Power PHEMTs - Beyond Power and Efficiency

M. Schindler, D. Teeter, A. Platzker, J. Griffiths, K. Kessler, A. Forbes
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. Todays wireless communications systems, however, require more than just power and efficiency. Linear power is also a requirement, specified by parameters such as NPR and ACPR. The PHEMT has proven itself a high performance device for these requirements. Beyond power, the PHEMT also has excellent noise and passive switch characteristics. 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. 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.

PHEMT PERFORMANCE

Since these devices were primarily developed for microwave power applications we routinely measure CW power performance. Discrete transistors are tuned at input and output at the fundamental frequency of interest, as well as at harmonics. Table 1 is a summary of single tone PHEMT power performance at several key frequencies. In addition to the CW performance shown in Table 1, excellent performance with complex waveforms has also been demonstrated as described below.

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.

Table 1. PHEMT CW 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	9.9	55.8	11.6
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

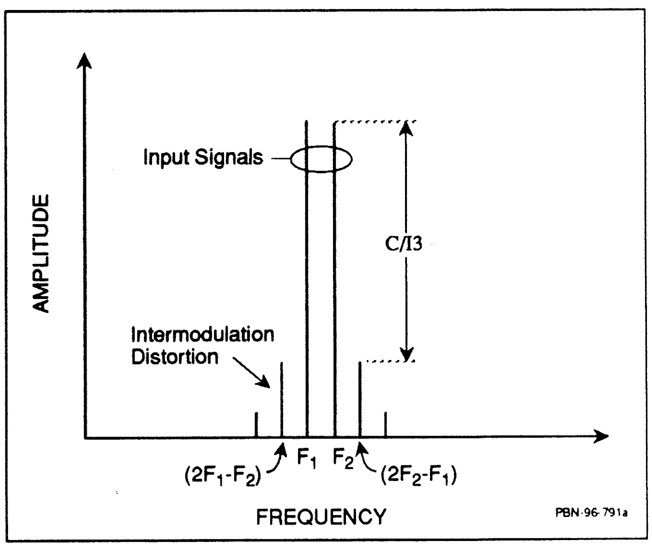

Figure 1. Frequency spectrum for Third Order Intermodulation (IM3).

POWER LINEARITY

Many of todays power amplifier requirements are for wireless communications systems. These are typically multichannel, complex waveform systems. Power amplifier efficiency remains a critical requirement, but low distortion is also needed. If distortion is high, products will spill into adjacent channels, in what is referred to as spectral regrowth. High distortion ultimately results in communcation errors.

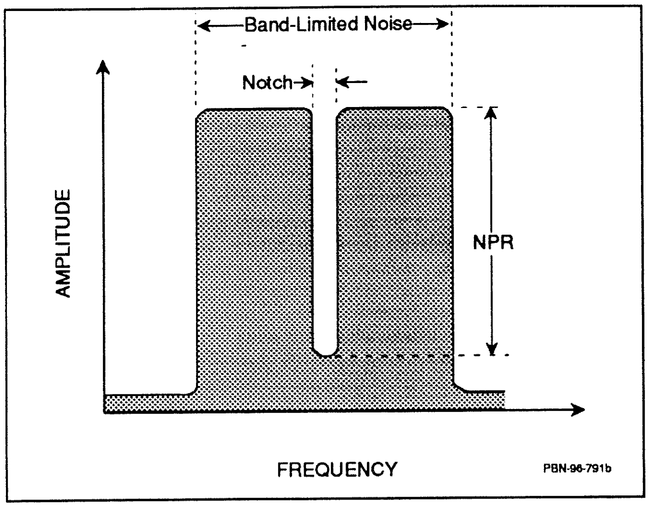

Figure 2. Frequency spectrum for Noise Power Ratio (NPR).

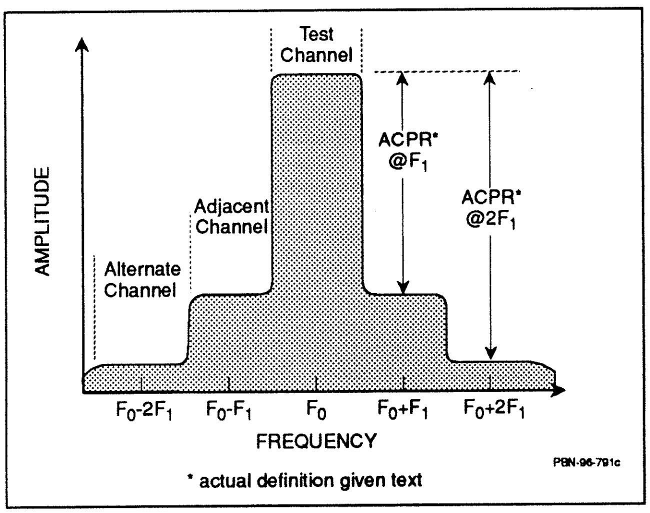

Figure 3. Frequency spectrum for Adjecent Channel Power Ratio (ACPR).

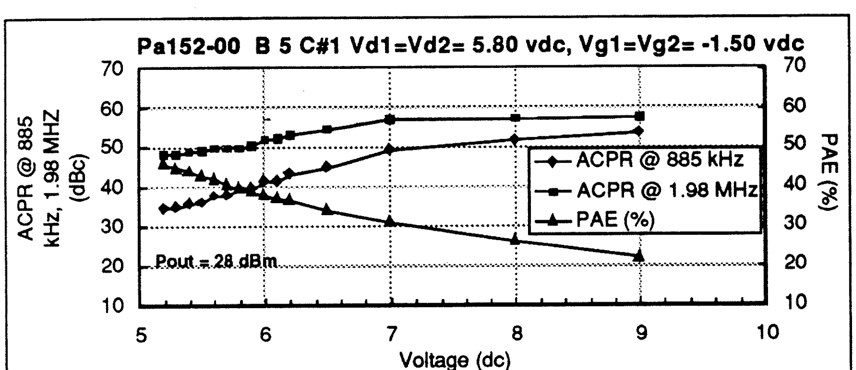

Figure 4. Power Amplifier Performance in CDMA mode.

Several different measures are used for power amplifier linearity. Primary among them is Third Order Intermodulation (IM3), Noise Power Ratio (NPR), and Adjacent Channel Power Ratio (ACPR). It is not simple to convert between these parameters, although it is possible if complex data is taken [8]. Typically each of these parameters is measured individually with a specialized test system.

IM3 is the simplest of the linearity measures, but also the least representative of wireless systems. It is illustrated in figure 1. Two tones of equal power, but slightly different frequencies (f1, f2) are used. Third order distortion products appear next to the fundamental signals (2f1-f2, 2f2-f1), and are measured with respect to the fundamental signals as C/I3in dBc. Although this measurement is related to Third Order Intercept (TOI or IP3), it is not the same. TOI is an extrapolation of small signal distortion, and is not valid in large signal operation.

NPR is used to simulate a multi-channel signal. It is illustrated in figure 2. In NPR, a noise signal is passed through a bandpass filter with a passband equivalent to the bandwidth of the desired multi-channel signal. A very narrow notch filter is then used to cut a deep notch into the signal. The test signal is amplified by the test device, and the resulting depth of the notch determines linearity. The depth of the notch is measured in dB. The NPR test signal may also be generated by numerous phase random signals across the band with one or more deleted to create the notch.

In an ACPR measurement the actual modulation signal used in the communication system (such as CDMA) is used as the test signal. It is illustrated in figure 3. ACPR is defined as the ratio of Adjacent or Alternate Channel Power (ACP) to Main Channel Power (MPC) as follows:

$$ACPR = \frac{ACP}{MCP}$$

$$ACP = k \int_{f_0+f_1-\Delta}^{f_0+f_1+\Delta} \left|v_{out}(f)\right|^2 RRC(f)df$$

$$MCP = k \int_{f_0-\Delta}^{f_0+\Delta} \left|v_{out}(f)\right|^2 RRC(f)df$$

where RRC is root raised cosine, and refers to a filter characteristic. ACPR provides an excellent representation of actual performance in a system, but requires that precise signal waveforms be generated.

APPLICATIONS

Numerous products for a wide range of applications have now been developed using the power PHEMT. PHEMTs are typically used at frequencies between 1 GHz and 60 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.

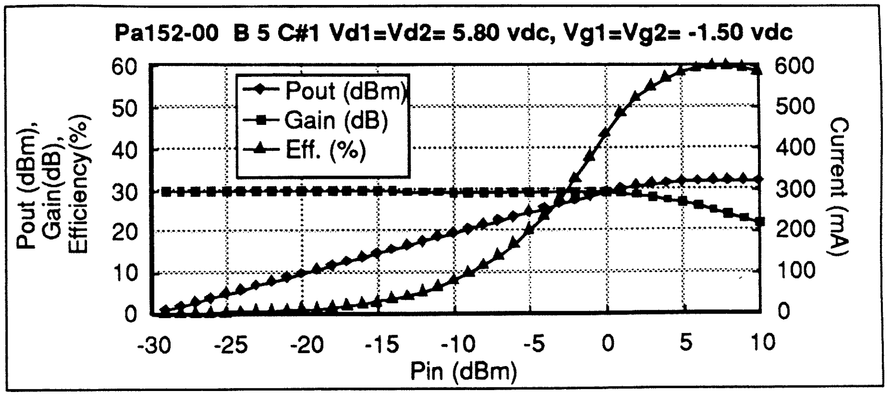

Figure 5. Power Amplifier Performance in AMPS mode.

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. 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.

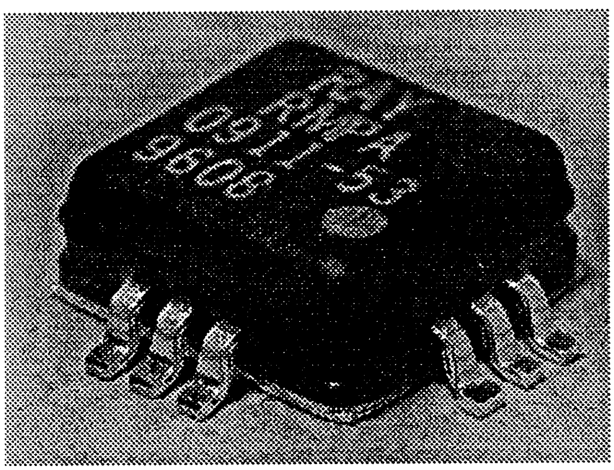

Figure 6. Packaged CDMA/AMPS Power Amplifier.

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 PHEMT power amplifiers are being developed for many other space applications. PHEMTs are also being used in both the Iridium® and Globalstar systems. Large periphery PHEMTs are being used and once again, a combination of high power, high efficiency and high linearity is required [7]. The performance of the Globalstar amplifier is shown in figure 9. Good linearity, measured as Noise Power Ratio (NPR), is achieved simultaneously with high efficiency.

The combination of low noise and efficient power makes the PHEMT an ideal candidate for transceivers. Such a circuit has been made with 0.25 µm Power PHEMTs, is shown in figure 10. This circuit includes an LNA, a PA and switches. Transmit and receive performance at 2.45 GHz are summarized in figure11.

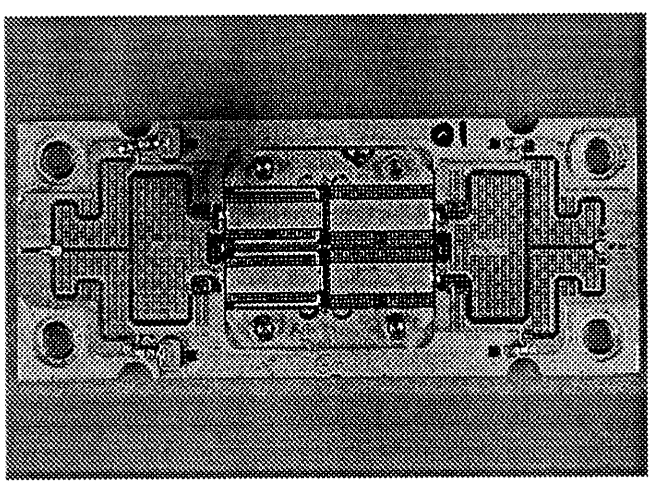

Figure 7. Photo a high performance 20 Watt PA for space applications.

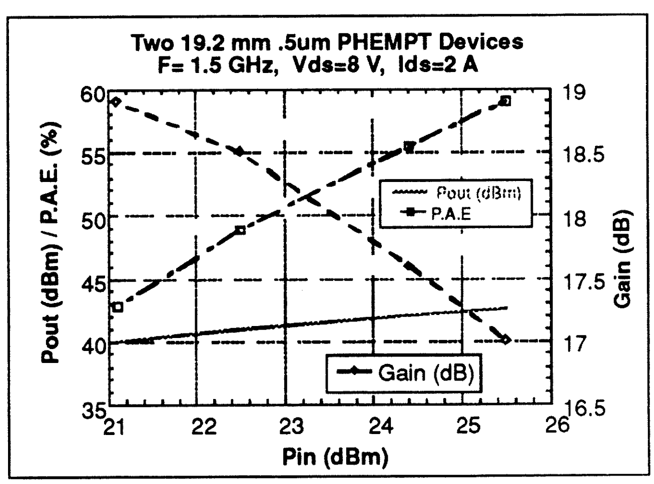

Figure 8. Performance of the 20 Watt PA.

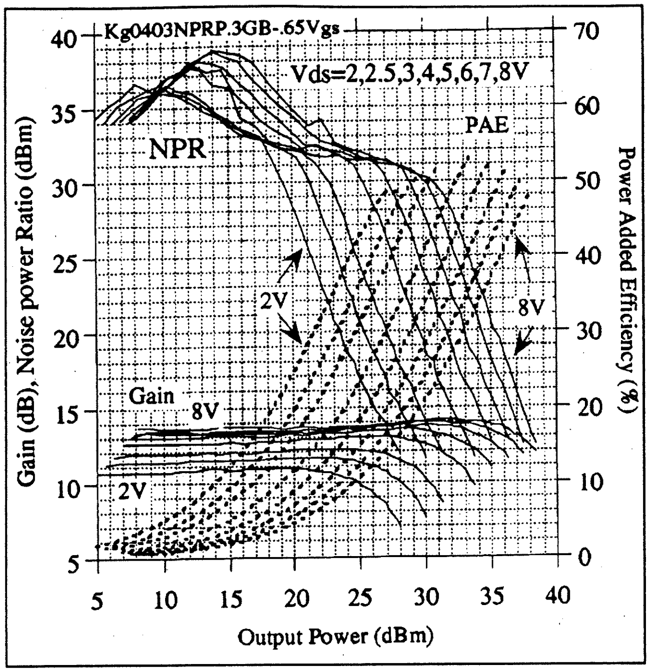

Figure 9. Performance of the 2.45 GHz linear power amplifier.

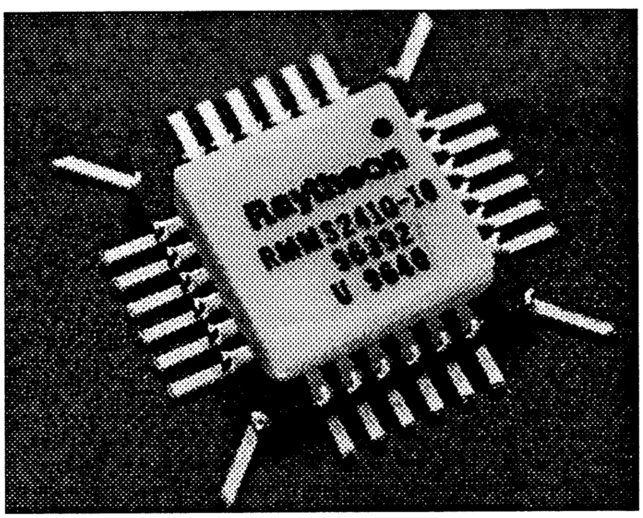

Figure 10. Packaged 2.45 GHz PHEMT Transceiver

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.

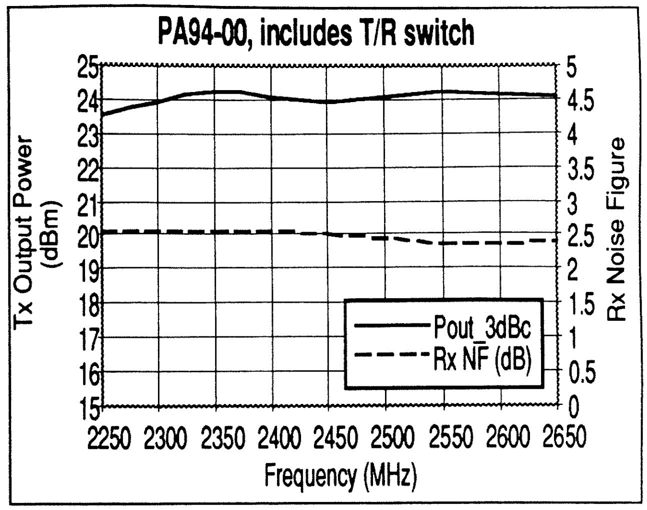

Figure 11. Transmit and Receive performance of the 2.45 GHz Transceiver.

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