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COMPUTER-CORRECTED LOAD-PULL CHARACTERISATION OF POWER MESFET'S

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A versatile system for the load-pull characterisation of power MESFET's is described. Computer-aided vector error correction techniques are used at the input and output of the transistor to provide accurate large-signal measurements of reflection coefficient and RF power.

Introduction

There have been a number of reports in recent years of load-pull measurement techniques for the large-signal characterisation of power transistors[1-4]. It is usual in these measurements for the large-signal reflection coefficient at the input and output of the device under test (DUT) to be determined using manual network analysers. This can seriously limit the accuracy of the reflection coefficient measurements, due to directivity, mismatch and cross-coupling errors associated with the network analyser components. In addition, measurements of the input and output RF power are limited in accuracy either by unknown tuner losses[1,3], or by directivity and mismatch errors[2,4]. For example, variable losses of several dB in a passive tuner have been reported[5]. These losses will cause significant power measurement errors if the output power meter is placed behind the tuner[1,3]. If the power is measured using directional couplers [2,4], errors can be significant when the VSWR is high. With a coupler directivity of 25dB the error in measured RF power can easily reach 1dB. To the authors' knowledge, there have been no reports of computer-aided vector error correction schemes for large-signal load-pull measurements.

This paper describes a new computer-corrected system for load-pull characterisation of power MESFET's. The system provides vector error correction at the input and output of the transistor and enables accurate large-signal measurements both of reflection coefficient and of RF power.

The New System

A block schematic of the new load-pull system is shown in Figure 1. Uncorrected large-signal reflection coefficients at the input and output port of the DUT are monitored using two dual directional couplers and RF network analysers. The signal levels at the inputs of the network analysers are attenuated so that they lie within the safe operating range of the harmonic frequency converters. Part of the signal for each network analyser is coupled into a power meter using a resistive power divider. These power meters monitor the (uncorrected) incident travelling power at each port. Since the input and output reflection coefficients are known, only one power meter is required at each port. The RF input signal is supplied from a signal generator and a travelling wave tube amplifier. Passive tuners are used to provide variable terminations to the DUT, but two-signal methods[2] or active tuning[4] can also be used.

A small computer is interfaced to the various items of hardware as shown. It performs the tasks of error-correction, instrumentation control, data acquisition, processing and storage. The computer outputs a continuously updated display of quantities such as the load reflection coefficient, output power and power added efficiency. This enables the device bias, loading and drive conditions to be optimised for a particular performance objective.

Error Correction

The error correction techniques described here are based on a signal flow graph model of the complete system. Since the dual directional coupler/network analyser/power meter configuration is similar at each port of the DUT, only the output port will be considered here. Results for the input port can be deduced by symmetry.

A detailed signal flow graph model has been obtained for the directional coupler and associated components at the output port. The model includes all sources of error such as coupler directivity, connector mismatch and cross-coupling. This detailed model can be reduced using signal flow graph techniques to the model shown in Figure 2. The only assumption required in this

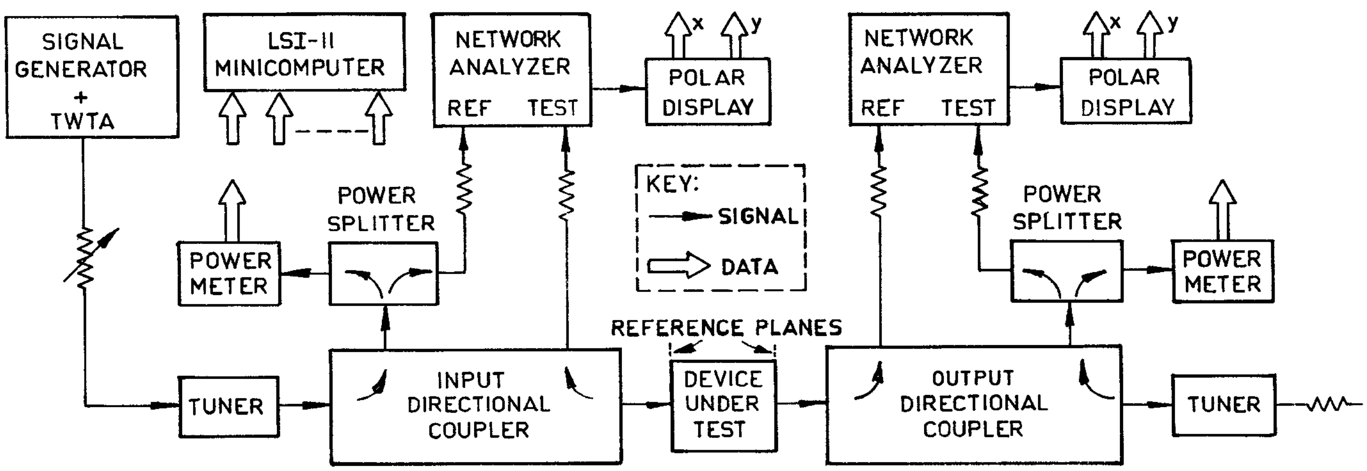

Figure 1: Block Schematic of the New Load-Pull System

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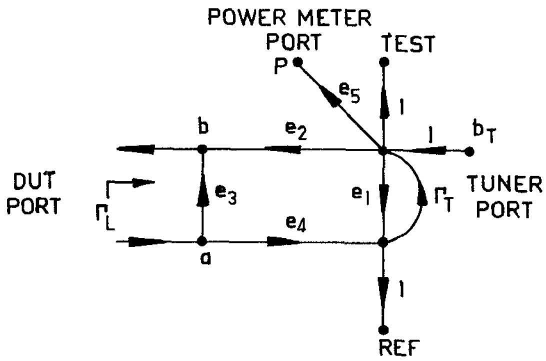

Figure 2: Error Model of the Directional Coupler/Network Analyser/Power Meter

reduction is that the terminations represented by the power sensor head and the reference and test inputs of the harmonic frequency converter are constant with power level. The model in Figure 2 is similar to the error model for one port of an automatic network analyser[6] (ANA). However the reference and test channels of the network analyser are transposed in the new system compared with an ANA. This is necessary to provide a reference signal for the network analyser which does not strongly depend on the tuner setting. Connected in this way, the network analyser gives a direct (but uncorrected) measurement of the load reflection coefficient set by the tuner. The tuner is represented in Figure 2 by the path Γ_T and the node b_T. This is a general form which describes passive, two-signal and active tuners. A passive tuner has a non-zero Γ_T term and zero b_T while two-signal and active tuners have a non-zero b_T.

The relationship between the corrected load reflection coefficient Γ_L and the uncorrected network analyser reading TEST/REF is given by the well-known expression[6]

$$\Gamma_L = e_3 + \frac{e_2 e_4 \text{TEST/REF}}{1 - e_1 \text{TEST/REF}} \qquad (1)$$

An expression can also be derived for the output power. The two travelling waves a and b at the output port of the DUT are related by Γ_L, and the net output power from the DUT is given by $|a|^2 - |b|^2$. Therefore it is sufficient to know the value of either $|a|^2$ or $|b|^2$ in order to determine the output power. An uncorrected measure of $|b|^2$ is obtained with the power meter connected in the test channel of the network analyser as shown in Figure 1. From Figure 2 it is easily shown that the corrected $|b|^2$ is given by

$$|b|^2 = \left|\frac{e_2}{e_5}\right|^2 \frac{|P|^2}{|1 - e_3/\Gamma_L|^2} \qquad (2)$$

where $|P|^2$ is the power meter reading.

This is a useful result since it means that the vector error correction of power and reflection coefficient measurements can be considered in a unified manner using *one* model.

Calibration

The values of the error terms e_1, e_3 and the product $e_2 e_4$ are obtained using conventional ANA calibration techniques[6]. A variety of possible standard terminations can be used. In the system described here, a short circuit, an offset short circuit and an open circuit were used. During calibration an RF signal b_T is injected at the tuner port to provide a reference signal for the network analyser. The standard terminations are connected in turn at the DUT port.

For power measurements, the unified modelling approach used in the new system enables a simple calibration procedure. Most of the information required has already been obtained above. With reference to (2) it can be seen that the only remaining unknown term is $|e_2/e_5|^2$. From Figure 2 it can be seen that with an RF signal b_T injected at the tuner port, the value $|e_2/e_5|^2$ is given by the ratio of $|b|^2$, the power measured at the DUT port, to $|P|^2$, the power measured at the power meter port. Therefore, only two scalar (power) measurements are needed to find the value $|e_2/e_5|^2$. This procedure assumes that the signal contribution from a via paths e_3 and Γ_T remains constant for both power measurements. The most convenient way of achieving this is to ensure that the voltage at a is zero by using a matched power sensor head and by terminating the DUT port in a matched load during the measurement at the power meter port.

For maximum accuracy, the system is initially calibrated at coaxial (APC7) reference planes at the input and output of the DUT. The reference planes can then be easily extended into microstrip using accurate models of the coaxial to microstrip transition[7] cascaded with the model of Figure 2.

The simplicity of the overall calibration procedure and the use of common ANA hardware components means that existing small-signal ANA setups can be extended to include load-pull capabilities. In the prototype system, an interactive computer program was written to perform all the calibration measurements and subsequent processing of measured data. This enables a virtually instantaneous display of the *corrected* RF power levels and reflection coefficients at each port of the DUT.

Results

Examples of measured large-signal data obtained with the new system are shown in Figures 3 and 4. Figure 3 shows the power saturation and power added efficiency characteristics of a DX3615 A device at 8GHz, biased at a drain-source voltage of 8V and a drain-current of 200mA. The input tuner was adjusted to match the input of the device. The characteristics are shown for three different values of load impedance as detailed in the caption. Figure 4 shows a set of computer generated load-pull contours of constant output power and constant power added efficiency for the same device with the same bias and input tuning conditions. The input power level is 125mW. The high accuracy of the measurement system enables the load for maximum output power to be clearly distinguished from the load for maximum power added efficiency.

Conclusions

A new computer-corrected system for the accurate large-signal characterisation of power MESFET's has been presented. Both reflection coefficient and RF power are error corrected using vector methods at each port of the DUT. This is the first reported application of vector error correction techniques to large-signal reflectometer load-pull measurements. A significant feature of the error correction scheme is that it treats the measurement of reflection coefficient and RF power in a unified manner. This enables a simple calibration procedure. The method described here is based on small-signal error correction techniques. Therefore it is possible to upgrade existing small-signal computer-aided measurement systems to include load-pull capabilities.

Acknowledgements

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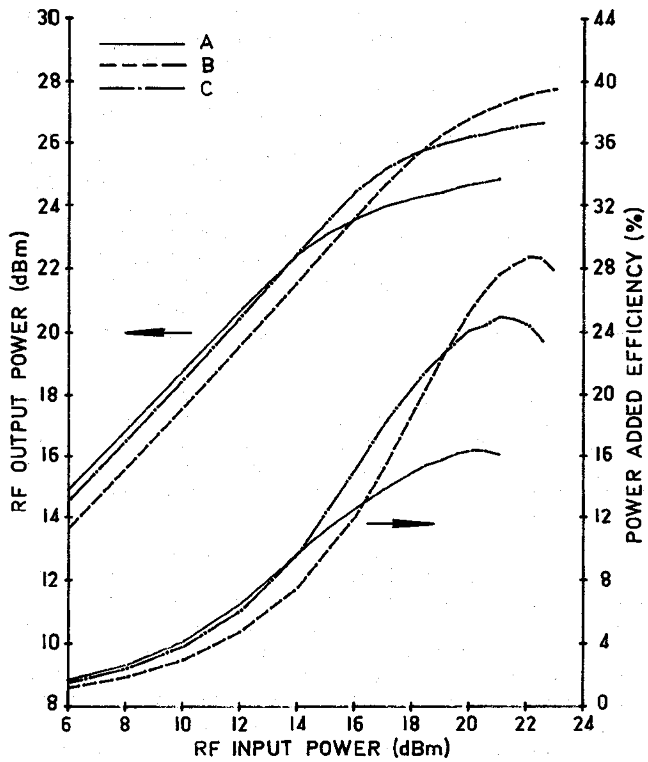

Figure 3: Power saturation and power added efficiency characteristics of a DX3615 A at 8GHz. In curves A, B and C the load was adjusted for maximum gain at input power levels of 6dBm, 23dBm and 17dBm respectively.

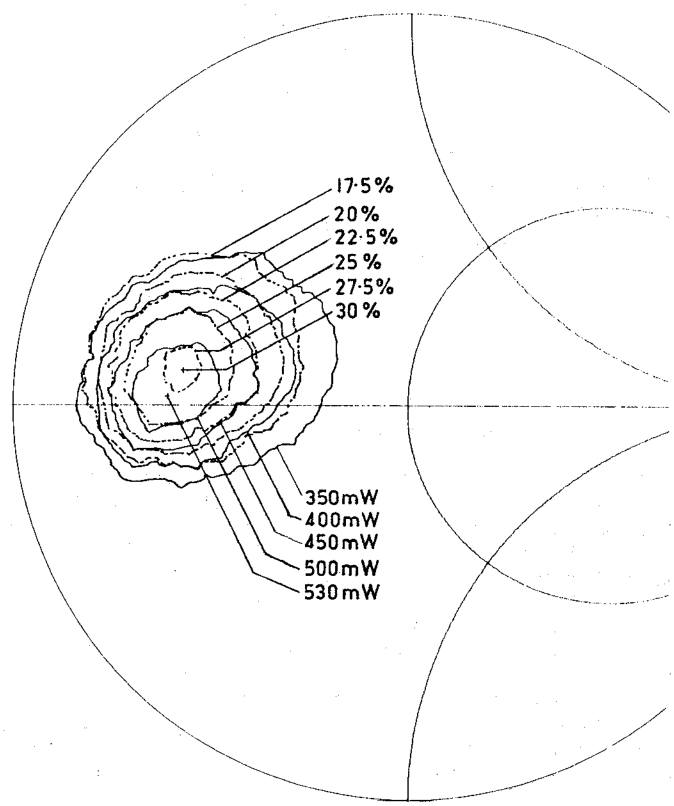

Figure 4: Contours of constant output power (————) and power added efficiency (— — — — —) on the load reflection coefficient plane for the DX3615 A with an input power of 125mW. The chart is normalised to 50Ω.

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