Design of GaN HEMT Transistor Based Amplifiers for 5 - 6 GHz WiMAX Applications

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***Abstract* — 2.5 and 5 Watt average power (15 and 30 Watt peak power) GaN HEMT amplifiers for WiMAX signal protocols have been designed and fabricated for use in the 5.5 to 5.8 GHz band. The 2.5 Watt PA produces 11 dB of gain and the 5 Watt PA produces 10 dB of gain with EVMs less than 2.5 % at the respective average power with drain efficiencies greater than 26% at average power. A design methodology for optimizing linear performance is described for these two transistors and resultant amplifiers.**

***Index Terms* – Power amplifier, Gallium Nitride HEMT, WiMAX**

I. Introduction

There has been increasing interest in a significantly more efficient transistor solution that can meet the linearity requirements for high peak to average ratio signals in the 5 GHz frequency band. We have created circuit designs for Cree CGH55015 and CGH55030 devices that allow customers to shorten their design cycle times in creating 5 GHz WiMAX amplifier products.

Power amplifiers for WiMAX signals offer particular design challenges [1]. These standards require excellent linearity over an extended dynamic range (~15 dB). A typical PA specification might be 2.5% maximum error vector magnitude for an output power range of 22 to 37 dBm. Another critical goal is to maximize DC-to-RF efficiency. This becomes particularly challenging with OFDM based signals since the high peak to average ratio leads to large amounts of "back-off" being required for linear operation. This in turn implies the transistor will not be operating in its most efficient region. Prior to this work transistor efficiencies have been reported in the 5% range, which presents a sometime insurmountable problem in terms of heat-sinking and cooling requirements [2-3]. Higher efficiency amplifiers enable the implementation of new system architectures such as remote radio heads and tower mounted amplifiers since they are now able to run at lower operating temperatures.

II. Circuit Synthesis and Simulations

The WiMAX RF band of interest for these amplifiers is 5.5-5.8 GHz, with the required instantaneous bandwidth being application dependent. The wide instantaneous bandwidth of GaN devices is a particular operational advantage especially in this band, which would normally require two different designs to cover all bands.

The CGH55015-TB and CGH55030-TB amplifier circuits were designed to use a deep class A/B bias in order to achieve high efficiency at backed-off power conditions. Care was taken in the selection of the quiescent bias current to ensure that a satisfactory trade-off of key parameters: gain, PAE and intermodulation distortion, could be achieved. Both the CGH55015 and CGH55030 devices were biased with +28Vdc drain supply and at a quiescent current of 75 mA and 250 mA respectively.

The first step in designing these amplifiers was to load-pull the large-signal device model to find the optimal power and gain impedances at 5.50, 5.65 and 5.80 GHz. In this work we used Cree's nonlinear CGH55015 and CGH55030 transistor models in Microwave Office™. The output impedances for both transistor models over the full band are shown in Figure 1. The non-linear performance at these impedances was then simulated over a 20dB dynamic range and found to be insufficient for the linearity goals. The impedances were then varied until the requisite linearity was achieved. Simple approximations of the input and output matching networks were then synthesized to provide transformation to the required impedances seen at the device.

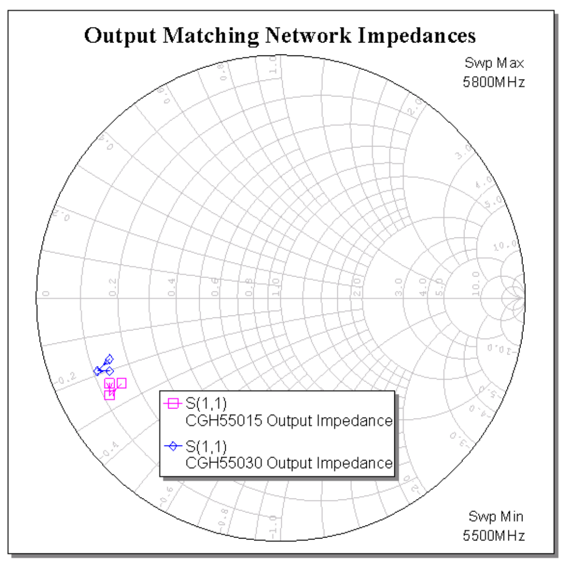

Figure 1. CGH55015 and CGH55030 transistor output impedances

Once synthesized, these networks along with appropriate baseband terminations (for correct loading of difference products) were combined with the transistor model and simulations of all parameters were performed over the entire frequency band and dynamic range. The networks were then further optimized. The objective of this optimization process was to minimize the distortion products over the full dynamic range, while also maintaining high peak power and acceptable gain, gain flatness and efficiency. Gain flatness is influenced mostly by the input circuit. The networks were then refined using EM simulations and Modelithics™ capacitor models ensuring that a tight relationship between the model and the actual physical circuit layout was maintained.

The final circuit designs apply a combination of surface mount components and distributed microstrip lines. The two amplifiers use the same basic topologies as shown in Figure 2.

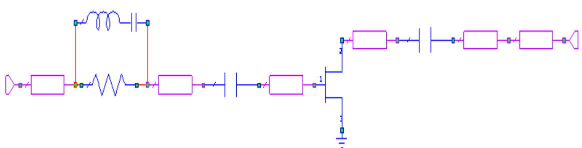

Figure 2. Simplified CGH55015-TB and CGH55030-TB amplifier topologies

The combination of inductor and capacitor at the input resonates in-band, to short out the damping resistor that is included for low frequency stability. GaN HEMT devices have considerable excess gain at low frequencies and it is essential that stability analysis be performed on the final amplifier circuit to avoid oscillations.

Simulations of the small signal performance of both the CGH55015 and CGH55030 amplifiers can be seen in Figure 3, whilst the linearity predictions for the CGH55015 and CGH55030 amplifier at center band can be seen in Figure 4 and Figure 5 respectively.

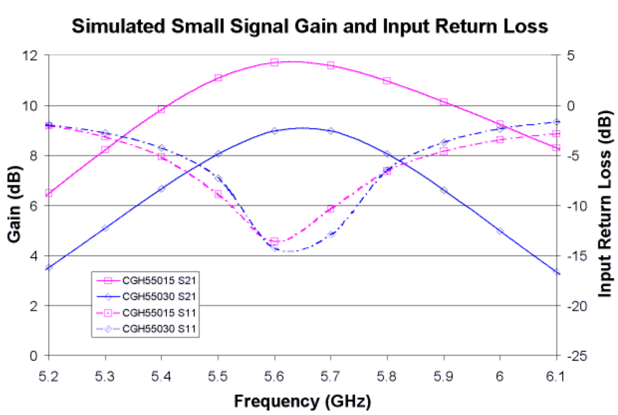

Figure 3. CGH55015-TB and CGH55030-TB amplifier small signal simulation

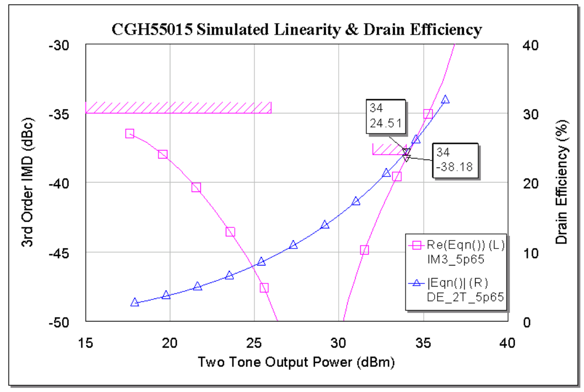

Figure 4. Simulation of linearity and efficiency vs. two tone output power for the CGH55015-TB amplifier @ 5.65 GHz

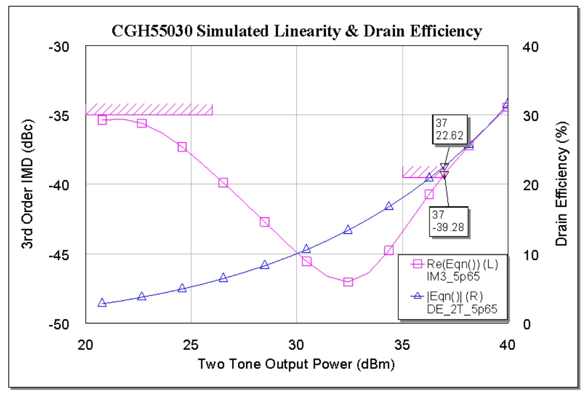

Figure 5. Simulation of linearity and efficiency vs. two tone output power for the CGH55030-TB amplifier @ 5.65 GHz

III. Test Circuit Construction

The construction involves commonly used, commercially available components and PCB material. Both test boards were made using Rogers RO4350 PCB material of 0.5 mm thickness. The PCB is soldered to an aluminium back plate that is used as a heat sink during test. The prototype amplifier dimensions are 1.7 inches (4.3 cm) wide by 2.6 inches (6.6 cm) tall. A photograph of both amplifier circuits is shown in Figure 6.

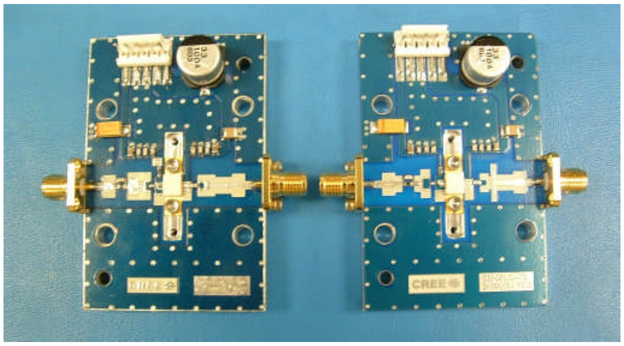

Figure 6. Photograph of CGH55015-TB and CGH55030-TB amplifier circuits with GaN HEMT devices

IV. Measured Circuit Performance

Both devices were tested using a WiMAX signal compliant with 802.16-2004 standards. The key characteristics of this WiMAX signal are that it uses 64 QAM modulation within the burst, which is 59 symbols long within a frame that is 5ms in length. This represents a condition of continuous data transmission. Consequently both the PAR of the burst and the complete signal are about equivalent at about 9.4dB at 0.01% probability. A complete description of the signal also includes details of the guard band, which in this case is 1/4 cyclic prefix and the coding type (RS-CC) and coding rate (2/3). These other parameters have little effect on the PAR of the signal or the power amplifier's performance.

In practical applications the burst length (set by the number of symbols) is likely to be significantly shorter in length than the frame duration. The network operators, however, are then likely to use this downtime in the frame to employ time domain duplex (TDD) operation to maximize system throughput. The test signal was chosen to represent the most demanding situation with maximum average power.

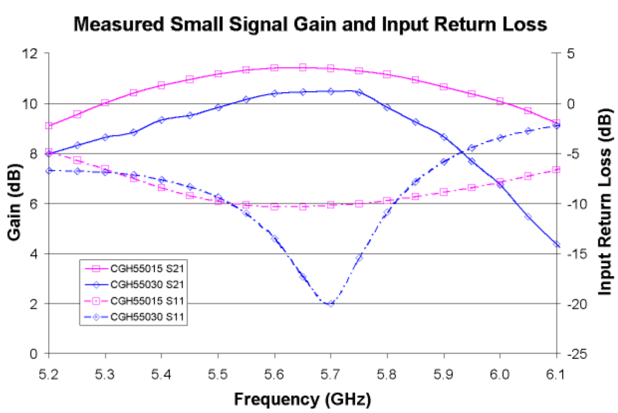

Figure 7. Measured small signal performance of the CGH55015-TB and CGH55030-TB amplifier circuits with GaN HEMT devices

The small signal parameters of the CGH55015 and CGH55030 amplifiers are shown in Figure 7. The gain of the CGH55015 design is greater than 11 dB across the band and the CGH55030 design shows better that 10 dB from 5.5 to 5.8 GHz. The input return losses of both designs are less than -10 dB over the band.

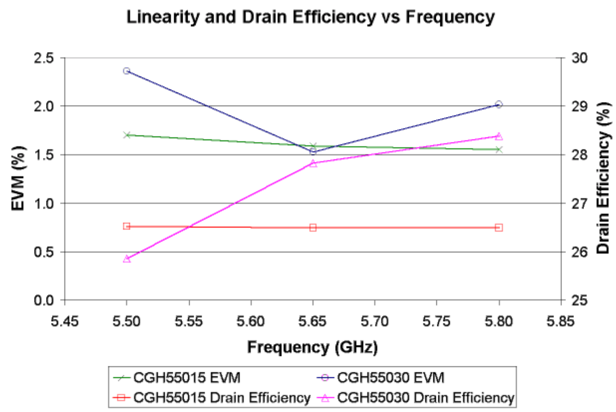

Figure 8. Measured EVM and efficiency vs. frequency of the CGH55015-TB and CGH55030-TB reference amplifiers

Error Vector Magnitude (EVM) was measured across the band at 2.5 Watt average, or 34dBm, for the CGH55015 amplifier and at 5 Watt average output power, or 37dBm for the CGH55030 amplifier. This represents about 8dB back-off from the nominal peak power of both devices. It can be seen in Figure 8 that the EVM is less than 2.5 % across the frequency band for both amplifiers. The efficiency at the maximum average power condition is also shown. This linearity is particularly impressive when considering that the PAR of the input signal is in fact 9.8dB. It is indeed the reduced amount of back-off that enables the associated high efficiencies. Figure 9 shows the drain efficiency of both amplifiers versus a normalized back-off.

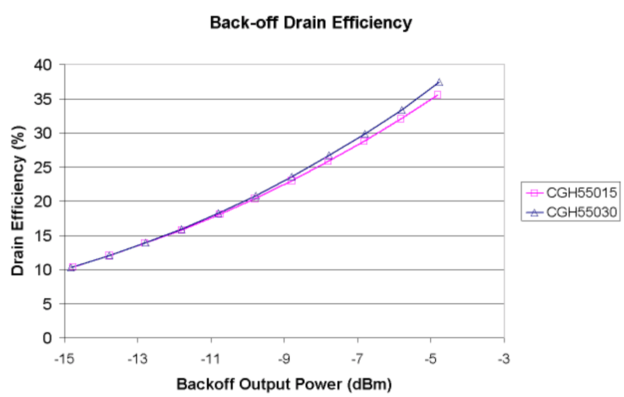

Figure 9. Measured drain efficiency vs. back-off for the CGH55015-TB and CGH55030-TB amplifier circuits

It was noted earlier in this paper that most WiMAX systems often require that linearity be maintained below a certain threshold even over a large dynamic range.

Figure 10 and Figure 11 show EVM versus average output power for the CGH55015 and CGH55030 device over a 20dB dynamic range. It can be seen that the CGH55015-TB and CGH55030 design actually maintain less than 2.5 % EVM up to about 4 W and 6 W of average output power. At these power levels the power added efficiency is 29 % and 31 % respectively.

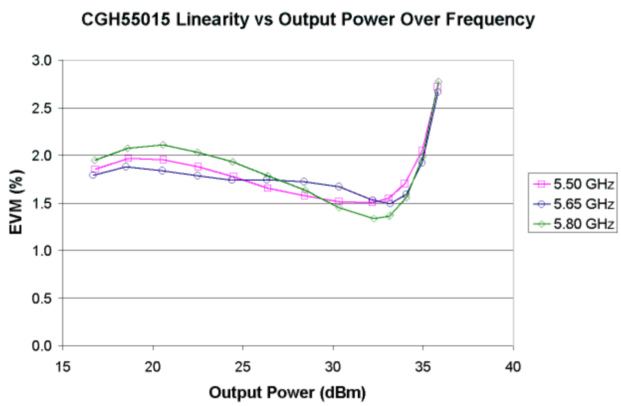

Figure 10. Measured EVM vs. average output power for the CGH55015-TB reference amplifier across frequency

Figure 11. Measured EVM vs. average output power for the CGH55030-TB reference amplifier across frequency

V. CONCLUSIONS

Two reference amplifiers have been designed for standard 15 Watt and 30 Watt Cree GaN HEMT devices that meet WiMAX linearity requirements instantaneously over the full 5.5 – 5.8 GHz frequency band. The CGH55015 device exhibits better than 11 dB of gain, 26 % of drain efficiency at 34 dBm P_{OUT}. The CGH55030 device demonstrates greater than 10 dB of gain and 28 % drain efficiency at 37 dBm P_{OUT} across the band. To the authors' knowledge the performance of both of these GaN HEMT amplifiers is the best ever reported.

ACKNOWLEDGMENT

The authors would like to thank Bill Pribble of Cree, Inc. for development of an accurate die model, which enabled this work. Thanks also go to Modelithics and American Technical Ceramics for providing substrate scaleable capacitor models. We would also like to acknowledge all those individuals in Cree's Wireless Business Group that helped in the generation of these amplifier designs.

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