A STATISTICAL LOAD PULL FOR MIXER DESIGN USING A COMMERCIAL CIRCUIT SIMULATOR

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ABSTRACT

This paper proposes a new approach allowing to simplify the design of mixers. As for power amplifiers, the aim of the developed load pull is to determine once for all the best parameters (loads, bias, LO pump signal...) which make a nonlinear device, used as mixing component, produce low conversion loss (or other fixtures). Knowing these data, mixers can be mainly designed using a linear approach . The method takes into account the loads at the spurious frequencies and leads to mixers which are less sensitive to these usually uncontrolled loads. It also allows to check this sensitivity. The statistical load pull has been successfully applied to the optimization of a quad of cold HEMT.

INTRODUCTION

The simulation of mixers is now well known. Commercial harmonic balance simulators are able to compute the mixing process with a good accuracy. But, on the contrary, there is no general methodology, dedicated to mixer design, which can be directly used with commercial softwares for all types of mixers. The main reason is probably that mixers involve simultaneously a great number of frequencies.

The mixing phenomenon produces not only the useful IF intermediate frequency (f_{LO}-f_{RF}) but also numerous spurious frequencies as $nf_{LO} \pm mf_{RF}$ products. The mixer conversion loss, at the nonlinear device ports, depends on the RF and IF loads, but also on the loads at these unwanted mixing frequencies. Many studies have shown that some frequencies as the Image ($2f_{LO}$-f_{RF}) or the Sum (f_{LO}+f_{RF}) frequency may have a significant effect on the conversion loss [1,2,3] . The simultaneous numerical optimization of the impedances at the nonlinear device ports, at all the generated frequencies may be possible but the corresponding matching network would be probably too difficult to design. Actually, the loads at the spurious frequencies are usually uncontrolled. Mixers are often tuned at the final design step.

The idea of the statistical load pull is then to make the spurious frequency loads vary at random, in a practical impedance range following a uniform statistical law. At microwave frequencies, the impedance values which can be matched, are quite limited by the 50Ω termination, the practical impedance transformers, the losses in the circuits... In this work, the chosen practical impedance range is [0,+200Ω] for the real part of the loads and [-200,+200Ω] for the imaginary part.

PRINCIPLE

The first step of the statistical load pull is to make the impedances at all the mixing frequencies (including RF and IF) vary at random, at the ports of the nonlinear device to be tested. All these loads can be separately controlled using a set of special filters (Figure1).

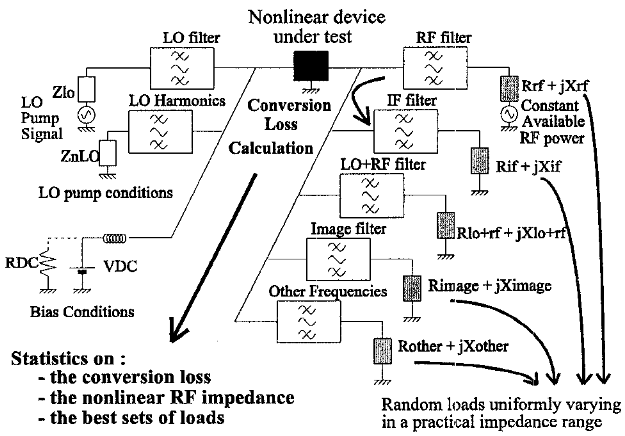

Fig 1 : Principle of the statistical load pull

The nonlinear component is excited under the same conditions (LO pump signal, LO harmonic terminations, bias) as it will be used in the mixer. The conversion loss is computed for all the random trials (one trial corresponds to a set of impedance values at all the mixing frequencies). This principle has already been used to study the mixing process with a resistive nonlinearity and to find general design rules for resistive mixers [4,5,6]. The last computer and harmonic balance algorithm improvements make possible the development of the statistical load pull for mixers. We have used in this study the Series IV simulator from HP-EEsof. We will discuss some results on this CAD technique with the example of a cold HEMT quad optimization (Figure2).

This approach leads to three main results.

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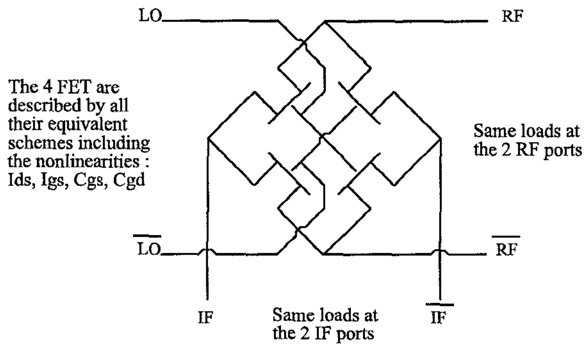


Fig 2 : The studied nonlinear structure : a quad of cold HEMT

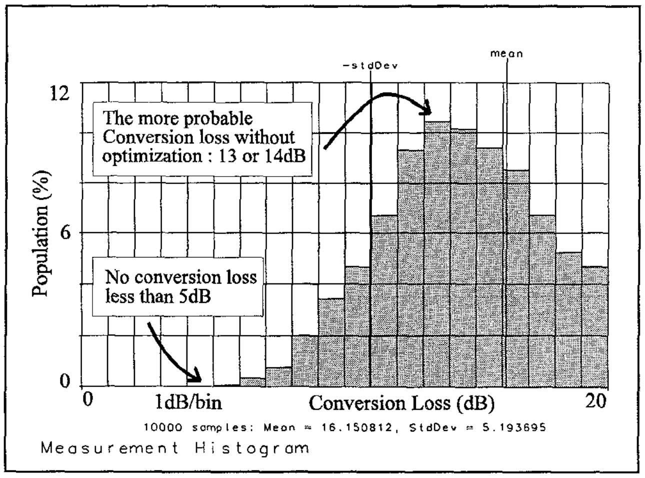


Fig 3 : Statistics on the conversion loss for a quad of 4x30µm HEMT, Vgs=-0.4V, VLO_{peak}=0.9V (sinusoidal LO voltage), RF=13GHz, LO=2.25GHz, IF=10.75GHz

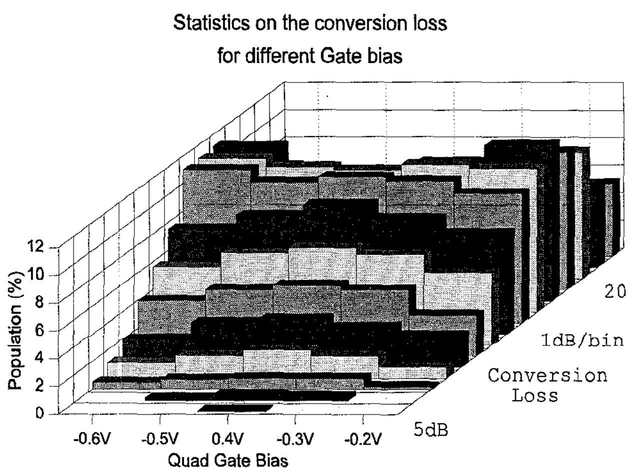


Fig 4 : Conversion loss statistics for the studied 4x30µm HEMT quad versus the Gate bias Vgs, VLO_{peak} is tuned to make the instantaneous sinusoidal Vgs always reach Vb=+0.5V

The first result is obtained by computing statistics on the conversion loss calculated from the previous random trials. These statistics show the potentialities of the chosen pumped nonlinear device (Figure3). The bias and the LO pump signal can be optimized using these statistics. The corresponding histograms, computed for different bias, are put side by side and make then a 3D diagram (Figure4). This diagram shows the bias and the LO pump signal allowing the lowest conversion losses for the greatest number of trials. These operating conditions lead then to the minimum loss but also increase the design reliability with regard to the uncertainty of the loads at some mixing frequencies.

The second result consists in the RF input impedance determination of the nonlinear device. It is possible to calculate this nonlinear input impedance for each trial. Statistics on this parameter show the possible range of the RF nonlinear impedance which has to be matched to minimize the conversion loss (Figure5). It is interesting to notice that this RF impedance range

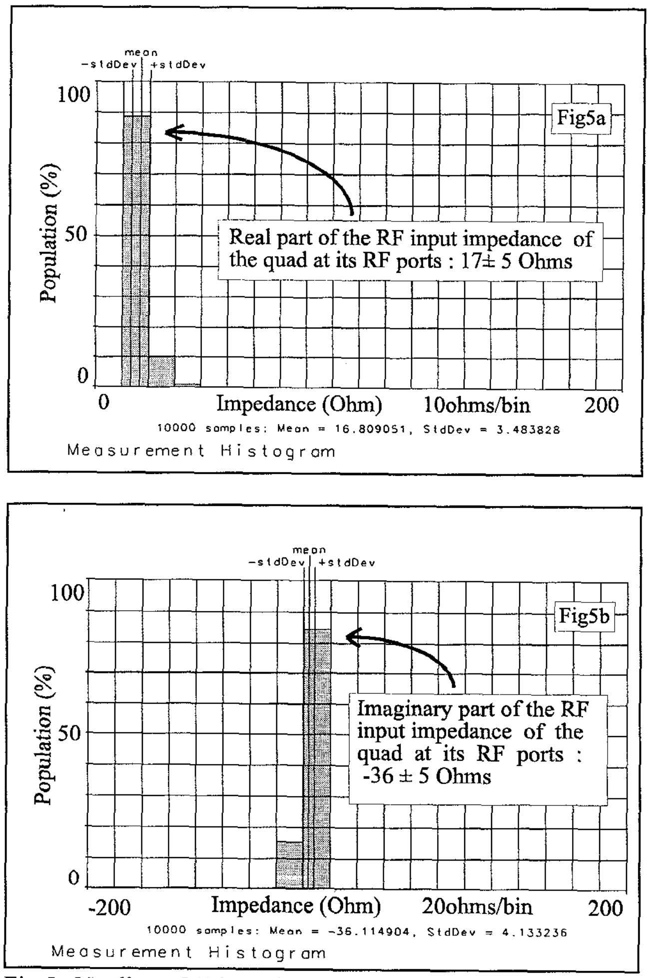
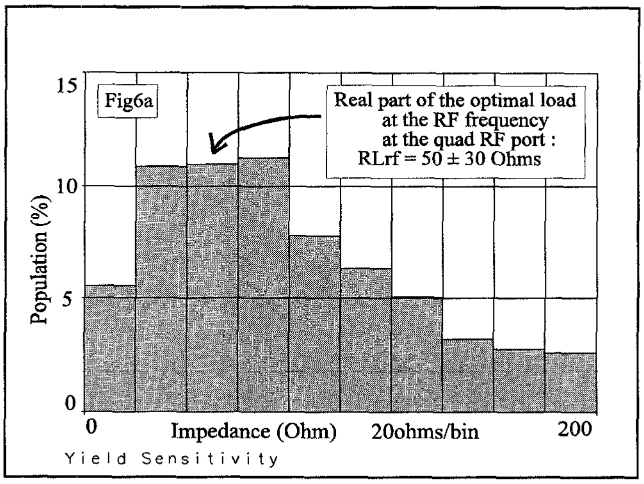
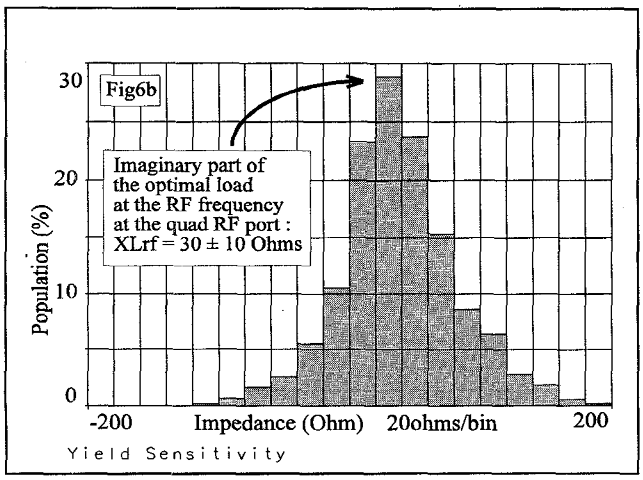
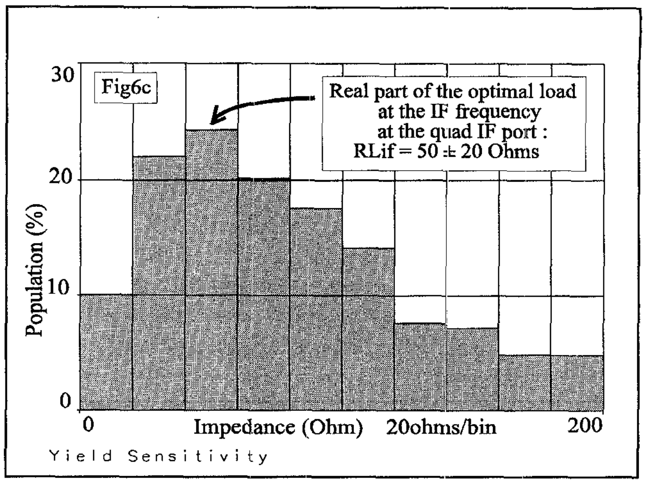


Fig 5 : Nonlinear RF input impedance : (17±5) -j (36±5) Oh takes into account all the possible variations of the loads at the different mixing frequencies. Choosing the RF impedance value in the previous range makes then the mixer less sensitive to the uncontrolled spurious frequency terminations. The component size is a compromise between a RF input impedance quite easy to match, low loss and a reasonable LO power.

The third result is the determination of the embedding impedances at the IF and at the other mixing frequencies, leading to low conversion loss. From the previous trials, the sets of embedding impedances corresponding to the lowest losses are selected. From these best trials, last statistics on the loads at each mixing frequency are performed to show which value is necessary to reach low conversion loss (Figure6). For these last statistics, we use the Yield Sensitivity Analysis of the Series IV simulator. This analysis has not been developed with this aim in view but can be directly used for this new application.







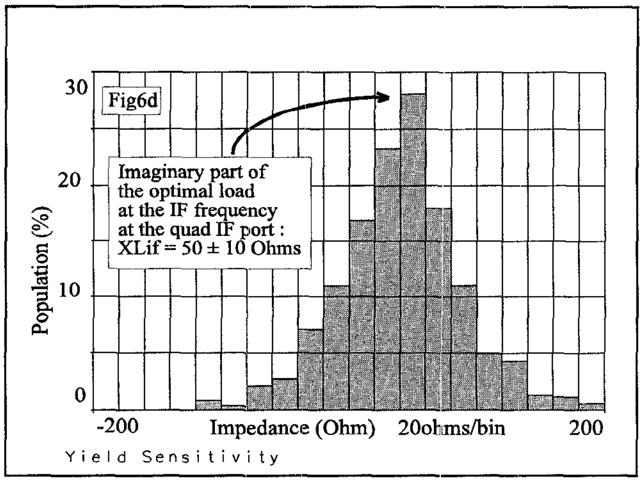


Fig 6 : Statistics made with the best random trials (Conversion Loss < 10dB). For the quad, only the RF load at RF ports and the IF load at the IF ports need a precise value. Statistics on the load at the other mixing frequencies present a uniform distribution showing a lower influence of these frequencies for the studied quad. This property is partly due to the balanced structure of the quad.

The statistical load pull also allows to verify the previous optimized parameters. Statistics are made on the conversion loss but the loads of the useful mixing frequencies only vary in the previously found impedance ranges. The other mixing frequency loads still vary in all the chosen practical impedance range. Figure7 shows the histogram obtained with the studied quad. Figure8 shows the nominal simulation performed with the Series IV simulator. For this simulation, only the RF generator impedance and the IF load have been fixed, according to the values given by the load pull. These last simulations show the efficiency of the method.

CONCLUSION

The statistical load pull allows to find the optimal parameters (loads at all the important mixing frequencies, bias, LO pump signal ...) which make a nonlinear device produce low conversion loss when it is used as mixing component. The optimization of cold HEMT quad using this new CAD technique on a commercial simulator, has shown the efficiency of the method even for a complex nonlinear structure. The proposed technique leads to mixers which are less sensitive to the uncontrolled loads at the spurious frequencies. It also allows to verify afterwards this sensitivity. The load pull has been successfully used for a single cold FET too and can be directly generalized to other nonlinear devices like diodes, bias FET, HBT... (in single or balanced structures) other mixer fixtures, other nonlinear phenomenons like the intermodulation, or even other functions like multipliers, power amplifiers...

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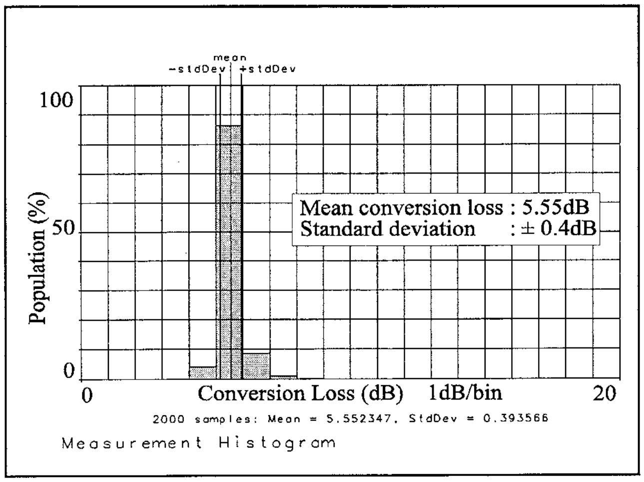

Fig 7 : Verification of the optimized parameters :
the RF loads at the RF port vary as (17±5) +j (36±5) Ω
the IF loads at the IF port vary as (50±20) +j (50±10) Ω
the loads at the other frequencies at both ports vary in all the practical impedance range

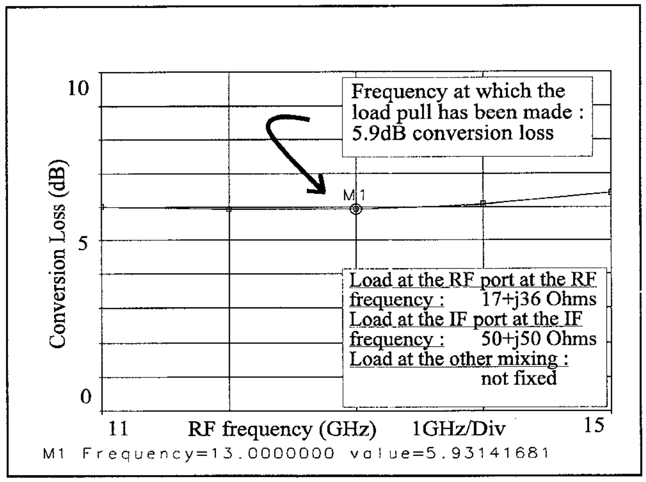

Fig 8 : Conversion loss versus the RF frequency Simulation performed with previous optimized parameters : 4x30μm quad, Vgs=-0.4V, VLO_{peak}=0.9V, LO=2.25GHz