Combining Yield Optimization with Circuit Level Electromagnetic Simulation

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Abstract

A method for first-pass MMIC design success is presented. In this paper we combine the power of statistical design and modeling with that of circuit level electromagnetic simulation in a CAD system, providing the ultimate crystal ball for predicting production success. The performance of the proposed CAD system is verified by comparing simulated vs. actual statistical response characteristics of a 3-stage, 7-11 GHz LNA GaAs MMIC from AT&T Bell Laboratories, Reading, Pennsylvania.

Introduction

Most present-day MMIC design practices overlook two important aspects required for accurate performance predictions: 1) inadequate modeling of parasitic coupling effects associated with circuit layout, and 2) statistical variations due to fabrication imprecision. Both of these design issues are addressed in the proposed CAD system for first-pass design success.

When a lumped design is distributed in a standard linear circuit simulator, a number of the parasitics are taken into account. Junctions, steps, and bends are integrated into the simulation to account for electromagnetic parasitics found in these discontinuities. These discontinuities contain parasitics which have been quantified into equivalent circuits and are described by analytical expressions. Many of these discontinuity models are available elements in commercial CAD tools. Thus, the skill of a MMIC designer is often displayed by his ability to include the significant parasitics in the matching networks and neglect the insignificant parasitics.

There are however, many more parasitic coupling interactions than discontinuity parasitics in compacted MMIC circuits. By performing an electromagnetic simulation of the full circuit, all parasitic interactions are accounted for.

CAD System Overview

The proposed CAD system for first-pass design success is shown diagrammatically in Figure 1. At the heart of the system is the ability to accurately model not only the statistical characteristics of the devices in the design, but also the effects of coupling between circuit elements (i.e., items 2 and 3 of Figure 1).

CAD System for First Pass Design Success

1 Yield Optimization
2 Accurate Statistical Models
3 Full Circuit Electromagnetic Simulation
4 Circuit Simulation
5 Layout/Schematic Editing

Figure 1. CAD System for First-Pass Design Success

For the implementation of item 2 in our system, we draw from previous works [1-5] where it was illustrated that the *Truth Model* is an excellent candidate for accurate and efficient statistical device modeling. In the current application, the Truth Model is extended to include device noise parameter statistics and, as such, is the first statistical device model to do so. Implementation of item 3 of the CAD system utilizes EMSim [7]. Electromagnetic simulation of full MMIC circuits using EMSim has been demonstrated and documented [6]. The following section presents a case study involving a 3-stage LNA designed using the CAD system for first-pass design success.

Case Study: A 3-Stage 7-11 GHz Low Noise Amplifier

Circuit Description: A 3-stage self-biased amplifier is designed to achieve the desired specifications for gain, noise figure, and input/output match over the 7 - 11 GHz frequency range, as shown in Figure 2. The first and second stages employ series feedback, while the final stage employs shunt feedback. The input match is designed to provide the optimum noise impedance, Γ_{opt}. The second stage, in conjunction with feedback and the interstage matching networks, ensures maximally flat gain and noise figure responses while maintaining low input/output VSWR. Active devices are represented by measured data, and the total chip dimensions are 1.48 x 1.42 x .1 mm.

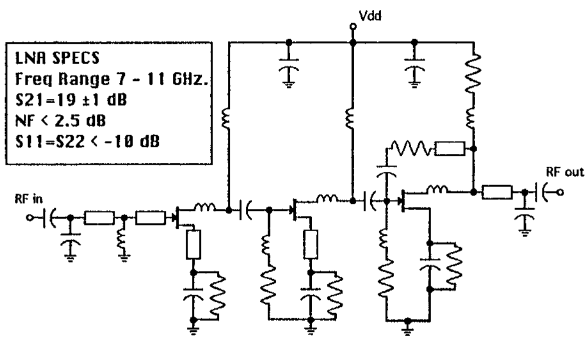

Figure 2. Schematic Diagram of the 7-11 GHz LNA GaAs MMIC

Nominal Design: Once initial element values for the matching networks are determined, single-point optimization is performed using the Libra minimax optimizer to flatten the responses and minimize the noise figure of the amplifier. Afterward, the design meets or exceeds the performance goals for a *typical* FET, but the average performance is lower, indicating a yield of only 25% (given the SPECS in Figure 2). To achieve a process-robust design, we employ the statistical design and accurate statistical modeling techniques resident within our proposed CAD system.

Robust Design: The methodology for robust design has two main parts: 1) powerful Monte Carlo-based design centering algorithms and, 2) accurate and efficient device statistical models. In this case study, the design centering algorithms from Libra are used.

As mentioned previously, the Truth Model is our choice for the device statistical model. To construct the Truth Model, both Scattering and noise parameters were measured on-wafer for 45 HFETs across five wafers from four lots. Based on empirical evidence, we believe this measurement database sufficiently represents process variation.

After designating *designable variables*, the automatic centering algorithm is used in conjunction with the linear simulator and the yield is optimized to better than 75% (given the SPECS of Figure 2). Figure 3 shows the statistical response of the LNA before (3a) and after (3b) design centering.

Statistical Electromagnetic Circuit Simulation: The final step in the design process using the new CAD methodology involves electromagnetic simulation of the design-centered circuit. Figure 4 shows the layout of the AT&T LNA with the current segment patching scheme used for the moment method based electromagnetic simulation. Figure 5 shows the expected statistical response of the LNA where a 10-port EMSim S-Parameter file is used in conjunction with the combined Scattering and noise parameter Truth Model. (The simulation has 332 unknowns and takes about 37 minutes per frequency on a SPARCstation IPC with 12 MB RAM.) Comparing Figure 5 to Figure 3b, note that the high end of the frequency band has greater deviations, primarily due to the greater impact of parasitic coupling of the elements in the matching networks. There is a change in S22 throughout the band, and further investigation is required to isolate the main factors contributing to this change. Here again though, the difference is most likely due to parasitic coupling.

The performance results given by the statistical electromagnetic simulation were deemed acceptable and the design is currently being fabricated.

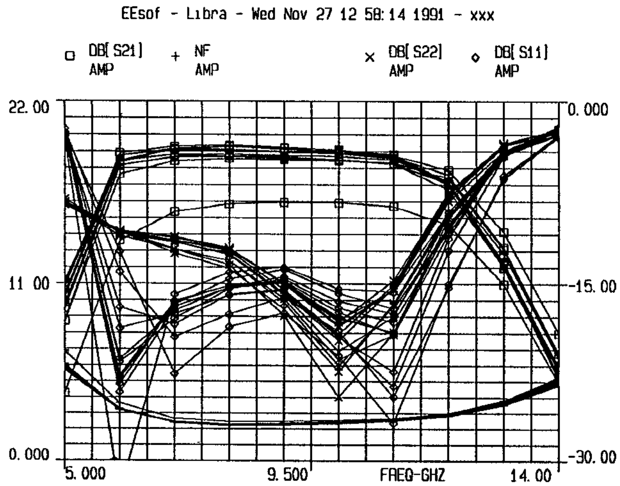

Figure 3a. LNA Statistical Response Before Design Centering with Libra

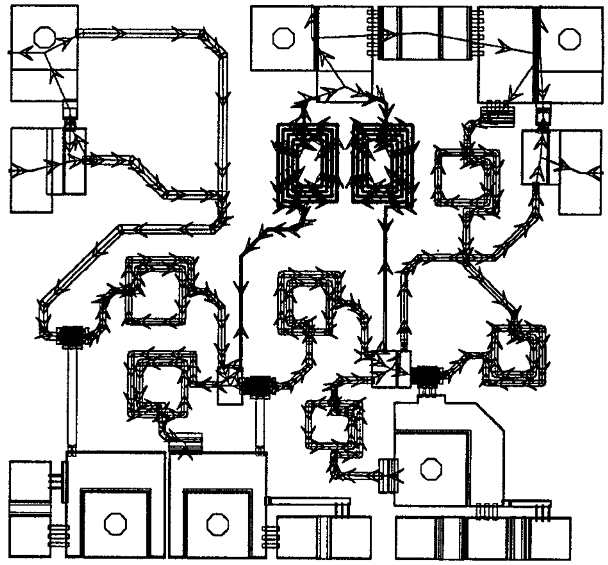

Figure 4. LNA Patched for Electromagnetic Simulation with EMSim

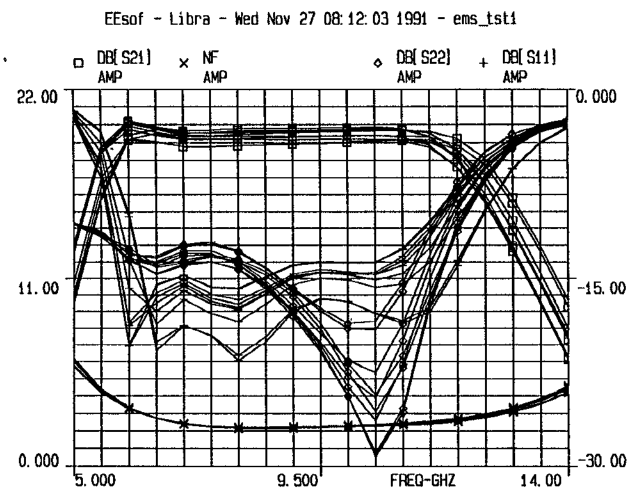

Figure 3b. LNA Statistical Response After Design Centering with Libra

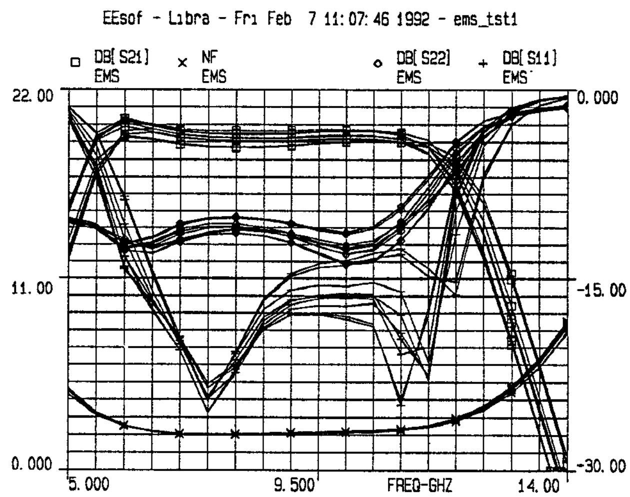

Figure 5. LNA Statistical Response from EMSim

Conclusions

The first comprehensive demonstration of a CAD system for first-pass success has been made. By combining powerful statistical design and modeling techniques with equally powerful circuit level electromagnetic simulation, the designer can go to production with a level of confidence never before attained.

Finally, note that wafer fabrication is under way and results will be available for the symposium.

References

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