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*Application Note 27*

# Harmonic Load Pull Solutions

Focus Microwaves offers and supports a variety of techniques that allow to control the Harmonic Load Impedances of power transistors and optimize their Efficiciency and Gain performance. This includes passive and active load pull techniques for variable and the use of special test fixtures for fixed harmonic loads.

## Introduction

RF and microwave amplifier designers know that optimum harmonic loading of power transistors significantly increases efficiency and gain of the amplifiers depending on frequency and transistor type [1,2]. The optimum amplitude of the the load reflection factor at the harmonic frequencies has been reported to be close to 1 (total reflection) whereas the optimum phase may cause improvemet or deterioration  of more than ±10 percentage points. The *wave shape* at the output of the transistor and its dynamic load line are modified by reflecting the harmonic power back into the device such that efficiency in particular can be enhanced considerably. Since harmonic components in the signal are suppressed by the high reflection the linearity of the transistor does not degrade either when this technique is used.

Focus Microwaves supports the following techniques for harmonic load pull:
1- Harmonic Test Fixture.
2- Passive Tuner Harmonic Load Pull.
3- Active Harmonic Load Pull.

This note describes these three techniques, as supported by Focus Microwaves and presents experimental setups and data.



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# Description of Harmonic Load Pull Techniques

The different techniques used in order to achieve the objective of "independent" harmonic tuning include simple techniques and more sophisticated setups and techniques:

1- *Harmonic Test Fixture* [3]: This technique employs a microstrip test fixture with $\lambda$ /4 open stubs connected at the output of the device at the two harmonic frequencies $2f_0$ and $3f_0$ . Focus Microwaves provides the design method that allows to generate specific harmonic load impedances.

2- *Passive Tuner Harmonic Load Pull* [4]: This setup includes three or four programmable tuners: One for source matching, one for load pulling the fundamental frequency and one or two more output tuners for the second and third harmonic. It also includes a low loss di- or triplexer at the output and complete control hard- and software for calibrating and de-embedding at the harmonic frequencies.

3- *Active Harmonic Load Pull System* [5]: This technique uses the DUT's output signal samples it amplifies and controls its phase and injects it back into the output of the DUT in order to "emulate" a variable load. By sampling, modifying and re-injecting the harmonic signals the active load pull system can also control load impedances at the harmonic frequencies independently on the load impedance at the fundamental frequency. A major advantage of the active system is that it can generate reflection factors at the fundamental and harmonic frequencies equal to 1 (total reflection).

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At this point of time the only practical way to vary and optimize the harmonic loads of a transistor is to use one of the experimental harmonic load pull systems, available at different research laboratories and universities [1,2,3,4].
Disadvantages of this method, except of prohibitive cost, is that it is not commercially available and requires a lot of experience to operate, in addition to the complex auxiliary instrumentation involved.

This note describes a simple method for full scale load pull at the fundamental frequency with the load at the harmonic frequencies $2f_0$ and $3f_0$ fixed at predefined values. The method uses a specially designed test fixture based on Focus' PTJ-0 [5]. This Note 24-A describes the concept for these measurements while note 24-B presents actual measured data.

Multi Harmonic load pull improves the Power Efficiency of Transistor (Bipolar and FET) power amplifiers.
This note describes a technique that uses a test fixture designed to determine and use optimum harmonic load impedances to the DUT during load pull at the fundamental frequency. Load pull impedances of far less than 1Ω are possible by simultaneous use of $\lambda$ /4 transformers.

Harmonic Tuning using ALPS

It has been reported that presenting to the transistors specific load impedances at the *second and third harmonic frequencies ($2f_0$ and $3f_0$)* may improve its gain and in particular the Power added Efficiency by roughly 10%, especially in class A-B, B and C operation. This happens when ***most of the power at those frequencies is reflected back into the device with an optimum phase***. The load reflection factors at $2f_0$ and $3f_0$ should therefore be close to 1. This has been recently confirmed from computations based on nonlinear models [8]. Table 1 shows a comparison between actually available solutions to Harmonic Tuning.

| System | $\|\Gamma_L(f_0)\|$ | $\|\Gamma_L(2f_0)\|$ | $\|\Gamma_L(3f_0)\|$ |
|---|---|---|---|
| ATN | ≤0.8 | ≤0.69* | ≤0.6 |
| **H-ALPS** | 1.0 _ | 1.0 _ | 1.0 _ |
| CCMT** | ≤0.9 _ | ≤0.8 | ≤0.85 |
| **Required** | **>0.9** | **>0.95** | **>0.95** |

* Not all phases.
** Using Low Loss Multiplexer and Transformer.

Active Load Pull has the capability of harmonic tuning by adding active load loops at the harmonic frequencies and tuning the network analyzer to measure those.

The harmonic Tuning option ALPS 308-H configuration is shown in figure 11:

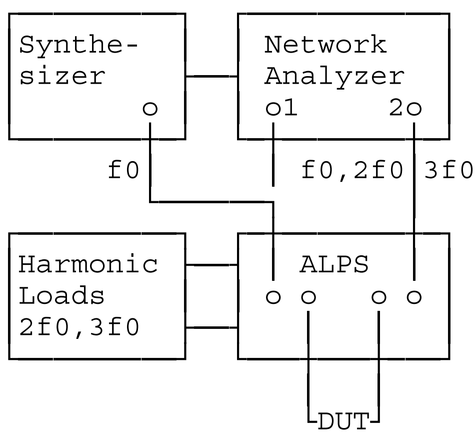


Figure 11: Setup for Load Pull and Harmonic Tuning using ALPS

The harmonic load pull setup includes, besides ALPS and the active load at the fundamental frequency $f_0$ , also an external synthesizer, connected at port 1 of ALPS and the external unit "***Harmonic Loads***". This unit includes the active loads for the frequencies $2f_0$ and $3f_0$, and works on the same principle as the fundamental load. The harmonic signals injected into this unit are sampled and filtered out of the basic ALPS unit at the output port of the DUT.
All components are controlled by the same PC via AIB and GPIB. By selecting the frequency of the reference synthesizer inside the network analyzer we have access

to the load impedance on either of the harmonic loads independently. The actual status of each harmonic load is controlled independently from the PC controller via AIB, which adjusts the value of the phase shifter and attenuator in each active harmonic loop ($2f_0$ and $3f_0$).

***Manual Load Tuning*** permits to alternatively select one of the harmonic loads and tune to a point of the Smith Chart and measure the DUT's performance at the fundamental frequency without affecting the loads at the other frequencies.