MT2000: High-Power (1 kW) Harmonic Load Pull for GaN Devices

Application Note / 2026-05-02

Abstract

High-power GaN devices operating from several hundred watts up to the kilowatt level place extreme demands on Load Pull measurement systems. Accurate characterization requires highly reflective fundamental and harmonic load impedances while maintaining measurement integrity, safety, and repeatability. Conventional passive or fully active Load Pull techniques face fundamental limitations at these power levels, driven by tuner loss, injected-power requirements, and harmonic isolation.

The Maury Microwave MT2000 system addresses these challenges using a hybrid passive–active harmonic Load Pull architecture. By combining passive pre-matching with controlled active impedance synthesis, the MT2000 enables accurate high-VSWR harmonic Load Pull measurements while minimizing injected power. This approach delivers practical, repeatable characterization of high-power GaN devices under operating conditions that closely reflect real amplifier applications.

High-Power Harmonic Load Pull Challenges

At kilowatt power levels, tuner insertion loss severely limits the maximum achievable reflection coefficient when using purely passive Load Pull systems. Conversely, fully active Load Pull requires extremely high injected power when the DUT output impedance is low, significantly increasing amplifier cost, complexity, and system risk. In addition, insufficient harmonic isolation can unintentionally perturb the fundamental impedance, obscuring the true impact of harmonic tuning on DUT performance.

As shown in Figure 1, for low output impedances, Active-Only Load Pull demands an order of magnitude more injection power than the DUT output itself, whereas hybrid impedance synthesis achieves the same target load with injection power levels close to the DUT output power.

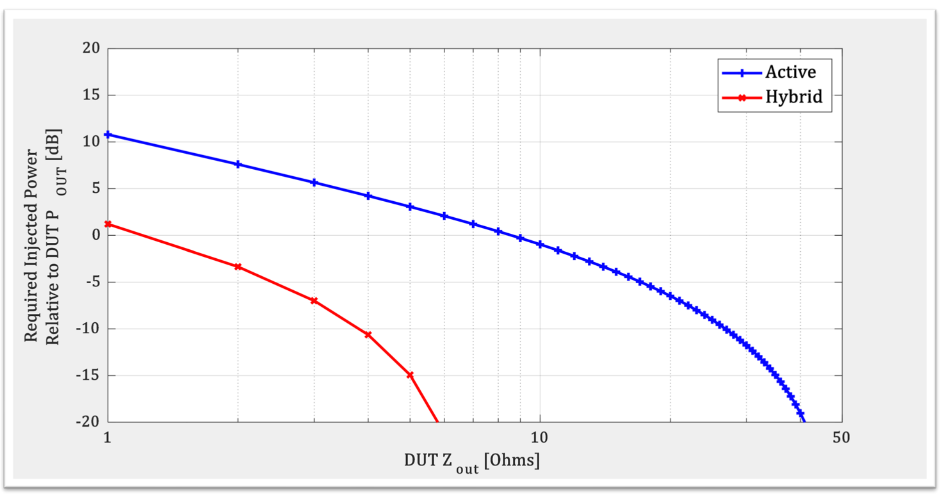

Figure 1. Comparison of injected power requirements: Active-Only versus Hybrid Load Pull.

MT2000 Hybrid Harmonic Load Pull Architecture

The MT2000 combines a high-power passive tuner with controlled active injection at the fundamental and harmonic frequencies. The passive tuner pre-positions the impedance close to the target reflection coefficient, while active injection compensates for residual loss. This hybrid impedance synthesis dramatically reduces required injected power while maintaining stability and calibration integrity (Figures 2 and 3).

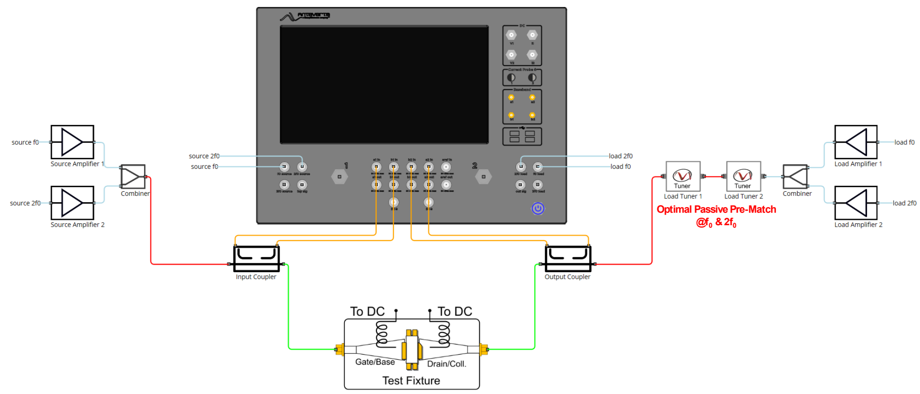

Figure 2. MT2000 high-power harmonic Load Pull system hybrid architecture (cascaded/ multi-harmonic-based tuning).

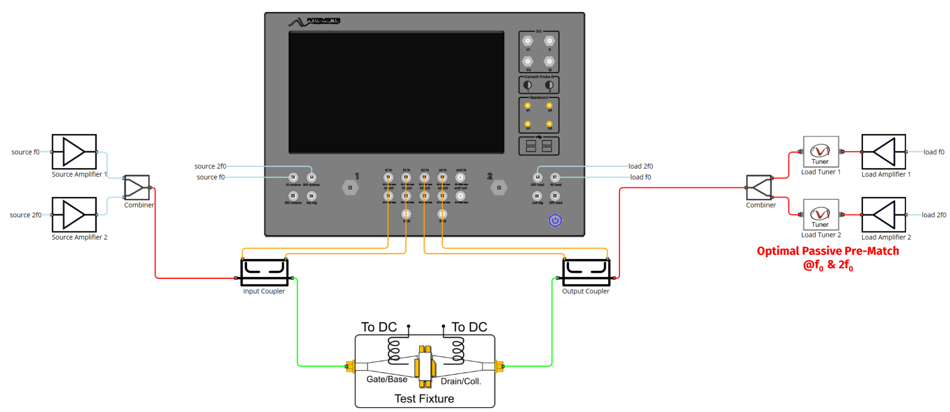

Figure 3. MT2000 high-power harmonic Load Pull system hybrid architecture (multiplexer-based tuning).

Background: Hybrid Impedance Synthesis and Mixed-Signal Theory

Hybrid impedance synthesis leverages both passive and active elements to construct a desired load reflection coefficient. From a mixed-signal perspective, the DUT output wave is vector-summed with an injected signal of controlled magnitude and phase. By aligning the passive tuner phase close to the desired target, the magnitude of injected power is minimized, which is especially critical for low output-impedance GaN devices at high power (Figure 4).

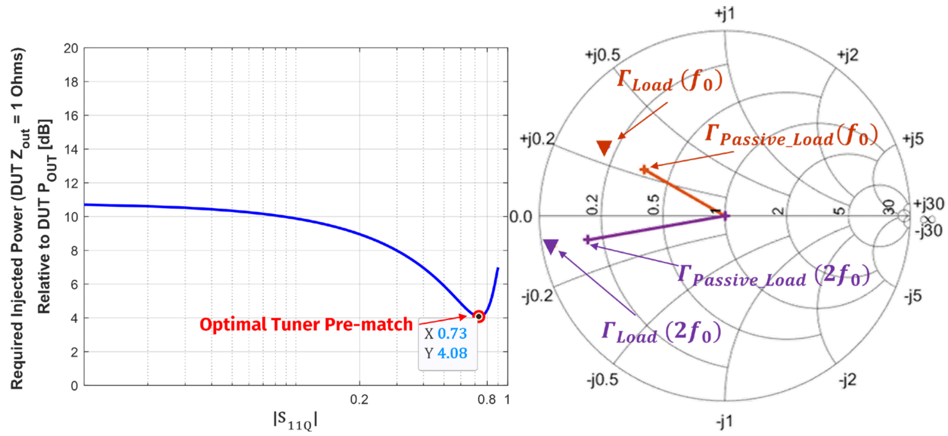

Figure 4. Hybrid impedance synthesis concept using passive pre-matching and active injection.

Comparison of Harmonic Tuning Methods

Three harmonic tuning approaches have historically been used in Load Pull systems: stub resonators, cascaded (multi harmonic) tuners, and multiplexer based tuning. All three approaches are supported by the MT2000 platform, providing maximum flexibility in user hardware configuration.

Stub resonator techniques rely on quarter wave structures and sliding contacts but suffer from limited tuning isolation, narrow bandwidth, and mechanical repeatability challenges. Cascaded (multi harmonic) tuner approaches improve bandwidth and Smith chart coverage; however, they have historically exhibited insufficient harmonic isolation, which can result in unintended perturbation of the fundamental impedance.

Multiplexer based harmonic tuning provides excellent isolation between fundamental and harmonic frequencies, ensuring that harmonic tuning introduces negligible impact on the fundamental load impedance.

Harmonic Isolation and Measurement Accuracy

High harmonic isolation is the most critical requirement for accurate harmonic Load Pull. Limited isolation at the second harmonic can produce fundamental impedance errors exceeding VNA calibration uncertainty. Multiplexer-based implementations achieve very high effective harmonic isolation, typically exceeding 70 dB, rendering harmonic pulling effects negligible compared to TRL calibration limits.

MT2000 Harmonic Load Pull Measurement Flow

Measurements begin with optimization of the fundamental load for output power or efficiency. Harmonic phase sweeps are then performed at achievable VSWR while holding the fundamental impedance fixed at its optimum value. Once the optimal harmonic phases are identified, the MT2000 automatically synthesizes the exact high-VSWR target impedance using hybrid impedance synthesis.

Example MT2000 High-Power GaN Load Pull Results

Using the MT2000 hybrid approach, high-power GaN devices have been characterized under extreme mismatch conditions approaching 1 kW output power (Figure 5). Harmonic tuning enables significant improvements in efficiency while maintaining safe operating conditions and repeatable measurements.

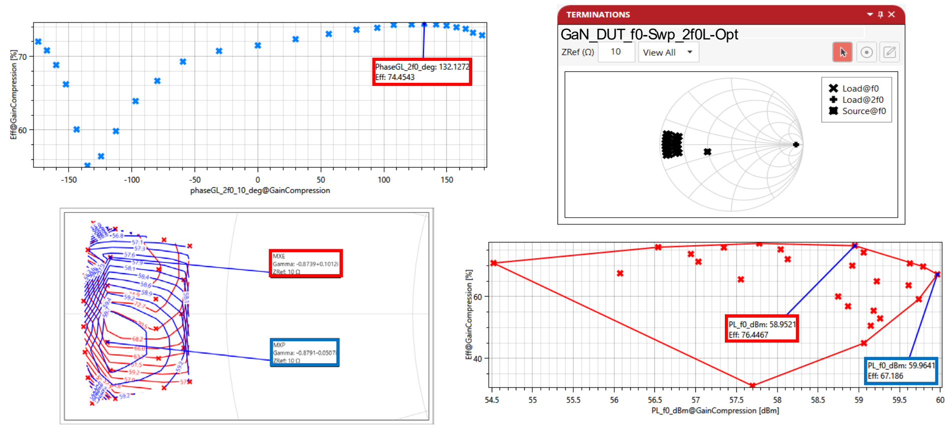

Figure 5. Example of hybrid harmonic Load Pull measurement of a high-power (1 kW) GaN device.

Conclusion

Hybrid harmonic Load Pull using optimized passive pre matching and controlled active injection provides a practical solution for fast and accurate high power device characterization. By automatically positioning the passive tuner to balance insertion loss and mismatch losses, the MT2000 minimizes the active injection power required to synthesize the target load impedance.

This hybrid approach enables accurate measurements up to $|\Gamma_{Load}| = 1$ while avoiding the excessive injected power requirements of fully active Load Pull. Combined with high isolation harmonic tuning, the MT2000 delivers fast, accurate, and repeatable harmonic Load Pull measurements at power levels beyond the reach of traditional systems, supporting next generation high power GaN power amplifier development.

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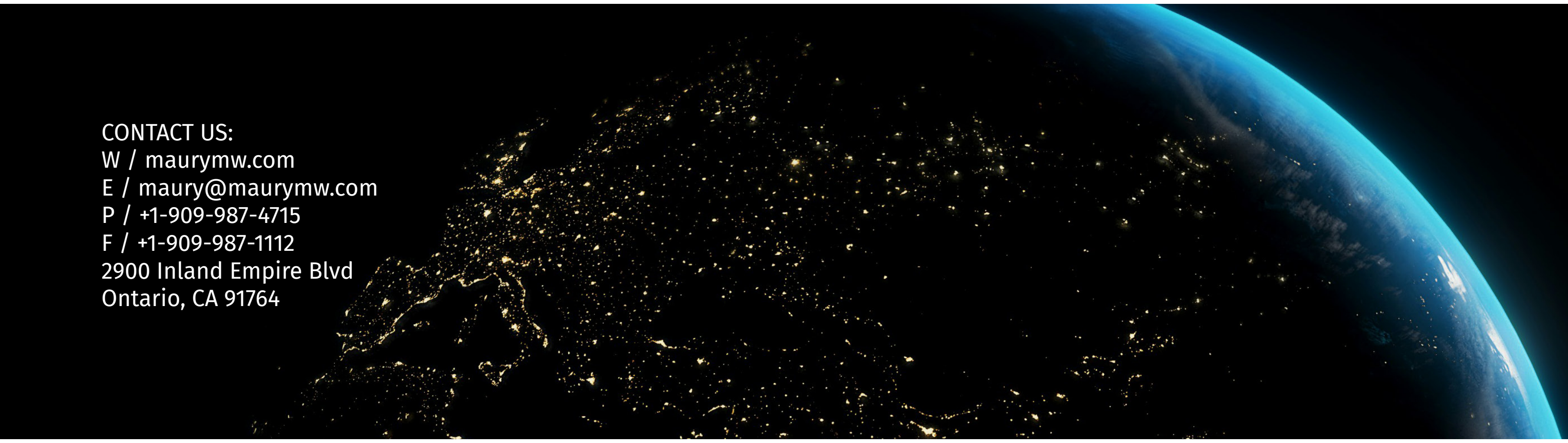

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