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REALIZATION AND PERFORMANCE ESTIMATION OF INTEGRATED CMOS LNA WITH F-INVERTED ANTENNA FOR MOBILE COMMUNICATION

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Abstract
The Ultra-wideband Transceiver systems are finding their mammoth existence with the mobile communication evolutions. The use of CMOS can not only miniaturized the system but also is designed to reduce convincingly overall thermal imprint and RF power consumption [1]. Nevertheless utilization of silicon as is traditional in the high-frequency Low Noise Amplifier market for short range products such as Bluetooth and WiFi, but this smart material faces a real confrontation for the signal amplification needed for longer-range mobile phone transmissions. This work focuses on the Integration of the CMOS LNA with F – Inverted Antenna for wide range of frequency. An F-Inverted Compact Antenna using standard commercial TSMC 90µm CMOS process technology is introduced. A Co-design of this Electromagnetic Radiator combined with a two-stage LNA including impedance matching network is implemented. This co-design allows a gain of more than 20 dB at 5GHz operational frequency with considerable limited on-chip area occupation. The simulation results indicate that at 5GHz with 2.5V signal, low noise amplifier has achieved power gain of 22dB, 1dB compression power output (P-1) of 13.2dBm and maximum power added efficiency (PAE) of 45.2% with power consumption of 17mW.

Keywords:
F-inverted Antenna, EM Radiator, LNA, Transceiver, Co-Design LNA-FICA

1. INTRODUCTION

During recent times the mobile communication systems require miniaturized structures, plenty of circuit integration and quite less surface-bonded devices as to achieve cost reduction, robustness and enhanced operation of the system [2]. The well established CMOS technology provides benefits of low cost and high integration with neighboring circuits. The Low Noise Amplifiers (LNA) involves a bunch of balancing different parameters, including power added efficiency (PAE), maximum output power, linearity, maximum stable gain, heat dissipation, stability, input/output matching, and breakdown voltages [3]. The RF designs include these requirements but have their own limitations and often depend on each other. For example, achieving good linearity usually comes with reduction in the power added efficiency parameter. Though these trade-offs of a LNA design changed from the requirement it possess. The amplifier circuits have been well in research over the years with many different design approaches documented. The design and implementation of such low noise amplifiers using CMOS technology has achieved higher efficiency, robust operation at optimum load and also better linearity. In addition to this, LNA also plays a pivotal role in analyzing the noise figure of a microwave receiver as it is the initial device of the receiver front-end placed just after the receiving antenna module. High gain criteria are mandatorily obligatory for the receiver model and LNA as mostly the received signal is with weak strength [4].

The inventions of Ultra Wideband devices have led the researchers to design electrically small feature sized antenna. Various types of miniaturized antennas such as micro strip antenna, patch antenna, inverted F-antenna, RF MEMS antenna, etc. has been developed with emergence of mobile handheld devices [5]. The success of these devices is mainly due to size reduction capabilities, high level of integration, low cost and highly efficient operation of integration. The CMOS technology provides benefits of low cost and high integration with the interfacing circuits. The F-inverted antenna (FICA) is an antenna type originally designed for low profile missile applications which now has seen extensive usage in mobile communications [11].

The main challenge in the design of a RF Low Noise Amplifier using CMOS technology is its limitations towards breakdown voltage and the hot carrier effect. The oxide breakdown sets a limit on the maximum signal swing on the transistors drain node. An operation just slightly above the break down voltage may cause damage to the device. The hot carrier effect has reliability issues and can increase the threshold voltage, thereby degrading the performance of the system over time. For integration, it is quite evident to consider the RF front-end LNA manufactured with the same deep-submicron CMOS technology as the rest of the circuitry. Therefore lower output impedance and a higher current is required as compared to traditionally used LNA to achieve the same output power.

The EM Radiator (F- Inverted Antenna) integrated with LNA affects the noise figure of a microwave receiver. As the gain provided by the LNA increases, overall noise figure reduces tremendously. Overall the LNA has to provide high gain, good input and output impedance matching and very low noise figure. To counter these design specifications, this work presents a 5GHz highly efficient Co-design F-inverted antenna with LNA using TSMC 90nm CMOS process. The passive matching technique is used at input and output to reduce the degrading effects of the low quality factor of on-chip inductors [6, 9].

2. DESIGN TOPOLOGY OF LOW NOISE AMPLIFIER

The basic building block in all receiver architecture is low noise amplifier (LNA) which determines the system noise level. A LNA consumed considerable power due to its noise suppression, gain and linearity requirements capabilities. To design a LNA at microwave frequency and acceptable performance using a standard CMOS process without high Q inductors is a very challenging task. This section describes the basic design topology of LNA which is designed at 5GHz. This topology is to recycle the bias current so that it can be used by more than one stage. Fig.1 shows the LNA topology combined with the inductive source degeneration architecture with common source amplifier stage.

The signal flows through a capacitor from drain of the first stage to the gate of the second stage. The capacitor at the drain of the second stage is made large such that it acts as an AC ground. In this paper, the objective is to propose design of a LNA at 5GHz frequency with minimal noise figure, higher gain, higher improved efficiency and better linearity.

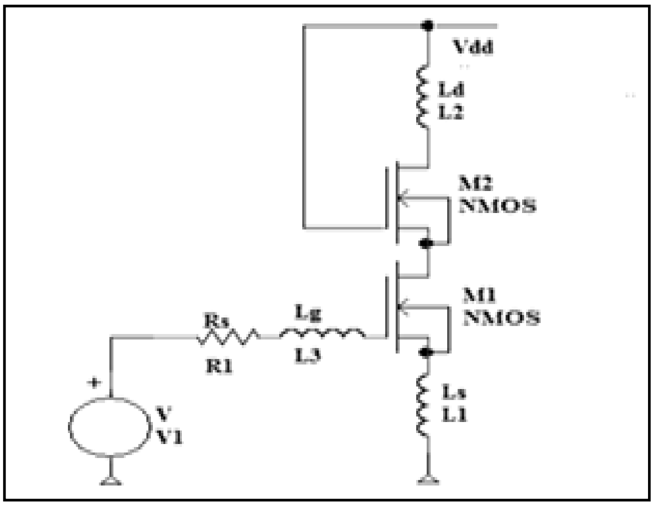

Fig.1. Topology used for designing LNA [8]

The selection of on-chip inductor is the key for designing a matching network for the determination of the quality for the matching network. The best power transmission is achieved by inter-stage matching between the first stage and the second stage by using good input/output impedance matching having 50Ω source and load impedance. This matching network could also be used to adjust the amplifier gain flatness and better amplification.

3. F-INVERTED ANTENNA CIRCUIT MODEL

A simple physical interpretation based circuit model has been devised, which helps in to interface antenna and rest of the circuit. The antenna is essentially a short monopole (0.024λ) over a ground plane with a helical impedance matching transmission line. This antenna has quite considerable radiation efficiency approximately around 50% and can be scaled to higher or lower frequency bands. The structure resembles like an inverted F. To achieve effective radiation, the antenna should contain a good radiating structure (the currents or electric fields add up in phase) to be able to transfer the power down into the transmission line. This indicates the impedance of the antenna to be roughly 50Ω (typically). Considering this objective, it is required to have the reactive component of the impedance (imaginary part) to be zero for maximum power transfer. The FICA antenna should have the feed which seeks a shorted transmission line. A shorted transmission line that is a small fraction of a wavelength (λ/4) creates an inductive reactive component. Similarly, the open circuited transmission on the FICA creates a capacitance to the right of the feed. The feed location is chosen to "balance out" the capacitance (to the right of the feed) and the inductance (to the left of the feed as indicated in the Fig.2). The inductance and capacitance cancel out, leaving just the radiation resistance. The FICA has the following advantages over traditional CMOS integrated Antenna: This circuit model provides a scenario to interface the antenna-circuit. It is physical based circuit model which only requires the information of two measured impedances and no complex optimization tools. The antenna efficiency is embedded in the circuit components of this model [13]. This explains the FICA impedance matching from an equivalent circuit point of view.

4. CO-DESIGN F-INVERTED ANTENNA WITH LOW NOISE AMPLIFIER

This part of the work introduced the implementation of an F-inverted antenna and LNA Co-design technique. This provides coupling of the FICA antenna equivalent circuit model and the LNA design and optimization methodology that have been separately described previously. The noise figure achieved for this design is only 1.5dB with 1mW power consumption. The design topology of Co-design F-inverted antenna integrated with low noise amplifier implemented utilizing Cadence Simulation tool has been depicted in Fig.3 below.

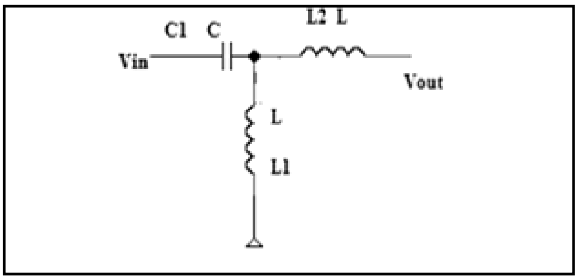

Fig.2. Equivalent Circuit model of FICA [8]

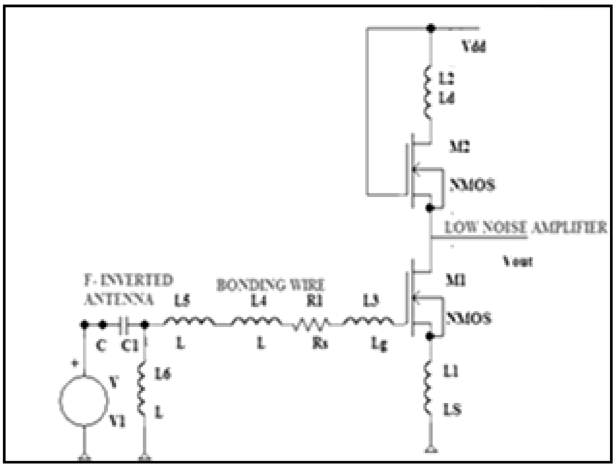

Fig.3. Design of implemented FICA integrated with Low Noise Amplifier

The conflicting requirements for noise, gain, and power consumption could be relaxed if a high quality factor (Q) input network is available. The FICA has low loss and high quality factor; this makes it more suitable for input matching networks. This design is very robust to noise due to its low noise sensitivity factor.

This proposed co-design method has great potential in commercial wireless radio receiver communication applications.

In this implemented circuit, both the input and output matching networks utilize the lumped inductors with low quality factor which causes high ohmic losses. The simplified circuit use resistor and inductor in series to model these inductors. Under constant power consumption, the gain S21 increases and the noise figure (NF) decreases with increasing Q of the inductors. At the output end, low Q inductors will decrease the amplifier gain, because the equivalent load impedance reduces with decreasing Q. At the input end, low Q inductors introduce thermal noise before amplification. In addition to this, low Q inductors at the input reduce the effective signal across the gate source capacitor of the input transistor which further reduces the amplifier gain. For these reasons, higher Q inductors are preferred at both the input and output wherever possible. Wound metal wire inductors have higher Q-value. Some antennas are resonating devices resembling high Q inductors. The external high Q antennas could be connected directly to integrated circuits (ICs) through bonding wires. This antenna-circuit co-design provides outstanding remedy for high level integration.

5. SIMULATION SETUPS FOR THE DESIGN

A detailed study of the co-design technique has been discussed previously. On the receiver side, the co-design got advantages of reduced size, cost and noise figure. The antenna input impedance has been achieved such that it requires no more constant and real impedance matching throughout the whole bandwidth. The dimensions of the Co-design can be further reduced. This work utilized the topology with inductor source degeneration in LNA side. In the design of LNAs, there are several objectives. These include minimizing the noise figure of the amplifier, providing high gain with sufficient linearity typically measured in terms of the third-order intercept point (IIP3) and providing a stable 50Ω input impedance to terminate an unknown length of transmission line which delivers signal from the antenna to the amplifier. A good input matching is even more critical when a pre-select filter precedes the LNA because such filters are often sensitive to the quality of their terminating impedances. The additional constraint of low power consumption which is imposed in portable systems further complicates the design process. The design of the LNA is one of the most critical tasks in building an RF front-end, as the LNA has the maximum contribution towards setting the overall noise figure of the system. The complete schematic co-design F-inverted antenna with LNA which can be used in receiver side for Ultra Wide Band (UWB) Mobile communication technology is illustrated in the Fig.3.

6. RESULTS AND DISCUSSION

In this section the most relevant simulation results of LNA design are presented. Simulations at the schematic level have been performed using Cadence Spectre RF tool. The library used is provided by TSMC 90nm CMOS process kit. State-of- the-art FICA integrated with LNA design should be highly efficient, high gain, desired output power device. The device technology choice also plays a crucial role for getting desired performance. The result indicates the maximum forward gain (S21) of around 4dB at 5GHz frequency. The input and output matching parameters S11 and S22 obtained to be -2.5dB and -3.5 dB respectively (as shown in Fig.4 and Fig.5 respectively).

Having same power consumption, the gain S21 increases and the noise figure (NF) decreases with increase in Q of the inductors. The quality factor of the inductor have its impact on the power consumed by the Co-design but also The peak power gain of Co-design antenna with LNA is found to be 11dB at 5GHz operating frequency (as shown in Fig.6). This is mainly due to low Q inductors at the input which reduces the effective signal across the gate source capacitor of the input transistor. This in turn would reduce the amplifier gain. The obtained noise figure has been depicted in Fig.8 where NF is obtained to be 1.5 dB at the centre frequency. The simulation results suggest that, about 10% and 10.75% of the total noise is contributed by each driving transistor and by each isolating transistor respectively.

The results obtained are compared with other research work [7, 14], given in Table.1.

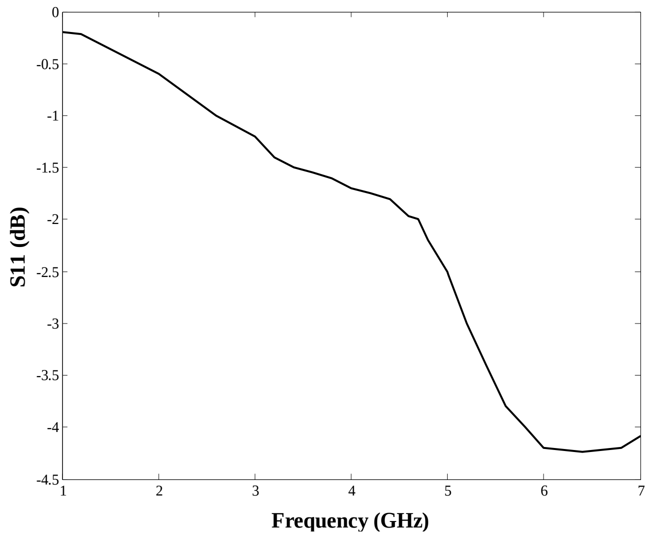

Fig.4. Obtained S11 parameter for the Co-design

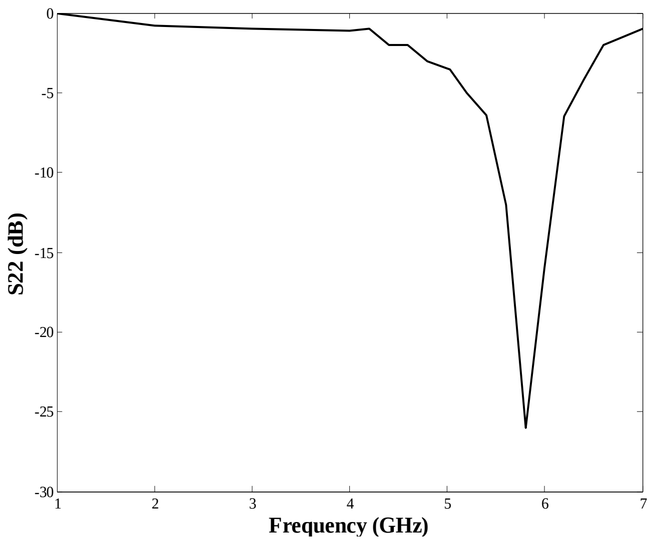

Fig.5. Obtained S22 parameter for the Co-design

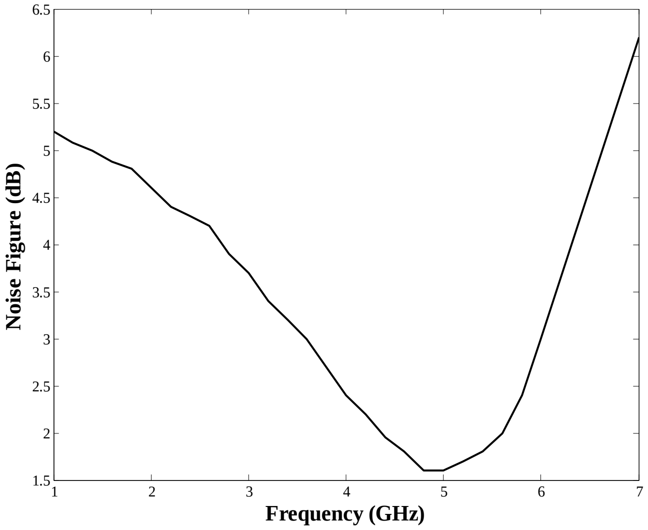

Fig.6. Obtained Noise Figure for the Co-design

Table.1. Comparative obtained results with other reported papers

	[14]	[7]	This work
Technology (μm)	0.25	0.18	0.09
Freq (GHz)	5.2	5	5
NF (dB)	3	2.96	1.5
Supply Voltage (V)	2	1.5	2
P_{dc}(mw)	10	10	1
S_{11} (dB)	-15	-9.23	-2.5
S_{22} (dB)	-30	-12.18	-3.5
Gain (dB)	10	NA	11
P_{out} (dBm)	NA	NA	10.25
1dB compression (dBm)	NA	NA	7.94
VSWR (dB)	NA	NA	3.7
PAE	NA	NA	35%
K-Factor	NA	NA	2.1

7. CONCLUSION

A Co-design F-inverted compact antenna (EM radiators) with LNA has been implemented in this work. The design utilized TSMC 90nm CMOS technology and can found its applications for the ultra wideband transceiver system mainly wide range Mobile Communications. The F-inverted antenna and single ended two stages Low Noise Amplifier using inductive source degeneration technique are used for realization of the circuit. The performance standards are met for this Co-design technique. Measurement results of the designed circuit obtained are a gain of 11dB, noise figure (NF) of 1.5dB, S11 of –2.5dB, and S21 of about 4dB with the DC power dissipation 1mW under 2V power supply. This work proposed a technique of electromagnetic radiator-LNA co-design method, which uses the antenna inductance, reduces or eliminates the need for on-chip input inductors, increases the level of system integration, reduces the LNA noise figure, increases the voltage gain and increases antenna efficiency.

8. FUTURE WORK

This work has further scopes for the future research in order to increase the performance of this Co-design. This work can be further improved in the design considerations through improved technology and by using different fabrication techniques. New inductors can be implemented for RF choke that can withstand current enough to supply the desired output power.

The Co-design can utilize the Carbon Nano Tube (CNT) technology such that it can be further miniaturized, more power efficient and more cost effective. This technique can be further employed with enhanced performance capabilities for Co-design of Power Amplifier-Radio Frequency MEMS Antenna.

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