Active Load Pull Surpasses 500 Watts!

The MT2000 mixed-signal active load pull system breaks the 500W barrier with the successful characterization of a GEN8 NXP base station transistor.

Authors: Steve Dudkiewicz, Maury Microwave Corporation, Mauro Marchetti, Anteverta-mw

With special thanks to Rob Heeres, NXP Semiconductors.

Introduction

The art of automated load pull has been used extensively by industry since Maury Microwave Corporation released the first automated slide-screw tuner in 1987. At least twenty years earlier, manual mechanical tuners of various forms were used to match transistor impedances when characterizing and designing amplifiers. Today, the importance of properly matching a transistor module when designing an amplifier is common knowledge; it is essential to use impedance matching networks on the input and output of a transistor in order to maximize power transfer, output power, gain and efficiency. The technique used to determine ideal matching network impedances is referred to as 'load pull'.

Of all the breakthroughs in load pull technology over the past decade, the most radical and industry-changing may be the commercialization of various forms of active load pull systems, enhancing and in many cases replacing traditional mechanical tuners. The most common and successful of these forms is the open-loop active load approach, where the VSWR/gamma/impedance presented to the DUT relies on an active tuning chain consisting of a signal source, a variable phase shifter, and a variable gain stage to inject a signal into the output of the DUT. Of all open-loop active load pull techniques, the most unique and capable is referred to as Mixed-Signal Active Load Pull (MSALP), invented by Anteverta-mw and commercialized by Maury Microwave as the MT2000 system.
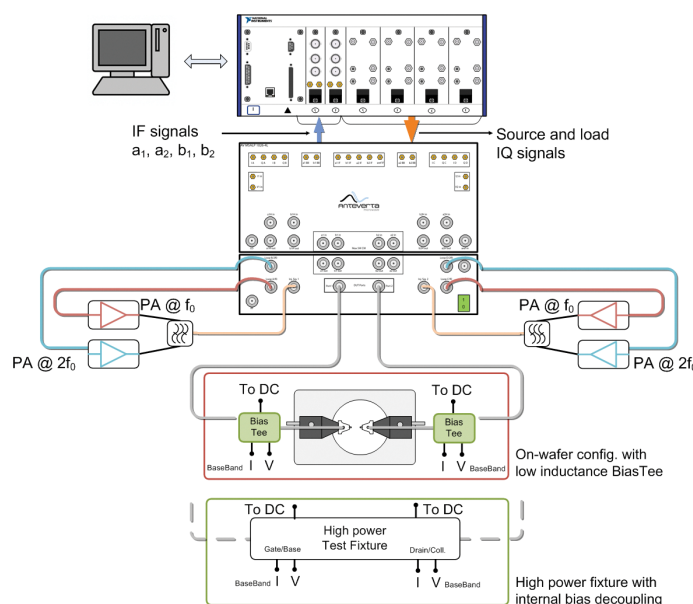
System Architecture

The MT2000 mixed-signal active load pull system consists of three primary components: the PXIe baseband synthesizer/analyzer, the RF test set, and system software shown in *Figure 1*.

The PXI baseband synthesizer/analyzer consists of digital-to-analog arbitrary waveform generators (AWGs)

and analog-to-digital analyzers (ADCs). These extremely wideband AWGs and ADCs are able to synthesize and analyze any user-defined signal with up to 120 MHz in bandwidth in the baseband frequency range (DC-120 MHz).

The RF test set consists of local oscillators (LOs) combined with IQ mixers to upconvert the baseband signal to fundamental and harmonic RF frequencies and inject source and load IQ signals into the DUT. The resulting outputted RF signal is then downconverted back to baseband and its a- and b-waves are analyzed.

In essence, the system acts as an extremely wideband vector-signal generator at RF frequencies defined by the test set, as well as a wideband vector network analyzer (VNA) capable of measuring a- and b-vector waves and s-parameters.

Figure 1. *System architecture of MT2000 mixed-signal active load pull system.*

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Signal Synthesis and Analysis

The first step in performing mixed-signal active load pull is to generate the input signal in baseband. This signal could be CW, pulsed-CW or even a wideband modulated signal. To generate a wideband signal, a repetitive time-domain modulated signal compliant with industry standards is generated, and is then analyzed in frequency domain which is composed of thousands of tones, shown in **Figure 2**.
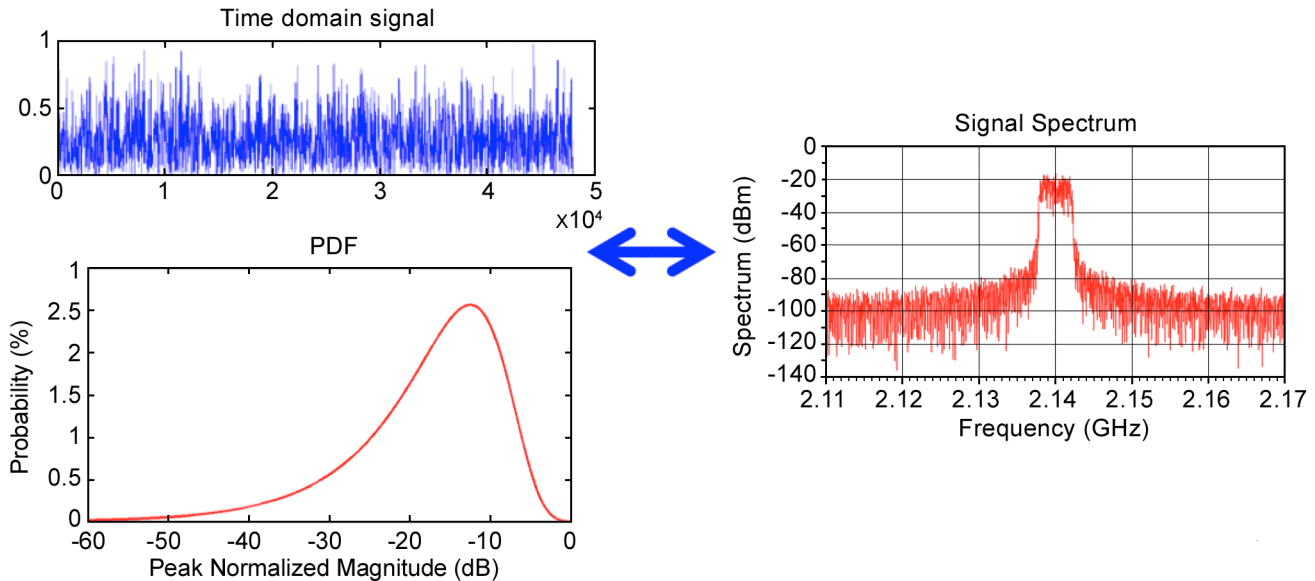
***Figure 2.*** *Example of a realistic wideband signal.*

The signal is then upconverted and injected into the DUT as a_s. The resulting output signal b_2 (created by the DUT) consists of a modified version of the original signal including an amplified signal at the fundamental frequency (with the possibility of signal distortion if modulated), and signals at the harmonic and baseband frequencies. Because the device is not physically matched, part of the signal is reflected at the input as b_1. This signal flow is shown in ***Figure 3***.
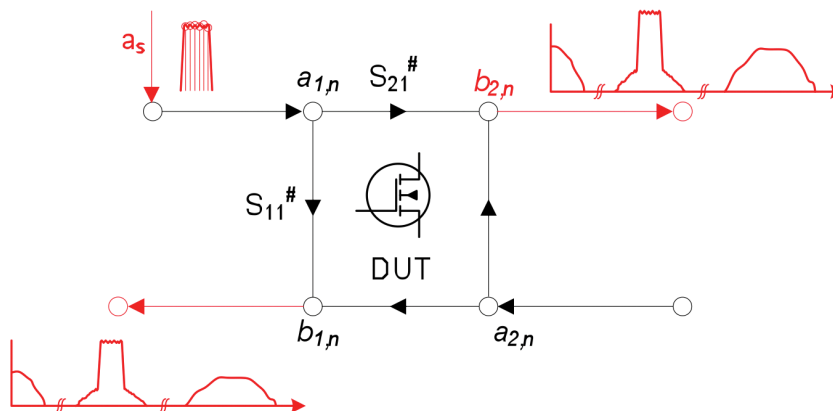
Figure 3. *Signal flow of original injected signal, reflected signal, and amplified signal in red.*

The second step in performing mixed-signal active load pull is to present user-defined load impedances to the DUT. Since the load impedance can be represented as $\Gamma_L = a_2/b_2$, it is a_2 which must be defined so that the ratio represents the desired load. The wideband AWGs are used to create the required CW, pulsed-CW or modulated a_2 signal at baseband so that the upconverted signal fulfils the desired impedance. The same technique can be used on the source to inject a signal a_1, as well as at harmonic frequencies $2F_0$ and/or $3F_0$.
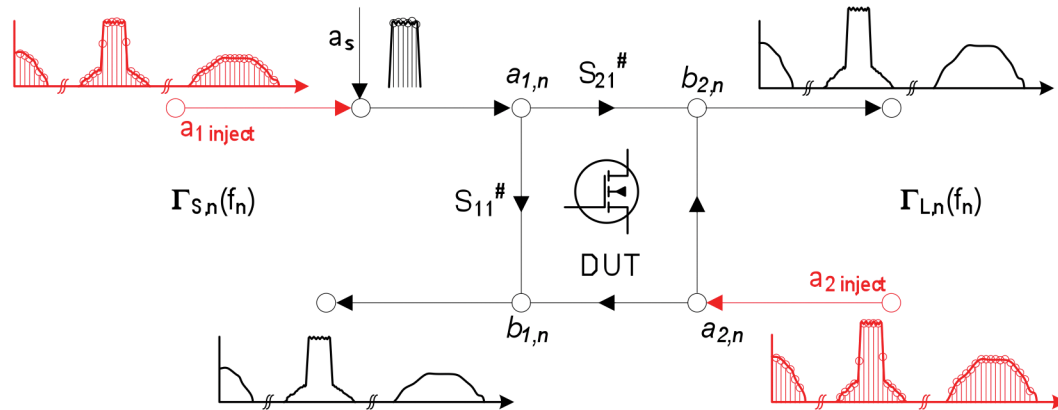
Figure 4. *Signal flow of original injected signal, reflected signal and amplified signal in black, and generated signals for active tuning in red.*

High Power Measurements

Different models of the MT2000 mixed-signal active load pull system are rated at different maximum power limits, with popular models at 20W and 100W CW, and up to 10X higher pulsed power handling capabilities.

The power required to actively load pull a device is governed by the following formula

$$P_{a_2} = P_{b_2} \cdot \frac{(1-|\Gamma_{DUT}|^2)}{(1-|\Gamma_{SYS}|^2)} \cdot \frac{|Z_{DUT}+Z_0|^2}{|Z_{SYS}+Z_0|^2} \cdot \frac{|Z_L-Z_{SYS}|^2}{|Z_{DUT}+Z_L|^2}$$

where the various components are described in the following equivalent circuit, shown in **Figure 5**.
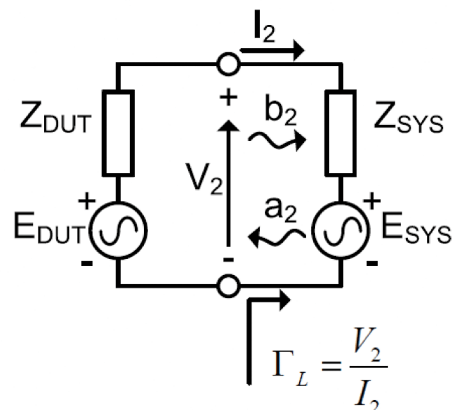
Figure 5. *Equivalent circuit of load pull system.*

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In the first test case, an NXP 7th generation LDMOS 130W-rated transistor was measured at 2.14 GHz, in a pulsed-CW condition with pulse width of 10 µS, duty cycle of 10%, using a prematch transformer test fixture at 7Ω. The power amplifier required to drive this DUT to Pout=195W was only 200W Psat, an almost 1:1 relationship with the device output power.

Figure 6 shows the measured power sweep result of this test case, with maximum power and maximum efficiency curves respectively highlighted in red and blue.
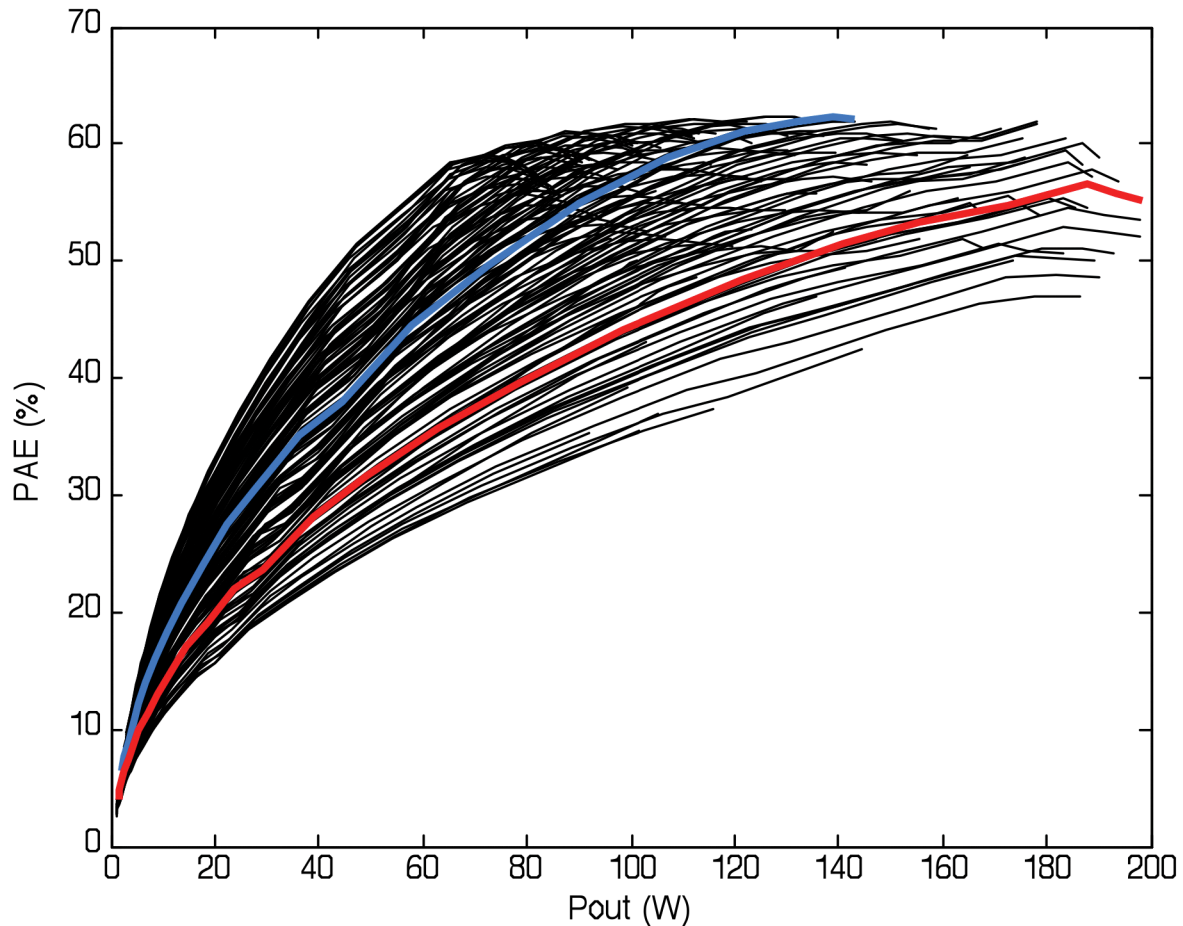
Figure 6. Efficiency as a function of Power measured up to 195W on NXP 7th generation LDMOS 130W-rated transistor.

Figure 7 shows the measured results of a power sweep over multiple impedances with only the points at 3 dB gain compression being plotted.   A maximum power of 195W and a maximum efficiency of over 62% were recorded (not concurrently).
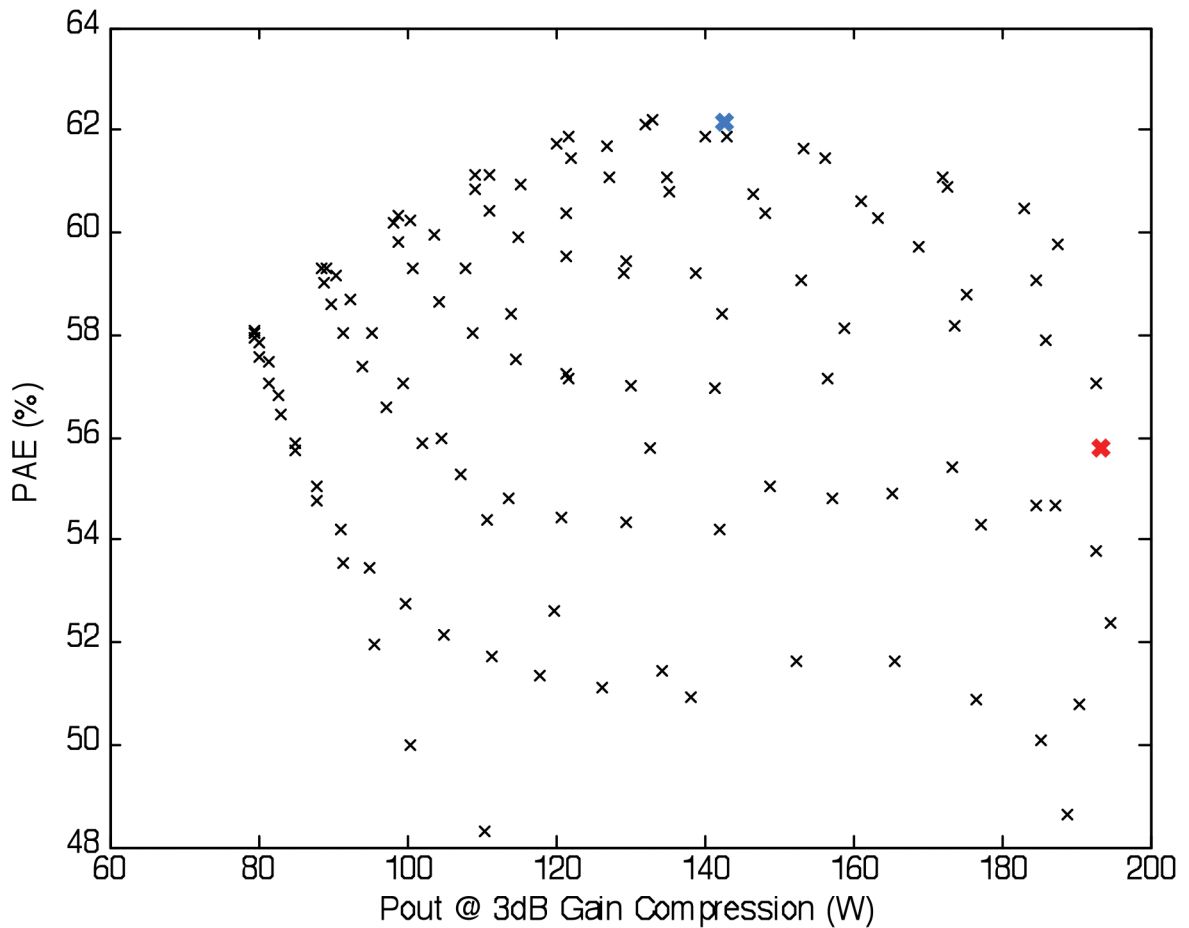

Figure 7. *Efficiency as a function of Power at 3 dB Gain Compression measured up to 195W on NXP 7th generation LDMOS 130W-rated transistor*

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Figure 8 shows Pout and PAE contours at 3 dB gain compression using 7Ω pre-match fixture (center of Smith Chart is 7Ω). Note that impedances as low as 0.7Ω (or Γ=0.97 or VSWR=70:1 with imaginary component) were presented to the DUT (in the DUT reference plane) and measured.
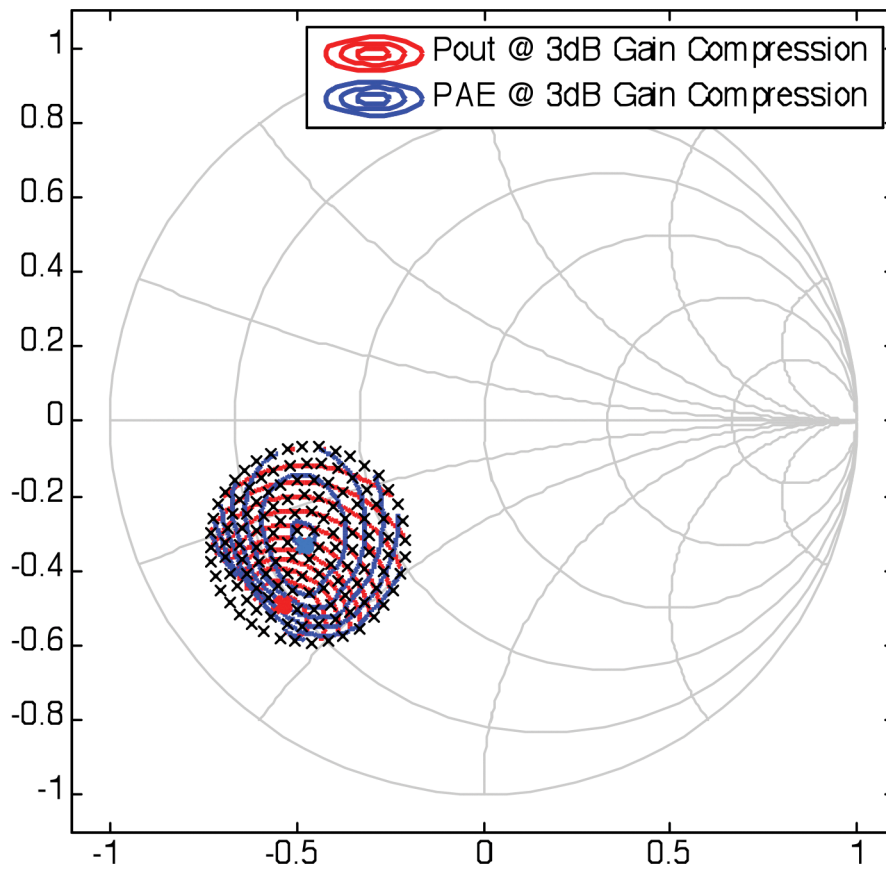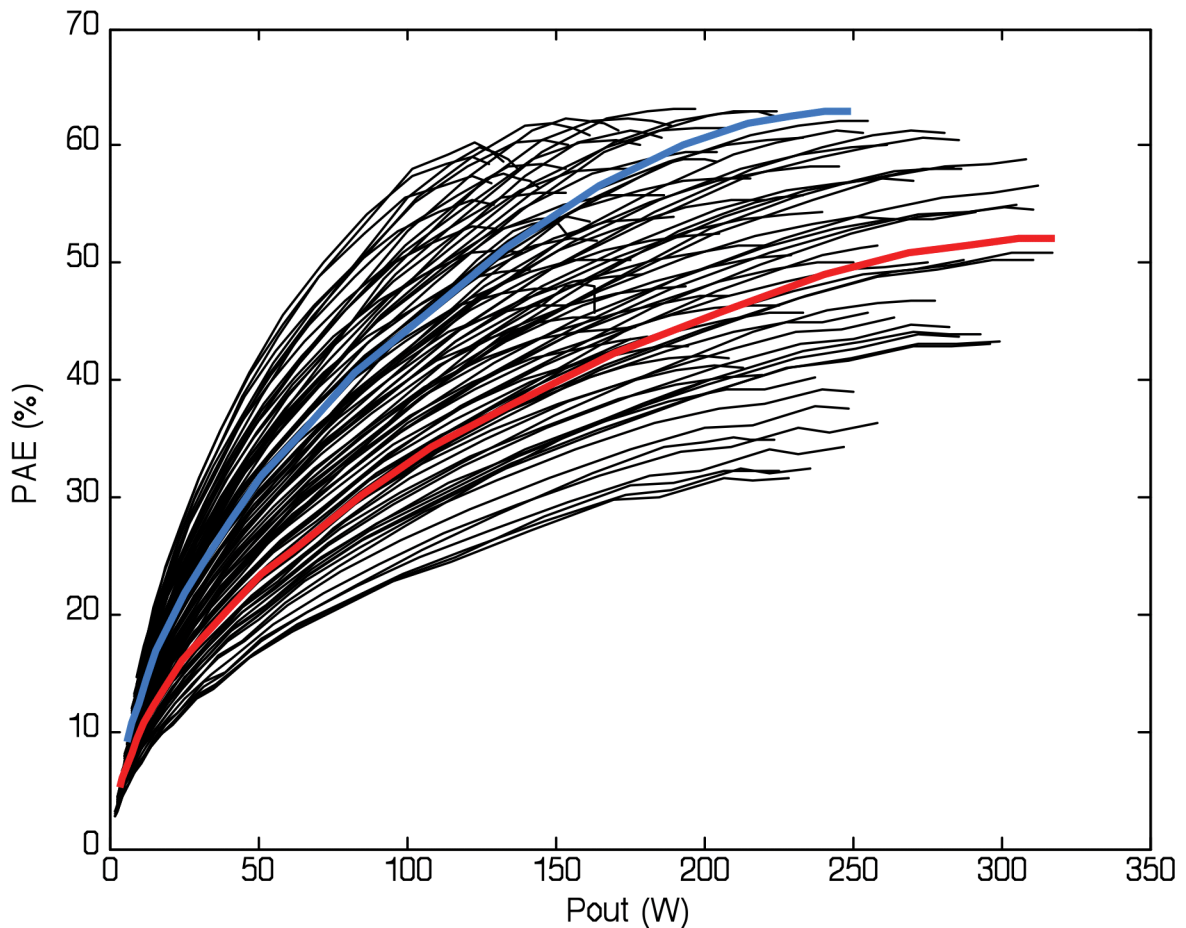

Figure 8. *Pout and PAE contours of a NXP 7th generation LDMOS 130W-rated transistor using 7Ω pre-match fixture (center of Smith Chart is 7Ω).*

In a second measurement, an NXP 7th generation LDMOS 200W-rated transistor was measured at 2.14 GHz, in a pulsed-CW condition with pulse width of 50 μS, duty cycle of 10%, using a prematch transformer test fixture at 7Ω. The power amplifier used to drive this DUT up to Pout=360W and down to 0.5Ω was a 500W NXP Doherty amplifier demo board.

Figure 9 shows the measured power sweep result of this test case, with maximum power and maximum efficiency curves respectively highlighted in red and blue.

Figure 9. *Efficiency as a function of Power measured up to 320W on NXP 7th generation LDMOS 200W-rated transistor.*

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Figure 10 shows the measured result of this test case, with a maximum power of over 320W (red) and a maximum efficiency of over 64% (blue) at 3dB compression (not concurrently).
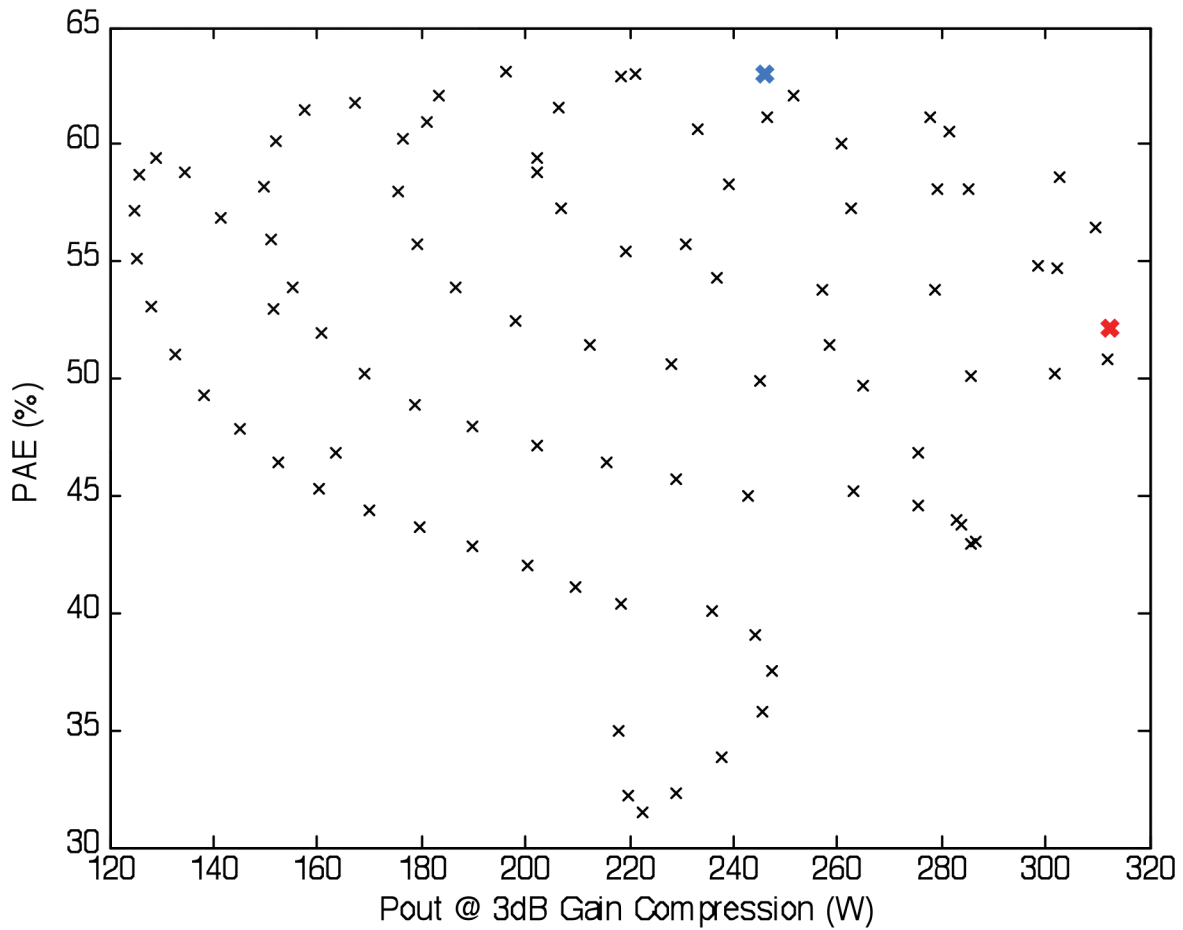

Figure 10. *Efficiency as a function of Power at 3 dB Gain Compression measured up to 320W on NXP 7th generation LDMOS 200W-rated transistor.*

Figure 11 shows Pout and PAE contours at 3 dB gain compression using 7Ω pre-match fixture (center of Smith Chart is 7Ω). Note that impedances as low as 0.5Ω (or Γ=0.98 or VSWR=100:1 with imaginary component) were presented to the DUT (in the DUT reference plane) and measured.
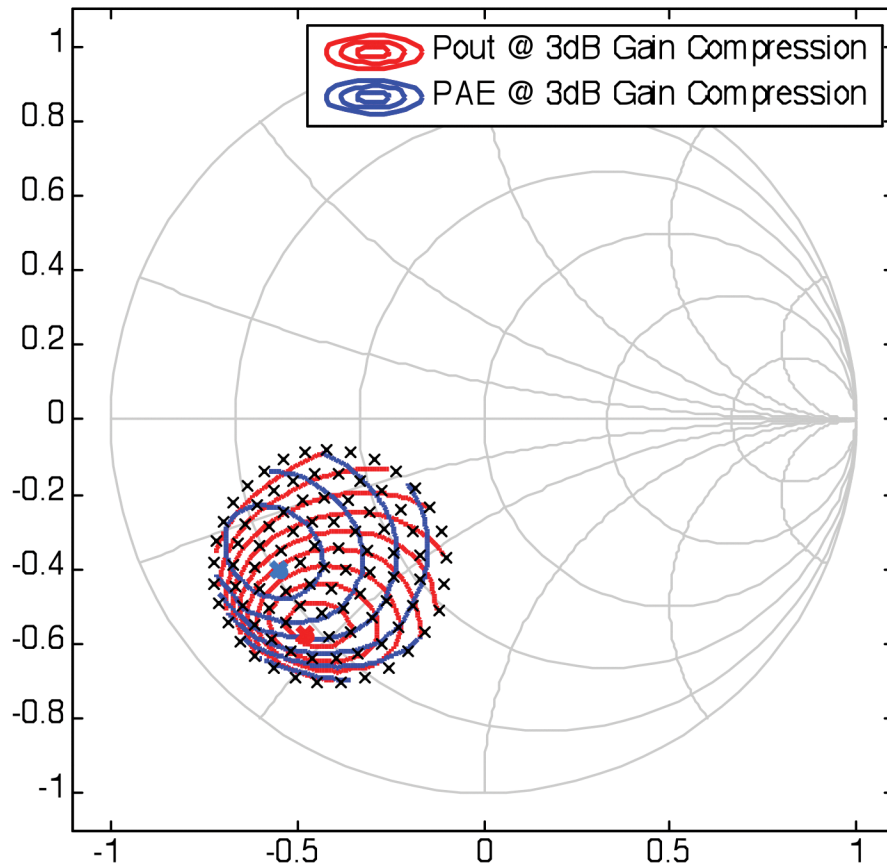

Figure 11. *Pout and PAE contours of a NXP 7ᵗʰ generation LDMOS 200W-rated transistor using 7Ω pre-match fixture (center of Smith Chart is 7Ω).*

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In a third measurement, an NXP 8th generation LDMOS 320W-rated transistor was measured at 2.14 GHz, in a pulsed-CW condition with pulse width of 50 μS, duty cycle of 10%, using a prematch transformer test fixture at 7Ω. The power amplifier used to drive this DUT up to Pout=500W and down to 1.5Ω was a 500W NXP Doherty amplifier demo board.

Figure 12 shows the measured power sweep result of this test case, with maximum power and maximum efficiency curves respectively highlighted in red and blue.
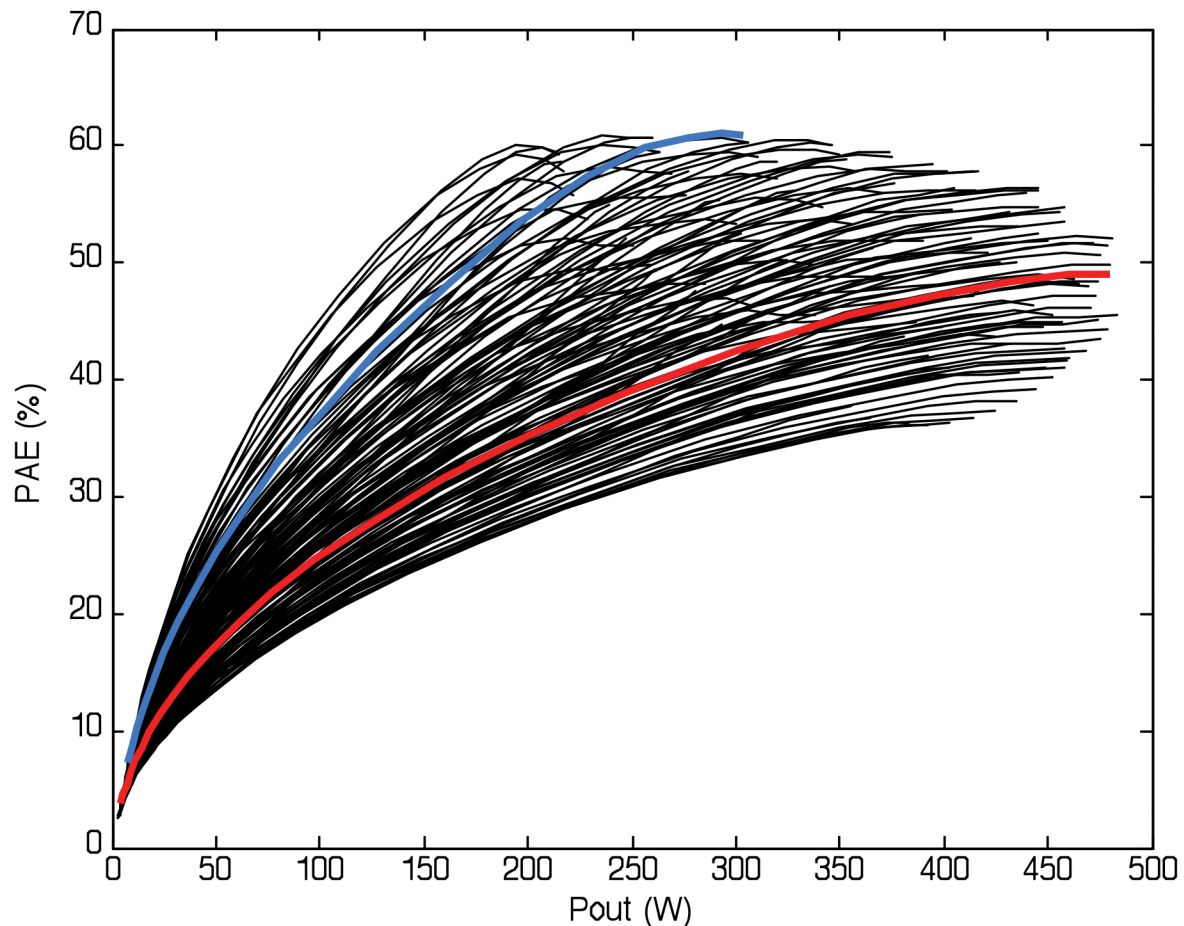
*Figure 12.* Efficiency as a function of Power measured up to 500W on NXP 8th generation LDMOS 320W-rated transistor.

Figure 13 shows the measured result of this test case, with a maximum power of over 470W (red) and a maximum efficiency of over 62% (blue) at 3 dB compression (not concurrently).
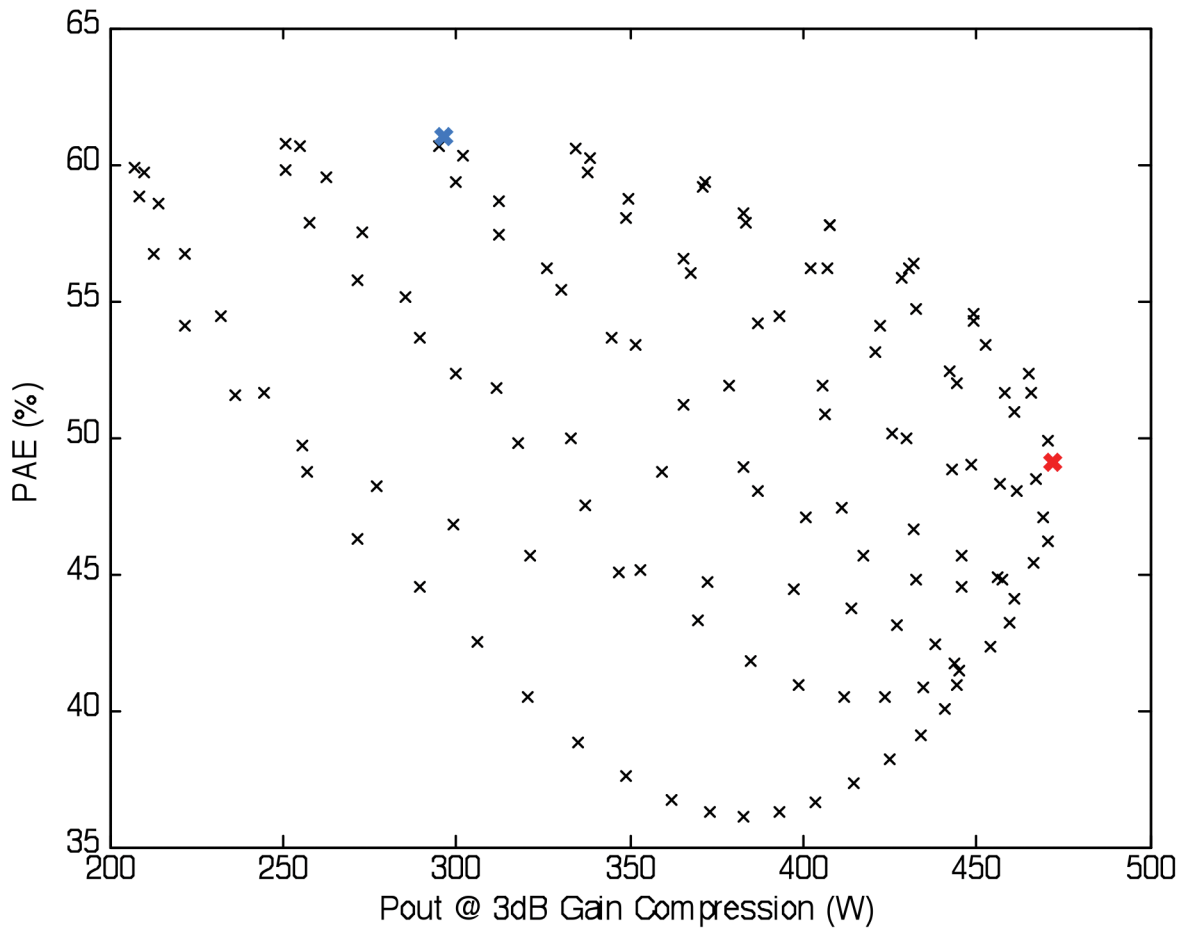
Figure 13. *Efficiency as a function of Power at 3 dB Gain Compression measured up to 500W on NXP 8th generation LDMOS 320W-rated transistor.*

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Figure 14 shows Pout and PAE contours at 3 dB gain compression using 7Ω pre-match fixture (center of Smith Chart is 7Ω).
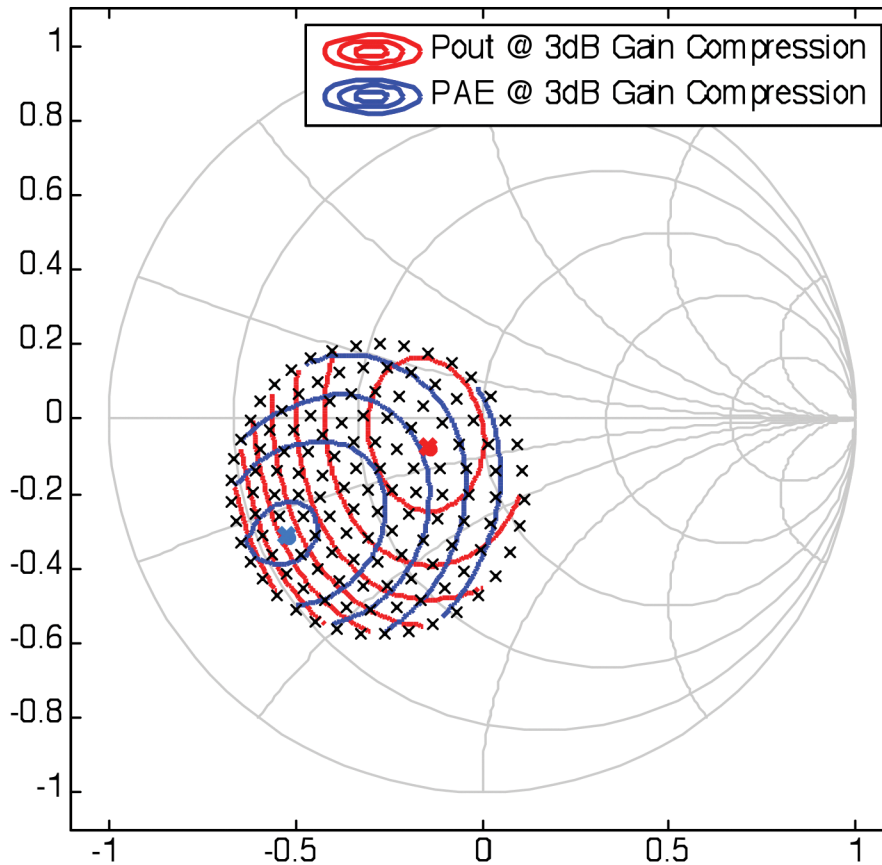
Figure 14. *Pout and PAE contours of a NXP 8th generation LDMOS 320W-rated transistor using 7Ω pre-match fixture (center of Smith Chart is 7Ω).*

It is important to note that all the above measurements were performed in a strictly active load pull environment with no passive mechanical tuners used in any hybrid capacity.

Conclusion

For the first time ever, a commercially available active load pull system was used to take measurements on a state-of-the-art 500W base-station transistor using generic amplifiers and a pre-matching test fixture. Measurements were performed under two modes of operation: high-speed with up to 1000 impedance/power states controlled and measured per minute, and with wideband impedance control using an industry-compliant modulated WCDMA signal. These measurements prove beyond doubt the viability of purely active load pull systems for high-power applications such as base-station and radar power amplifier design and test.