OPTIMIZED C.A.D. OF POWER AMPLIFIERS, FOR MAXIMUM ADDED POWER OR MINIMUM THIRD ORDER INTERMODULATION, USING AN OPTIMIZATION SOFTWARE COUPLED TO A SINGLE TONE SOURCE AND LOAD-PULL SET-UP

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ABSTRACT

An automatic symmetrical source and load pull single tone set up is described. It allows the definition of optimum parameters such as input power, impedances to be presented at each port of the F.E.T., so as to obtain maximum added power. After suitable processing of the date file it is possible to optimize the same parameters in order to minimize the third order intermodulation products.

INTRODUCTION

One of the major problems encountered by communication systems designers is the determination of the optimum operating-conditions for power transistors in terms of added power and third order intermodulation. Using the narrow bandwith approximation, we will show that the optimization of these two features can be made with a symmetrical source and load-pull single tone measurement set-up coupled to an appropriate optimization software routine.

In the first part of this paper we will describe the particular characteristics of the measurement system that we have designed and built.

The three key points are the following :

* The set-up has a completely symmetrical topology (allowing simultaneous active source and load-pull).

* The device under test is loaded by 50 ohms at the harmonic frequencies.

* Finally, a rigorous calibration procedure has been implemented and validated at low power levels by comparison with an HP 8510 network analyzer.

In the second part of this paper, the data acquisition software will be described, and large signal experimental results will be given for a typical transistor.

In the third part, using the narrow bandwidth approximation we will show how the data file may be processed to calculate and optimize third order intermodulation [1].

This set-up has shown itself to be a good general tool for automatic design of optimized power amplifiers.

SOURCE AND LOAD-PULL MEASUREMENT METHOD

1) Principle of the method

The proposed computer-aided single tone measurement system, is based on a symmetrical active source and load-pull technique. It is an extension of TAKAYAMA's method [2] [3].

The non-linear fundamental frequency behaviour of an active two-port device is described figure 1.

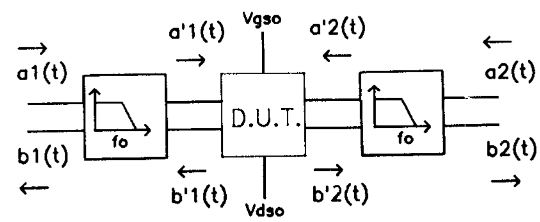

FIGURE 1

For given frequency and bias voltages, let us consider two incident waves : $a1(t)=A1\cos(2\pi fot)$ and $a2(t)=A2\cos(2\pi fot+phi)$ each driving one port of the device. The expressions for the reflected waves may be written as :

$b'1(t) = F[a'1(t), a'2(t)]$

$b'2(t) = G[a'1(t), a'2(t)]$

Where F and G are non-linear time-domain functions, which may be expressed in terms of a FOURIER series expansion.

If harmonic frequency components are filtered, we obtain the fundamental frequency reflected-waves in the external reference planes as :

$b1(t) = B11 \cos(2\pi fot+\theta 11)$

$b2(t) = B21 \cos(2\pi fot+\theta 21)$

Now B11, B21, θ11, θ21 are non-linear functions of A1, A2, phi.

Varying the independent variables : fo, vgso, vdso, A1, A2, phi, a file containing the corresponding values of B11, B21, θ11, θ21 is built. The set of variables (fo, vgso, vdso, A1, A2, phi, B11, B21, θ11, θ21) fully characterize the non-linear active device at the fundamental frequency.

2) Automatic symmetrical measurement system

The bock diagram of the computer-aided source and load-pull system is given figure 2.

A high level signal, provided by the TWT, is divided into two signals at the same frequency which drive each port of the device under test. The power levels of the two incident waves and the phase shift between these two waves are controlled with two variable attenuators and a phase shifter.

The heart of the measurement system is composed of two bidirectional couplers, switches, filters (presenting the characteristic impedance (R0=50 ohms) to the harmonic components of the reflected waves) and a network analyzer (HP 8410-8411). In fact, only the first two harmonic frequencies are loaded by 50 ohms because of the

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limited bandwidth of the isolators used.

Once the calibration is achieved, large signal measurements may be performed. Adjustments of the attenuators and the phase shifter are automatically controlled by the software.

The input and output powers are calculated "in situ". Once the maximum added power is reached, corresponding parameters are extracted. Figure 3 shows experimental results for a typical transistor. These results have been validated by practical fabrication of amplifiers loaded at each frequency by the predicted values.

3) Associated software

A great number of measurement points is necessary to fully characterize a non-linear FET. This led us to conceive a completely automatic set-up and high level routines which select the zones where the FET has an active behaviour in order to reduce the number of measurement points (figure 4.)

The data file contains experimental values of the different complex waves : A1, A2, B1, B2.

Finally the processing of this data file will give optimum parameters for any desired objective (figure 3).

EXTENSION TO THE ANALYSIS OF THE INTERMODULATION

1) Mathematical model

Let us consider a non-linear two port driven by an input wave :

$$e(t) = E\cos(wt) = \mathrm{Re}(E\exp(jwt))$$

Assuming the classical narrow bandwidth approximation, the output can be written in terms of a complex envelope gain function [4] [5].

(1) $s(t)=\mathrm{Re}(S(E)\exp(jwt+\theta(E))=\mathrm{Re}(F(E)\exp(jwt))$

$G(E)=F(E)/E=(S(E)\exp(j\theta(E)))/E$ is the complex gain which takes into account combined effects of amplitude non-linearity and AM-PM conversion.

From a file containing experimental values (Ei, Si, θi), the complex gain G(E) may be approximated by a polynomial expansion.

(2) $$G(E) = \sum_{n=1}^{n=\infty} A_{2n-1}(E)^{2n-1}$$

where A_{2n-1} are unknown complex coefficients to fit :

$$A_{2n-1} = X_{2n-1} + j\,Y_{2n-1}$$

2) Application to the analysis of third order intermodulation

For two carriers with identical level the input signal can be written as follows :

(3) $e(t) : E(\cos(w1t+\theta 1)+\cos(w2t+\theta 2))$

If we put :

$w1=w0+dw$; $w2=w0-dw$; $\theta 1=\theta+d\theta$; $\theta 2=\theta-d\theta$; $dw<<w0$

Using trigonometrical relationships, one can write:

(4) $e(t)=\mathrm{Re}(2E\cos(dwt+d\theta).\exp(j(w0t+\theta)))$

This input signal appears as a single level modulated carrier. According to equation (1), the response s(t) is :

(5) $s(t)=\mathrm{Re}(F(2E.\cos(dw+d\theta)).\exp(j(wt+\theta)))$

$F(2E\cos(dwt+d0))$ is a periodic function and therefore, can be written in terms of a FOURIER series expansion. After calculations s(t) can be written in the following form :

(6) $s(t)=\mathrm{Re}(C1(\exp(jw1t+\theta 1)+\exp(jw2t+\theta 2))$
$-C3(\exp(j(2w1-w2)t+(2\theta 1-\theta 2))+\exp((j2w2-w1)t+(2\theta 2-\theta 1)))+..)$

Fundamental and third order intermodulation output powers are defined as :

$$Pout(w1)=Pout(w2)=10\log(|C1|)^2$$

$$Pout(2w1-w2)=Pout(2w2-w1)=10\log(|C3|)^2$$

The third order intermodulation may be defined as :

$$IM3 = 20\,\mathrm{Log}\,(|C3/C1|)$$

From the load-pull data, constant added power contours may be drawn on a Smith chart diagram.

For every constant added power contour, the optimized output impedance point corresponding to the minimum third order intermodulation may be calculated using the narrow bandwidth approximation.

Joining these points we get a graphical representation of optimized output impedance locus for minimum IM3 as a function of added power.

Note that this optimization is generally interesting in the neighbourhood of the maximum added power locus. Detailed calculations will be given in the final paper.

CONCLUSION

In this paper an original automatic source and load-pull set-up has been presented.

We have shown how to optimize added power and third order intermodulation for field effect transistors.

So this set-up coupled to an appropriate optimization software is a good general tool for radio-communication amplifier design. This method may be extended to the millimeter wave domain.

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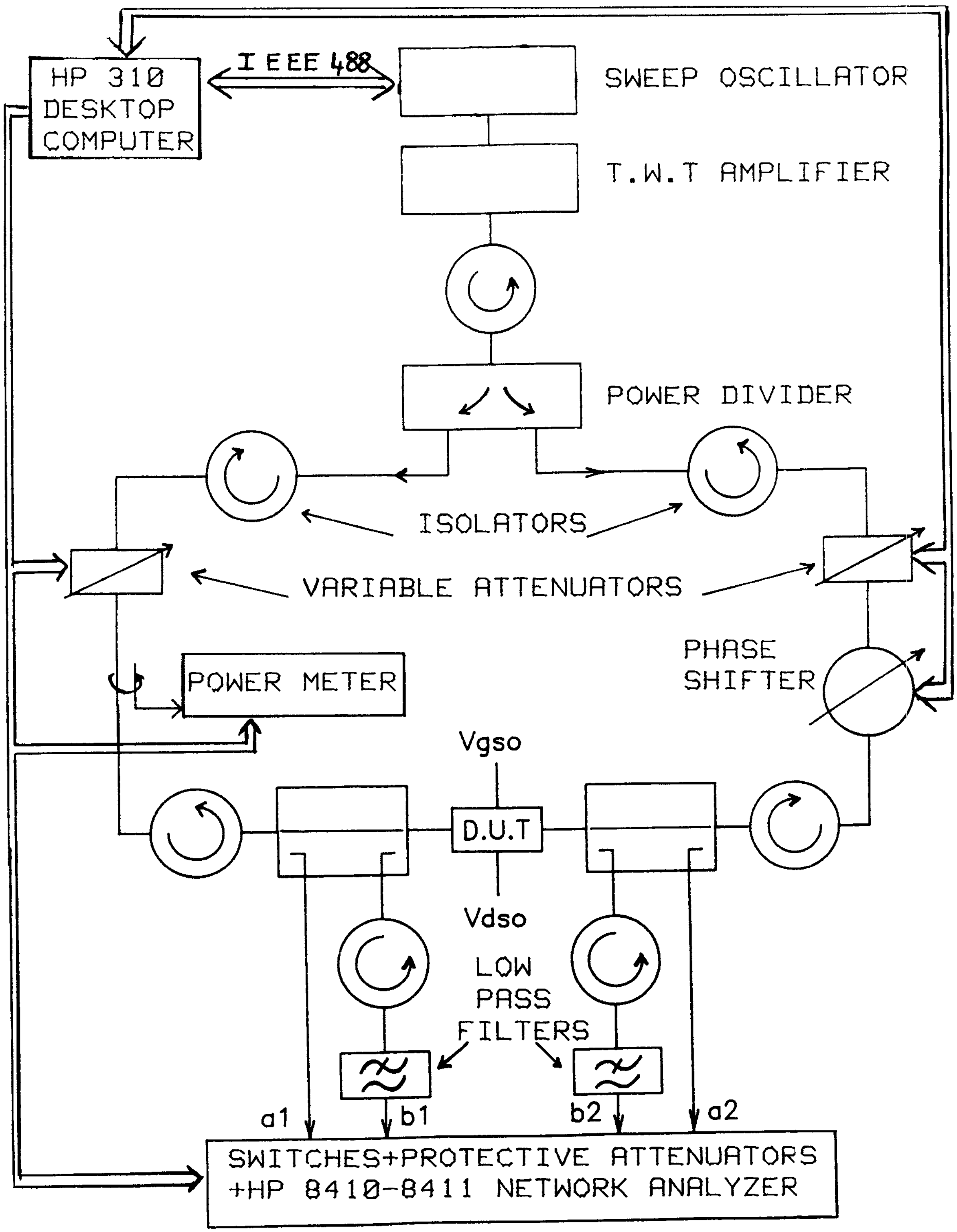

SOURCE AND LOAD-PULL MEASUREMENT SET-UP
FIGURE 2

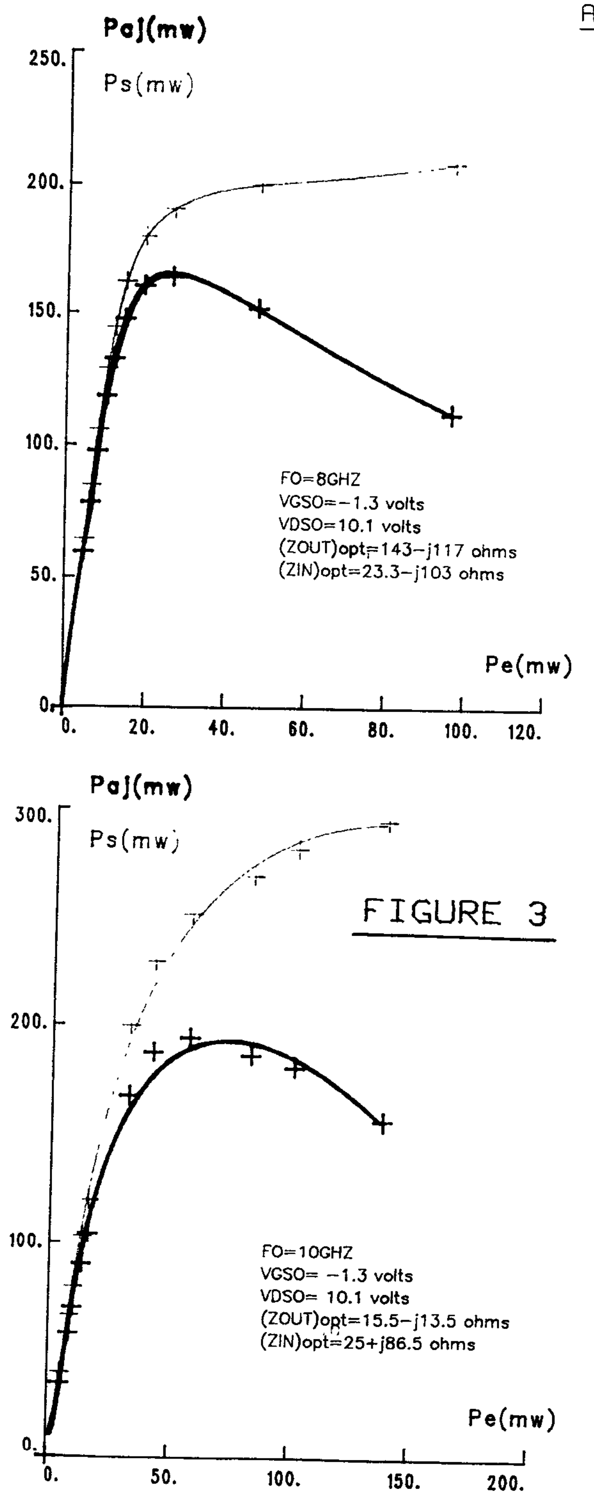

FIGURE 3

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AUTOMATED MEASUREMENT PROCEDURE FLOWCHART

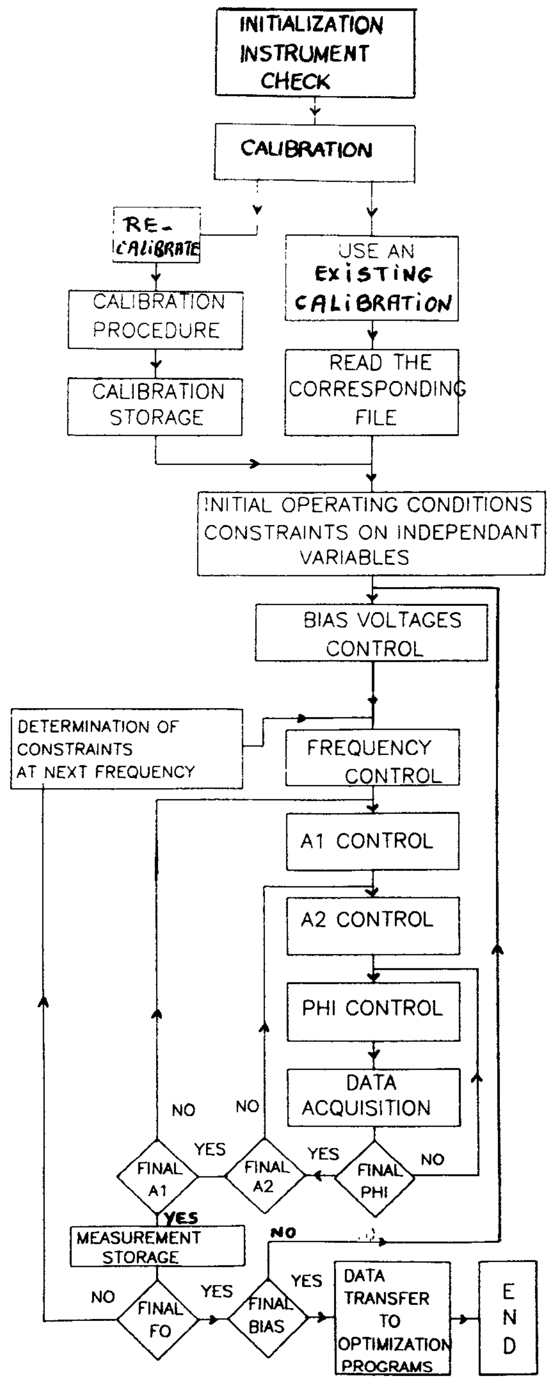

FIGURE 4