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DEVICE CHARACTERIZATION WITH HARMONIC SOURCE AND LOAD PULL

Automated source and load pull is widely used in power amplifier development to determine device capability and matching network requirements. Recently, harmonic load pull has become increasingly important, especially for optimizing efficiency and linearity.

Harmonic source pull is also very significant for optimizing performance. Measured data shows that harmonic source tuning can sometimes have as big or bigger effect than the harmonic load tuning. When performance is critical, harmonic source tuning should be part of the process.

Passive tuner systems are the most common because of their simplicity and versatility. They typically have a wide matching range, but this can be reduced by losses in the setup. Tuning range can be extended with pre-matching or with active tuners.

Pre-matching in the test fixture shifts the device-under-test (DUT) impedance to a range that can be easily matched with the tuner setup. It does require knowledge of approximate device impedance ahead of time. It may also affect the harmonic tuning, although a quarter wave transformer approach should have minimal effect at the 2nd harmonic. If the pre-matched fixture is characterized, the source and load pull data can still be deembedded to the DUT planes.

A typical passive tuner system is shown in **Figure 1**. Two tuners are used to simultaneously tune the source and load at the fundamental frequency. Tuning at the harmonic frequencies is uncontrolled, although the harmonic terminations can be known. This is useful for first order matching network design, and for validating device models[1], but does not show how to terminate the harmonics for best performance.

A system with harmonic source and load pull is shown in **Figure 2**. In this case, diplexers are used on both the input and output of the DUT to separate the signal paths at the fundamental and 2nd harmonic frequencies. Separate tuners are connected to each diplexer output, so the two frequencies can be tuned independently.

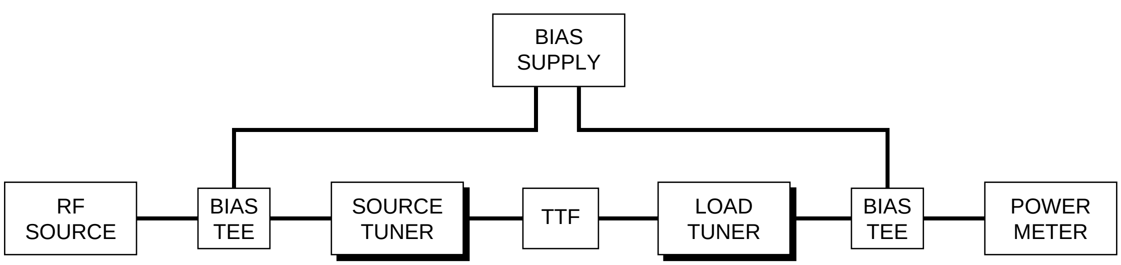

Figure 1: Passive Tuner System for Basic Power Measurements

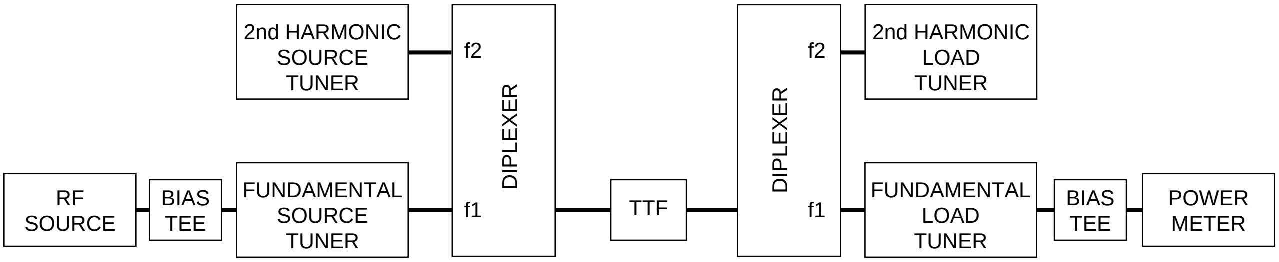

Figure 2: Passive Tuner System with 2nd Harmonic Source and Load Tuning

The harmonic tuning can be extended to include the 3rd harmonic, as shown in **Figure 3**. Here, a triplexer is used on both the input and output of the DUT to separate signal paths at the fundamental, 2nd harmonic, and 3rd harmonic frequencies. Separate tuners are connected to each triplexer output, so all three frequencies can be tuned independently.

NOTE: *The same power parameters at the fundamental frequency will be measured even while tuning the harmonic frequencies. The goal is to find the impedances at all of the frequencies which optimize the fundamental performance. Once these are determined, the matching networks can be designed for the best possible operation.*

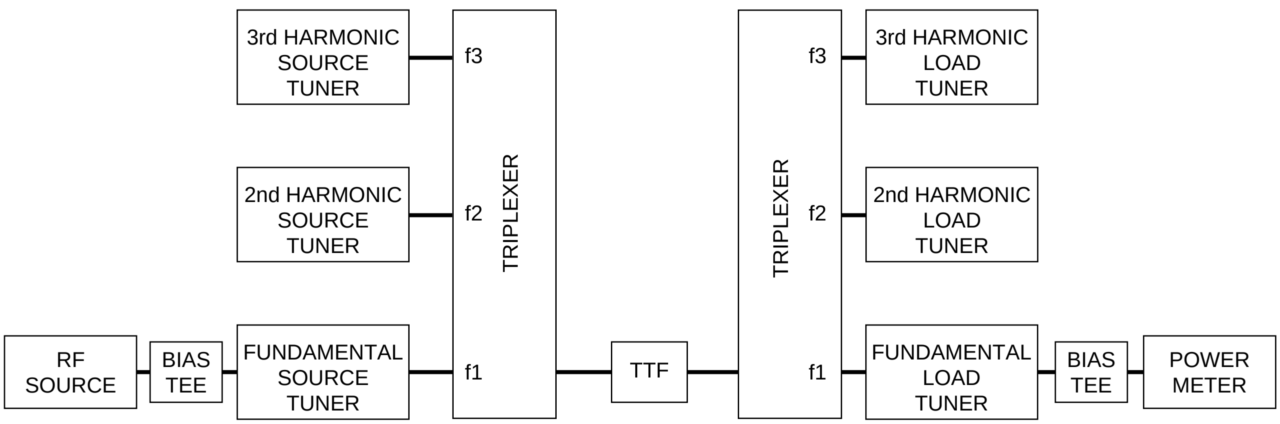

Figure 3: Passive Tuner System with 2nd and 3rd Harmonic Source and Load Tuning

The passive harmonic tuning still has a limit to the matching range, just like the fundamental tuning. It is also affected by any losses in the diplexer or triplexer. Since any harmonic power absorbed by the load is wasted, complete reflection is desirable, so the only design question is — what reflection phase is needed. Even with a matching range limit, harmonic load pull will still show the optimum phase of the harmonic tuning.

Measured Harmonic Data

Figure 4 shows 2nd harmonic load pull data for measurements at 850 MHz using the setup of **Figure 2**. The DUT is a small signal bipolar device, operating just below the 1 dB compression point. The other three tuners were all tuned for best efficiency. The harmonic load pull produced a 13 percent variation from the worst to the best measured point. (The range of variation would likely be several

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percent larger if tuning to the edge of the Smith chart were available.) The best data occurs over a fairly wide phase range which allows some leeway in the matching network design.

Figure 5 shows 2nd harmonic source pull data for the same device and setup as in **Figure 4**. The other three tuners were all tuned for best efficiency (the best value is the same as for **Figure 4**). The harmonic source pull produced over 15 percent variation from the worst to the best measured point. This is a larger variation than the harmonic load pull produced. As in **Figure 4**, the performance is somewhat limited by tuning range, but the optimum phase is clear.

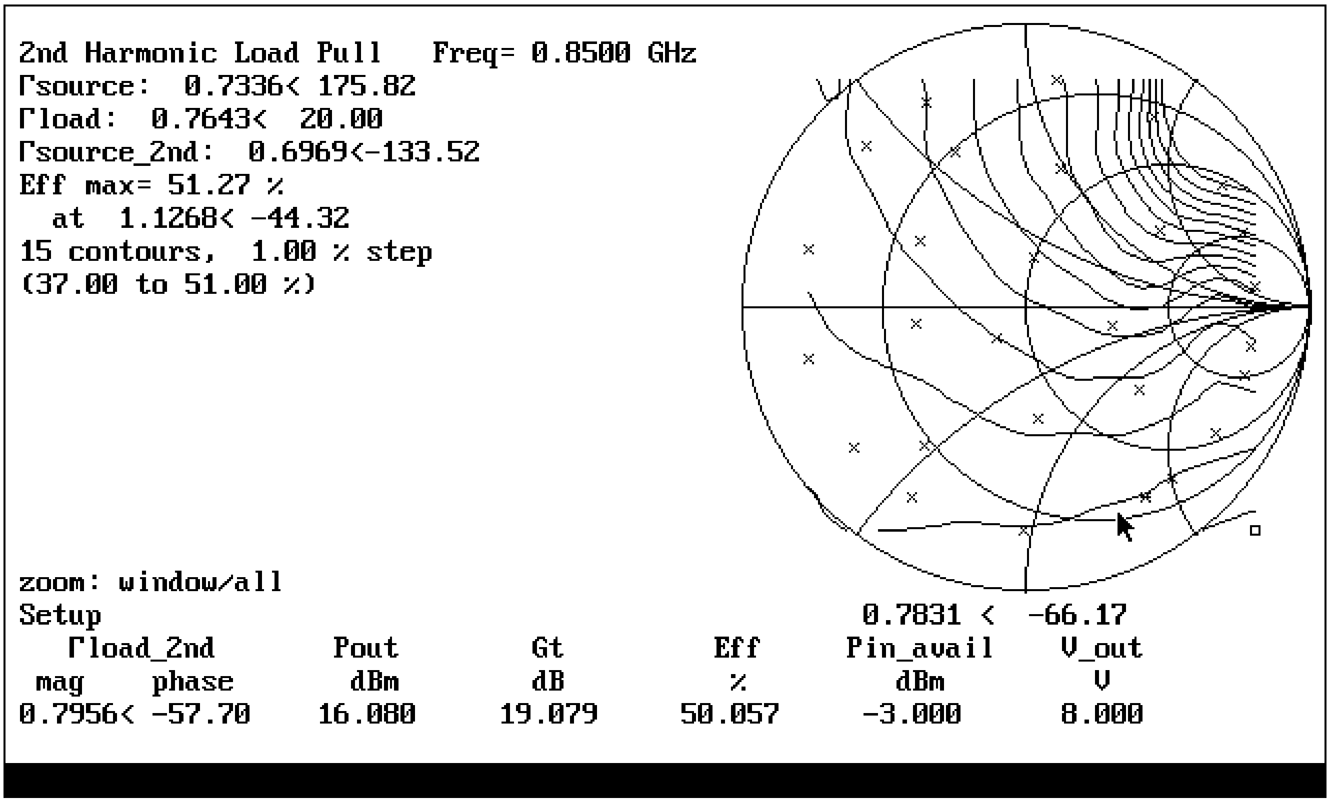

Figure 4: Efficiency vs. 2nd Harmonic Load Tuning

The relative effect of harmonic source and load pull depends on a variety of factors, including device type, bias, drive level, and fundamental tuning. Efficiency variations of over 23 percent due to harmonic load pull have been reported[2]. Some measurements (like **Figures 4** and **5**) show the harmonic source pull to have a larger effect than the harmonic load pull. In other measurements, it is reversed.

Active Load Pull System (ATTS):

Maury now offers a line of Active Tuning Test Sets (**ATTS**) for independent fundamental and harmonic load pull in the characterization of power devices. It uses propriety design for the absolute stability of the active loop up to higher reflection coefficient irrespective of DUT gamma. It incorporates PoliPull software in Windows® NT/2000 to measure data in "real time" with state of the art accuracy for device modeling or power amplifier design applications.

Using **ATTS**, there is no need to pre-match the device (in the case of very low impedance devices) and also offers the capability to measure DUT input reflection coefficient. As the system is VNA based, it gives full vector correction resulting in excellent measurement accuracy. Please refer to Maury application note 5C-046.

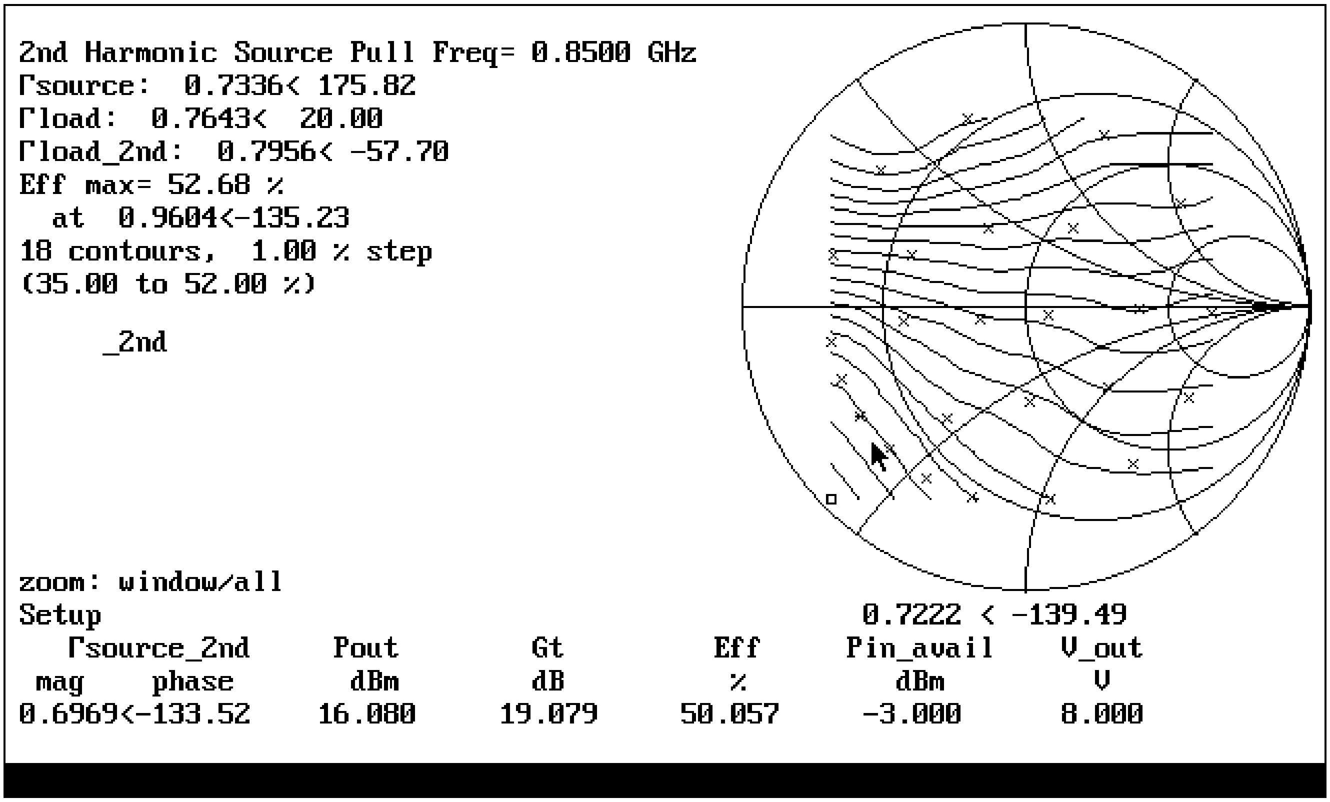

Figure 5: Efficiency vs. 2nd Harmonic Source Tuning

Summary

Harmonic tuning, both on the source and on the load, is very important in achieving optimum device performance. Using separate tuners to tune the fundamental and harmonic frequencies with a low loss diplexer or triplexer, independent harmonic tuning can be achieved because the diplexers/ triplexers exhibit high isolation.

Diplexers, triplexers, and fixture losses reduce the matching range of passive tuners but this can be overcome, if needed, by using fixture pre-matching.

Harmonic tuning is compatible with existing systems for basic power measurements, as well as intermod and adjacent channel power measurements. Harmonic tuning software and hardware can be added when needed.

References

[1] Sevic, McGuire, Simpson, and Pla, "Data-based Load-pull Simulation for Large-signal Transistor Model Validation", Microwave Journal, March 1997, pp. 124-128.

[2] Simpson and Vassar, "Importance of 2nd Harmonic Tuning for Power Amplifier Design", 48th ARFTG Digest, December, 1996.

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