# Application of GaN Class E Amplifers in EER/ET Amplifier Systems

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Class E amplifiers offer significant advantages for high efficiency operation, although they have been largely limited to relatively low microwave frequencies and/or low output powers. GaN HFETs are well suited to Class E at high powers and high frequencies, inasmuch as their output capacitance is particularly low for a device with a given output power, and has little voltage dependence. Very high efficiency has recently been demonstrated in Class E amplifiers configured with GaN HEMTs [1]. To apply Class E amplifiers to signals with time-varying envelope such as used in basestations, complex architecture such as Chereix or EER/ET in necessary. In this work, we demonstrate the use of an EER/ET system in conjunction with a GaN-based Class E amplifier. DSP predistortion is used to maintain appropriate linearity. Using a WCDMA single carrier input signal, a power-added efficiency in excess of 48% was achieved, at an average power level of 1.4 W (and peak power of >8W).

The GaN HFET used in this work was produced by MOCVD on a semi-insulating SiC substrate. Class E circuitry corresponds to the design reported by Pribble et al. [1]. The maximum power under CW operation is 10W; the output power for cw input tones scales approximately according to the square of the power supply voltage, as shown in fig. 1. The EER/ET system used is shown in fig. 2. The signal is generated using a DSP system, with separate paths for envelope and RF (synchronized by adaptive DSP procedures). The envelope amplifier is capable of providing wide bandwidth, high power and high efficiency, by means of an architecture which combines a switching dc-dc converter stage (primarily used for low frequencies) and a linear amplifier stage (primarily used for high frequencies). A similar system has been reported recently, in conjunction with a low power (200mW) Class E amplifier, for broadband mobile (low power) applications [2].

To modulate the output-envelope, the power supply voltage Vdd was chosen to vary with the input power approximately as $Vdd=K_1 P_{in}^{1/2} + K_2$ (where $K_1$ and $K_2$ are constants). The input RF signal was also envelope modulated (unlike for a classical EER amplifier), which was necessary to minimize distortion near the zero crossings of the envelope. The gain of the Class E amplifier was found to vary with power supply voltage, and as a result, DSP predistortion was needed to maintain flat gain vs output power. Figure 3 illustrates the output voltage amplitude vs input voltage amplitude, before and after predistortion.

The amplifier was tested with a WCDMA single carrier signal, which was decrested and "detroughed" to improve overall performance. The peak-to-average power ratio was 7.6dB. The overall characteristics of the amplifier, including input and output power, supply voltage variation and RMS power error, are shown in table 1. To arrive at a proper value for power added efficiency, the power dissipated in the envelope amplifier as well as in the RF stage is included. However, a portion of the bias current of the envelope amplifier was omitted, since the envelope amplifier used was designed for higher power applications (peak powers in excess of 100W), and it exhibits some bias power that would not be present if the present RF stage were scaled up, or if the present envelope amplifier were scaled down.

This work demonstrates that outstanding performance can be obtained from GaN HFETs in conjunction with EER/ET architectures for basestation applications. It also shows that Class E amplifiers are attractive for very high power systems, even with time-varying envelope signals.

**References:**

[1] W. Pribble, J. Milligan and R. Pengelly, "High Efficiency Class-E Amplifier Utilizing GaN HEMT Technology", submitted to this conference.
[2]F.Wang et al., "Wideband Envelope Elimination and Restoration Power Amplifier with High Efficiency Wideband Envelope Amplifier for WLAN 802.11g Applications, *2005 International Microwave Symposium*

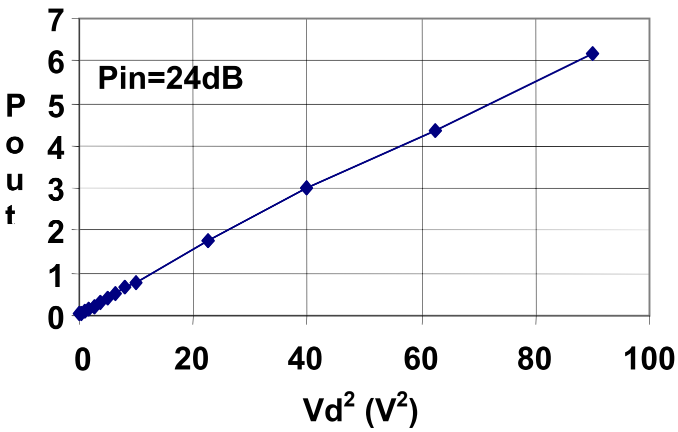


Fig.1: Output power (in W) for CW inputs to Class E amplifier vs square of supply voltage.

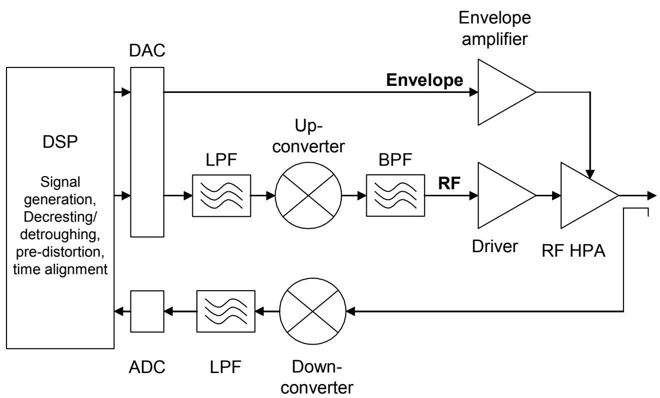


Fig.2: Block diagram of EER/ET amplifier system

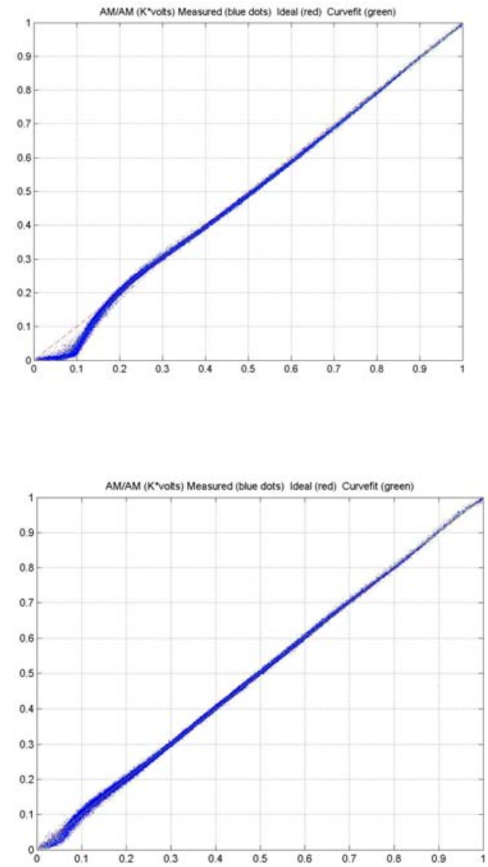


Fig.3: Normalized output voltage amplitude vs input voltage amplitude:a) prior to predistortion; b) after predistortion

Table 1: Characteristics of EER/ET Amplifier (envelope amplifier open circuit bias power has been subtracted)

| Before PD | Parameter | After PD |
|---|---|---|
| 0.138W | RF Power In | 0.139W |
| 1.41W | RF Power Out | 1.44W |
| 2.69Wdc* | DC Power In | 2.69W* |
| 10.09dB | Gain | 10.13dB |
| -3.97Vdc | Gate Bias | -3.97Vdc |
| 31Vp, 13.2Vavg | Drain Voltage | 31Vp, 13.2Vavg |
| 52.4% | Drain Efficiency | 53.5% |
| 47.2% | PAE | 48.4% |
| 20% | EVM | 2.6% |
| 7.6dB | Peak to Avg | 7.6dB |