Freescale MC1321x/MC1322x ZigBee Range Extension Utilizing the RFaxis RFX2401 Single-Chip RFeIC™

Test Results, Technical Notes and Application Schematics

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1. Introduction

The Freescale MC1321x and MC1322x are a family of IEEE 802.15.4 compliant, ultra-low power wireless System-on-Chips (SoCs) operating in the 2.4GHz ISM band. It is a popular solution for a wide range of ZigBee applications including wireless mouse, remote control, asset tracking, monitoring, medical sensor, home automation, gaming, and more. The maximum transmitted output power of the MC1321x and MC1322x is +3dBm.

These SoCs are primarily used for short range application, and a typical solution to extend this range involves adding a Power Amplifier (PA) for the transmit path, optionally a Low Noise Amplifier (LNA) for the receive path, and one or two RF switches to allow the transceiver to control the RF path for transmit or receive operation. This greatly increases and complicates the Bill of Material (BOM) and requires a lot a real estate on the application platform. As shown in section 2, the RFaxis RFX2401 RFeIC™ (RF Front-End IC) contains an LNA for the receiver path, a PA for the transmit path, and two RF switches, all in a single-package/single-die. Incorporating the RFX2401 into the application design can increase the transmitted power and reduce the receiver NF providing range extension and more robust communications. This document will provide design details and summarize the benefits of adding the RFX2401 to a Freescale MC1321x and MC1322x platform IC system.

In this document, Section 2 gives a brief overview of the architecture of the RFX2401. Section 3 describes the different setups used to collect experimental results, while Section 4 highlights range improvements provided by the LNA in the RFX2401 for the RF receiver path. Section 5 contains details on the improvements to the transmitter power contrasted against the additional current used by the RFX2401 for the increased output power, and section 6 contains the experimental results of the transmitter receiver pair including the range extension. Section 7 details the design schematic and the connection between the MC1321x and MC1322x with the RFaxis RFX2401.

2. RFaxis RFX2401 Architecture

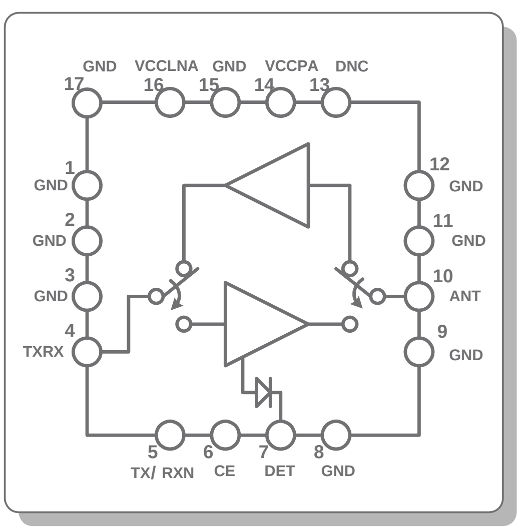

Figure 1: RFaxis RFX2401 RFeIC Block Diagram

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 the ZigBee transceiver is an effective way to extend the range and make communications more robust without a complicated BOM.

3. Test Setup

The test setup was implemented on the Freescale Remote Control demonstration board set (1321XCSK-BDM) that consists of two ZigBee platforms showcasing a TV remote control function. This demo includes things like changing the channel, setting the volume level, and so forth while utilizing RF4CE and a low data rate within the ZigBee Standard. When a command is sent from the Remote Control side, a confirmation reply is sent from the Receiving Unit.

During the test scenarios, attenuation was gradually applied in steps between the ZigBee platforms to simulate RF propagation loss that would occur with greater distance or the presence of walls or other RF impediments. After a given amount of attenuation is applied to the RF link, the Remote Control is exercised on one end, and then confirmed on the Receiving Unit end of the link, as well as the reply back from the Receiving Unit. The results were then recorded and tabulated for the following test scenarios.

In order to measure the improvements provided by the RFX2401 for the MC132xx SoCs, the following test plan was followed. The units were first tested with no improvement (Figure 3), followed by tests with the improved output power and noise figure added to one side at a time (Figure 4 and Figure 5), followed by improvements added to both ends of the link (Figure 6). Figure 2 shows for reference a real world implementation of a ZigBee system, including the over-the-air RF link.

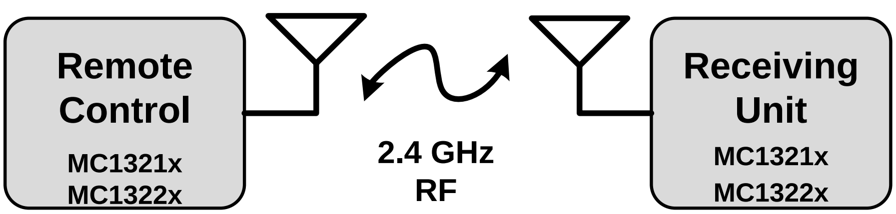

Figure 2: Real world ZigBee system

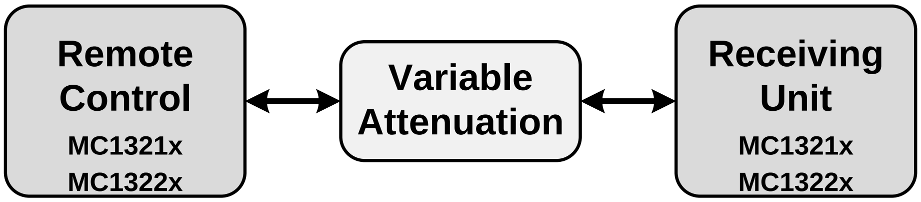

Figure 3: Setup 1 baseline measurement

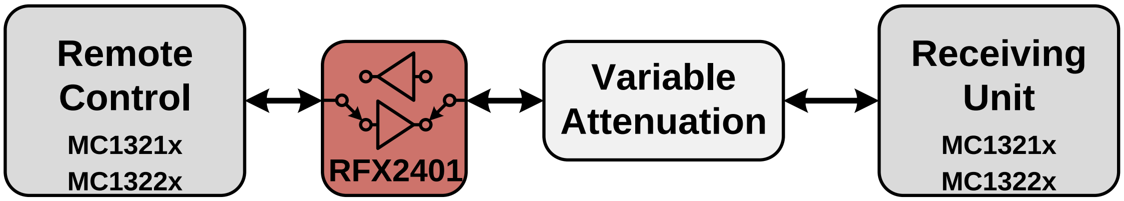

Figure 4: Setup 2 with an RFX2401 connected to the “Remote Control” side

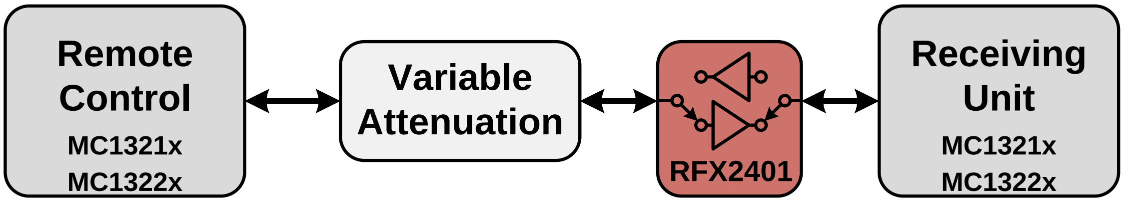

Figure 5: Setup 3 with an RFX2401 on the "Receiving Unit" side

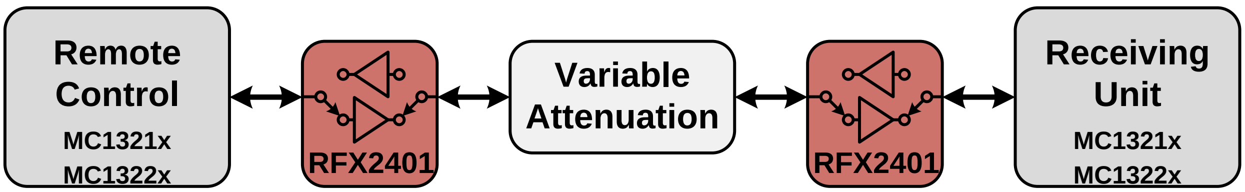

Figure 6: Setup 4 with RFX2401 at both ends

The experiment consists of the following steps:

- Networking the Remote and Receiver pair
- Applying attenuation to the RF channel in steps
- Sending 10 control commands with the Remote
- Verifying the commands were received and acknowledged
- Attenuating the link until 0 out of 10 commands were received

4. Receiver Sensitivity Improvement with RFX2401

To demonstrate the improvement provided by the RFX2401 for the MC1321x and MC1322x receivers, results from Setup 1 (Figure 3) and Setup 3 (Figure 5) are compared and shown in Figure 7. As shown in the graph, the sensitivity difference between Setup 1 and Setup 3 is 6dB. The plots show that adding the RFX2401 improves the noise figure at the receiver. The range improvement results from the addition of the LNA which increases the system sensitivity.

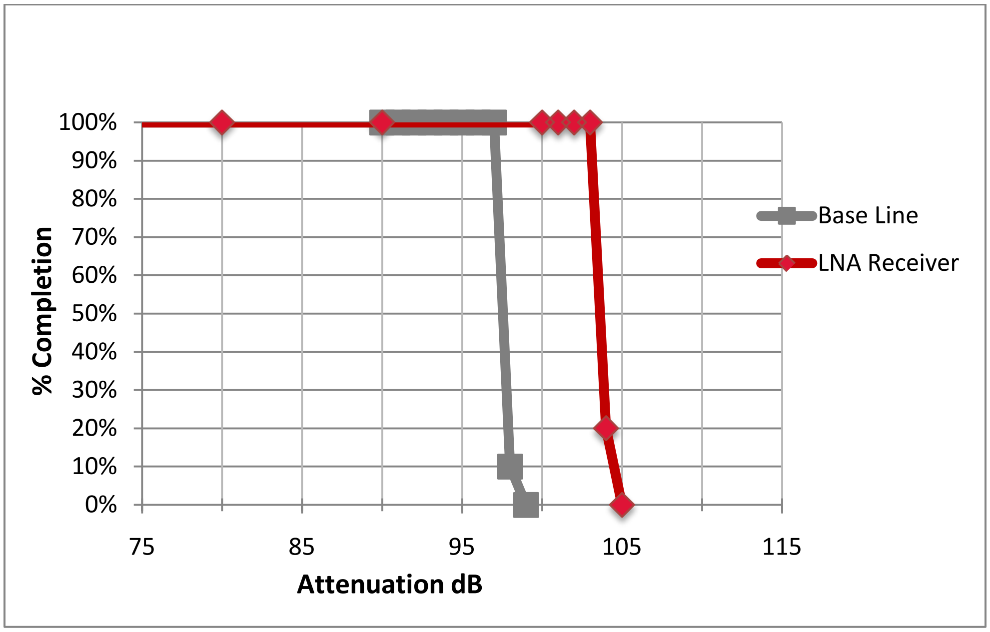

Figure 7: Improvement from the RFX2401 LNA verses the baseline measurement

5. Boosting Transmitter Output Power with RFX2401

The range extending capability of the RFX2401 with the MC1321X is very robust for the transmit function. As the PA adds additional output power, the system can then extend the range by that same amount of loss, as plotted in Figure 8. The improvement is shown to be greater than 25 dB, though the unaided system can output additional power that is not reflected in the chart. With the transceiver set at maximum power, the improvement would still be in the range of 22 dB.

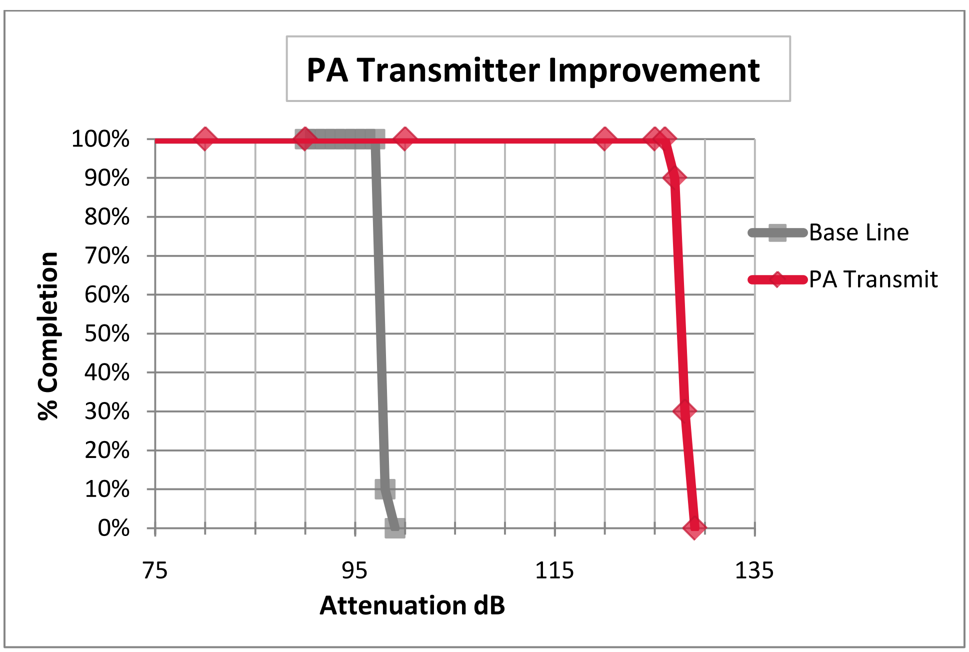

Figure 8: Improvements for the RFX2401 PA verses the base line measurement

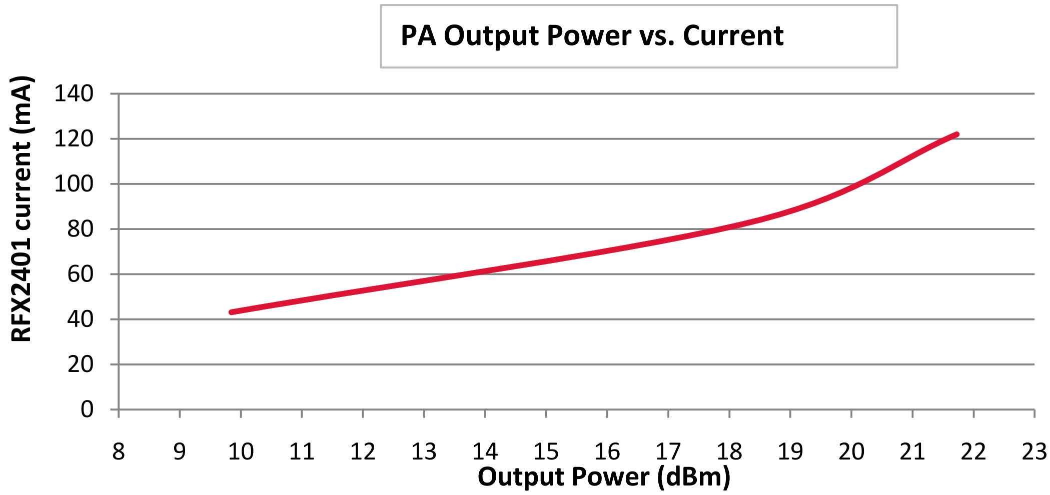

Figure 9: RFX2401 PA current consumption during transmit as a function of RF output power

Figure 9 shows the current requirements of the RFX2401 during transmit. As the transmit time is short and of a low duty cycle, this impact to the system power demand will be minimal.

6. Range Extension

Free Space Propagation is the ability of a give frequency radio wave to travel a given distance with a definable amount of loss. Many factors in addition to free space propagation will affect the strength of the signal at the receiver including multipath and obstacles between the receiver and the transmitter. For the purpose of this exercise, we are discussing only the free space propagation as a reference point to give an indication of possible performance improvement for the MC132xx / RFX2401 combination platform IC system. Figure 10 is a plot of system dB increase vs. distance improvement factor for 2.45 GHz.

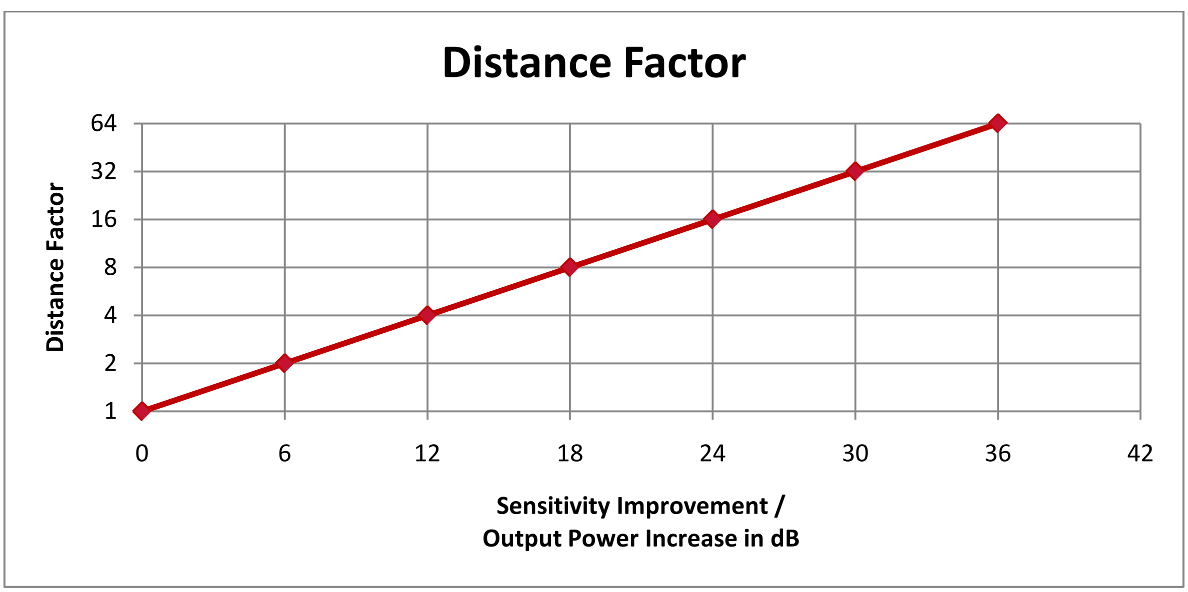

Figure 10: System Improvement in dB verses distance

The stand-alone MC1321x system baseline measurements are shown in Figure 7 and 8 for the units tested in this report. By referring to Figure 10, it can be seen that the potential distance improvement with the addition of the RFX2401 will be greater than 32 times over a system without the addition of the RFeIC.

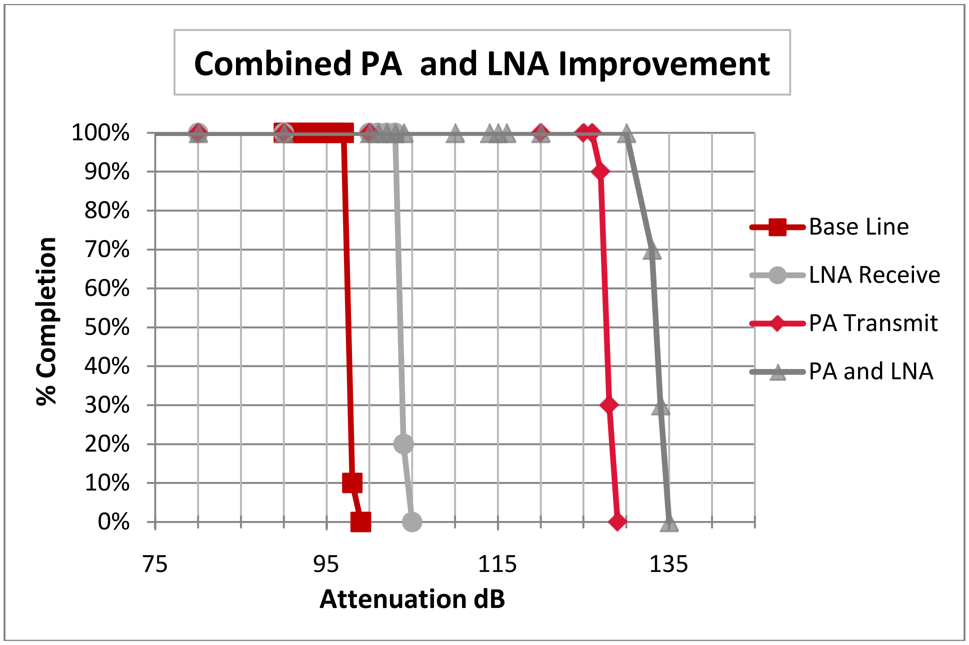

Figure 11: Combined RFX2401 PA and LNA improvement

The PA and LNA combined improvement is shown in Figure 11. With the addition of the RFX2401 on both ends of the RF link, the sensitivity of the link will improve by 31 dB making RF link connections possible over distances greater than 1Kilometer.

7. Application Schematic

The schematic in Figure 12 shows the optimized configuration of the RFX2401 and the MC1321x SoC. Note the use of the single RF port configuration for the MC1321x. This configuration will result in significantly improved noise figure and output power, but eliminates any external switch reducing the BOM costs. Note also the harmonic filter that is useful for compliance testing.

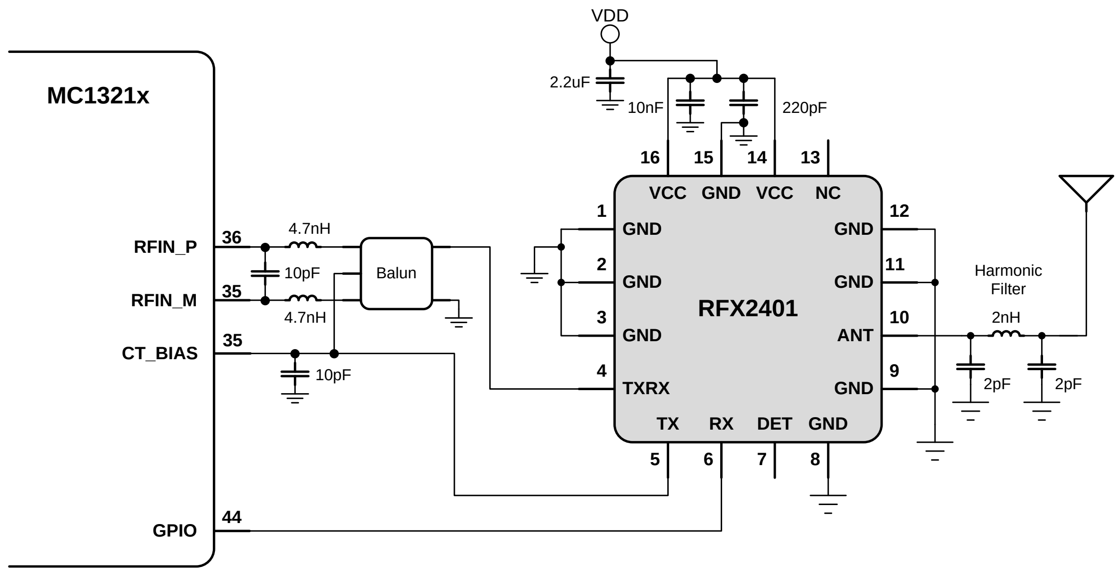

Figure 12: Connection schematic between MC1321x and RFX2401

The schematic in Figure 13 shows the configuration of the RFX2401 and the MC1321x SoC as tested in this report. Noise figure is improved by placing the RFX2401 LNA between the antenna and the external switch and balun, and output power is greatly increased through the use of the PA.

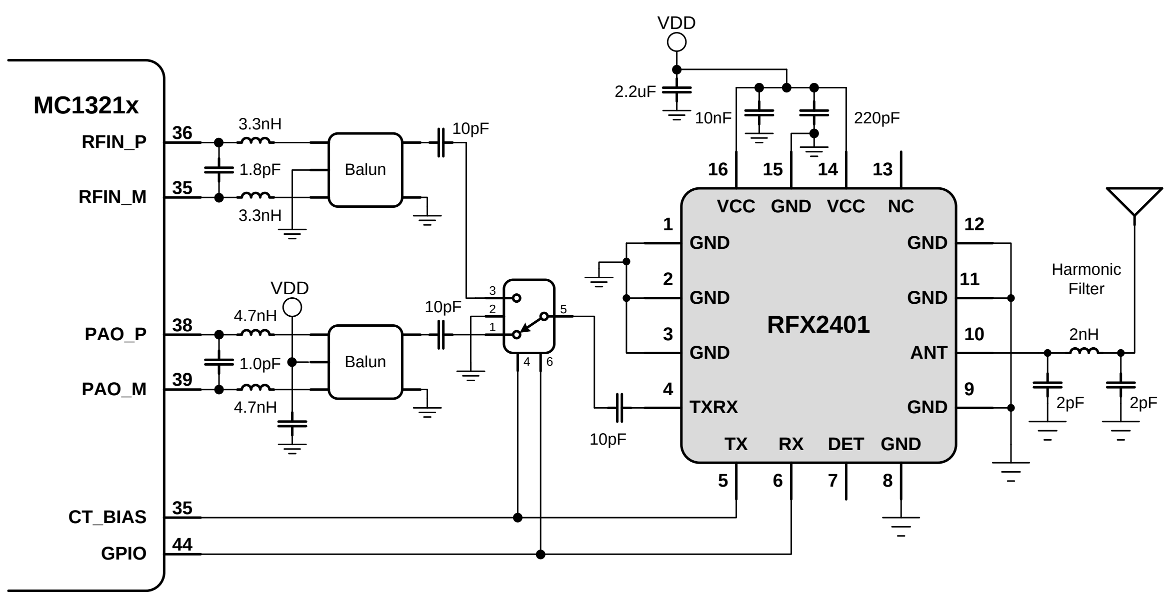

Figure 13: Alternative connection schematic between MC1321x and RFX2401

The Freescale MC1322x SoC is a highly integrated device which includes an internal balun. As such it lends itself well to an extended range design with a very simple BOM and schematic, as detailed in Figure 14.

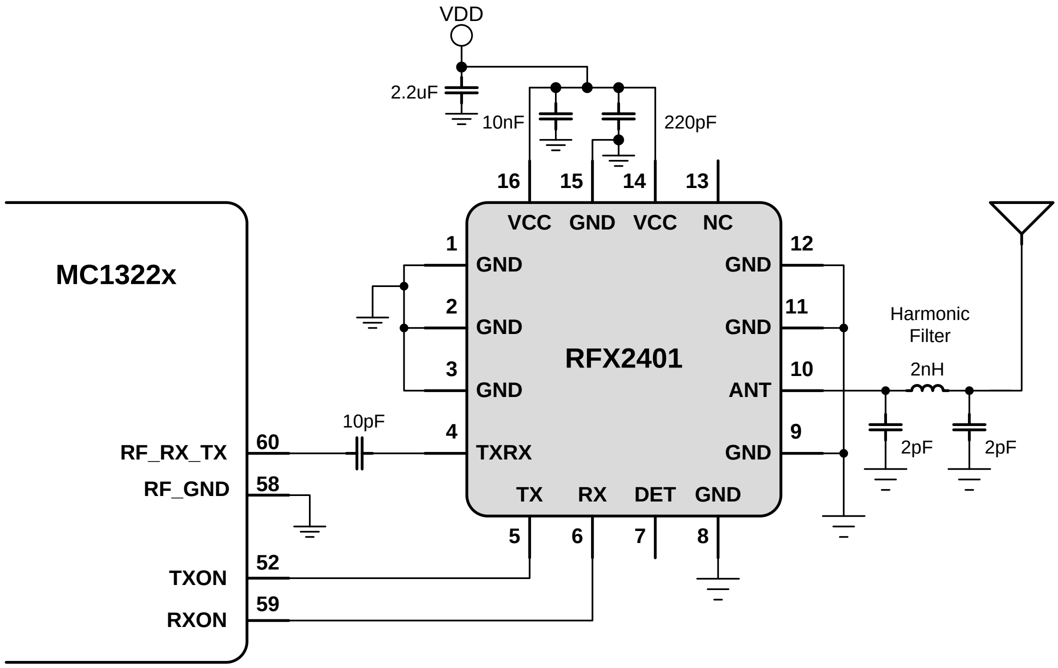

Figure 14: Connection schematic between MC1322x and RFX2401

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 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 15 is the actual spurious response of the MC1321XCSK-BDM reference evaluation board with the added RFeIC RFX2401 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.

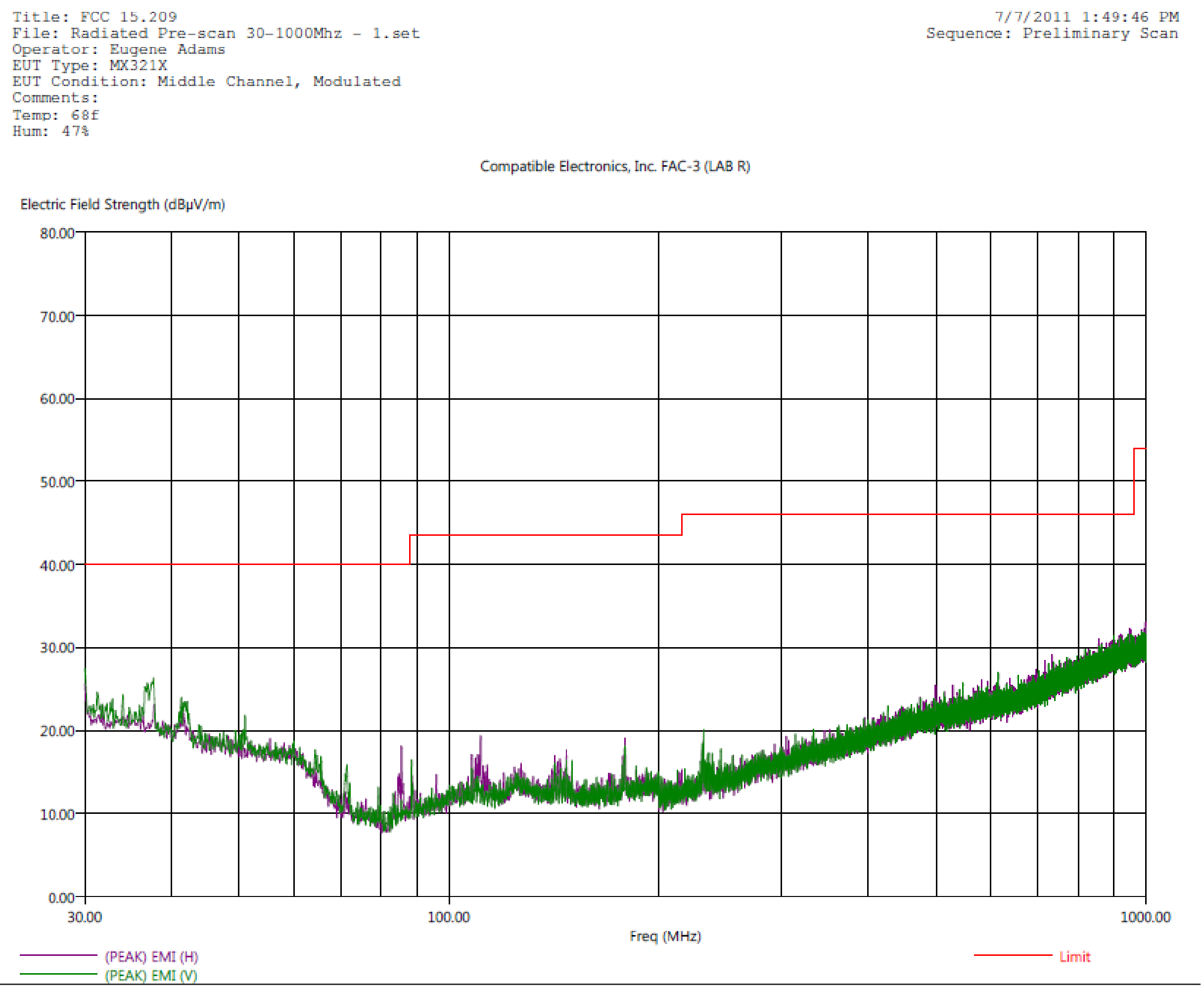

Figure 15: Spurious Response of the MC1321x and RFX2401 on the BDM reference board

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 15 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 at set at +20dBm, which indicates this design is compliant when including the harmonic filter on the RFX2401 output.

FCC 15.247
RF Axis
Zigbee Device
Model: Freescale
Comments:

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

Fundimental Channel
2424 MHz

Freq. (MHz)	Level (dBuV)	Pol (v/h)	Limit	Margin	Peak / QP / Avg	Ant. Height (m)	Table Angle (deg)	Comments
4848	62.77	V	74	-11.23	Peak	128	277	**07 TX setting**
4848	50.33	V	54	-3.67	Avg	128	277	**07 TX setting**
7272		V	74	-74	Peak			**No Emission Found**
7272		V	54	-54	Avg			**No Emission Found**
9696		V	74	-74	Peak			
9696		V	54	-54	Avg			
12120		V	74	-74	Peak			
12120		V	54	-54	Avg			
14544		V	74	-74	Peak			
14544		V	54	-54	Avg			
16968		V	74	-74	Peak			
16968		V	54	-54	Avg			
19392		V	74	-74	Peak			
19392		V	54	-54	Avg			
21816		V	74	-74	Peak			
21816		V	54	-54	Avg			
24240		V	74	-74	Peak			
24240		V	54	-54	Avg			

Figure 16: Harmonic Response of the MC1321x and RFX2401 on the BDM reference board

9. Conclusion

Adding the RFX2401 at the receiver side improves the link sensitivity by 6dB. This is the result of improvement in the system noise figure in the MC1321x /MC1322x due to the low noise of the RFX2401 LNA combined with the gain of the amplifier. Adding the RFX2401 for the transmitter side improves the link output power by as much as 27dB which is a direct result of the RFX2401 power amplifier output and gain. The maximum link extension is achieved by including the RFX2401 at both ends of the RF communication chain which combines to achieve an overall net gain 33dB.

By increasing the quality of the RF link through the use of the RFX2401, greater distance can be achieve, but also higher bandwidth at closer distances. This can result in significant average current drain savings as a result of faster data transmission and a quicker transition to sleep mode, even with the additional current required for the external PA and LNA.

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 or call 949-336-1360 or email at market@rfaxis.com.

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