Ku-Band 10W High Efficiency HJFET Power Amplifier

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ABSTRACT

This paper describes a record power performance of a Ku-band power amplifier fabricated with a one-chip 0.45μm gate GaAs-based heterojunction FET (HJFET). The developed HJFET amplifier with 16.8mm gate periphery exhibited a 40.1dBm(10.2W) output power with 50% power-added efficiency(PAE) and 9.5dB linear gain at 12GHz. This is the highest PAE, gain and output power combination achieved by a single FET power amplifier at this frequency.

INTRODUCTION

There is a growing demand for solid state power amplifiers (SSPAs) that are capable of delivering increased output power with reasonable efficiency. Power GaAs MESFETs with over 10W output power have already been reported at Ku-band[1],[2]. However, because of the increased chip size and the limited gain performance of the GaAs MESFETs, further improvements in the output power from a single MESFET chip are becoming rather difficult.

Recently, a GaAs-based heterojunction FET (HJFET) has emerged as a viable candidate for microwave power applications. This device has demonstrated excellent performance of high output power, gain and PAE, making it attractive for various SSPA applications[3-11]. This is due to its inherent high drain current and high gain characteristics along with its high gate breakdown voltages[5],[7],[10-12]. To minimize power combining loss in the multi-watt power amplifiers, large-periphery devices capable of providing higher output power density with higher efficiency are of great interest.

To date, GaAs-based heterojunction FETs with small gate periphery have already demonstrated impressive power performance. These include an output power of 0.6W, 75.8% PAE with 1.2mm gate-width at 10GHz[7] and 0.97W, 70% PAE with 1.2mm gate-width at 10GHz[9]. More recently, impressive results have been reported on larger-periphery devices, in which an output power level of 6W with PAE of greater than 50% has been achieved at 12GHz[11],[13]. In order to further improve the output power level under high PAE, we have developed a larger gate-width HJFET with state-of-the-art output power and efficiency at Ku-band.

In this paper, a record power performance of an amplifier composed of a single HJFET chip with internal matching circuits is described.

POWER HJFET DEVICE

Step-recessed 0.45μm gate-length HJFETs were fabricated on a 3-inch GaAs substrate[13]. The active part of the MBE-grown HJFET structure consists of a 130Å undoped $In_{0.2}Ga_{0.8}As$ channel layer sandwiched between two Si-doped $Al_{0.22}Ga_{0.78}As$ layers. The doping densities for the upper (80Å) and the lower (40Å) AlGaAs donor layers are 4.5×10^{18} and $4\times10^{18}cm^{-3}$ respectively. To achieve high gate-to-drain breakdown voltage (BV_{gd}) while maintaining high maximum drain current (I_{max}), an n^+/n^- dual cap layer and an undoped AlGaAs Schottky layer were employed[12]. The wafer processing began with first wide recess formation, followed by a standard AuGeNi metallization for the source and drain Ohmic contacts. The narrow recess was then formed using wet chemical etching to a desired current level. WSi metal was sputter-deposited onto the recessed undoped AlGaAs Schottky layer to form a 0.45μm T-shaped gate. The wide recess width is 2.0μm. The devices were passivated with a plasma-enhanced CVD silicon-nitride film. Then, the wafer was thinned to 30 μm. Slot via-holes were etched underneath each source pad, and the flip-side of the wafer was plated with 20μm of gold to ensure low thermal resistance.

The front view of the finished device with a total gate-width of 16.8mm is shown in Fig.1. The device has a unit finger width of 100μm. The device exhibited an I_{max} of 550mA/mm with a drain saturation current of 270mA/mm. I_{max} was measured at a gate bias of +1V. The device exhibited a maximum transconductance of 370mS/mm and a BV_{gd} of more than 12V. Microwave S-parameter measurements, performed from 0.5 to 40GHz for a 100μm device, exhibited a peak power-gain cutoff frequency of 158GHz.

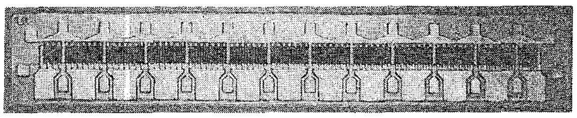

Fig.1. Front view of a 0.45μm gate-length and 16.8mm gate-width step-recessed HJFET.

AMPLIFIER CIRCUIT DESIGN

The output matching circuit was designed using a large-signal load impedance (Z_{L0}) determined from load-pull measurements performed on a 1.05mm HJFET. The value of Z_{L0} which provides maximum output power was 27.4+j30.5Ω at 12GHz with a drain bias voltage (V_d) of 7V. The gate bias condition was optimized to class-AB operation. The resulting Z_{L0} was then scaled to model a 16.8mm HJFET as a power amplifier building block. An equivalent circuit of the 16.8mm HJFET power amplifier is shown in Fig.2. The input and output matching circuits were designed using L-C-L section transformers, quarter wave transformers and low-impedance transmission lines. The input matching circuit was designed to achieve higher gain by using the small-signal equivalent circuit of the 16.8mm HJFET. The low-impedance transmission lines were used to reduce the loss in the matching circuits at a designed frequency.

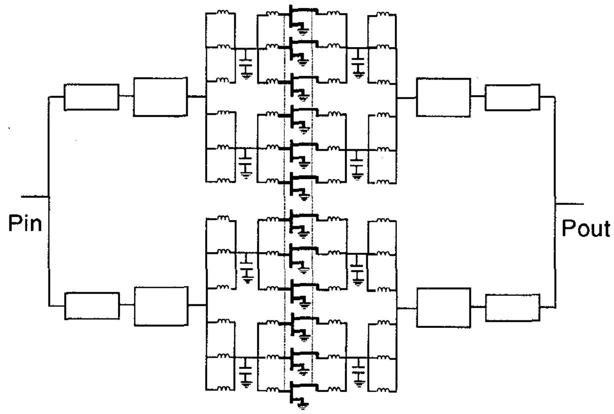

Fig.2. Equivalent circuit of a 16.8mm HJFET amplifier.

Figure 3 shows the photograph of internally matched HJFET power amplifier. The L-C-L section transformer consists of a Metal-Insulator-Metal capacitor with 150μm thick Barium Titanate and bonding wire inductors. The quarter wave transformer and low-impedance transmission lines were formed on a 250μm thick alumina substrate. The package size of the power amplifier, excluding the bias lines, was 16.5×9.7mm^2 with actual circuit size of 5.0×7.5mm^2.

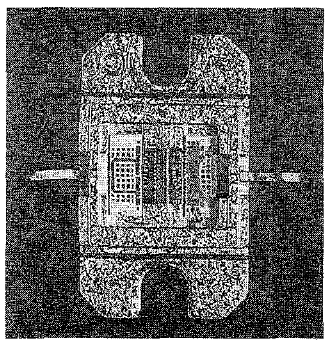

Fig.3. Photograph of internally matched HJFET amplifier.

AMPLIFIER PERFORMANCE

The power amplifier was mounted on a specially designed waveguide test fixture for gain, return loss and large-signal power evaluation. The fixture loss was de-embedded from all measurement results.

Figure 4 shows the measured small signal gain, input and output return losses of the power amplifier as a function of frequency. The small signal gain was 9.5dB at 12GHz with V_d=8V. The input and output return losses were less than -29dB and -33dB, respectively.

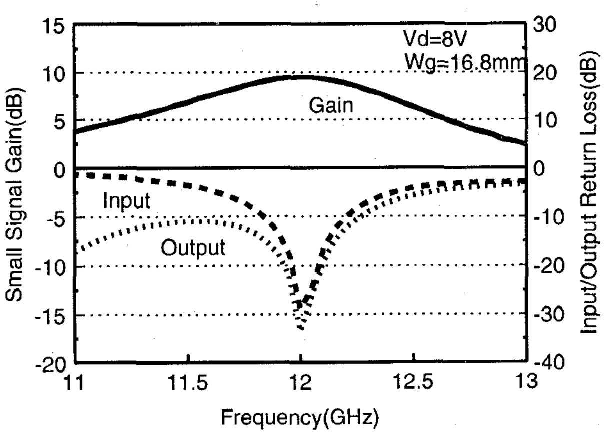

Fig.4. Measured small signal response of power amplifier. V_d=8V.

The measured power characteristics are shown in Fig.5. The fabricated power amplifier demonstrated an output power of 39.5dBm(8.9W) with 10dB linear gain and 55% PAE with V_d=7V under C.W. operating conditions at 12GHz. At V_d=8V, it delivered 40.1dBm(10.2W) output power with 9.5dB linear gain and 50% PAE. To the authors' knowledge, this is the highest output power ever achieved from a single FET power amplifier at this frequency. At 1dB gain compression operation point, 40.0dBm(10.0W) output power and 47% PAE were obtained with V_d=8V.

The frequency dependence of the power characteristics were shown in Fig.6. Over the 11.8-12.2GHz frequency range, the amplifier exhibited 9.0-10.2W output power with PAE of 43-50% and associated gain of 7.6-8.1dB under V_d=8V and an input power of 32dBm.

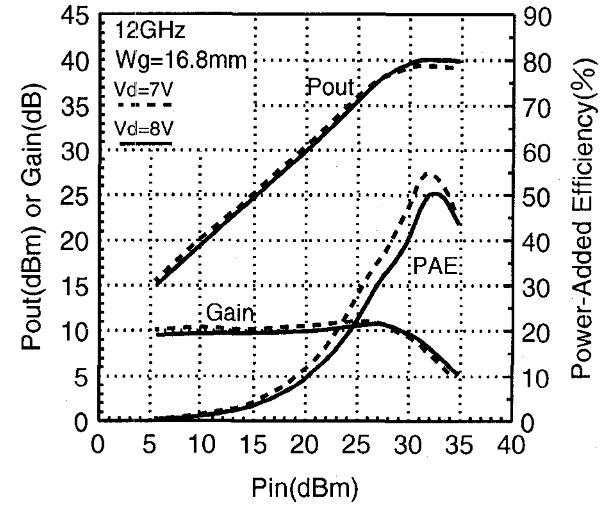

Fig.5. Measured output power, gain and power-added efficiency as a function of input power at 12GHz for internally matched 16.8mm HJFET power amplifier. V_d=7 and 8V.

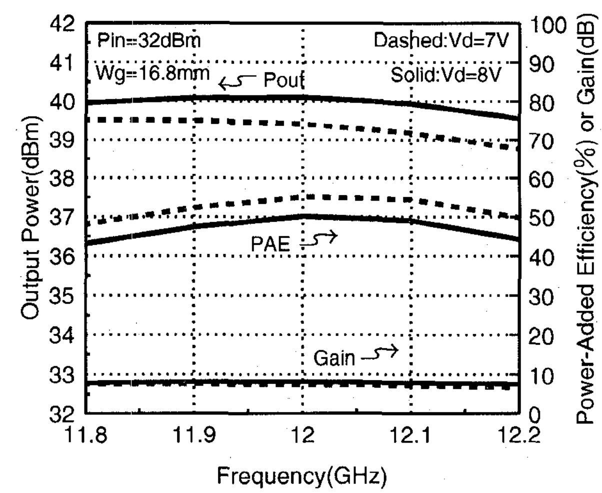

Fig.6. Measured frequency response of the amplifier utilizing 16.8mm device over a 11.6-12.4GHz band.

Power performances measured for various gate periphery devices, including 1.05, 8.4, 12.6 and 16.8mm, are shown in Fig.7[13]. The output power is approximately a linear function of the gate periphery, indicating an output power density of 0.6-0.8W/mm. It should be noted that the maximum PAE value is kept almost constant(50-55%) over the 1.05-16.8mm gate-width range investigated.

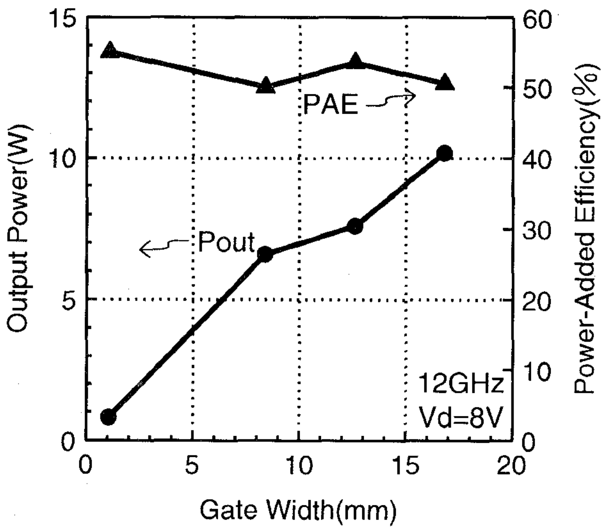

Fig.7. Power performance as a function of total gate width at 12GHz. V_d=8V.

CONCLUSIONS

High output power amplifier fabricated with a one-chip 0.45μm gate HJFET was demonstrated at Ku-band. The developed HJFET amplifier with 16.8mm gate periphery delivered a 40.1dBm(10.2W) output power with 50% power-added efficiency and 9.5dB linear gain at 12GHz. To the authors' knowledge, this is the highest output power ever achieved from a single FET power amplifier at this frequency. Using the developed HJFET technology, more than 0.6W/mm output power density is available, suggesting great potential of the HJFET approach for the future multi-10W power amplifier applications at Ku-band.

The present power HJFET technology is promising for various satellite communication and radar system applications.

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