Power Efficient Wideband Power LNA for WSN

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Abstract. This paper proposes a power-efficient low noise amplifier (LNA) for wireless sensor networks (WSN) applications. The energy consumption of LNAs plays a significant role in the design of WSN applications seeking less energy consumption. The transistor (BP1V01M0) is used in this article to get a low noise figure (NF) of 1.2dB and high power gain of 12.63 dB. The design covers the transistor biasing circuit, the transistor stability test, and, finally, the matching network establishment. The results of the simulation show that the proposed LNA design operates at 2.4 GHz with a wideband impedance bandwidth of 2 GHz with a low power consumption of 1 mW.

Keywords: Low noise power amplifier, LNA, wideband, Wireless sensor networks, AWR.

1. Introduction
Nowadays, wireless RF technologies have grown rapidly to be vitally deployed in most daily life applications. One of these technologies is the wireless sensor networks. Monitoring human activities, recording biological data, being deployed in fields where human's presence is forbidden, and alarming any up normality in these activities are just a few features of these wireless networks. Designing these technologies is not an easy task as they require accuracy, reliability, and power efficiency. Research efforts have been focusing on designing the electronic parts of those networks to meet their requirements. LNA, e.g., is a critical part that should be designed carefully not to just meet the targeted aspects but also to consume less energy.

A WSN is a special case of a data communication network composed of a large number of nodes (the sensor nodes), which communicate by multiple hops (multi-hop) through tiny radios, and are equipped with embedded processors, memory, and sensors [1-3]. In some cases, the communication is made by optical signals (light or laser). The purpose of a sensor network is to measure (sensor) and collect data from the environment at different points in a region and transmit [4,5]. WSNs find applications in several areas: military, industrial, domestic, environmental, agricultural, and others. For all these applications, it is important to know the location (absolute or relative) of the sensor nodes and the quality of the connections between them. For this, you must have a good radio signal strength measurement system.
To be used in WSN, [1] proposes an LNA to resonate at BW of (0.1-3) GHz. The NF is 2.8 dB while the gain is 16.5 dB consuming almost 1mW for 1.8 supply voltage. A narrowband cascaded MOSFET LNA is designed in [2] to operate at 2.4GHz with 1.2V of supply, NF of 11.2 dB, and $S_{11}$ of 22 dB. In [3], a wideband LNA with low power consumption is presented to resonate at 600MHz with a supply voltage of 0.8V, NF of 4dB, and power gain of 14dB. An electronic receiver proposed in [4] includes 5.8 GHz LNA with 1.5V of supply. Another design for LNA is suggested in [5] to have a wideband of operation (5.8-13) GHz. This design provides an average gain of 23dB, an average NF of 3dB with 1.2 supply voltage. Serving sensor networks, [6] has proposed a UWB LNA, which covers frequencies below 960MHz achieving 13dB of gain and 3.6dB NF, with a supply voltage of 1.2V. The negative feedback technique is deployed in [7] to achieve a high power gain LNA of 20.1dB and NF of 3.2dB. The band of this LNA is 3.3GHz to consume 1.3mW. The operation frequency of the LNA presented in [8] is (0.1-6) GHz offering a power gain of 13dB and NF of 3dB consuming 3.6mW at 1V supply voltage. The Common Gate Architecture is used in [9] to propose an ultra-low-power LNA, which consumes 300 μw but with NF of 7.3dB. The same previous architecture is also utilized in [10] to propose an LNA operating at 2.4GHz with 18.2 dB of gain and 3.38 of NF. The power consumption is almost 1mW. Authors of [11] have proposed an LNA to operate at 2.3GHz, achieving a gain of 18.8B and NF of 2.9dB. Using the technology of Forward Body Bias (FBB), [12] presents fully-integrated LNA whose 1.8GHz resonance frequency resulting an NF of 3.38dB with 2.16 MW of power draw. A wideband (0.1-2.2) GHz LNA is designed in [13] to produce a gain of 12.3dB and NF of 4.9dB, drawing 400 μA. An LNA with high linearity and wide BW of 2.96 GHz is suggested in [14] to get a power gain of 18.55 dB and NF of 3.63dB, consuming 4.15 MW of power. Another LNA design in [15] is suggested to work at 1.7GHz applying noise cancellation technique achieving a gain of 14.5 dB and NF of 3dB. The LNA draws 6mA at 1.8V supply. The LNA design shown in [16] operates at 2.4 GHz and offers a power gain of 13 dB and NF of 2.2 dB, consuming 1.5 MW of 1.5V supply voltage. A 5 GHz LNA using the technology of Forward Body Bias is demonstrated in [17]. The achieved gain is 10.23 dB, while the NF is 4.1 dB. This LNA consumes 0.8mW. Four cascaded stages LNA to operate at 60 GHz band are designed in [18] to consume 4.4 MW producing a gain of 12.5 dB and NF of 5.4 dB. As low as 0.95 dB, NF is achieved in the proposed LNA by [19] to operate at 5GHz, reflecting a gain of 11 dB and consuming 12 MW of power. The LNA suggested by [20] offers the operation in either multi narrowband or wideband. The power consumption is 3.8 MW at 1.8V of supply. A power-wake up receiver with low power consumption is proposed in [21] to be deployed in WSN applications. A dual-band LNA presented in [22] is compatible with a reconfigurable receiver, which offers two bands of operations, (0.1-1.5) GHz and (1-5) GHz. The study performed in [23] proposes dual-band LNA to operate either in 3GHz or in 5GHz using RF switch. This LNA consumes 7.2mW with 1.2V supply voltage. Interesting multi-band LNA to serve WLAN and WiMAX applications is proposed in [24] to operate at (1.8, 2.4, 3.5, or 5.2) GHz. This LNA consumes 7.2mW when supplied by 1.8V. Using the enhanced gain technique, [25] presents a 2.4/5.2 GHz dual-band LNA to produce a high gain of 12.9 dB and NF of 3.7dB, consuming a 7.6mW of power from a 1V supply. A wideband LNA (2-5) GHz consuming 1mW at 1.8V supply voltage and achieving a gain of 13 dB and NF of 6 dB as designed in [26]. The article [27] presents a design and development of micropower LNA to operate at 1GHZ with an NF of 4.6 dB and a gain of 13.6 dB. According to the different surveyed LNAs in the previous literature, the gap is the trade-off sacrifices in the amplifier power gain and noise figure. Most of the designed LNAs mentioned above have achieved low power consumption as well as low supply voltage requirements. However, the gain and noise figure values were not promising in the area of WSN applications. This article, indeed, has aimed to target this gap by designing an LNA for WSN applications at 2.4GHz with no sacrifices on power gain and noise figure.

This article proposes an LNA design for the WSN applications whose operating frequency of 2.4GHz. The designing procedure steps are presented in section II. Section III illustrates and discusses the simulation results. Section IV, finally, draws the conclusion.
2. Designing Procedure

After selecting a suitable RF transistor (BP1V01M0), according to the applications desired for that LAN, the procedure to design the LNA involves three main steps: biasing circuit design, stability test, and input-output matching networks.

2.1. Biasing Circuit

The main aspect of designing the biasing circuit is to maintain the operation of the transistor in the active region. Through forward and reverse DC biasing of the emitter-base and collector-base junctions, respectively, the transistor works as an amplifier.

The transistor (BP1V01M0) specifications included in the datasheet, is designed as a low noise amplifier are collector current (Ic= 1mA), forward base-emitter voltage (VBE=0.74V), DC current gain (hFE=390), and collector-emitter voltage (VCE=1V). Then, from equation (1), the value of IB equals to 2.56 µA. The RB2 current is approximately ten times the base current IB [7]. Therefore, RB2 =29 KΩ. From equation (3), RB1 =27 KΩ.

Applying VCC of 1.5 V, the RC can be calculated from Equation 4 to be 486 Ω. The biasing circuit of the transistor (BP1V01M0) is illustrated in Figure 1.

![Transistor biasing circuit](image)

### Equation (1)

\[ I_B = \frac{I_C}{h_{FE}} \]

### Equation (2)

\[ R_{B2} = \frac{V_{BE}}{10I_B} \]

### Equation (3)

\[ R_{B1} = \frac{V_{CE} - V_{BE}}{11I_B} \]

### Equation (4)

\[ R_C = \frac{V_{CE} - V_{CE}}{I_C + 11I_B} \]

2.2. Stability Test

A stability test should be performed for the transistor BP1V01M0. As the AWR is the tool to carry out the designing procedure in this study, K factor, known as Rollet factor and SCIR, will be evaluated to test the stability of the transistor. In the SCIR smith chart plot, whether the transistor is stable or not
can be identified by the location of the stability curve. In case the curve lies inside the SCIR circle, the transistor BP1V01M0 is unstable, and if that curve is outside the circle, the transistor is stable. Furthermore, the Rollet factor plot can also identify the stability of the targeted operation frequency of 2.4 GHz. For a stable transistor, the Rollet factor should be slightly more than 1. Figure 2 shows the Rollet factor curve of the transistor operating at a range of frequencies, including 2.4 GHz, while Figure 3 shows the SCIR plot of the transistor.

![Figure 2. The stability test using Rollet factor K](image1)

![Figure 3. The stability test using SCIR](image2)

From Figure 2 and 3, the transistor is obviously unstable at 2.4 GHz. As a result, adding a series or parallel resistor at the collector of the transistor is needed. After deploying the AWR tuner, a 86 Ohm resistor in series is connected to achieve stability of the transistor as it is illustrated in Figure 4. The plots of Rollet factor and SCIR after connecting the series resistor are respectively shown in Figure 5 and 6.
**Figure 4.** The schematic of the stable transistor

**Figure 5.** The Rollet factor $K$ of the stable transistor
2.3. Input and Output Impedance Matching

A typical configuration of an RF amplifier should have matching networks which terminate the transistor to perfectly match the source and the load. The parameters, $S_{11}$ and $S_{22}$, of the BP1V01M0 transistor are shown in Figure 7. The aim of designing the input matching circuit is to create matches between the transistor with the 50Ω source impedance and consequently minimizing the return losses as much as possible. Furthermore, the transistor has to be terminated to an input matching circuit to achieve a minimum noise figure (NF). This matching circuit should have an impedance, which is the conjugate of the $S_{11}$ parameter. In AWR, the NFCIR graph is plotted in a polar form at the targeted frequency of 2.4 GHz to figure out the value of the input impedance to be matched. Figure 8 shows the NFCIR plot, which evaluates the input impedance of (0.965+i1.1176). Hence, this impedance has to be normalized by 50Ω and then conjugated. After that, the conjugated normalized input impedance is located on a smith chart to determine the values of the lumped elements needed to get this impedance matched.

Figure 7. $S_{11}$ and $S_{22}$ parameters
The output impedance can be determined from the $S_{22}$ parameter polar plot in AWR. This plot, shown in Figure 9, shows the output impedance at 2.4 GHz, which equals to $(2.093 - i 1.388)$. This complex output impedance should be normalized to a 50Ω but not conjugated this time.

Figure 8. The NFCIR plot

Figure 9. The $S_{22}$ polar plot
After locating the input normalized conjugated impedance in the smith chart, the lumped elements to be needed for the matching process are only a series inductor of 3.7 nH. The lumped elements required for the output matching network, on the other hand, using the same procedure are a series capacitor of 1 pF and a parallel inductor of 4.8 nH. The configuration of input and output matching terminals can be seen in Figure 10.

3. Simulation Results
The S-parameters of the transistor schematic after terminating the matching networks are shown in Figures 11. It can be clearly seen that the targeted frequency of 2.4 GHz is within the operating range of this designed LNA. However, the center frequency is shifted away from 2.4GHz towards lower frequencies. Therefore, an optimization process is required using the built-in AWR optimizer. The final optimized lumped elements schematic is illustrated in Figure 12. The lumped elements' values are approximated to the nearest standard values.

Figure 10. The input and output matching networks

Figure 11. $S_{11}$ and $S_{22}$ parameters after matching
The $S$-parameters for the optimized schematic are shown in Figure 13. Clearly, the $S_{22}$ parameter value at the targeted frequency 2.4 GHz is about -44.43 dB.

Good values of both power gain and noise figure have been achieved at 2.4 GHz as presented respectively in Figures 14 and 15. The noise figure is 1.2 dB, and the power gain is 12.63 dB.
Looking at the values of the compared literature's specifications listed in Table 1, some of the designed LNAs achieved low power consumption with low supply voltage. However, these achievements were on vital scarifies in noise, gain, and impedance bandwidth. Thus, the aim of this work is to design an LNA with better trade-off limitations on the overall performance to serve the wireless sensors networks (WSN) applications. The designed LNA has achieved considerably low power consumption using applicable supply voltage for WSN applications. These achievements were concatenated with wide impedance matching, high power gain, low NF, and very low return losses.

Table 1 Performance comparison of already existing LNAs

| Specification               | [1] | [3] | [6] | [12] | [16] | [17] | [18] | [19] | [20] | [25] | [27] | This work |
|----------------------------|-----|-----|-----|------|------|------|------|------|------|------|------|-----------|
| Supply voltage (V)         | 1.8 | 0.8 | 1.2 | 0.86 | 1.5  | 0.6  | 1    | 1.5  | 1.8  | 1    | 1    | 1.5       |
| Power consumption (mW)     | 0.98| 0.4 | 0.72| 2.16 | 1.5  | 4.4  | 12   | 1.5  | 3.8  | 7.6  | 0.26 | 1         |
| Gain (dB)                  | 16.5| 14  | 13  | 9.5  | 13   | 10.23| 12.5 | 11   | 14.1 | 12.9 | 13.6 | 12.63     |
| Noise figure (dB)          | 2.9 | 4   | 4   | 3.38 | 2.2  | 4.1  | 5.4  | 0.95 | 8.5  | 3.7  | 4.6  | 1.2       |
| Input return loss (dB)     | -   | -   | -   | -11  | -17.9| -33  | -12  | -13.1| -10  | -44.4|       |
| Reverse isolation (dB)     | -   | -   | -   | -42.8| -17  | -28  | -    | -    | -    | -18.3|       |

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Figure 14. Achieved power gain of the optimized schematic
4. Conclusion
In conclusion, the designed LNA can efficiently serve the wireless sensor networks applications at 2.4 GHz. This LNA consumes as low as 1mW of power with a low supply voltage of 1.5V. Moreover, the proposed design offers 2GHz of -10 dB impedance bandwidth. Meanwhile, the proposed LNA achievement in power consumption has no sacrifices on the noise and power amplification performances. The achieved NF is 1.2 dB, while the power gain is 12.63 dB with a return loss of -44.43 dB. Therefore, this design is effectively applicable to be deployed in WSN as it consumes low power, requires low voltage supply, achieves reasonable power gain, and maintains a low level of noise. The interesting future idea is to design an LNA with micro power consumption to serve the health care electronic devices and applications.

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