E-PHEMT, Single Supply, Power Amplifier for Ku Band Applications

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***Abstract* – The development of enhancement mode PHEMT (E-PHEMT), single supply, 10.5 to 18GHz wide band power amplifier MMICs is described. The amplifier was designed with pre-matching techniques utilizing a 0.5μm GaAs E-PHEMT production process. The designed power amplifier exhibit 13 dB of small signal gain, 26.5dBm 1dB gain compression output power at 16 GHz. This MMIC was fabricated in Agilent's advanced E-PHEMT process and have been demonstrated in fully production capability.**

I. Introduction

Wideband, low-cost, power amplifiers (PA) will be crucial to the development of K-band commercial wireless links such as Local Multipoint Distribution Service (LMDS), and point-to-point radio, as the market for these applications mature. Most manufacturers of K-band power amplifiers have focused on wide bandwidth and high gain performance by using technologies with the highest f_T available, which tend to be the least mature and most expensive solutions. Meanwhile, system designers are waiting for low cost components with enough performance. Excellent design results have been published demonstrating microwave power amplifiers developed in various advanced technologies [1-3]. Although E-PHEMT process has many advantages such as;

1) The E-PHEMT device does not need the negative biasing supply,
2) 0.5-μm E-PHEMT has a robustness of the gate metal under high RF power driving, and
3) 0.5μm E-PHEMT can be fabricated by matured stepper lithography, and has low production cost compared with 0.15um E-beam based MMICs that are currently used for advanced MMIC technologies,

E-PHEMT technology has never been focused on as a practical approach to design into sub mm-wave PA market. This work demonstrates that 0.5μm E-PHEMT is a viable technology choice because it offers the lowest cost solution for the required performance for many sub mm-wave PA applications up to 40GHz. In this paper, we report three stages MMIC PA achieved more than 13dB small signal gain and more than 26.5dBm 1dB-gain compression power at 16 GHz frequency.

II. E-PHEMT Process and CAD Tools

Agilent's E-PHEMT process uses a recessed 0.5μm gate. The device has a f_T of 29 GHz, and f_{max} of 76 GHz at Vds=2V, Vgs=0.6V. DC parameters for the device are shown in Table 1. Plots of Gm and Ids versus Vgs are shown in Figure 1. Frequency response of $|h_{21}|^2$ and $G_{A\max}$ for a 100μm device is shown in Figure 2. The wafer material is selected for high power and breakdown with some compromises for noise. A Ti/Pt/Au T-gate is used for low input resistance and high-reliability. The process is designed to operate with a DC drain voltage up to 5V. All steps are defined using stepper lithography on 6-inch wafers.

The MMIC process is equipped with passive components which include a 213Ω/ bulk resistor, 0.4 fF/μm^2 Si_3N_4 MIM capacitor, 27pH backside via and two metal layers for transmission lines.

Table 1. DC Parameters for the E-PHEMT

Parameter	Mean
Gm (mS/mm)	580
Vgs @ peak Gm (V)	0.8
Ids @ peak Gm (mA/mm)	187
Imax (mA/mm) @Vgs=0.9V	246
BVgd @ 1mA/mm (V)	-12
Vto @1mA/mm (V)	0.9
Vth (V)	0.1

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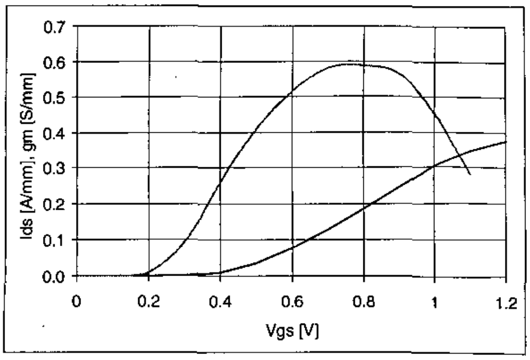

Figure 1. A plot of Gm and Ids versus Vgs for the E-PHEMT device at Vds=3.5V

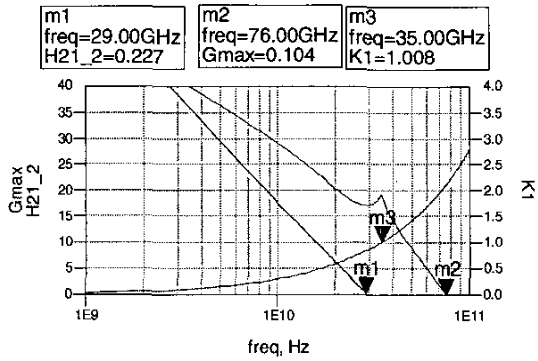

Figure 2 A plot of $|h_{21}|^2$ and $G_{A\max}$ versus frequency for the 100um PHEMT at Vds=2V, Vgs=0.6V. $G_{A\max}$ is not available below the maker3 frequency because the K-factor is less than 1

III. Power Amplifier Design

In the PA design, the DC biasing condition should be selected by the best compromise between gain, output power, and gate conduction current. E-PHEMT based amplifier design requires careful selection of the DC biasing condition, because the Vgs at Gm peak is fairly close to the V_{TO} (See the Figure 1). In this design, we selected $0.32I_{max}$-biasing condition, and the major cause of the power limitation is the forward conduction current.

Figure 3 shows a layout of the single-ended amplifier. A simplified schematic diagram of the single-ended amplifier is shown in Figure 4. It consists of a 3-stage, power amplifier design with one 600μm E-PHEMT in the first stage driving two 600μm E-PHEMTs in the second stage, and the two 600μm cells in the second stage driving four 600um cells in the final stages. The 600μm E-PHEMTs are configured internally as ten, 0.5 x 60μm gate fingers. The amplifier consists of 600μm E-PHEMTs, input, inter-stage, and output matching circuits. Since all E-PHEMT cells are employed identical gate periphery, identical inter-stage matching circuits are employed between first, second, and final FETs. The input, inter-stage and output matching circuits are composed of pre-matching circuits and impedance transformers. As pre-matching circuits which make the frequency-dependence of input and output impedance of FETs small, a constant resistance network is employed for the input side of the FET, and a parallel resonant stub is employed for the output side of the FET [7]. As impedance transformer, Chebyshev low-pass filter configuration is employed [8]. A reactive output matching network provides the final stage FETs with optimum load impedance for maximum output power across the band. The optimum load was determined by using a load-pull simulation based on the large-signal model.

A single positive power supply capability is realize by using a current mirror circuit for the gate biasing, and the schematic is shown in Figure 4. Current mirror is less sensitive to process variation, which is mainly caused by the threshold voltage (Vth), than a resistor-ladder-network or external fixed supply. Since FET based current source consists part of a voltage divider as shown in Figure 4, the Vth difference adjusts the voltage divider ratio. Therefore, the current mirror automatically adjusts the best gate biasing voltage against the Vth variation.

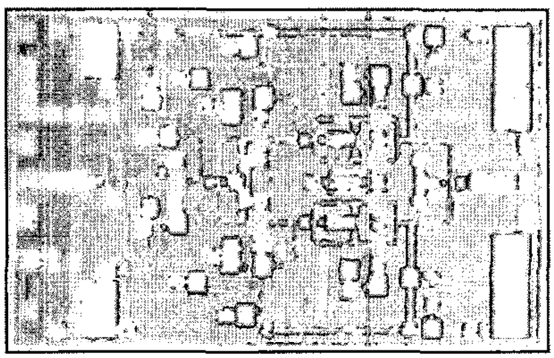

Figure 3. Layout of the power amplifier (2300 x 1250 μm)

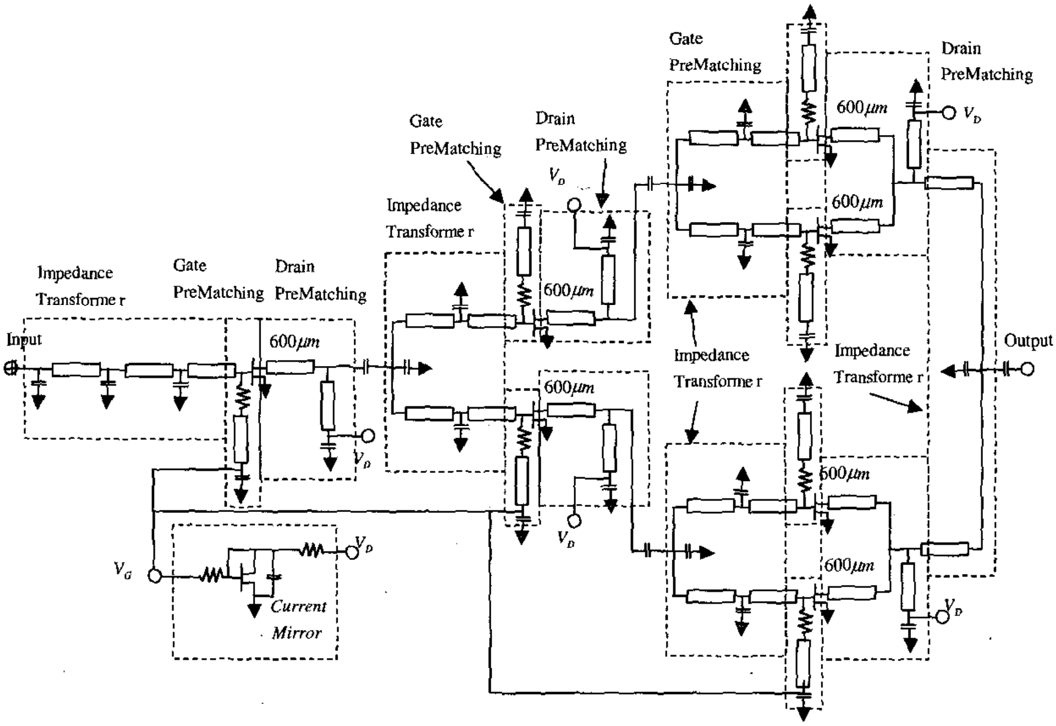

Figure 4. A simplified schematic for the power amplifier

IV. Measurement Results

The MMIC amplifier in this paper was fabricated at Agilent's 6" GaAs IC production fab. in Fort Collins, CO.

For the small-signal measurement, the PA was biased at Vds=5V and Id=0.32Imax, and tested on-wafer environment. The small-signal data for the single-ended amplifiers is shown in Figure 5 over the 5 to 25 GHz frequencies. The single-ended PA demonstrated a gain of typically 13 dB from 10.5 to 18 GHz.

Power performances of the amplifier were measured using an Agilent's 84000 mm-wave automated test system. Measured output power (P-1) and the power added efficiency (PAE) at 1dB gain compression are shown in Figure 6. The amplifier demonstrated more than 22dBm out put power at 1dB gain compression point (P-1) over the 13 to 18GHz frequencies. Measured output power (Pout), Gain, Gate current (Ig), Drain current (Id), and PAE versus input power at Frequency=16GHz. Vds=5V, Ids=0.32Imax are shown in Figure 7. The amplifier showed 24dBm P-1 with 18% PAE. In this condition, the amplifier requires 1mA forward conduction gate current. Figure 8 shows the Pout, Gain, Ig, Id, and PAE versus Pin performances at Ids=0.5Imax condition. The amplifier showed 26.5dBm P-1 with 21% PAE. In this condition, the amplifier requires 2mA forward conduction gate current. The E-PHEMT PA showed that the 0.5Imax is the best condition for the P-1 and PAE performances; however, this condition requires higher quiescent drain current.

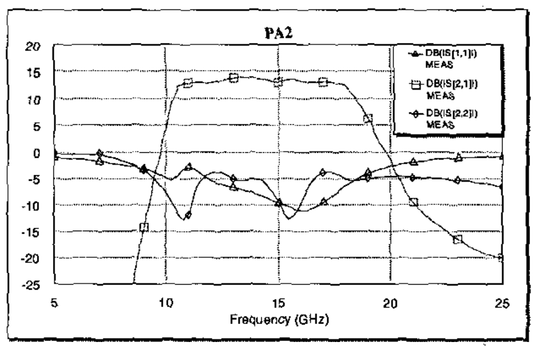

Figure 5. Measured small-signal performance of the single-ended power amplifier, Vds=5V, Ids=0.32Imax

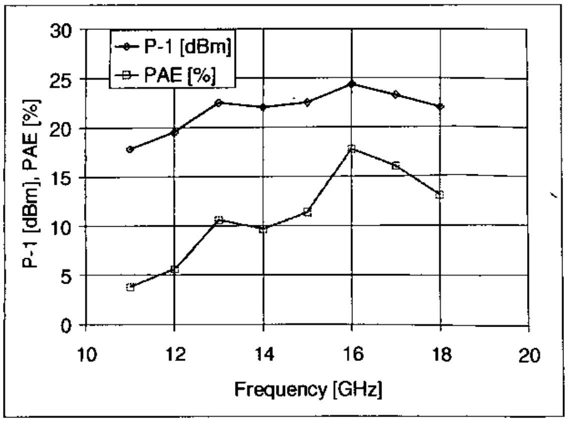

Figure 6. Measured output power and PAE at 1dB gain compression for the single-ended amplifier. Vds=5V, Ids=0.32Imax

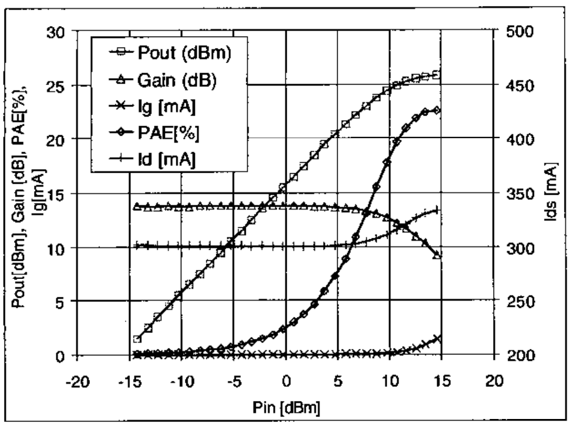

Figure 7. Measured output power (Pout), Gain, Ig, Id, and PAE versus input power (Pin) at Frequency=16GHz. Vds=5V, Ids=0.32Imax

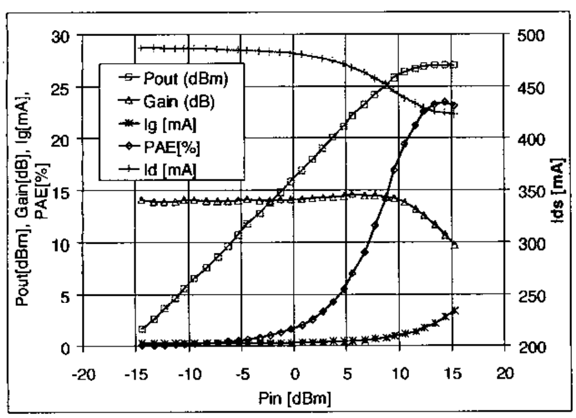

Figure 8. Measured output power (Pout), Gain, Ig, Id, and PAE versus input power (Pin) at Frequency=16GHz. Vds=5V, Ids=0.5Imax

A spectrum analyzer was used throughout the entire testing procedure and the amplifier is stable under any RF drive condition or DC bias condition. No attempt was made to individually bias each stage to get improved gain or efficiency performance.

V. Conclusion

We have described the design and performance of E-PHEMT, single supply, MMIC power amplifiers for the Ku band radio links. All were fabricated in Agilent's 0.5μm E-PHEMT technology, well capable of reliable volume production. Photographs, descriptions, and measured results have been shown. To our knowledge, this is the first publication that the 0.5μm E-PHEMT technology has a capability to realize the single supply, power amplifiers up to 40GHz frequencies.

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