Investigation and Optimization of RF LNA Energy Efficiency

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***Abstract*— This paper investigates a particular energy efficiency problem concerning radio frequency low noise amplifiers, IEEE 802.15.4 (ZigBee) 2.45GHz receiver sensitivity. The trade-off between low noise figure and power consumption is highlighted. Using a low energy low noise amplifier to improve the receiver sensitivity and resulting in extended range is demonstrated.**

***Index Terms*— Noise Figure (NF), low noise amplifier (LNA), receiver sensitivity, power efficiency, ZigBee.**

I. Introduction

A well-known standard method to improve a receiver sensitivity is to utilize a low noise amplifier (LNA) as shown in figure. 1.

The RF signal received by antenna is usually amplified by the LNA at first, so the specifications of the LNA are very important. According to the noise figure cascade equation (1), receiver system noise figure (NF) is dominated by the NF of the LNA.

$$F_{sys} = F_{LNA} + \frac{F_2 - 1}{G_1} \qquad (1)$$

$$P_{\langle in,min|dBm\rangle} = -\frac{174dBm}{Hz} + NF_{dB} + SNR_{min/dB} + 10logB \qquad (2)$$

According to equation (2), the sensitivity of the receiver is determined by signal bandwidth, the signal to noise (SNR) and NF. Assuming that the LNA is the first gain stage in the receiver, the corresponding noise figure would be directly added to that of the receiver system. With a duplexer NF of approximate 2dB, the overall noise figure value of 4dB, if the noise of the stages following the LNA is neglected. An SNR of 8dB in a bandwidth of 200 KHz is required, and the receiver sensitivity is about -109dB [1]. To improve the receiver sensitivity of the receiver, decreasing the NF of LNA is quite important.

Nevertheless, the larger gain of LNA will make the NF larger. The challenge we encountered is to reduce the NF of the LNA to improve the receiver sensitivity based on ensuring the gain of the LNA.

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Meanwhile, low energy efficiency is also a problem that should be addressed. For instance, a typical E-PHEMT low noise device may have an energy efficiency less than 1%. To improve energy efficiency, we need to reduce the DC power supplied while maintaining satisfied gain and linearity. However the relationship (3) is not linear and also depends on optimal matching techniques.

$$NF > 1 + \frac{\overline{i_d^2}}{\overline{i_s^2}} \qquad (3)$$

This report investigates the trade-off between DC power and NF for E-PHEMT devices. A design of experiments focuses on IEEE 802.4 (2.45 GHz) but the objective is to extend the optimization techniques to higher frequency bands (e.g. 802.11p uses 5.9 GHz band) by using modeling tools such as Keysight ADS.

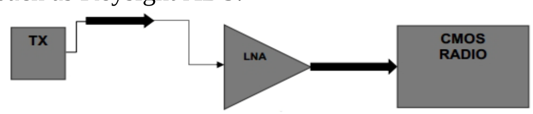

Fig.1.Reference model

II. Design of The LNA

A. *Receiver sensitivity*

Generally, receiver sensitivity can be measured directly by using a noise source and a network analyzer. However, some noise (especially 2.4GHz emissions) may interfere with the testing process. To prevent this situation, the best method is to test the receiver sensitivity in a screened anechoic chamber. As shown in the Figure.2, the procedure is to test the receiver sensitivity with a reference ZigBee radio (ETRX357-no LNA only Integrated 2.4GHz Antenna) and an enhanced ZigBee radio (ETXRX357-LRS integrated 2.4GHz antenna and integrated LNA) respectively.

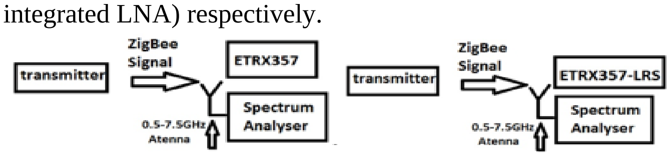

Fig. 2. Comparison of the receiver sensitivity with ETRX357 and ETRX357-LRS in the Anechoic Chamber in ITT Dublin

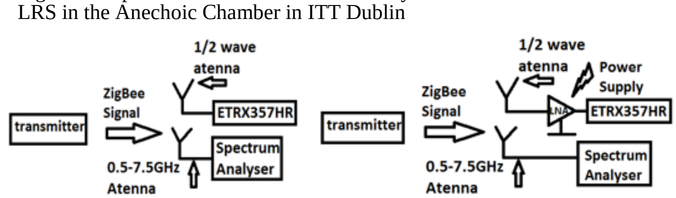

Fig. 3. Comparison of the receiver sensitivity with ETRX357HR and ETRX357 (plus external LNA) in the anechoic chamber in ITT Dublin

The integrated LNA is a component of the ETRX357-LRS radio and power supply is constant. In order to test the effect of DC power reduction, an external LNA based on an E-PHEMT device is utilized. Figure.3 shows the comparison of the receiver sensitivity with ETRX357HR (plus only external antenna) and ETRX357HR (plus external antenna and external LNA). Three different voltages (1.6V, 3.14V and 3.52V) are applied to the external LNA and the results are extracted for each condition.

B. Energy Consumption Optimization

Equation (4) defines the power energy efficiency of the LNA. DC power consists of the supply power of LNA and ZigBee radio IC. On the basis of ZigBee board specification, the supply power of the ZigBee board is 3dBm. Hence, supply power change of LNA dominantly determine dominantly DC supply power change. Moreover, with different drain current of LNA, noise figure and gain of LNA can be affected which leads to the different receiver sensitivity from part A. When drain current increases, output RF power and DC supply power also increases. Therefore, it is possible to adjust the drain current to find the best energy efficiency.

$$Energy\ Efficiency\ \eta = \frac{RF\ Output\ Power}{DC\ Supply\ Power} \quad (4)$$

III. RESULTS

A. Receiver sensitivity

1. Internal LNA

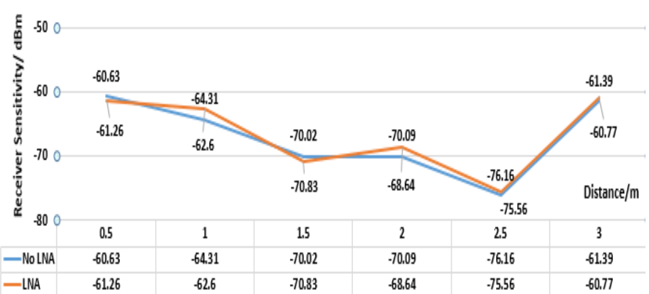

Fig. 6. Investigation for internal LNA in the Anechoic Chamber

According to Fig.6, the results of receiver sensitivity with internal LNA and without LNA are nearly almost equal. However, in the theoretical analysis, the receiver sensitivity with LNA is higher. The result of spectrum analyzer is the receiver sensitivity at the receiver antenna which means that it doesn't pass by the internal LNA for ETRX357-LRS. This is the reason that why the results of different conditions are equal.

2. External LNA

In the Fig.7, receiver sensitivity values with LNA are lower than that without LNA. Generally, the receiver sensitivity values of same ETRX radio are equal. By adding the LNA, antenna with LNA needs lower receiver sensitivity than antenna without LNA because LNA improves the receiver sensitivity. In addition, the improved receiver sensitivity is affected by the power supply. While improved receiver sensitivity is nearly 8dBm at supply voltage 1.6V of LNA, it is nearly 12dBm at supply voltage 3.14V. What's more, it reaches the maximum point about 14dBm at supply voltage 4.52V.

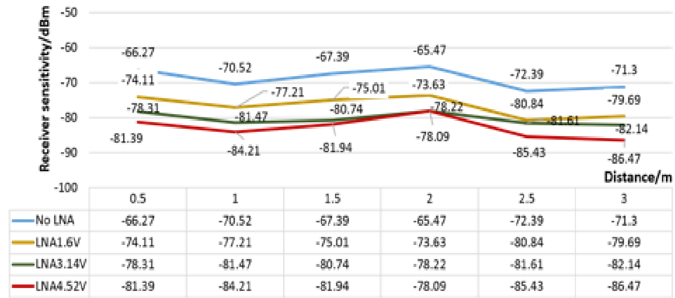

Fig. 7. Investigation of external LNA in the anechoic chamber

B. Energy Efficiency

Table.1

Output Power (dBm)	Energy efficiency (%)		
	4.52V & 48.2mA	3.14V & 30.7mA	1.6V & 11.6mA
-40	0.001137067	0.001626	0.003891
-45	0.00355333	0.00065	0.001216
-50	0.000111042	0.00026	0.00038
-55	3.47005E-05	0.000104	0.000119

Due to adding a LNA, the receiver sensitivity can be improved. With the different drain current, noise figure and gain of LNA are different, which leads to different receiver sensitivity. When drain current becomes larger, the receiver sensitivity is larger and output RF power is larger in the same output power. According to equation (4), it is easy to calculate energy efficiency, which shows in the Table.1.

IV. CONCLUSION

In this project, with the help of ZigBee board and external LNA, it concludes that adding a LNA can improve the receiver sensitivity. Moreover, drain current of LNA have an impact on noise figure and gain of LNA then affects the receiver sensitivity. Higher drain current produces higher RF output power because of higher receiver sensitivity. However, higher drain current needs higher supply power. By adjusting the drain current, when drain current is 11.6mA and output power is -40 dBm, maximum energy efficiency can be achieved about 0.003891%.

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