

Wideband Doherty Amplifier for WiMAX

Introduction

This application note describes the operational theory and characterization of a Doherty amplifier reference circuit that incorporates two Nitronex NPT25015 GaN transistors. The amplifier is designed for operation over the 2.5 - 2.7 GHz WiMAX band.

WiMAX orthogonal frequency-division multiplexed (OFDM) and orthogonal frequency-division multiple access (OFDMA) signals typically have peak-to-average envelope excursions of 8-12 dB or more. To avoid clipping, power amplifiers must be significantly backed off saturation. Unfortunately, backoff is accompanied by a dramatic drop in drain efficiency. To boost efficiency in complex modulation environments such as WCDMA and WiMAX, load modulation techniques such as the Doherty amplifier configuration are becoming more widely adopted.

The Nitronex family of GaN devices is well suited for implementing the Doherty amplifier configuration. The NPT25015 is a 15W peak power HFET with a saturated efficiency >50% and is inherently broadband since it contains no internal matching structures. Within the Doherty circuit the NPT25015 devices operating at 10 dB back-off typically exhibit >30% drain efficiency over a 200 MHz operating bandwidth. This level of performance may be difficult or impossible to achieve with other transistor technologies such as LDMOS and GaAs.

The Doherty amplifier circuit is more complex than a two stage parallel amplifier. However, the increased complexity is offset by a more flexible amplifier architecture. That is, Doherty circuit operation can be tailored by adjusting the transition point to trade off efficiency, gain and linearity. For example, the transition point can be increased to enhance efficiency at the expense of linearity. The ability to adapt the amplifier operating point is an important feature of the Doherty configuration.

Doherty Theory of Operation

The Doherty configuration employs two transistors in a quadrature-like configuration, as shown in Figure 1.

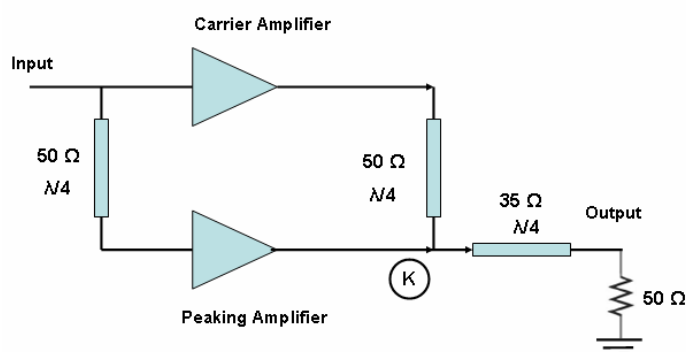


Figure 1: Doherty amplifier functional diagram.

The upper device is termed the Carrier or Main amplifier. It is biased in the linear class AB mode. The amplifier shown beneath the carrier amplifier is termed the Peaking or Auxiliary amplifier. It is biased in the non-linear class C mode. High efficiency results from 1) dynamically adapting the load presented to the main and peaking amplifiers over their dynamic range and 2) operating the peaking amplifier in the highly efficient class C mode.

The dynamic load adaption is produced by an impedance inverter, used in conjunction with an impedance transformer. A 50 ohm quarter wave transmission line impedance inverter is used in classical Doherty designs, accompanied by a $50/\sqrt{2}$ (35 ohm) quarter wave transformer. The transformer rotates the 50 ohm system characteristic impedance down to 25 ohms at point “K” in Figure 1. At low power levels, the main amplifier acts as a current source while the class C biased peaking amplifier is pinched off. Ideally, the peaking amplifier “off-state” impedance (looking into the peaking amplifier output match) is infinite, effectively appearing as an open

circuit to the carrier amplifier. The carrier amplifier voltage swing looking into a higher transformed load increases, thereby producing higher gain and efficiency. The higher gain compensates somewhat for the gain lost from the as yet non-contributing auxiliary amplifier.

The point at which the peaking amplifier begins to turn on is the Doherty amplifier transition point. At the transition point the carrier amplifier loaded such that it is near saturation. As the amplifier is driven harder the load at point “K” appears larger. The impedance reflected back from point “K” to the carrier amplifier decreases. The carrier amplifier remains near saturation while load adapts dynamically, maintaining a high efficiency as power output increases. At rated power both 50 ohm amplifiers are in parallel, so 25 ohm net impedance is seen at “K”. The output transformer rotates the 25 ohm impedance to 50 ohms, ideally matched to the system characteristic impedance. At maximum power output both amplifiers are operating near saturation and Doherty efficiency reaches a maximum.

In a large peak-to-average signal environment like WiMAX, the peaking amplifier contributes power to the load only during short bursts when the instantaneous power exceeds the average power. Otherwise the peaking amplifier is inactive. With proper phasing, the Doherty amplifier produces the same peak power as two class AB amplifiers in parallel, but with higher efficiency under high backoff conditions.

GaN Doherty Circuit Architecture

The carrier and peaking amplifiers utilize the Nitronex NPT25015 device. The NPT25015 is a 15W, unmatched, 8 mm gate periphery plastic overmolded GaN HFET. The matching circuit for both the main and auxiliary amplifier is shown in Figure 2.

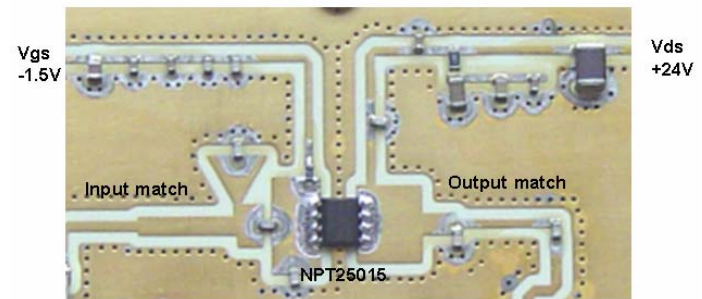


Figure 2: GaN amplifier circuit diagram

A 3 dB quadrature splitter divides the input signal equally between the carrier and peaking amplifiers. At the output a microstrip quarter wave impedance inverter combines the carrier and peaking amplifier signal paths. The combined output signal is applied to a quarter wave microstrip impedance transformer. An RF/DC crossover is used to bridge the drain feed connection before reaching the output RF connector.

Powering up the GaN Doherty Circuit

When working with GaN HEMT devices, it is important to follow the proper biasing sequence. Please refer to Nitronex Application note AN-1 for the correct method to bias GaN devices.

The Doherty reference fixture is shown in Figure 3. Gate bias for the main and auxiliary amplifiers is supplied via two BNC connectors. The drain voltage is supplied through a single BNC connector. A two position jumper connects the drain supply to both amplifiers. A second BNC connector can be added to the fixture to facilitate independent main and auxiliary drain voltages. If a second drain voltage supply is used, the two position jumper must be removed. The main amplifier bias voltage should be set for approximately -1.3V to establish the main amplifier I_{DQ} at 180 mA. The auxiliary amplifier gate bias should be set to -2.75 V for highest peak power and best efficiency. Auxiliary amplifier bias adjustment changes the Doherty amplifier transition point, which can be useful in customizing Doherty circuit performance.

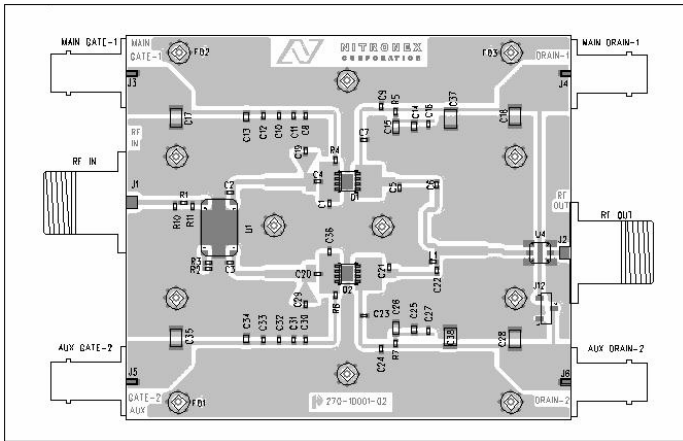


Figure 3: GaN Doherty Reference Circuit

Once the bias points are established, the drain voltage can be safely applied. The carrier and peaking amplifier use the same drain voltage (24V). There is a two position jumper on the fixture board which should be set so a common drain voltage can be applied to the drains. With the jumper set, increase the drain voltage to 24V. I_{DQ} should be 180 mA at 24V. The carrier amplifier gate bias voltage may require some adjustment to achieve 180 mA I_{DQ} . Refer to the “Measured Results” section for typical performance with a WiMAX signal.

Once the amplifier has been exercised over a range of bias and drain voltages, the designer can choose the best tradeoff between gain, linearity and efficiency for a particular application.

Characterizing the Doherty Circuit

It is recommended that the GaN Doherty be initially characterized for AM-AM and AM-PM responses as well as return loss. A preamplifier is required to boost the network analyzer drive to put the Doherty circuit into full compression. The test setup is shown in Figure 4.

The Doherty fixture is supplied with SMA type RF input and output connectors. The reference design test fixture also supports optional N-type flange connectors. With the input and output connected to a 50 ohm generator and load, set the carrier and peaking amplifier bias point, following the bias setting procedure described in AN-1.

AM_AM and AM_PM Testing Platform

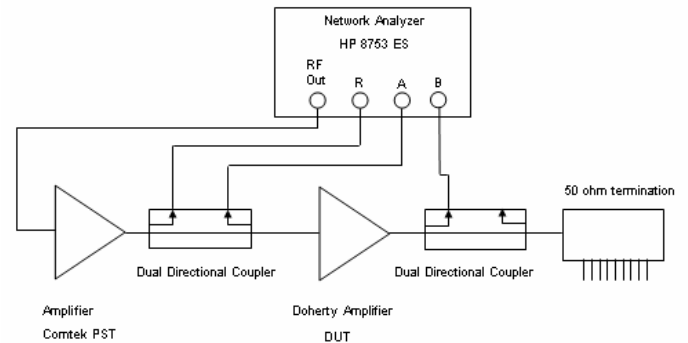


Figure 4: Doherty Power Sweep Platform

The AM-AM and AM-PM responses are captured with the network analyzer in the power sweep mode at 2.5, 2.6 and 2.7 GHz. The power gain should be about 10 dB at low drive levels, and then falls off with compression. A typical swept measured response at 2.6 GHz is shown in Figure 5.

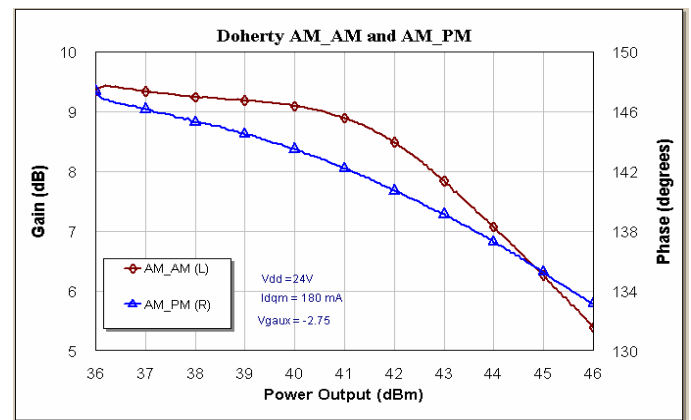
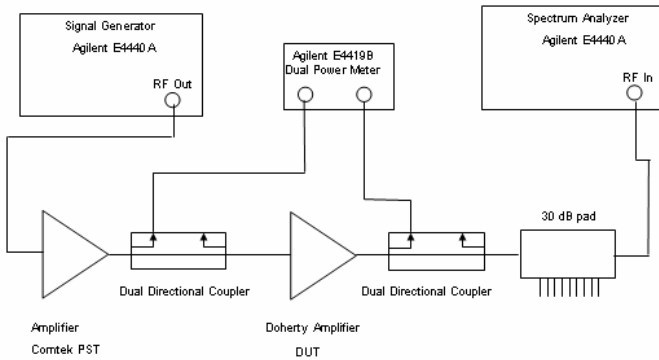


Figure 5: 2.6 GHz Doherty AM-AM and AM-PM.

Experiment with the relationship between drain voltage value and main and auxiliary amplifier bias settings and the Doherty 1 dB compression point to observe performance tradeoffs.

A high peak to average signal such as WCDMA or OFDM/OFDMA should be used to characterize Doherty linearity. The linearity test setup is shown in Figure 6. The network analyzer in Figure 5 is replaced by a dual channel power meter and a wide bandwidth capable spectrum analyzer.

Linearity Testing Platform

Figure 6: Doherty Linearity Testing Platform

The signal generator must be able to generate high peak to average waveforms. The preamplifier should be capable of delivering 40 dBm peak power to the Doherty. The setup is used to capture linearity metrics such as ACP, EVM and drain efficiency. Again, note how linearity is influenced by adjusting the supply voltage and main and auxiliary amplifier bias points. Increasing the drain supply voltage will typically improve ACP and EVM at high power levels, but at the expense of efficiency. Do not exceed 32V drain voltage.

Measured Results

Using the nominal Doherty operating point parameters shown in Table 1, the NPT25015 Doherty reference design amplifier delivers 46.5 dBm typical peak power from 2.5 to 2.7 GHz. WiMAX systems have demanding linearity requirements, defined by Error Vector Magnitude (EVM) and adjacent channel leakage ratio (ACLR). Because the peaking amplifier is a highly non-linear amplifier, Doherty EVM and ACLR are generally poorer than conventional class AB amplifiers. Fortunately, linearity can be substantially enhanced with the application of Digital Pre-Distortion (DPD) techniques.

Predistorted measured results were captured with an open loop Matlab based predistortion platform without applying memory mitigation.

Table 1: Recommended bias point settings

Drain voltage	Main amp I_{DQ}	Peaking amp V_{GSQ}
24V	180mA	-2.75V

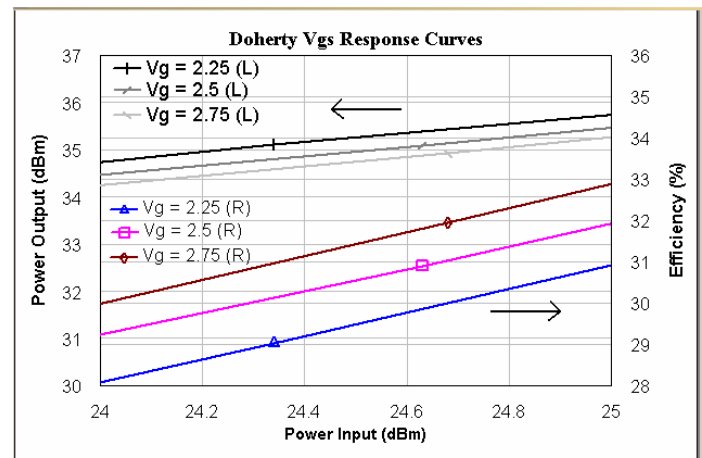
Table 2 summarizes the typical Doherty configuration responses at 2.6 GHz using operating point parameters from Table 1. Doherty testing was performed with a 10 MHz bandwidth 64QAM 3/4 OFDMA signal with a 9.5 dB PAR @0.01% CCDF during the TX period of a 50% duty cycle TDD waveform.

Table 2: Summarized Doherty Amplifier Performance
Summarized Doherty performance with single carrier 10 MHz OFDMA signal and digital predistortion (DPD)

	Gain (dB)	P_o (W)	DE (%)	PAE (%)	EVM (%)	ACLR (dBc)
No DPD	10.1	6	31.8	28.4	3.7	-37
DPD	10.1	6	31.8	28.4	1.3	-43.8

- ▶ OFDMA 64 QAM 3/4 10 MHz 9.5 dB PAR during TX period of a 50% duty cycle TDD waveform. 5 ms frame length.
- ▶ 6W output power during TX period of 50% duty cycle TDD waveform. (3W average power output)
- ▶ DE: drain efficiency as measured with 3W average power
- ▶ PAE: power added efficiency as measured with 3W average power
- ▶ DPD is memoryless
- ▶ Average power out at 2% EVM = 3.5 W: DE = 35%, PAE = 31%, ACLR = -35.5

Gain and drain efficiency can be traded off by adjusting the peaking amplifier bias point (V_{GSAUX}). Figure 7 characterizes Doherty efficiency and gain against peaking amplifier bias point (V_{GS}) adjustments.


Figure 7: Doherty V_{GSAUX} response curves

Figures 8 and 9 illustrate Doherty performance using DPD linearization. Figure 8 shows Doherty single carrier spectral performance at 32 dBm average power (35 dBm during transmit) with a 10 MHz bandwidth 64QAM 3/4 OFDM signal with a 9.5 dB PAR @0.01% CCDF at 2.6 GHz. The bias points and supply voltages are provided in Table 1. Conventional DPD correction is shown in blue. Memory mitigation DPD is shown in purple. The GaN based Doherty reference design exhibits negligible memory effects, so memory mitigation provides little to no benefit.

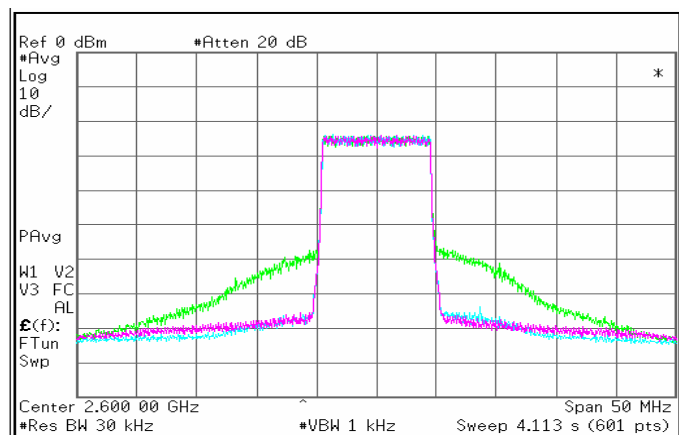


Figure 8: Doherty spectrum with/ without DPD

Figure 9 illustrates Doherty EVM with and without DPD, gain, and efficiency performance with a TDD OFDMA waveform.

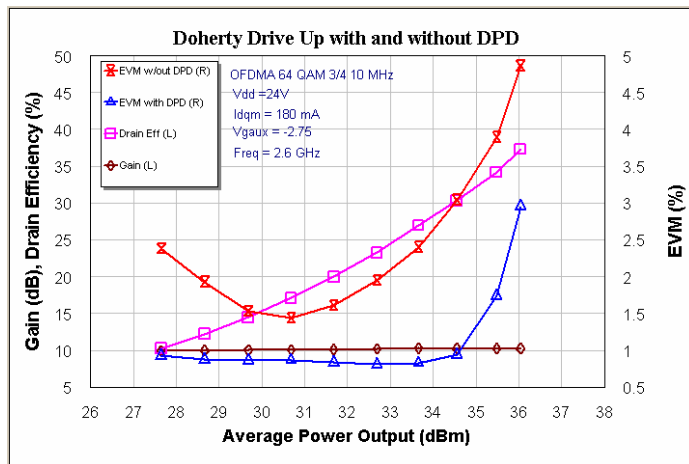


Figure 9: Doherty performance with/without DPD.

Summary

The Doherty reference design incorporates two state of the art NPT25015 GaN transistors from Nitronex to demonstrate a versatile load modulation technique. The reference design achieves broadband performance and high saturated efficiency with a complex modulated TDD waveform. The reference design enables designers to quickly become familiar with tailoring the Doherty amplifier to meet the demanding efficiency, gain, emissions and EVM requirements in the 2.5-2.7 GHz WiMAX band.