Design Methodologies for Radio Frequency Low Noise Amplifier for IEEE Standards under IEEE 802.11 b/g and IEEE 802.15

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Abstract: *In present day society where communication technologies are advancing at spiral rate, the need for efficient integrated circuit design to transmit and receive signals at unlicensed frequency spectrum is inevitable. At receiving front end, the low noise amplifier design, being the first building block to receive the signal puts a tremendous challenge on modern day radio frequency engineers to meet real world problems involving trade-off in design issues. In this paper the trade-offs were streamlined in concurrence to IEEE 802.11 b/g and IEEE 802.15.*

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

I. INTRODUCTION

The wireless market is developing very fast in this world. An increasing number of users and the need for higher data rates have led to an increasing number of various wireless communication standards like IEEE 802.11 WLAN. As present day market are highly sensitive to price, the result turns out in shape of demand for flexible and low-cost radio architectures for portable applications is increasing.

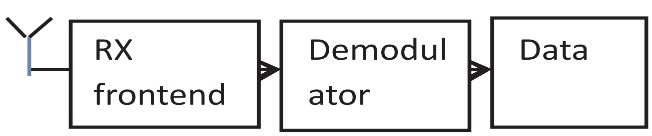

Fig. 1: Schematic diagram of a generic receiver

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, noise figure for a receiver is dominated by the power gain, noise figure provided by LNA. 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. *Wireless Local Area Networks*

While mobile phone data transfer is designated for global communications withlarge coverage range, higher performance can be obtained in local environments equipped with WLANs (Wireless Local Area Networks). In addition to data communication via base stations, WLAN devices can also operate peer-to-peer [3]. WLAN systems with very short coverage below about 10 m are segmented into WPANs (Wireless Personal Area Networks) or WBANs (Wireless Body Area Networks). Among the most important WLANs are the 802.11 standards [4]. Potential applications are high-speed short-range communication, internet access, video streaming, traffic control, medical imaging, security systems, sensors and many more.

Table 1: Summary of WLAN 802.11 (b/g) Standards [5, 6]

	IEEE Standard 802.11(b)	IEEE Standard 802.11(g)
Release	Sep-1999	June-2003
Frequency	2.4 GHz	2.4 GHz
Max. data Rate	11 Mbps	54 Mbps
Modulation	DSSS	DSSS, OFDM
Indoor Range	35 m	38 m
Output range	140m	140 m

B. Bluetooth

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

Table 2: Summary of Bluetooth IEEE 802.15 specifications [7]

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.

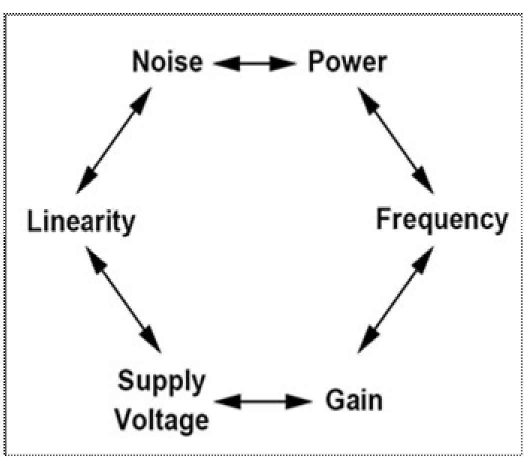

Fig. 2: Design trade-offs for LNA

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 [8]. 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 [9].

III. LNA OPERATING FREQUENCY

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

Table 3: Microwave frequency allocations according to IEEE

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	L, S, C band used for present work
Frequency range	18-27 GHz	27-40 GHz	40-75 GHz	75-110 GHz	

The L, S and C 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 [10]. RF covers 3 Hz to 300 Hz while microwave occupies the higher frequency at 300MHz to 300 GHz.

IV. CHOICE OF TECHNOLOGY

The choice of technology points towards the transistors to be emplyoed in design of LNA which may include any one of the following as: CMOS, BiCMOS, MESFET, HEMT, Bipolar transistors, HBT [12]. The (Process Design Kits) PDKs available by different vendors with process technology as GLOBALFOUNDRIES, IBM Semiconductor Solutions, united monolithic semiconductors, Global Communication Semiconductors (GCS), Taiwan Semiconductor Manufacturing Company (TSMC), TSMC 28nm, TSMC 40nm, TSMC 45nm, TSMC 55nm, TSMC 65nm, TSMC 90nm, TSMC 0.13µm, TSMC 0.18µm [13]. The choice of technology dectates the biaing voltage and biasing current for the design of LNA.

V. CHOICE OF MATERIAL

The present day integrated circuits for radio frequency are widely implemented in silicon (Se), silicon germanium(SiGe), gallium arsenide (GaAs) or indium phosphide (InP), while future technologies are ramping towards Silicon carbide and gallium nitride. The characteristic comparison gives a judicious choice for material to be employed for distinct applications.

Table 4: Key characteristic comparison for the choice of materail [11]

	Si	**SiC**	**InP**	**GaAs**	**GaC**
Electron mobility (cm^3/Vs)	1500	700	5400	8500	1000-2000
Substrate resistance (&!cm)	1-20	1-20	>1000	>1000	>1000
Number of transistors in IC	> 1 billion	<200	<500	<1000	<50
Costs prototype/ mass fabricaiton	High low	Very high/ n.a.	High/ very high	Low/ high	Very high/ n.a.
Bandgap (eV)	1.1	3.26	1.3	1.42	3.49
Critical breakdown field(MV/cm)	0.3	3.0	0.5	0.4	3.0

VI. CHOICE OF TOPOLOGY

The commonsource circuit exhibits both voltage and circuit gain. Consequently, the common-source circuit has superior power gain performance. Due to the capacitiveand high-ohmic characteristics, impedance matching is mandatory to achieve maximum performances at 50-Ù terminations. The high power gain cannot be exploited towards high frequencies due to the large Miller capacitance seen at the input, which acts as lowpass filter [14]. The cascode topology provides the best performance towards highest frequencies since it has a much lower Miller effect and a higher output impedance which lowers the output losses of the transistors offering high voltage gain but no current gain, the common gate circuit provides a smaller power gain than the common source topology. Due to the low andresistive input impedance, the input matching is simplified. Thus, the configurationis well suited for input stages of wideband amplifiers. Due to the low impact of the Miller effect, a high bandwidth can be achieved. By proper choice of thebias and gate width of the transistor, 50 Ù input matching can be achieved without inductive elements. This makes the design of compact circuits possible [15]. The common drain configuration has a high current gain and no voltage gain.It features a low and resistive output impedance simplifying the output matching. Hence, the configuration is a favourable candidate for output stages of wideband amplifiers.

Table 5:. Topological choice for requisite LNA design for various applications where Zin = Input impedance, Zout = Output impedance, MAG = Maximum allowable gain, BW = Bandwidth

	Common source (CS)	**Common gate (CG)**	**Common Drain (CD)**	**Cascode**
Zin	High, mainly capacitive	Low, mainly resistive	High, mainly capacitive	High, mainly capacitive
Zout	High	High	Low	Very High
Mag	High	Moderate	Low	Very High
BW	Limited by Miller effect	Larger than CS	Larger than CS	Larger than
Fmin	$1 + \frac{2}{\sqrt{5}} \frac{W}{W_t} \sqrt{\gamma\delta (1 - \lvert c^2 \rvert)}$	=CS	<<CS	>CS
Superior application	High power gain, frequency converters	Moderate power gain, input	Output buffer e.g. for VCO	Highest power gain at highest

Since the voltage gain is smaller than unity, the equivalent Miller capacitance is low minimising the loading of previous stages. Thus, the commondrain topology is frequently used as output buffer, e.g. for VCOs [16].

VII. DESIRED PARAMETER EXTRACTION

Many vendors provide CAD tools for simulation. Design kits (PDKs), technology files that support a variety of CAD tools, e.g. Cadence, Mentor, Synopsys and Tanner. These are distributed free of charge and are made available through our document server after signature of the customer agreement and the vendor required agreements. MOSIS provides CAD tool support files for specific platforms and tools. A set of desired trade-offs operations need to be performed recurcively to get the most balanced performance.

VIII. CONCLUSION AND FUTURE WORK

The present work provides a sightful guide for various facets involved in design of a low noise amplifier for IEEE 802.11b/g and for bluetooth standards. Future work involves selection and concretization of various parameters into a simulation model to evolve prospective design stategies for LNAs.

REFERENCES

[1]. Thomas H. Lee, "The Design of CMOS Radio-Frequency Integrated Circuits" 2nd Edition, Cambridge University Press, 2004, ISBN 0-521-61389-2.

[2]. Inder J. BAHL, "Fundamentals of RF and Microwave Transistor Amplifiers" first Edition, WILEY, 2009, ISBN 978-0-470-39166-2.

[3]. Aki Silvennoinen, Teemu Karttima, Michel Hall, Sven-Gustav Haggman, "IEEE 802.11b WLAN capacity and performance measurements in channel with large delay spreads," IEEE Military Communications Conference, Oct.2004, vol. 2, pp.693-696.

[4]. V.dasarathan, M.Muthukumar and Dr. Bill William Turney, "Outdoor channel measurement, Path loss modelling and system simulation of 2.4 GHz WLAN IEEE 802.11g in indian rural environments," IEEE Asia-Pacific Microwave Conference, APMC 2007, Dec.2007, pp.1-4.

[5]. Jun Zhao, Zihua Guo and Wenwu, "Power efficiency in IEEE 802.11a WLAN with cross-layer adaption," IEEE International Conf. On Communications, ICC 2003, May 2003, vol. 3, pp.2030-2034.

[6]. Josep Soler-Garrido, Daisuke Takeda and Yoshimasa Egashira, "Experiment evaluation of an IEEE 802.11n wireless LAN system employing lattice reduction aided MIMO detection," IEEE Global Telecommunications Conference, GLOBECOM 2010, Dec.2010, pp.1-5.

[7]. Younquan Zheng and Zhenming Feng, "Simplifications of the bluetooth radio devices," IEEE International Workshop on Networking Appliances,2002, pp.107- 115.

[8]. J.Kaukovuori, J.Ryynanen, and K.Halonen, "CMOS Low-Noise Amplifier Analysis and Optimization for Wideband Applications," IEEE Research in Microelectronics and Electronics, September 2006, pp. 445-448.

[9]. Massimo Brandolini, Paolo Rossi, Danilo Manstretta and Francesco Svelto, "Toward Multi-standard Mobile Terminals-Fully Integrated Receivers Requirements and Architectures,"IEEE Transactions on Microwave Theory and Techniques, March 2005, Vol. 53, pp. 1026-1038.

[10]. Bagher Afshar and Ali M. Niknejad, X/Ku band CMOS LNA design techniques," IEEE Custom Integrated Circuits Conference, CICC 06 , September 2006, pp. 389- 392.

[11]. Seon-SikMyoung, Sang-Hoon Cheon, Jong-GwanYook, "Low-Noise and High Linearity LNA based on InGap/GaAS HBT for 5.3 GHz WLAN," IEEE Gallium Arsenide and Other Semiconductor Application Symposium EGAAS 2005, Oct. 2005, pp. 89-92.

[12]. Yuan Gao, YuanjinZheng, Ban-Leong Ooi., "A 0.18ìm CMOS UWB LNA with 5GHz Interference Rejection," RFIC Symposium, June 2007, pp. 47-50.

[13]. Y.S.Wang, L.-H. Lu, "5.7 GHz Low-Power Variable Gain LNA in 0.18ìm CMOS," IEEE Electronics Letters, Jan. 2005, Vol. 41, pp. 66-68.

[14]. P. Rossi, A. Liscidini, M. Brandolini, and F. Svelto, "A variable gain rf front-end, based on a voltage-voltage feedback LNA, for multistandard applications," IEEE J. Solid-State Circuits, Vol. 40, no. 3, pp. 690–697, March. 2005.

[15]. Jaime Martinez-Castillo and Alejandro Diaz-Sanchez, "Differential transimpedance amplifiers for communications systems based on common-gate topology," IEEE International Symposium on Circuits and Systems, ISCAS 2002, Aug.2002, Vol. 2, pp.97-100.

[l6]. A. Scholten, L. Tiemeijer, R. van Langevelde, R. Havens, A. Van Duijnhoven, R. de kort and D. Klaassen, " Compact modelling of noise for RF CMOS circuit design," IEEE proceeding-Circuits, Devices and Systems, April 2004 Vol. 151,pp. 167-174.

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