The New Load Pull Characterization Method for Microwave Power Amplifier Design

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Abstract

This Paper reviews and discusses the most important non-linear load-pull techniques used in the design of the power amplifiers. It discusses and elaborates on the proper change in the load-pull configuration required in order to make them optimally useful for an on-wafer device characterization. Finally, the distinct case studies for a device characterization and the Power Amplifier design that utilizes a load-pull system is reported. In this paper, an overview of an actual state of the art in the load-pull techniques along with the emerging trends is presented. In section II, overview of basics load-pull technique for amplifier design is discussed. Section III presents a detailed discussion on the realization of load-pull techniques and their application domain. Section IV discusses common load-pull techniques and Section-V provides PA design case using load pull technique.
Keywords: Semiconductor Device Characterizations, Power Amplifier Design, Active Load-Pull Technique, Passive Load-Pull Technique

I. INTRODUCTION

The Power amplifier in a communication transponder along with the transmit antenna decides the EIRP (Effective Isotropic Radiated Power) of the satellite. With the increased requirement of the higher channel capacity and the better coverage, these days a higher EIRP is required. The Effective Isotropic Radiated Power (EIRP) is available from a communication payload that generally depends upon the antenna gain, the coverage requirements and the output power capability of the RF amplifier present in the downlink channel. The Gain of a transmitting antenna is proportional to its size and larger antennas cannot be accommodated on the payload. So, the power amplifier plays an important role in meeting the EIRP requirement of a satellite. There are two types of power amplifiers used in a transponder viz. Travelling Wave Tube Amplifiers (TWTAs) or Solid State Power Amplifiers (SSPAs). For higher frequencies, generally the TWTAs are employed to do the job however size is a constraint at lower frequencies the Solid State Power Amplifier are used.

The growing application in the wireless communication standards leads to an increased demand from power amplifiers in terms of an efficiency, output power, gain and linearity. The traditional build-and-test Power Amplifier design technique, although precise and reliable, it is not suitable for mass production and also faster time to market simultaneously. Recently, the most important advancement in the nonlinear simulation tools has expedited the Power Amplifier design process but this comes with a serious limitation. The performance of the PAs designed using the model is completely dependent on an accuracy of the device model. The device models which are available within the simulators by device's vendors are strictly suboptimal as until now there have been no generic approaches to develop the nonlinear models of the power transistor devices.

The drawbacks and the limitations of the build-and-test and the model-based design approaches therefore the necessity of an alternative design process which incorporates the positive aspects of the techniques but at the same time overcomes the limitations. The load-pull based Power Amplifier design technique provides good performance metrics and faster time to-market considering that the design is fully based on a real time measurement data. In addition, the load-pull measurement data also provides the development of nonlinear transistor models for any specific application. Therefore the load-pull technique plays a dual role, it aids in the design of high performance PAs and highly efficient harmonically tuned PAs and/or switching mode PAs , it also helps in generating data for the development of nonlinear transistor models for measurement based models or polynomial based models .

II. BASICS OF LOAD-PULL TECHNIQUE

The non-linear effects refer to the distortion of the signal waveform which is caused by the limiting behavior of a transistor. As the power amplifiers are operated at or beyond 1 dB compression point, the cut off and the clipping behavior of the transistors become stronger, and hence an amplifier becomes more non-linear. The design of the power amplifier often demands for the two contradictory requirements of an efficiency and a linearity. While the efficiency translates into the longer battery life in the payload, the linearity is required to maintain signal integrity. In a linear power amplifier design, the device is presented with the power match that extracts the maximum power from the device. Figure 1 represents the compression characteristics for the conjugate matched and the power matched device.

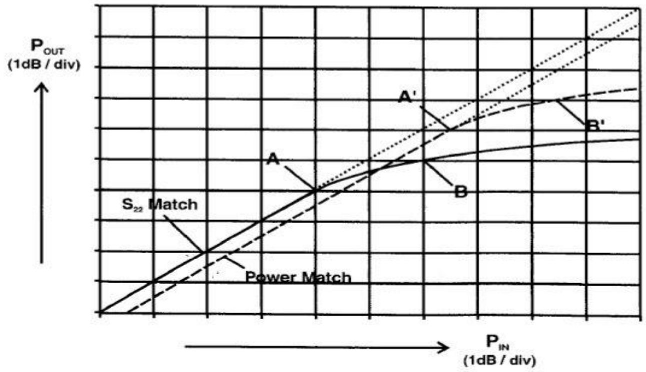

Fig. 1: Compression characteristics of conjugate match (solid-curve) and power match (dashed-curve)

It can be observed from a figure that the low signal gain is smaller for the power matched device than that for the conjugate matched device. However, it can also be observed that the 1 dB compression point for a conjugate matched amplifier reaches earlier than for a power matched device. The power matched device is able to deliver more power than the conjugate matched device. Therefore, it is in the view of this response that the load pull technique is used. Load pull technique does the job of finding a suitable power match for the device. The input is fixed and the load is varied so that an optimum termination can be found out. The delivered power, the power added efficiency (PAE) and the IMD figure are normally the parameters of interest. As the load termination is varied, the measure of these parameters is tabulated. The contours of a delivered power, PAE and IMD are then plotted on a Smith Chart. The intersection of these contours indicates the best termination meeting of all these requirements or at least making the best compromise between them.

III. REALIZATION OF LOAD PULL TECHNIQUE

Load-Pull is a system that enables a synthesis of varying impedance environments at an output port of the device under test (DUT) in some applications where the transistor device performance needs to be experimentally determined in the specific systematic manner. In other words, the load-pull refers specifically to presenting a priori known impedance to the DUT in a precisely controlled form in order to extract optimal performance from a DUT. In the context of PA's design, the best loading conditions depend on the distortions and the nonlinearity exhibited by the DUT. These loading conditions are quite different from the linear case, where the optimum loading conditions are directly identified from the S-parameters. The load-pull systems aid in the identification of the optimum loading conditions experimentally, while the physically changing load reflection coefficient, ΓL, as shown in Fig. 2, for the extraction of the design parameters, such as the output power, the DC to RF power conversion efficiency η, the operating power, the gain and gain compression, the power-added efficiency from transistor device .Thus it can be concluded that the load pull system or the technique allow the analysis of active device performance under the varying conditions and leading to the design of matching circuits.

The desired matching impedance, ZL, and the incident & the reflected traveling waves, a2 and b2, at the output port and the reflection coefficient, ΓL, are related by the following relationships:

$$\Gamma_L = \frac{a_2}{b_2}$$

$$\Gamma_L = \frac{Z_L - Z_0}{Z_L + Z_0}$$

Where Z0 is the characteristic impedance of the system in which the DUT is going to be used where Z0 is normally 50Ω.

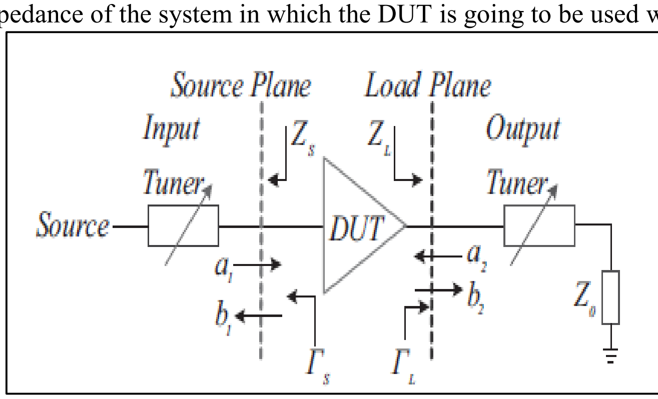

Fig. 2: The depiction of the reflection coefficients at the load and source ports

Essentially the load-pull system consists of a load-tuner, an active or a passive and the controlling mechanism precisely sets the tuner impedance to achieve desired impedance.

IV. COMMON LOAD-PULL TECHNIQUES

Primarily the load-pull techniques can be bracketed under either the passive or the active load-pull.

A. Passive Load-Pull Technique

In passive technique, the required impedance is scanned by varying the reflection coefficient of impedance controlling Element as shown in Fig. 3.

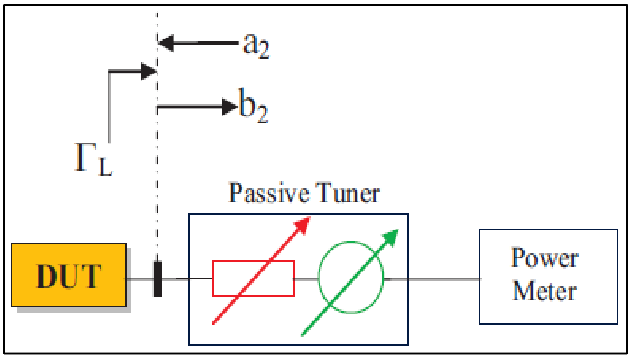

Fig. 3: The basic representation of passive load-pull technique

In this case the reflection coefficient is varied by tuning of its phase and the amplitude with the help of the passive tuner. The main advantages of this passive techniques are: (i) The fast impedance synthesis, (ii) The relatively high power handling capability and the measurements of the high power devices without any of the non-linear effect, (iii) the ease of usage, (iv) low maintenance cost, and (v) the relatively low implementation cost and absence of any of oscillation. The main disadvantage of this technique is the limitation of a synthesized impedances in term of magnitude of the associated reflection coefficients. The state of the art passive load-pull structures are able to the synthesize reflection coefficient of the order of 0.95 in magnitudes, but the prices of such systems are extremely so much high. The passive load-pull structure, with the reasonable price, can be typically synthesized the reflection coefficient with the magnitude of 0.85. The limitation becomes critical in the case of the device that requires load impedances near the edge of a Smith chart, such as for the characterization of high power transistor devices.

B. Active Load-pull Technique

To overcome the limitation in the above case, many load-pull systems based on the active structures have been proposed in the literature. Active load-pull systems consist of either the active open loop or the active closed loop architectures. In both the techniques, the reflection coefficient is synthesized at the DUT access plane by injecting a signal. In principle it can be done by controlling the complex gain around the active structure.

C. Active Open Loop Load pull Technique

In the case of active open loop technique, as shown in Fig. 4, the reflection coefficient, ΓL, presented to the DUT access, is synthesized by controlling and varying the attenuator ATT and phase-shifter DEPHr to fix the magnitude and the phase of a travelling wave a2. so, the synthesized reflection coefficient depends on the ATT, DEPH and the delivered power of a RF generator. Due to this reason in the case of power sweep or during the load-pull procedure, the custom algorithms are needed to synthesize a given ΓL since the travelling wave, b2, is not constant.

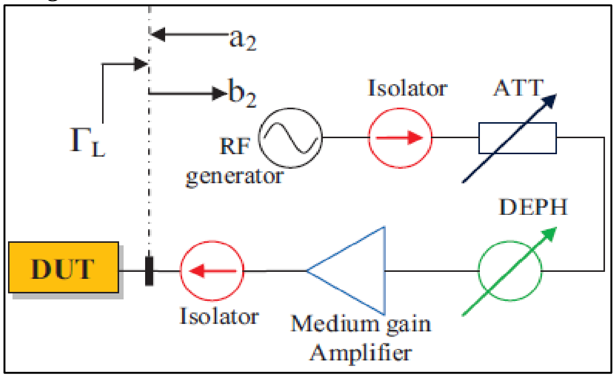

Fig. 4: The generic setup architecture of active open-loop technique

D. Active Closed loop Load pull Technique

In this case the synthesized reflection coefficient, ΓL, depends on the loop parameters, such as, an amplifier gain, an attenuator and a phase-shifter values as shown in fig.5. The main disadvantages of this structure are the risk of the oscillations that can happen since a closed loop structure is used, and a necessity of the use of a high linearity and high gain amplifier in the loop path. The incorporation of the highly selective filter in the loop solves the oscillation problem to some extent.

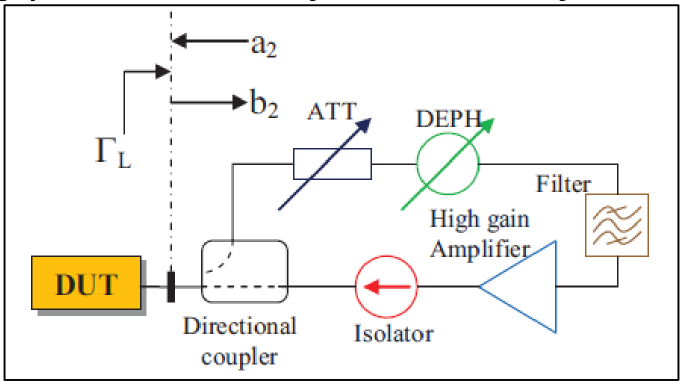

Fig. 5: The generic setup architecture of active closed-loop technique

V. PA DESIGN AND SIMULATION USING LOAD PULL TECHNIQUE

The Load pull technique is the modeling technique, done in the simulation environment with the help of the non-linear device model and using Harmonic balance simulator. It is used for the power amplifier design to get the maximum delivered power as a function of load impedance. So it has been used to find out an optimum load impedance needed to get the required output power from a device. Load impedance is varied using the load tuner over the wide range of values specified by the load tuner coverage area. The Power added efficiency (PAE) and the delivered power are calculated over all these values of load impedances and the load-pull contours for PAE and delivered power. The plot of PAE and the delivered power are drawn simultaneously because both are important parameter for the high power amplifier design.

We are considering one example of power amplifier design using Load pull technique. The Power Amplifier is designed to deliver minimum 12watt output power with 37% efficiency at operating Vds of 9V at C-band. It provides the output power of 40.8dBm from the input power of 32.7 dBm. Source impedance at the input side of the device is chosen to get a maximum gain at that particular output power.

To find the power match for the device load pull technique is used. ADS provides the equation based S parameter block which can provide the different values of the reflection coefficients. This S parameter block is used as the load tuner which means that depending upon that selected S parameter value, it provides the different loads to the circuit. The simulated values of these reflection coefficients can thus be called as the load reflection coefficients. The optimum load, which can provide the desired output power and the power added efficiency, is found by a coarse tuning of the load termination. After this, the load tuner is made to provide the different loads in proximity of an optimum load using this S parameter block. The output power and the Power Added Efficiency for all these loads are further calculated. These values can then be used to draw the contours using the inbuilt functions in ADS. The Plot illustrated in Fig. 6, represents the surface samples of all the load reflection coefficients with the values of Load Impedance, PAE and Delivered Power at each sample point. This gives the precise load impedance value for the required output power of 42 dBm with 37.60 % PAE.

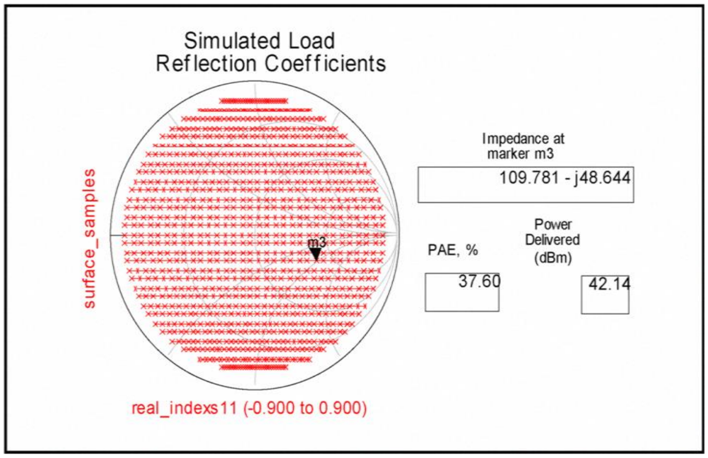

Fig. 6: Simulated Load Reflection Coefficients

The Source and load impedances are then transformed to the input and output termination impedances respectively which is 50 Ohm.

VI. CONCLUSION

In this paper we reviewed and discussed common load-pull techniques and systems used in the design of PAs. The onwafer devices require special care and it has been highlighted in this paper. An example of amplifier design using load pull technique is also represented. this design is presented to show the usefulness of load-pull techniques.

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