Noise Figure analysis of S-band low noise amplifiers for IEEE 802.11 b/g and IEEE 802.15 for recent process technologies

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Abstract: The sensitivity of communications systems is limited by noise. Noise figure for low noise amplifier (LNA) design is highly relevant for LNA’s prima-facie function for adding as low as noise to be added to the desired signal amplification when simulated for system level configuration for varied frequencies ranges. In this paper the noise figure was analyzed as performance parameter for S-band for 0.18 μm CMOS LNA designs for IEEE 802.11 b/g and IEEE 802.15. This paper further concluded that noise figure experienced minima at 0.18 μm CMOS while it increased towards maxima when deviations were studied in process technology dimensions.

Keywords: Low noise amplifier (LNA), Scattering parameters, S-matrix, S-band, WLAN, noise, noise figure, cascade, gain, topology, process technology.

1. 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. 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. Thus, a low noise amplifier (LNA) is an amplifier which amplifies the signal with low noise addition, that is, a LNA doesn’t amplify the noise signal however the signal of interest is amplified with the LNA gain.

2. DESIGN TRADE-OFFS

The design of a low noise amplifier revolves around six design trade-offs. To clearly measure noise input by amplifier while amplifying the desired signal, the decibel unit noise figure is used.

Fig. 1: Design trade-offs for LNA
The design trade-offs give 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 [3]. 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 [4].

A. Wireless Local Area Networks

While mobile phone data transfer is designated for global communications with large 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 [5]. 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 [6].

Table I: Summary of WLAN 802.11 (b/g) Standards [7, 8].

<table>
<thead>
<tr>
<th>Band</th>
<th>L</th>
<th>S</th>
<th>C</th>
<th>X</th>
<th>Ku</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency range</td>
<td>8-2 GHz</td>
<td>2-4 GHz</td>
<td>4-8 GHz</td>
<td>8-12 GHz</td>
<td>12-18 GHz</td>
</tr>
<tr>
<td>Band</td>
<td>K</td>
<td>Ka</td>
<td>V</td>
<td>W</td>
<td>S band used for present work</td>
</tr>
<tr>
<td>Frequency range</td>
<td>18-27 GHz</td>
<td>27-40 GHz</td>
<td>40-75 GHz</td>
<td>75-110 GHz</td>
<td></td>
</tr>
</tbody>
</table>

3. 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

<table>
<thead>
<tr>
<th></th>
<th>IEEE Standard 802.11(b)</th>
<th>IEEE Standard 802.11(g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Release</td>
<td>Sep-1999</td>
<td>June-2003</td>
</tr>
<tr>
<td>Frequency</td>
<td>2.4 GHz</td>
<td>2.4 GHz</td>
</tr>
<tr>
<td>Max. data Rate</td>
<td>11 Mbps</td>
<td>54 Mbps</td>
</tr>
<tr>
<td>Modulation</td>
<td>DSSS</td>
<td>DSSS, OFDM</td>
</tr>
<tr>
<td>Indoor Range</td>
<td>35 meter</td>
<td>38 meter</td>
</tr>
<tr>
<td>Output range</td>
<td>140 meter</td>
<td>140 meter</td>
</tr>
</tbody>
</table>

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 [9]. RF covers 3 Hz to 300 Hz while microwave occupies the higher frequency at 300 MHz to 300 GHz.

4. CHOICE OF TECHNOLOGY

The choice of technology points towards the transistors to be employed in design of LNA which may include any one of the following as: CMOS, BiCMOS, MESFET, HEMT, Bipolar transistors, HBT [10]. The (Process Design Kits) PDKs available by different vendors with process technology as GLOBAL FOUNDRIES, 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 [11]. The choice of technology dictates the biasing voltage and biasing current for the design of LNA.

5. NOISE FIGURE FOR LNA

Low power applications, where the signal power is limited, noise plays an important role. A loose definition of noise may be the sum of any random signals uncorrelated to the signal of interest. Thus, within the frequency band of the desired signal, the filtering of noise is very difficult or even impossible.

Noise figure may be calculated as:

\[ NF = \frac{SNR_{in}}{SNR_{out}} = \frac{S_{in}/N_{in}}{S_{out}/N_{out}} \]  

(1)

As a function of device

\[ NF = \frac{N_{device} + G \cdot N_{source}}{G \cdot N_{source}} \]  

(2)

where G is Power gain of the device.

For a low noise amplifier, the noise figure may be calculated as:

\[ NF_{frontend} = NF_{LNA} + \frac{NF_{subsequent} - 1}{G_{LNA}} \]  

(3)

\[ NF - 1 = NF_1 - 1 + \frac{NF_2 - 1}{G_1} + \frac{NF_3 - 1}{G_1G_2} + \ldots + \frac{NF_K - 1}{G_1G_2\ldots G_{K-1}} \]  

(4)

Fig. 2: Noise figure calculation for cascaded amplifier

Fig. 3: Noise approximation for various noise present in electrical engineering domain

Noise figure of a general MOS transistor can be calculated as:

\[ NF = \frac{N_{device} + G \cdot N_{in}}{G \cdot N_{in}} = 1 + \frac{4kT \gamma g_m}{4kTR_i g_m} \frac{1}{1 + \omega^2 R_i g_m (g_m / C_{gs})^2} \]

\[ = 1 + \gamma \frac{g_m}{R_i g_m} (1 + \omega^2 R_i^2 C_{gs}^2) \]

\[ = 1 + \gamma \frac{g_m}{R_i g_m} + \gamma R_i g_m \frac{\omega^2}{(g_m / C_{gs})^2} \]  

(5)

or the above equation can be written as:
Noise performance for low frequency approximation can be considered for the case when input is matched i.e. 
\[ R_c = R_t = R \]
Therefore noise figure can be approximated for S-band 0.18 μm CMOS low noise amplifiers (LNAs) for IEEE 802.11 b/g and IEEE 802.15 as:
\[ NF \geq 2 + \frac{4\gamma}{g_m R} \]  

\[(7)\]

6. PERFORMANCE EVALUATIONS FOR NOISE FIGURE FOR S-BAND LNA DESIGN

The recent process technologies revolve around 0.13μm, 0.18μm 0.35μm CMOS and SiGe BiCMOS, for which a comprehensive study is tabularised. The foremost requirement for a consumerable design for LNA is the minimum noise figure for the amplifier. A simple study of table III reveals that the best choice of design for LNA is the design conceived by Hyung jin Lee, 2005 [15] for 0.18 μm CMOS technology, however table for interdisciplinary process technology states that as the process technology dimensions approaches to 0.18 μm, the noise figure decreases while the noise figure considerably increases as the process technology dimensions deviate in both directions. In present day world when most of consumer items are already in market with 0.18 μm CMOS technology, this relevations from this paper is highly motivating.

Table III: Performance evaluations of Noise Figure for design of LNA with recent process technology

<table>
<thead>
<tr>
<th>Technology</th>
<th>NF (dB)</th>
</tr>
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<tbody>
<tr>
<td>K Han, 2008 [12]</td>
<td>0.13 μm CMOS</td>
</tr>
<tr>
<td>Hanil Lee, 2006 [13]</td>
<td>0.13 μm CMOS</td>
</tr>
<tr>
<td>Bagher Afshar, 2006 [14]</td>
<td>0.18 μm CMOS</td>
</tr>
<tr>
<td>Hyung jin Lee, 2005 [15]</td>
<td>0.18 μm CMOS</td>
</tr>
<tr>
<td>K. Onsato 2004 [16]</td>
<td>0.35 μm CMOS</td>
</tr>
<tr>
<td>A. Ismail, 2004 [17]</td>
<td>SiGe BiCMOS</td>
</tr>
</tbody>
</table>

7. CONCLUSION

The present work provides a sightful guide for various facets involving noise figure as performance parameter for S-band design of a low noise amplifier for IEEE 802.11b/g and IEEE 802.15 standards for the latest process technologies. It is further concluded that noise figure experiences minima at 0.18 μm CMOS while it increases towards maxima when deviations are studied in process technology dimensions.

REFERENCES


