

# Advances in Ultra-High Linearity E-Mode GaAs PHEMT MMIC Amplifiers for use in broadband, high dynamic range applications using complex digital waveforms

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**Abstract** – Recent advances in MMIC GaAs PHEMT amplifiers have pushed intermodulation (IM) distortion performance beyond the traditional relationship between intercept point and compressed output power levels making them ideal candidates for use in broadband digital transmission using complex modulation such as OFDM and QAM. Single-ended and push-pull structures have improved IP3 and IP2 performance; however, real benefits are exemplified when characterized for ACPR, EVM and MER. This paper will discuss the performance of a variety of MMIC amplifier designs based upon E-Mode PHEMT technology and the method to characterize these amplifiers for applications that employ complex digital modulation

**Index Terms** – PHEMT, WCDMA, LTE, DOCSIS, Intermodulation, MMIC amplifiers.

## I. INTRODUCTION

Digital communication systems, whether wireless telecom, optical networks or digital cable TV stress the linearity of the RF chain in many ways different from classical FM, AM or PCM systems. These systems employ phase and amplitude modulation which are often characterized in terms of spectral mask and modulation accuracy.

Over the past several years, a new class of MMIC amplifier has emerged based upon an Enhanced Mode GaAs PHEMT (E-PHEMT) semiconductor technology. This class of MMIC Amplifiers provides users advantages in both broadband noise figure and intermodulation performance setting them apart from previous generations. GaAs PHEMT based designs are historically known for their extremely low noise figure. PHEMT's have also been used extensively in the mobile PA market; however, it is only recently that designs have proven to possess the combination of low noise and high intermodulation distortion which improve both ends of the dynamic range over broad bands.

A key performance differentiator of MMIC amplifiers made from this technology is the inherent linearization relative to multi-tone or signals with peaks in voltage or power. Broadband Class A E-PHEMT Amplifiers are exhibiting outstanding intermodulation distortion performance relative to output power at 1 dB compression and consumed DC current. Previous generation MESFET Amplifiers would typically exhibit 10 dB separation between P1dB and OIP3. Single ended, broadband MMIC

Amplifiers made from E-PHEMT are able to push that separation to 20 dB. This is critical for use in high dynamic range systems; however, the real test is how these amplifiers perform when exposed to complex modulated signals.

The following table summarizes three 50 Ohm MMIC amplifiers we will use as basis of comparison and to demonstrate the performance relative to complex waveforms and digital system specification parameters.

TABLE I  
E-PHEMT MMIC AT 2 GHz

Model	NF (dB)	P1dB (dBm)	OIP3 (dBm)	DC Supply
PMA-545+	0.96	+19.8	+36	3V, 80mA
PHA-1+	2.48	+22.6	+41	5V, 180mA
PHA-1X+	2.2	+22.6	+43	5V, 140mA

Furthermore, it is important to note that these MMIC E-PHEMT amplifiers are all broadband, and employ no linearization circuit technologies such as pre or post distortion. They are all single stage Class A designs. The PHA-1X+ is the most recent generation of E-PHEMT and is distinguished through its higher IP3 performance at reduced DC power consumption.

## II. CHARACTERIZING AMPLIFIERS WITH COMPLEX DIGITAL WAVEFORMS

Historically, amplifiers were characterized using CW signals to take relatively simple measurements such as intermodulation distortion and compression measurements (AM to AM and AM to PM). While these measurements remain quite useful, the wireless industry discovered that amplifiers behave differently when stimulated with a complex signal with a high peak to average ratio than they would with an un-modulated CW signal. As a result, it is desirable for the characterization of wireless amplifiers to include measurements made with "real world" complex waveforms. The most common measurements are Adjacent Channel Power Ratio (ACPR) and Modulation Accuracy.

The complex waveforms used in wireless communications produce distortion products called spectral regrowth. ACPR measures this regrowth and is defined as the ratio of the main channel power to the adjacent channel

(see Fig. 1). Some wireless standards require a spot measurement where power measurements are made at specific frequency offsets in the main and adjacent channels [1]. Other standards require an integrated power measurement where the spectrum analyzer individually computes the total power across the entire main channel and each of the adjacent channels.

Accurate ACPR measurements can be challenging when using older spectrum analyzers. Features have been added to the modern spectrum analyzer to make measurements easier and more accurate. RMS averaging is used to eliminate errors which occur when averaging is done on a log scale. An Average Detector is also used because it accurately measures the complex waveforms with noise like characteristics. In addition to having these core features, modern analyzers also offer one button measurement capability for easy and repeatable standard compliant measurements.

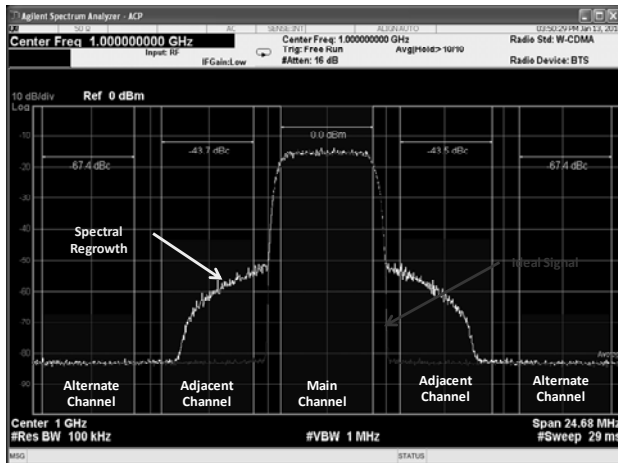


Fig. 1. ACPR Measurement - WCDMA

Modulation Accuracy measurement has also become valuable during amplifier characterization because it represents a summation of all impairments on the signal. The most common Modulation Accuracy measurement is referred to as Error Vector Magnitude (EVM) – see Fig. 2. EVM is a quantitative figure of merit that represents the quality of digitally modulated signals. Different applications may use different terms such as Relative Constellation Error (RCE) in WiMAX or Modulation Error Ratio (MER) in Cable TV applications, but the fundamental measurement is essentially the same; the difference between the measured signal and an ideal reference signal.

The analyzer demodulates the signal and recovers the intended symbols. It then mathematically re-modulates the signal to create an ideal reference signal. EVM is the resulting vector between the two, representing both the amplitude and phase errors. Typically it is expressed as a percentage of the peak ideal signal.

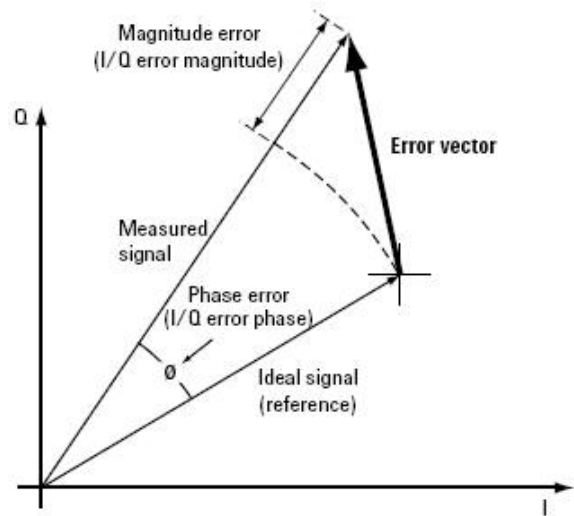


Fig. 2 Error Vector Magnitude - is equal to the ratio of the power of the error vector to the Root Mean Square (RMS) power of the reference.

### III. AMPLIFIER PERFORMANCE RELATIVE TO COMPLEX DIGITAL WAVEFORMS

For comparative purposes, all units are first characterized for their traditional RF linearity parameters, namely: Output Power at 1dB Compression, Output IP3 and Output IP2 (Fig.3-5). Although all these MMIC amplifiers are considered high dynamic range, the variation in Intercept Point is indicative of the specific circuit design and FET structure.

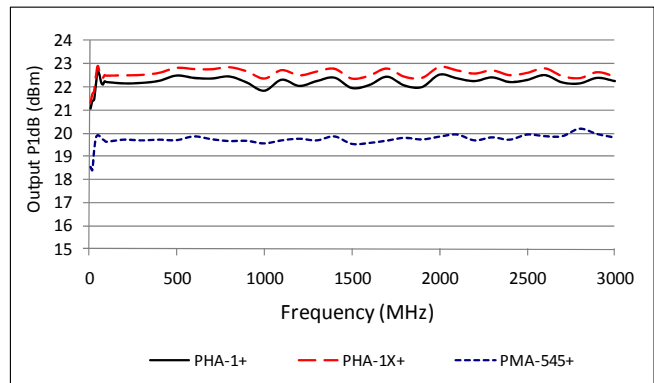


Fig. 3 Output Power at 1 dB Compression

Both the PHA-1+ and the PHA-1X+ exhibit comparable gain compression performance whereas the lower bias PMA-545+ is approximately 3 dB lower in output power capability. Also, you will observe that the PHA-1X+, constructed using our latest E-PHEMT process, does not exhibit the reduction in IP3 performance at the low end of the frequency range, and has significantly greater IP2 performance up to approximately 1000 MHz.

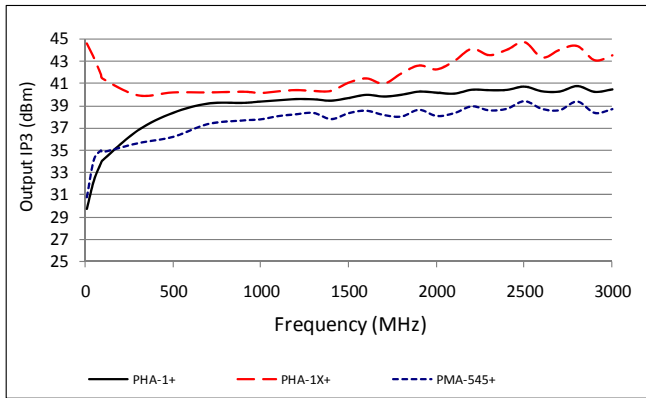


Fig. 4 Output Third Order Intercept Point (IP3)

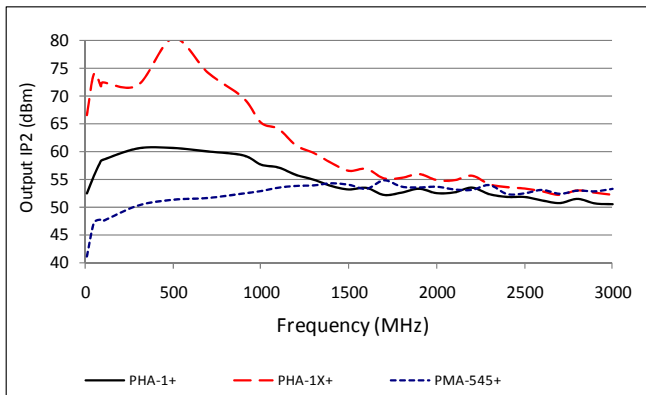


Fig. 5 Output Second Order Intercept Point (IP2)

#### IV. ACPR – EVM – MER MEASUREMENTS

Complex digital waveform characterization often is performed in accordance with industry standard test models which will define the center frequency, channel bandwidth, number of carriers, number of active channels and a number of other parameters that detail the digital signal structure. From the perspective of the amplifier, these parameters manifest themselves in a power distribution. The Complementary-Cumulative-Distribution-Function (CCDF) defines the statistics of a test signal and specifies the signals probability of exceeding a specific power threshold.

Digital waveforms are configured using Agilent’s Signal Studio software suite and generated using the Agilent MXG-N5182A Vector Signal Generator. Both spectrum and modulation accuracy measurements are made using the MXA-N9020A Vector Signal Analyzer which provides a variety of different measurements; however, as previously described the most commonly used test parameters are ACPR and EVM which is observed in a display similar to that shown respectively in Figures 1 and 6.

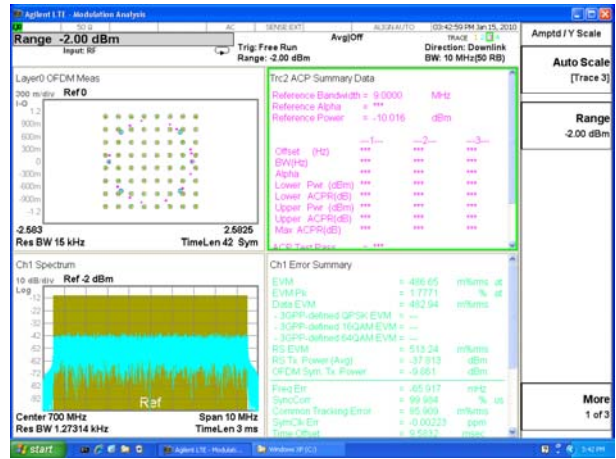


Fig.6 – Typical output screen of MXA Vector Signal Analyzer showing IQ Modulation Analysis including EVM measurements

A summary of performance over a range of output powers is the ideal means of comparison. These measurements were automated using the same measurement equipment sweeping input power; however, since each amplifier has different gains, the measurements are all referenced to the power at the output of the device and are shown in Fig. 7 through Fig. 9.

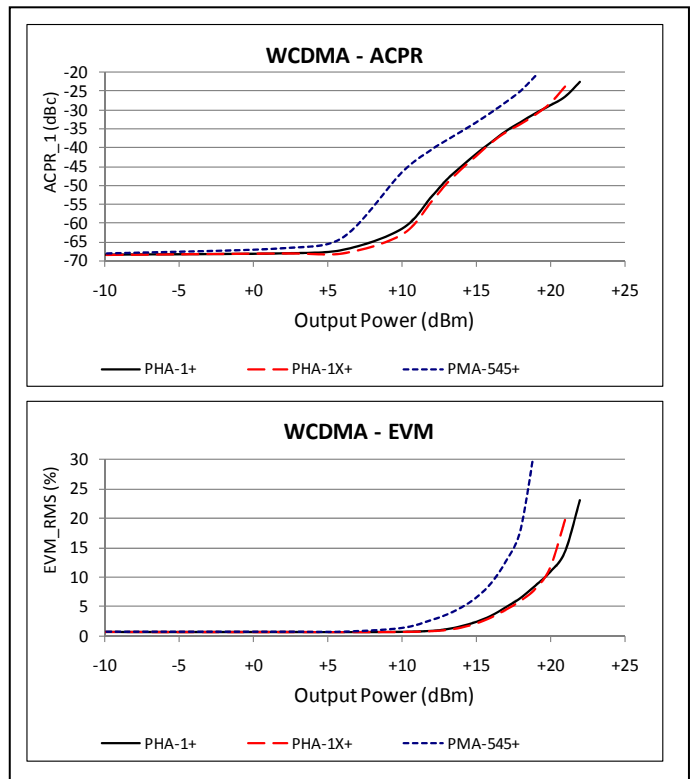


Fig.7 WCDMA – Test Model 1, 2100 MHz, 1 Carrier, 64 Channels

Fig. 9 DOCSIS – 64 QAM\_1C, 500 MHz

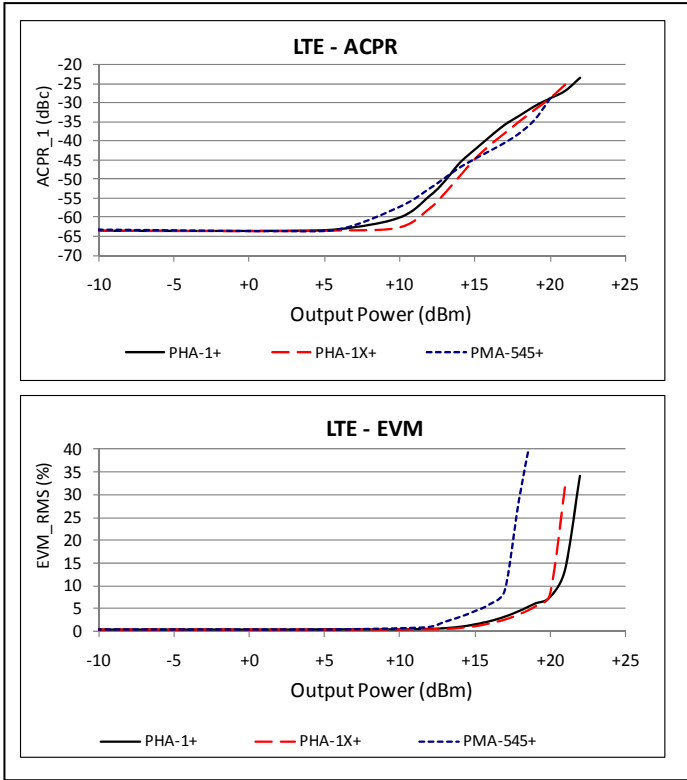
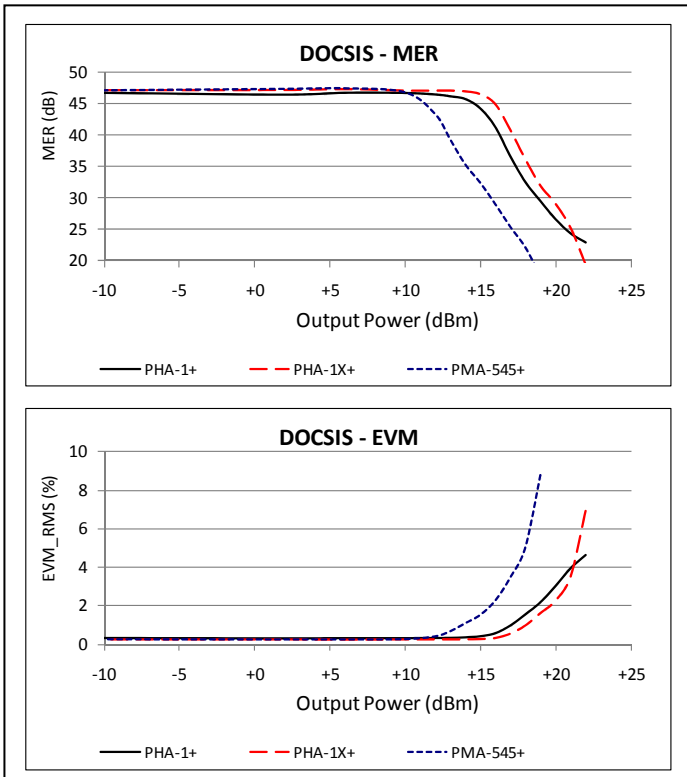


Fig. 8 LTE – FDD, 700 MHz, 1 Carrier, 10 MHz



## V. CONCLUSION

The three E-PHEMT MMIC amplifiers are readily characterized for WCDMA, LTE and DOCSIS using off-the-shelf equipment and waveforms. In both the case of spectral regrowth and modulation accuracy, there is an observable difference between the PMA-454+ and both PHA-1+ series. This is expected based upon the 1dB Compression and Intercept Point data. However, it is also apparent that is impossible to directly correlate either compression or two-tone intermodulation performance to spectral regrowth or modulation accuracy. Therefore, when making use of high dynamic range amplifiers within digital communication systems using complex, high peak to average ratio signals, the proper means to determine the contribution to system error and spectral degradation is direct measurement using waveforms and measurement systems similar to the one used within this paper.

## VI. ACKNOWLEDGEMENTS

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## VII. REFERENCES

- [1] "Optimizing Dynamic Range for Distortion Measurements"; *Agilent Technologies Product Note*, literature number 5980-3079EN, November 28, 2000.