Range Extension for Nordic nRF24LE1 with RFaxis RFX2401 Single-Chip RFeIC™

Results Summary, Technical Notes and Application Schematic

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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 RFX2401 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 RFX2401 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 RFX2401 to a transmitter receiver pair of nRF24LE1.

Section 1 gives a brief overview of the architecture of the RFX2401. Section 2 describes the different setups used to collect experimental results. Section 3 highlights improvements in the range caused by adding the RFX2401 at the receiver side. Section 4 contains improvements in the transmitter power together with the extra current used by the RFX2401 as a function of the output power. Section 5 contains the experimental results of the transmitter receiver pair. It also emphasizes the resulting range extension. Section 6 summarizes the implementation schematic of the connection between the nRF24LE1 and RFX2401. Section 7 summarizes the results of FCC Compliance testing of the setup.

1. RFaxis RFX2401 Architecture

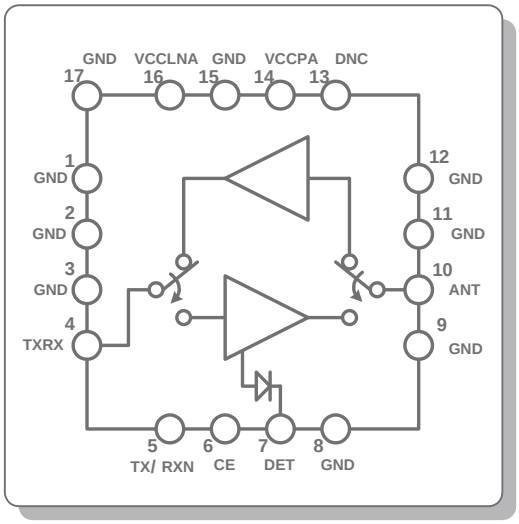

Figure 1: RFaxis RFX2401 RFeIC™ Block Diagram

The RFaxis RFX2401 is a fully integrated RFeIC™ which incorporates the PA, LNA, Transmit and Receive switching circuitry, the associated matching network, and the harmonic filter all in a single-chip, single-die silicon device as shown on Figure 1. It is designed for use in 2.4GHz ISM band and supports the 802.15.4 ZigBee standard. Using the RFX2401 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.

2. Experimental Setup

In order to measure the effect of the RFX2401 on the nRF24LE1 transmitter receiver pair range, four setups are used. The setups are shown in Figure 2, Figure 3, Figure 4 and Figure 5.

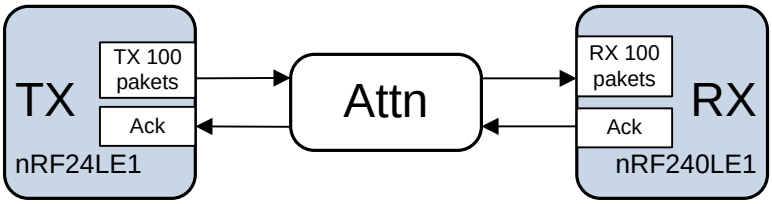

Figure 2: Setup 1 with two nRF24LE1

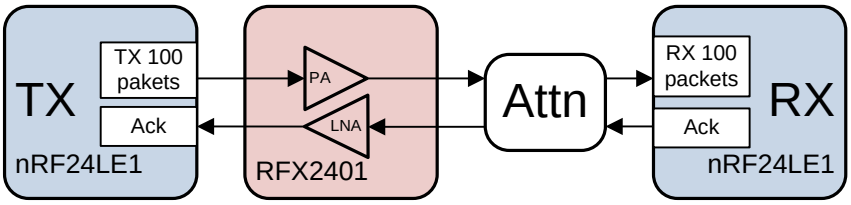

Figure 3: Setup 2 with one RFX2401 at the TX side

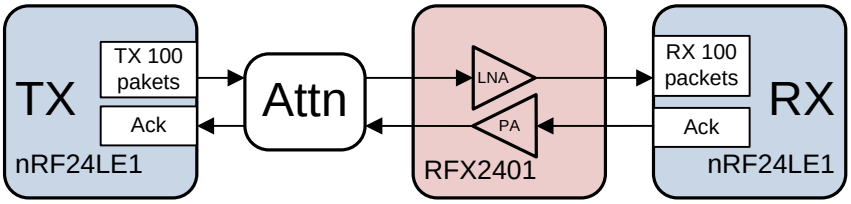

Figure 4: Setup 3 with an RFX2401 at the RX side

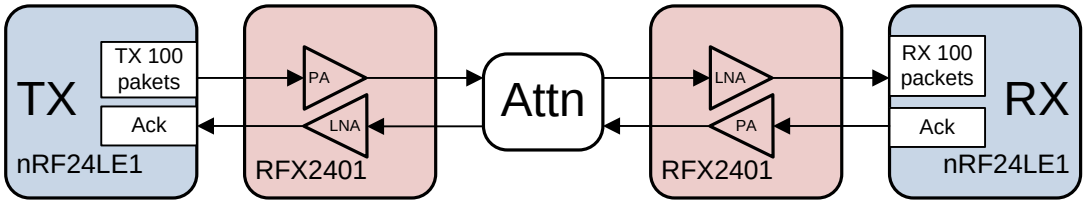

Figure 5: Setup 4 with RFX2401 at both ends

The experiment consists of the following steps:

- Setting up a transmitter and receiver pair
- The transmitter sends 100 packets of data to the receiver
- The receiver acknowledges every packet received
- Attenuating the link until the number of received packets is 99%

The experiment was conducted with the four setups shown in Figure 2, Figure 3, Figure 4 and Figure 5.

3. Receiver Sensitivity Improvement with RFX2401

To quantify the effect of the RFX2401 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 5dB. The plots show that adding the RFX2401 at the receiver side improves the link budget by 5dB. The range improvement results from the difference in noise figure before and after adding the RFX2401.

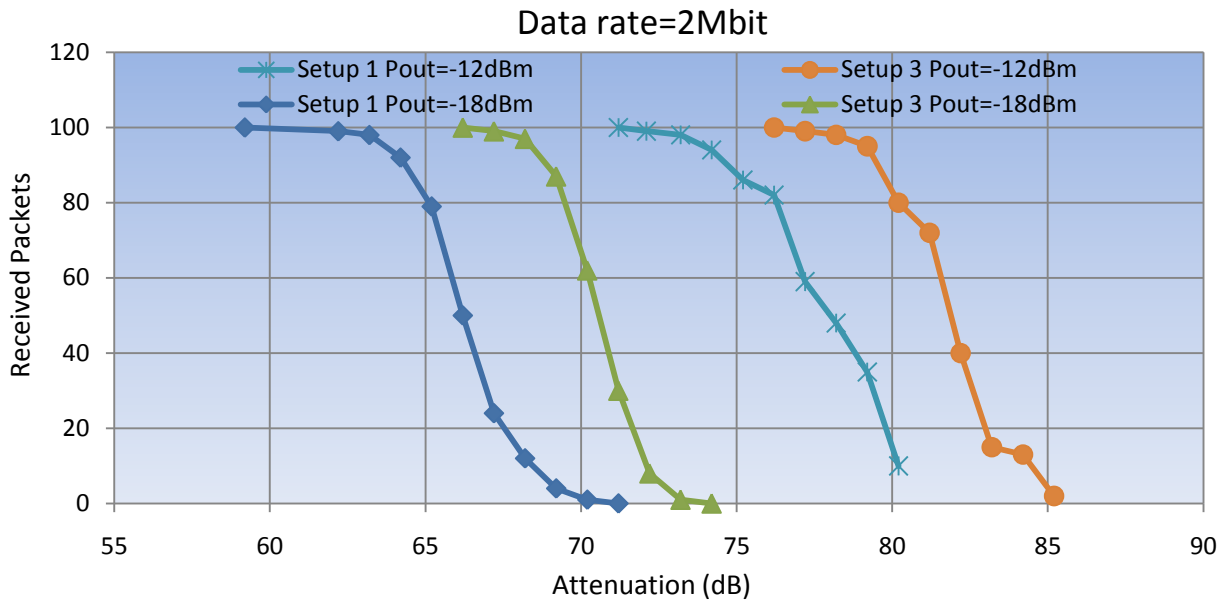

Figure 6: Effect of Receiver LNA on link extension

4. Boosting Transmitter Output Power with RFX2401

The nRF24LE1 transmitter has four output power settings: -18dBm, -12dBm, -6dBm and 0dBm. The maximum output power is with 0dBm settings. Adding the RFX2401 TX in the front end allows the increase of the transmitter antenna power by up to 27dB. The desired level can be set at the nRF24LE1 to up to 21.7dBm. At the highest power setting, the maximum output power of the setup is 21.7dBm. Figure 7 shows the measured output power out of the nRF24LE1 with and without the RFX2401. The corresponding RFX2401 current consumption during transmit burst as a function of output power is shown in Figure 8.

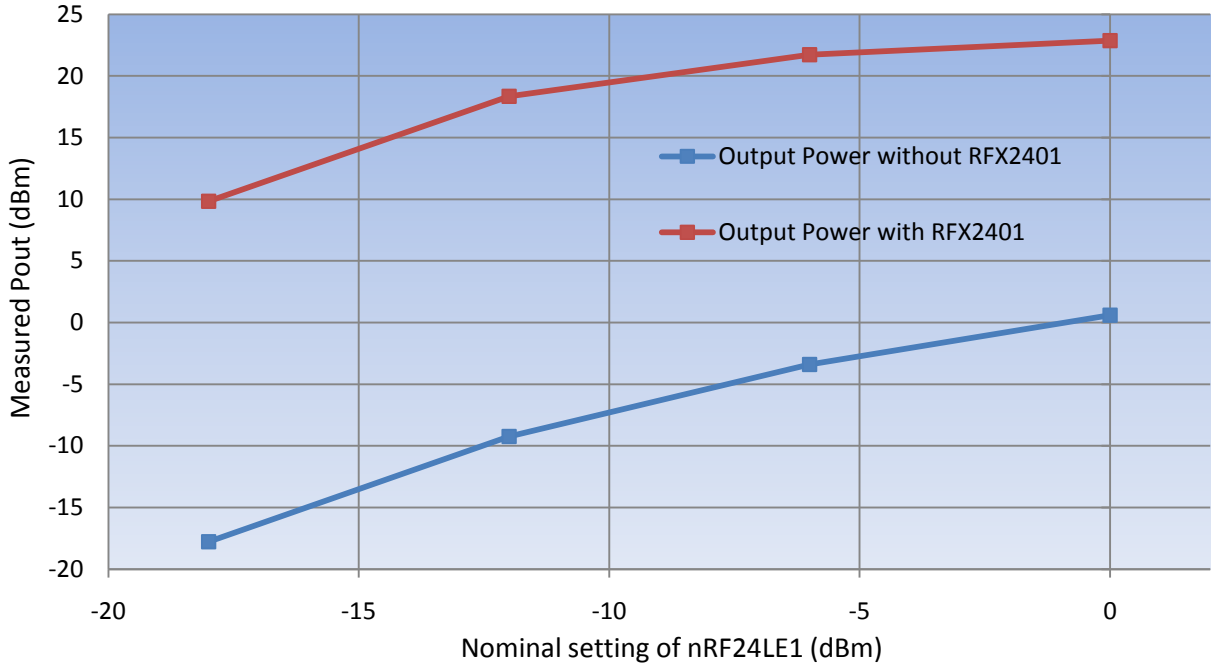

Figure 7: Measured output power with and without RFX2401

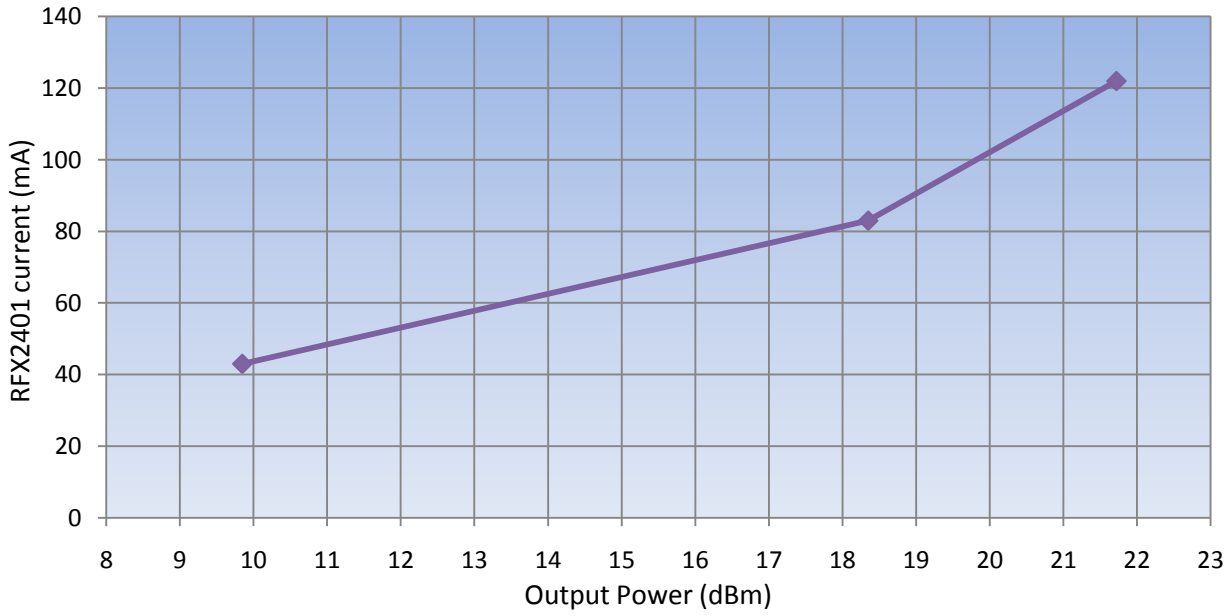

Figure 8: RFX2401 current consumption as a function of total output power

The corresponding attenuation results are shown in Figure 9. The PA of the RFX2401 improves the link by about 25~26 dB. The improvement is caused by the RFX2401 power amplifier gain.

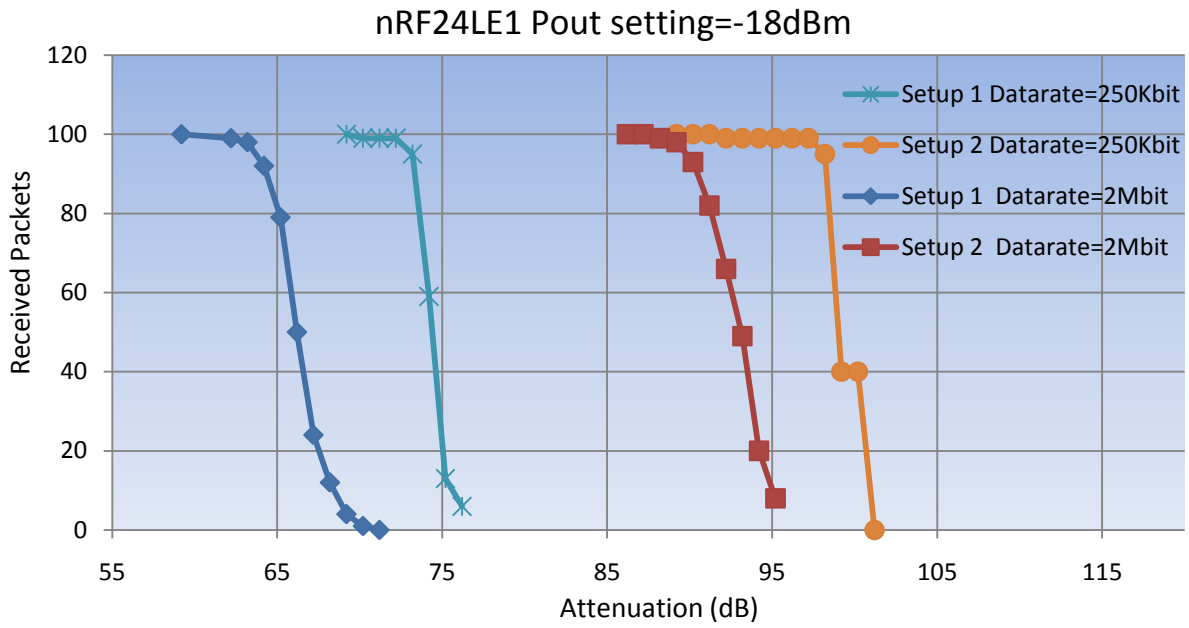

Figure 9: Effect of Transmitter PA on link extension

5. Range Extension

Figure 10 shows the results of range extension with the RFX2401 at both ends. The results show the difference in attenuation between Setup 1 and Setup 4 for different nRF24LE1 output power settings. Adding the RFX2401 at both ends of the link increases the range by 26~33dB. The maximum output power of the RFX2401 PA is about 21.7dBm. At 0dBm nRF24LE1 output power setting, the range extension is about 26dB. This is resulting from the RFX2401 PA output power of 21.7dB and 5dB from the RFX2401 receiver noise figure. The effective distance improvement is shown in Figure 11. For line of sight in free space, the RFX2401 improves the distance 20 times at the highest nRF24LE1 output power setting and up to 40 times at lower output power settings.

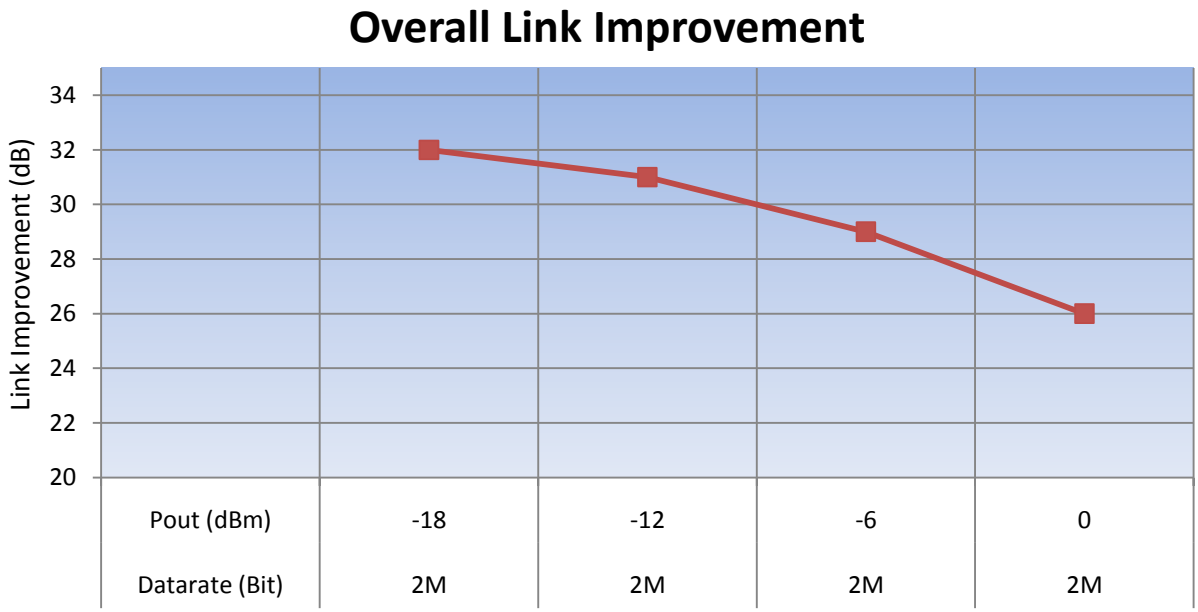

Figure 10: Range Extension with RFX2401

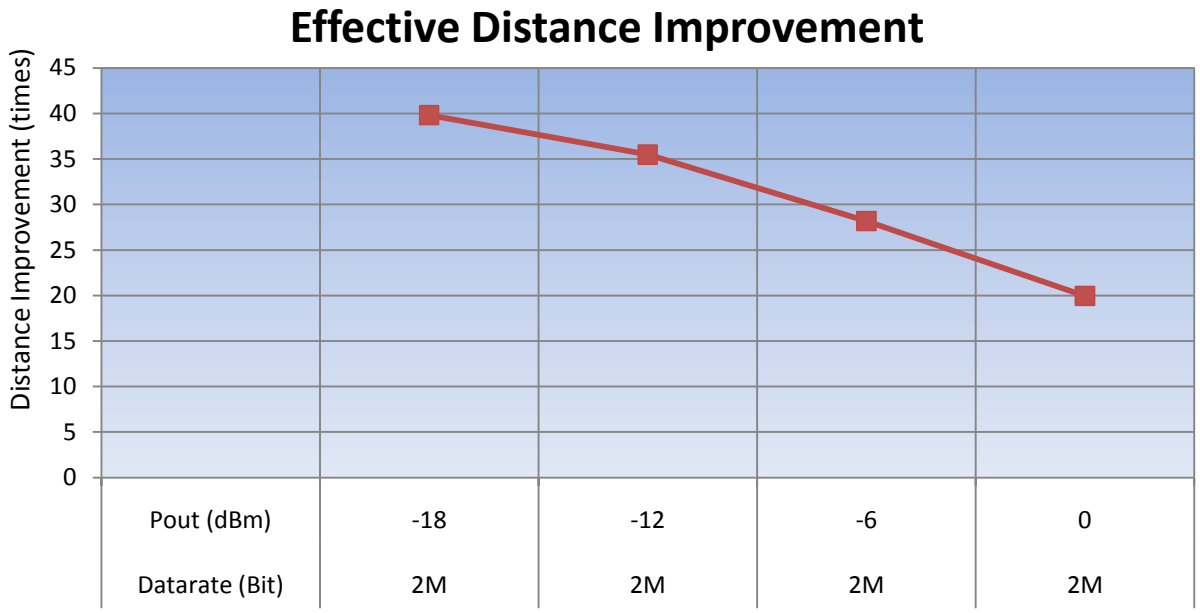

Figure 11: Effective overall distance improvement

6. Application Schematic

The schematic in Figure 12 shows the typical connections between the nRF24LE1 and RFX2401. The schematic shows that the required BOM is simple. An LO trap and an external harmonic filter can be added to the RFX2401 for FCC Compliance.

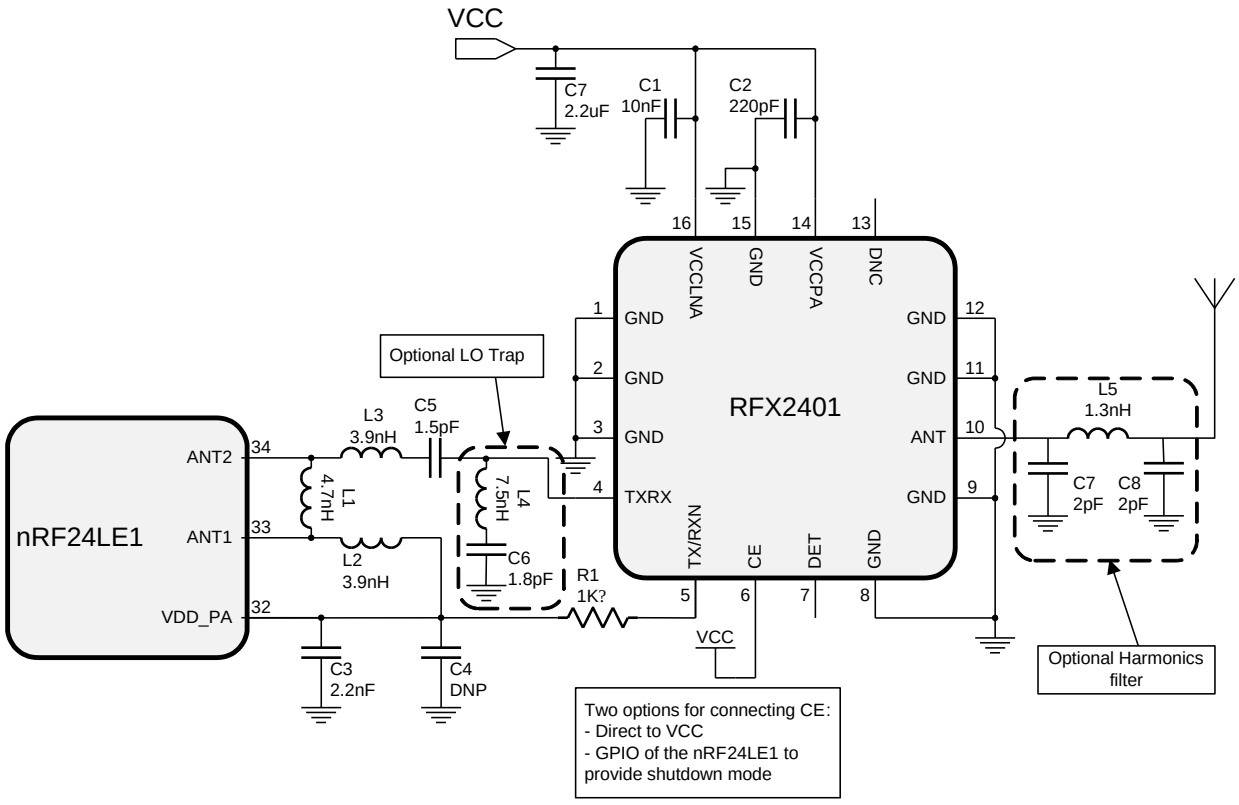

Figure 12: Typical connection schematic between nRF24LE1 and RFX2401

7. FCC Compliance Testing

Regulatory compliance testing is an important part of any product development effort, and is best addressed in the earliest stages of engineering. In order to provide an easy path to certification for future customers of this design configuration, an FCC pre-scan was performed on the reference design noted in Figure 12. Not every required test was performed during this scan, but a thorough overall evaluation was given to the design especially to the tests that are typically the most difficult to pass. This includes the spurious emissions and the harmonics, which can be especially difficult in an RF transmitting system with a power amplifier.

Figure 13 shows the actual spurious response of the design as depicted in Figure 12. As can be seen, the emissions are well below the limit line, which shows the design would easily pass this part of the test. It is worth noting that these emissions are typically not a function of the power amplifier design, but are usually due to other high speed digital and analog systems in the design. Careful design practices should always be followed to assure a compliant final product.

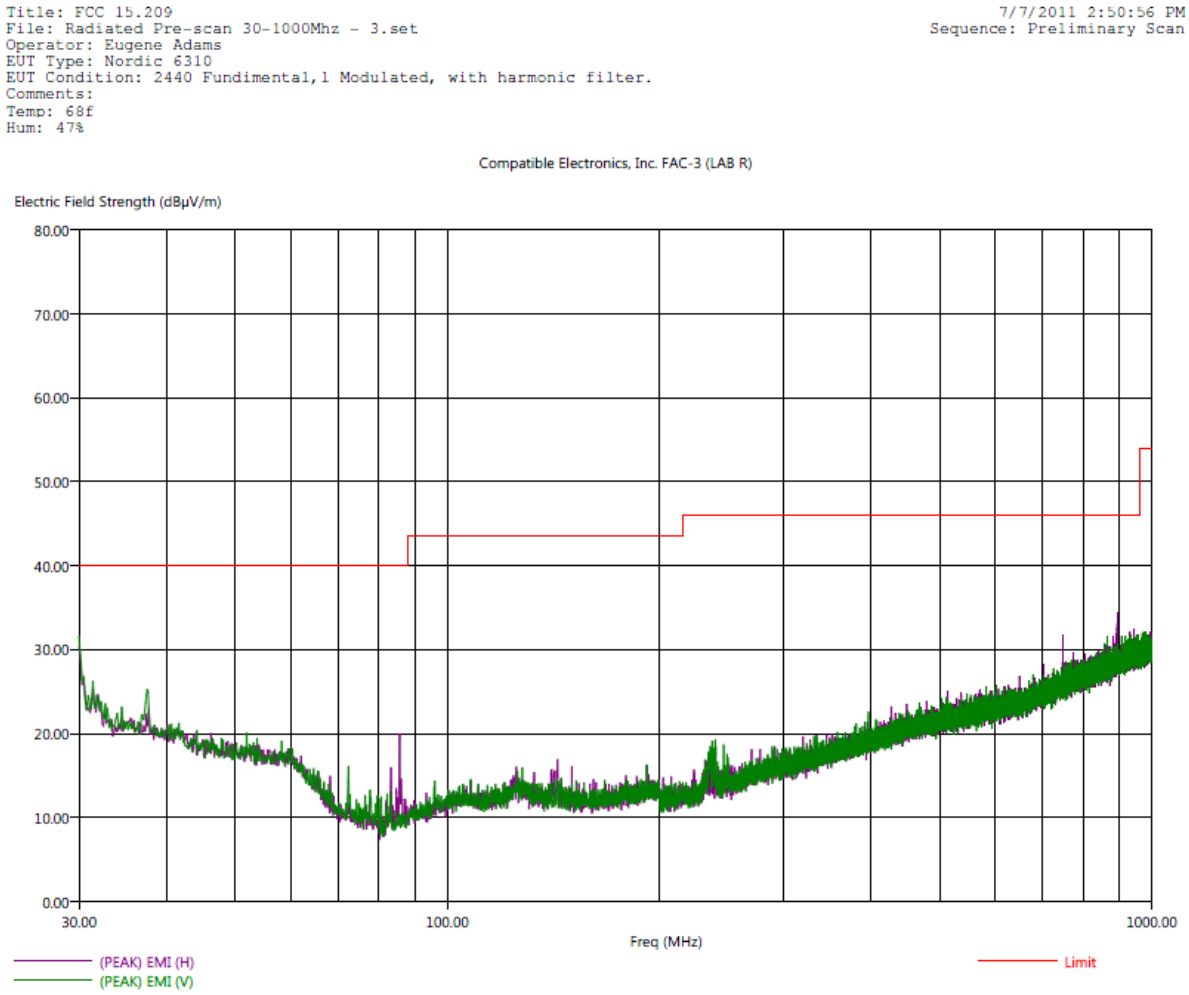

Figure 13: Spurious Response of the nRF24LE1 and RFX2401

Harmonic testing is a very important aspect of FCC compliance which is directly related to the power amplifier design and operation. The hard limit for harmonics of the transmitted signal under FCC Part 15.247 at 3 meters is 74 dBuV peak, and 54 dBuV average. The table in Figure 14 of the measured results shows a compliance margin of greater than 3 dB on the average and

11 dB on the peak. These results were obtained with the output power set at +20dBm, which indicates this design is compliant when including the harmonic filter on the RFX2401 output.

FCC 15.247
RFaxis, Inc.
Zigbee Device
Model: Nordic

Date: 07/07/2011
Lab: R
Tested By: Eugene Adams

Fundamental Channel
2440 MHz

Freq. (MHz)	Level (dBuV)	Pol (v/h)	Limit	Margin	Peak / QP / Avg	Ant. Height (m)	Table Angle (deg)	Comments
4880	62.90	V	74	-11.1	Peak	129	98	-12dBm TX setting
4880	51.87	V	54	-2.13	Avg	129	98	-12dBm TX setting
7320		V	74	-74	Peak			No Emission Found
7320		V	54	-54	Avg			No Emission Found
9760		V	74	-74	Peak			No Emission Found
9760		V	54	-54	Avg			No Emission Found
12200		V	74	-74	Peak			
12200		V	54	-54	Avg			
14640		V	74	-74	Peak			
14640		V	54	-54	Avg			
17080		V	74	-74	Peak			
17080		V	54	-54	Avg			
19520		V	74	-74	Peak			
19520		V	54	-54	Avg			
21960		V	74	-74	Peak			
21960		V	54	-54	Avg			
24400		V	74	-74	Peak			
24400		V	54	-54	Avg			

Figure 14: Harmonic Response of the nRF24LE1 and RFX2401

Conclusion

Adding the RFX2401 at the receiver side improves the link by 5dB. This is caused by the delta in noise figure between the nRF24LE1 and the RFX2401 LNA. Adding the RFX2401 at the transmitter side improves the link by 27dB which results from the RFX2401 power amplifier gain. The overall link extension is achieved by connecting the RFX2401 at both ends of the link. At the highest nRF24LE1 output power setting, the RFX2401 gives 27 dB link extension which is equivalent to 20 times distance improvement.

About RFaxis, Inc.

Incorporated in January 2008, RFaxis, Inc. is an Irvine, California-based company specializing in the design and development of RF semiconductor and antenna solutions for connectivity and mobility applications. With its patent pending technologies, the company leads the way in next-generation wireless solutions designed for the multibillion dollar Bluetooth, WLAN, 802.11n/MIMO, ZigBee/ISM, WiMAX, wireless video streaming, and cellular mobile handset markets. Leveraging pure CMOS and BiCMOS 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). www.nordicsemi.com