Range Extension for Nordic nRF51 Series with RFaxis RFX2411N RFeIC™

Results Summary, Technical Notes and Application Schematic

RFaxis Inc.
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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 +0dBm, and the receiver sensitivity can be in the range of -90 dBm. The nRF51 is intended for short range applications, but can be configured to include range extension components which involve adding a transmit power amplifier, switches, and optionally a receive LNA. This can 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. Including the RFX2411N in the system design can increase the transmitted power and improve the receiver sensitivity leading to considerable range extension and more robust communications. 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.

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

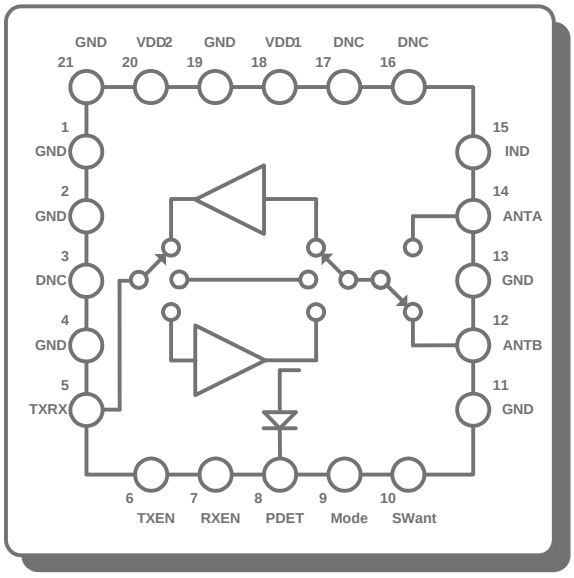

Figure 1: RFaxis RFX2411N RFeIC™ Block Diagram

The RFX2411N is a fully integrated, single-chip, single-die RFeIC (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 realize extended RF range and make wireless communication more robust without a complex design and extensive BOM.

2. Range Extension Verification Setup

As mentioned in the introduction, the nRF51 communicates wirelessly using various protocols, but the principle is the same regardless of the modulation, frequency, or bit rate. (Figure 2) 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 utilized conducted RF signals fed through a variable attenuator detailed in Figure 3. Figure 4 and 5 show the test setup with the addition of the RFX2411N integrated PA/LNA device on one side and both sides of the RF link.

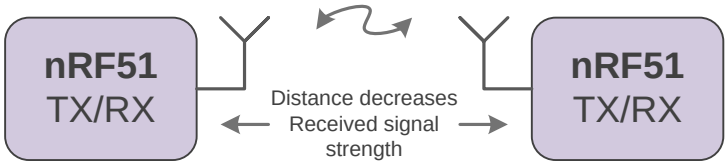

Figure 2: Operational nRF51 configuration

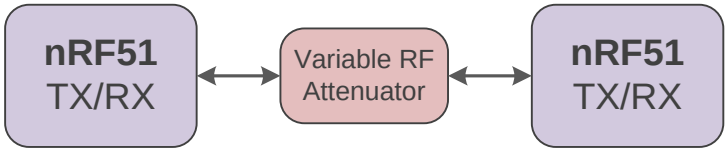

Figure 3: Setup 1 - Quantifying the effects of distance with a variable RF Attenuator

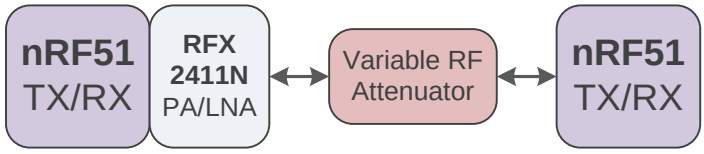

Figure 4: Setup 2 - Measuring the Improvement realized with the addition of one RFX2411N

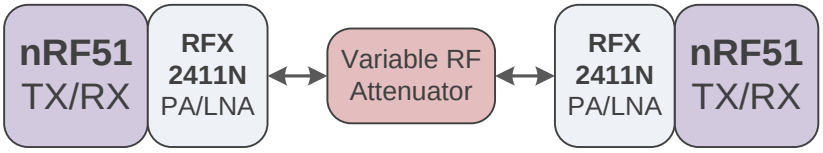

Figure 5: Setup 3 - Measuring the Improvement realized with the RFX2411N on both sides

The range extension verification tests consisted of the following:

- Setting up a pair of RF connected nRF51 devices.
- The transmitter was configured to continuously send a communication signal
- The receiver was continuously monitored for received data
- The conducted RF link attenuation was increased until packet errors were noted

3. Receiver Sensitivity Improvement with RFX2411N

The nRF51 series devices were 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 using the LNA in the receive path (Figure 4) are compared. The results are shown in Figure 6. For 99% error free transmission reception of the data packets, the range (attenuation) difference between Setup 1 and Setup 2 is 8dB. The plot shows that adding the RFX2411N at the receiver side improves the link budget by 8 dB. The range improvement 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.

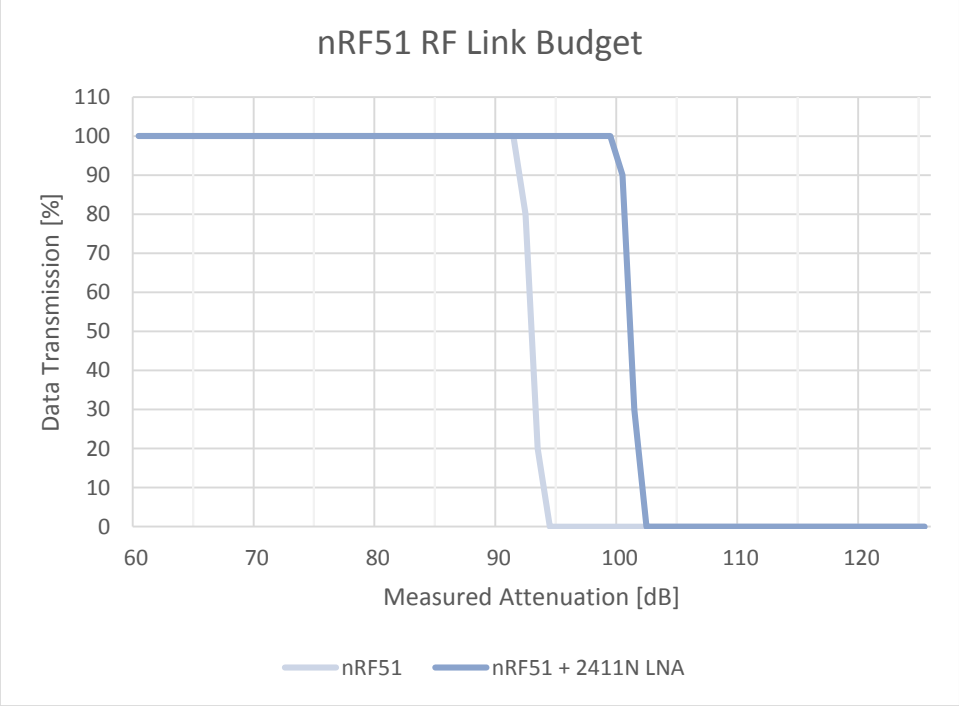

Figure 6: Improvement in the Link Budget by Adding the RFX2411N LNA

RFX2411N increases the link budget of the transmitted signal by ~8dB, which can be observed by comparing tables 1 and 2. The receive sensitivity of the nRF51 with the test signal used for this verification was measured at -93 dBm.

Setup 1: nRF51 Stand Alone Sensitivity	
nRF51 Output Power	-0.5dBm
Measured Attenuation [Link Budget]	92.8dB
nRF51 Minimum Received Power	-93.3dBm

Table 1: Setup 1 nRF51 Stand Alone Sensitivity

Setup 2: nRF51 Sensitivity with RFX2411 LNA	
nRF51 Output Power	-0.5dBm
Measured Attenuation [Link Budget]	100.8dB
nRF51 RFX2411N LNA Minimum Received Power	-101.3dBm

Table 2: Setup 2 nRF51 Sensitivity Measured with RFX2411 LNA

4. Boosting Transmit Output Power with RFX2411N

As shown in section 2, the RFX2411N has a PA with a typical maximum TX output power of +21dBm. Figure 7 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 8.

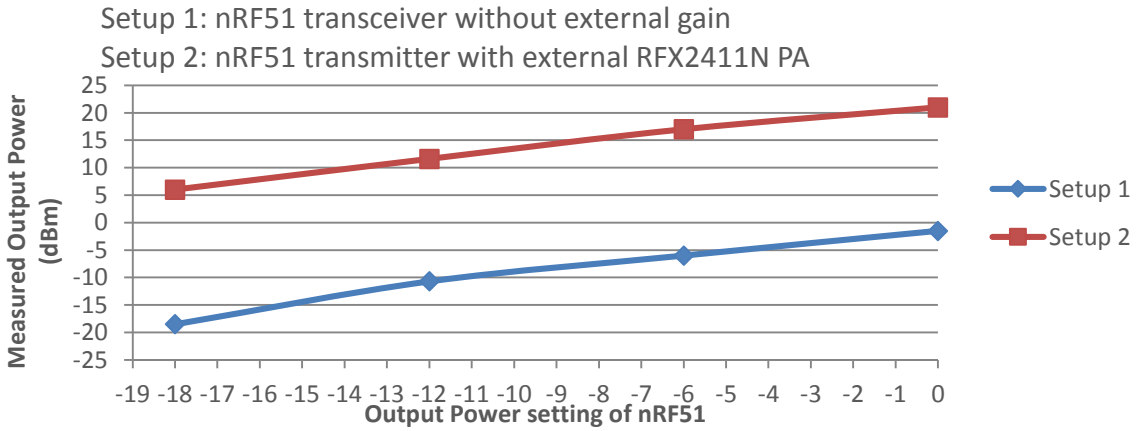

Figure 7: Measured output power with and without RFX2411N PA

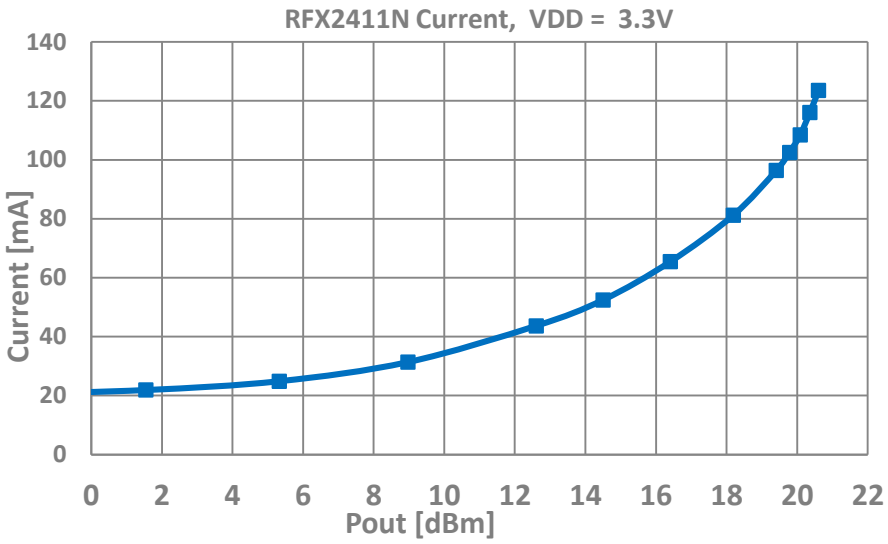

Figure 8: RFX2411N current consumption as a function of total output power

As clearly shown in figure 8, the output power verses current for large signal performance highlights the very low current consumption of the RFX2411N. In a real application environment with short bursts and small duty cycles, the additional average current used by adding the RFX2411N will be very small. When the shutdown mode is supported, the standby current is around 1 uA.

The effect of adding RFX2411N to the transmitter side can be observed in Table 3 (Setup 2) when compared to Table 1 (Setup 1). The link budget of the transmitted signal is increased by 20.4dB, with the corresponding attenuation results shown in Figure 9.When the communication is measured only in the TX direction, the total link budget improvement will be 20.4dB. Improvement can be realized in both directions by adding the RFX2411N to both the receiver and the transmitter as will be discussed in Section 5.

Setup 2: nRF51 Sensitivity with RFX2411 PA	
nRF51 Output Power	-0.5dBm
RFX2411N Output Power	19.9dBm
Measured Attenuation [Link Budget]	113.2dB
nRF51 Minimum Received Power	-93.3dBm

Table 3: nRF51 Sensitivity Measured with the RFX2411N PA

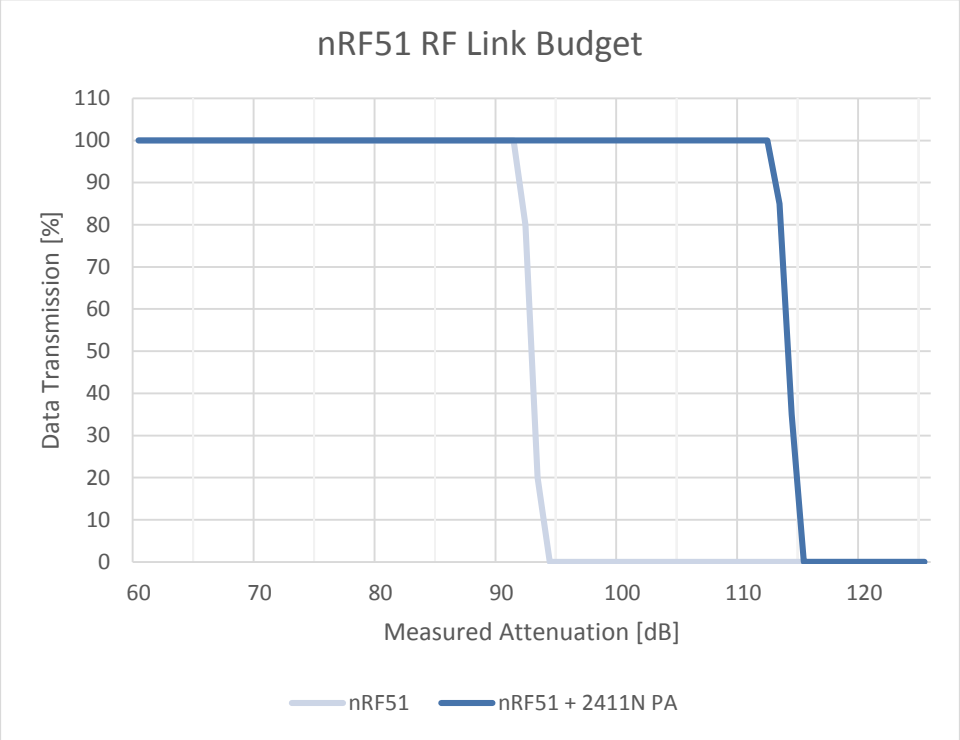

Figure 9: Improvement in the Link Budget by Adding the RFX2411N PA

5. Range Extension

Figure 10 shows the link budget improvement with a RFX2411N added on both the transmit side and receive side of the RF link. By comparing Table 1 (Setup 1) and Table 4 (Setup 3) it is shown that adding the RFX2411N increases the link budget by 28dB. This is a result of the RFX2411N PA increased output power of ~20dB and ~8dB increased sensitivity from the RFX2411N LNA.

Setup 3: nRF51 Sensitivity with RFX2411 PA and LNA	
nRF51 Output Power	-0.5dBm
RFX2411N Output Power	+19.9dBm
nRF51 RFX2411N LNA Minimum Received Power	-101.3dBm
Measured Attenuation [Link Budget]	121.2dB

Table 4: nRF51 Sensitivity Measurement with the RFX2411N PA and LNA

The effective distance improvement is calculated as $10^{\frac{ATTEN}{20}}$, where ATTEN is the additional gain in the link budget in dB. The RFX2411N improves the range by as much as 28dB which is equivalent to a factor of 25 distance improvement. 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 link budget can also result in improved connectivity under less than ideal conditions such as when RF impairments are present.

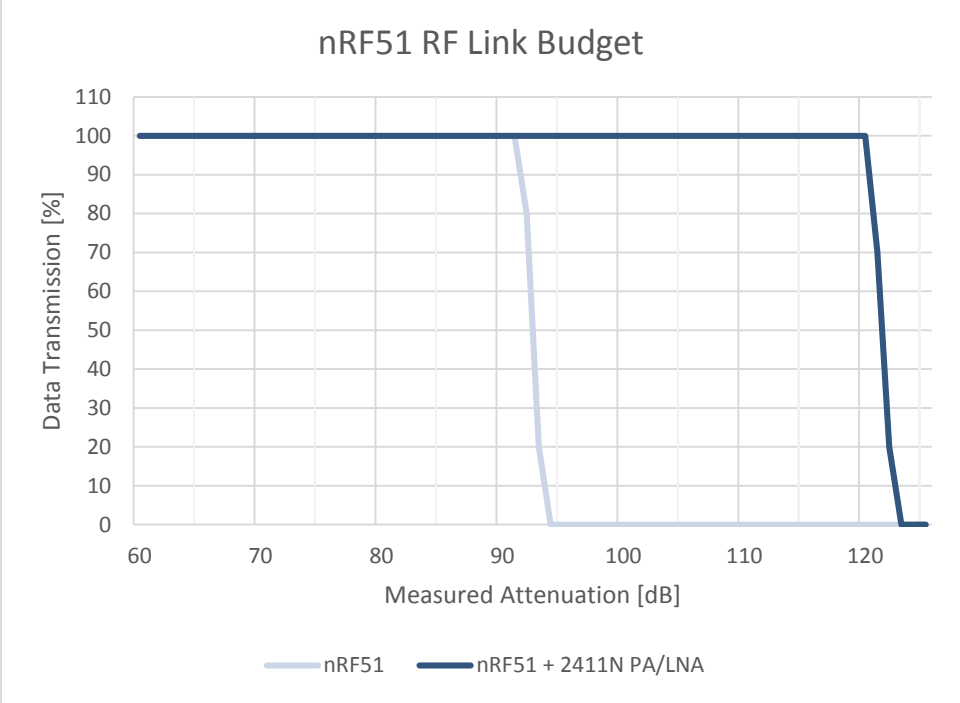

Figure 10: Improvement in the Link Budget by Adding the RFX2411N PA and LNA

6. Application Schematic and settings

The schematic in Figure 11 shows a typical 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 tied high or optionally connected to nRF51 GPIO
- Pdet (Pin 8) can be left floating or optionally connected to an analog input on the nRF51 for output power detection
- Mode can be tied low or optionally connected to an nRF51 GPIO for RF Bypass
- SWant can be tied low or optionally connected to an nRF51 GPIO for antenna diversity

The optional ANT2 circuit supports antenna diversity for both TX and RX modes. Optional control signal interconnects can be used to support Bypass Mode, Shutdown Mode, and PA output power detection, as well as controlling antenna diversity. The output harmonic filter is recommended for compliance testing support. Please contact RFaxis, Inc. for additional configuration details and application support.

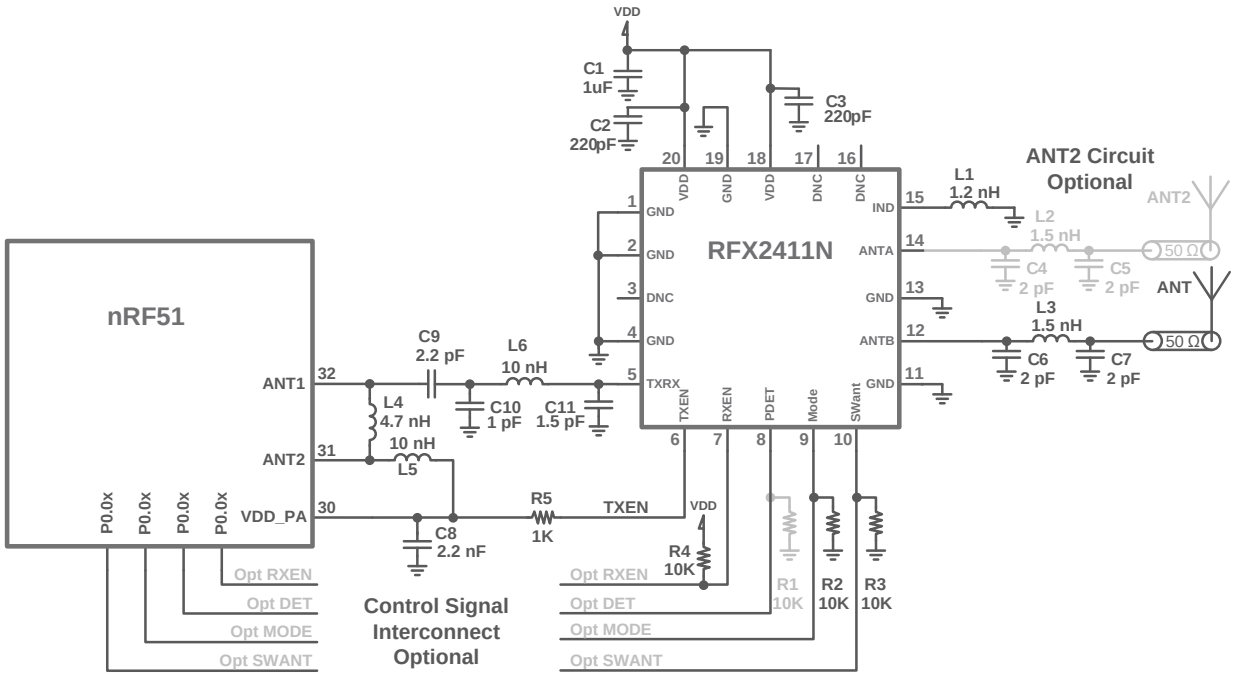

Figure 11: Typical connection schematic between the nRF51 and RFX2411N

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 5: Logic control signal truth tables for the RFX2411N

7. Conclusion

The addition of the RFX2411N integrated PA/LNA/Switch RFeIC will improve the link budget 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 gain of the RFX2411N LNA and delta in noise figure between the nRF51 and 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 of the link. With the RFX2411N on both sides of the link, a 28dB improvement in total link budget can be realized**,** which is equivalent to a factor of 25 LOS improvement in wireless connection 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