The $0.15 \times 60\ \mu m^2$ PHEMT showed a d.c. transconductance of 600 mS/mm, an f_t of 133 GHz, and an f_{max} of 186 GHz for $V_d = 2$ V and $I_d = 6$ mA. The minimum noise figure and associated gain were 0.8 dB and 8 dB at 30 GHz, 1.6 dB and 6.5 dB at 60 GHz, 2.5 dB and 4.3 dB at 90 GHz.

3. Millimeter-Wave Low-Noise MMIC Amplifiers

Photographs of the Ka-band 3-stage, V-band single-stage, and W-band 2-stage MMIC amplifiers are shown in Figs. 1, 2, and 3, respectively. The chip size is $1.8 \times 2.6 \times 0.1$ mm^3 for Ka-band and $1.2 \times 2.6 \times 0.1$ mm^3 for V- and W-bands.

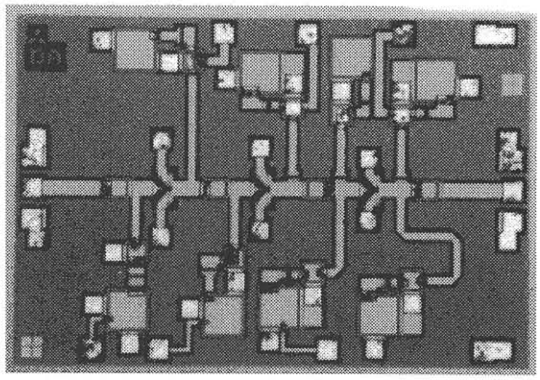

Fig. 1 Photograph of the Ka-band 3-stage MMIC amplifier

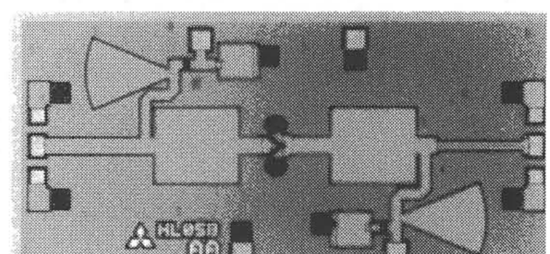

Fig. 2 Photograph of the V-band single-stage MMIC amplifier

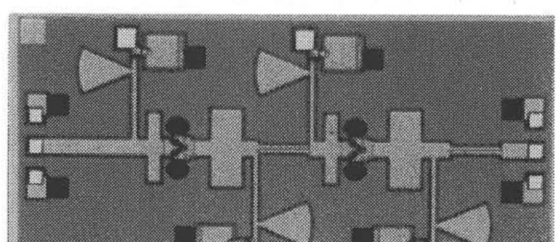

Fig. 3 Photograph of the W-band 2-stage MMIC amplifier

Circuit Design

In the design of the Ka-band amplifier, the design method to use source inductors is employed to achieve small reflections and low noise simultaneously. The values of the source inductors were designed to be large for the 1st-stage and small for the final-stage to achieve the best compromise between noise figure, gain, and return loss as a 3-stage amplifier. In the design of the V- and W-band amplifiers, a reactive matching method is employed in the design of input noise matching and output gain matching circuits to achieve low noise and high gain of the amplifier. The matching circuits are comprised of $\lambda/4$ impedance transformers for V-band and double open-circuited stubs for W-band. In addition to these matching circuits, the amplifiers employ edge-coupled lines for d.c. block, radial stubs for r.f. bypass, and resistors in the gate and drain bias circuits for high stability at lower frequencies.

Circuit Fabrication and Performance

The MMIC process is conventional except that small via holes with the area of 2800 μm^2 are placed on both sides of the PHEMT and that a passivation film is thinned down to 1000 Å to reduce gate-to-source and gate-to-drain intrinsic capacitances. The calculated and measured noise figures, gains, and return losses of the Ka-, V-, and W-band amplifiers are plotted in Figs. 4, 5, and 6, respectively. The Ka-band 3-stage amplifier has achieved a noise figure of 1.6 dB, a gain of 22.8 dB, an input return loss of 29 dB, and an output return loss of 24 dB at 28 GHz. The best noise figure was 1.3 dB at 30 GHz. The V-band 2-stage amplifier shows a noise figure of 2.5 dB with a gain of 20.4 dB at 51.5 GHz. The W-band 2-stage amplifier shows a noise figure of 3.4 dB with a gain of 8.7 dB at 91 GHz. The calculated and measured results for both noise figure and gain are in good agreement, as shown in Figs. 4, 5, and 6. Taking account of the minimum noise figure of 0.15×120 and $0.15\times60\ \mu m^2$ PHEMTs, a good noise matching has been accomplished for all amplifiers.

4. Conclusion

Our current results of millimeter-wave low-noise MMIC amplifiers have been introduced, describing the circuit design and fabrication techniques.

References

[1] H. Uchida, *IEICE Tech. Report*, MW97-148, 1998.

[2] Y. Itoh, et al, *IEEE MGWL*, vol.5, 2, pp. 48-49, 1995.

[3] Y. Itoh, et al, *IEEE MGWL*, vol.5, 2, pp. 59-61, 1995.

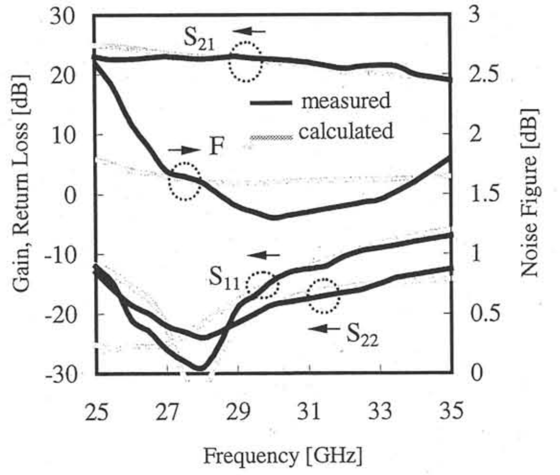

Fig. 4 Calculated and measured noise figures, gains, and return losses of the Ka-band 3-stage MMIC amplifiers

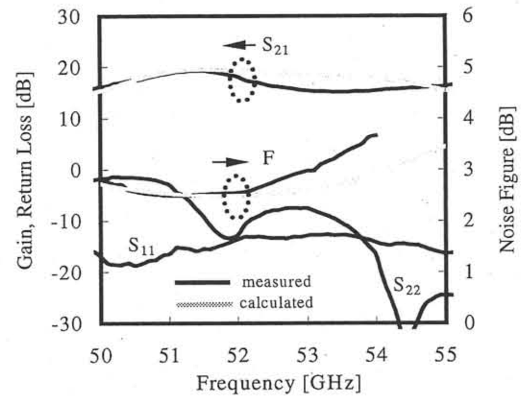

Fig. 5 Calculated and measured noise figures, gains, and return losses of the V-band 2-stage MMIC amplifiers

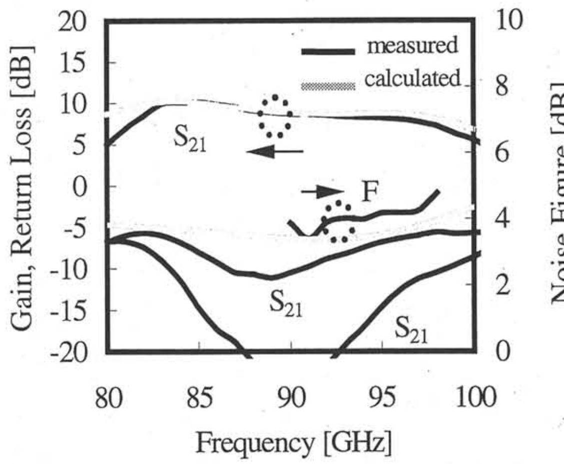

Fig. 6 Calculated and measured noise figures, gains, and return losses of the W-band 2-stage MMIC amplifiers