GaAs Power PHEMT Technology and its Applications

Manfred J. Schindler
Raytheon Microelectronics, Research Laboratories
362 Lowell St., Andover, MA 01810

ABSTRACT

The GaAs Pseudomorphic High Electron Mobility Transistor (PHEMT) has demonstrated excellent power performance over a wide range of frequencies and applications. In addition to providing excellent efficiency, the PHEMT is capable of delivering power with very good linearity. It is therefore the device of choice for multi-signal communications systems. The low noise figure of the PHEMT is also well established. Compared to low noise PHEMT, the noise figure of a power PHEMT represents only a minimal compromise. The PHEMT is therefore also an ideal candidate for multifunction ICs.

INTRODUCTION

GaAs Metal Semiconductor Field Effect Transistors (MESFETs) have been produced since the 1970's. HEMTs and PHEMTs are high performance variants of the MESFET. Although originally developed as a low noise transistor, techniques have been developed to provide exceptional power performance from PHEMTs [1], [2]. These properties are obtained by increasing the breakdown voltage to as high as 20 volts, allowing high efficiency operation with a 7 volt supply.

Because the PHEMT is based on well established GaAs MESFET technology, transition from research demonstration to high volume production occurred quickly. At Raytheon, for example, the first research demonstration of the power PHEMT occurred in 1990 [1], and production began in 1992 [3]. Power PHEMTs are now being produced in very high volumes for a large number of applications, both commercial and military. The power PHEMT is attractive for these applications because of its exceptional efficiency, excellent reliability, and modest cost.

PHEMT OPERATION

In a MESFET, carriers from n-type doping are transported through the channel under the gate. The gate potential modulates the carriers in the channel. The high mobility of GaAs allows high gain. Scattering due to dopants in the channel is one of the major performance limitations in a conventional MESFET. The PHEMT structure makes a number of improvements over the conventional MESFET. Referring to Figure 1, the channel is in the layer of undoped InGaAs. The carriers are introduced with thin doping pulses above and below the channel. Energy band discontinuities ensure that most of the carriers transfer from the doping pulses into the channel. Since there is no dopant in the channel, scattering is minimized, resulting in excellent electron transport. The channel is grown with a significant percentage of Indium, typically 15 to 25%. Higher levels of Indium yield higher electron mobility in the channel. InGaAs is not lattice matched to GaAs, so InGaAs layers are strained (hence the device is pseudomorphic). This limits the amount of Indium that can be grown into the channel, and the thickness in the channel.

PHEMT PERFORMANCE

The basic performance evaluation we make for power PHEMTs is in power amplifier configuration. Discrete transistors are tuned at input and output at the fundamental frequency of interest, as well as at harmonics. Typically

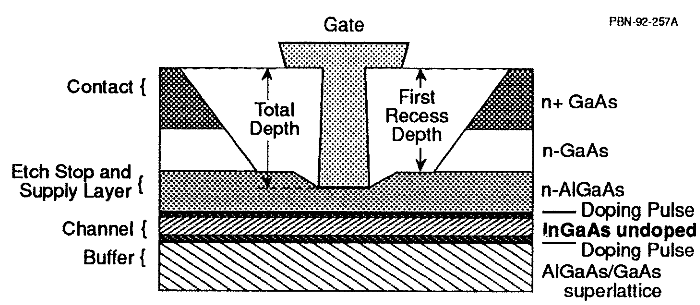

Figure 1. Cross section of a Power PHEMT.

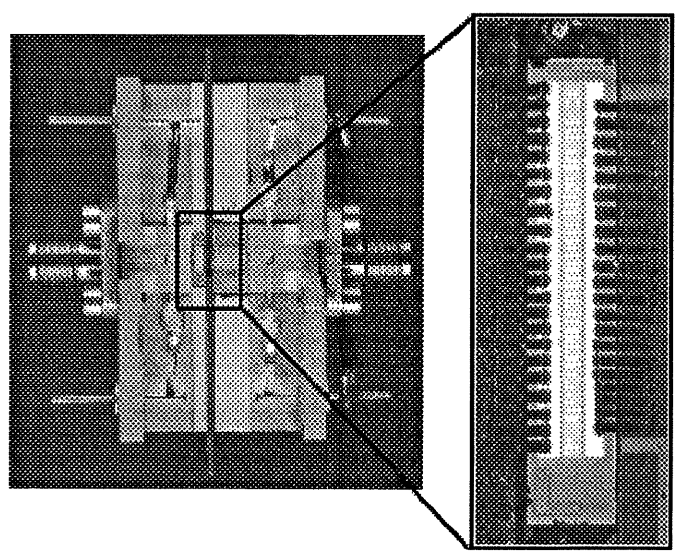

Figure 2. A large periphery PHEMT in a 8 GHz tuned amplifier assembly.

several device sizes (peripheries) are evaluated at any frequency. Table 1 is a summary of power PHEMT performance at several key frequencies.

An example of a tuned transistor is shown in figure 2. This illustrates a large periphery PHEMT in a laboratory test fixture with 8 GHz tuning elements at the input and output. A complete power performance curve at 8 GHz, as well as performance of several PHEMT peripheries at 8 GHz is shown in figure 3 [4]. It can be seen that power scales linearly with periphery, but gain drops as periphery is increased. Power Added Efficiency (PAE) also drops off, because of the drop in gain.

Table 1. PHEMT Power Performance Summary

Frequency (GHz)	Periphery (mm)	Power (Watts)	Power Added Efficiency (%)	Associated Gain (dB)
2.45	36.5	18.0	59.4	12.1
8.0	16.8	8.7	53.0	13.4
14.0	3.0	2.5	53.8	10.8
18.0	3.0	1.8	50.6	9.9
35.0	0.6	0.5	44.2	6.0
44.0	0.6	0.4	35.0	5.2

The power PHEMT also has attractive noise performance and passive mode switch characteristics. The noise characteristics of Raytheon's 0.25 μm gate length power PHEMT, for example, are excellent: Fmin is 0.65 dB at 10 GHz with and associated gain of 10.5 dB. The passive mode switch characteristics are also very good: Ron is typically 1.9 Ω-mm, and Coff 0.30 pF/mm for a switching figure-of-merit fc of 280 GHz.

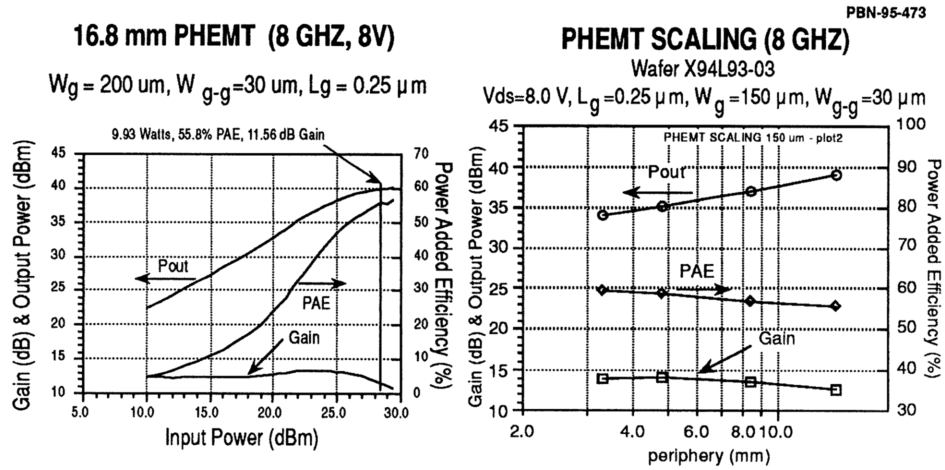

Figure 3. Power performance of a 16.8 mm PHEMT at 8 GHz (left). Performance of several peripheries a 8 GHz (right).

APPLICATIONS

Numerous products for a wide range of applications have now been developed using the power PHEMT. Examples of these products, and their performance are included below. PHEMTs are typically used at frequencies between 1 GHz and 50 GHz, although examples outside this range exist. As the examples below illustrate, some PHEMT applications use a MMIC implementation, some a hybrid/MIC implementation, and some a combination of MMIC and hybrid.

The performance of a MMIC power amplifier for CDMA or AMPS applications is shown in figures 4 and 5. This is a 2 stage MMIC using a 0.5 μm gate length PHEMT.

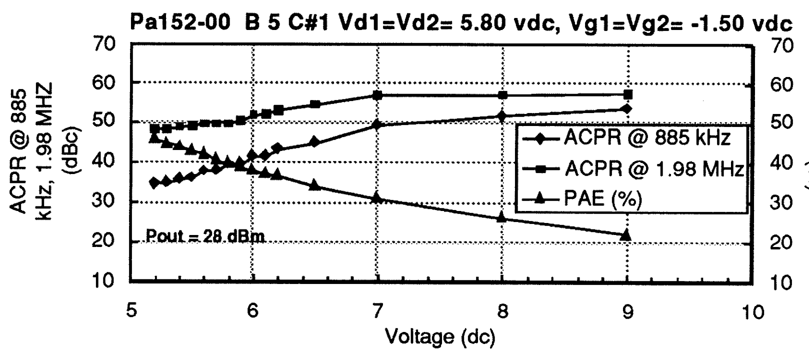

Figure 4. Power Amplifier Performance in CDMA mode.

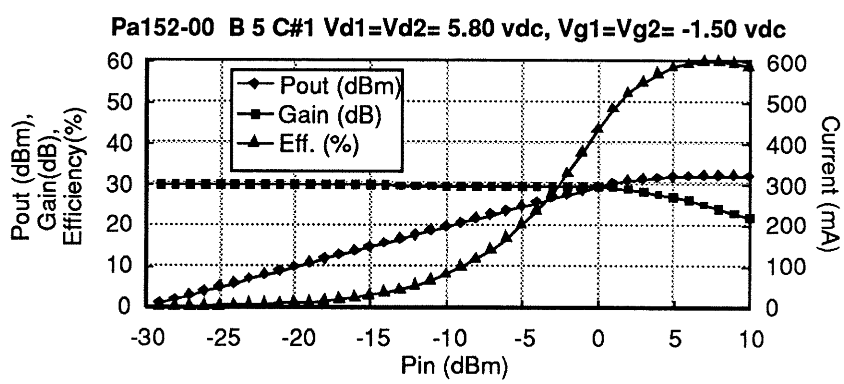

Figure 5. Power Amplifier Performance in AMPS mode.

Performance is measured in the low cost plastic package shown in figure 6. At 850 MHz PAE is over 60 % in AMPS mode, over 45% in CDMA mode with an adjacent channel power ratio (ACPR) of better than 45 dBc.

The power PHEMT can also be used to generate far higher levels of power. An example is shown in figure 7. This is a 20 Watt hybrid/MIC power amplifier for space applications. As the performance curves in figure 8 show, excellent performance is achieved. A similar amplifier achieved 44 watts of power with 52% power added efficiency and 13 dB associated gain at 2.45 GHz [6].

Because of their high performance and reliability, power PHEMTs power amplifiers are being developed for many other space applications. PHEMTs are also being used for both the T/R module for the Iridium® main mission antenna and the individual subscriber units (ISU). The power amplifier for the ISU is shown in figure 9. Four large periphery PHEMTs are power combined to achieve the required linear power. Similarly, a single large periphery PHEMT is being used in the Globalstar Transmit module, shown in figure 10. Here again, a combination of high power, high efficiency and high linearity is required [7]. The performance of the amplifier is shown in figure 11. Good linearity, measured as Noise Power Ratio (NPR), is achieved simultaneously with high efficiency.

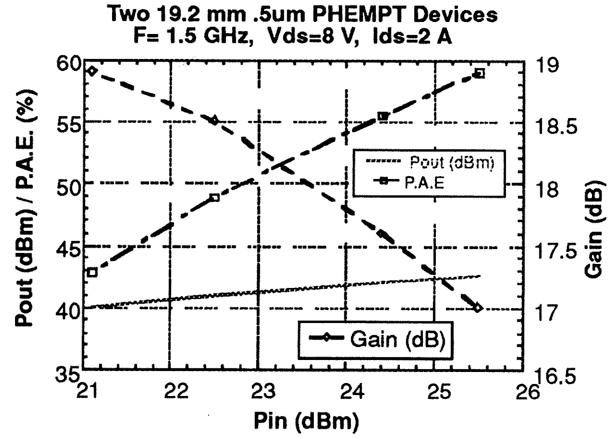

Figure 8. Performance of the 20 Watt PA.

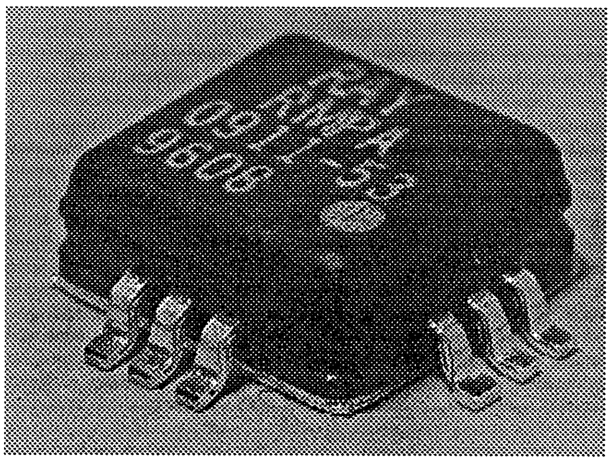

Figure 6. Packaged CDMA/AMPS Power Amplifier.

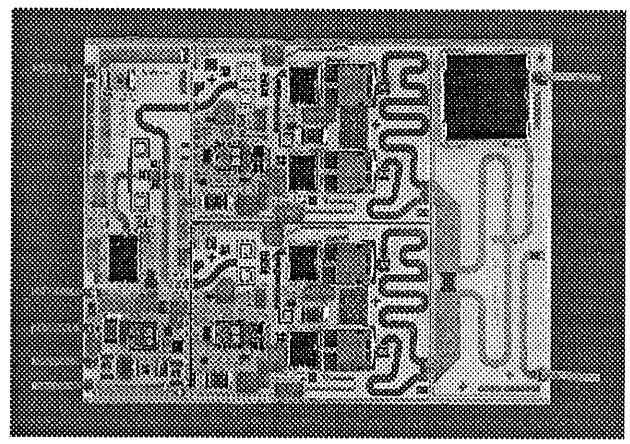

Figure 9. Photo of a power amplifier for Iridium® individual subscriber units.

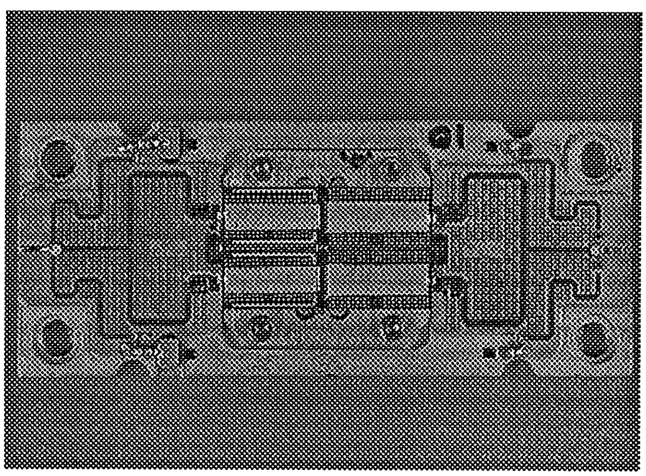

Figure 7. Photo a high performance 20 Watt PA for space applications.

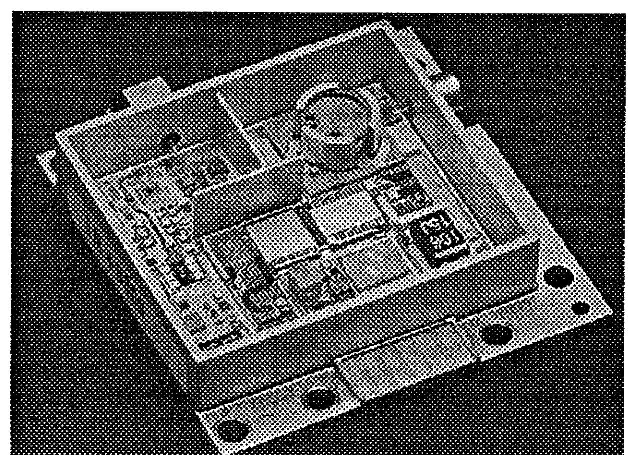

Figure 10. A 2.45 GHz Transmit Module for Space Applications.

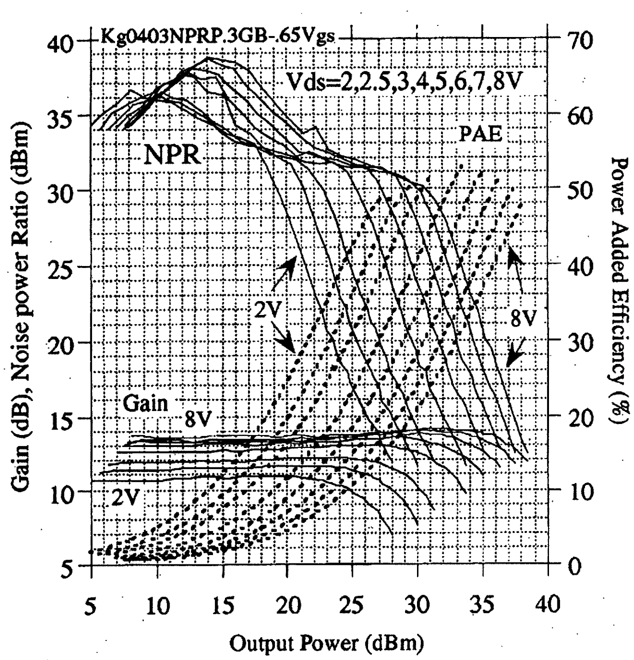

Figure 11. Performance of the 2.45 GHz linear power amplifier.

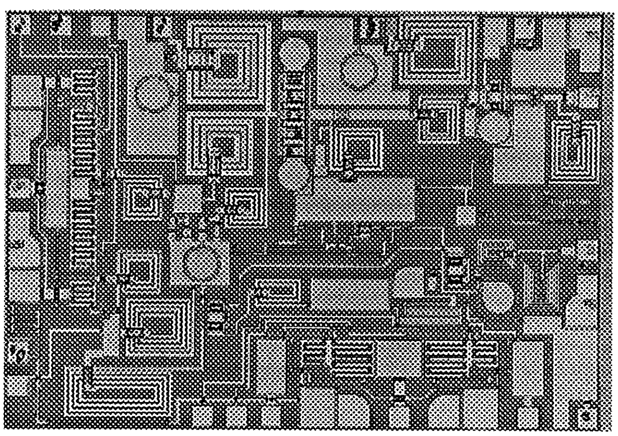

Figure 12. 2.45 GHz PHEMT Transceiver.

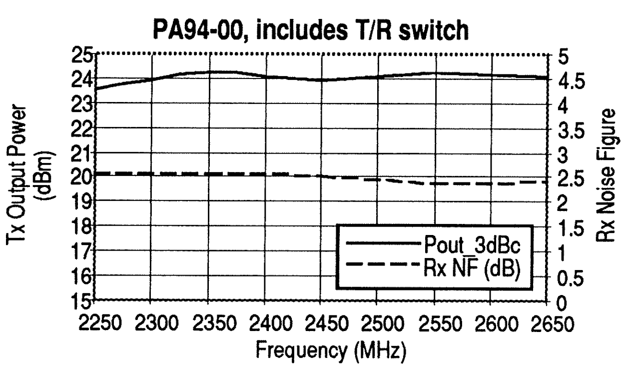

Figure 13. Transmit and Receive performance of the 2.45 GHz Transceiver.

The combination of low noise and efficient power makes the PHEMT an ideal candidate for transceivers. Such a circuit, made with 0.25 μm PHEMTs, is shown in figure 12. This circuit includes an LNA, a PA and switches. Transmit and receive performance at 2.45 GHz are summarized in figure 13.

CONCLUSION

The GaAs power PHEMT is a recently developed device that has made a rapid transition to productization and has shown excellent power performance up to 50 GHz. Power levels of up to 50 Watts have been demonstrated and efficiencies of 50 to 60% are routinely achieved. Power amplifiers made with PHEMTs can exhibit excellent linearity simultaneously with efficiency. The excellent noise performance of the power PHEMT, as well as it's attractive passive mode switch characteristics, make it an ideal device for multifunction circuits such as transceivers. A wide range of applications can benefit from PHEMT technology, including RF power generation, radar and communications.

ACKNOWLEDGMENTS

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