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A 125-GHz 140-mW InGaAs/InP composite-channel HEMT MMIC power amplifier module

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Abstract: A millimeter-wave power amplifier module achieves 140 mW maximum output power and 80 mW output 1-dB gain compression point at 125 GHz. The 0.08 μm gate length InGaAs/InP composite-channel HEMTs were applied to single-chip coplanar-design amplifier MMIC. The module's output power in this frequency band is a record to the best of our knowledge.

Keywords: millimeter-wave, power amplifier, HEMT

Classification: Microwave and millimeter wave devices, circuits, and systems

References

[1] A. Hirata, T. Kosugi, H. Takahashi, R. Yamaguchi, F. Nakajima, T. Furuta, H. Ito, H. Sugahara, Y. Sato, and T. Nagatsuma, "120-GHz-band millimeter-wave photonic wireless link for 10-Gb/s data transmission," *IEEE Trans. Microw. Theory Tech.*, vol. 54, no. 5, pp. 1937–1944, 2006.

[2] L. Samoska, "Towards Terahertz MMIC Amplifiers: Present Status and Trends," *IEEE MTT-S Int. Microw. Symp. Digest 2006*, pp. 333–336, 2006.

[3] H. Sugiyama, T. Kosugi, H. Yokoyama, K. Murata, Y. Yamane, M. Tokumitsu, and T. Enoki, "High-Performance InGaAs/InP Composite-Channel High Electron Mobility Transistors Grown by Metal-Organic Vapor-Phase Epitaxy," *JJAP*, vol. 47, no. 4, pp. 2828–2832, 2008.

[4] L. Samoska, "65-145 GHz InP MMIC HEMT Medium Power Amplifiers: Present Status and Trends," *IEEE MTT-S Int. Microw. Symp. Digest 2001*, pp. 1805–1808, 2001.

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1 Introduction

Broadband wireless data transmission system at carrier frequencies above 100 GHz is one of the promising ways to realize data capacity of 10 Gbit/s or more instantly [1]. However, one problem associated with such a high-frequency is the luck of power amplifiers with sufficient output power and linearity [2]. In this paper, we present a power amplifier MMIC and its waveguide module operating from 117.5 to 132.5 GHz for wireless data transmission. The MMIC features composite-channel HEMTs [3] with high breakdown voltage and a circuit topology for good linearity. We obtained 140-mW maximum output power and 80-mW output 1-dB gain compression point ($P_{1\,dB}$) with a single-chip amplifier MMIC waveguide module at 125 GHz.

2 Amplifier design

2.1 Composit channel HEMT

The 0.08 μm gate length InGaAs/InP composite-channel (CC) HEMT's were used for the power amplifier IC. The use of an InGaAs/InP CC is effective for increasing the breakdown voltage while maintaining high-frequency performance. The on-state and off-state breakdown voltages of the device are around 4 and 10 V, respectively. These values are almost two times higher than those for conventional lattice-matched InP-HEMTs [4]. The devices typically have a transconductance of 1.9 S/mm, a unity current gain frequency f_t of 180 GHz, and a maximum oscillation frequency fmax of 580 GHz under an optimized bias condition. The standard deviations of the device parameters, such as V_{th}, g_m, and f_t, are fairly small in CC-HEMTs [3]. The high uniformity of the device parameters is the key to establishing equal power distribution to and combination from FETs, which leads to high output power and the suppression of unintentional odd-mode oscillation of the amplifier.

2.2 Circuit design

Figure 1 shows the overall circuit configuration of the power amplifier. The amplifier has three-stage common-source configuration. A small-signal equivalent circuit of the device was used to design first and second stages of the amplifier. We optimized the matching circuits, aiming at flat gain and delay in the frequency range of 117.5-132.5 GHz. Prior to circuit design, we examined the maximum gate finger length that would provide high output power in a small layout area. With increasing finger length, the associated gain of the FET deteriorates due to increasing gate resistance. We therefore chose 30-μm gate finger length was chosen at 125 GHz, considering both power and associated gain. To obtain high output $P_{1\,dB}$, the total finger lengths of first and second amplifier stages were set to be equal to that of the final stage. Because of the large power margin, the gain compression due to first and second amplifier stages can be neglected. To increase total power handling capability, we divided the amplifier into eight medium-power amplifiers (MPAs) with on-chip power divider (eight-way) and combiner (eight-way). Each MPA handles only one-eighth of the total RF and DC power. Therefore,

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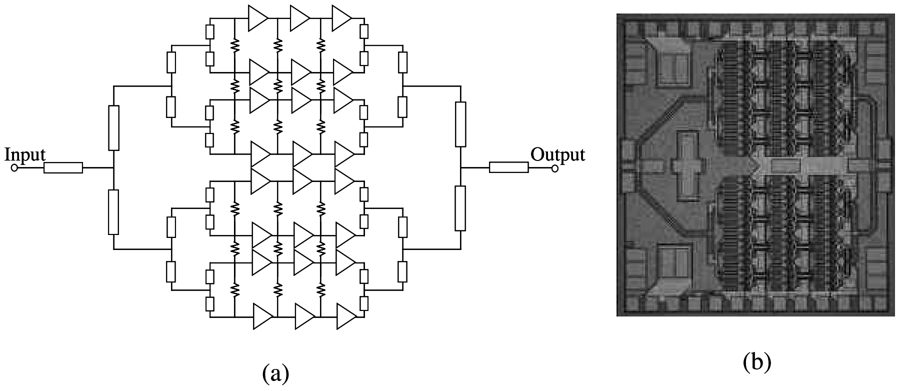

Fig. 1. (a) Circuit diagram of the amplifier MMIC consisting of eight medium-power amplifiers and power combiners/dividers and (b) the photograph of die.

narrow transmission lines with a high cut-off frequency and low radiation loss can be used in the circuit design. This improves reproducivity in design and contributes to the stable operation of the MMIC. The total device periphery of each stage was set to 3.72 mm.

The output matching circuit of the final amplifier stage was designed to prohibit the load line from deeply penetrating the high bias stress region of the drain IV curves. This leads to a slight deterioration of output return loss but is effective for reducing the stress to the final stage FET. A large-signal FET model in HSPICE was used to optimize the load line. Then the matching condition was determined by computational load-pull calculation. The load line was optimized on the basis of the results of bias-temperature accelerated aging tests of a device measured at VDS of 1.5, 2.5, and 4.0 V at 175°C.

We used double-layer interconnections, a BCB interlayer, and MIM capacitors in the process. Coplanar waveguides and thin film microstrip lines were used in the layout. The chip dimensions are 2.0 mm × 2.2 mm. The wafer was thinned to 0.15 mm to reduce thermal resistance.

3 Measurement results

The measured S-parameters of the amplifier MMIC implemented in a WR-8 2-port waveguide module are shown in fig. 2. The bias conditions were VGS = −0.1 V, VDS = 1.8 V, IDS = 3.8 A. The measurement indicated that the amplifier has 7-dB averaged gain, less than −4 dB input return loss, less than −6 dB output return loss, and less than −34 dB isolation in the frequency range of 117.5-132.5 GHz. The measured coupling loss of the waveguide module is about 1.6 dB. The on-chip power combiner (eight-way) and divider (eight-way) have approximately 3.0 and 2.5 dB RF losses, respectively. Therefore, the small signal gain of each amplifier stage of the MMIC is estimated to be 4.7 dB at 125 GHz. The low gain of each amplifier stage is mainly due to the margin for stable operation and the parameter adjustment of output matching circuit as previously discussed. The variation of the group

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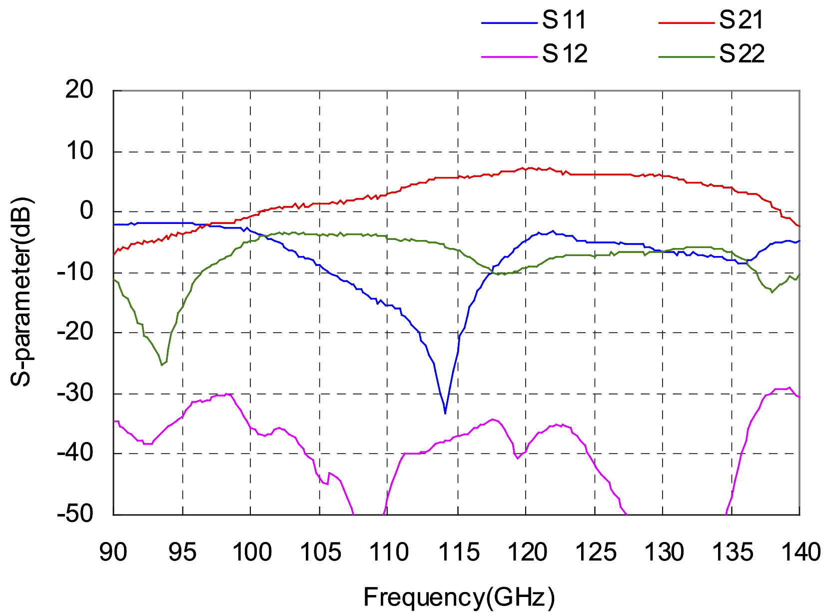

Fig. 2. Measured S-parameter of the amplifier module.

delay in the frequency range calculated using the measured S-parameter is 17 ps. To test the stability of the amplifier module, we measured the integrated output power without input signal. Unconditionally, it was less than −30 dBm in the frequency range of 90-140 GHz.

Figure 3 shows the input and output characteristics of the amplifier module. The bias conditions were the same as in the S-parameter measurement. Thanks to the high-breakdown-voltage InGaAs/InP CC-HEMTs and a circuit topology optimized for linearity, the maximum output power is 140 mW with 4-dB associated gain, and output $P_{1\,dB}$ reaches 80 mW with 6-dB associated gain at 125 GHz. The flatness of the gain around $P_{1\,dB}$ is 2.5 dB in the frequency range of 115-132.5 GHz.

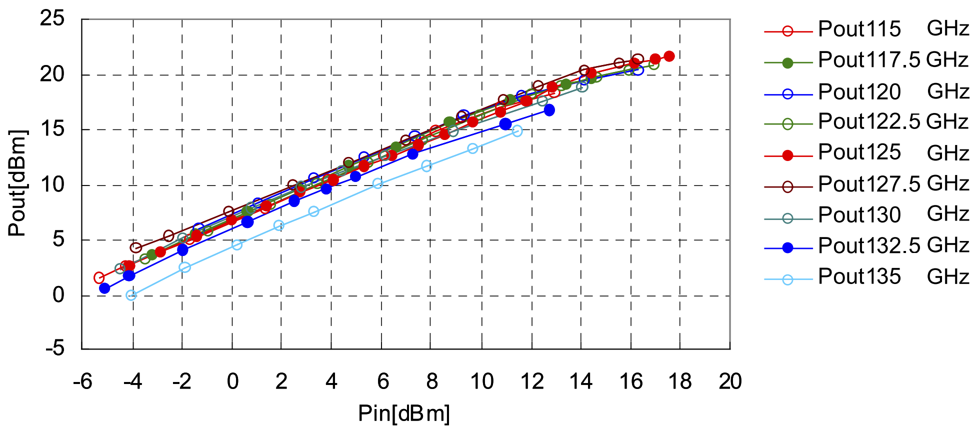

Fig. 3. Input and output characteristics of the amplifier module.

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4 Conclusion

The 125-GHz power amplifier module using InGaAs/InP composite-channel HEMT MMIC has outstanding performance in the F-band. The maximum output power of the module reached 140 mW at 125 GHz.

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