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TND6275/D

RF Transceiver Reference Design Tuned for 915 MHz Using Wireless MCU AXM0F243

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REFERENCE DESIGN

REFERENCE DESIGN OVERVIEW

Introduction

This reference design contains a compact and efficient reference design for the AXM0F243 that demonstrates its operation in the European 915 MHz ISM band. By using the design detailed below to implement the AXM0F243, it is intended that the time and risk associated with designing and certifying a final product can be greatly reduced.

The source design and fabrication files can be downloaded from the DVK−AXM0F243−915−x−GEVK web page located at www.onsemi.com.

Design Schematic Overview

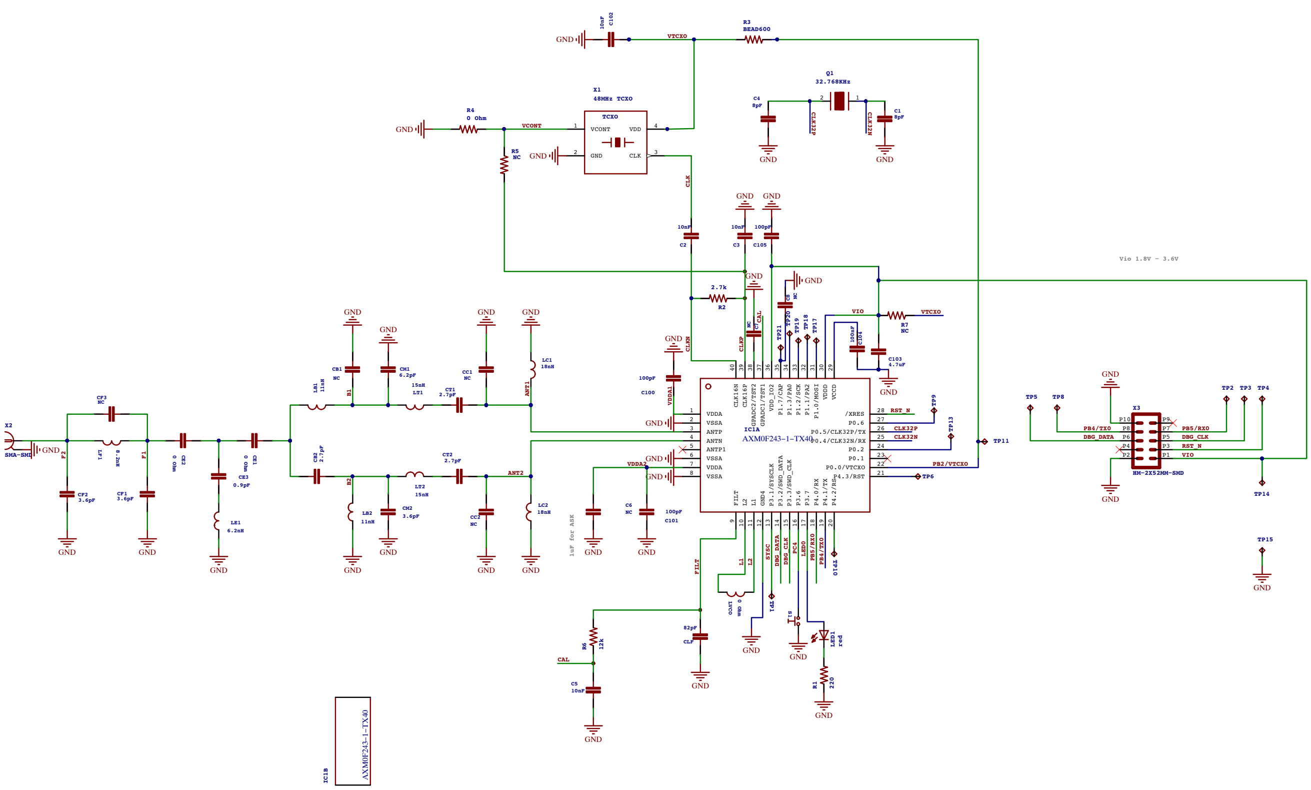


Figure 1. Design Schematic Overview

Class−E Amplifier and Match Network

The AXM0F243 utilizes a class−E power amplifier, which includes components both internal and external to the IC. For this reason, the selection of component values between ANTP / ANTN and the antenna is not merely an impedance matching problem, but an amplifier design problem as well. This network must be tuned to the desired operating frequency for proper RF performance. Reference designs, including this one, have been provided by ON Semiconductor for commonly used frequencies. For additional details on tuning this network to different frequencies, see the References section at the end of this document. Note that typically this network is designed for optimal TX performance, and the frequency and gain tracking loops in the receiver will compensate to maintain the optimum RX sensitivity.

The network used in this design is shown in greater detail below. The components LC1/2, CC1/2, CT1/2, LT1/2, and CM1/2 are part of the class−E amplifier. CB1/2 and LB1/2 form a balun, and are used to transform the differential signal to single−ended. CE1/2/3, LE1, CF1/2/3, and LF1 are components of harmonic filters used to achieve an output spectrum that is compliant with regulations.

The values for 915 MHz are shown in the following image, as well as the bill−of−materials below. Note that the components labeled “NC” are not necessary and can be removed for applications at this frequency.

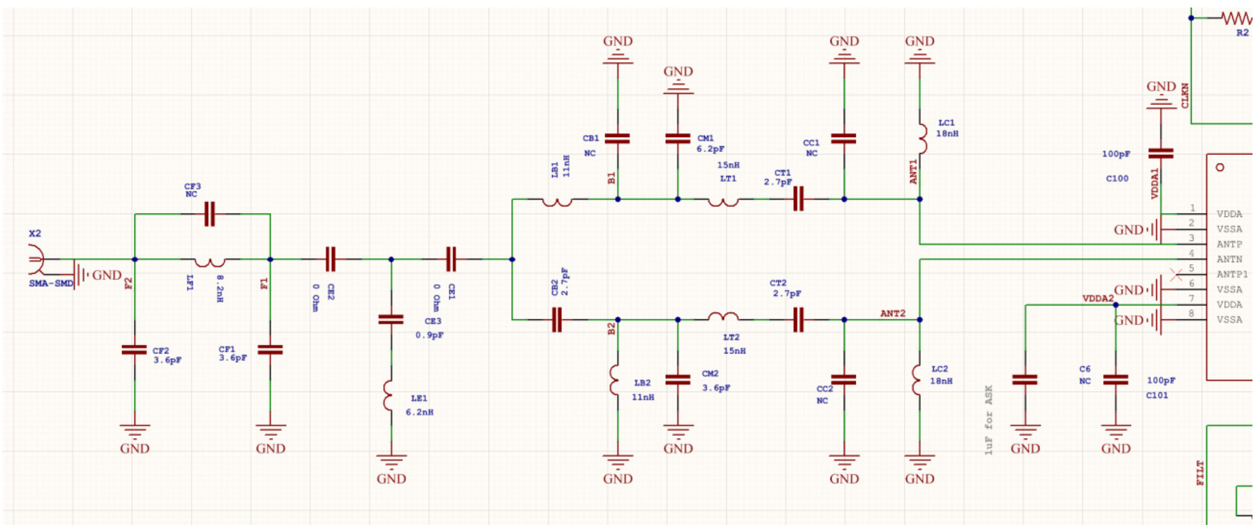


Figure 2.

TCXO and Optional Crystal

In order to achieve stable RF performance over temperature, a 48 MHz TCXO is employed as a clock reference. This clock is connected internally to the radio transceiver core, but can also be made available to the M0+ MCU core with software configuration. There is also an optional 32.768 kHz crystal that connects directly to the MCU core. The schematic for these components is shown in detail below:

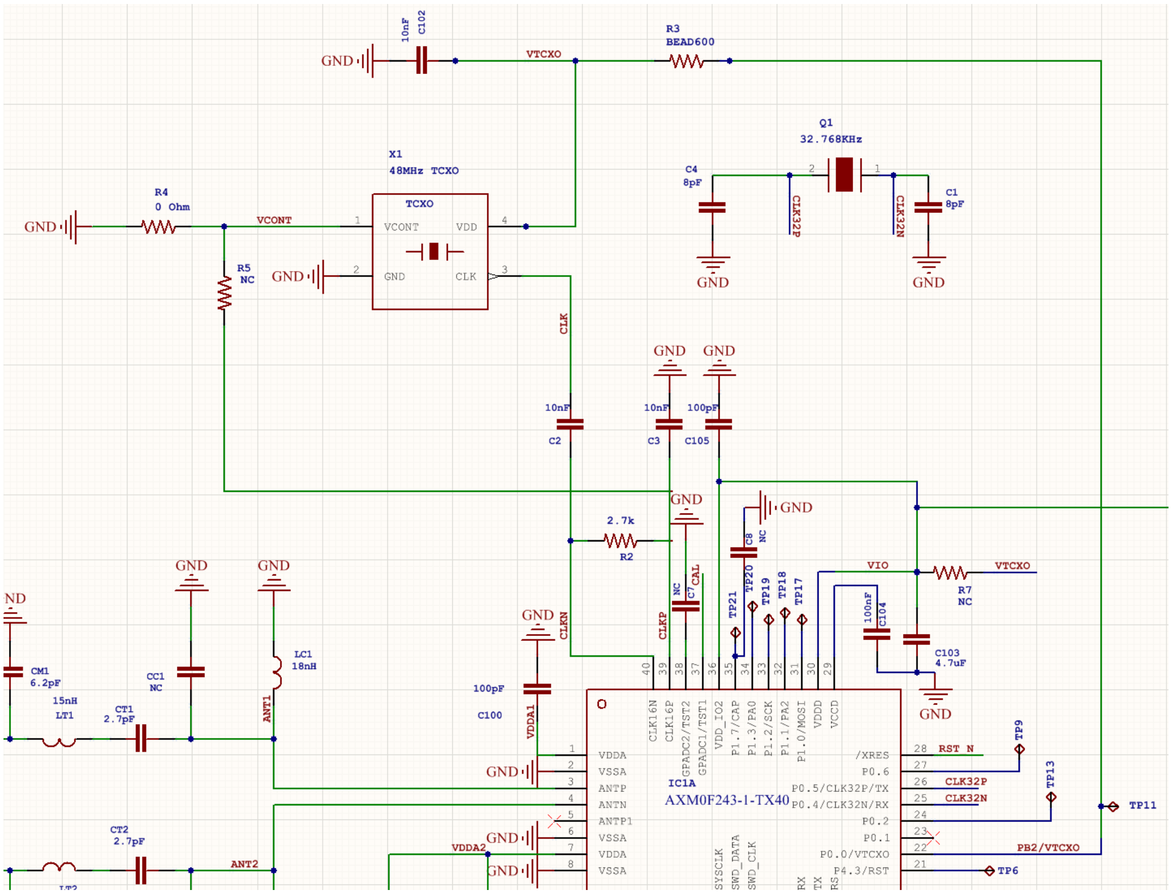


Figure 3.

VCO Calibration Hardware

In order to optimize the phase noise of the RF synthesizer, an optional VCO current calibration algorithm has been included in easyAX5043.c – a library that is used by AX−RadioLab. In order to utilize this calibration routine, the following network between FILT and TST1 is required. TST2 must also be left floating. Detailed views are shown below.

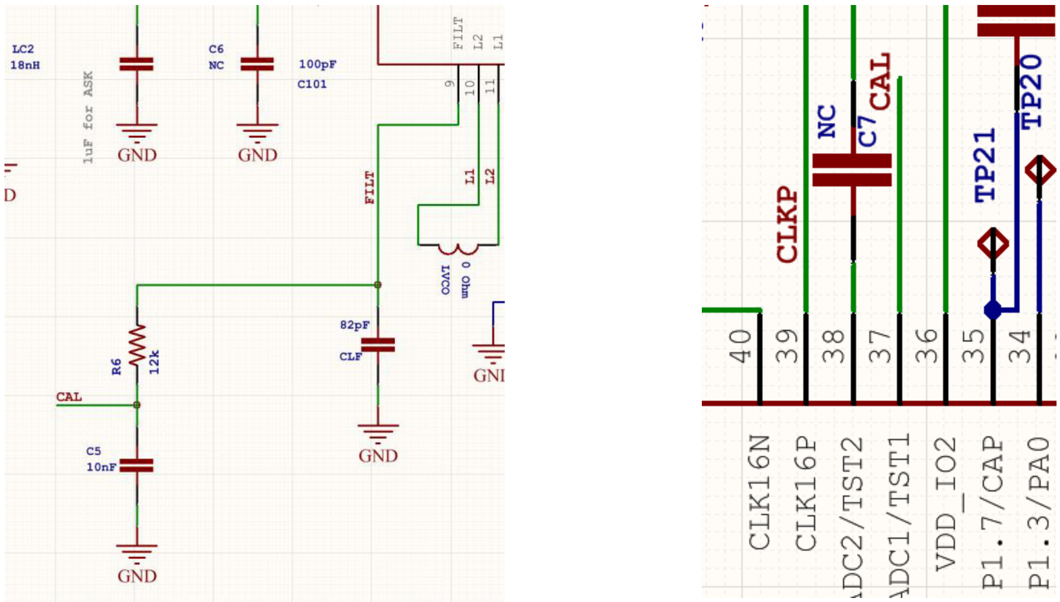


Figure 4.

PCB Layout & Construction

Top Layer:

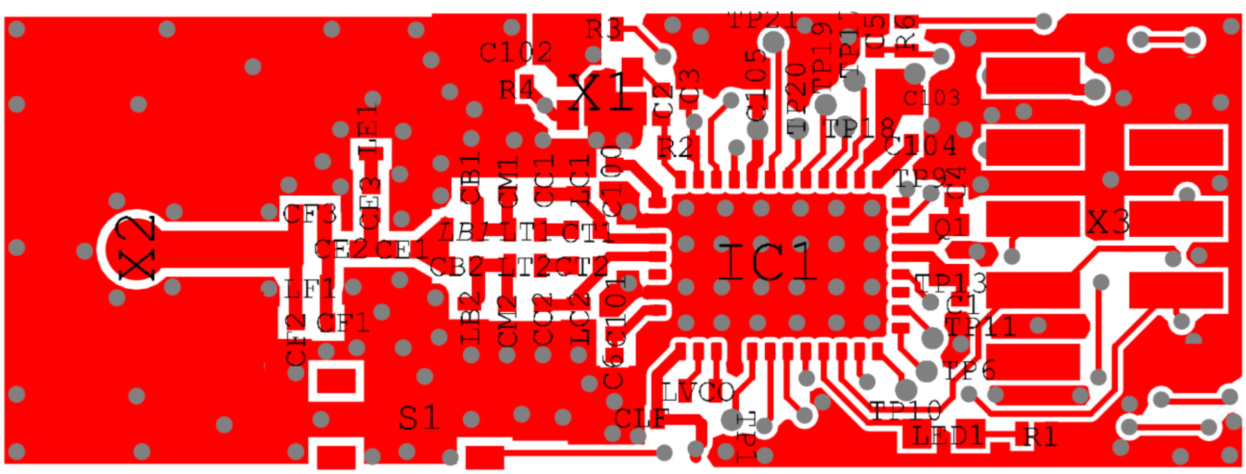


Figure 5. Top Layer

Bottom Layer (Mirrored to Reflect Physical View):

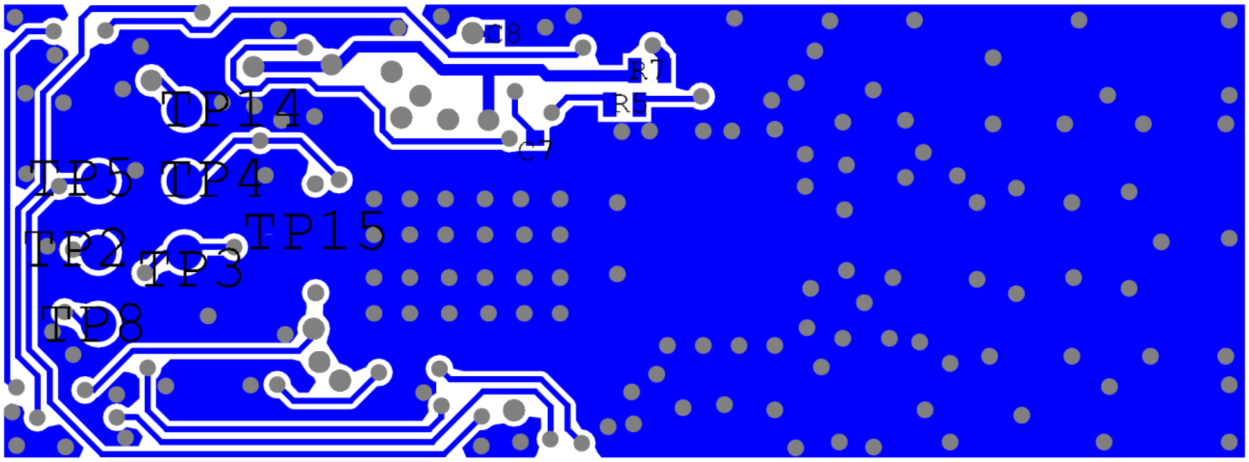
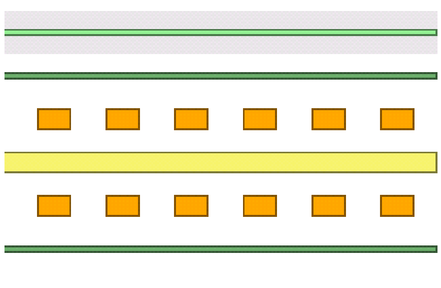


Figure 6. Bottom Layer (Mirrored to Reflect Physical View)

Layer Stack Up:

Table 1. LAYER STACK UP
(Standard two layer PCB, FR4, 1 mm core, 35 μm (1 oz) copper. No impedance control di−electric instead.)

Stack Up		Layer Stack			
1		Top Overlay			
		Top Solder	Solder Resist	0.024	3.5
		Top	Copper	0.054	
		Dielectric 1	FR−4	1	4.6
		Bottom	Copper	0.054	
2		Bottom Solder	Solder Resist	0.024	3.5
	Height :			1.156	

Bill of Materials

Table 2. BILL OF MATERIALS

Designator	Quantity	Description	Value	Tolerance	Footprint	Manufacturer	Manufacturer Part Number
C1, C4	2	CAP CER 8PF 25V NP0 0402	8 pF	0.25pF	C0402	Murata Electronics	GRM1555C1E8R0CA01D
C2, C3, C5, C102	4	CAP CER 10000PF 25V X7R 0402	10 nF	10%	C0402	Murata Electronics	GRM155R71E103KA01D
C6, C7, C8, CB1, CC1, CC2, CF3, R5, R7	9		NC		C0402	Murata Electronics	
C100, C101, C105	3	CAP CER 100PF 50V NP0 0402	100 pF	5%	C0402	Murata Electronics	GRM1555C1H101JA01D
C103	1	CAP CER 4.7UF 6.3V X5R 0603	4.7 μF	10%	C0603	Murata Electronics	GRM188R60J475KE19J
C104	1		100 nF	5%	C0402	Murata Electronics	GRM155R71C104JA88D
CB2, CT1, CT2	3	CAP CER 2.7PF 50V NP0 0402	2.7 pF	0.1pF	C0402	Murata Electronics	GRM1555C1H2R7BA01D
CE1, CE2, R4, LVCO	4	RES SMD 0.0OHM JUMPER 1/16W 0402	0 Ω	5%	R0402	Yaego	RC0402JR−070RL
CE3	1	CAP CER 0.9PF 50V NP0 0402	0.9 pF	0.05pF	C0402	Murata Electronics	GRM1555C1HR90WA01D
CF1, CF2	2	CAP CER 3.6PF 50V NP0 0402	3.6 pF	0.1pF	C0402	Murata Electronics	GRM1555C1H3R6BA01D
CLF	1	CAP CER 82PF 50V NP0 0402	82 pF	2%	C0402	Murata Electronics	GRM1555C1H820GA01D
CM1	1	CAP CER 6.2PF 50V NP0 0402	6.2 pF	0.1pF	C0402	Murata Electronics	GRM1555C1H6R2BA01D
CM2	1	CAP CER 3.6PF 50V NP0 0402	3.6 pF	0.1pF	C0402	Murata Electronics North America	GRM1555C1H3R6BA01D
IC1	1	SoC, RF, Range 27 − 1050 MHz			QFN40	ON SEMICONDUCTOR	AXM0F243−1−TX40
LB1, LB2	2	FIXED IND 11NH 500MA 140 MOHM	11 nH	2%	L0402WW	Murata Electronics	LQW15AN11NG00D
LC1, LC2	2	FIXED IND 18NH 370MA 270 MOHM	18 nH	2%	L0402WW	Murata Electronics	LQW15AN18NG00D
LE1	1	FIXED IND 6.2NH 250MA 700 MOHM	6.2 nH	2%	L0402WW	Murata Electronics	LQW15AN6N2B00D
LED1	1		red		LED0603	Murata Electronics	LTST−C191KRKT
LF1	1	FIXED IND 8.2nH 500MA 170 MOHM	8.2 nH	2%	L0402WW	Murata Electronics	LQW15AN8N2G00D
LT1, LT2	2	FIXED IND 15NH 460MA 160 MOHM	15 nH	2%	L0402WW	Murata Electronics	LQW15AN15NG00D
Q1	1	32.768KHz EXS00A−MU00788, NX2012SA	32.768 KHz Crystal		TF20	Nihon Dempa Kogyo Co Ltd	NX2012SA
R1	1	RES SMD 220 OHM 5% 1/16W 0402	220 Ω	5%	R0402	Yaego	RC0402JR−07220RL
R2	1	RES SMD 1K OHM 5% 1/16W 0402	2.7 kΩ	5%	R0402	Yaego	RC0402JR−072K7L
R3	1	FERRITE CHIP 600 OHM 300MA 0402	BEAD 600 Ω		R0402	Murata Electronics	BLM15AG601SN1D
R6	1	RES SMD 12K OHM 5% 1/16W 0402	12 kΩ	5%	R0402	Yaego	RC0402JR−0712KL
S1	1	Tactile Switch SPST−NO Top Actuated Surface Mount	TASTER4−PAD−SMD−SMALL		TASTER_SMALL_SMD_4PAD	C&K	PTS810 SJK 250 SMTR LFS
X1	1		48 MHz TCXO		X2016	NDK (Nihon Dempa Kogyo Co. Ltd)	NT2016SA 48 MHz END4910A
X2	1	CONN SMA JACK STR 50OHM SMD	SMA−SMD		SMA−SMD	Linx Technologies Inc.	CONSMA001−SMD−G
X3	1	CON_2X5 2MM−SMD_DEBUG	CON_2X5 2MM−SMD_DEBUG			Harwin Inc.	M22−5320505

FCC TITLE 47 PART 15 PRE−COMPLIANCE TESTING

Overview of Regulations

US FCC title 47 part 15 regulates the use of radio frequency devices. The following sections are relevant to this context:

1. *US FCC 47 § 15.247* – Contains the regulations covering the frequency bands including 902 − 928 MHz
2. *US FCC 47 § 15.249* – Contains regulations for frequency bands including 902 − 928 MHz. This section allows for more flexibility in the modulation scheme and use case, but has a lower transmit power limit
3. *US FCC 47 § 15.205* – Defines the restricted bands of operation
4. *US FCC 47 § 15.209* – Defines the radiated field strength limits for emissions in the restricted bands of operation.

The purpose of this section is to detail the subset of tests that have been performed, along with their results, to demonstrate the compliance of a typical AXM0F243 902 − 928 MHz application with the FCC standard. For the context of this document, only the compliance with section 15.247 will be examined.

Section 15.247 Summary

Section 15.247 requires devices operating in the 902−928 MHz band to use either a frequency hopping or digital modulation scheme. Due to the wide bandwidth requirement for the specified digital modulation scheme, and the fact that the AXM0F243 is a narrow−band transceiver system−on−chip, the device will be tested using the frequency hopping requirements.

Compliance with the frequency hopping scheme is determined by the following specifications:

1. Frequency hopping systems shall have hopping channel carrier frequencies separated by a minimum of 25 kHz or the 20 dB bandwidth of the hopping channel, whichever is greater. [§ 15.247(a)(1)]
2. The system shall hop to channel frequencies that are selected at the system hopping rate from a pseudo randomly ordered list of hopping frequencies. Each frequency must be used equally on the average by each transmitter. [§ 15.247(a)(1)]
3. If the 20 dB bandwidth of the hopping channel is less than 250 kHz, the system shall use at least 50 hopping frequencies and the average time of occupancy on any frequency shall not be greater than 0.4 seconds within a 20 second period; if the 20 dB bandwidth of the hopping channel is 250 kHz or greater, the system shall use at least 25 hopping frequencies and the average time of occupancy on any frequency shall not be greater than 0.4 seconds within a 10 second period. The maximum allowed 20 dB bandwidth of the hopping channel is 500 kHz. [§ 15.247(a)(1)(i)]
4. The maximum peak conducted output power of the intentional radiator shall not exceed the following: 1 watt for systems employing at least 50 hopping channels; and, 0.25 watts for systems employing less than 50 hopping channels, but at least 25 hopping channels. [§ 15.247(a)(2)(b)(2)]
5. In any 100 kHz bandwidth outside the frequency band in which the spread spectrum or digitally modulated intentional radiator is operating, the radio frequency power that is produced by the intentional radiator shall be at least 20 dB below that in the 100 kHz bandwidth within the band that contains the highest level of the desired power, based on either an RF conducted or a radiated measurement, provided the transmitter demonstrates compliance with the peak conducted power limits. [§ 15.247 (d)]
6. Radiated emissions which fall in the restricted bands, as defined in § 15.205(a), must also comply with the radiated emission limits specified in § 15.209(a) [§ 15.247 (d)]

Because the AXM0F243 is a software−configurable transceiver system−on−chip, and ON Semiconductor has provided firmware libraries that give the developer control over operating frequency, compliance with the frequency hopping components of the FCC regulations is determined by the final application. For this reason, tests specifically related to the use of frequency hopping channels are omitted from this document. The regulatory tests detailed in this document are the following:

1. 20 dB Bandwidth
2. Peak Conducted Power
3. Spurious Conducted Emissions

The purpose of this section is to detail the subset of tests that have been performed, along with their results, to demonstrate the compliance of a typical AXM0F243 915 MHz application with the FCC regulatory standard. Note that the following is not a complete certification report. Several specifications required for certification were not applicable to the context of this design note and are not included.

Test Setup & Equipment

All tests were performed using conducted mode. Python scripts were used on the host PC to control the testing equipment, gather, and process the collected data. This section provides an overview of the test setup and equipment. Details pertaining to each test are given in the following section.

Equipment Used:

Table 3. EQUIPMENT USED

Lab Equipment	Type	Manufacturer
Signal Analyzer 13.6 GHz	FSV−13	Rhode & Schwartz
Signal Generator	SMU200A	Rhode & Schwartz
6 1/2 Digit Multimeter	34461A	Keysight
USB / GPIB Interface	GPIB−USB−HS	National Instruments

Equipment Setup:

The following block diagram and photo detail the setup for the transmitter tests:

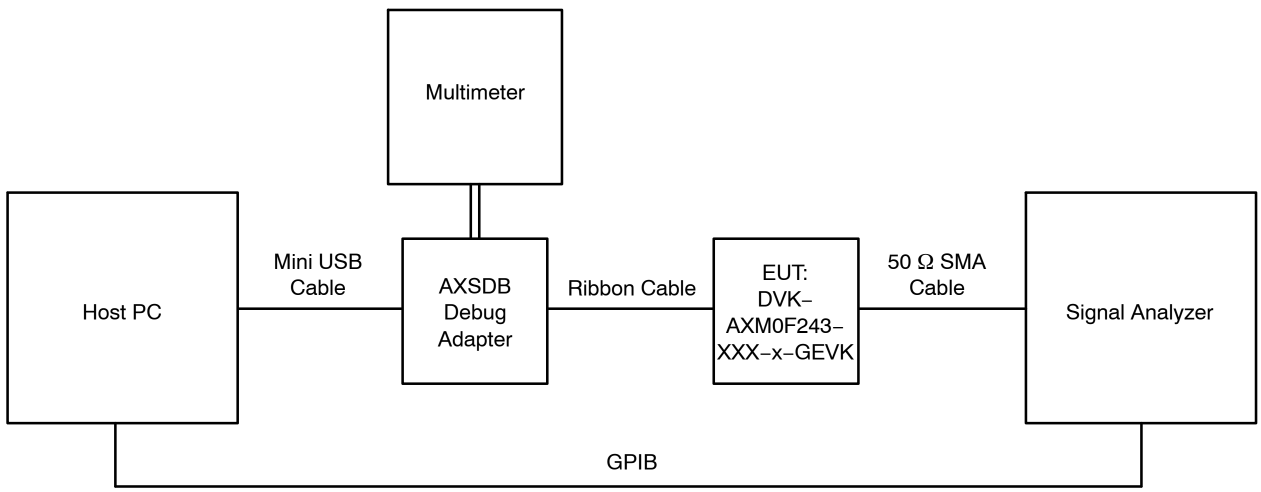


Figure 7.

While US FCC title 47 part 15 only requires emission testing for the 902 to 928 MHz band, the sensitivity of the receiver was measured, and the following setup was used:

For sensitivity tests, the following test equipment setup was used:

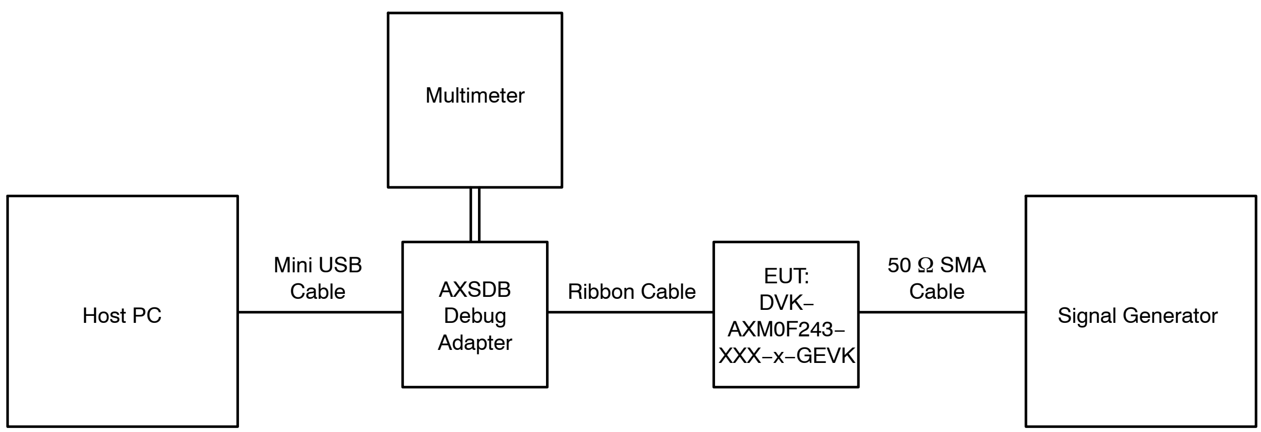


Figure 8.

Cable Loss

The loss in the cable connecting the transmitter to the signal analyzer was measured to be 0.95 dBm. The results shown below are the values recorded directly from the measurement equipment, and do not account for the cable loss.

Test Signal Description

For each transmitter test, the EUT was programmed with AX−RadioLab to transmit a random stream of bits with the following physical layer parameters:

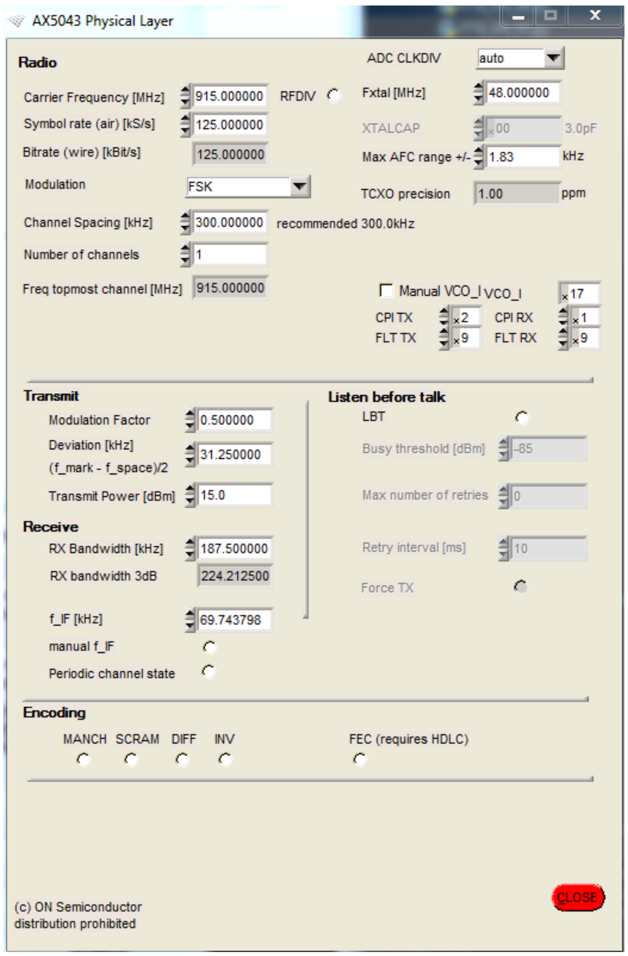


Figure 9.

Temperature & Supply Voltage

All tests were conducted at room temperature. For a full certification test, temperature and supply voltage extremes would need to be tested for most specifications.

Test Results

20 dB Bandwidth

This test measures the 20 dB bandwidth of a modulated signal, which is used to determine the required number of frequency hopping channels as per § 15.247(a)(1)(i). The measurement parameters used are shown below:

Table 4.

Measurement Parameters	
Detector:	Positive Peak
Sweep Time:	Auto
Resolution Bandwidth:	5 kHz
Video Bandwidth:	15 kHz
Span:	1 MHz
Trace Mode:	Max Hold

Results:

As shown in the spectrum plot below, the measured 20 dB bandwidth of the given modulated signal is 169.6 kHz. This signal represents a data rate toward the upper limit of the capability of the narrowband AXM0F243, thus in most applications, 50 frequency hopping channels should be used.

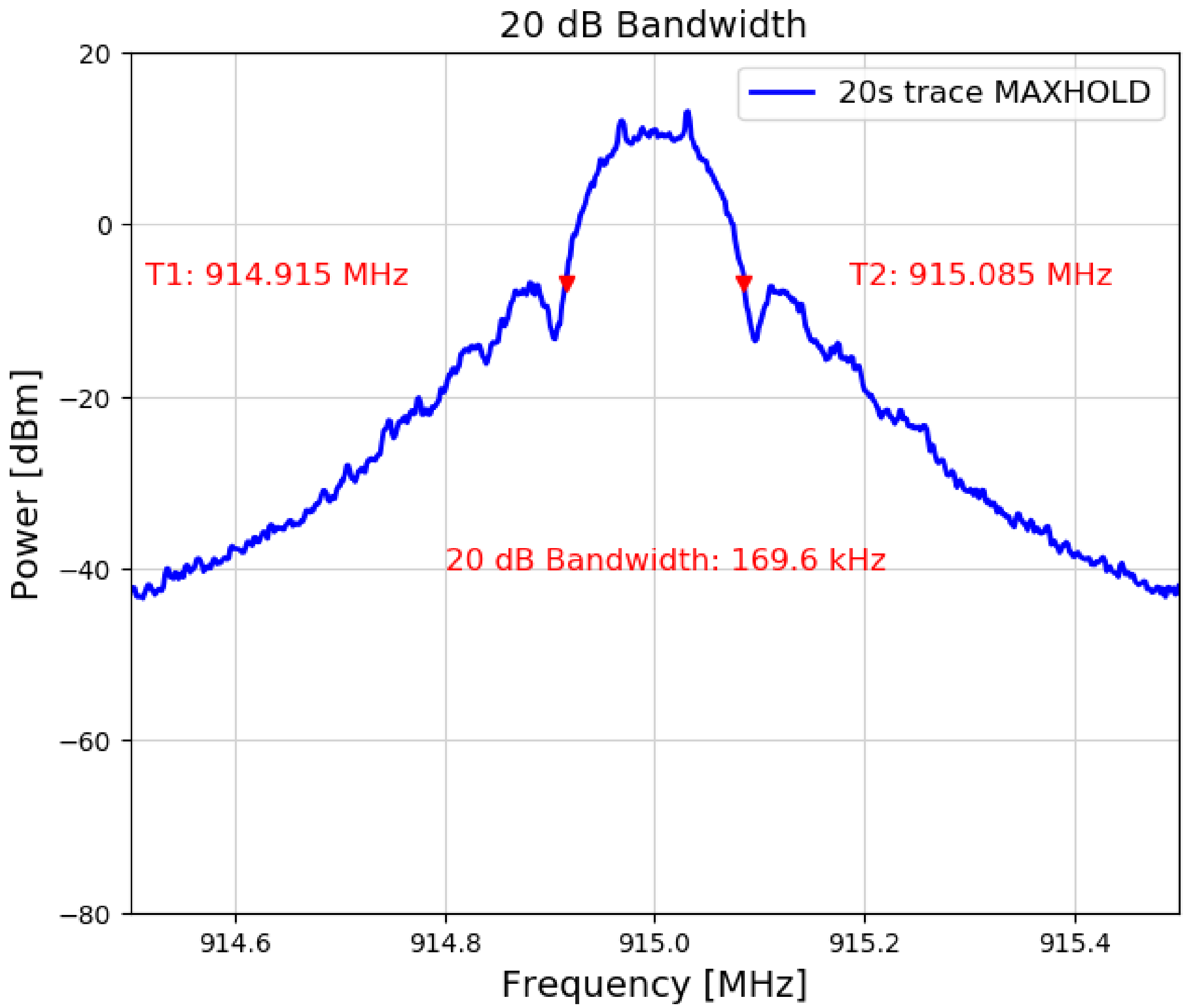


Figure 10.

Peak Conducted Power

Description:

This section demonstrates the procedure for measuring the peak output power. The limit defined in § 15.247(a)(2)(b)(2) is 1 watt, or 30 dBm.

Table 5.

Measurement Parameters	
Detector:	Positive Peak
Sweep Time:	Auto
Resolution Bandwidth:	200 kHz
Video Bandwidth:	200 kHz
Span:	1 MHz
Trace Mode:	Max Hold

Results:

The measured maximum output power of DVK−AXM0F243−915 (shown below) is well below the limit. An external PA can be utilized to increase the output power.

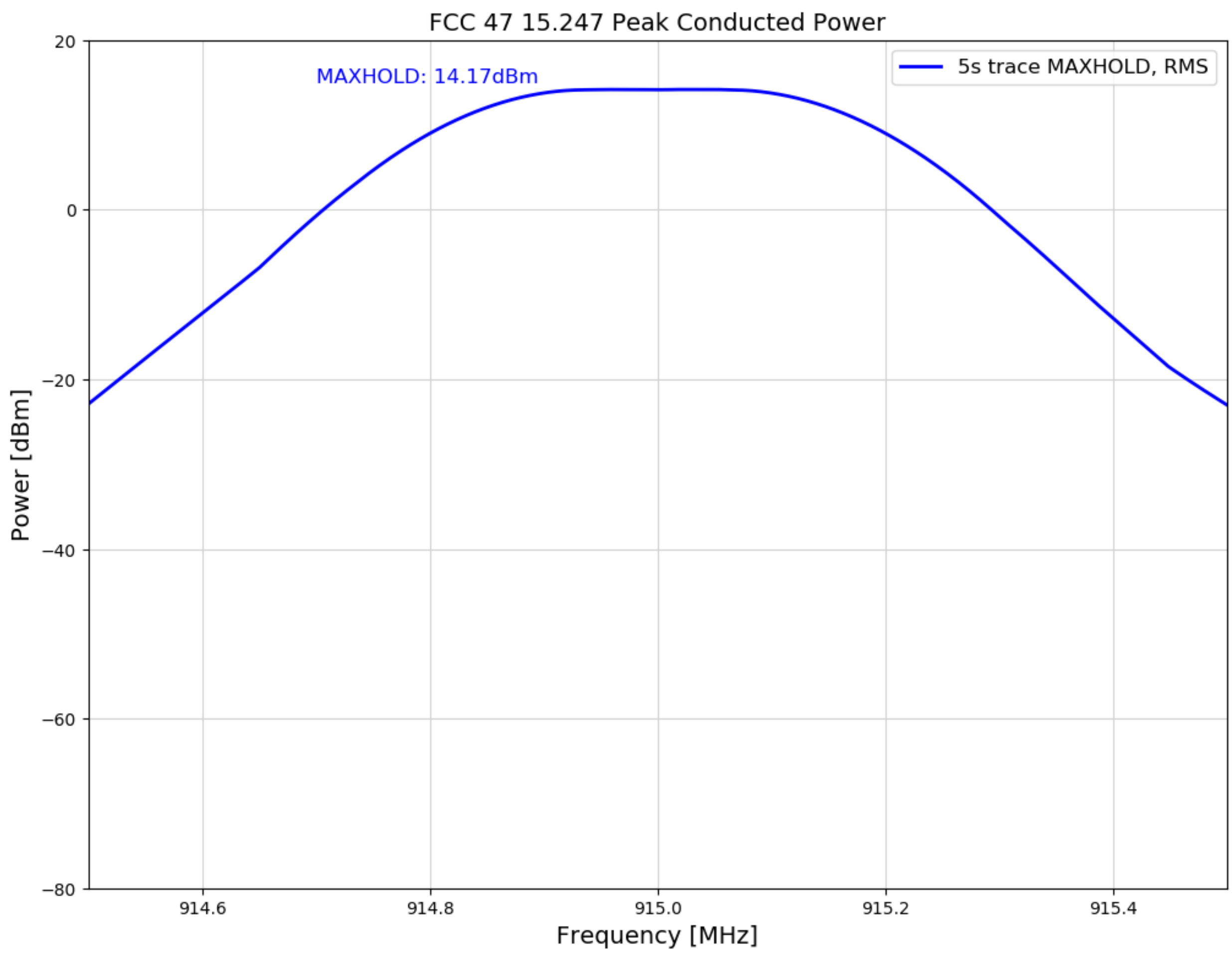


Figure 11.

Spurious Conducted Emissions

Description:

This test measures the output spectrum and verifies that the spurious emissions of the given modulated signal do not exceed the defined limits.

Table 6.

Measurement Parameters	
Detector:	Positive Peak
Sweep Time:	Auto
Resolution Bandwidth:	100 kHz
Video Bandwidth:	300 kHz
Span:	See Plots below
Test Signal:	Max Hold

Results:

The output spectrum plot is shown below, and is masked with the restricted bands and corresponding power limits The power limits were calculated from the field strength limits given by § 15.205(a) and § 15.209(a) in the following manner:

$$P_{dBm} = 10\log_{10}\left(\frac{P}{0.001}\right) \quad \text{(eq. 1)}$$

Where

$$P = 0.3\,(E \cdot 1 \cdot 10^{-6})^2 \quad \text{(eq. 2)}$$

P is the conducted limit in Watts, P_{dBm} is the conducted limit in dBm, and E is the given field strength limit, given in μV/m.

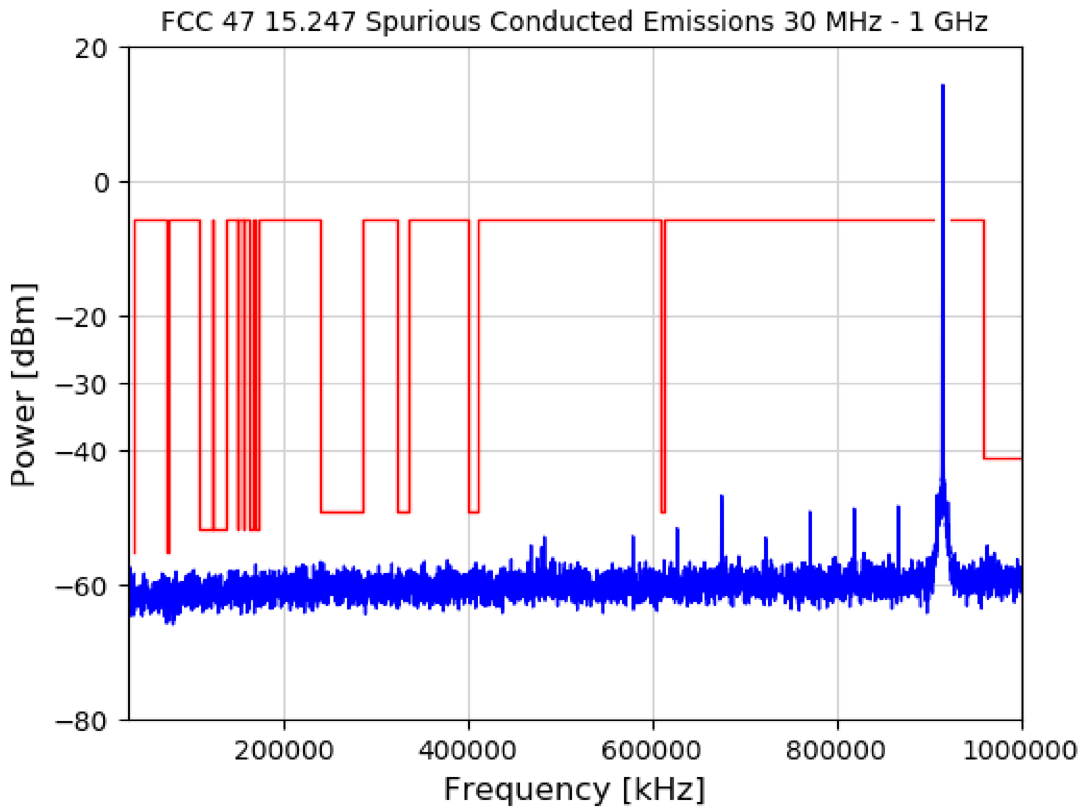


Figure 12.

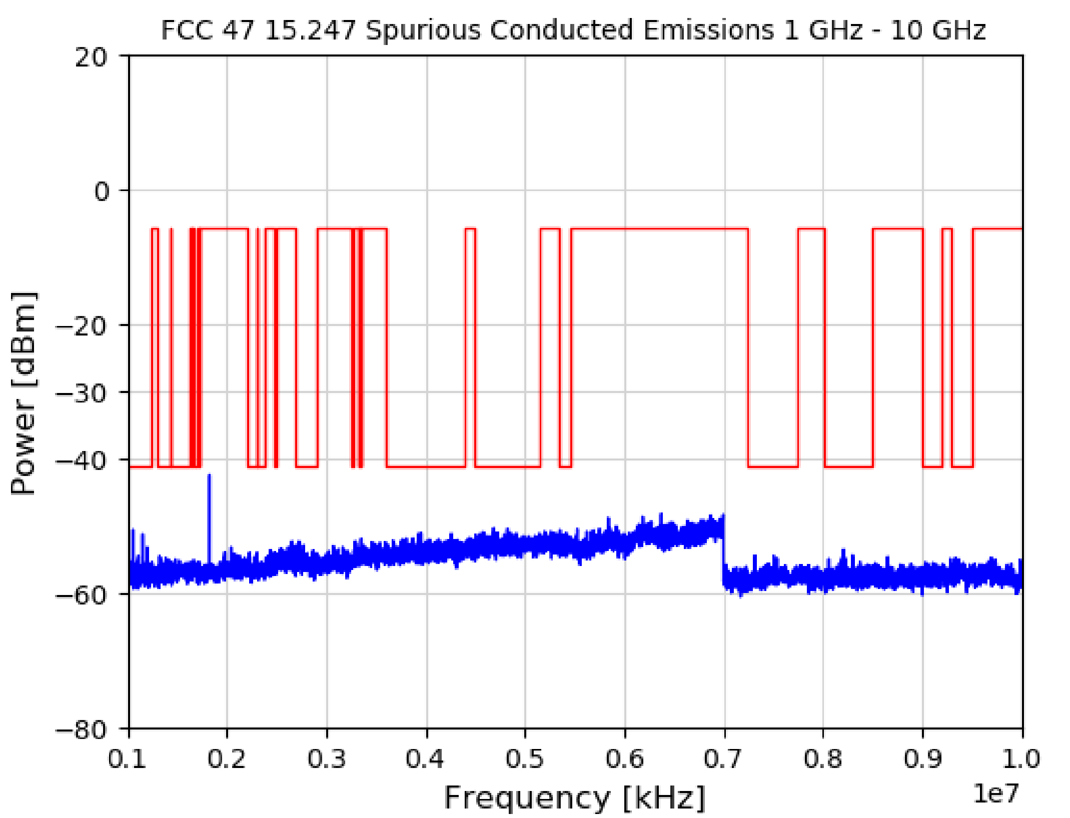


Figure 13.

ADDITIONAL PERFORMANCE TESTS

TX Power vs. Current Consumption

The given signal was output from the device. Power level was measured using the spectrum analyzer. Current was measured with the multimeter by probing jumper #3 on the AXDBG debug adapter. Current values represent the consumption by the AXM0F243 SoC, and consist of the combined consumption for both the microcontroller and radio cores. Note that the output power amplifier and match network have been optimized for maximum TX power output. The component values can be modified to optimize power efficiency at low TX output power levels. The measured current consumption is shown in the table below:

Table 7.

Measured TX Power (dBm)	TX Power w/ Cable Loss (dBm)	Measured Current Consumption (mA)
14.72	15.67	80.2
6.6	7.55	42.5
−0.8	0.15	29.4
−11.2	−10.25	23.3

RX Sensitivity

The receiver sensitivity was measured with the test setup described previously. The EUT was configured to receive a FSK 1010 signal from the generator and send the calculated BER to the host PC via UART. The power of the modulated signal from Generator A was reduced until a BER of 0.001 was observed. The sensitivity values are reported in the table below. The RX current value is also shown below, which includes the current for the radio, MCU, and LED.

Table 8.

915 MHz FSK Sensitivity			
Datarate (kbps)	Measured Sensitivity (dBm)	Sensitivity w/ Cable Loss (dBm)	Current (mA)
1	−121	−121.95	23.79
10	−114	−114.95	23.3
100	−103	−103.95	23.3
125	−101	−101.95	24.2

REFERENCES & LINKS

ON Semiconductor Resources

1. AXM0F243 Device Page:
https://www.onsemi.com/PowerSolutions/product.do?id=AXM0F243

FCC

1. US FCC 47 § 15.247:
https://www.govinfo.gov/content/pkg/CFR−2013−title47−vol1/pdf/CFR−2013−title47−vol1−sec15−247.pdf
2. US FCC 47 § 15.249:
https://www.govinfo.gov/content/pkg/CFR−2009−title47−vol1/pdf/CFR−2009−title47−vol1−sec15−249.pdf
3. US FCC 47 § 15.205:
https://www.govinfo.gov/content/pkg/CFR−2001−title47−vol1/pdf/CFR−2001−title47−vol1−sec15−205.pdf
4. US FCC 47 § 15.209:
https://www.govinfo.gov/content/pkg/CFR−2002−title47−vol1/pdf/CFR−2002−title47−vol1−sec15−209.pdf
5. Test procedures for measuring Digital Transmission System (DTS):
https://apps.fcc.gov/oetcf/kdb/forms/FTSSearchResultPage.cfm?switch=P&id=21124
6. ANSI C63.10:
https://standards.ieee.org/standard/C63_10−2013.html

Class−E Amplifier and Output Network Design

1. Load Network Design Techniques for Class E RF and Microwave Amplifiers:
http://rfcafe−com.secure38.ezhostingserver.com/references/articles/Load−Network−Design−Techniques−for−Class−E−RF−and−Microwave−Amplifier.pdf
2. Balun component calculator:
http://analog.intgckts.com/impedance−matching/lumped−lc−balun/

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