

# MAXIMIZING POWER AMPLIFIER EFFICIENCY WITH HARMONIC LOAD PULL MEASUREMENTS

Harmonic load pull measurements explore potential device efficiency to find the best design topology.



Load pull setup with the R&S®ZNA vector network analyzer at its core.

Load pull applications help improve power amplifier characterization and optimization. Efficient amplifiers are used in the non-linear region close to saturation where they produce a significant amount of harmonic power. To optimize power amplifier (PA) efficiency, these harmonic signals need impedance optimized for harmonic frequencies.

## Your task

As a developer of RF power amplifiers, you focus on mandatory specifications such as gain, output power, frequency coverage along with sufficiently flat linearity, EVM and ACLR across the supported bandwidths. Significant effort is put into enhancing efficiency to differentiate

from other suppliers on the market. When the amplifier is run close to saturation, it produces harmonic content. Different operating modes such as class A or class B are used to optimize between linearity and efficiency. These classes are called waveform engineering since the current and voltage curves applied on the transistor are tuned. While classes A and B are tuned by bias voltage, classes E and F use harmonic controls to optimize efficiency. A harmonic load pull system offers full insight into the E and F modes and can explore the most efficient operating modes for a DUT (amplifier). Efficiency enhancements in the 10% to 20% range are realistic, depending on the device and its operation modes.

Application Card | Version 01.00

**ROHDE & SCHWARZ**

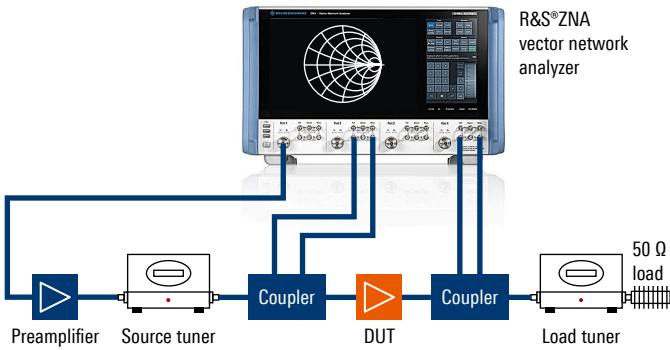
Make ideas real



## Rohde & Schwarz and Maury Microwave collaborate on a turnkey harmonic load pull system

Traditionally, load pull systems use mechanical tuners in passive systems to apply different impedance levels to a transistor (see Fig. 1). The active load pull system uses a different approach, where an active feedback system sends a signal to the amplifier output with a defined level and phase relative to the signal, replacing the tuner. The approach allows a wider tuning range across the Smith chart, since losses from the passive tuners are eliminated and more power is applied for a wider tuning range. A mixed approach (hybrid load pull) can also be used.

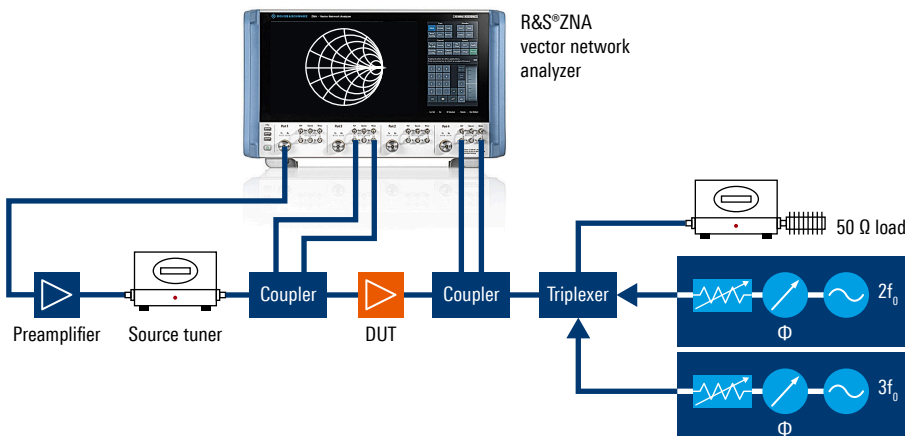
**Fig. 1: Basic passive vector receiver load pull setup**



When tuning harmonic frequencies, similar concepts are applied. Passive tuning uses multiplexed mechanical tuners for the first ( $f_0$ ), second ( $2f_0$ ) and third ( $3f_0$ ) harmonics. They are combined via a triplexer or a cascaded mechanical tuner with three internal carriages for the harmonics. A wider tuning range and greater flexibility are available with an active system which provides controlled harmonic frequency signals to the DUT.

A common approach combines a passive tuner for the fundamental frequency signal, since they support much higher power levels, with active signals for the second and third harmonics (see Fig. 2).

**Fig. 2: Harmonic vector receiver load pull setup**



Maury Microwave, AMCAD Engineering and Rohde & Schwarz have a joint turnkey system with software that can calibrate and run the entire system.

The solution uses four independently adjustable yet synchronized signal sources unique to the R&S ZNA, which can generate fundamental frequency signals for the input as well as second and third harmonics with phase and amplitude control for active harmonic load pulling (see Fig. 3). Alternatively, the fourth R&S ZNA source can replace the mechanical tuner on the load side with an active  $f_0$  signal. This is reasonable for devices with lower output power, as otherwise the signal at  $f_0$  driving into the output of the DUT would have to be excessive. A hybrid approach with a mechanical tuner plus an active signal to the DUT is the most flexible solution.

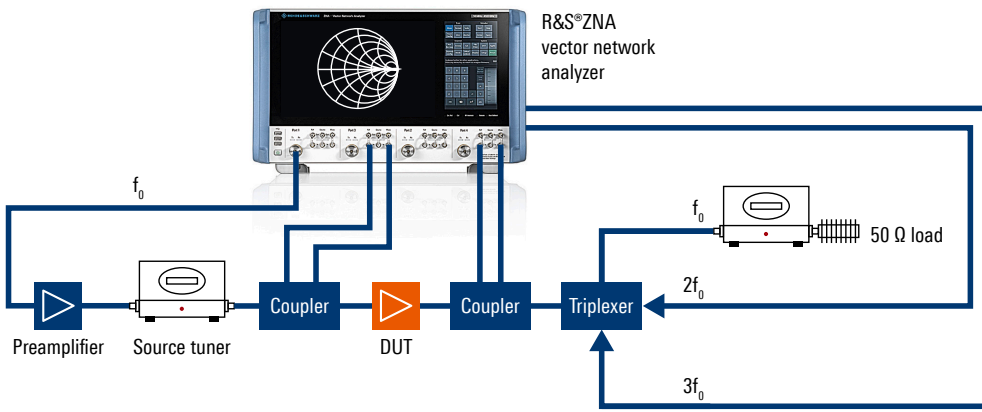
The R&S ZNA has four internal sources for a very compact, fast and stable setup that saves the cost of external sources or harmonic tuners.

### Application

A measurement-aided approach characterizes the DUT using different conditions to search for an overall solution and generate the greatest efficiency. A multi-step approach that uses a system fully calibrated down to the DUT is common. The typical steps are (see Fig. 4):

- Step 1:** The  $f_0$  impedance is swept looking for the best PA efficiency while  $2f_0$  and  $3f_0$  are set to a  $50 \Omega$  termination.
- Step 2:** The  $2f_0$  impedance is swept while the  $f_0$  is fixed to the impedance found in step 1 for the best efficiency.  $3f_0$  remains at  $50 \Omega$ .
- Step 3:** The  $3f_0$  impedance is swept while the  $f_0$  impedance and  $2f_0$  impedance are fixed to the impedance found in steps 1 and 2 for the best efficiency.
- Step 4:** Fine tuning the  $f_0$  impedance: The  $f_0$  impedance is swept again while the  $2f_0$  and  $3f_0$  impedances are fixed to those found in steps 2 and 3 for the best efficiency.

**Fig. 3: Active harmonic vector receiver load pull setup using R&S®ZNA sources**



This scheme provides data to select impedance matching at the different harmonics for the best amplifier efficiency. Since these plots typically show efficiency over output power with multiple curves for different impedance levels, the P1dB or P3dB compression point can be selected as the optimal point for maximum output power or a point with better linearity can be selected by using a back-off greater than 3 dB.

**Summary**

The joint solution from Maury Microwave, AMCAD Engineering and the R&S®ZNA from Rohde&Schwarz is a unique and compact approach to harmonic load pull measurements when developing the latest amplifiers.

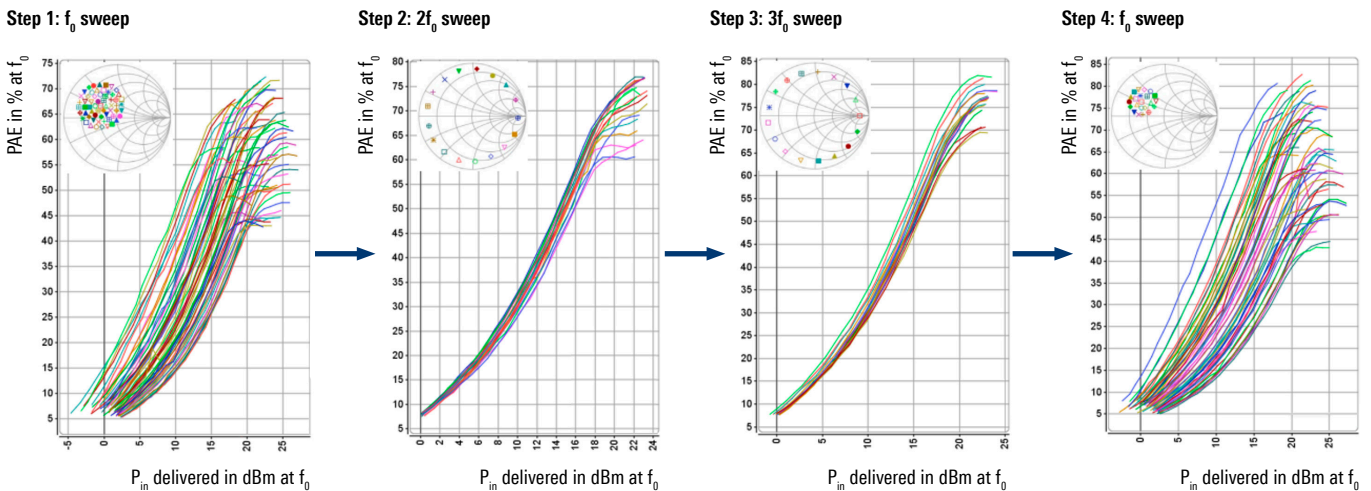
Since advanced amplifier classes, such as classes F or J are commonly used in modern wireless communications systems, having the best efficiency and harmonic termination are important to keeping power consumption as low as possible.

**See also**

- R&S®ZNA vector network analyzers: [www.rohde-schwarz.com/product/zna](http://www.rohde-schwarz.com/product/zna)
- RF power amplifier characterization: [www.rohde-schwarz.com/solutions/test-and-measurement/rf-microwave-components/amplifiers/rf-power-amplifier-characterization\\_253712.html](http://www.rohde-schwarz.com/solutions/test-and-measurement/rf-microwave-components/amplifiers/rf-power-amplifier-characterization_253712.html)

**Fig. 4: Efficiency curves along the optimization path**

The plots show power added efficiency (PAE) over the output power delivered at the output of the transistor. The range of impedance variation is also shown on the Smith chart for each step. The y-axis scaling changes to allow room for larger PAE values when the impedance is changed to achieve the best efficiency.



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