Statistical Design for Microwave Systems

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ABSTRACT

This paper presents, for the first time, a proposed methodology for statistical system design using the commercial simulator OMNISYS(TM). Using two examples, a simple amplifier chain and filter, and a complete satellite receiver system, the application and benefits of statistical system design are demonstrated. The nonlinear characteristics of the system amplifiers and mixers are accounted for in this work. The specification of group delay, signal to noise ratio, and power out are all considered in these statistical designs.

I. Introduction

In the last year, statistical circuit design algorithms, i.e. design for high manufacturing yield, have been introduced to the microwave community [1]. This paper presents for the first time the application of state of the art statistical design techniques to systems rather than circuits. We use the commercial CAD systems package OMNISYS(TM) [2] for this paper, however these techniques can be applied by modifying any systems level simulator.

Typically systems are over designed in order to exceed the specified performance. This gives the design a performance margin to handle the inevitable performance degradation during manufacturing or during the system's lifetime operation. For instance, expensive ultra linear amplifiers are used to be sure and meet a harmonic distortion specification. However any performance margin can be costly if not properly managed and analyzed. In most cases it is felt by the authors that application of these techniques will allow the system designer to relax the individual element specifications in systems design, and still meet all performance and yield specifications for the system. This will result in less system cost, with no sacrifice in the systems specifications or reliability.

This paper first introduces a few of the important definitions for statistical design in Section II. Statistical system design is introduced in Section III. In this section a systematic method for statistical systems design is proposed. Sections IV. and V. present two examples of statistical system design. The first is a simple amplifier and filter system, and the second is a complete satellite system receiver. Section VI. presents conclusions.

II. Yield and Yield Factor Histograms

Yield

Yield is roughly defined as the number of permutations (in terms of component parameter values) of a system that pass specification, divided by the total number of permutations of that system that are simulated, in the limit as the number of permutations gets large.

$$\text{Yield} = \frac{\#\text{ of systems passing spec}}{\text{total }\#\text{ of systems simulated}}$$

Yield can be separated into two types: 1) those systems that don't pass specifications because of individual component failure, and 2) those systems that don't pass specifications because parameters vary too far from their specified (nominal) value. Either of these errors can cause system failure. Only type 2) errors will be dealt with in this paper.

Yield Factor Histogram

Knowing the statistical variation of system component parameters allows the designer to calculate system performance variation as these values vary according to their statistics. Once this experimental exploration of a system's reaction to these variations is determined, it is necessary to present this data in a usable format. A technique for presenting this data is called the "Yield Factor Histogram"[1,3].

Yield factor histograms show the variation of the component parameter value

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(generally the x axis), and its relative yield in percent (generally the y axis). Two examples of yield factor histograms are presented in Figure 1. Figure 1a shows a component whose parameter variation has little effect on the system yield, possibly a cheaper component will do the job. Figure 1b shows that the nominal value of this component (the center value of the histogram) should be lowered (if possible without affecting another parameter) to increase yield. Figure 1b also shows a component whose statistical variation is too great and a tighter parameter variance with a lower nominal value should be considered.

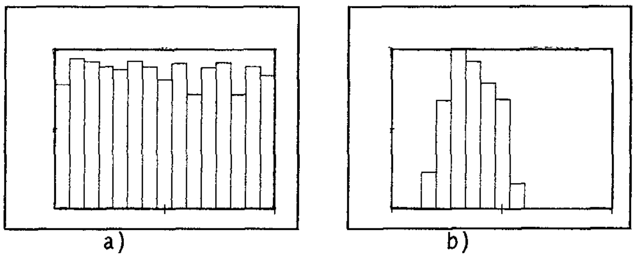


Figure 1 - a) No effect b) Center and Tolerance.

III. Statistical System Design Methodology

As briefly described in section II system component parameters are being varied to determine their effect on yield. These components could consist of amplifiers, mixers, filters, transmission lines, etc. The following steps briefly outline a method for statistical systems design.

System STATistical Optimization (SSTATO) is accomplished following these steps.

Step 1 - Statistical parameter model
Step 2 - Specify system performance
Test:
Step 3 - Analyze the system
Step 4 - Tolerance and sensitivity
Step 5 - Optimize by design centering

Step 1 - Statistical parameter model

Determine all of the parameters of interest and ascribe statistical information to them. An example of this is an amplifier. Besides gain, it also has input and output refection coefficients, third order intercepts, and one db compression points that describe its linearity. Nominal values (i.e. average values) as well as statistical distributions (i.e. Gausian, Uniform, etc.) and correlations must be assigned to each system parameter. High order statistical models may be necessary for accurate design and analysis.

Step 2 - Specify system performance

A criterion for entire system acceptance must be established. This is done by determining the system performance specification which depends on the system's application. For example it might be necessary to achieve a certain signal to noise ratio out of the system, or perhaps group delay, or power. These constraints on the system se the acceptance and rejection criterion for yield analysis.

Step 3 - Analyze the system

Once all of this statistical information is determined and the desired performance is set, the system component parameters should be exercised to the full extent of their statistical variation, and the system yield determined. This is best done by Monte Carlo yield analysis.

Step 4 - Tolerance and sensitivity

The system performance can then be analyzed as a function of parameter variation, referenced to yield using the yield factor histogram. The system parameter variation can then be tightened (tolerance), moved (design centered), or left alone (variation has no affect). This step is iterated on as many times as necessary to come close to the desired yield and system performance. This manual step is needed to both improve the designers "feel" for the system and speed the design process.

Step 5 - Optimize by design centering

Finally the optimal parameter nominal values are determined by use of statistical analysis software, hence optimizing system yield (design centering).

IV. Example 1 - Two amplifiers and a filter

This simple example helps to introduce the procedure for system statistical analysis and design. The two amplifiers have gain a1 and a2 (in dB) respectively and the gains are independent and vary uniformly ±10%. The filter bandwidth is also either a statistical variable which varies ±90% or ±50%. IP3 is the third order intercept point of the amplifier (in dBm) and 1DBC is the one dB compression point in dBm. The input drive level for each example is -70dBm.

The measurement specification for this example are chosen as signal to noise at the filter output, (s/n) in dB; group delay at the output in micro seconds, usec.; and power out in dBm, pw. These were chosen because good group delay requires a wide bandwidth, while good s/n requires a narrow bandwidth. Also good s/n requires linear amplifiers to avoid harmonic distortion and subsequent loss of carrier power.

Example 1 - Nonlinear amplifier and a filter

This system is shown in Figure 2. For this example, the second amplifier's IP3 was set so that it is operating in its nonlinear region. Specifications and results of yield calculations are shown in Table 1. Nominal parameter values and changes due to design centering are found in Table 2. Typical yield factor histograms are shown in Figure 3.

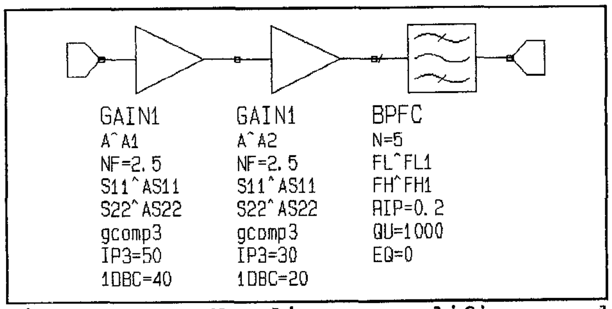


Figure 2 - Non-linear amplifiers and filter schematic.

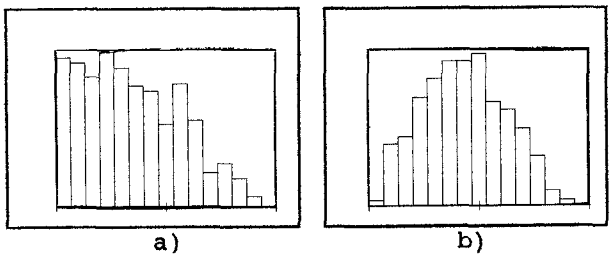


Figure 3 - Yield Factor Histograms: non-linear system.
a)Yield is affected by the gain of ampl and nonlinearity of amp2.
b)Combined effect of gain1 on yield due to signal to noise ratio and power.

For the linear case the system yield is not dependent on the gains of the amplifiers. The yield for the linear amplifier case therefore goes up to 73.8% uncentered and 80.6% design centered.

V. Example 2 - Satellite Receiver System

The second example involves analysis of a 4.0 GHZ satellite downlink receiver system with similar specifications and parameter variations as in the above example. A simplified system block diagram is shown in Figure 4. The exact block diagram of the system is in the OMNISYS (TM) applications manual [6].

ampl varies amp2 varies BW varies spec's	a1= 72±10% a2= 30±10% BW=1m hz±90% s/n>10 gd<.05	a1= 72±10% a2= 30±10% BW=1m hz±50% s/n>10 gd<.05	a1= 72±10% a2= 30±10% BW=1m hz±50% s/n>10 gd<0.05 pw>16
s/n only	40.9%	35.5%	35.5%
gd only	77.3%	99.9%	99.9%
pw only	no spec	no spec	80.0%
all spec'd	20.9%	33.5%	22.3%
design center	no data	no data	32.0%

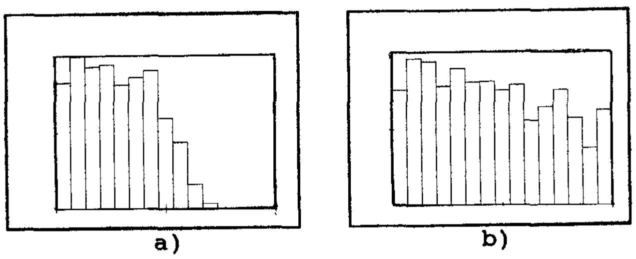
Table 1. Non-linear amplifiers, confidence intervals(1000 trials)±3%.

	Nominal	D.C.*	Change
a1	72	72	0
a2	30	30.5	+0.5dB
BW1	0.1	0.081	0.019ghz

Table 2 - Nominal parameter values and change. (* Design Center)

Four statistical parameters were chosen for this system. They are two amplifier gains (a1, a2), a mixer local oscillator frequency (lo1), and finally the system output filter bandwidth (BW1). Otherwise the system was used as given. After system component parameter tolerance and sensitivity changes were made the yield was improved from 23.4% to 100%. The histograms before design centering are in Figure 5.

Specifications and results of yield analysis are shown in Table 3. Nominal parameter values and change are found in Table 4.



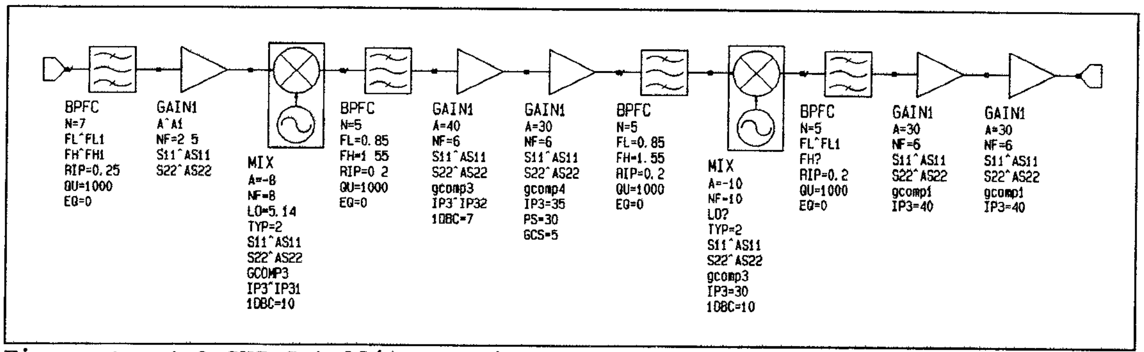


Figure 4 - 4.0 GHZ Satellite Receiver System Block Diagram.

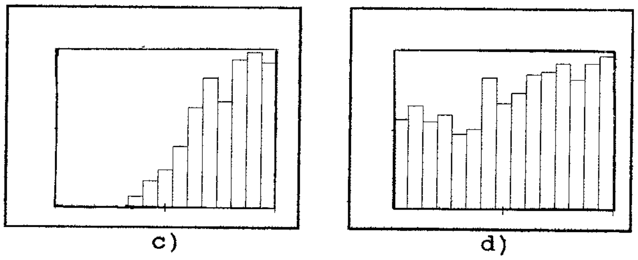


Figure 5 - Non-centered histograms a) a1 b)a2 c)lo1 d)BW1.

amp 1 amp 2 local osc. band-width spec's	a1=45±50% a2=-10±50% lo1= 1.70±1% BW1=33±50% s/n>11 gd<0.45	a1=45±10% a2=-10±10% lo1= 1.70±0.25% BW1=33±10% s/n>11 gd<0.45
s/n	26.4%	no data
gd	91.3%	no data
s/n and gd	23.7%	20.9%
design center	74.4%	100%

Table 3 - Satellite receiver, 95% confidence intervals (1000 trials) < 2%.

	Nominal	D.C.*	Change
a1	45	38.24	-6.76dB
a2	-10	-9.93	+0.07dB
lo1	1.70	1.71	+0.01ghz
BW1	0.033	0.037	+0.004ghz

Table 4 - Nominal parameter values and change. (* Design Center)

VI. Conclusions

The application of established circuit statistical analysis and design techniques to systems can be very beneficial. These tools applied to systems design can allow the systems engineer to perform statistical sensitivity studies to determine sensitivities and tolerance of the important systems components. Robust and reliable systems designs can result from the applications of these techniques. Future applications include antennas, phased array radar, and cellular communications, to name a few.

Acknowledgements:
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VII. References

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