IMPORTANCE OF 2nd HARMONIC TUNING FOR POWER AMPLIFIER DESIGN

Abstract

Load pull measurements are widely used to determine matching impedances required for optimum power amplifier design. In the past, this has typically been done at the fundamental frequency only. However, the harmonic terminations can have a significant effect. This paper presents some typical data which indicates the importance of second harmonic tuning to the power amplifier designer.

Introduction

Power amplifiers used in communications must typically be as efficient as possible to minimize operating cost or extend battery life. High efficiency requires operation in a large signal mode, so design based on small signal s-parameters becomes invalid. Non-linearity also causes intermodulation which can interfere with other frequency bands.

A widely used design approach for power amplifiers is to use tuners to determine the optimum matching impedances, and then create matching networks to synthesize those impedances.

With automated tuners, a device may be measured at full operating power as a function of matching impedance. Overlaid contours of various specified parameters show the tradeoffs for different matching impedances. From this, the power amp designer can select the optimum set of impedances to synthesize in the matching network design.

A basic power measurement setup is shown in **Figure 1**. The list of measured parameters is selected based on the application requirements, and usually includes at least output power, gain, and efficiency. Other equipment may be added as needed to measure additional parameters, such as two-tone intermodulation, or Adjacent Channel Power (ACP) measurements for various digital modulation formats.

The majority of tuner systems currently in use control the impedances only at the fundamental frequency. By proper tuner characterization, harmonic impedances occurring during the fundamental load pull can be known, but not controlled independently. This provides enough information to design a basic power amplifier, but does not directly show the effect of matching at the harmonic frequencies.

Tuning at Harmonic Frequencies

The power amplifier design objective usually covers performance only at the fundamental frequency, but this can be significantly influenced by tuning at the harmonic frequencies. To measure this, extra tuners may be added to allow independent load tuning at the harmonic frequencies.

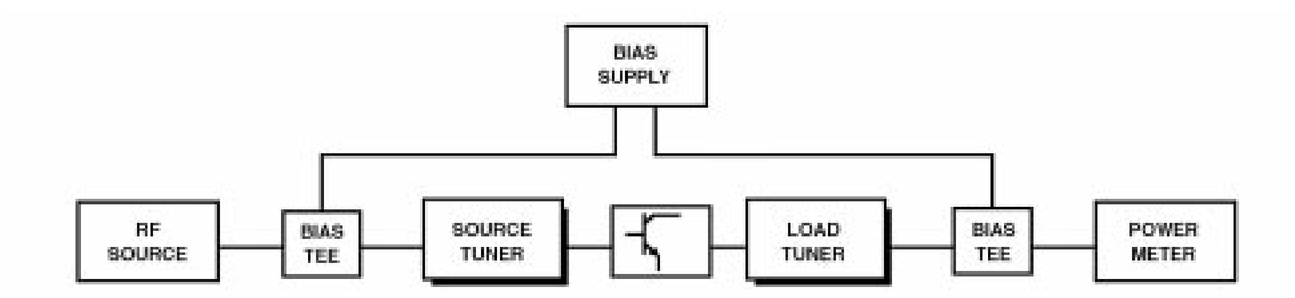

Figure 1: Basic Power Measurement Setup with Tuners.

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Figure 2 shows a basic power setup which includes independent load tuning at the 2nd harmonic frequency. The load tuners are connected through a diplexer, which is essentially a dual filter. The path from the device to the fundamental tuner passes the fundamental frequency, and blocks the 2nd harmonic. The path from the device to the harmonic tuner passes the 2nd harmonic, but blocks the fundamental. Tuning at either frequency will therefore have no effect on matching at the other frequency.

The measured parameters in **Figure 2** are primarily output power, gain, and efficiency, determined as a function of input and output matching impedances. The parameters will be measured only at the fundamental frequency, even when the harmonic tuning is being done.

Measured Data

Figure 3 shows load contours of output power at the fundamental frequency. This was done to optimize the fundamental match prior to doing the harmonic load pull. The Device Under Test (DUT) was a small silicon bipolar device, and was operating at approximately 1 dB gain compression when matched.

After the fundamental source and load matches were optimized, those tuners were left a the optimum points, and a 2nd harmonic load pull was done. An active tuner was used to get up to unity reflection magnitude at the DUT plane. The resulting contours of efficiency are shown in **Figure 4**. Without changing the tuning at the fundamental frequency, the efficiency was varied over an approximately 8.5% range. In the optimum tuning area of the 2nd harmonic Smith chart, the efficiency variation is slow, meaning that it's not very sensitive to tuning. However, in other parts of the same chart, sensitivity is much worse.

This is a very significant result. Without this 2nd harmonic tuning data, the 2nd harmonic match would be uncontrolled, so performance would likely be less than what could be. This can slow down the design process, and can be critical in competitive markets.

This also explains differences between measurements in different test setups, or between the test setup and the final amplifier. The harmonic tuning data is essential to designing a power amp that will work as expected.

The degree of dependence on harmonic tuning undoubtedly depends on the device type, bias class, and amount of saturation. Another example is shown in **Figures 5**, **6**, and **7**. The DUT is a 1 Watt device, completely different from the DUT of **Figure 4**.

Figure 5 shows 2nd harmonic contours of output power and efficiency after the source and load were both tuned for best power output at the fundamental frequency. The efficiency variation is about 8%.

Figure 6 shows 2nd harmonic contours after the source was tuned for best power output and the load for best efficiency at the fundamental frequency. The efficiency variation is higher, about 14.7%.

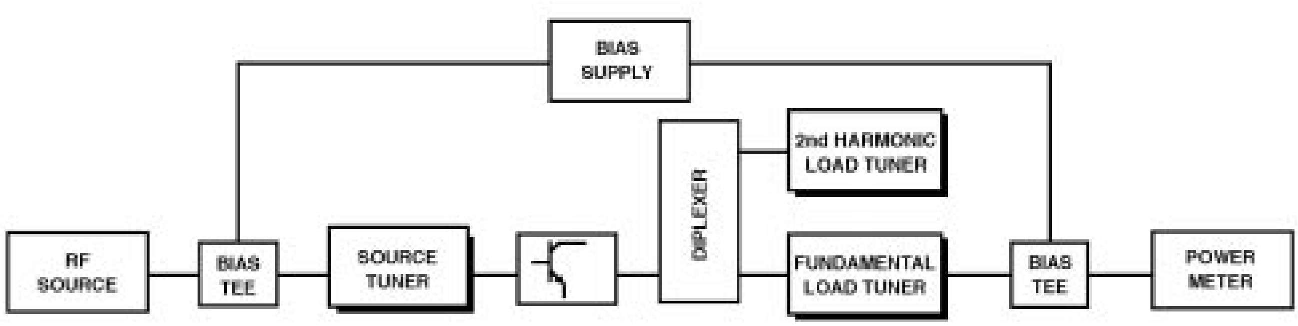

Figure 2: **Basic Power Measurement Setup with 2nd Harmonic Load Tuning.**

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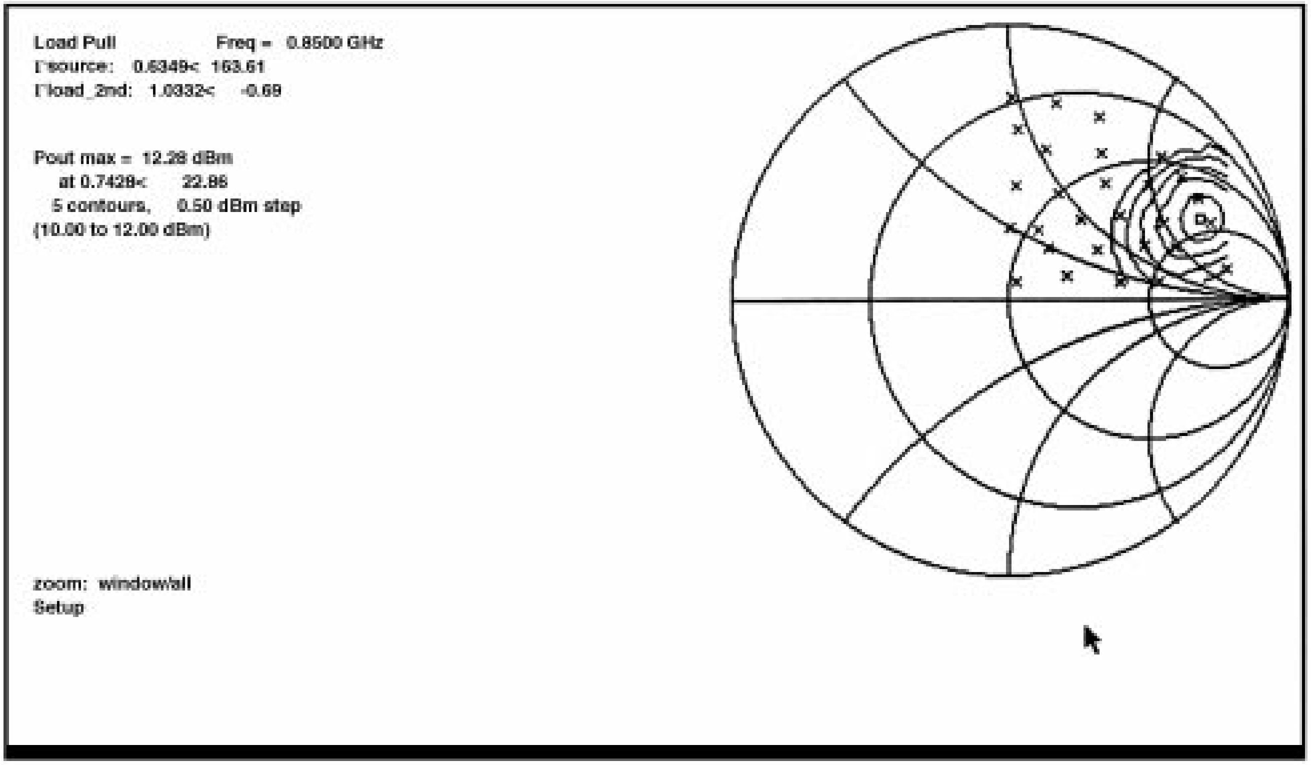

Figure 3: Contours of Constant Output Power at the Fundamental Frequency.

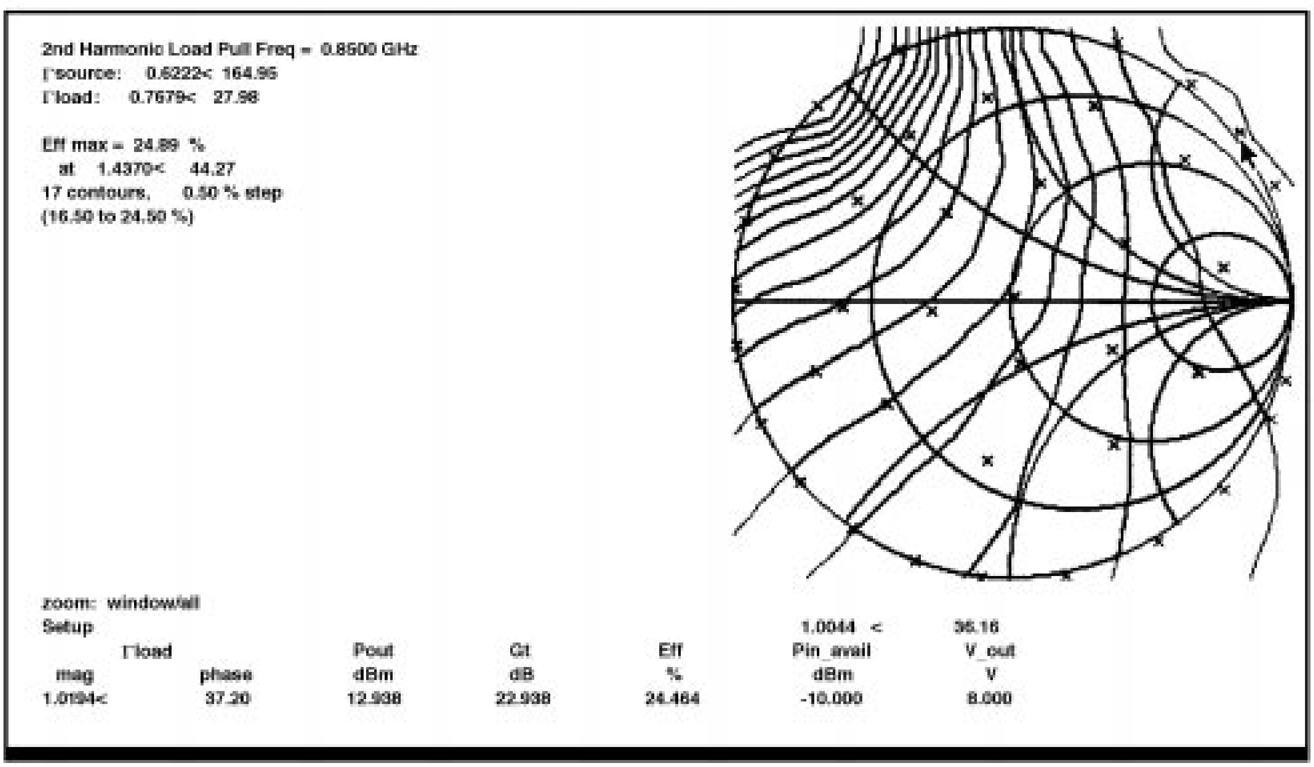

Figure 4: Contours of Constant Efficiency vs. Harmonic Load Tuning.

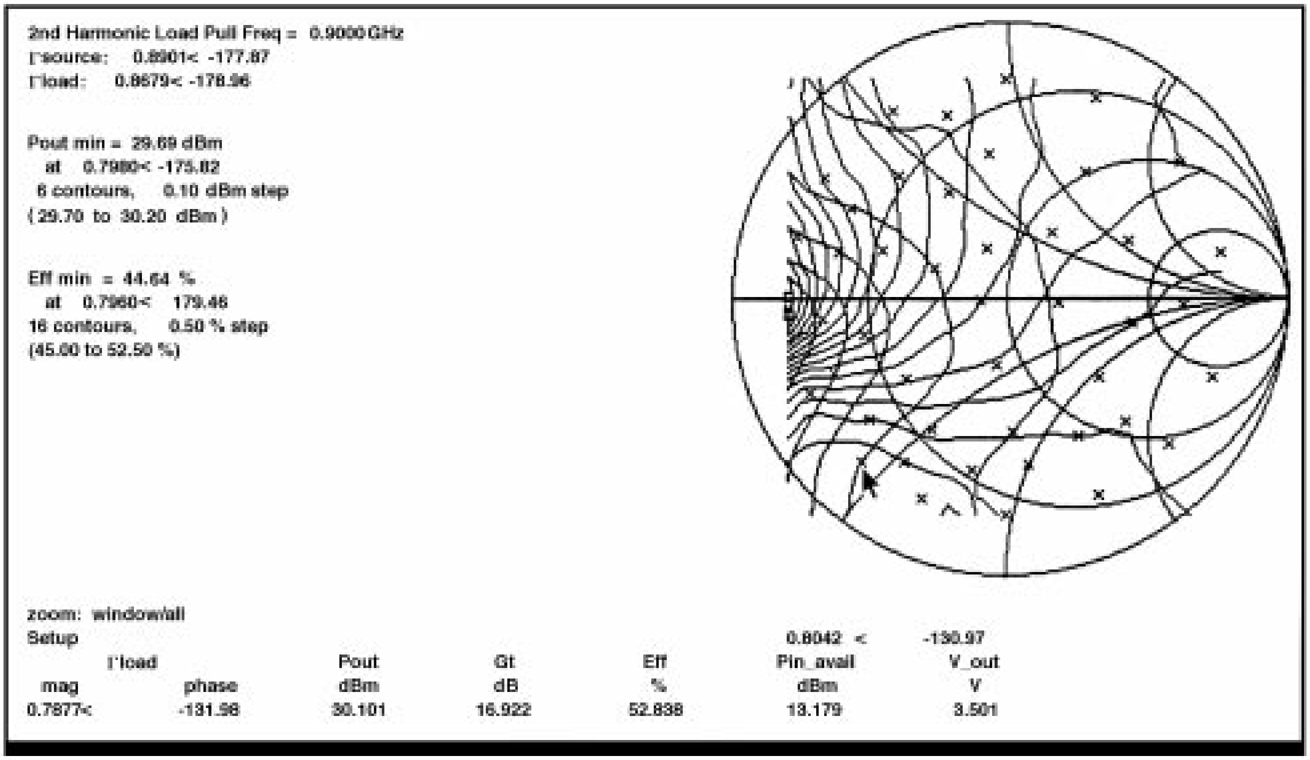

Figure 5: **Contours of Constant Output Power and Efficiency vs. Harmonic Load Tuning (source and load power matched at fundamental).**

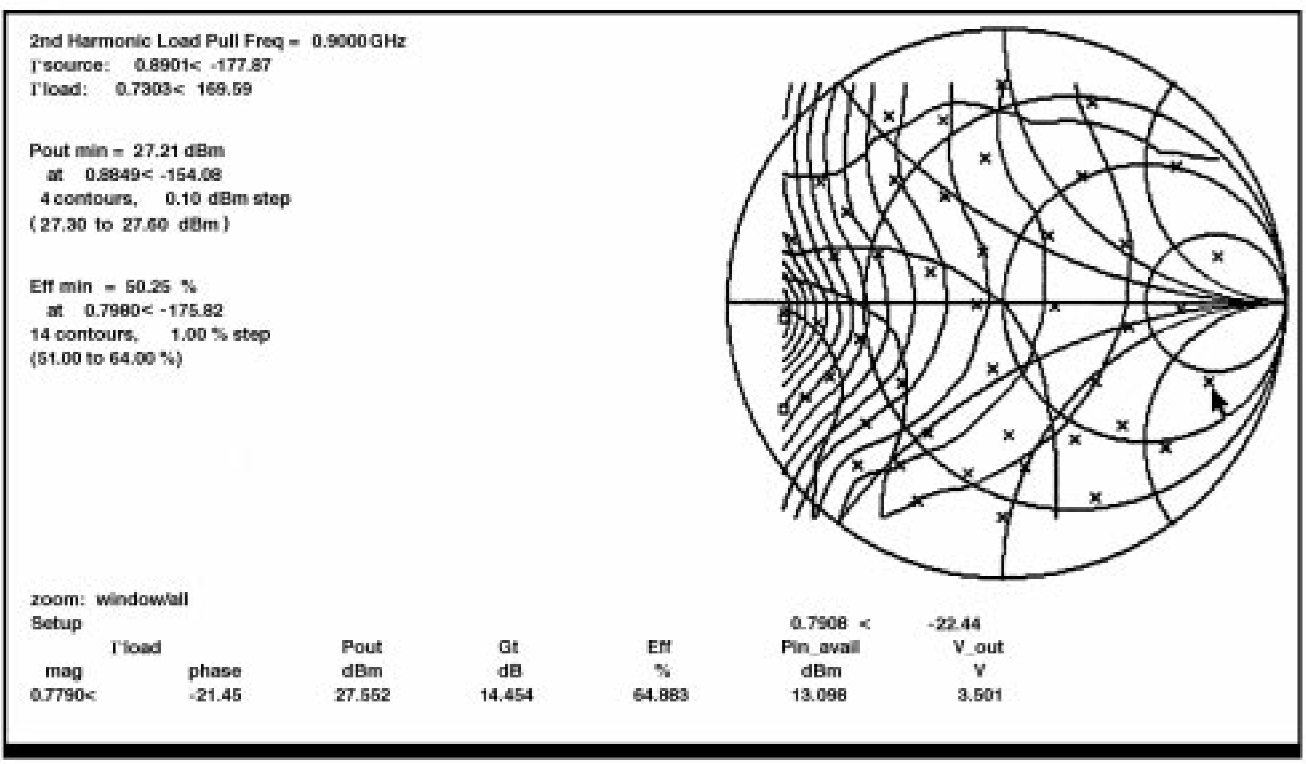

Figure 6: **Contours of Constant Output Power and Efficiency vs. Harmonic Load Tuning (source power matched and load efficiency matched at fundamental).**

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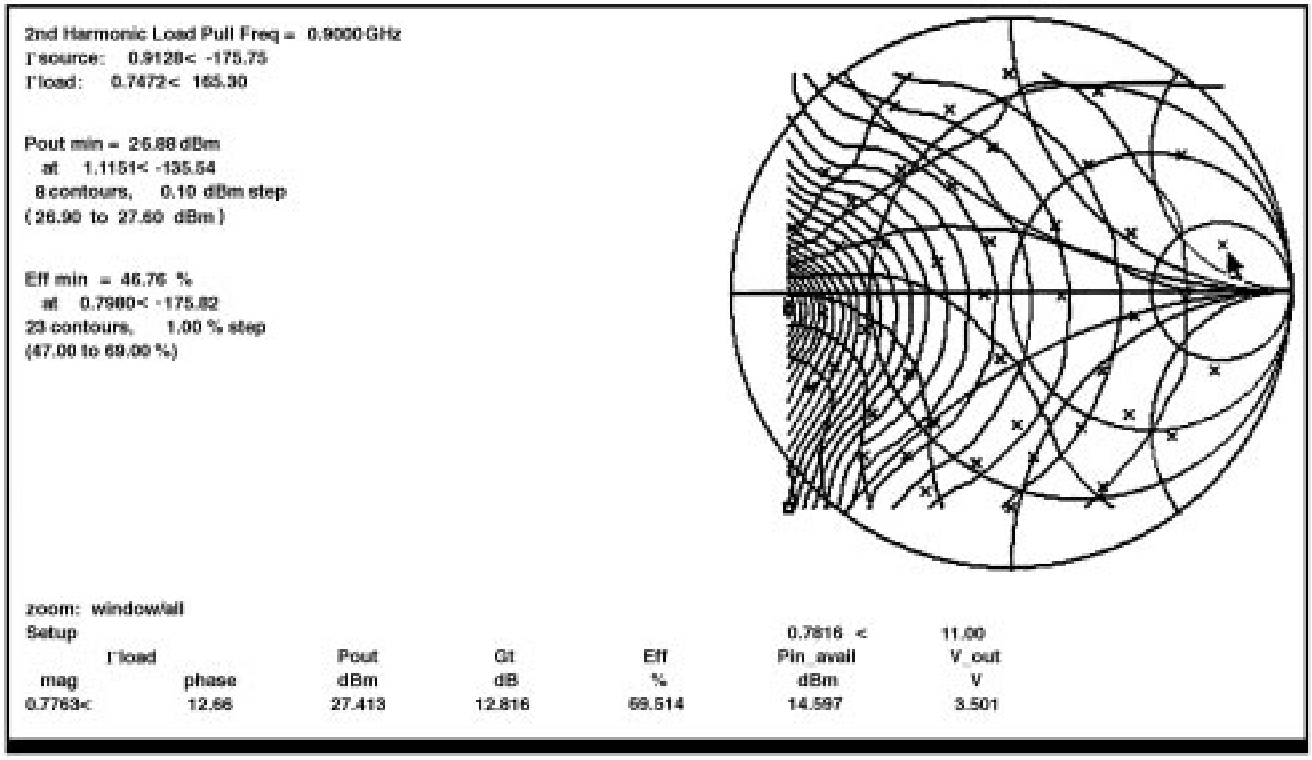

Figure 7: Contours of Constant Output Power and Efficiency vs. Harmonic Load Tuning (same as Figure 6, except slightly higher input power).

Figure 7 is the same as Figure 6, except that the load match at the fundamental frequency was optimized at a slightly higher input power and with the 2nd harmonic tuner set for maximum efficiency. The efficiency variation due to harmonic tuning is higher yet, about 22.7%. And tuning to the edge of the Smith chart would increase the variation even more.

The measurement system can be extended to include 3rd harmonic load tuning by using a triplexer instead of the diplexer. This should have a smaller effect than the 2nd harmonic, but may still be significant. The setup is also being modified to measure harmonic source pull.

Conclusions

It is clear from the measured data that harmonic tuning has a very significant effect on the operation of a power amplifier. Matching at the fundamental frequency is still the first step, but optimizing the harmonic match is critical to getting the best performance out of a device.

Without the harmonic tuning data, the power amp designer will have to settle for less performance than what could be. Also, the performance of the finished amplifier may be different than expected. As communications become more of a mass consumer market, the power components are becoming more cost and performance competitive. Using harmonic tuning to optimize the power amplifier design is becoming an important part of the design process.

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