HARMONIC LOAD-PULL

by

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ABSTRACT

A unique operator-interactive load-pull system which allows independent tuning of a signal and its harmonics is presented. Various tuning techniques are described and data on MESFET's in amplifier and oscillator configurations is presented.

Introduction

Harmonic signal content of an oscillator or amplifier is of major concern to the microwave circuit designer. Present device characterization techniques such as s-parameter measurement or load-pull [1, 2, 3] terminate the harmonic signals into 50Ω or, often, into an unknown and uncontrollable impedance; determining potential circuit harmonic performance from these techniques is difficult. A system capable of separately measuring and tuning load impedances presented to a microwave device at a frequency and its second harmonic is presented and we discuss some very interesting data obtained using the new technique.

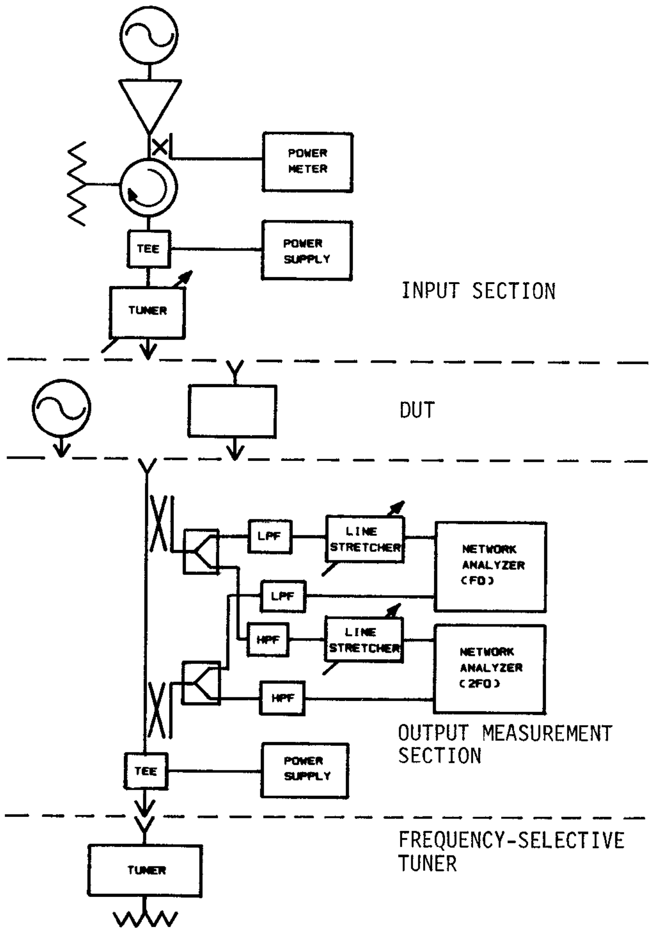

FIGURE 1: LOAD-PULL SYSTEM (FUNDAMENTAL AND SECOND HARMONIC ONLY)

The System

The basic harmonic load-pull system is shown in Figure 1. The impedance measurement is performed by a coupler reflectometer and two network analyzers. The measurement system is broadband, operating over the 2-12 GHz range. Independent measurement of the load impedance at a fundamental frequency and its second harmonic is accomplished with power splitters and the appropriate filters ahead of the network analyzers. A fundamental source is required for two-port amplifier measurements; for oscillator measurements, the DUT acts as the system's source.

Establishing the reference plane at the DUT presents a problem because the electrical length of couplers is very hard to measure. Instead, an indirect substitution technique must be used. If we connect another network analyzer at the DUT port of our system, we can directly measure the load presented at this plane. The load-pull system can then be matched to this by offsetting electrical lengths in one coupler's arm. Rotation back to the actual device plane can be done now after a conventional electrical length measurement of the device fixture.

Independent tuning of the fundamental frequency and its second harmonic is accomplished by the scheme shown in Figure 2.

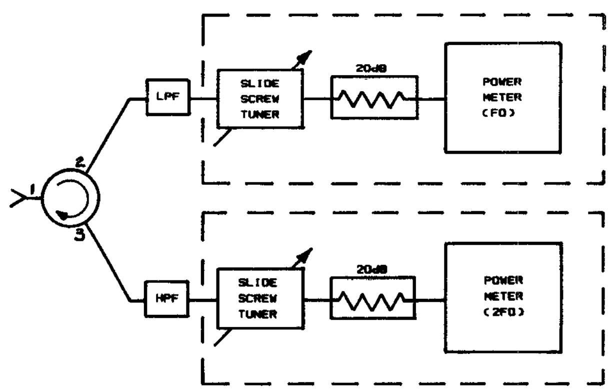

FIGURE 2: FREQUENCY-SELECTIVE TUNER

A signal with harmonics enters port 1 of the circulator. At the second port the portion of this signal which is within the filter passband passes through, is tuned by the tuner, and is reflected back into the circulator. The portion of the signal outside of the passband is totally reflected to the third port of the circulator. At this port a filter with a different passband picks off another portion of the signal for tuning. The signal exiting the first port of the circulator is the composite of the independently tuned fundamental and second harmonic signals. The third and higher order harmonics are presented with roughly 50Ω as the circulator cuts off above the second harmonic, becomes very lossy, and reflects very little signal back to the DUT.

This technique is extendable to n-1 independently tuned harmonic signals with an n-port circulator of sufficient bandwidth and the appropriate bandpass filters. Unfortunately, present circulators are limited to 2:1 bandwidths, hence our constraint to fundamental (fo) and second harmonic (2fo) tuning.

Due to circulator and reflectometer losses, .7 is the maximum load reflection coefficient achievable with metallic slug or slide-screw tuners. To overcome this limitation an active tuner was developed (see Figure 3).

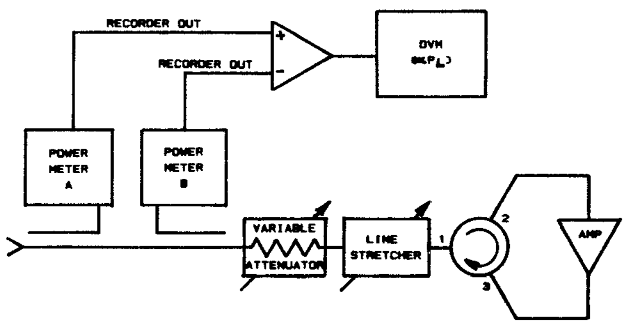

FIGURE 3: ACTIVE TUNER

Power to the load must be measured indirectly in this tuner; this is accomplished by measuring the linear power difference between incident and reflected waves at the entrance to the tuner. Stability of this tuner is guaranteed if the gain of the amplifier is less than the isolation between ports two and three of the circulator and also less than the return loss of the DUT added to the tuner loop insertion loss. High power tube amplifiers are available where the power limitations of this tuner approach are critical.

Data and Discussion

A first application of this system is basic fo and 2fo characterization of a 1x500 μ GaAs MESFET. Figure 4 shows contours of constant fo and 2fo power as a function of the load presented to this device at fo with 2fo tuned to 50Ω. Under these bias and input power conditions the load for peak fo power corresponds almost exactly to the load for minimum 2fo generation. Indeed, even with the device driven several dB into compression, the second harmonic is 33 dB below the fundamental power. Conversely, Figure 4 also demonstrates the utility of this FET as a frequency doubler in that we can extract second harmonic at 0 dB conversion loss if the fo load moves towards a pure inductive reactance.

If fo is matched for maximum fo power output, we can examine the effect of 2fo tuning. Figure 5a shows contours reminiscent of the fo power contours shifted in phase. Figure 5b shows similar contours on the 2fo load plane when fo is tuned for maximum 2fo generation.

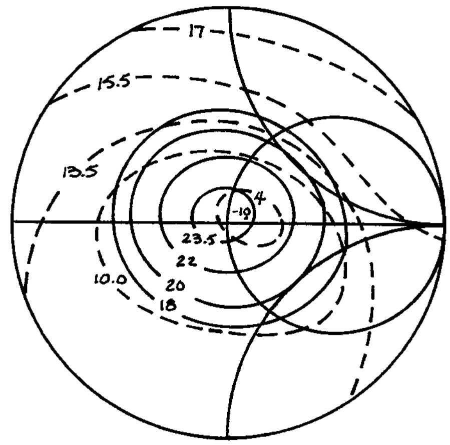

FIGURE 4: MESFET FUNDAMENTAL TUNING
—— fo power ---- 2fo power (dBm)
2fo tuned to 50Ω, Pin = 17 dBm
fo = 6 GHz, Vds = 5V, Vgs = 0V

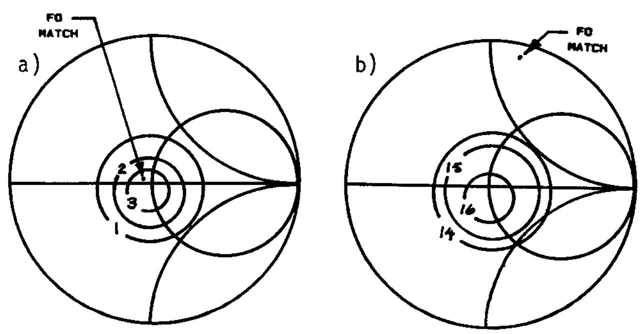

FIGURE 5: SECOND HARMONIC TUNING
2fo power (dBm), same conditions as Figure 4
a: fo at power match
b: fo at doubler match

These are essentially identical. Also, fo power is unaffected by 2fo load. Thus we can conclude that the second harmonic generation mechanisms are totally governed by the fundamental tuning; tuning at the harmonic frequency only affects power transfer out of the FET at that frequency. We also found that 2fo generation is independent of input tuning since the fo and 2fo power tracked the input tuning in the manner expected from mismatch loss considerations.

Given this information and the fact that 2fo generation peaks at an fo load corresponding to an open circuit shifted by the FET conjugate phase, we can conclude that the drain conductance nonlinearity is the predominant second harmonic generator in this MESFET; if it had peaked at a short circuit we could infer that the transconductance nonlinearity predominates.[4] The fact that a 2fo null appears indicates the presence of an opposing nonlinearity. This is the transconductance nonlinearity as the input diode nonlinearity was eliminated by the input's insensitivity to tuning. Also, the extreme bias and power sensitivity we noted in the null location further supports the output conductance as the predominant nonlinearity, as it has the strongest bias dependance of the FET parameters.[5]

Another application of the harmonic system is in oscillator characterization. A 1x500 µ GaAs MESFET is mounted as in Figure 6.

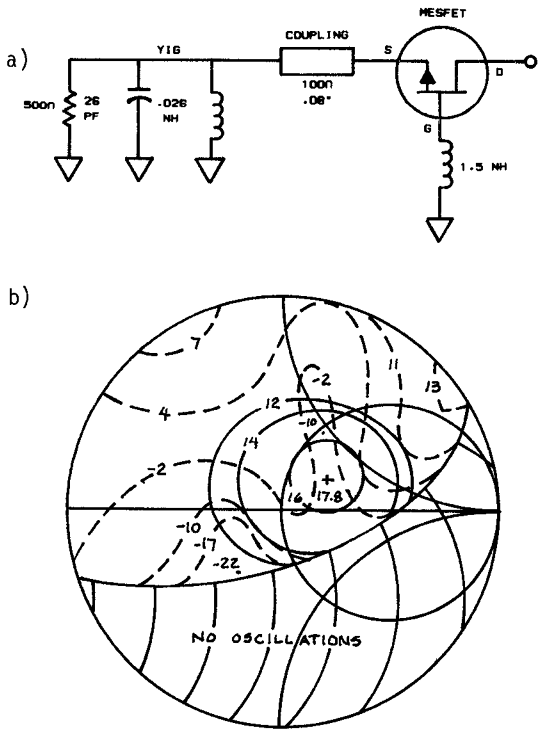

FIGURE 6: a: MESFET YIG Oscillator Configuration
b: Fundamental tuning
—— fo ---- 2fo (dBm)
Vds = 5V, Vgs = 0V, 2fo tuned to 50Ω
YIG tuned to 6 GHz

The fo power contour replicates that of an amplifier up to the boundary of oscillation.[6] 2fo has a pair of nulls; one near maximum fo (16 dBm with -26 dBc at 2fo) and the other near the edge of oscillations (12 dBm with -34 dBc at 2fo). This chart also exposes an interesting YIG oscillator design possibility: with the resonator tuned to 6 GHz, we can directly extract 13 dBm at 12 GHz under the proper load conditions. Hence a high frequency YIG oscillator can be built with a lower frequency magnet structure and the resulting reduced drive requirements.

Conclusion

We have presented a basic load-pull system and some tuning methods which make possible a novel system: harmonic load-pull. Two techniques make this system a reality: the circulator-filter configuration separates the harmonic loads presented to a device into independently tunable entities and the active tuner scheme overcomes circuit losses so reflection coefficients of 1 or greater can be presented to the device under test.

Data has been presented in two areas: First, a basic MESFET load-pull was presented which demonstrates the utility of the technique in low distortion and high distortion (multiplier) amplifier design and, second, the system was applied to oscillator characterization. We believe this technique will be useful in a wide range of future applications.

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