RESEARCH NOTE

NONLINEAR ANALYSIS OF A POWER AMPLIFIER IN C BAND AND LOAD-PULL TECHNIQUE CALCULATION USING VOLTERRA SERIES

K. Mafi-Nejad and A Pourzaki

Department of Electrical Engineering, Ferdowsi University of Mashhad
Mashhad, Iran, kh-mafi@yahoo.com - a_pourzaki@yahoo.com

M. Kalantari

Department of Communications, Khaje Nasiroddine Tousi University
Tehran, Iran, kalantar@eetd.kntu.ir

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Abstract In recent years, nonlinear circuit analysis techniques have been extensively investigated. One of the most important reasons is the application development of solid-state devices at microwave frequencies. Different methods have been used to analysis large signal behavior of these devices. In this paper load-pull curves (one of design requirement) are obtained using Volterra series. The main advantage of this technique is shortening the time of computations for weak nonlinear analysis in cases such as Class A power amplifiers. The proposed procedure has been coded in MATLAB. Using iterative methods, loads with constant output power have been obtained. Finally the results are compared to experimentally measured values and a fair degree of calculation between them is observed.

Key Words Volterra Series, Nonlinear Analysis, Power Amplifier, and Load-Pull.

چکیده در سالیان اخیر توجهٔ بیشتری به موضوع تحلیل مدارات غیرخطی می‌شود که یکی از مهمترین علل آن کاربرد قطعات حالت جامد در فرکانسهای مایکروویو است. تحلیل این عناصر در سیگنال بزرگ به روشهای مختلفی صورت می‌گیرد. در این مقاله منحنی های load-pull (یکی از ملزومات طراحی) به کمک سری ولترا بدست می‌آیند. علت استفاده از سری ولترا مزیت آن در کم شدن زمان محاسبات برای تحلیل مدارهای غیرخطی ضعیف مانند تقویت‌کننده‌های قدرت کلاس A است. در محاسبات تحلیل مدار از نرم افزار Matlab استفاده شده است و به کمک روشهای تکرار بارهایی که به ازای تطبیق ورودی توان خروجی ثابتی را نتیجه می‌دهد، بدست آورده شده است. در انتها نتایج محاسبات با مقادیر اندازه گیری شده مقایسه شده و نزدیکی خوبی بین نتایج مشاهده می‌شود.

1. INTRODUCTION

For years, nonlinear circuits have been an attractive and popular topic for researchers, as clearly shown by the large number of related technical papers [1]. The main reason for this increasing popularity is the advances of solid-state circuits in microwave frequencies.

The design of power amplifier matching circuit (one of the main tasks of the designer) requires the information about transistor input and output impedance in large signal behavior [2]. To access the input or output impedance of nonlinear circuits, measurement techniques such as "load-pull"[7] are used. In this method special characteristic of power amplifier is obtained by load value changing (both amplitude and phase of load). Another kind of load-pull methods is using dummy load where a second signal is injected at the output instead of variation of the amplitude and phase of the load. In this method, signals with the same frequency but different in magnitude and phase are injected to the output. However, if a precise and complete large signal model of transistor is accessible, there is no need for excessive time and costly measurements.

Previously, harmonic balance method has been used in load-pull curve simulation [3]. In this paper load-pull curves are obtained using Volterra series. The main advantage of this technique is its computational speed for analyzing weak nonlinear circuits such as Class A power amplifiers. Lack of need for any iterative approach is another advantage of this method. In addition, maximum output power of the power amplifier will be obtained using Volterra series.

In this paper a review of nonlinear analysis methods is first presented. Then calculated and measured load pull curves are compared. In this paper RTC-126 BJT transistor has been used. The frequency band is C (3.7-4.2GHz), which is used in satellite telecommunication systems

2. NONLINEAR ANALYSIS METHODS

Generally, power amplifiers are nonlinear circuits. To analyze a nonlinear circuit it is separated into two linear and nonlinear subcircuits.
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2.1 Time Domain Methods In this method both linear and nonlinear subcircuits are analyzed in time domain. The advantage of time domain analysis is that semiconductor devices are usually described in time domain. However, such methods generally suffer from a major drawback, i.e. numerical efficiency. The analysis based on time domain equations would typically spend most of its computational effort on transient state evaluation, while most of the user's interest is concentrated on steady state information. An example of a computer aided analysis technique using this approach is the popular software SPICE[4].

2.2 Frequency Domain Methods In this method both linear and nonlinear subcircuits are analyzed in frequency domain. Hence, with increasing reactive elements, analysis will not be complicated. Frequency domain methods do not suffer from the limitation of harmonic balance. That is, both linear and nonlinear subcircuits are analyzed in the frequency domain so that the time consuming transformation between frequency and time domains are avoided and the number of independent frequencies is not limited.

However, modeling of nonlinear devices is the weakest point of the frequency domain approach. Because nonlinear components are traditionally modeled in the time domain by using algebraic equations to describe the nonlinear effects. Such a model can easily be converted to the frequency domain by polynomial expansions. But, approximation of strongly nonlinear functions with power series requires a large number of terms in the series, which excessively extend computational time. So this procedure is restricted to relatively weak nonlinear circuits. One of the most widely used frequency domain methods is "Volterra series" method that "Electronic WorkBench" software uses this approach.

2.2 Hybrid Methods In hybrid methods linear and nonlinear subcircuits are analyzed in frequency and time domain respectively. Steady state conditions of this approach are determined directly (with respect to time domain) [5]. The well known "harmonic balance" method is in this group.

Harmonic balance simplifies nonlinear circuit analysis to a nonlinear algebra system. In this method, discrete Fourier transform is used to transform a linear frequency domain solution to a nonlinear time domain solution and vise versa. Discrete Fourier transform, DFT,[6] may cause errors that reduce the accuracy. APLAC software uses harmonic balance in nonlinear circuit analysis.

Harmonic balance methods have been matured in analysis of nonlinear microwave circuits. However, when the circuit has several excitation frequencies, the analysis becomes impractical due to the long computation time. Even with only two independent tones, the analysis may be very slow.

In 1910 Volterra introduced functional expansion that could be used with a large class of nonlinear systems [7]. Weiner further developed his work in 1950's for the expansion of functions in term of orthogonal polynomial series. Weiner's functional expansions, is now known as Volterra nonlinear transfer functions [8]. It can handle frequency dependent systems with single valued input-output characteristics. Unfortunately, Volterra nonlinear transfer function analysis is, in general, restricted to weakly nonlinear systems. This is caused by the algebraic complexity of determining high order Volterra nonlinear transfer functions (as required by strongly nonlinear systems or large signals). Because of this, systems are described by typically third order Volterra series. Lack of need for any iterative approach is another advantage of this method.

In summary, if one is interested in transient response, a time domain method is suggested. But if circuit is driven by a periodic signal and only we are considered with the harmonics contend, harmonic balance method is more effective. Finally, for the weak nonlinear circuits, if the applied signals are not harmonically related, Volterra series method is the most effective technique.

3. LOAD-PULL METHOD IMPLEMENTATION USING VOLTERRA SERIES

Practically, one can access output impedance of large signal nonlinear circuit such as power amplifiers in different approaches. One of these methods is the load pull method where graphical representation of circuit characteristic parameters such as gain, efficiency, intermodulation and output power versus source and/or load impedance is observed. In this method different load impedances applied to the DUT (Devise Under Test), The device characteristic at any point is measured and pointed out on Smith Chart. So one can easily view areas of load that have special characteristics. However, without suitable instruments, the error may be too high and takes a long time. Generally amplifier behavior investigation on load tolerance (load-pull) using measurement, require a lot of time and experimental cost.

In this paper load-pull method is realized using Volterra series by MATLAB. Transistor nonlinear behavior is modeled by five nonlinear elements as can be seen in Figure 1. In Volterra series analyzing each nonlinear element should be described by a nonlinear current source, which describes nonlinear current element in the power series and via voltage(s) of circuit nodes.

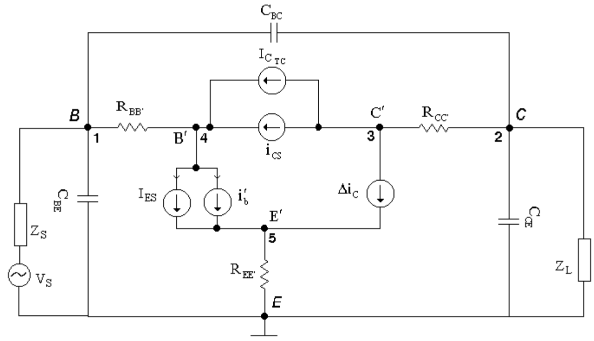

Figure 1. Nonlinear transistor model with source and load impedances.

TABLE 1. Calculated and Measured Results Comparisons at 4GHz.

	$P_{out(max)}$	Load (in $P_{out(max)}$)
Calculated	427mw	3.5-j16□
Measured	415mw	5.5-j18□

One of the measurement load-pull methods is using dummy load where a second signal is injected at the output instead of variation of the amplitude and phase of the load.. In this method, signals with the same frequency but different in magnitude and phase are injected to the output. In this paper this measurement system result is used [9].

In Table 1 at 4GHz frequency, available powers for RTC-126 transistor that is accepted from calculation and from measurement are compared (permitted from [9]). Calculated output power is 427 mw and measurement result is 415 mw. The error is less than %3. In this table, optimum load impedance is also shown for maximum power. This load determines the output matching element values. In this situation maximum output is given to real load (usually 50Ω). In Figures 2 and 3 calculated and measured load-pull curves in 250mw and 350mw output powers are compared.

4. CONCLUSION

By varying output and input impedance in large

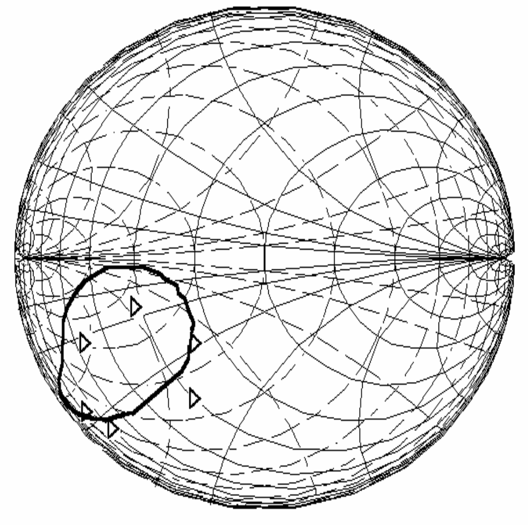

Figure 2. Load-pull curves at 4 GHz and in 250 mw: Calculated: ____ Measured: Δ Δ Δ (permitting from [5]).

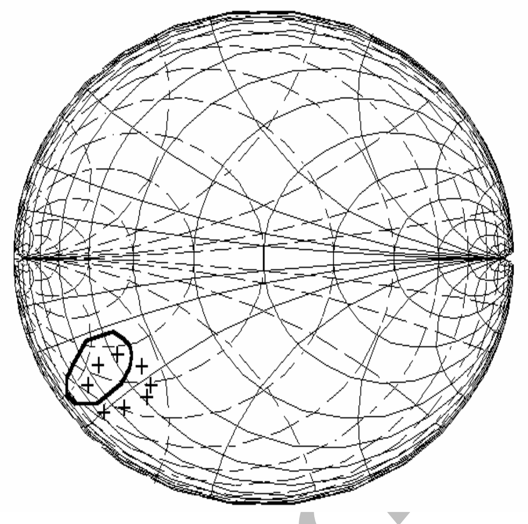

Figure 3. Load-pull curves at 4 GHz and in 350 mw: Calculated: ____ Measured: +++ (permitting from [5]).

signal conditions we can obtain optimum load for maximum output power. This approach needs a lot of measurement effort and hence costly measurement instruments. In practise, a dummy load is used in which a second signal is injected at the output instead of variation of the load. This approach needs less time but requires precise measurement instrument and test line.

In this paper load-pull curves using Volterra series is obtained. This method is analyzed in MATLAB. Using iterative methods loads are obtained that lead to constant output power and have been showed on Smith chart (load-pull curves). Beside this work, maximum output power of transistor is obtained (table 1). As has been shown, using nonlinear analysis of transistor output power is available with satisfactory and low output error (less than %3), so maximum output power of transistor with adequate precision by using Volterra series is accessible.

Use of this method is recommended where the designer is restricted to control and depressing harmonics and intermodulation in power amplifier output.

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