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Ultra-Wideband 45-nm CMOS Low-Noise Amplifier Noise Figure – Gain trade-off for IEEE 802.15

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Abstract: In this paper the recent trends for noise figure are streamlined in concurrence to Ultra Wide Band (UWB) radio transmission spectrum. A comparative study is made between design of single-stage differential low-noise amplifier and inductor-less broadband LNAs in a digital 45 nm CMOS technology. As we move from inductor less impedance to capacitive impedance, the average noise figure decreases in decibel scale with decrease in gain when low noise amplifiers are operated for UWB frequency spectrum.

Keywords: Low noise amplifier (LNA), WLAN, Bluetooth, noise, gain, topology, ADS, CADENCE.

I. INTRODUCTION

Radio frequency design in present day is a multidisciplinary in nature. It involve various branches of engineering such as signal processing for radio frequency signals, microwave theory to understand various scattering phenomenon along with network theory for two-port parameters. In addition radio frequency designs involve various IEEE wireless standards to operate with communication theory. The most significant of all, a radio frequency design enthusiast must have a good knowledge of computer aided design (CAD) tools for present day design and simulation.

Radio frequency integrated circuit design using CMOS is entirely different from conventional radio frequency integrated circuit design. As radio frequency consumer market is growing at a very fast pace, low noise amplifiers are poised to be the research area. UWB being precisely operational at low emission levels such as device peripherals, handhelds, a UWB system extend only for indoor applications. Ultra-wide band wireless radios send short signal pulses over a broad spectrum. For example, a UWB signal centered at 5 GHz.

The wide signal allows UWB to commonly support high wireless data rates of 480 Mbps up to 1.6 Gbps at distances up to a few meters. At longer distances, UWB data rates drop considerably.

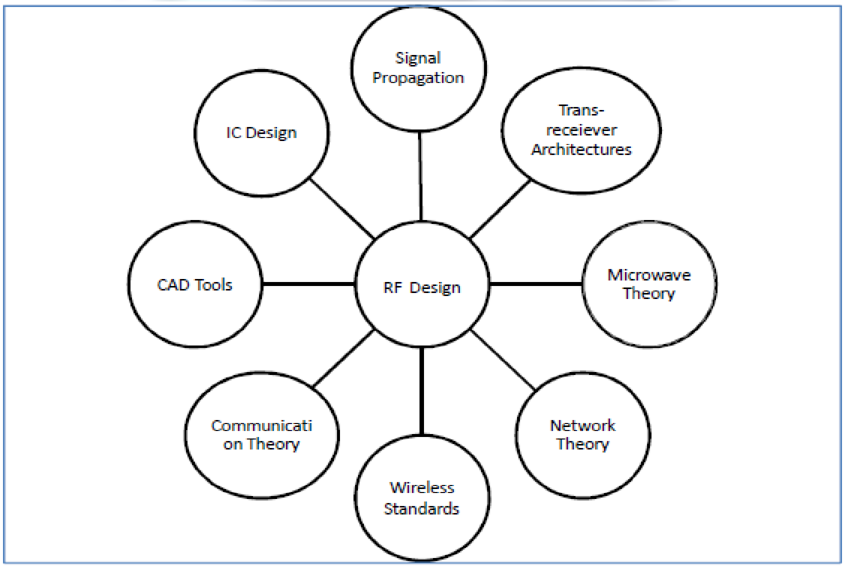

Fig. 1: Multidisciplinary nature of Radio frequency design

The very first stage of a receiver is a low-noise amplifier (LNA), whose main function is to provide enough gain to overcome the noise. Aside from providing this gain while adding as little noise as possible, an LNA should accommodate large signals without distortion and frequently must also present specific impedance, such as 50 ohms to the input source [1].

The power gain of an electrical network is the ratio of an output power to an input power. Unlike other signal gains, such as voltage and current gain, "power gain" may be ambiguous as the meaning of terms "input power" and "output power" is not always clear. Three important power gains are operating power gain, transducer power gain and available power gain. Power gain is an important performance measure for analogue circuits such as amplifiers.

The LNA is a non-linear characteristic device causes two main problems one is blocking and other is inter-modulation [2]. Low noise amplifier is use to reduce the external as well as internal noise. An amplifier will not only amplify the signal but also amplify the noise as well. So amplifier with minimum noise addition is required.

A. Bluetooth

It is a low-cost low-power technology for wireless personal area networks (WPANs), and is commonly used in hands free.

Table I: Summary of Bluetooth IEEE 802.15 specifications [3].

Parameter	Value
Frequency	2402-2480 MHz
Channel spacing	1 MHz
Number of channels	79
Multiple access method	Frequency hop (1.6K hops/s)
Duplex method	TDD
Users per channel	200(7 active)
Modulation	GFSK
Symbol rate	1 MS/s

II. DESIGN TRADE-OFFS

The design of a low noise amplifier revolves around six design trade-offs.

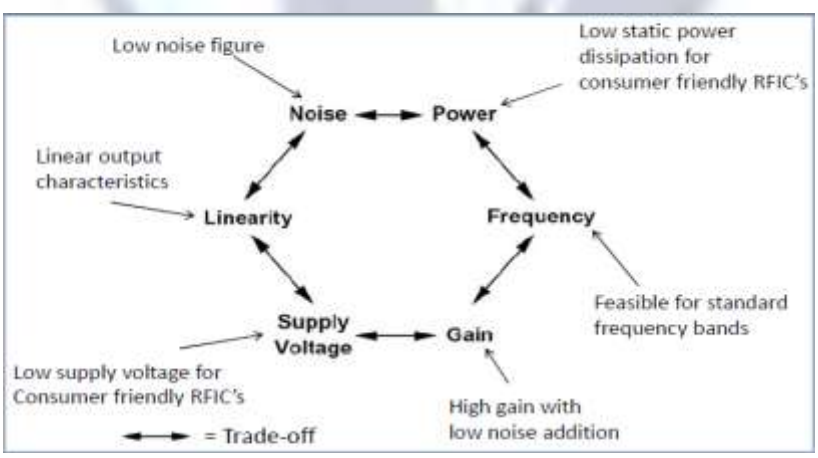

Fig. 2: Design trade-offs for LNA

The design trade-offs gives a clear view about the amount of complexities involved in designing a LNA which includes the choice of operating frequency which depends upon the application, the amount of external as well as internal noise added by LNA taking the amount of power dissipation and gain into consideration [4]. The power supplied and biasing provided depends upon the nano-meter (nm) technology used along with the range for which the LNA provides linear operation. The above discussed trade- offs are repeatedly simulated and emulated for the desired response varying for varying applications for which design of LNA is sought [5].

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III. LNA OPERATING FREQUENCY

The foremost is the determination of the frequency spectrum for which the design of LNA is sought.

Table II. Microwave frequency allocations according to IEEE [4]

Band	L	S	C	X	Ku
Frequency range	.8-2 GHz	2-4 GHz	4-8 GHz	8-12 GHz	12-18 GHz
Band	K	Ka	V	W	C, X band used for present work.
Frequency range	18-27 GHz	27-40 GHz	40-75 GHz	75-110 GHz	

The C and X bands have been intensively used for mobile and wireless communications and are the area of interest for this paper. Radio frequency (RF) range- 3 KHz to 300 GHz. Microwave is the subset of the RF range [6]. RF covers 3 Hz to 300 Hz while microwave occupies the higher frequency at 300MHz to 300 GHz.

IV. GAIN-BANDWIDTH TRADE-OFF FOR NOISE FIGURE FOR UWB LNA DESIGN

The recent process technologies revolve around 0.13µm, 0.18µm, 0.35µm, 45nm, 65nm, 90nm CMOS and SiGe BiCMOS. The present work revolves about 45nm process technology.

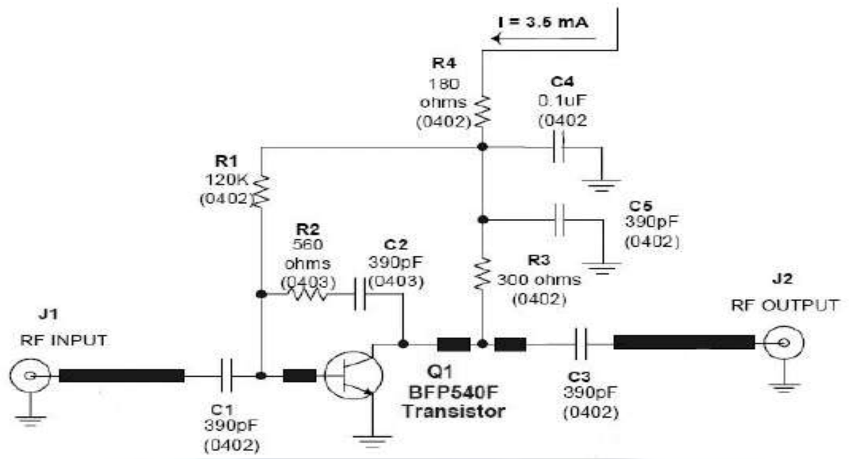

Fig. 3: Schematic of UWB LNA using BJT [9]

Table III: Gain-Bandwidth trade-off for Ultra- Wideband 45-nm CMOS Low-Noise Amplifiers.

Process Technology	BW (-3 dB) [GHz]	Gain [dB] Peak	Gain [dB] Ripple	NF [dB] min	NF [dB] max	NF [dB] average
45nm [7]	2.5-12.0	10.5	1.3	4.6	5.6	5.3
45nm [7]	2.8-12.0	14.2	2.1	5.1	6.3	5.6
45nm [7]	2.3-9.8	9.3	4.0	5.1	6.0	5.7
45nm [7]	2.5-9.6	12.5	4.3	5.5	6.5	5.9
45nm [8]	10.0	12.9	-	2.0	2.6	-
45nm [8]	10.1	12.0	-	2.4	2.9	-

The foremost requirement for a consumerable design for LNA is the minimum noise figure for the amplifier. The insight study for Gain-Bandwidth trade-off for Ultra-Wideband 45-nm CMOS Low-Noise Amplifiers (LNAs), two state-of-the-art CMOS technologies, a planar bulk one and a SOI FinFET one, featuring 45-nm minimum gate length are considered and compared. An LNA designer can use at least five methods for circuit stabilization. The first one consists of resistive loading of the input. This method, although capable of improving the stability of the circuit, also degrades the noise of the LNA and is almost never used. Output resistive loading is preferred method of circuit stabilization. This method should be carefully used because it effects are lower gain and lower P1dB point (thus IP3 point).
The third method uses collector to base resistor-inductor-capacitor (RLC) feedback to lower the gain at the lower frequencies and hence improve the stability of the circuit. The fourth method consists of filter matching, usually used at the output of the transistor, to decrease the gain at a specific narrow bandwidth frequency. [9] Ponton et al [7] deals with the design of single-stage differential low-noise amplifiers for ultra-wideband (UWB) applications while comparing state-of-the-art planar bulk and silicon-on-insulator (SOI) FinFET CMOS technologies for 45-nm gate length. A. Bevilacqua et al [8] uses shunt-shunt resistive feedback used to design inductorless broadband LNAs in a digital 45 nm CMOS technology give 18 dB gain over a 10 GHz bandwidth. When the work of Ponton et al. and A. Bevilacqua et al we find superior cutoff frequency of planar devices in the inversion region, which allows the achievement of noise figure and voltage gain comparable to the

FinFET counterpart, with a smaller power consumption. As we move from inductor less impedance to capacitive impedance, the average noise figure decreases in decibel scale with decrease in gain when low noise amplifiers are operated for UWB frequency spectrum.

V. CONCLUSION AND FUTURE WORK

The present work provides a sightful guide for various facets involved in design of a low noise amplifier for UWB. Future work involves selection and concretization of various parameters into a simulation model to evolve prospective design stategies for LNAs.

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