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TND6274/D

RF Transceiver Reference Design Tuned for 868 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 868 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−AXM0F243−868−x−GEVK web page located at www.onsemi.com.

Design Schematic Overview

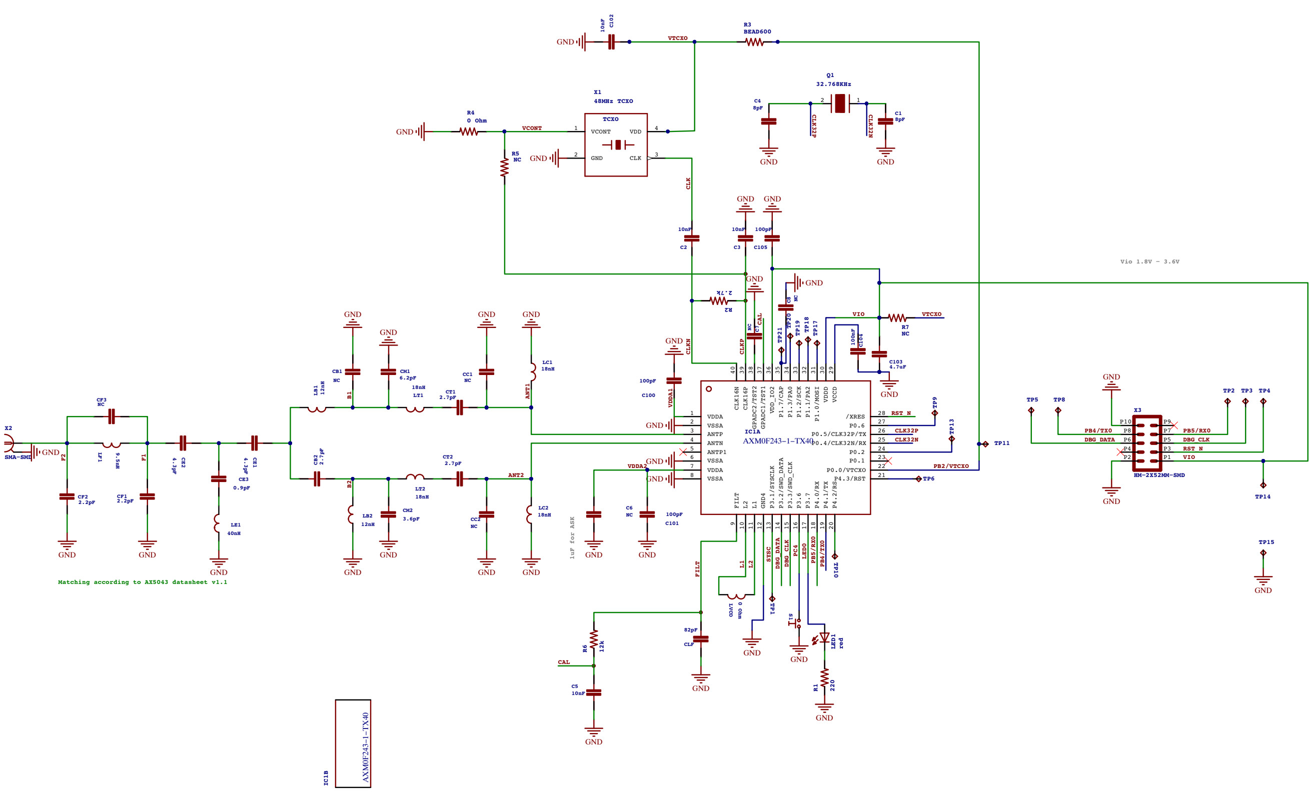

Figure 1. Design Schematic Overview

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 868.3 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.

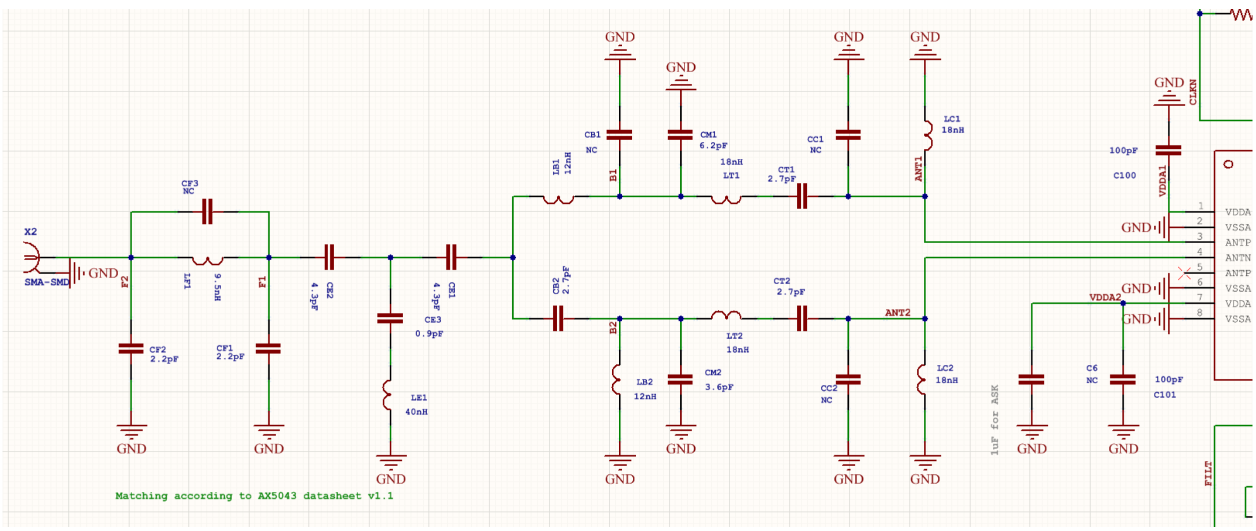

Figure 2.

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:

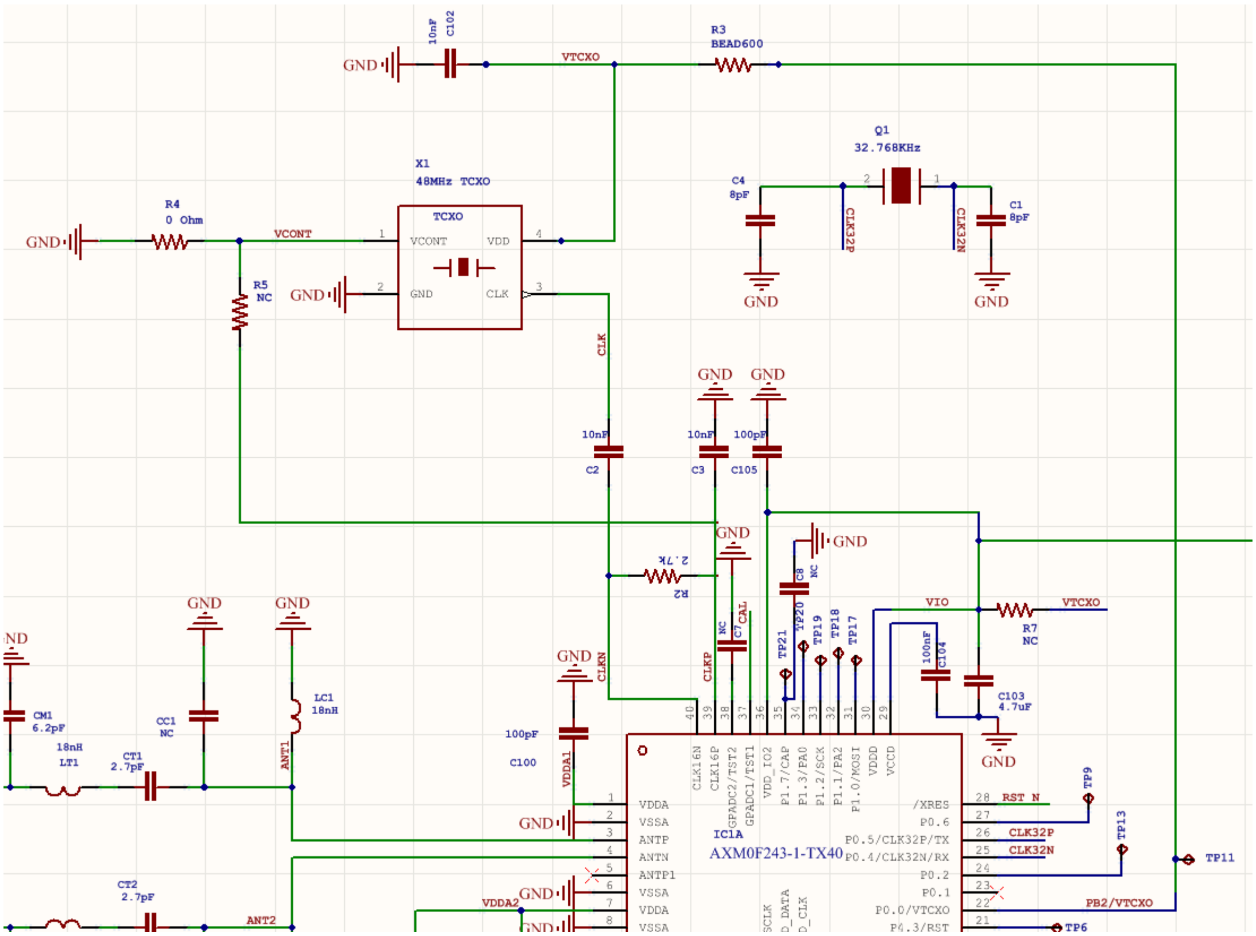

Figure 3.

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.

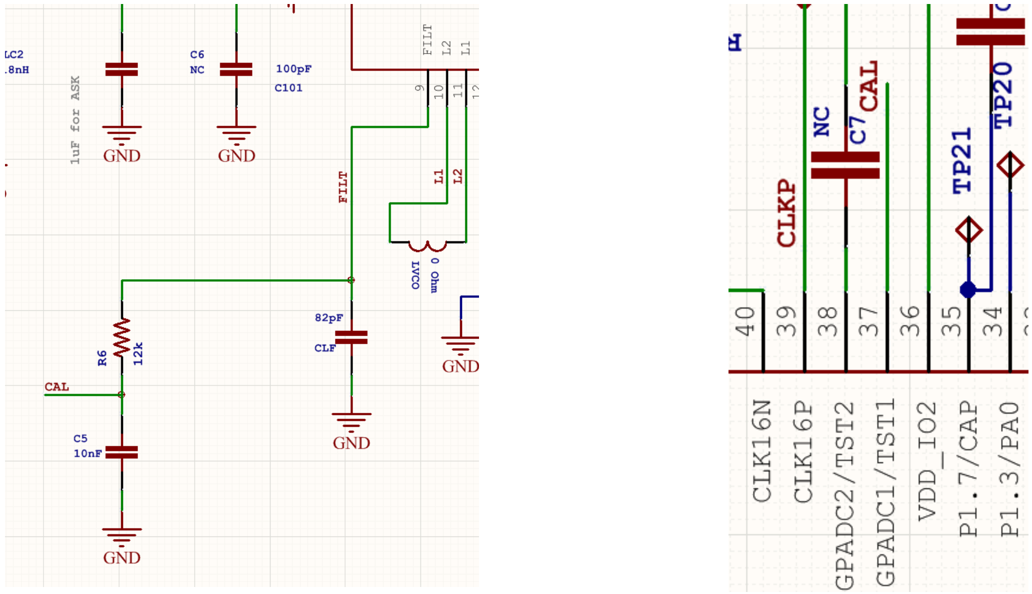

Figure 4.

PCB Layout & Construction

The PCB has been designed using a 2−layer board and a compact layout design to demonstrate the small footprint required to implement the AXM0F243.

Top Layer:

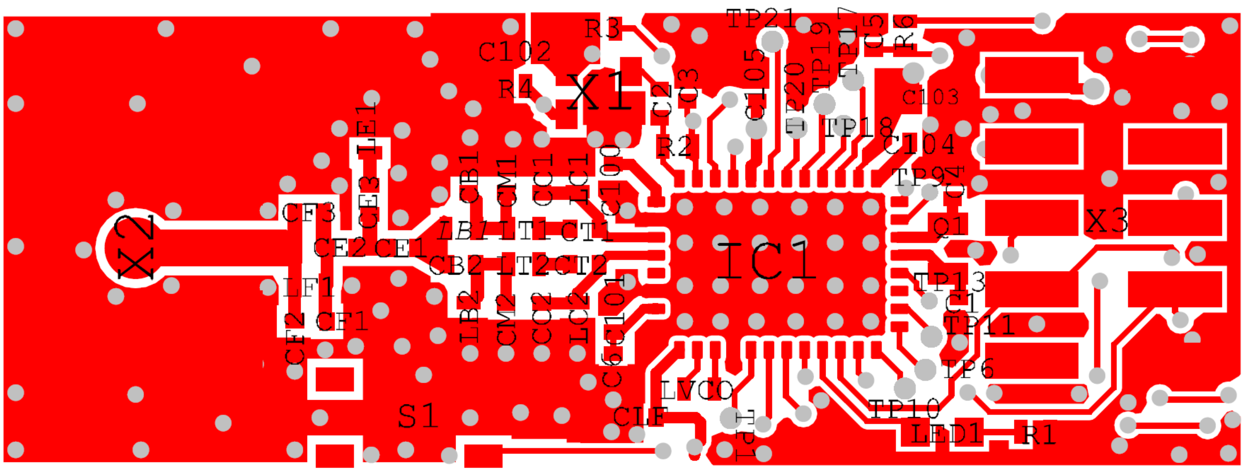

Figure 5. Top Layer

Bottom Layer (Mirrored to Reflect Physical View):

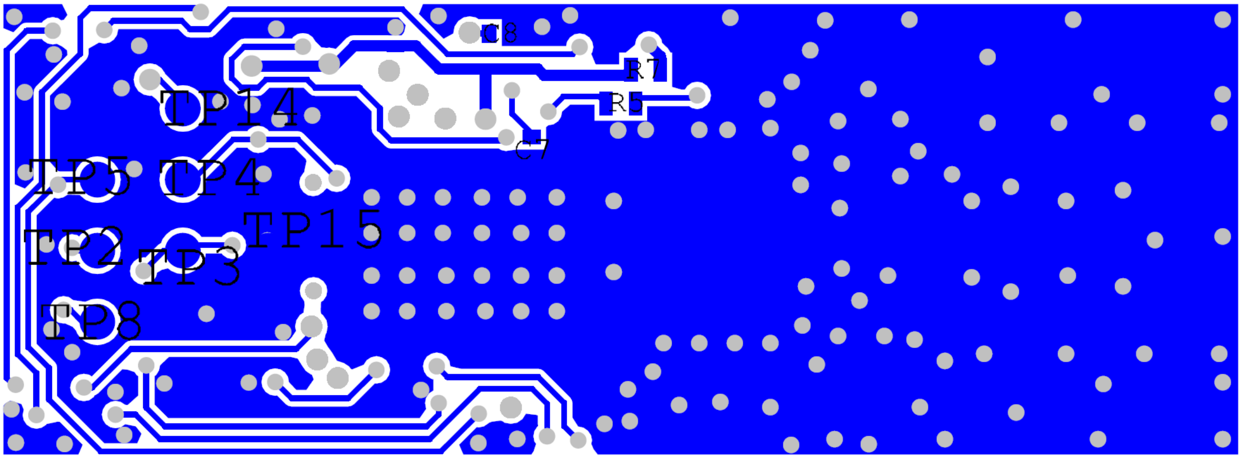

Figure 6. Bottom Layer (Mirrored to Reflect Physical View)

Layer Stack Up:

Table 1. LAYER STACK UP

Stack Up		Layer Stack			
Layer	**Board Layer Stack**	**Name**	**Material**	**Thickness (mm)**	**Constant**
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	Substitution Allowed	Lead Free
C1, C4	2	CAP CER 8PF 25V NP0 0402	8 pF	0.25 pF	C0402	Murata Electronics	GRM1555C1E8R0CA01D	Yes	Yes
C2, C3, C5, C102	4	CAP CER 10000PF 25V X7R 0402	10 nF	10%	C0402	Murata Electronics	GRM155R71E103KA01D	Yes	Yes
C6, C7, C8, CB1, CC1, CC2, CF3, R5, R7	9		NC		C0402	Murata Electronics		Yes	Yes
C100, C101, C105	3	CAP CER 100PF 50V NP0 0402	100 pF	5%	C0402	Murata Electronics	GRM1555C1H101JA01D	Yes	Yes
C103	1	CAP CER 4.7UF 6.3V X5R 0603	4.7 μF	10%	C0603	Murata Electronics	GRM188R60J475KE19J	Yes	Yes
C104	1		100 nF	5%	C0402	Murata Electronics	GRM155R71C104JA88D	Yes	Yes
CB2, CT1, CT2	3	CAP CER 2.7PF 50V NP0 0402	2.7 pF	0.1 pF	C0402	Murata Electronics	GRM1555C1H2R7BA01D	Yes	Yes
CE1, CE2	2	CAP CER 4.3PF 50V NP0 0402	4.3 pF	0.1 pF	C0402	Murata Electronics	GRM1555C1H4R3BA01D	Yes	Yes
CE3	1	CAP CER 0.9PF 50V NP0 0402	0.9 pF	0.05 pF	C0402	Murata Electronics	GRM1555C1HR90WA01D	Yes	Yes
CF1, CF2	2	CAP CER 2.2PF 50V NP0 0402	2.2 pF	0.1 pF	C0402	Murata Electronics	GRM1555C1H2R2BA01D	Yes	Yes
CLF	1	CAP CER 82PF 50V NP0 0402	82 pF	2%	C0402	Murata Electronics	GRM1555C1H820GA01D	Yes	Yes
CM1	1	CAP CER 6.2PF 50V NP0 0402	6.2 pF	0.1 pF	C0402	Murata Electronics	GRM1555C1H6R2BA01D	Yes	Yes
CM2	1	CAP CER 3.6PF 50V NP0 0402	3.6 pF	0.1 pF	C0402	Murata Electronics North America	GRM1555C1H3R6BA01D	Yes	Yes
IC1	1	SoC, RF, Range 27 − 1050 MHz			QFN40	ON SEMICONDUCTOR	AXM0F243−1−TX40	No	Yes
LB1, LB2	2	FIXED IND 12NH 500MA 140 MOHM	12 nH	2%	L0402WW	Murata Electronics	LQW15AN12NG00D	Yes	Yes
LC1, LC2, LT1, LT2	4	FIXED IND 18NH 370MA 270 MOHM	18 nH	2%	L0402WW	Murata Electronics	LQW15AN18NG00D	Yes	Yes
LE1	1	FIXED IND 40NH 250MA 700 MOHM	40 nH	2%	L0402WW	Murata Electronics	LQW15AN40NG00D	Yes	Yes
LED1	1		red		LED0603	Murata Electronics	LTST−C191KRKT	Yes	Yes
LF1	1	FIXED IND 9.5NH 500MA 170 MOHM	9.5 nH	2%	L0402WW	Murata Electronics	LQW15AN9N5G00D	Yes	Yes
Q1	1	32.768KHz EXS00A−MU00788, NX2012SA	32.768 KHz Crystal		TF20	Nihon Dempa Kogyo Co Ltd	NX2012SA	Yes	Yes
R1	1	RES SMD 220 OHM 5% 1/16W 0402	220 Ω	5%	R0402	Yaego	RC0402JR−07220RL	Yes	Yes
R2	1	RES SMD 1K OHM 5% 1/16W 0402	2.7kΩ	5%	R0402	Yaego	RC0402JR−072K7L	Yes	Yes
R3	1	FERRITE CHIP 600 OHM 300MA 0402	BEAD 600 Ω		R0402	Murata Electronics	BLM15AG601SN1D	Yes	Yes
R4, LVCO	2	RES SMD 0.0OHM JUMPER 1/16W 0402	0 Ω	5%	R0402	Yaego	RC0402JR−070RL	Yes	Yes
R6	1	RES SMD 12K OHM 5% 1/16W 0402	12 kΩ	5%	R0402	Yaego	RC0402JR−0712KL	Yes	Yes
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	Yes	Yes
X1	1		48 MHz TCXO		X2016	NDK (Nihon Dempa Kogyo Co. Ltd)	NT2016SA 48 MHz END4910A	Yes	Yes
X2	1	CONN SMA JACK STR 50OHM SMD	SMA−SMD		SMA−SMD	Linx Technologies Inc.	CONSMA001−SMD−G	Yes	Yes
X3	1	CON_2X5 2MM−SMD_DEBUG	CON_2X5 2MM−SMD_DEBUG			Harwin Inc.	M22−5320505	Yes	Yes

ETSI PRE−COMPLIANCE TESTING

Overview of Regulations

ETSI EN 300 220 covers the use of Short Range Devices operating in the frequency range 25 MHz to 1000 MHz. There are two parts to this standard that are applicable to this context:

1. ETSI EN 300 220−1 v3.1.1 (2017−02) – Part 1: Technical Characteristics and methods of measurement
2. ETSI EN 300 220−2 v3.1.1 (2017−02) – Part 2: Harmonised Standard covering the essential requirements or article 3.2 of Directive 2014/53/EU for non specific radio equipment

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 868 MHz application with the ETSI EN 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
3 dB Splitter / Combiner	ZFSC−2−4	Mini−Circuits

Equipment Setup:

TX: The following block diagram shows the setup for the transmitter tests.

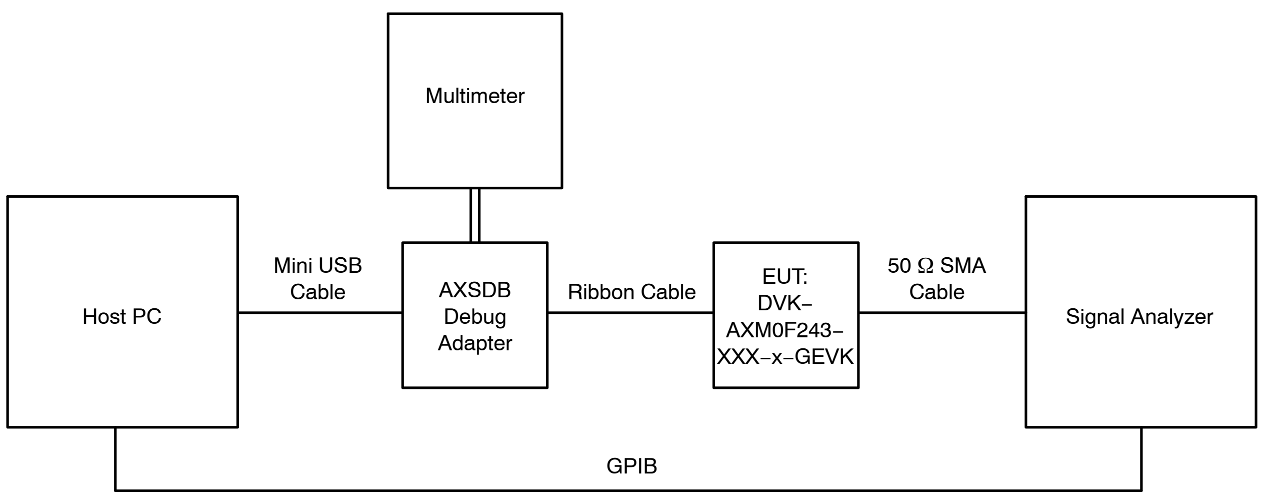

Figure 7.

RX: the following block diagram shows the setup for the RX blocking test.

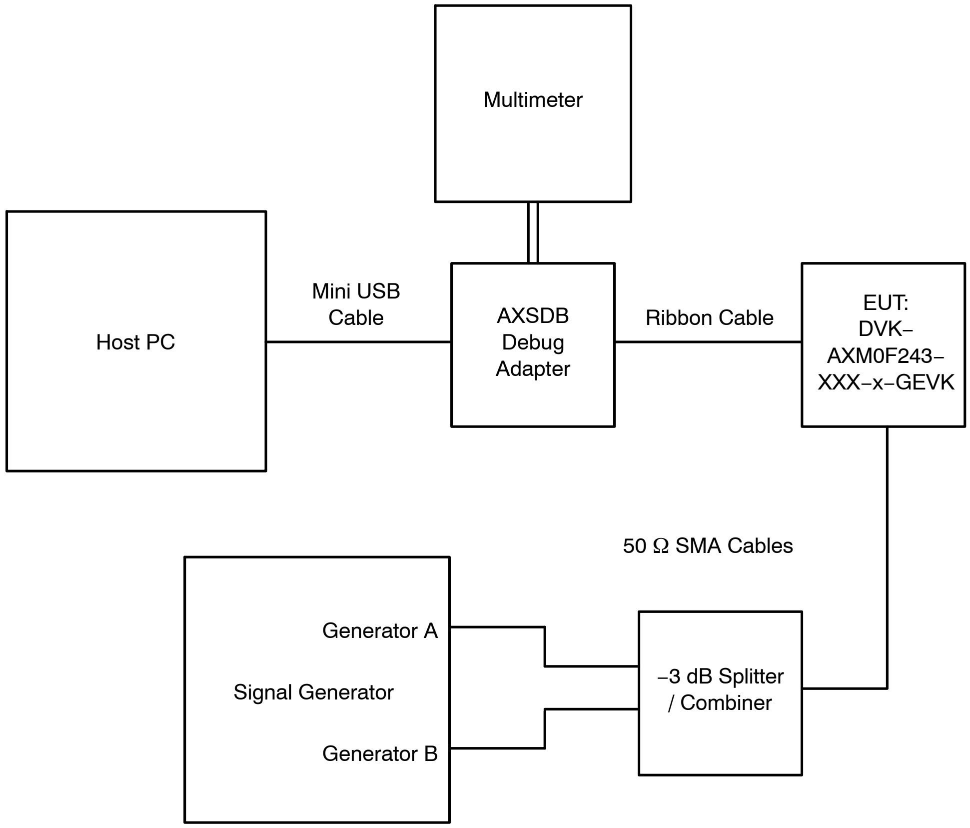

Figure 8.

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

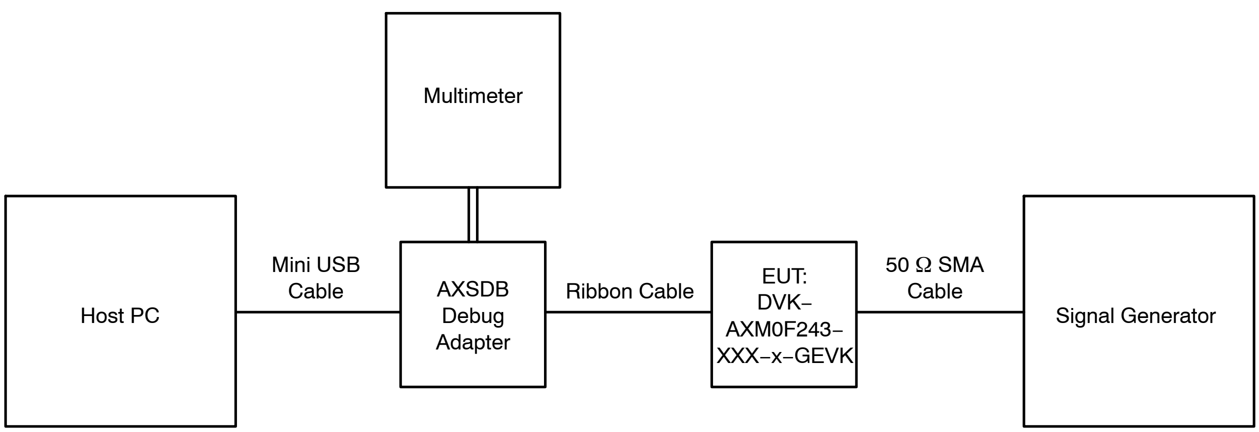

Figure 9.

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 to transmit one of the following signals, as defined in ETSI EN 300 220−1 v3.1.1, clause 4.3.1:

- D−M1: A test signal consisting of an unmodulated carrier.
- D−M2: A test signal consisting of a modulated carrier representative of normal operation and generating the greatest occupied RF bandwidth.
- D−M3: A test signal representative of normal operation of the EUT.

For D−M2, a continuous pseudo−random sequence of bits was used. For D−M3, a pre−defined data packet was transmitted intermittently every 0.3 seconds.

For the receiver sensitivity and blocking tests, a continuous stream of 1010 was provided by the signal generator.

All signals shared the following physical layer parameters as defined in AX−RadioLab, as shown below:

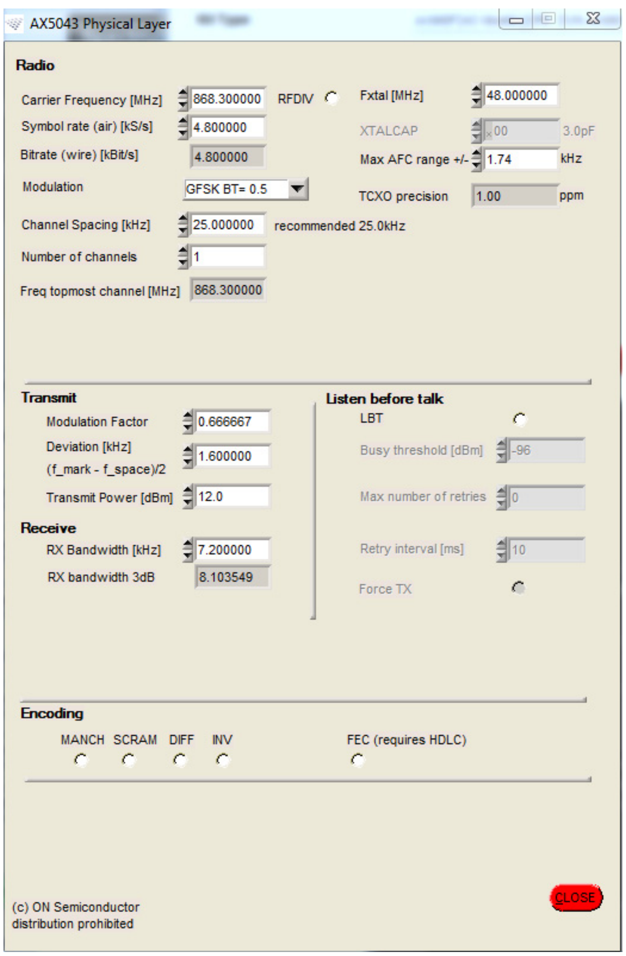

Figure 10.

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.

General Test Parameters

- Frequency band: 868.0 MHz – 868.6 MHz
- Channel Bandwidth (OCW): 600 kHz

Test Results

This section provides a summary of the specifications that were tested and their results.

Effective Radiated Power

Description:

ETSI EN 300 220−1 v3.1.1 clause 5.2.1 provides the following description:

The effective radiated power (e.r.p) is the power radiated in the direction of the maximum radiated power under specified conditions of measurements for any condition of modulation. For equipment with a permanent or temporary antenna connection it may be taken as the power delivered from that connector taking into account the antenna gain.

Measurement:

Table 4.

Measurement Parameters	
Detector:	Positive Peak
Sweep Time:	Auto
Resolution Bandwidth:	1 MHz
Video Bandwidth:	3 MHz
Span:	5 MHz
Trace Mode:	Max Hold
Test Signal:	D−M2

Limits:

14 dBm, as defined in ETSI EN 300 220−2 V3.1.1, clause 4.3.1

Results:

The captured spectrum shown below shows that the peak power is below the 14 dBm limit (13.73 dBm with cable loss included). Note that in all applications, the output power should be controlled by the firmware to maintain compliance with this requirement.

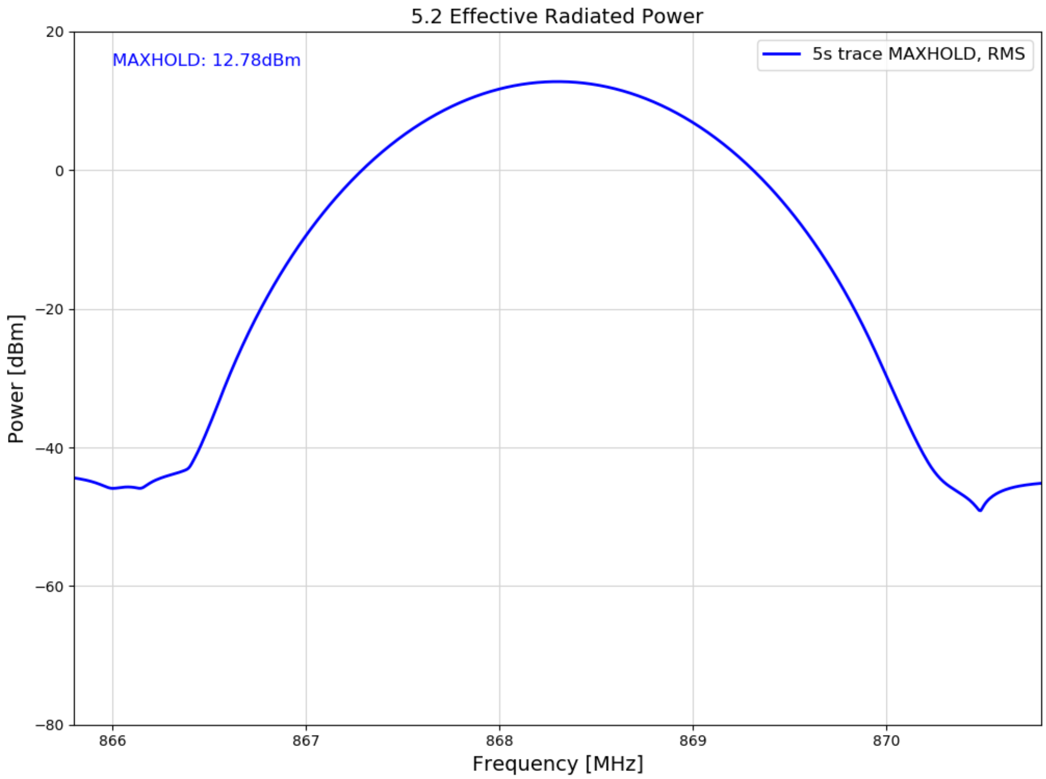

Figure 11.

Occupied Bandwidth

Description:

ETSI EN 300 220−1 v3.1.1 clause 5.6.1 provides the following description:

The occupied bandwidth (OBW) is the Frequency Range in which 99% of the total mean power of a given emission falls. The residual part of the total power being denoted as β, which, in cases of symmetrical spectra, splits up into β/2 on each side of the spectrum. Unless otherwise specified, β/2 is taken as 0,5%.

Measurement:

Table 5.

Measurement Parameters	
Detector:	RMS
Sweep Time:	Auto
Resolution Bandwidth:	10 MHz
Video Bandwidth:	30 MHz
Span:	1.2 MHz
Measurement Procedure:	OBW 99%
Trace Mode:	Max Hold
Test Signal:	D−M2

Limits:

From ETSI EN 300 220−1 v3.1.1, clause 5.6.2:

The Operating Channel shall be declared and shall reside entirely within the Operational Frequency Band.

The Maximum Occupied Bandwidth at 99% shall reside entirely within the Operating Channel defined by F_{low} and F_{high}.

Results:

The results are shown below for the given signal. Under a complete certification test, both the highest and lowest frequencies in the selected application would need to be tested. Note that the operating frequency of the final application will need to be selected such that the requirements of this clause are met.

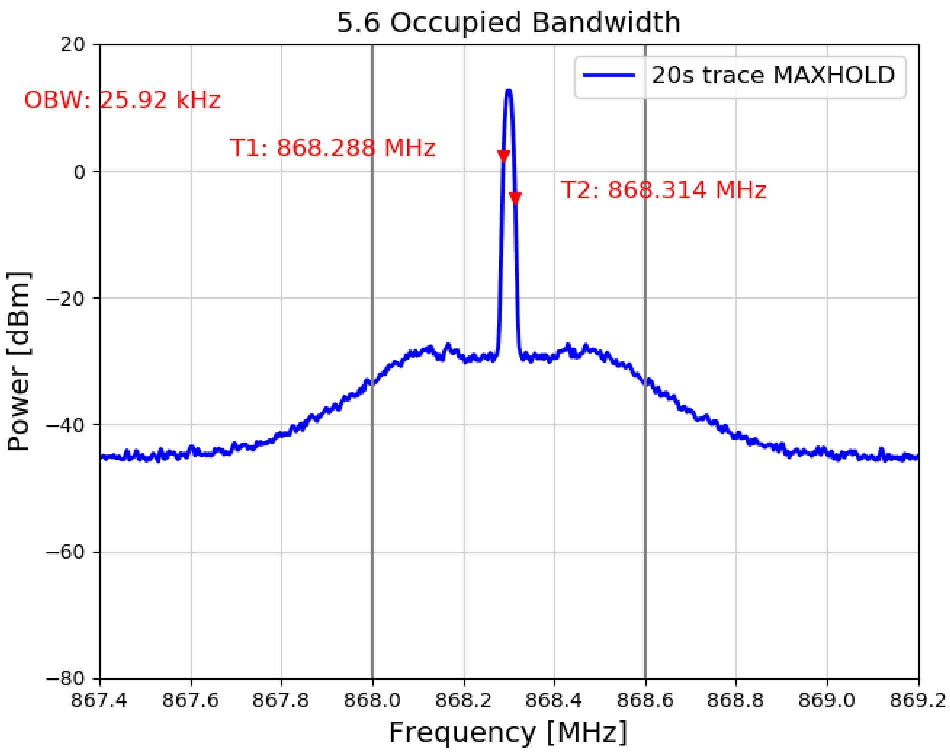

Figure 12.

Frequency Error

Description:

ETSI EN 300 220−1 v3.1.1 clause 5.7.1 provides the following description:

Frequency error is the difference between the measured unmodulated carrier frequency under extreme conditions and the nominal Centre Frequency as stated by the manufacturer. This measurement procedure only applies if the EUT can generate an unmodulated carrier (test signal D−M1).

Measurement:

Table 6.

Measurement Parameters	
Detector:	RMS
Sweep Time:	Auto
Resolution Bandwidth:	100 Hz
Video Bandwidth:	300 Hz
Span:	20 kHz
Test Signal:	D−M1

Limits:

No limit has been defined specifically for this clause, rather this measurement should be a factor in determining compliance with other clauses.

Results:

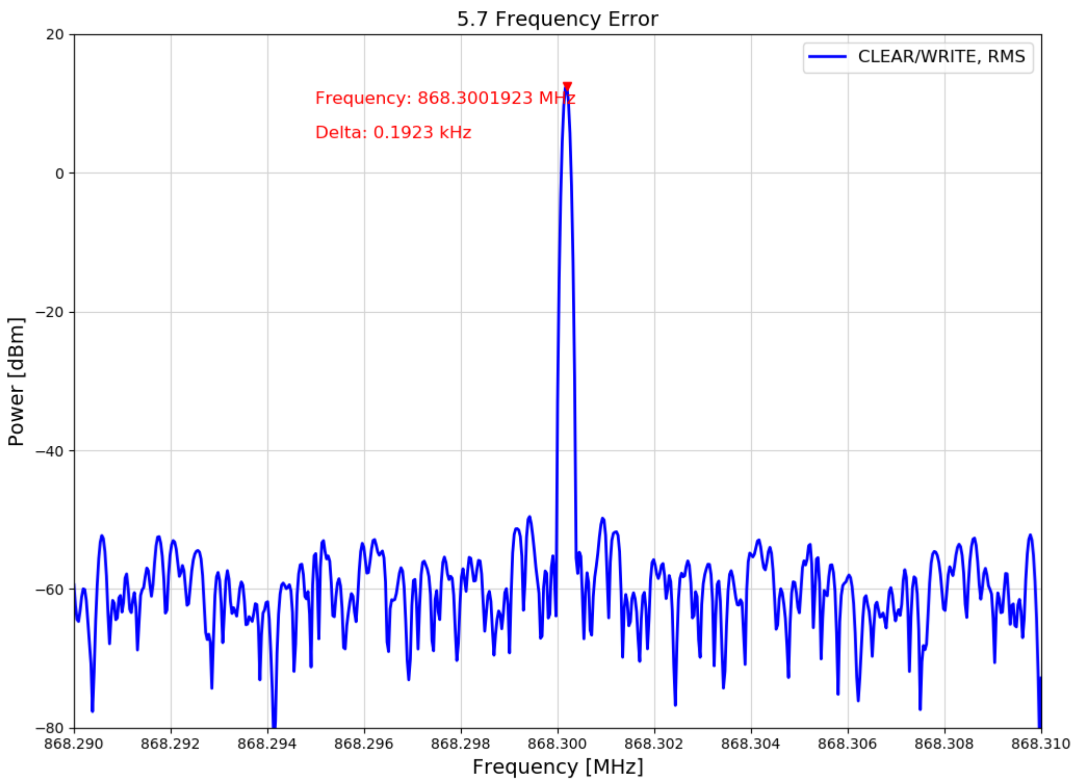

Figure 13.

TX Out−of−Band Emissions

Description:

The out−of−band domain consists of frequencies immediately above and below both the operating channel and operating band. See ETSI EN 300 220−1 v3.1.1 clause 5.8.1 for a complete description.

Measurement:

Table 7.

Measurement Parameters	
Detector:	RMS
Sweep Time:	Auto
Resolution Bandwidth:	1 kHz
Video Bandwidth:	3 kHz
Test Signal:	D−M2
Span:	3.6 MHz for Operating Channel, 1.068 MHz for Operational Frequency Band
Center Frequencies:	Low: 868.034 MHz, High: 868.226 MHz

Limits:

See ETSI EN 300 220−1 v3.1.1 clause 5.8.2 for the emission limits for OOB domains. The defined limits are shown with an overlay in the spectrum plots below.

Results:

The frequencies of 868.05 MHz and 868.55 MHz were selected for this test. In a final application, operational frequencies must be properly selected such that the requirements of this clause are met.

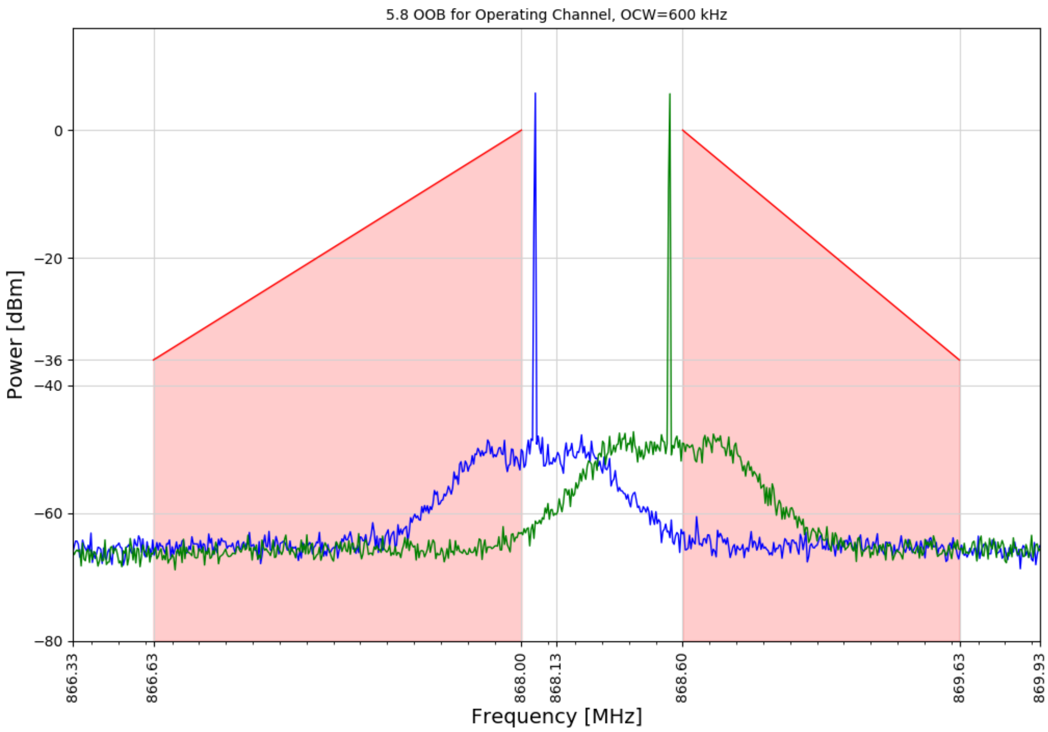

Figure 14.

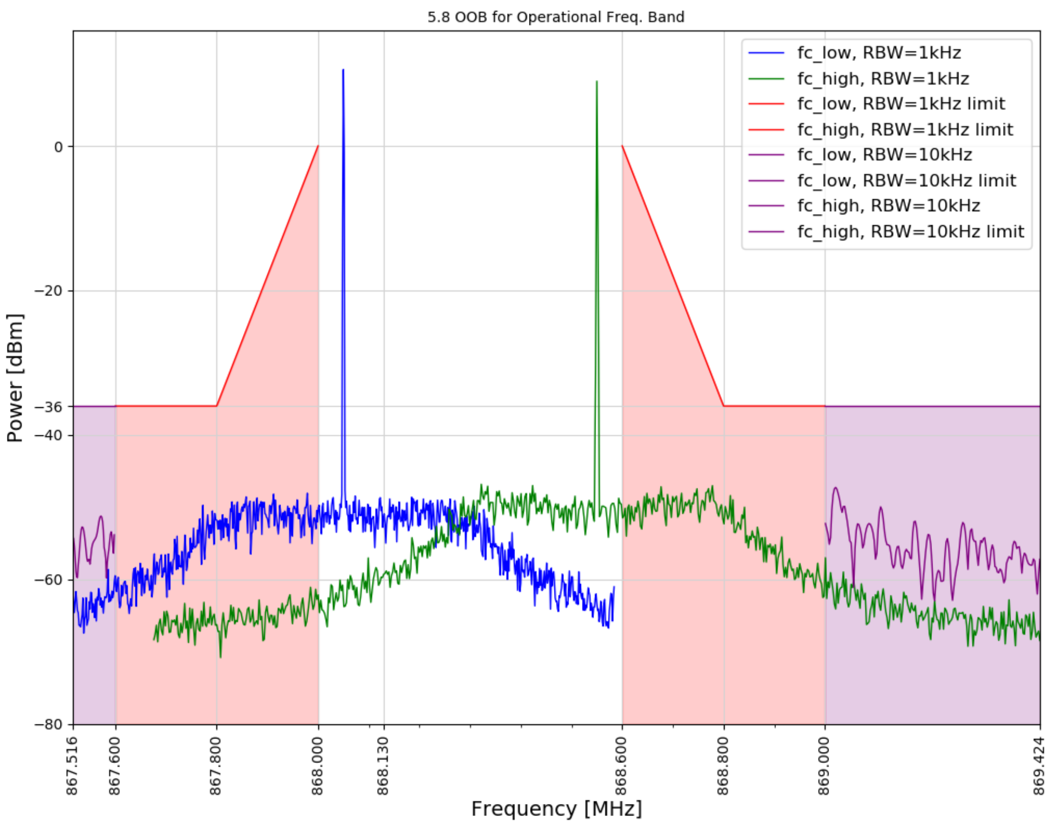

Figure 15.

Unwanted Emissions in the Spurious Domain

Description:

The spurious domain includes frequencies not included in the operating channel or the OOB domain. See ETSI EN 300 220−1 v3.1.1 for a complete description.

Measurement:

Table 8.

Measurement Parameters	
Detector:	RMS
Sweep Time:	Auto
Resolution Bandwidth: • f is the measurement frequency • f_c is the operating frequency • m is 10 x OCW, or 500 kHz, whichever is greater • n is 4 x OCW, or 400 kHz, whichever is greater • p is 2.5 x OCW	9 kHz ≤ f ≤ 150 kHz — 1 kHz 150 kHz ≤ f ≤ 30 Mhz — 10 kHz 30 MHz ≤ f < f_c − m — 100 kHz f_c − m ≤ f ≤ f_c − n — 10 kHz f_c − n ≤ f ≤ f_c − p — 1 kHz f_c + p ≤ f ≤ f_c + n — 1 kHz f_c + n ≤ f ≤ f_c + m — 10 kHz f_c + m ≤ f ≤ 1 Ghz — 100 kHz 1 GHz ≤ f ≤ 6 Ghz — 1 MHz
Video Bandwidth:	3 x RBW
Span:	See plots
Test Signal:	D−M2
Trace Mode:	Max Hold

Limits:

See ETSI EN 300 220−1 v3.1.1 clause 5.9.2 for the emission limits for the spurious domain. The defined limits are shown with an overlay the spectrum plots below.

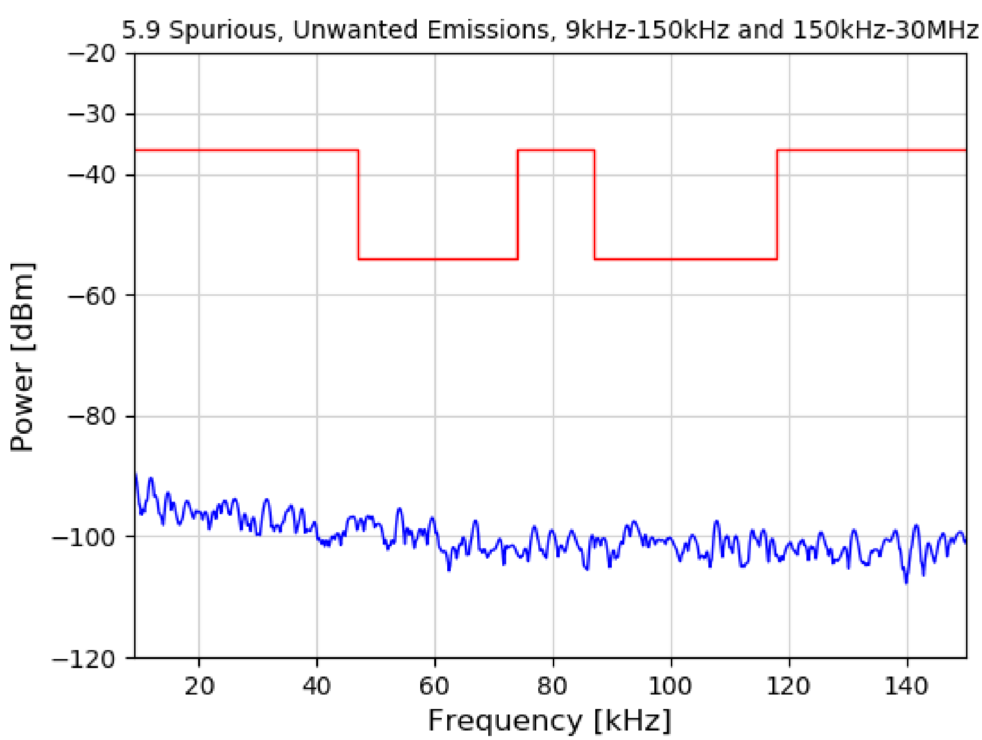

Figure 16.

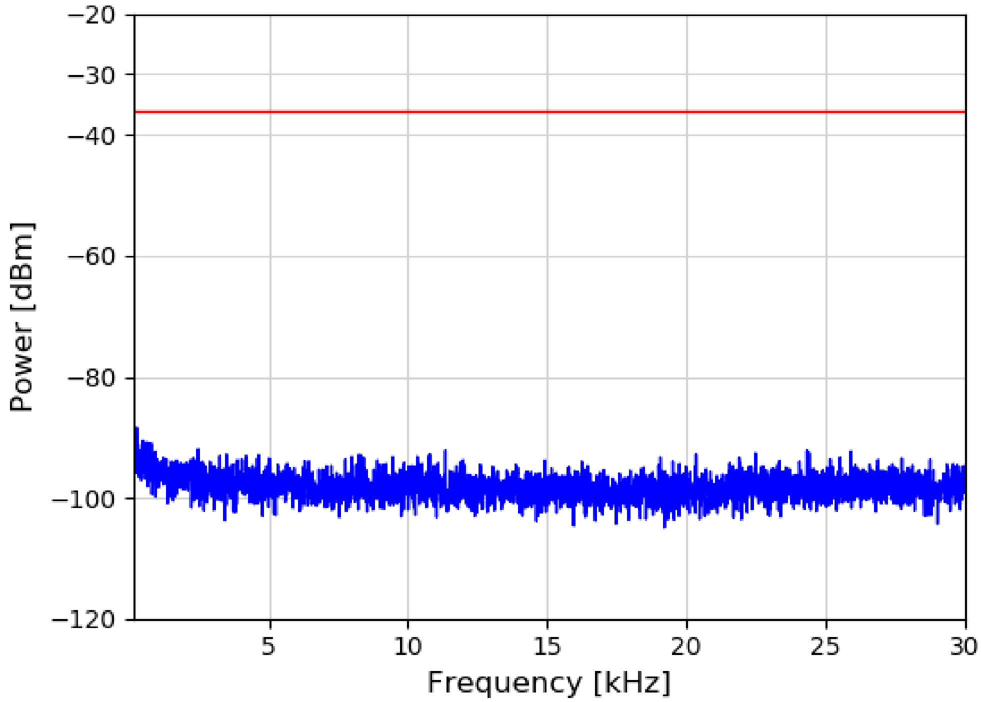

Figure 17.

Results:

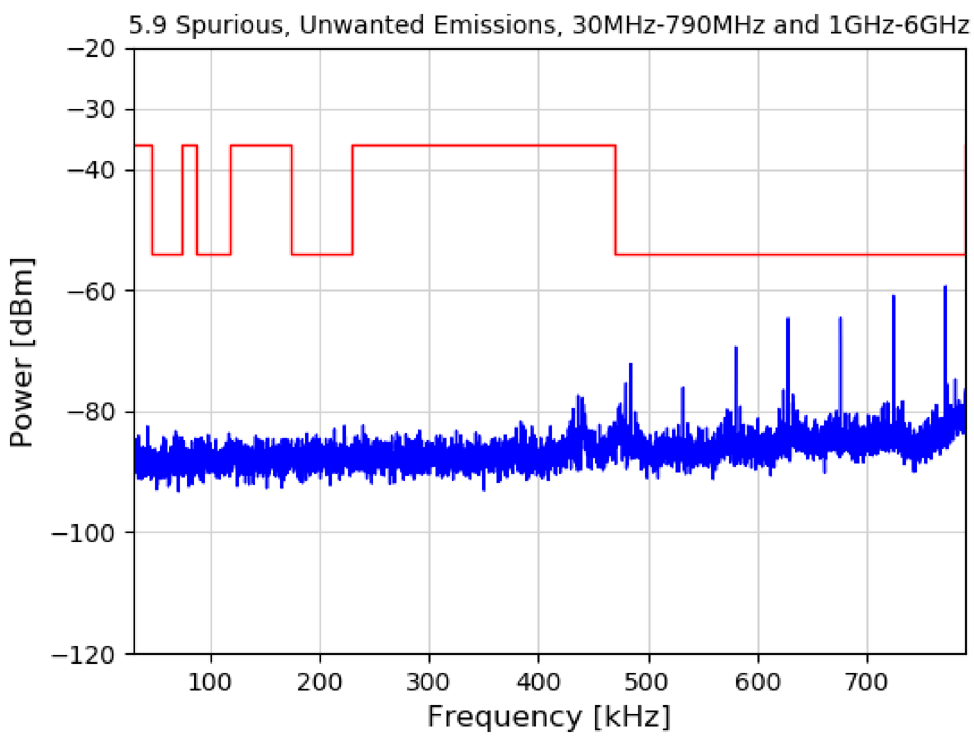

Figure 18.

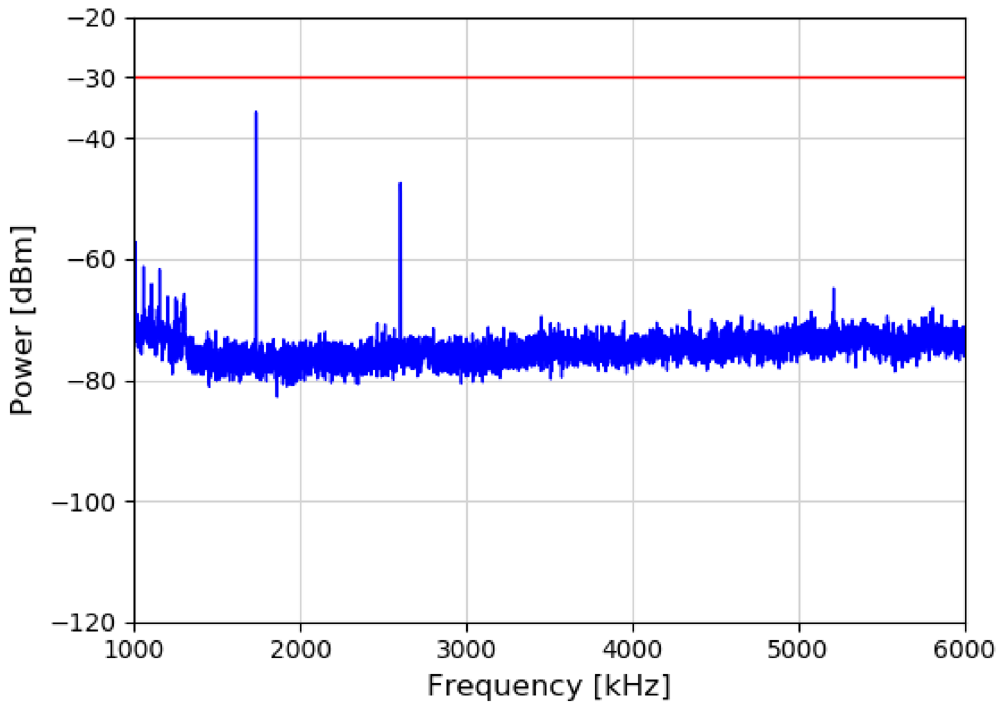

Figure 19.

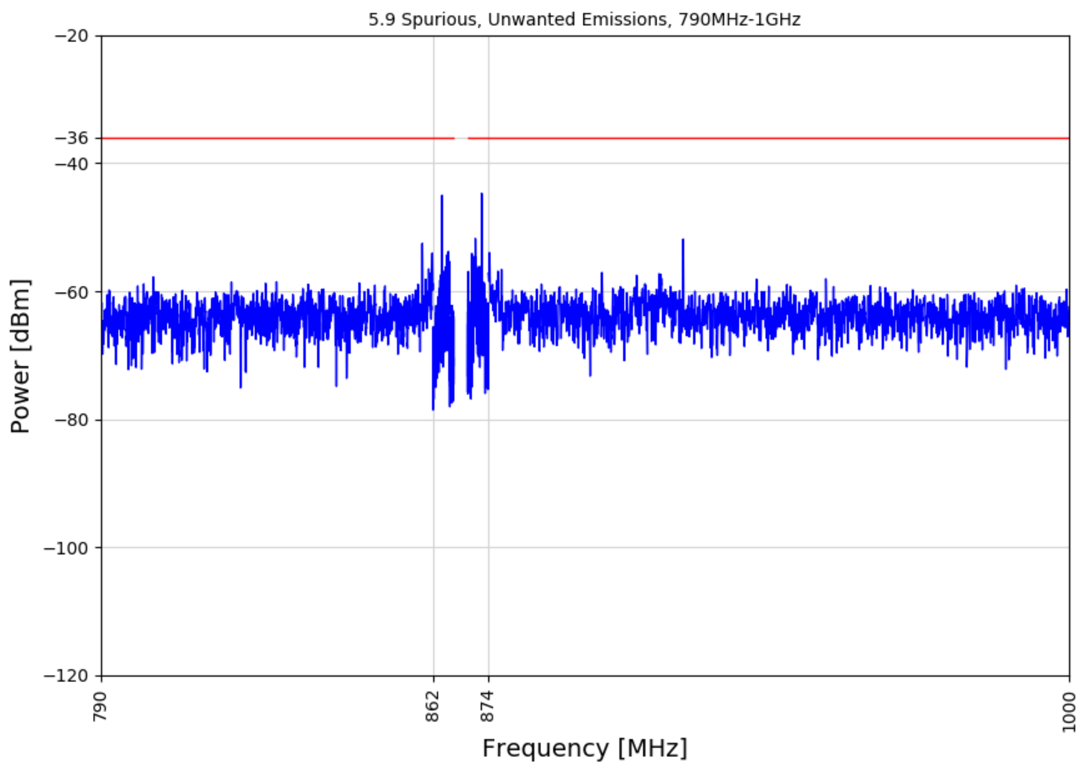

Figure 20.

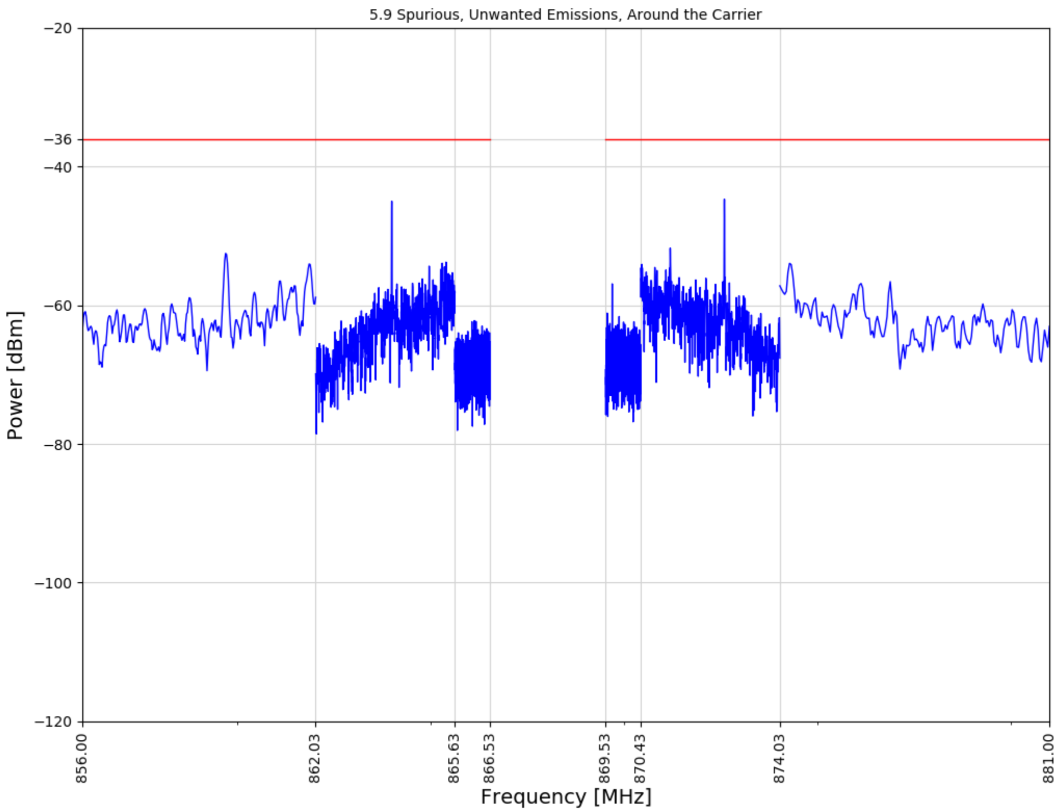

Figure 21.

Transient Power

Description:

ETSI EN 300 220−1 v3.1.1 clause 5.10.1 provides the following description:

Transmitter transient power is power falling into frequencies other than the operating channel as a result of the transmitter being switched on and off.

Measurement:

Table 9.

Measurement Parameters	
Detector:	RMS
Sweep Time:	624 ms
Resolution Bandwidth:	See Table below
Video Bandwidth:	10 x RBW
Test Signal:	D−M3
Span:	Zero Span
Sweep points:	625
Trace Type:	Max Hold

From EN 300 220−1 v3.1.1, clause 5.10.3.2, the required RBW is defined:

Table 10.

Measurement Parameters for RBW		
Measurement Points	**Analyzer RBW**	**RBW_{REF}**
For OCW > 25 kHz: • −0.5 x OCW – 3 kHz • −0.5 x OCW + 3 kHz	1 kHz	1 kHz
For OCW < 25 kHz: • ± max (12.5 kHz, OCW)	Max (RBW pattern 1 ,3, 10) ≤ Offset frequency / 6	1 kHz
−0.5 x OCW – 400 kHz −0.5 x OCW + 400 kHz	100 kHz	1 kHz
−0.5 x OCW – 1200 kHz −0.5 x OCW + 1200 kHz	300 kHz	1 kHz

Limits:

The limits are defined in EN 300 220−1 v3.1.1, clause 5.10.2 as:

Table 11.

Absolute Offset from Center Frequency	RBW_{REF}	Peak Power Limit Applicable at Measurement Points
≤400 kHz	1 kHz	0 dBm
<400 kHz	1 kHz	−27 dBm

Results:

Table 12.

Frequency	Limit (dBm)	RBW (kHz)	Upper f (MHz)	Lower f (MHz)	Upper Max (dBm)	Lower Max (dBm)	Scaled Max with 1 kHz (dBm)	Pass / Fail
fc ± OCW / 2 ± 3 kHz	0	1	868.233	868.027	−26.56	−27.75	−26.56	Pass
fc ± OCW	0	30	868.33	867.93	−21.88	−22.14	−36.65	Pass
fc ± OCW / 2 ± 400 kHz	−27	100	868.63	867.63	−36.3	−35.96	−55.96	Pass
fc ± OCW / 2 ± 1.2 kHz	−27	300	869.43	866.83	−40.52	−40.24	−65.01	Pass

Blocking

Description:

ETSI EN 300 220−1 v3.1.1 clause 5.18.1 provides the following description:

Blocking is a measure of the capability of the receiver to receive a wanted modulated signal without exceeding a given degradation due to the presence of an unwanted input signal at any frequencies other than those of the spurious responses or the adjacent channels or bands.

Measurement:

Table 13.

Measurement Parameters	
Test Signal:	D−M3 (1010 from Signal Generator A), CW interfering signal from generator B

For this test, the EUT was configured to receive the D−M3 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 interfering signal from generator B was then introduced, and the power was increased until the BER increased above 0.001. This is the value reported in Generator B.

Limits:

The receiver is category 2, and the limits are defined in EN 300 220−1 v3.1.1 clause 5.18.3:

Table 14.

Requirement	Limits
	Receiver Category 2
Blocking at ±2 MHz from OC edge fhigh and flow	≥ −69 dBm
Blocking at ±10 MHz from OC edge fhigh and flow	≥ −44 dBm
Blocking at ±5% of Centre Frequency or 15 Mhz, whichever is the greater	≥ −44 dBm

Results:

Table 15.

Frequency Offset	Frequency (MHz)	Generator B (dBm)	Limit (≥ dBm)	Pass / Fail
Carrier + OBW/2 + 2 MHz (MHz)	870.1588	−56	−69	Pass
Carrier − OBW/2 − 2 MHz (MHz)	866.1012	−56	−69	Pass
Carrier + OBW/2 + 10 MHz (MHz)	878.1588	−38	−44	Pass
Carrier − OBW/2 − 10 MHz (MHz)	858.1012	−37	−44	Pass
Carrier + 5%	911.5365	−34	−44	Pass
Carrier − 5%	824.7235	−33	−44	Pass

ADDITIONAL PERFORMANCE TESTS

TX Power vs. Current Consumption

A DM1 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, as well as the LED on the DVK. 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 16.

Measured TX Power (dBm)	TX Power w/ Cable Loss (dBm)	Measured Current Consumption (mA)
13.99	14.94	63.3
7.5	8.45	37.8
−0.4	0.55	28.1
−7.3	−6.35	24.5

RX Sensitivity

The receiver sensitivity was measured with the test setup described previously. The EUT was configured to receive the D−M3 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, and includes the current for the radio, MCU, and LED.

Table 17.

868 MHz FSK Sensitivity			
Datarate (kbps)	Measured Sensitivity (dBm)	Sensitivity w/ Cable Loss (dBm)	Current (mA)
1	−126	−126.95	23.79
10	−116	−116.95	23.5
100	−104	−104.95	23.5
125	−102	−102.95	23.9

REFERENCES & LINKS

ON Semiconductor Resources

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

ETSI

1. ETSI – Short Range Devices: https://www.etsi.org/technologies−clusters/technologies/radio/short−range−devices
2. ETSI 300 220−1 v3.1.1 (2017−02): https://www.etsi.org/deliver/etsi_en/300200_300299/30022001/03.01.01_60/en_30022001v030101p.pdf

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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