Range Extension for Nordic nRF24LE1 Series with RFaxis Single-Chip RFX2401C RFeIC™

Test Summary, Technical Notes and Application Schematic

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1. Introduction

The Nordic nRF24LE1 is an ultra-low power wireless system on-chip (SoC) operating in the 2.4GHz ISM band. It is a popular solution for a wide range of applications including wireless mouse, remote control, asset tracking, monitoring, medical sensor, home automation, and gaming. The maximum transmitted output power of the nRF24LE1 is about +0dBm. The receiver noise figure is ~8dB. The nRF24LE1 is mainly used for short range application. Typical solution to extend the range involves adding a power amplifier to increase the transmitted power and a switch to change from transmitter to receiver path. This can increase and complicates the BOM. As shown in section 1, the RFaxis RFX2401C RFeIC™ (RF Front-End IC) contains an LNA for the receiver, a PA for the transmitter and two switches all in a single die. Adding the RFX2401C can increase the transmitted power and reduce the receiver Noise Figure leading to range extension and more robust communication. This document summarizes the benefits of adding the RFX2401C to a transmitter receiver pair of nRF24LE1.

Section 2 gives a brief overview of the architecture of the RFX2401C. Section 3 describes the different setups used to collect experimental results. Section 4 highlights improvements in the range by adding the RFX2401C at the receiver side. Section 0 contains improvements in the transmitter power together with the extra current used by the RFX2401C as a function of the output power. Section 6 contains the experimental results of the transmitter receiver pair. It also contains the resulting range extension. Section 7 summarizes the implementation schematic of the connection between nRF24LE1 and RFX2401C.

2. RFX2401C Architecture

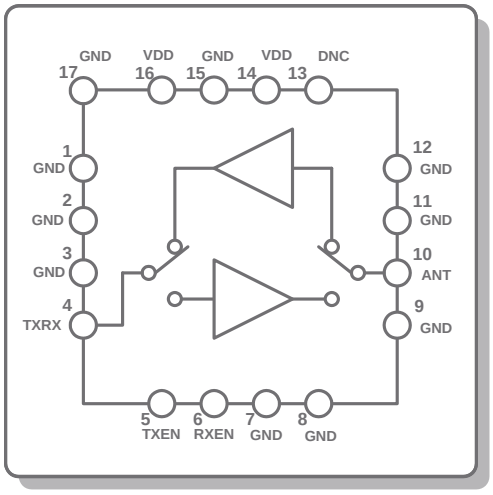

Figure 1: RFaxis RFX2401C RFeIC™ Block Diagram

The RFX2401C is a fully integrated, single-chip, single-die RFeIC (RF Front-end Integrated Circuit) which incorporates all the RF functionality needed for IEEE 802.15.4/ZigBee, wireless sensor network, and any other wireless systems in the 2.4GHz ISM band. The RFX2401C architecture integrates the PA, LNA, Transmit and Receive switching circuitry, the associated matching network, and the harmonic filter all in a CMOS single-chip device. Using the RFX2401C together with a transmitter receiver pair is a simple and effective way to extend the range and make the communication more robust without complicated BOM.

3. Experimental Setup

For this experiment, the nRF24LE1 transceiver is used. In order to measure the effect of the RFX2401C on the transceiver, four setups are tested. The setups are shown in Figure 2, Figure 3, Figure 4, and Figure 5. P1 through P8 in the figures refer to the signal power at different stages.

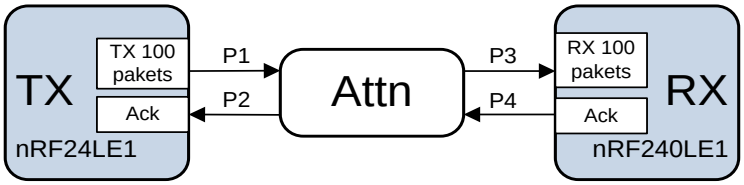

Figure 2: Setup 1 with two nRF24LE1

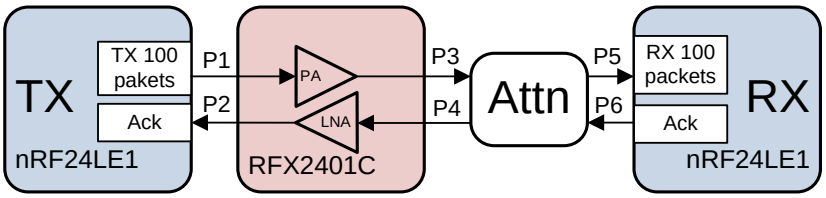

Figure 3: Setup 2 with one RFX2401C at the TX side

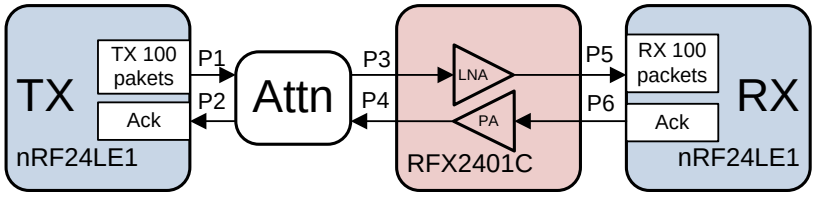

Figure 4: Setup 3 with an RFX2401C at the RX side

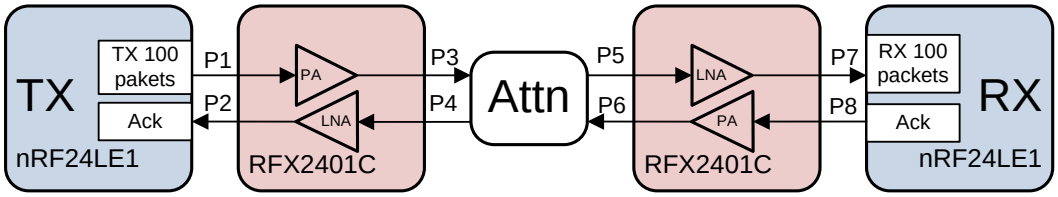

Figure 5: Setup 4 with RFX2401C at both ends

The experiment consists of the following steps:

- Setting up a transmitter and receiver pair
- The transmitter sends 100 packets of data to the receiver. Data rate of each packet is 2 Mbit
- The receiver sends back an acknowledge signal for each packet, indicating that the packet was received
- Attenuating the link until the number of received packets is 99%

The nRF24LE1 transmitter has 4 different output power settings varying from -18dBm to 0dBm. The optimum output power is 0dBm and it is used for all the experiments done in this paper.

4. Receiver Sensitivity Improvement with RFX2401C

To quantify the effect of the RFX2401C on the nRF24LE1 receiver, results from Setup 1 (Figure 2) and Setup 3 (Figure 4) are compared. The results are shown in Figure 6. For 99% of the received packets, the range difference between Setup 1 and Setup 3 is about 6dB. The plots show that adding the RFX2401C at the receiver side improves the link budget by 6dB. The range improvement results from the difference in noise figure of the RFX2401C LNA and nRF24LE1 LNA and also the gain of the RFX2401C LNA. The RFX2401C LNA draws about 10mA of current.

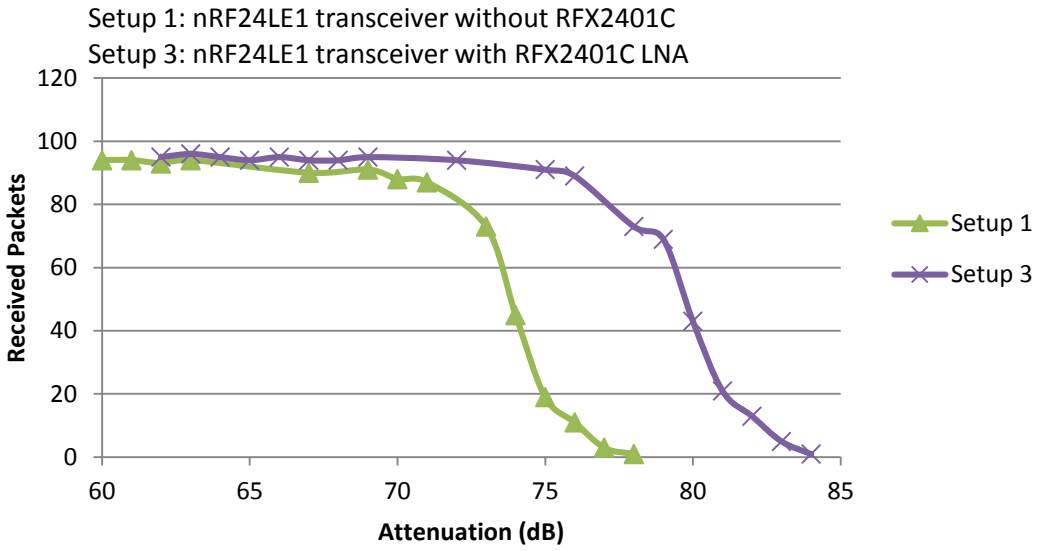

Figure 6: Effect of Receiver LNA on link extension

RFX2401C increases the link budget of the transmitted signal by 6dB. This can be observed by comparing tables 1 and 2. In this setup the link budget for the Acknowledge signal is increased by 21dB due to RFX2401C PA at the receiver side, however, the LNA gain of 6dB will be the bottleneck.

*P1-P8 refer to the signal power at different stages as specified by Figures 2-5.
** The receive sensitivity of nRF24LE1 is -82dBm.

Setup 1 Power Values	
Transmitted Signal	
P1 = nRF24LE1 Output Power	0dBm
P3 = nRF24LE1 Received Power	-82dBm
P1-P3 = Link Budget	82dB
Acknowledge Signal	
P4 = nRF24LE1 Output Power	0dBm
P2 = nRF24LE1 Received Power	-82dBm
P4-P2 = Link Budget	82dB

Table 1: Setup 1 Power Values

Setup 3 Power Values	
Transmitted Signal	
P1 = nRF24LE1 Output Power	0dBm
P3 = RFX2401C Received Power	-88dBm
P5 = nRF24LE1 Received Power	-82dBm
P1-P3 = Link Budget	88dB
Acknowledge Signal	
P6 = nRF24LE1 Output Power	0dBm
P4 = RFX2401C output Power	21dBm
P2 = nRF24LE1 Received Power	-82dBm
P4-P2 = Link Budget	103dB

Table 2: Setup 3 Power Values

5. Boosting Transmitter Output Power with RFX2401C

As shown in section 2, the RFX2401C has both LNA and PA. The maximum TX output power of the RFX2401C is 21dBm. Figure 7 shows the measured output power of the nRF24LE1 standalone and with the RFX2401C at different output power settings of nRF24LE1. The corresponding RFX2401C current consumption as a function of output power is shown in Figure 8.

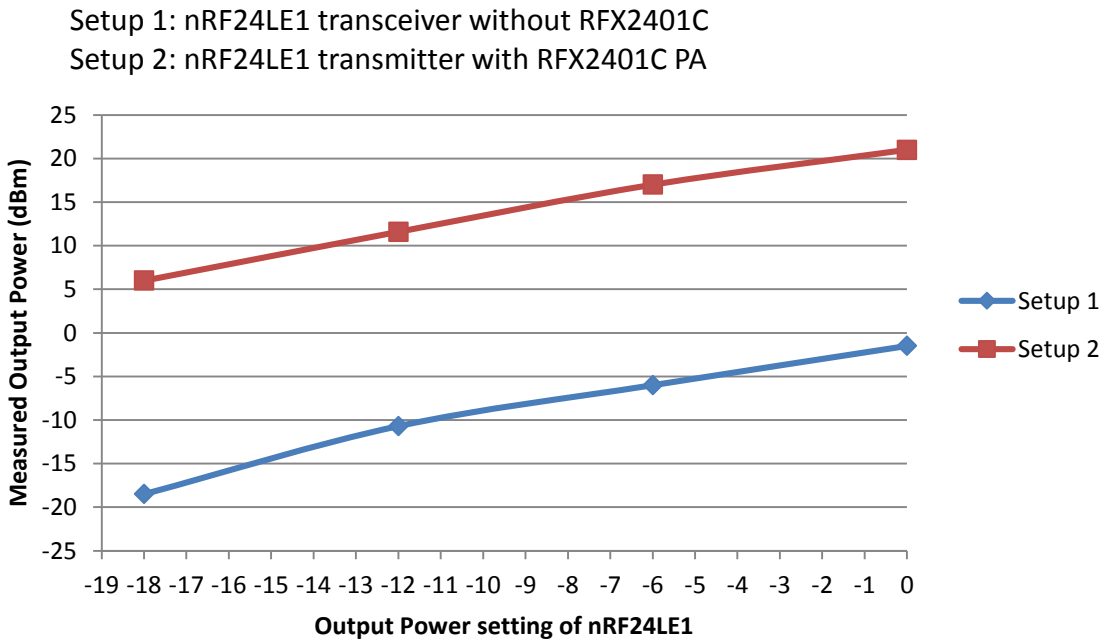

Figure 7: Measured output power with and without RFX2401C

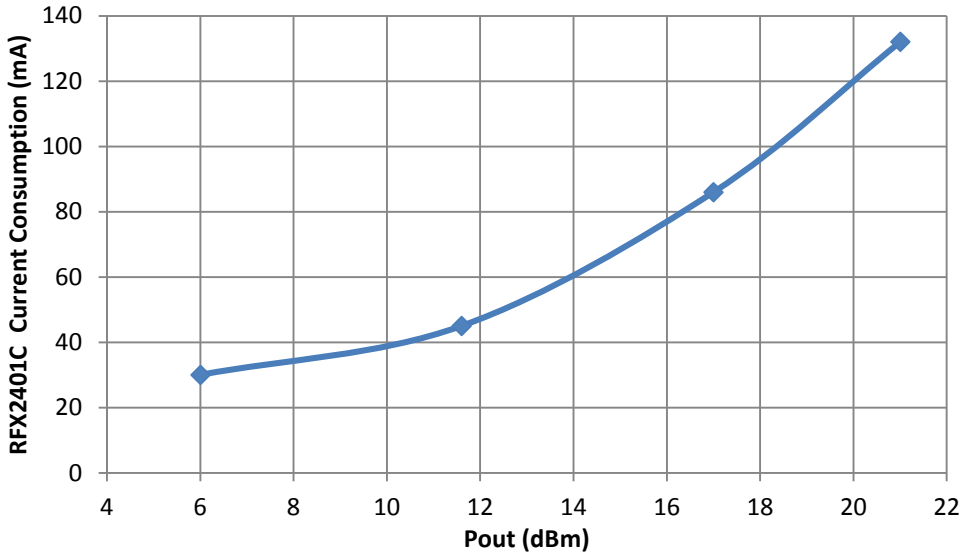

Figure 8: RFX2401C current consumption as a function of total output power

The effect of adding RFX2401C to the transmitter side can be observed in Table 3 **(**Setup 2**)** with comparison to **Table 1** (**Setup 1**). The link budget of the transmitted signal is increased by 21dB. The link budget of the acknowledge signal is increased by 6dB in comparison to Setup 1. The corresponding attenuation results are shown in Figure 9. In this setting the link budget of the acknowledge signal will be the bottleneck. If the communication is done in single direction, the total link budget will be 21dB. This issue, however, will be solved by adding the RFX2401C to both the receiver and the transmitter as discussed in Section 6.

Setup 2 Power Values	
Transmitted Signal	
P1 = nRF24LE1 Output Power	0dBm
P3 = RFX2401C Output Power	21dBm
P5 = nRF24LE1 Received Power	-82dBm
P3-P5 = Link Budget	103dB
Acknowledge Signal	
P6 = nRF24LE1 Output Power	0dBm
P4 = RFX2401C Received Power	-88dBm
P2 = nRF24LE1 Received Power	-82dBm
P6-P4 = Link Budget	88dB

Table 3: Setup 2 Power Values

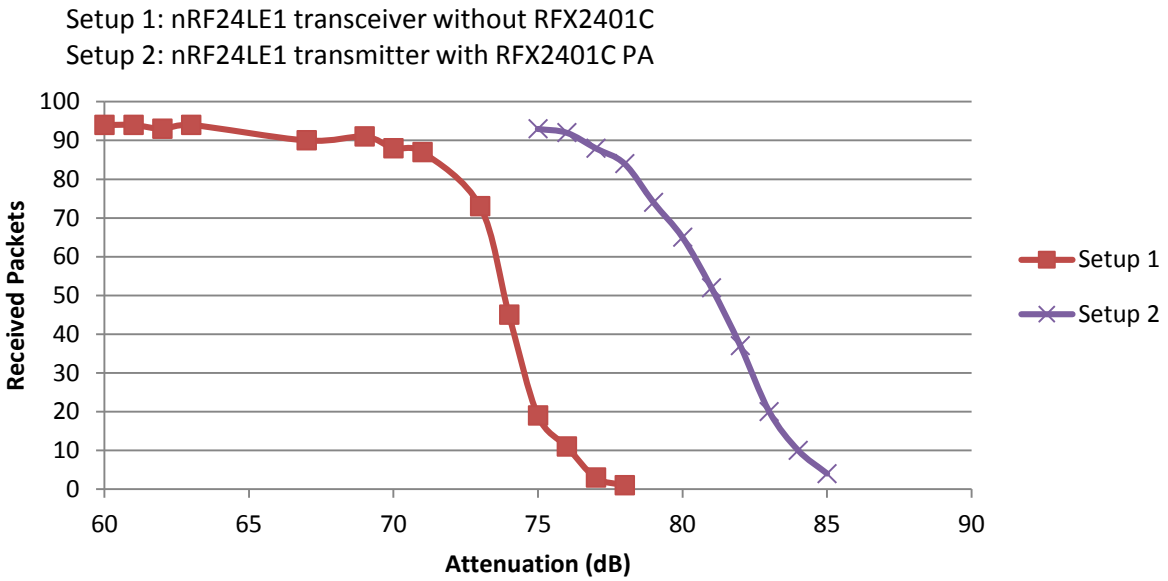

Figure 9: Effect of Transmitter PA on link extension

6. Range Extension

Figure 10 shows the results of range extension with a RFX2401C at each ends. By comparing Table 1 (Setup 1) and Table 4 (Setup 4) it is evident that adding the RFX2401C increases the range by 26dB. This is resulting from the RFX2401C PA increased output power of ~21dB and ~5dB from the RFX2401C receiver noise figure along with increased LNA gain.

Setup 4 Power Values	
Transmitted Signal	
P1 = nRF24LE1 Output Power	0dBm
P3 = RFX2401C Output Power	21dBm
P5 = RFX2401C Received Power	-88dBm
P7 = nRF24LE1 Received Power	-82dBm
P3-P5 = Link Budget	103dB
Acknowledge Signal	
P8 = nRF24LE1 Output Power	0dBm
P6 = RFX2401C output Power	21dBm
P4 = RFX2401C Received Power	-88dBm
P2 = nRF24LE1 Received Power	-82dBm
P4-P2 = Link Budget	103dB

Table 4: Setup 4 Power Values

The effective distance improvement is calculated as $10^{\frac{ATTEN}{20}}$, where ATTEN is the extra gain in link budget in dB. RFX2401C improves the range by 26dB which is equivalent to about 20 times distance improvement. This range extension is based on the assumption that there is direct line of sight between the transmitter and the receiver. If there is any obstruction between the transmitter and the receiver, range will be different.

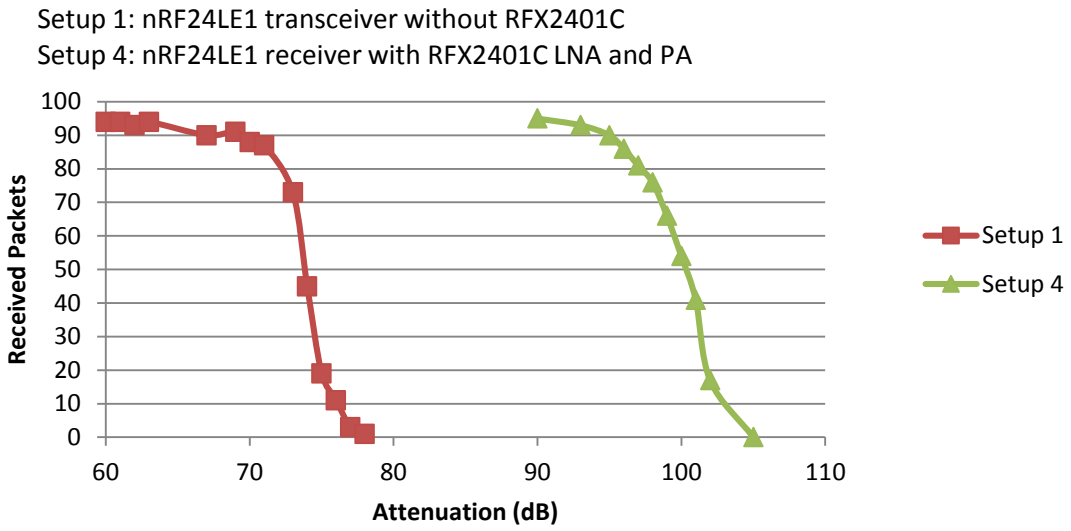

Figure 10: Effect of Transmitter PA and Receiver LNA on link extension

7. Application Schematic and settings

The schematic in Figure 11 shows the typical connections between the nRF24LE1 and RFX2401C. The setup is as follows:

- TXRX port (Pin 4) of RFX2401C is connected to the ANT1 and ANT2 port of nRF24LE1 (Pin assignment depends on the packaging)
- RXEN (Pin 6) of RFX2401C is connected to GPIO
- TXEN (Pin 5) is connected to VDD_PA of nRF24LE1.

The GPIO connected to RXEN must be programmed accordingly. Optional harmonic filter can be added at the antenna pin if the application is required to pass FCC. The schematic (Figure 10) shows that the required BOM is simple.

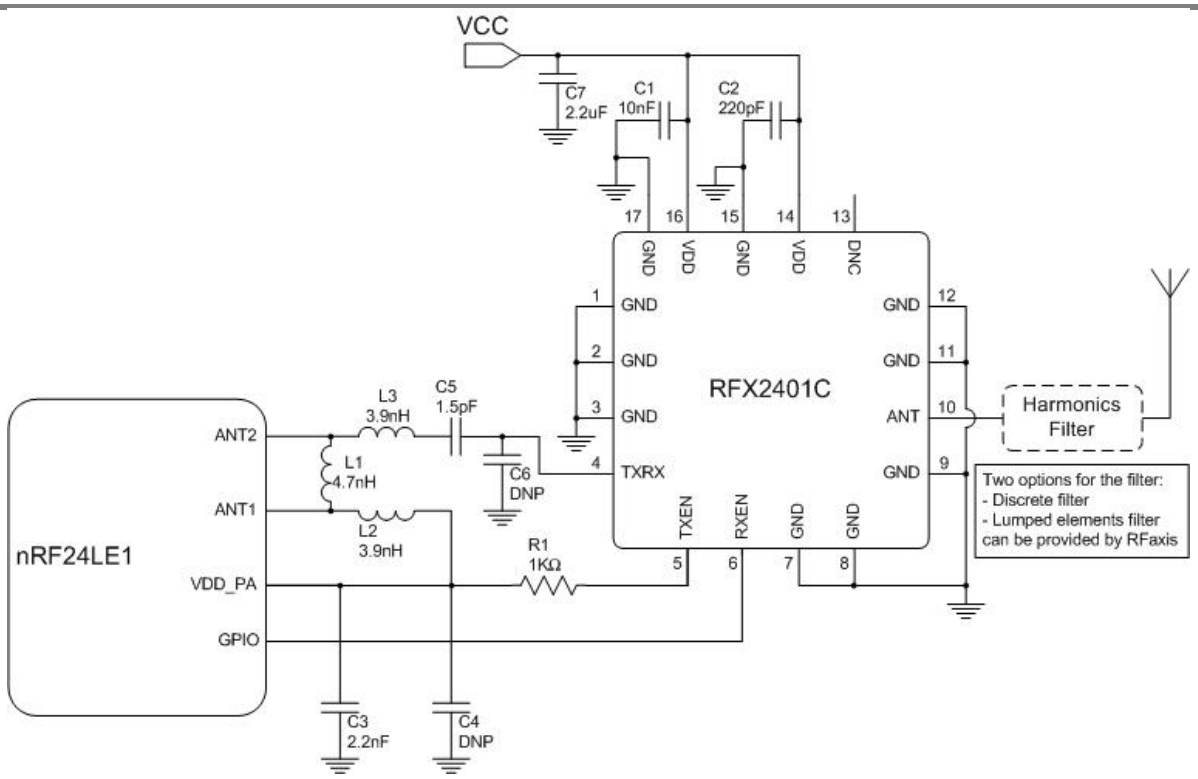

Figure 11: Typical connection schematic between nRF24LE1 and RFX2401C

8. Conclusion

Adding the RFX2401C at the receiver side improves the link by ~6dB. This is resulted from the gain of the RFX2401C LNA and delta in noise figure between the nRF24LE1 and the RFX2401C LNA. Adding RFX2401C to the transmit side will increase the output power of the setup to 21dBm if the communication is done in single direction. The overall range extension is achieved by connecting the RFX2401C at both ends of the link. The RFX2401C gives 26dB improvement in total link budget - which is equivalent to about 20 times improvement in LOS distance.

About RFaxis, Inc.

Incorporated in January 2008, RFaxis, Inc. is an Irvine, California-based company specializing in the design and development of RF semiconductors. With its patented technologies, the company leads the way in next-generation wireless solutions designed for the multi-billion dollar WLAN 802.11n/ac MIMO, Bluetooth, ZigBee/ISM/Smart Energy, and WHDI markets. Leveraging pure CMOS technology in conjunction with its own innovative approach and technology, RFaxis is home to the world's first RF Front-end Integrated Circuit (RFeIC). More information can be found at: www.rfaxis.com.

About Nordic Semiconductor

Nordic Semiconductor ('Nordic') is a fabless semiconductor company specializing in ultra low power (ULP) short-range wireless communication in the license-free 2.4GHz and sub-1-GHz Industrial, Scientific and Medical (ISM) bands. Nordic is a Norwegian public company listed on the Oslo stock exchange (OSE: NOD). Visit www.nordicsemi.com