Co-Design and Co-Optimization of ultra-wide band LNA-Antenna

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ABSTRACT:
In this paper, we proposed a low noise amplifier (LNA) for ultra wideband (UWB) applications using TSMC 0.18µm CMOS technology. LNA and high frequency H-shaped antenna have been utilized to solve problems of each block, such as the necessity of being matched with 50 Ohm impedance, so we have one more degree of freedom and a more complex system, although our choosing ability is increased. The targeted is Ultra Wide Band where this architecture and a Co-Designed version, with UWB-LNA architecture offer one of the best compromises between gain and noise figure. For having the best trade-offs between these two cases in UWB-LNA, both Multi-Objective Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) are used successfully. Symmetric nature is obtained both in terms of S-parameter as well as flatness over a wide bandwidth for gain and noise figure. To have better Co-Design; in this work another optimization on antenna parameters performed with ADS Software. In co-optimization with the aid of two techniques; LNA parameters improvement utilizing evolutionary algorithms and antenna parameters enhancement in co-design output S-parameters had more promising results. Results show gain-flatness is being enhanced in desired frequency band. Noise factor is improved by more1.5 dB over the whole bandwidth [3.1GHz-8.1GHz]and supply voltage of 1.8V.

KEYWORDS: Low noise amplifier; Ultra-wideband; CMOS; Multi-Objective algorithm; Co-Optimization; Co-Design; Patch Antenna.

1. INTRODUCTION

ULTRA-wideband (UWB) technology using the unlicensed frequency band from 3.1 to 10.6 GHz has become more popular than other techniques for broadband wireless communication research due to its several advantages such as low complexity, low cost, low power consumption, high security, robustness for multi-path fading , and high data transfer rate wireless connectivity. The possible applications of UWB technology can be useful for imaging systems, vehicular and ground penetrating radars, and communication systems.

One of the major challenges in wideband communication systems is the design of a wideband low-noise amplifier (LNA). As the first active component in the receiver chain, the LNA should provide high gain and low noise Figure over a wide bandwidth to amplify the weak signal received by the antenna. In most applications, it is desirable to obtain wideband on-chip input matching to a 50 antenna/LNA, good linearity, and low power consumption. In addition, gain-flatness over the entire frequency range of interest is necessary to meet the design specifications. These properties are the cornerstones of the wideband LNA design, which affect the total characteristics of broadband communication system [1], [2].

In CMOS technologies, it is difficult to achieve 50 ohm input impedance for the UWB-LNA and having high gain and low noise concurrently.

With the development of RF integrated technology, Co-Design between RF circuits or between circuits and antennas [3], [4] have proposed and used in RF end designs. Co-Designing essentially changes the structure of a circuit. It combines the function of the circuits and reduces the connection between the components. This function could be split into the antenna and the low noise amplifier (LNA). Usually, both elements are matched each others to a pure resistive 50 Ohm (or 75Ohm) impedance, matching the elements enables to maximize the power transfer. Nevertheless, in the context of Co-integration where antenna is close to the amplifier others solution than 50 Ohm impedance could be investigated in order to relax some constraints and to increase performances for the some power consumption.

In this case, the challenge of Co-Design consists in finding the best trade off between the maximum power gain of the LNA and the feasibility of an antenna with impedance which differs from 50 Ohm. Few works have been carried out on this topic because of lack of co-simulation software between electromagnetic simulator for antenna and circuit simulator [4], [5].

In this project we did a Co-Design of a wideband 0.18um CMOS LNA with H-Shaped Patch Antenna without the need to use a Matching Network or a Band Pass Filter between the Antenna and the LNA and well suited for both 3–5- and 3–10-GHz UWB.

Several heuristic algorithms are available for finding the solutions of optimal designs for RF circuits such as: genetic algorithm (GA), simulated annealing, PSO, etc. in order to improve efficiency on the IC design cycle. The approach combines a robust optimization, Machine learning techniques and a distributed processing capability which is able to deal with multi-objective and constrained optimization problems. To produce trade-off between solutions, we used evolutionary algorithms based on Hspice and Matlab software for UWB-LNA.

To have better co-design; in this work another optimization on antenna parameters performed with ADS platform.

We have four main parts, firstly, UWB-LNA designing in order to expose the co-design methodology in other parts.Secondly, optimized first part with evaluation algorithm(GA and PSO). Thirdly, a high frequency H-Shaped patch antenna is presented. Fourth, a comparison between a 50 Ohm and the co-designed version is drawn out so as to estimate the advantage of a co-designed approach, and Co-optimization on antenna parameters performed with ADS Software.

2. UWB-LNA DESIGN AND ANALYSIS

The CMOS LNA was designed and implemented by a standard 0.18µm CMOS process. The designed LNA circuit can be divided into two parts; cascade amplifier and shunt resistive feedback stage [6].

The LNA is targeted for low noise figure; at the same time, it has to provide sufficient gain and lower Noise Figure (NF). Fig. 1 shows the schematic diagram of the low noise amplifier, which is composed of a cascode stage (M1, M2) and a common source stage (M3). The cascode topology is used to reduce Miller effect, improve the stability, and enhance the isolation. The common source topology is used to provide sufficient gain at the output port, and to decouple the input matching with the NF by cancelling the output noise from the matching device [2], [7]. By choosing the appropriate device sizes and bias condition, the noise generated from the common source device Ml and the common gate device M2 can be cancelled at the output port. Besides this noise cancelling technique, the device M3 can also form a feedback path to enhance the stability of the cascade structure. If we treat the transistors M1, M2, and M3 as the device building block in this LNA, this device block preserves high gain, low noise, and good stability without consuming more dc power.

Approximately, from [Fig. 1], we can get the equations for calculating the voltage gain of the stages as Equations (1), and (2), that could used in Equation (3) for calculation overall voltage gain.

$$AV_1 \approx g_{m1} \cdot [(g_{m1} \cdot r_{o2} \cdot r_{o1}) \| R_{LD2}] \quad (1)$$

$$AV_2 \approx g_{m3} \times R_F \quad (2)$$

$$AV = AV_1 \times AV_2 \quad (3)$$

This equation shows that the gain is proportional to gm3 which is the transconductance of the transistor M3, and RL and RF are the load and feedback resistances, respectively.

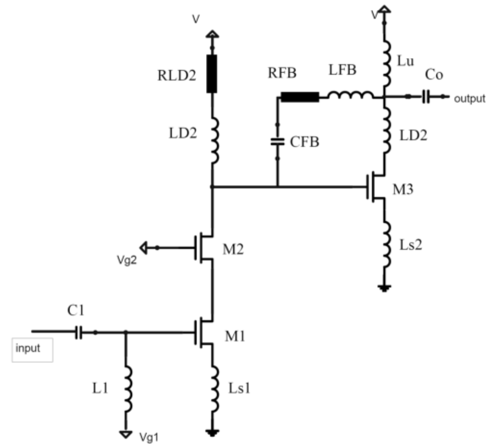

Fig. 1. Schematic of the proposed LNA with High pass Filter

The simulations involved 21 independent variables for optimization (variables such as Inductance, capacitor, size of transistors and so on). The optimization targets were: average power gain, average NF, input reflection coefficient and input\output matching.

3. OPTIMIZATION ALGORITHMS

Even we are in the digital age and digitalcircuits directly benefit from advances in IC technologies, RF circuits do not as much. This issue is exacerbated by this fact that RF circuits often require external components - for example, inductors – where it is difficult bringing of them into the chip even in modern IC processes. In fact, computer aided analysis and synthesis tools for RF ICs are still in their infancy which it is forcing the designers to rely on experience, intuition, or inefficient simulation techniques to predict the performance; Therefore, developing reliable automatic tools in RF IC design seems very attractive. One solution to this problem is employing Evolutionary Computing [8].

The concept of GA and PSO has been applied to an LNA design scenario to find optimum suitable point settings for the different stages of the LNA [6]. It has been observed that there is significant improvement in the performance at the variables obtained from the optimization technique, as compared to any random one.

Genetic Algorithm is a global search algorithm, which it models the process of the natural evolution in order to optimize the parameters of a problem. Genetic algorithm utilizes a non-gradient based random search and is used in the optimization of complex systems [9].

Particle Swarm Optimization (PSO) is an evolutionary computation method based on the social behaviour, movement and intelligence of swarms searching for an optimal location in a multidimensional search area. The approach uses the concept of population and a measure of performance similar to the fitness value used with evolutionary algorithms. Population consists of potential solutions called particles. Each particle is initialized with a random position value [10].

Our proposed applications of an optimization technique using GA & PSO have been successfully applied to LNAs, optimizing variable conditions at the simulation and design stage. The technique can also be extended to optimizing variable conditions in any active circuit.

RF HSPICE tool was used to evaluate the performance of the solutions that generated by optimization tool in each iteration. The procedure was able to provide significant performance improvement at the end of optimization. In order to have the best performance, values of all elements were optimized using genetic algorithms [11-14].

Optimization techniques was written based on the maximum and minimum values of the noise figure and gain in all the frequency range and improving input/output matching, gain, noise figure and other variables of an LNA, and they can also be prioritized to find out the range of variables where an LNA can be optimized, according to the algorithm iteration.

In this section, the aim is to optimize the circuit to be flat over the entire frequency range, because broad band matching and the flat gain are the two important factors for the UWB circuits.

Fig. 2 shows Genetic Algorithm results for making trade off between average of noise and Gain in UWB-LNA Flatness over Bandwidth of less than 3dB.

In This Paper, N=21 variables and we have2000 iterations.

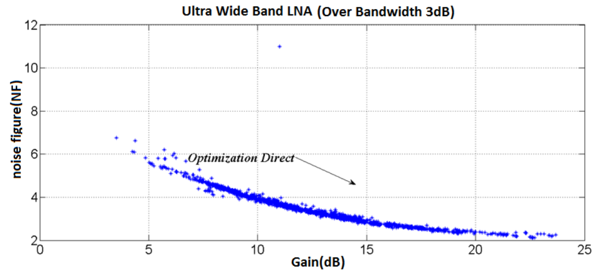

Fig. 2.GA results for making trade off between average of noise and Gain in UWB-LNA

Fig. 3 shows regression line for output data (Minimum-Maximum value) if regression line slop converge to one, the difference of maximum and minimum values converges to zero. Consequently Flatness over Bandwidth of less than 3dB.

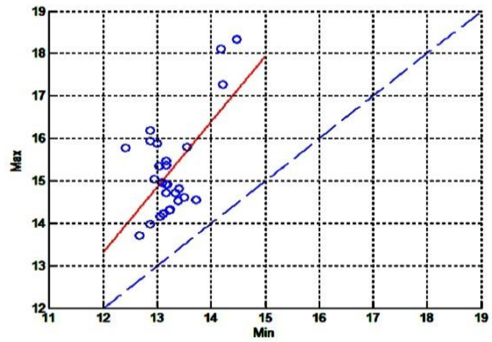

Fig. 3. Regression Plot

Fig. 3 shows Genetic Algorithm results for making trade off between average of noise and Gain in UWB-LNA Flatness over Bandwidth of less than 3dB.

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Figure 4 shows comparison between Genetic and Simulation in power Gain. We could have High Flat Gains in best GA simulation results.

Table 1.GA and PSO Values for UWB LNA (with matching 50 ohm)

	Before Apply Algorithm	**Genetic1**	**Genetic2**	**Genetic3**	**PSO1**	**PSO2**	**PSO3**
Gain	16.72	15.93	14.08	13.9	16.78	16.3	14.31
Gain(MIN)	10	17.2	14.54	14.6	18.13	17.5	14.89
Gain(MAX)	21.8	14.2	13.71	13.5	15.14	14.8	13.52
Max-Min	11.8	3	0.83	1.1	2.99	2.67	1.37
NF	2.99	2.8	3.17	3.23	2.7	2.85	3.1

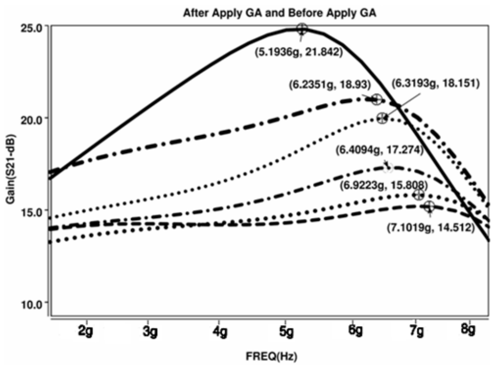

Fig. 4.Comparison Genetic with Simulation in power Gain

Our first purpose was High flat Power Gain; as shown comparison between Genetic results. TABLE 1 shows three-gain and noise figure from Genetic and PSO; as consequence of simulations both Genetic and PSO are good optimization algorithm.

4. ANTENNA PRESENTATION

This includes employing slot at the patch antenna such as the H-Antenna slot and H-shaped slot (as shown in figure5).

An H-shaped patch antenna suitable for wireless and satellite communications is used. The antenna has some advantages compared to other patch antennas, such as small size, a fewer number of modes, no harmonic resonance. In this work, an H_shaped patch antenna is used, which is suitable for UWB applications [15].

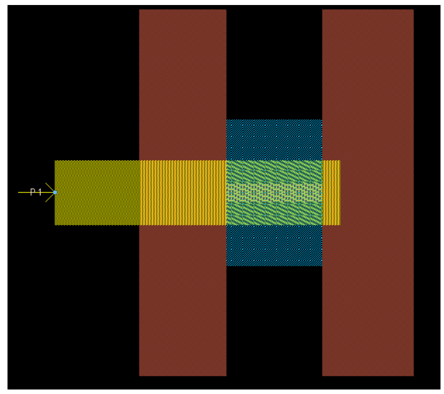

Fig. 5. H_shaped antenna

The dimensions of patch antenna (length, width and thickness) proposed as co-optimization parameters. The initial optimization was performed with the default changes for all parameters. (All parameters are in millimetres)

In other section this antenna is used for co-design methodology.

5. THECO-DESIGN

5.1. Co-Design Strategy

With the advance of integration we no longer need to have separate parts connected together with coaxial cables and hence we are no longer constrained to the 50 ohm interface impedance, or for that matter any other standard impedance level. With this new degree of freedom, we can explore a wider design space. By viewing the MOS device as a trans conductance, rather than as a power gain device, the function of the antenna can be viewed simply as providing to the LNA. Since the high input impedance, capacitive MOS device converts its gate voltage to a drain current, we need not concern ourselves with the power transfer into the input of the LNA, and are consequently free to investigate other performance metrics.

Due to the tight coupling of the antenna and LNA, and possible nonstandard interface impedances, testing becomes more complex. The antenna can be designed to deliver the best possible voltage signal to the input of the LNA, so that we are free to choose the characteristic impedance. This however does not constrain subsequent interfaces, which can be independently optimized for signal to noise ratio and, in fact, could be optimized for other values if the test equipment compatibility was not required.(As shown in figure6).

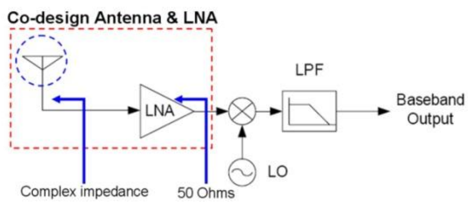

Fig. 6. Co-Design Antenna and LNA

Our Co-Design Strategy has these steps:

- Assuming that the input to the LNA is a MOSFET, and that the MOSFET device is primarily a V to I converter, not a power gain device.
- Then the Antenna and RF Filter (L-C) should present the maximum possible voltage over the frequency band of interest only. They should attenuate voltages outside the band.
- The antenna, filter and LNA should ultimately maximize the SNR at the output of the LNA.
- For a given gain, SNR is maximized by minimizing noise figure (NF).
- NF is a strong function of the impedance seen at the input to the LNA, in this case, the filter.

5.2. LNA and Antenna Co-optimization

Because of the direct integration of the patch antenna and the LNA into a compact design, a joint circuit/full-wave Optimization is required to simultaneously design the antenna and LNA to meet the desired specifications. The design flow is sketched in Fig. 6 and 8. The gist of the design strategy is to control the complex antenna impedance and match it to the impedance for optimal noise performance of the LNA. Therefore, the antenna dimensions and several well-chosen parameters of the LNA were chosen as degrees of freedom for the optimization cycles.

- The system cannot exceed the received SNR at the terminals of the antenna.
- Any loss in the path from the antenna to the circuits shows up directly as noise.
- Therefore, we want an impedance match at the antenna to filter interface.
- The last segment is terminated by the input to the LNA, so it will support a standing wave as well, due to the reflection.
- Also, since there is a full reflection, we will get double the input voltage to the LNA for free, versus a power (impedance) match.
- This situation also results in a very near optimum noise figure for the LNA.

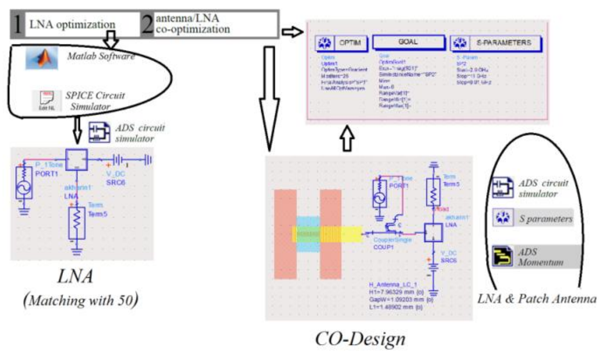

Fig. 7. Co-optimization

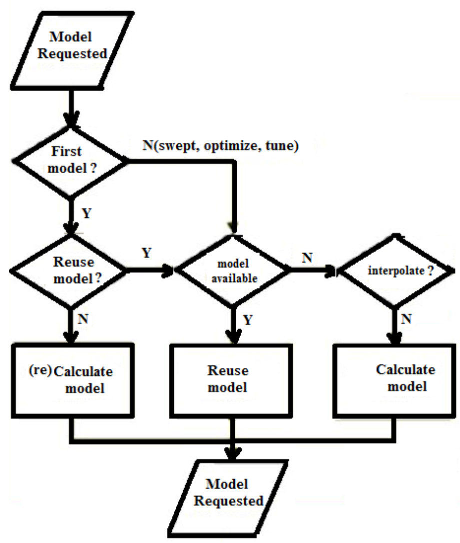

Fig. 8. Optimization flowchart in ADS GOAL

As shown in figure 7, firstly LNA optimized with Hspice and Matlab in this optimization our purpose is

High flat Power Gain and low noise. Output of this step is used as input parameters in ADS circuit simulator.

Secondly as shown in figure 7, we have LNA/Antenna Co-Optimization. LNA and Antenna are coupled and chosen parameters are optimized concurrently.

5.3. Comparison with standard 50 ohm Approaches

In this section we have complex impedance instead of 50 ohm and this limitation is removed.

As obvious in figure 9-11 optimized Co-Design has better results compared with standard 50 ohm Approaches.

Figure 9 shows the optimal S21 parameter for both 50 ohmand co-designed version. This gain is calculated with a 50ohmreference input port for the LNA 50ohm version and the antenna complex impedance for the co-designed version. Maximumgain(which occurs at bandwidth of frequency) reaches 16.77dB in the co-designed version against 13.4 dB in the 50ohmone. This gain enhancement was possible because of the novel optimization of antenna and LNA parameters. In the 50ohmversion the evolution of S21 fits perfectly with the maximal transducer power gain. It shows that there is an ideal matching between the amplifier and the 50ohmantenna. We can check this conclusion by looking at the input reflection coefficient on Figure 10 which stays below -10 dB over the whole bandwidth [3 GHz-8 GHz].

Figure 11 shows an improvement from 0.5dB up to 1.5 dB on noise factor over the whole bandwidth.

Figure 12 shows improvement output reflection coefficient with result 50 ohm matching in LNA.

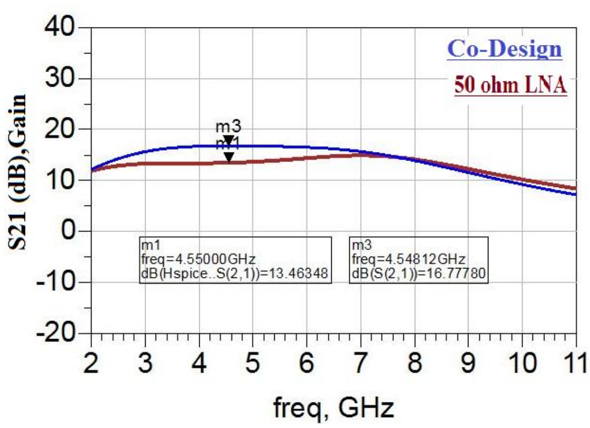

Fig. 9. Power gain for 50 Ohm and co-designed versions

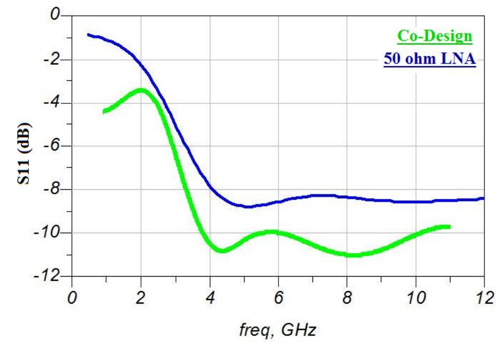

Fig. 10. Input reflection coefficient for 50 ohm and co-designed versions

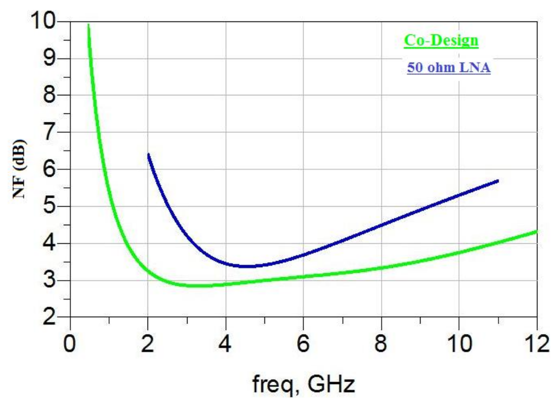

Fig. 11. Noise factor for 50 Ohm and co-designed versions

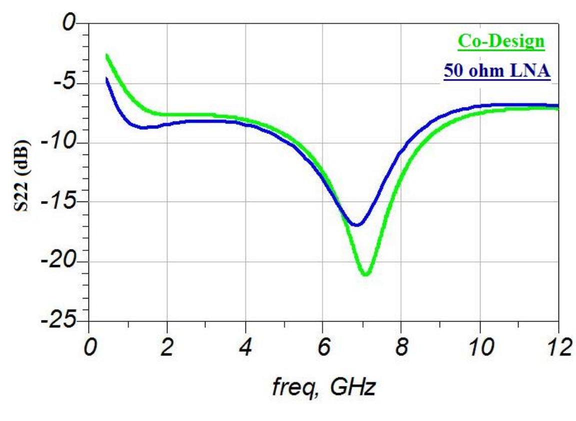

Fig. 22. S22 for 50 Ohm and co-designed versions

6. CONCLUSION

In this work, an UWB LNA has been designed in a 0.18-µm CMOS technology. HSPICE and MATLAB have been linked and provided a multi-objective genetic and PSO algorithm in order to find the optimum parameters.Significant results have been obtained in circuit design.

LNA and high frequency H-shaped antenna have been applied with the aim of overcoming the problems accompanied with each individual block, like the necessity of being matched with 50 Ohm impedance, so a one level increase in degrees of freedom is obtained.

In LNA and antenna co-design due to increase in number of parameters, different optimization techniques have been used (fig7). This has led to promising enhanced in the quality and the speed of designing process in comparison to manual methods.

Comparing the blocks individually, and their co-design with and without applying co-optimization techniques-consisted of Advanced Design System and GA optimization-, revealed that S-parameters are being improved.Results show gain-flatness is being enhanced in desired frequency band. Noise factor is improved by more1.5 dB over the whole bandwidth [3.1GHz-8.1GHz] and supply voltage of 1.8V.

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