



Range Extension for Nordic nRF51 Series with RFaxis RFX2411N RFeIC™

Results Summary, Technical Notes and Application Schematics

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Introduction

The Nordic nRF51 is an ultra-low power wireless system on-chip (SoC) operating in the 2.4GHz ISM band. This device is a popular solution for a wide range of applications that utilize ANT[™], Bluetooth low energy, Gazell, Enhanced Shockburst[™], and many other 2.4 GHz protocol implementations. The maximum transmit output power of the nRF51 is around +4dBm, and the receiver sensitivity can be in the range of -90 dBm. The nRF51 is intended for short range applications, but the range can be extended by adding external components including a transmit power amplifier, switches, and optionally a receive LNA. If this is implemented with discrete components, it will increase costs significantly and complicates the hardware design and bill of material.

As shown in section 1, the RFAxis RFX2411N RFeIC[™] (RF Front-End IC) contains an LNA for RF reception, a PA for RF transmission, and three RF switches all in a single die. The RFAxis RFX2411N can provide excellent range extension at a very low cost with ease of integration. This document summarizes the benefits of incorporating the RFX2411N in RF communication systems composed of nRF51 series devices. Some of the benefits of adding the RFX2411N to the nRF51 communication link are as follows:

- Improved Receiver sensitivity (Section 3, 5)
- Increased Transmitter output power (Section 4, 5)
- Extended Receiver dynamic range (Section 6)
- Enhanced Antenna coverage through Antenna diversity (Section 6)

Section 1 gives a brief overview of the architecture of the RFX2411N. Section 2 describes the different setups used to collect experimental results. Section 3 highlights improvements in the range by adding the RFX2411N at the receiver side. Section 4 contains improvements in the transmitter power together with the extra current used by the RFX2411N as a function of the output power. Section 5 contains the experimental results of the transmitter receiver pair and the resulting range extension. Section 6 details the implementation schematic including the connections between nRF51 and RFX2411N.

1. RFX2411N Architecture

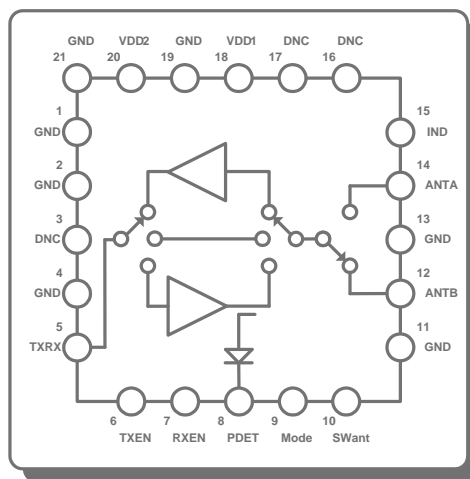


Figure 1: RFAxis RFX2411N RFeIC[™] Block Diagram

The RFX2411N is a fully integrated, single-chip, single-die RFIC (RF Front-end Integrated Circuit) which incorporates all the RF functionality needed for a variety of protocols implemented in the 2.4GHz band. The RFX2411N architecture integrates the PA, LNA, dual Transmit and Receive switches, antenna diversity switch, the associated matching network, and the harmonic filter all in a CMOS single-chip device. In addition to these standard features, the RFX2411N also includes a directional coupler based integrated power detector, and a bypass mode for managing strong signals in close proximity to the antenna. Using the RFX2411N together with the nRF51 is a simple and effective way to implement extended RF range and make wireless communication more robust without a complex design and extensive BOM.

2. Range Extension Measurement Setup

As mentioned in the introduction and shown in Figure 2 the nRF51 communicates wirelessly using various protocols, but the principle is the same regardless of the modulation, frequency, or bit rate. The further the transmitter and receiver are separated, the weaker the RF signal becomes at the receiver. In order to quantify the effects of distance, the range extension verification setup uses conducted RF signals fed through a variable attenuator as shown in Figure 3. Figure 4 and 5 show the test setup with the addition of the RFX2411N integrated PA/LNA device on either side of the link, and figure 6 shows an RFX2411N on both sides of the RF link.

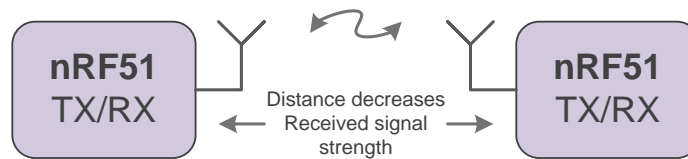


Figure 2: Operational nRF51 configuration

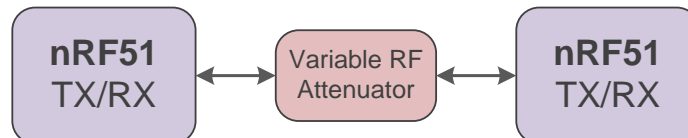


Figure 3: Setup 1 - Quantifying the effects of distance with a variable RF Attenuator

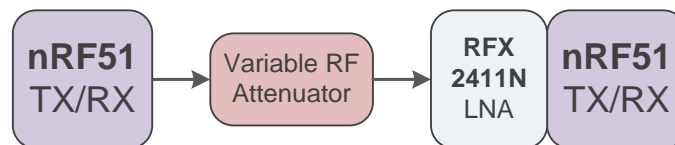


Figure 4: Setup 2 - Measuring the Improvement realized with the addition of RFX2411N at RX Side

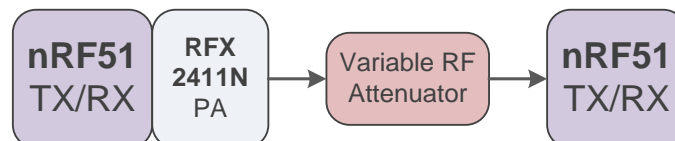


Figure 5: Setup 3 - Measuring the Improvement realized with the addition of RFX2411N at TX Side

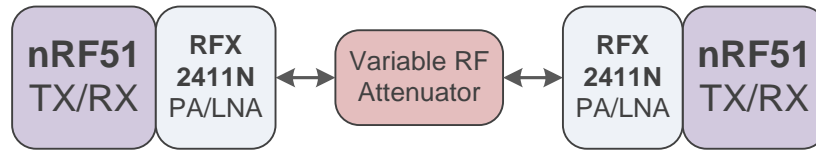


Figure 6: Setup 4 - Measuring the Improvement realized with the RFX2411N on both sides

The range extension verification experiment consists of the following steps:

- Setting up a pair of RF connected nRF51 devices
- Configuring the transmitter to continuously send a communication signal
- Continuously monitoring the receiver for received data
- Increasing the RF link attenuation until packet errors are observed

3. Receiver Sensitivity Improvement with RFX2411N

The nRF51 series devices are tested using the Nordic proprietary communication scheme based on GFSK modulation. The bit rate in this scheme is selectable from 250 Kbps to 2 Mbps.

To quantify the effect of adding the RFX2411N ahead of the nRF51 receiver, results from Setup 1 (Figure 3) and Setup 2 (Figure 4) using the LNA in the receive path are compared. The results are shown in Figure 7. For 99% error free transmission reception of the data packets, the range (attenuation) difference between Setup 1 and Setup 2 is 8 dB. The plot in Figure 7 shows that adding the RFX2411N at the receiver side improves the range by 8 dB. The range extension is a result of the difference in noise figure between the RFX2411N LNA and nRF51 receiver combined with the additional gain provided by the RFX2411N LNA. The RFX2411N LNA draws about 8 mA of current.

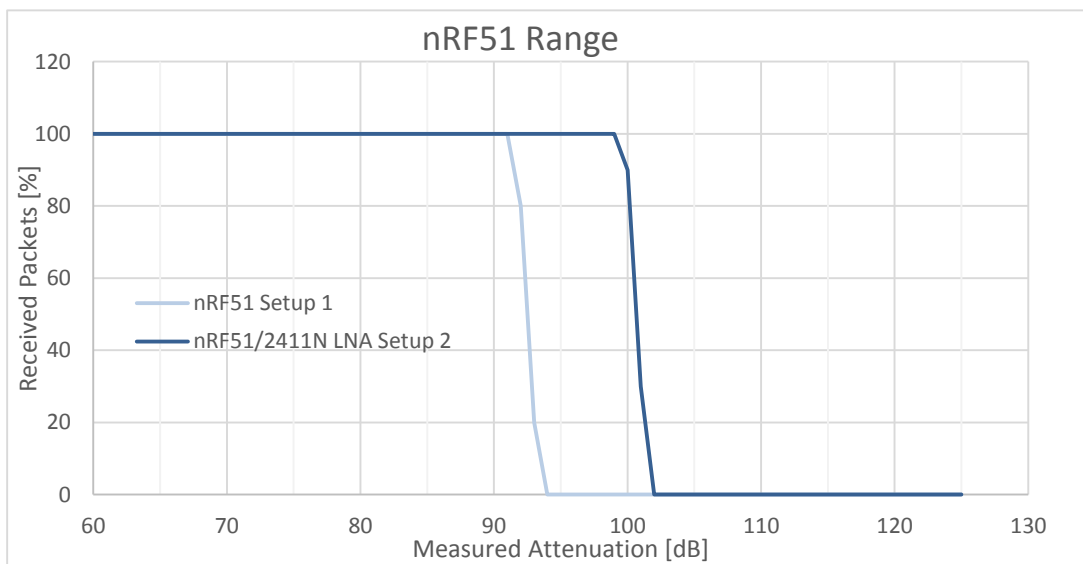


Figure 7: Range Extension by Adding the RFX2411N LNA

RFX2411N increases the range of the received signal by ~8dB, which can be observed in table 1. The receive sensitivity of the nRF51 with the test signal used for this verification is shown to be -93 dBm.

Metric	nRF51 Setup 1	nRF51 and RFX2411N Setup 2
Measured nRF51 Output Power	-0.5dBm	-0.5dBm
Measured Attenuation [Link Budget]	92.8dB	100.8dB
Calculated Minimum Received Power	-93.3dBm	-101.3dBm

Table 1: Setup 1 and Setup 2 Range Extension Compared

Increased Receiver Dynamic Range can also be implemented in the RFX2411N by activating the bypass mode. In this mode the RFX2411N has a loss of 4 dB compared to the LNA active mode with a gain of 12 dB. The 16 dB increase in dynamic range can be used to manage very strong signals in close proximity to the receive antenna. The bypass mode is bi-directional.

4. Boosting Transmit Output Power with RFX2411N

As mentioned in section 2, the RFX2411N has a PA with a typical maximum TX output power of +21dBm. Figure 8 shows the measured output power of the nRF51 standalone and the output power of the RFX2411N when combined with the nRF51 at various output power settings. The corresponding RFX2411N current consumption as a function of output power is shown in Figure 9.

The nRF51 has a sustained maximum output power of +4 dBm. The RFX2411N has a maximum output power of +21 dBm with a small signal gain of 25 dB. The RFX2411N can operate in gain saturation with the nRF51 maximum output signal at the input, but to maintain the highest efficiency, it is recommended that the system operate with the nRF51 at 0 dBm output as no additional range extension will be realized with a higher input level.

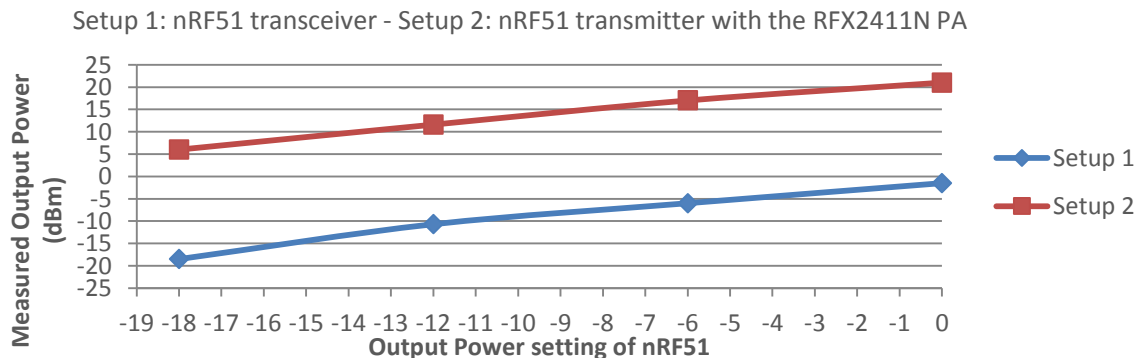


Figure 8: Measured output power with and without RFX2411N PA

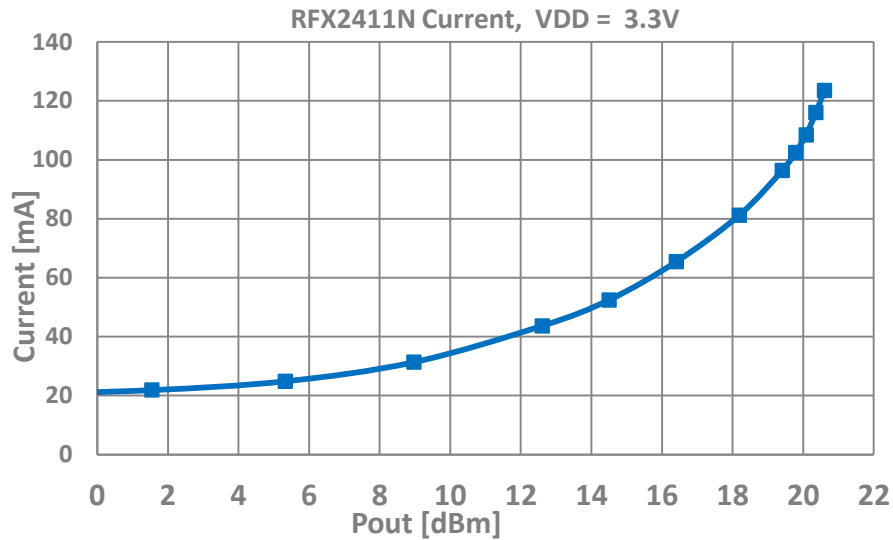


Figure 9: RFX2411N current consumption as a function of total output power

The output power verses current for large signal performance highlights the very low current consumption of the RFX2411N (Figure 9). In a real application environment with short bursts and small duty cycles, the average current consumption of the RFX2411N is very small. Additional power can be saved by operating the RFX2411N on VDD as low as 2.4V with a minor loss of gain and output power. When the shutdown mode is supported, the standby current drops to 1 uA. Contact RFAxis for full details on the RFX2411N.

The effect of adding RFX2411N to the transmitter side can be observed in Table 2 which compares Setup 3 (Figure 5) with Setup 1 (Figure 3). The power of the transmitted signal is increased by 20.4dB, with the corresponding improvement in the attenuation results shown in Figure 10. When the communication is measured only in the TX direction, the total range extension will be 20.4dB.

Metric	nRF51 Setup 1	nRF51 and RFX2411N Setup 3
Measured nRF51 Output Power	-0.5dBm	
RFX2411N Output Power		19.9dBm
Measured Attenuation [Link Budget]	92.8dB	113.2dB
Calculated Minimum Received Power	-93.3dBm	-93.3dBm

Table 2: Setup 1 and Setup 3 Range Extension Comparison

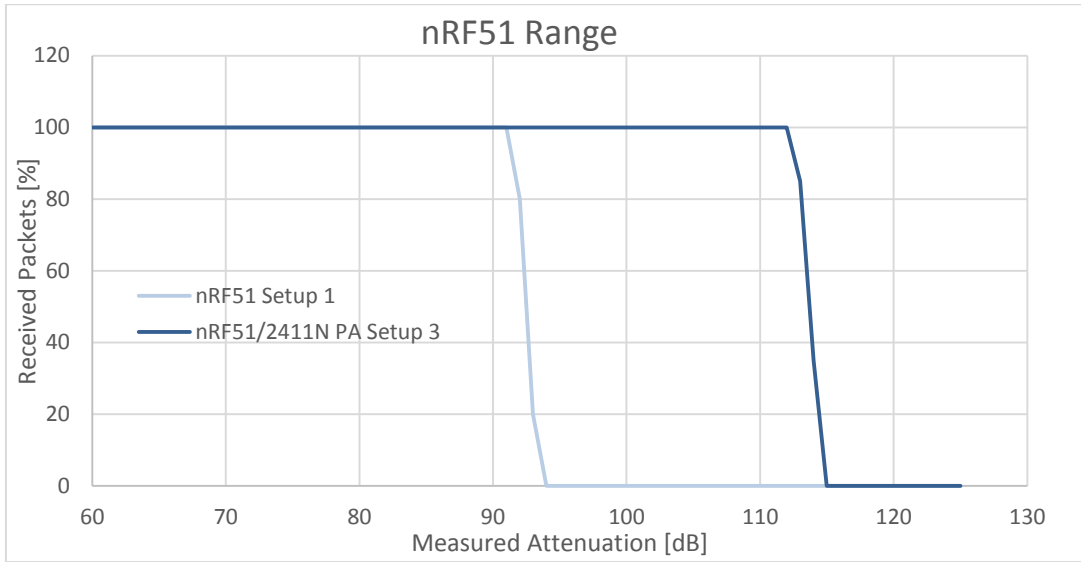


Figure 10: Range Extension by Adding the RFX2411N PA

5. Range Extension

Figure 11 shows the range extension with a RFX2411N added on both the transmit side and receive side of the RF link. Table 3 compares Setup 1 (Figure 3) with Setup 4 (Figure 6). The range extension realized by connecting the RFX2411N to the nRF51 is 28 dB. This is a result of the RFX2411N PA increased output power of ~20dB and ~8dB increased sensitivity from the RFX2411N LNA.

Metric	nRF51 Setup 1	nRF51 and RFX2411N Setup 4
Measured nRF51 Output Power	-0.5dBm	
RFX2411N Output Power		19.9dBm
Measured Attenuation [Link Budget]	92.8dB	121.2dB
Calculated Minimum Received Power	-93.3dBm	-101.3dBm

Table 3: Setup 1 and Setup 4 Range Extension Comparison

The effective distance improvement is calculated as $10^{\frac{ATTEN}{20}}$, where ATTEN is the additional gain in the range extension in dB. The RFX2411N improves the range by as much as 28dB which is equivalent to a factor of 25 distance improvement. When the nRF51 operates at maximum output power (+4 dBm) the range extension is 24dB with a distance improvement factor of 17. The difference in range extension between the nRF51 Pout = 0 dBm and +4 dBm results from the RFX2411N gain compression.

This range extension is based on an RF link with a direct line of sight (LOS) between the transmitter and the receiver. If there are any obstructions between the transmitter and the receiver (i.e. objects, buildings, reflective surfaces), the range may be different. The improved range extension can also result in improved connectivity under less than ideal conditions such as when RF impairments are present.

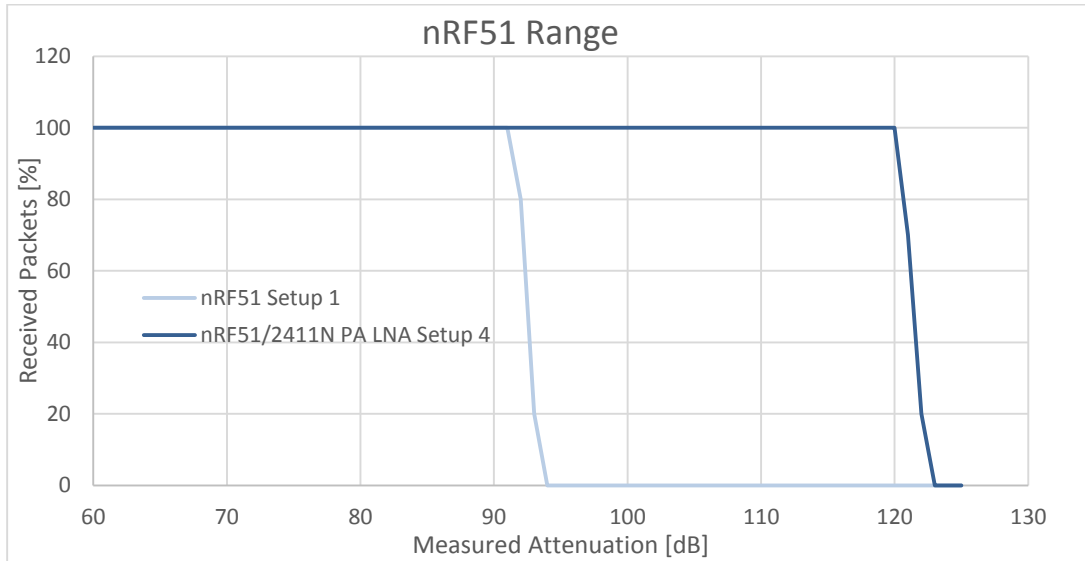


Figure 11: Range Extension by Adding the RFX2411N PA and LNA

6. Application Schematic and Settings

The schematic in Figure 12 and Figure 13 show the recommended application circuit incorporating the RFX2411N with the nRF51. The configuration is as follows:

- TXRX port (Pin 5) of RFX2411N is connected to the ANT1 and ANT2 port of nRF51 through Nordic specified matching components
- TXEN (Pin 6) is connected to the nRF51 VDD_PA through an isolation resistor
- RXEN (Pin 7) of RFX2411N is connected to the nRF51 GPIO
- Pdet (Pin 8) can be left floating or optionally connected to an analog input on the nRF51 for output power detection
- Mode (Pin 9) can be connected to the nRF51 GPIO for RF Bypass of the PA/LNA
- SWANT (Pin 10) can be connected to the nRF51 GPIO for antenna diversity
- All 4 control pins (TXEN, RXEN, MODE, and SWANT) must be terminated properly

Increased Receiver Dynamic Range can be implemented through the LNA bypass mode. In this mode the RFX2411N has a loss of 4 dB compared to the LNA active mode with a gain of 12 dB. The total increased dynamic range of 16 dB can be used to manage very strong signals in close proximity to the receive antenna. Antenna diversity is supported to provide better antenna coverage through spatial and polarization techniques.

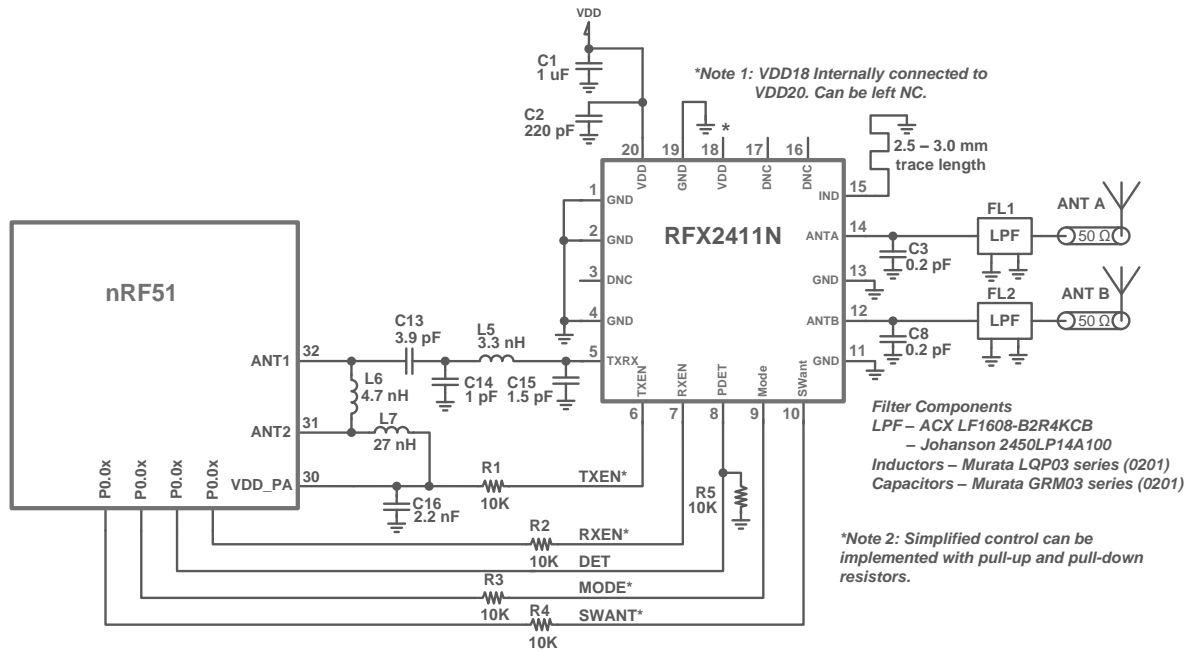


Figure 12: Typical connection schematic between the nRF51 and RFX2411N with Low Pass Ceramic Filters

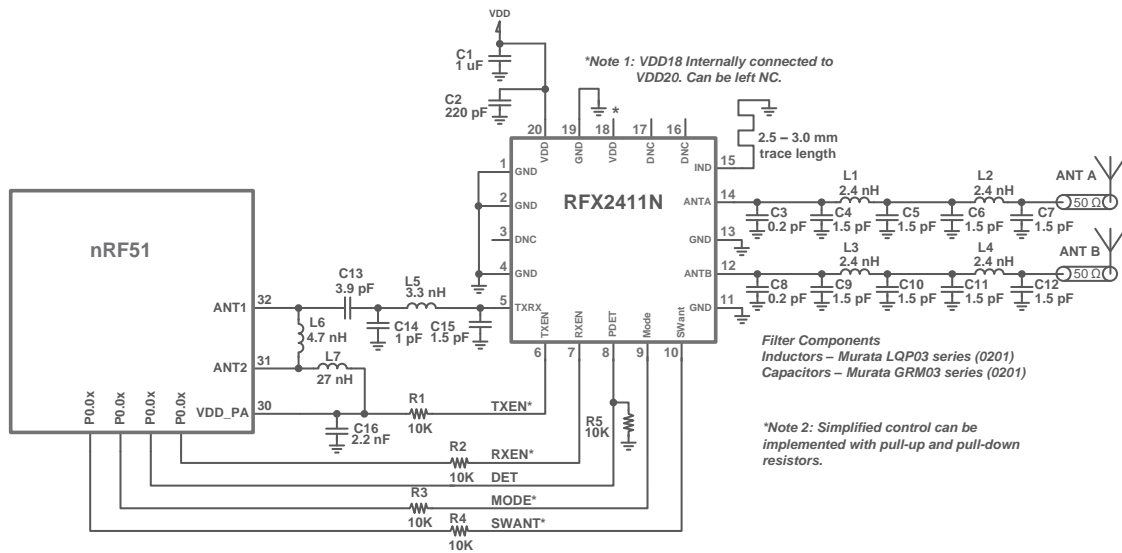


Figure 13: Typical connection schematic between the nRF51 and RFX2411N with Lumped Element Filter

Figure 12 shows the harmonic filter for regulatory compliance utilizing ceramic filter components. Figure 13 shows a typical compliance filter based on the lumped element approach. Series resistors are included on the control lines to provide isolation and prevent voltage spikes from damaging the control logic input circuits.

Table 4 details the control logic truth table for operation of the RFX2411N device. For additional application details please contact RFAxis Inc.

TXEN	RXEN	MODE	Mode of Operation
0	0	0	Shutdown Mode
X	X	1	Bypass Mode
1	X	0	Transmit Mode
0	1	0	Receive Mode

SWant	Mode of Operation
1	ANTA port enabled
0	ANTB port enabled

Table 4: Logic control signal truth tables for the RFX2411N

7. Conclusion

The addition of the RFX2411N integrated PA/LNA/Switch RFIC improves the range of a wireless communication system based on the Nordic nRF51 while keeping the design simple and minimizing current consumption. Adding the RFX2411N at the receiver side improves the link by ~8dB. This is a result of the delta in noise figure between the nRF51 and the RFX2411N LNA combined with the gain of the RFX2411N LNA. Adding RFX2411N to the transmit side will increase the output power of the system to +20dBm. The maximum range extension is achieved by including the RFX2411N at both ends of the link, though some benefit is realized with the RFX2411N on just one side or the other of the link. With the RFX2411N on both sides of the link, up to 28 dB range extension is realized, which is equivalent to a factor of up to 25 LOS improvement in wireless connection distance.

The RFX2411N also provides additional benefits to the communication system by supporting antenna diversity, which allows better antenna receiver coverage through spatial separation and polarization offsets. In addition, the RFX2411N has a bi-directional bypass mode to

accommodate strong signals present at the receiver or to bypass the PA for power savings. With this extensive feature set and ease of integration, the RFX2411N is an excellent choice for range extension applications.

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