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

Test Summary, Technical Notes and Application Schematic

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1. Introduction

The Nordic nRF24LE1 is an ultra-low power RF system on-chip (SoC) operating in the 2.4GHz ISM (Industrial, Scientific and Medical) 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 +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 complicate the BOM. As shown in section 2, the RFaxis RFX2401C contain an LNA for the receiver, PA for the transmitter and two switches all in a single die. Adding the RFaxis RFX2401C RF Front-End IC (RFeIC™) 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 5 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 emphasizes the resulting range extension. Section 7 summarizes the implementation schematic of the connection between nRF24LE1 and RFX2401C. Section 8 summarizes the results of FCC Compliance testing of the setup.

2. RFX2401C Architecture

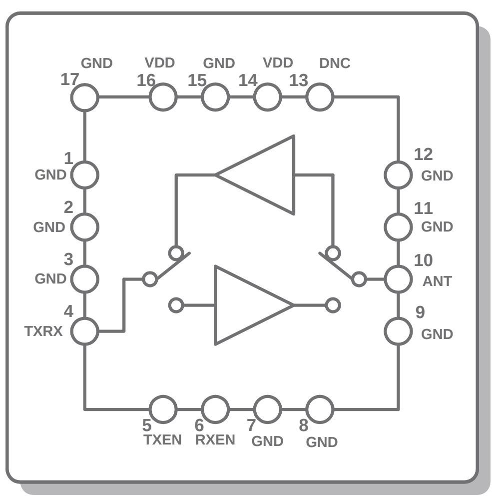

Figure 1: RFaxis RFX2401C RFeIC™ Block Diagram

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.

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.

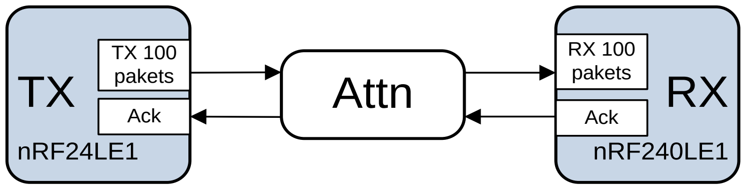

Figure 2: Setup 1 with two nRF24LE1

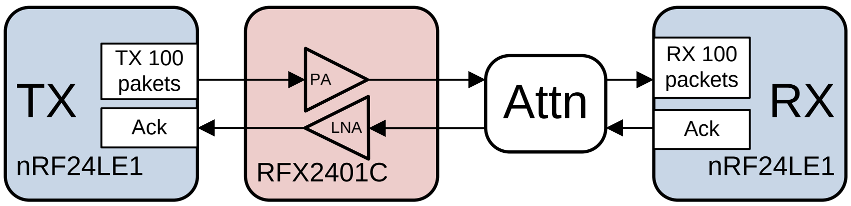

Figure 3: Setup 2 with one RFX2401C at the TX side

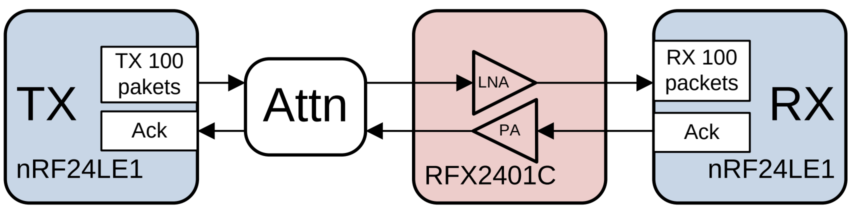

Figure 4: Setup 3 with an RFX2401C at the RX side

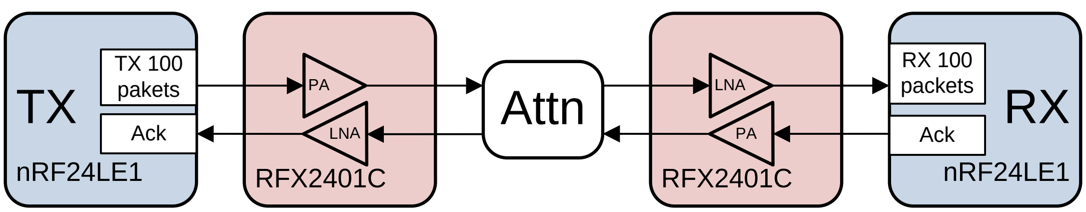

Figure 5: Setup 4 with RFX2401C at both ends

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
- 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.

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 5~6dB. 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.

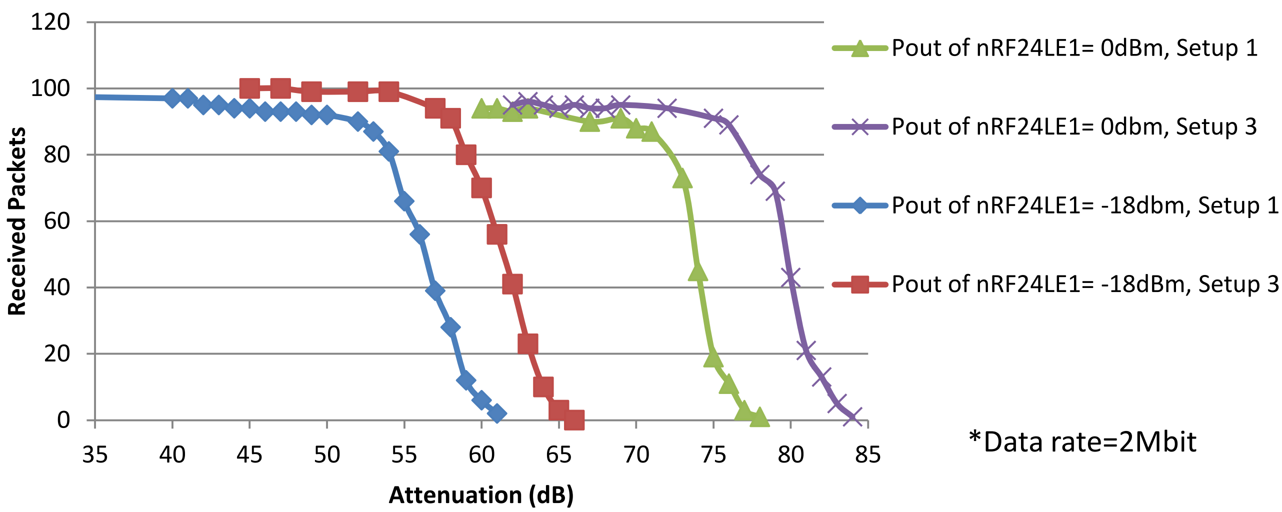

Figure 6: Effect of Receiver LNA on link extension

5. Boosting Transmitter Output Power with RFX2401C

As shown in section 2, the RFX2401C has both LNA and PA. When the nRF24LE1 output power is set to -18dBm, the gain of RFX2401C PA increases the transmitted antenna power by up to 24dB. At 0dBm output power setting of nRF24LE1, the maximum output power of the RFX2401C PA is 21dBm. Figure 7 shows the measured output power out of the nRF24LE1 standalone and with the RFX2401C. The corresponding RFX2401C current consumption as a function of output power is shown in Figure 8.

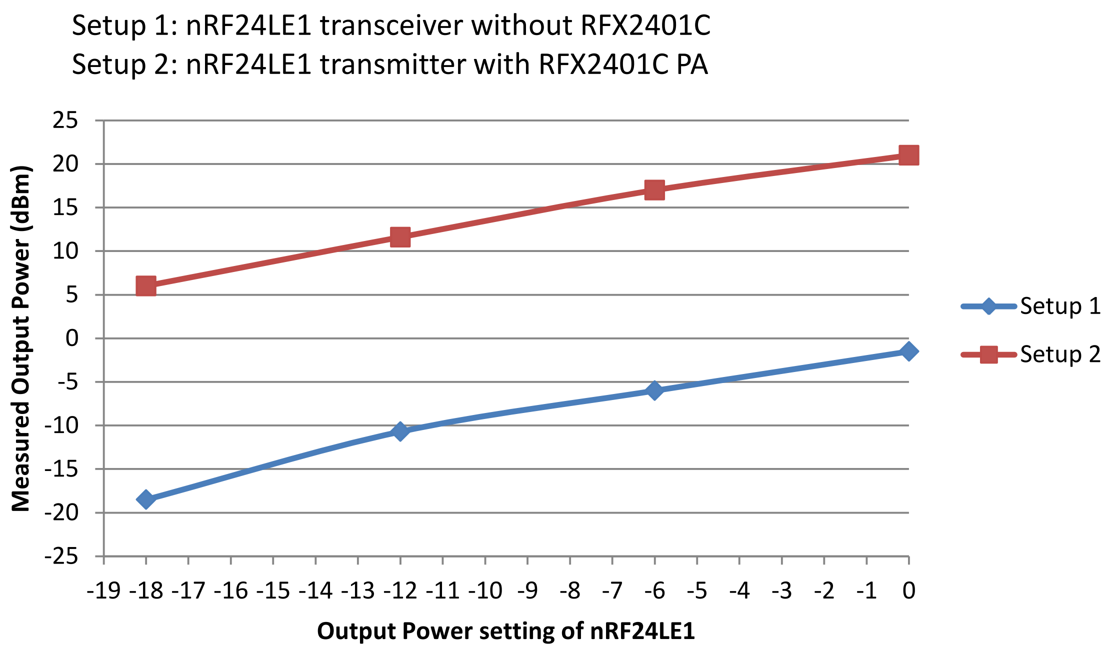

Figure 7: Measured output power with and without RFX2401C

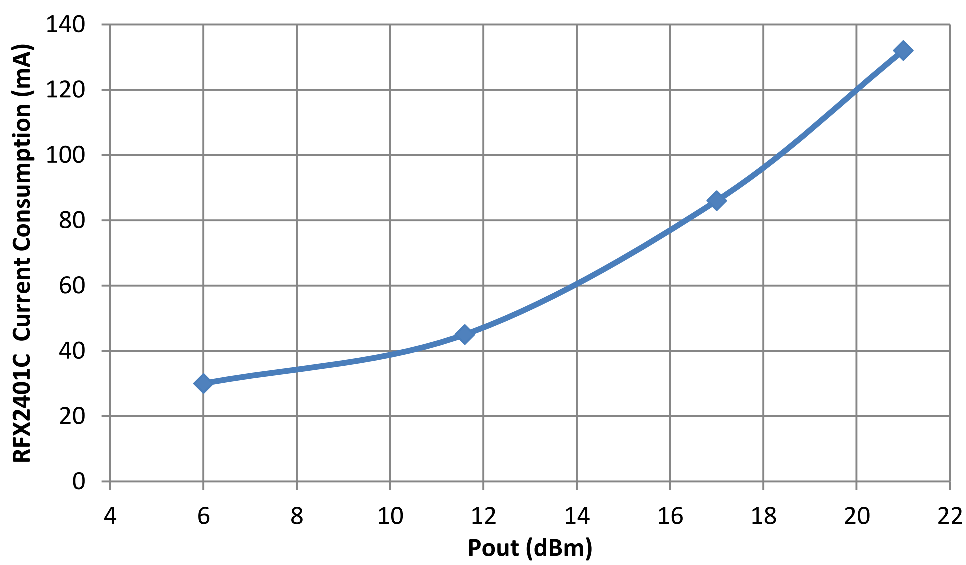

Figure 8: RFX2401C current consumption as a function of total output power

The corresponding attenuation results are shown in Figure 9. Adding the RFX2401C only to the transmitter improves the link by 6~24 dB. This large variation exists because the communication is bi-directional and using the RFX2401C only at one side does not amplify the transmit and receive signals by the same amount. In this setup, at higher power levels (0dBm in this case) the range can only be extended until the Acknowledge signal dies down because it is only amplified by the RFX2401C LNA. This limitation, however, does not exist when RFX2401C is used at both the receiver and the transmitter. This will be apparent in the next section.

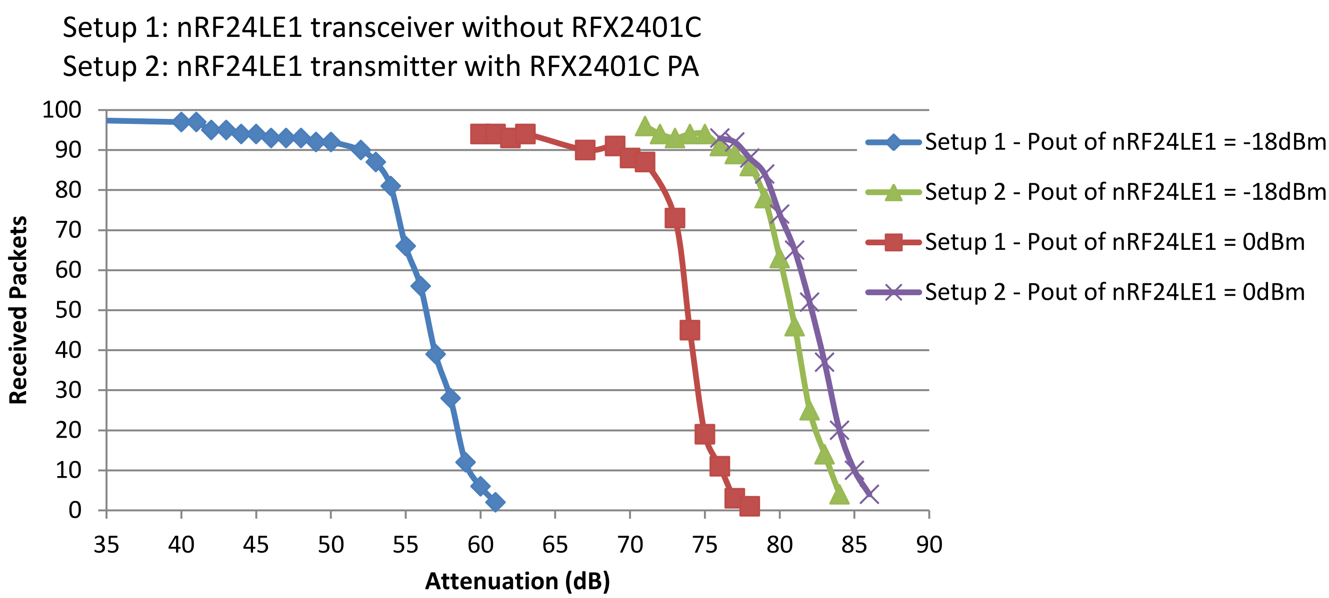

Figure 9: Effect of Transmitter PA on link extension

6. Range Extension

Adding the RFX2401C at both ends of the link increases the range by 26~35dB. The maximum output power of the RFX2401C PA is about 21dBm. At 0dBm nRF24LE1 output power setting, the range extension is about 26 dB. 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.

The effective distance improvement is calculated as $10^{\frac{ATTEN}{20}}$, where ATTEN is the extra gain in dB. At 0dBm output power of NRF24LE1, 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.

7. Application Schematic and settings

The schematic in Figure 12 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.

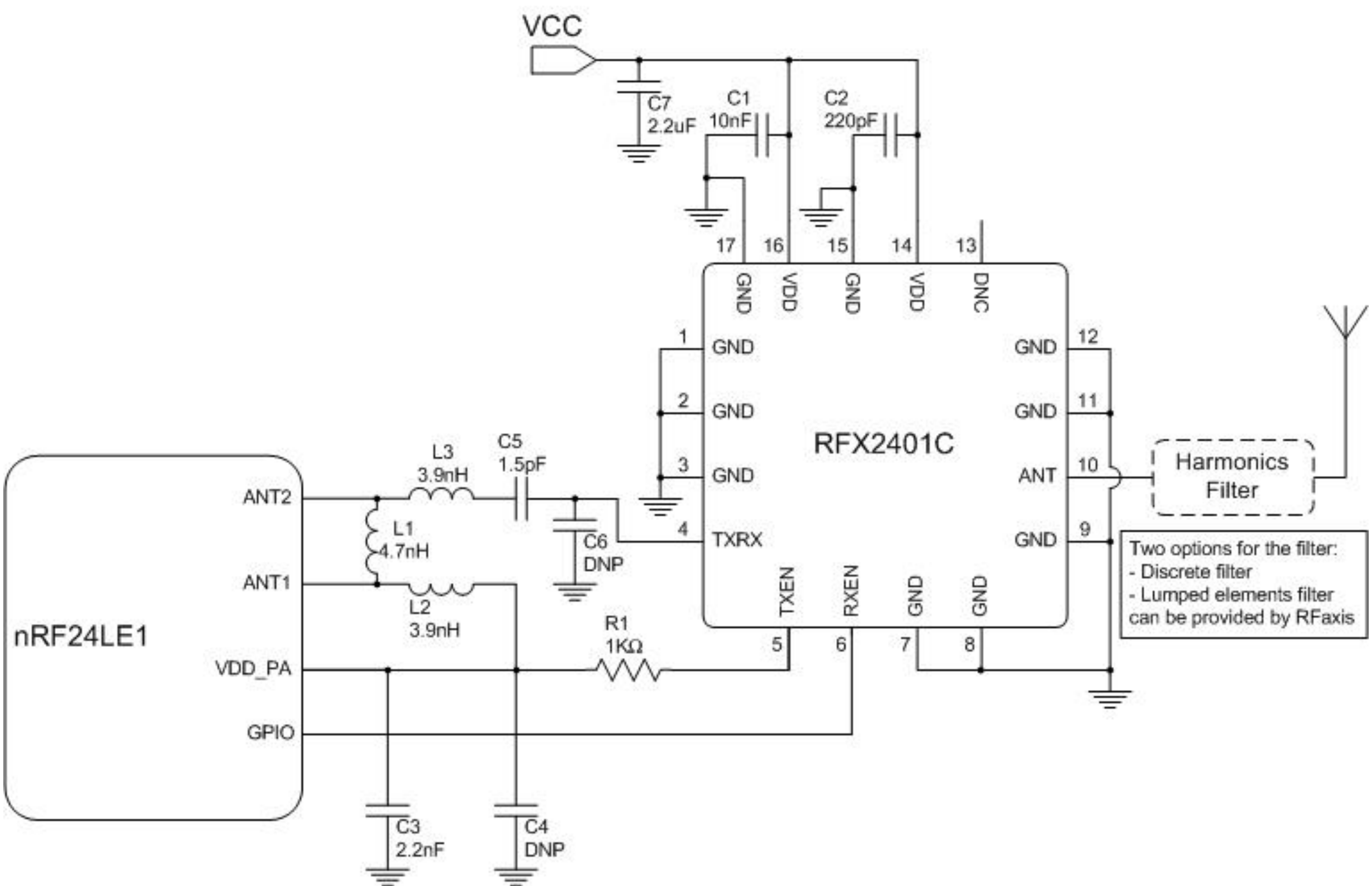

Figure 10: Typical connection schematic between nRF24LE1 and

8. 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 **Error! Reference source not found.**. 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 shows the actual spurious response of the design as depicted in **Error! Reference source not found.**. 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.

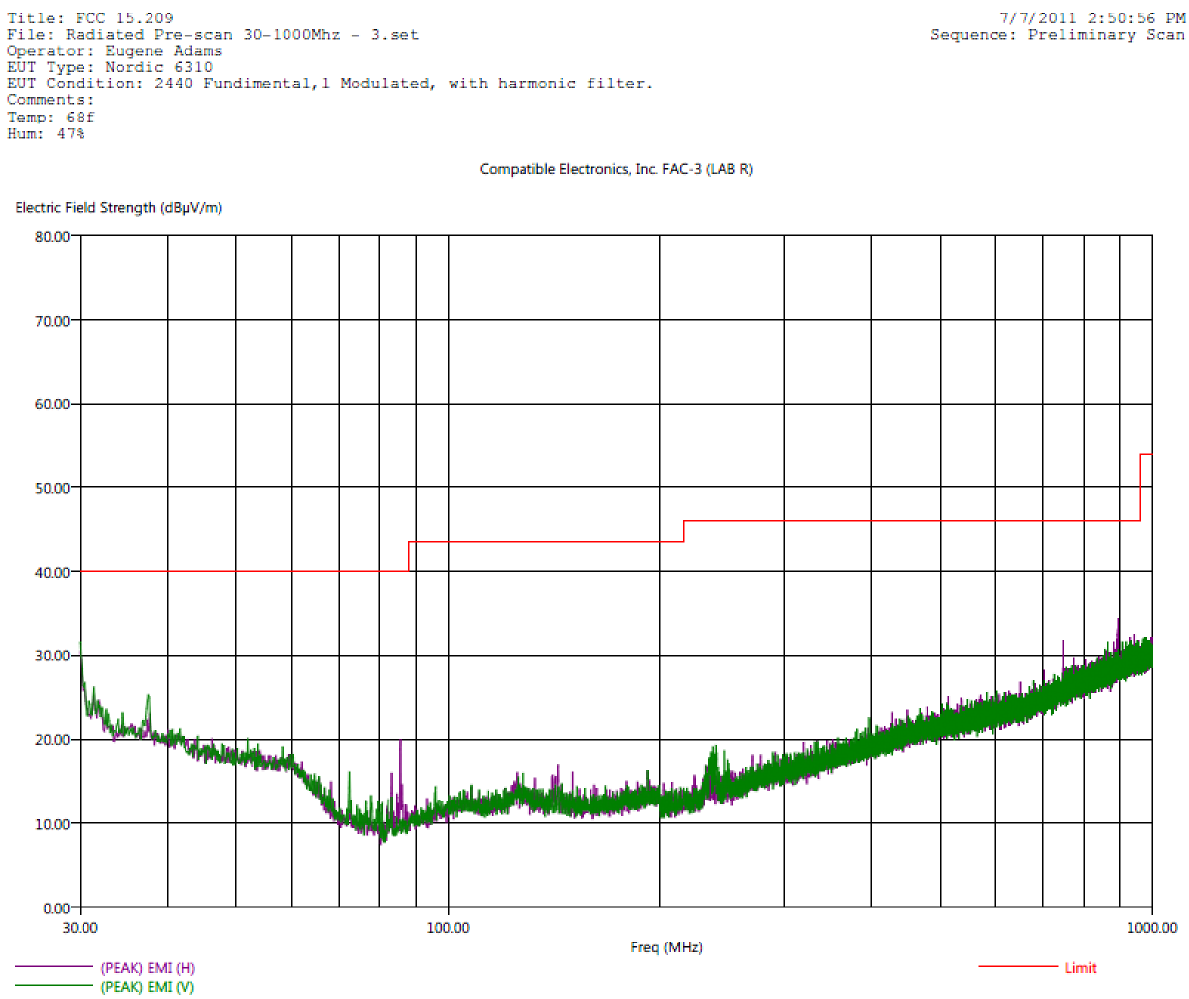

Figure 11: Spurious Response of the nRF24LE1 and RFX2401C

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 1 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 RFX2401C 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 1: Harmonic Response of the nRF24LE1 and RFX2401C

9. Conclusion

Adding the RFX2401C at the receiver side improves the link by ~5dB. This is resulting 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. The overall range extension is achieved by connecting the RFX2401C at both ends of the link. At the 0dBm output power setting of nRF24LE1, the RFX2401C gives 26dB improvement in total link budget **-** which is equivalent to about 20 times improvement in LOS distance.