LARGE SIGNAL PULSED NETWORK ANALYZER OPERATION

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ABSTRACT

A new method for measurement of pulsed RF impedance, gain, and phase information is presented. This method provides for direct network analyzer measurement in a pulsed high power environment. Enhanced performance was obtained by making measurements in a low impedance system.

INTRODUCTION

The need for direct impedance, gain, and phase measurements under pulsed RF conditions is quite apparent when one considers how pulsed RF power devices are typically characterized. Previous efforts [1,2] have relied upon indirect measurement (bridge) techniques to obtain RF impedance data, or have required the characterization path to be broken for tuner impedances to be measured, followed by calculations at each frequency. The following measurement system description provides a new and direct means of determining one port impedances (load pull data), two port insertion and reflection (gain and phase) pulsed amplifier data, and the large signal S-parameters under pulsed RF conditions. Furthermore, the measured data is obtained in a low impedance reference system so accuracy is enhanced in addition to providing for the desired behavior of the nonlinear device. The system was originally set up for characterization of pulsed power transistors in the 960 MHz to 1225 MHz band.

MEASUREMENT SYSTEM DESCRIPTION

An HP8505A network analyzer is used to perform the required level and phase comparison measurements. The HP8505A is a phase locked system with a maximum bandwidth of 10 KHz. If one allows an order of magnitude margin for settling time, accurate data will be available 1 mSec. after application of an RF pulse. Since we are interested in short-pulse (pulse width $\leq$ 10 μSec.) characterization, a minimum pulse width of 1 mSec. is unacceptably long. There is a solution to this problem, without resorting to any modification of the 8505A. It is reasonable to expect quasi-static behavior of the device to be characterized, since after the first 100 nSec. (approx.) of each pulse the device behavior has stabilized. So, instead of applying a 1 mSec. pulse, a burst of short pulses is gated for 1 mSec. The burst and overall duty factors can be then set consistent with the device limitations. The bandwidth of the network analyzer is too narrow to allow response to individual pulses, but instead responds to average signal levels across the 1 mSec. burst. Hence, the average signal levels perceived by the network analyzer are down, consistent with the burst duty factor. What is important here is the measured values are unchanged, since each measurement is performed by comparison against a reference signal which is reduced by the same factor. Since an unnecessarily low duty factor (during the pulse burst) limits the system's dynamic range, it should be set near the allowed limits of the device to be characterized.

At the end of the 1 mSec. burst, the data which is available at the rear panel of the 8505A is sampled and held until the next update. This information can be applied to an X-Y plotter. The LED and CRT displays on the 8505A convey the same information when operation is in the "CW+ΔF" mode with ΔF=0 and a marker positioned in the display time when RF is present. Z-axis blanking is applied to the network analyzer to suppress inter-burst noise.

The measurement system has two primary modes of operation. These are detailed in Figures 1 and 2.

Figure 1 illustrates operation of the system for device level characterization of optimum load impedance and corresponding input impedance. Coaxial relays select either the reference path or the device test path of the test fixture. The test fixture is designed to provide a constant impedance transformation. For 960 MHz to 1225 MHz operation, this was done with three impedance stepped (Dolph array)[3] $\lambda/4$ lines. Initially, a short is used to establish the reference plane at the device input (through length l_1). The load is adjusted to optimum and Zin is recorded. When the reference path is viewed, the optimum load impedance is immediately obtained, since the measurement plane and the device output port are both located a distance l_2 from the output port.

Chip level impedances can be obtained by de-embedding[4]. The pulsed network analyzer (PNA) system has been used for chip level data by establishing the measurement plane at the 50 Ω level and deembedding both fixture and package transformations. When viewed through the package parasitics, the chip level impedance data is in close agreement with direct measurement package level data.

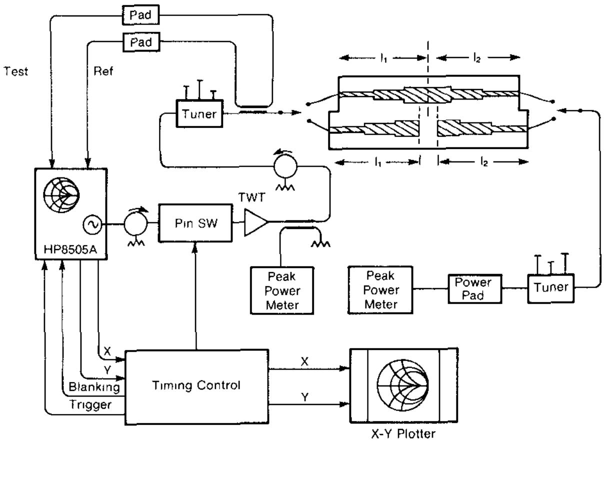

Fig.1 Pulsed Power Device Characterization: Z_{in}, $Z_{l\,opt}$

Operation of the system for pulsed amplifier testing is indicated in Figure 2. Network analyzer corrections of reference, Test A and Test B, are to a_1, b_1, and b_2, respectively. Channel A provides input magnitude and angle information, while insertion gain (magnitude and angle) is obtained from channel B. Peak power meters are used to monitor absolute levels. The group delay of a pulsed amplifier can be determined from incremental phase slope measurements.

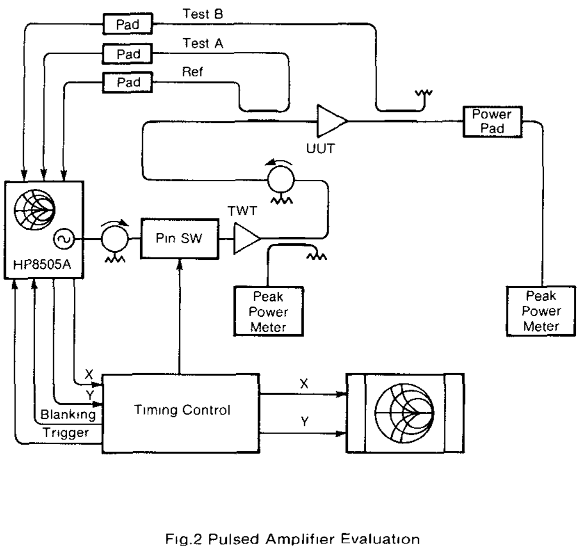

Fig.2 Pulsed Amplifier Evaluation

The pulsed network analyzer system has also been used for large signal S-parameter characterization with the two signal method [5]. To date, this has been the least used configuration since large signal S-parameters are not essential for power amplifier work. Due to the non-linear nature of the device, its behavior can change with changes in interfacing impedance levels. Hence, to be meaningful, the fixture impedance level must be near the intended operating impedance levels. Pulsed large signal S-parameters have been useful for pulsed power oscillator work.

ACCURACY ASSESSMENT

The accuracy of the PNA system is fundamentally set by the accuracy of the HP8505A. Since the effective signal levels viewed by the instrument are down by the duty factor, the accuracy will be slightly reduced from that of a CW measurement at the same peak power level. For example, the dynamic accuracy of the instrument, from -20 dBm to -40 dBm, is ± .01 dB/dB. If we select attenuation, such that the peak level applied to the instrument is -30 dBm, a 10% duty factor will cause the magnitude uncertainty to degrade from ± .1 dB to ± .2 dB. Similarly, the phase uncertainty is degraded from ± .2° to ± 2°. However, these effects are small when compared to the frequency response specifications for the instrument: ± .3 dB and ± 5°.

Clearly, the external accuracy limitations depend upon the test configuration. Source match, directivity errors and tracking errors are the principal error contributors for pulsed amplifier measurements. Note that by employing matched directional couplers, gain tracking errors are canceled (see Fig. 2). For device characterization, directivity errors are the most important. High directivity (40 dB) directional couplers which are matched for frequency tracking have been used here. When viewing a 1 Ω impedance level in a 5 Ω system, a 40 dB directivity coupler contributes up to 5% error. This follows from $|\rho'| = \frac{|\rho| + d}{1-|\rho| d}$, where d is the directivity ratio, $|\rho|$ is the reflection coefficient magnitude and $|\rho'|$ is the apparent reflection coefficient magnitude. Errors in the fixture transformer behavior also contribute directly, when deembedding is not used. Fixture transformation errors should be kept below 3%. If we allow ± .4 dB error contribution from the instrument, the total worst case error for a 1 Ω measurement is 1.2:1 or ± .7 dB. Typical errors are less than this, since the probability of simultaneous worst case contribution from each constituent is quite low.

RESULTS

Figure 3 represents a typical sample of device characterization data which is obtainable with the pulsed network analyzer system. The data was obtained from a 160 w, 25% duty factor common base BJT which was internally matched for the 960 MHz-1215 MHz band. Note that this package interface impedance data was obtained directly in a 5 Ω system. Measured performance from an amplifier, which was designed from the data of Fig. 3, is listed in Table 1. Numerous other pulsed RF power amplifiers have been designed and successfully realized from data obtained with this measurement system.

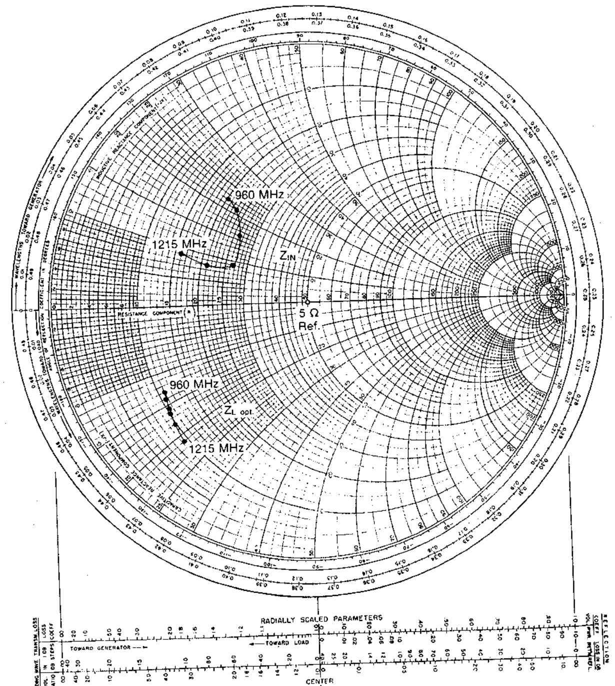

Fig.3 Measured impedances

Table 1 MEASURED AMPLIFIER PERFORMANCE
at Po= 160w, 25% Duty Factor
Statistical Data For Sample of 10 Typical Transistors

Frequency	$\overline{G}$	σ	Gmin	Gmax
960	8.16 dB	.171 dB	7.8 dB	8.4 dB
1090	7.94 dB	.232 dB	7.5 dB	8.3 dB
1215	7.85 dB	.259 dB	7.3 dB	8.2 dB

Frequency	$\overline{\text{Ret. Loss}}$	σ	Ret. Loss min	Ret.Loss max
960	17.39 dB	1.85 dB	15.1 dB	20.6 dB
1090	20.68 dB	1.67 dB	17.7 dB	23.5 dB
1215	20.07 dB	2.20 dB	16.4 dB	23.2 dB

Frequency	$\overline{\eta}$	σ	η min	η max
960	41.84%	2.79%	38.8%	47.8%
1090	40.37%	1.69%	37.4%	42.6%
1215	45.43%	2.92%	42.4%	50.1%

CONCLUSIONS

A new method for obtaining pulsed RF impedance, gain and phase information has been presented. The system provides for direct measurement of the desired parameters, and represents a significant advancement to pulsed RF power characterization methods.

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