Atmel AT04464: Wireless SoC Reference Design with RFMDs RF6505

Atmel MCU Wireless

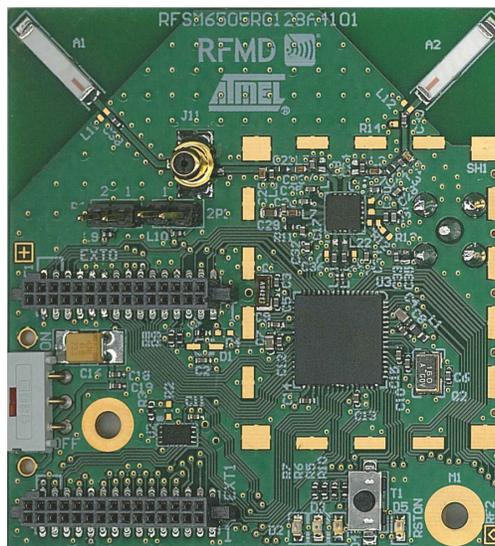## Description

The Atmel[®] RF6505RC128A-410 Demo Board is a reference design partnership between RFMD and Atmel Corporation presenting a complete 2.4GHz ZigBee[®] IEEE[®] 802.15.4 based compliant radio transceiver solution and to conform to FCC CFR47 part 15. Atmel introduces the ATmega128RFA1 [1] and ATmega256RFR2 [2] as its ZigBee platform which incorporates a low power 2.4GHz radio frequency transceiver and a High Performance, Low Power AVR[®], 8-bit microcontroller into a single 9mm x 9mm x 0.9mm 64-pin QFN package.

RFMD presents a world class Front End Module (FEM), the RF6505 [3], for efficient extended output power above 27dBm with harmonic filtering, diversity switch, and LNA with bypass.

Features

- +27dBm (1/2 Watt) of output power
- Industry leading 129dB link budget
- Sensitivity: -102.5dBm, 1% PER
- Low Harmonic Content
- Antenna Diversity
- RoHS Compliant
- Single differential bidirectional TX/RX interface

Table of Contents

1. Overview

1.1 RF6505

The RF6505 FEM serves as a single-chip medium power (24 to 27dBm) Smart Energy front end solution. The RF6505 integrates the PA with harmonic filtering, LNA with bypass, SPDT switch for TX/RX functionality, DP2T switch for antenna diversity, and a 100Ω Balun for single differential bidirectional TX/RX interface all on a single 3.5 x 3.5 x 0.55 QFN 20-pin package.

1.2 Atmega128RFA1/ATmega256RFR2

The IC integrates a powerful, AVR RISC 8-bit microcontroller, an IEEE 802.15.4-compliant transceiver, and additional peripheral features. The built-in radio transceiver supports the worldwide accessible 2.4GHz ISM band. The system is designed to demonstrate standard-based applications such as ZigBee/IEEE 802.15.4, ZigBee RF4CE, and 6LoWPAN, as well as high data rate ISM applications.

The RF6505RC128A-410 demo board can be purchased from RFMD estore [4] and RFMD support contact email SmartGrid@rfmd.com.

1.3 Hardware

The RF6505RC128A reference design serves as a proven ½ Watt range extension for the Atmega128RFA1/ATmega256RFR2 with a link budget of 129dB. The RF6505, RF6555, RFFM6201, RF6545, and RF6575 [5] also serve as range extensions for the ATmega128RFA1/ATmega256RFR2 and AT86RF231 radio transceivers.

1.4 Software

The RF6505RC128A-410 demo board comes pre-flashed with the Performance test EVK application from MAC 2.8.0 stack software interface to allow for performance verification. For information about IEEE MAC Stack 2.8.0 and the user guide for the Atmel AVR2025: IEEE 802.15.4 MAC Software Package visit, http://www.atmel.com/tools/IEEE802_15_4MAC.aspx for details.

Summary: This application note serves to provide a developer with data, evaluation steps, and design tools to implement a ZigBee solution using the RF6505RC128A reference design.

1.5 Applications

This application note serves to provide a developer with data, evaluation steps, and design tools to implement a ZigBee solution using the RF6505RC128A reference design.

- ZigBee 802.15.4 Based Systems for Remote Monitoring and Control
- Communications Hub for Smart Energy/Home Automation
- Smart metering for energy management applications
- Building Automation

2. Functional Descriptions

2.1 Connectors

The RF6505RC128APCBA-410 is equipped with two 50mil, 30-pin connectors (EXT0/1), which are parallel to each other and 22mm apart. These are for interfacing with the Sensor Terminal Board [8] or RCB-Breakout Board [7].

2.2 EEPROM

An EEPROM is provided on the RF6505RC128APCBA-410 to identify the transceiver and software. It also has the production calibration and MAC address information stored. This EEPROM may not be required on the final product once the user's design is complete.

2.3 RF Communication

The RF6505RC128APCBA-410 boards are also equipped to with two PCB antennas A1 and A2 for antennal diversity over the air testing. The reference design also supports conducted testing by use of J11 an MS-147 receptacle which is Digi-Key P/N H2800DKR-ND that mates to Digi-Key P/N H2802-ND. It also contains SMA female connector X1, which is Digi-Key P/N J500-ND which is also for conducted measurements.

3. Mechanical Descriptions

Note: It is highly recommended by RFMD to follow the PCB layout as closely as possible as deviations from the layout can change the reference design's performance.

3.1 Layer Stack-up

The RF6505RC128APCBA-410 is made using a 4-layer design on standard FR4 material (IS400) with a total thickness of 66mils. It can be designed on a two-layer board [6]. The top and bottom layers are large copper planes whose grounds are stitched together with through-hole vias that are in close proximity of GND pins of critical RF components [6].

1. The top layer contains a solid 1oz base copper and plating for digital ground plane and is used for RF and digital signal routing. It has isolation in-between digital and RF traces.
2. Mid layer 1 is a solid digital ground.
3. Mid layer 2 is an internal layer and a solid power plane with nets to VCC and V_RCB. The power plane should be surrounded with through-hole ground vias, which connect the ground layers together.
4. The bottom layer is a digital ground plane shared with RF and made with solid 1oz base copper and plating. The filter-balun B1 requires a solid ground connection. See Figure 3-1 for layer stack-up details.

Figure 3-1.   RF6505RC128APCBA-410 Layer Stack-Up
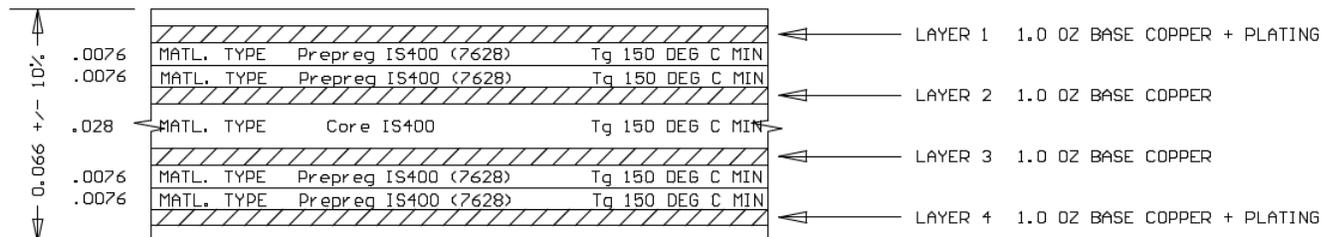
3.2   Shielding

A metal shield is not provided with the reference design but it may be necessary to protect the ICs from external noise and strong interferers. The shield can also be used to suppress radiated harmonics from the reference design even lower, but is not necessary. Also check with the local test houses whether RF shield is mandatory for local FCC or ETSI regulatory requirements. The recommended shield size is 30mm x 25mm.

3.3   RF Layout Optimization

The RF6505 ground pad via pattern is a 3 x 3 pattern (Figure 3-2) with through-hole vias that route from top layer to bottom layer. The via hole size is 12mils and the diameter is 24mils. This is for thermal dissipation and to provide a short return path for the signal. The final product may include removing the solder mask or solder resist from the bottom layer beneath the ground pad for improved thermal dissipation.

Figure 3-2.   RF6505 Ground Slug Via Pattern
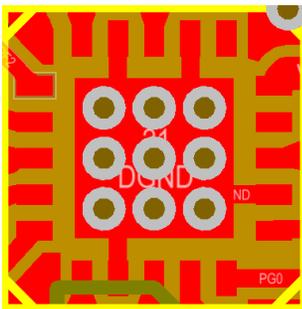
4.   Evaluation and Configuration

4.1   Required Equipment

- Sensor Terminal Board (STB) [8] or Radio Controller Board Breakout Board (RCB-BB) [7]
- Signal or Spectrum analyzer for conducted measurements
- Computer with a terminal emulator application like PuTTY
- SMA MS-147 cables (2 Nos)
- RCB Breakout Board RS232 cable (if using RCB-BB)
- USB cable (if using STB)
- 3V – 4VDC supply (if using RCB-BB)
- Power meter

4.2   Evaluation Boards

The RF6505RC128A-410 demo board is evaluated on the Atmel RCB Sensor Terminal Board (Figure 4-1) or the Atmel Radio Controller Board Breakout Board (Figure 4-2). The Sensor Terminal Board (STB) is intended to establish a USB-based UART connection, programming interfaces, and to provide an RCB power supply using the USB cable. The Radio Controller Board Breakout Board (RCB-BB) is intended for connection with an RS-232 serial port, JTAG programming interface, and remote power supply. Ordering information for the STB and RCB-BB, as well as descriptions, technical data, documentation, and drivers can be found at www.dresden-elektronik.de/funktechnik/products/boards-and-kits/development-boards/. These drivers support Windows® XP and Windows 7 environments.

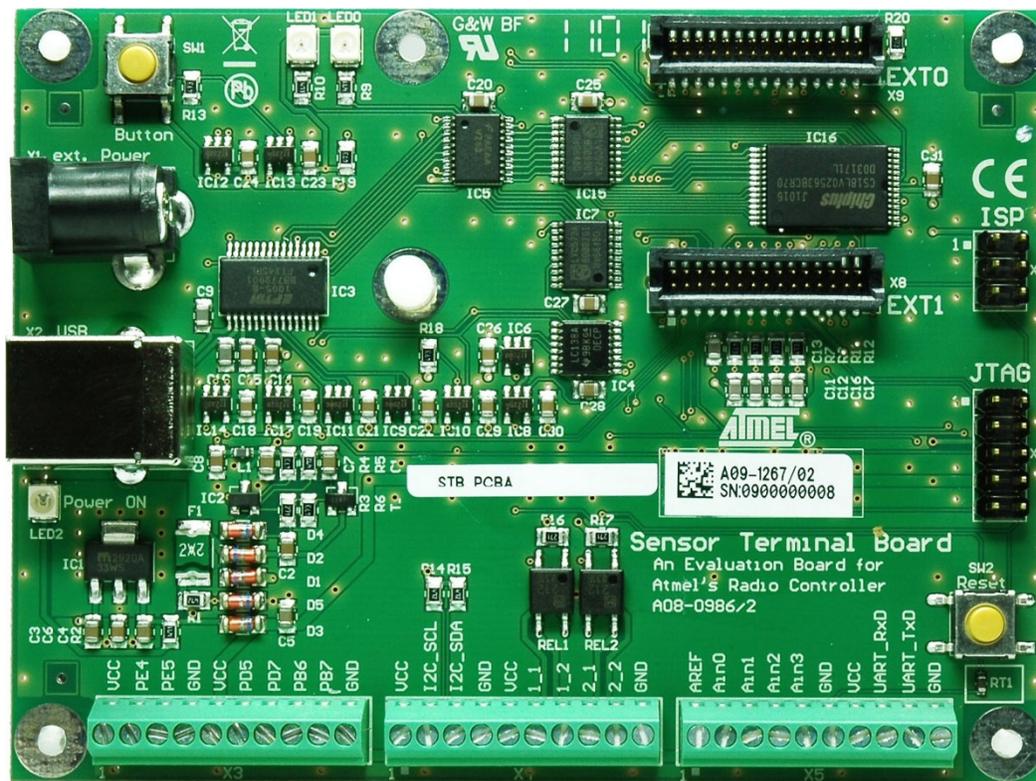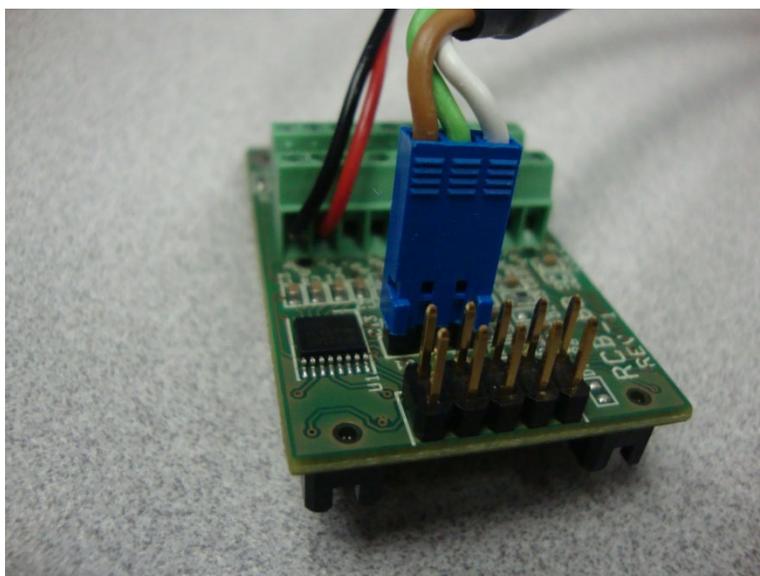**Figure 4-1. Sensor Terminal Board**

Figure 4-2. RCB Breakout Board RS232 Cable Connected to RCB-BB

4.3   Configuration

To control the RF6505RC128A-410 demo board, which is mounted on the STB, a USB connection between the STB and the host computer is required. If using the RCB-BB, a RCB Breakout Board RS232 Cable, which is connected to a COM port on a host computer, is required to establish connection.

RF6505RC128A-410 may be evaluated using onboard antennas A1 and A2, or by placing SMA connectors on J11 (MS-147) for Antenna 1, or X1 for Antenna 2.

Note: RF6505RC128A-410 demo boards are shipped with connector X1 out-of-circuit. In order to evaluate the demo board using connector X1, the following component modifications must be made:

1.   Remove capacitor C39.

2.   Populate R14 with a 0Ω 0402 resistor.

3.   Remove resistor R16 (located between X1 and balun).

4.4   Steps for Installing and Configuring the Demo Board

- If Sensor Terminal Board is used, connect cable to 'X2' of the STB. Depending on the operating system used the driver software for the STB may automatically install.
  If not, go to www.ftdichip.com/Products/ICs/FT245R.htm to download the necessary driver. The drivers for the FT245R does provide support for 32- and 64-bit Windows 7, and 32- and 64-bit Window XP

- See the FT245 USB FIFO IC datasheet for details;
  http://www.ftdichip.com/Support/Documents/DataSheets/ICs/DS_FT245R.pdf.
 Once installed, note the COM port number assigned to the device as shown in Figure 4-3

Figure 4-3.   Device Manager after Driver Installation
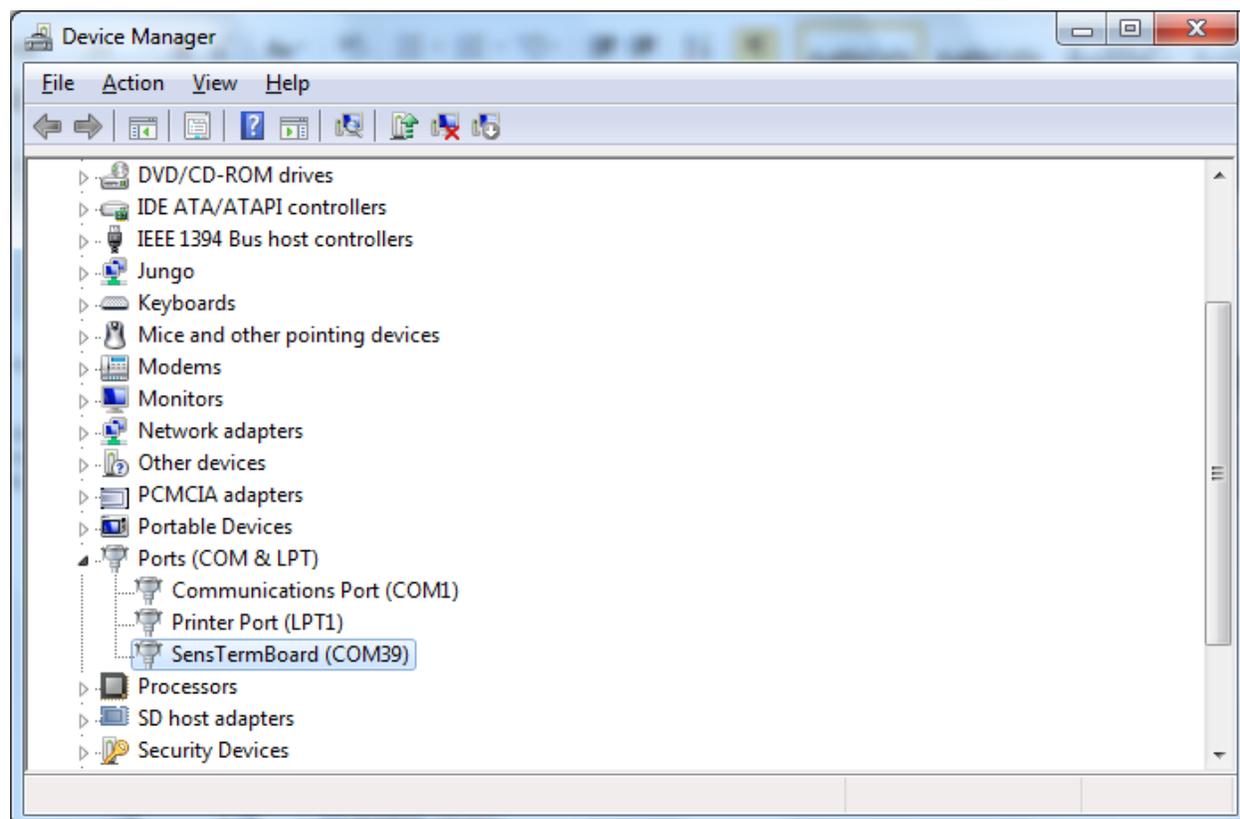
- If Breadout-Board (RCB-BB) is used, connect the RCB-BB breakout cable to the RS-232 serial port of a computer terminal and to J1 of the RCB-BB as shown in Figure 4-2

- If using the Sensor Terminal Board, current is limited to 400mA by the onboard voltage regulator, which limits the output power to 24dBm. No external power source is needed

- If using RCB-BB, external 3.3-4.0V should be applied to J3 as shown in Figure 4-2

- Set relevant COM port ('Port Settings' tab in Figure 4-4) to the following settings:
  - Baud (Bits per second):   9600
  - Parity: None
  - Data Bits: 8
  - Stop Bits: 1
  - Flow Control   None

Figure 4-4.   USB Port Settings
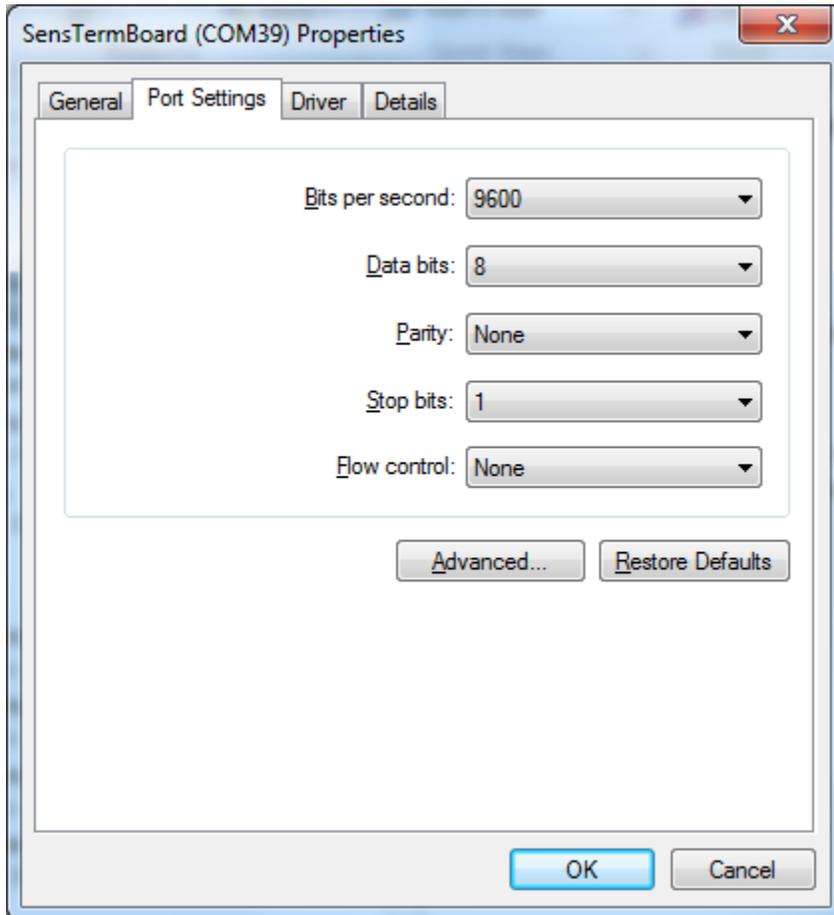
- To establish a connection to the RF6505RC128A-410 demo board and enable the test menu options; set your chosen terminal emulator application to the proper COM port and the settings listed in previous step
- Press any key (send ASCII character) to establish communication with the RF6505RC128A-410 demo board

Note: Once properly connected to the computer terminal the RF6505RC128A will begin searching for a peer device (a feature that allows a remote RF6505RC128A to operate without a computer terminal). For transmission performance testing (single node) mode, skip this search by pressing 'Enter'. The screen in Figure 4-5 will be shown. This is the Main menu for the Transmission Performance Evaluation section. If a peer device is detected, both devices will assume PER testing mode. Screens will be shown as in Figure 4-6, where the 'Transmitter Terminal' screen is the Main menu for the PER Evaluation section.

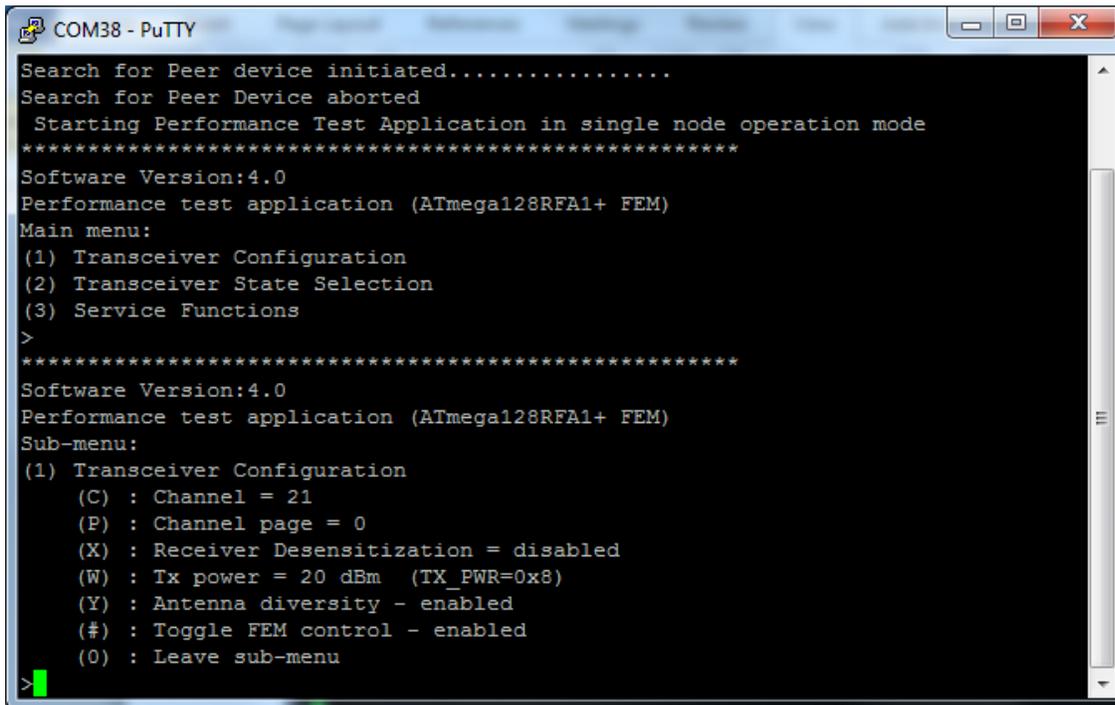**Figure 4-5. RF6505RC128A-410 Demo Board Terminal Emulator Main Menu**
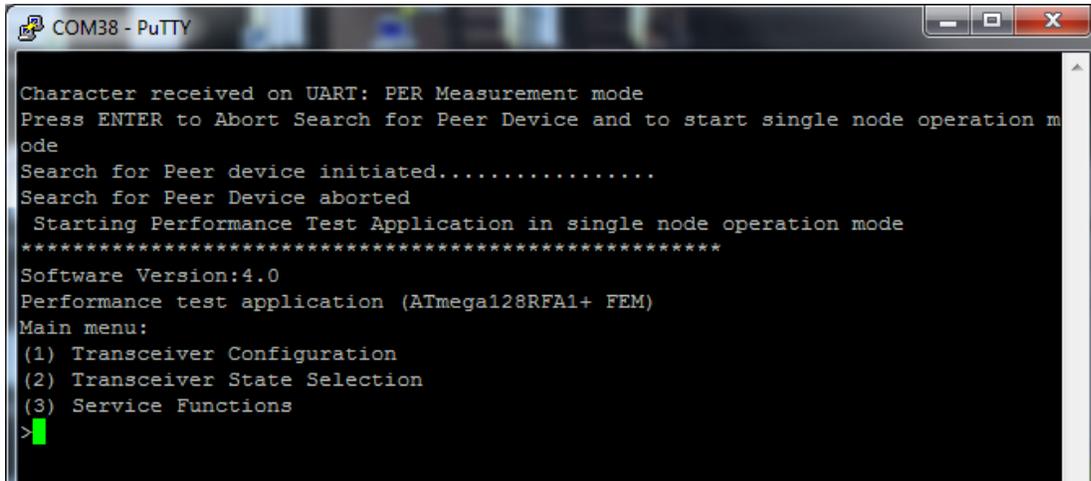
4.5 Transmission Performance Evaluation

4.5.1 Steps for Transmission Verification Test Setup

1. From the single-node main menu, press '1' to enter the 'Transceiver Configuration' menu.

Figure 4-6. Transceiver Configuration Menu Screen

2. Set the Channel to the channel to test. The default is Channel 21. To change the channel press '(C)', type channel number (11…26) and press 'Enter'.

3. Set the TX power level, the default is 20dBm. To change the power level press 'W' then 'A' for 'absolute' and type the power level in dBm or 'R' for 'register value' and type a two-digit hex value (00…0F). Then press 'Enter'.

4. To select antenna, press 'Y' then enter '1' or '2'. Pressing 'Y' again will re-enable 'Antenna diversity' wherein both antennas are used. Antenna diversity should be disabled for the purposes of this testing.

5. Press 'O' to leave 'Transceiver Configuration' menu.

6. From the main menu, press '2' to enter 'Transceiver State Selection' menu (Figure 4-7).

Figure 4-7.   Transceiver State Selection Menu Screen

7. Set 'Antenna diversity' if not already set. This can be set the same as described for 'Transceiver Configuration' menu.

8. Press 'U' to begin transmission, and then select 'C' for continuous waveform, or 'P' for modulated (Pseudo Random Binary Sequence) waveform. At this point the demo board is transmitting a signal.

9. Press any key to terminate transmission.

### 4.5.2   Packet Error Ratio (PER) Evaluation

Two RF6505RC128A-410 demo boards are required to perform PER testing; one board as transmitter, which requires a computer terminal, and a second board as receiver where a computer terminal is optional.

Figure 4-8. PER Test Setup

Block diagram of PER test setup
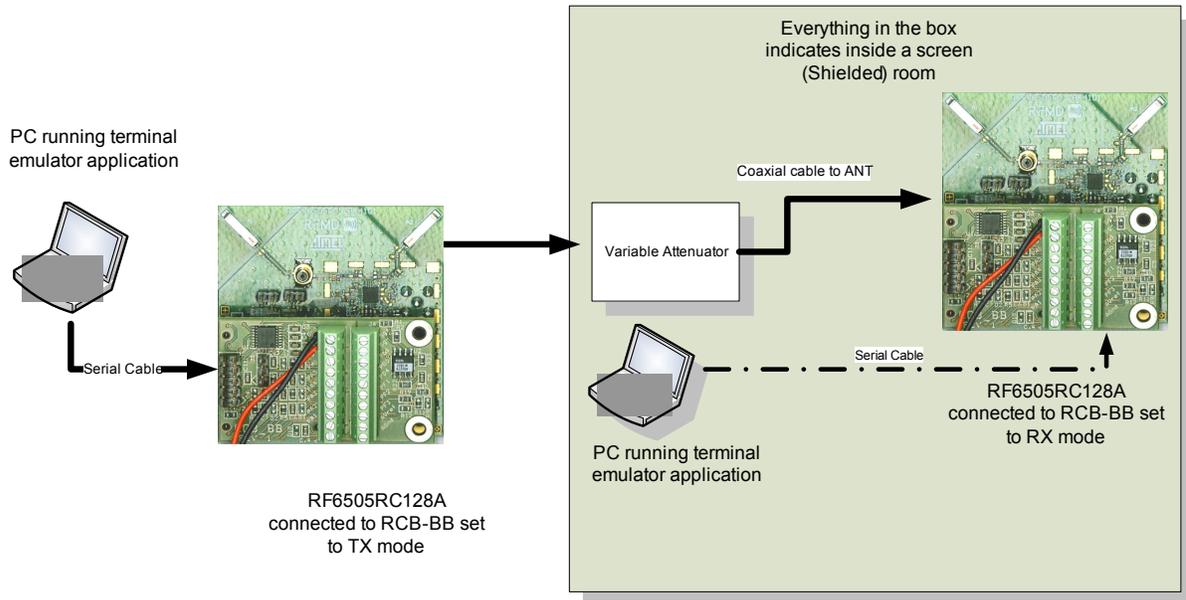
1. Apply power to the transmitter board. With terminal emulator window active, press any key to begin search for peer device (receiver), as shown in Figure 4-10. While the transmitter is searching (approximately 12 seconds), apply power to the receiver board. When the receiver is detected, the transmitter and receiver will display screens as shown in Figure 4-11. All of the desired settings for the receiver can then be set from the transmitter terminal.
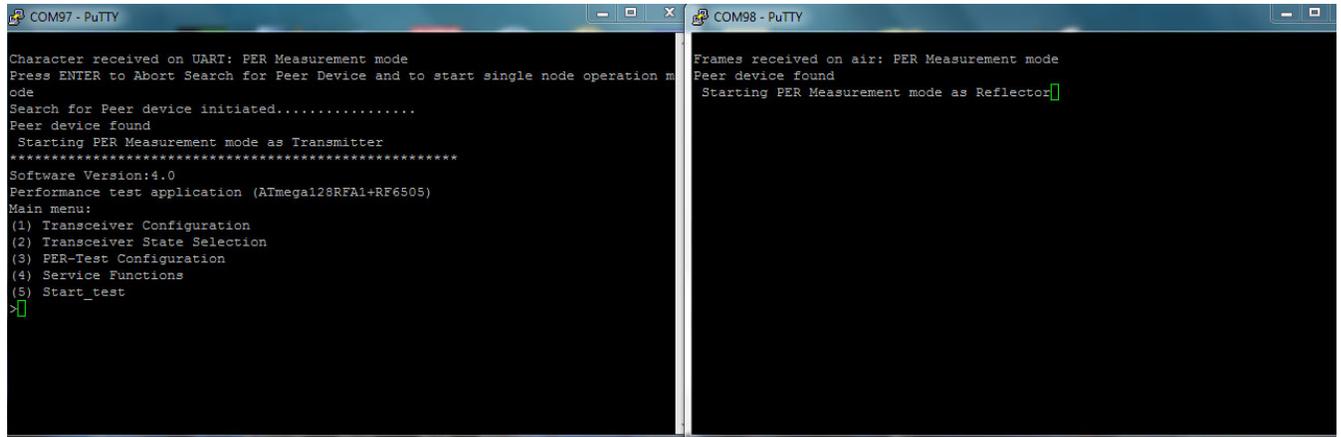
Figure 4-9. Transmitter Node
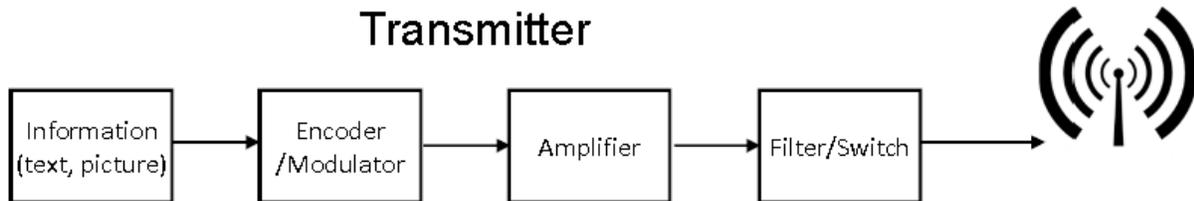
**Figure 4-10. Transmitter Node Searching for Peer Node**

Figure 4-11. Successful Detection of Peer Node

2. Set the Channel to the channel to test. The default is Channel 21. To change the channel press 'C', then type the two-digit channel number (11...26), and press 'Enter'.

3. Set the transmit power. The default power level is 20dBm. To change the power level press 'W', then 'A' for 'absolute', and type the power level in dBm or 'R' for 'register value', and type a two-digit hex value (0F...00). Then press 'Enter'.

4. Toggle ACK request until it reads 'no ACK requested' by pressing 'A'.

5. Toggle Frame retry until it reads 'false' by pressing 'F'.

6. Toggle CSMA enabled until it reads 'false' by pressing 'M'.

7. Select the antenna for transmission. Toggle the antenna by pressing 'Y'. For validating one Receiving antenna it is required to disable antenna diversity and choose that particular antenna.

Figure 4-12. Terminal Screens After Transceiver Configuration
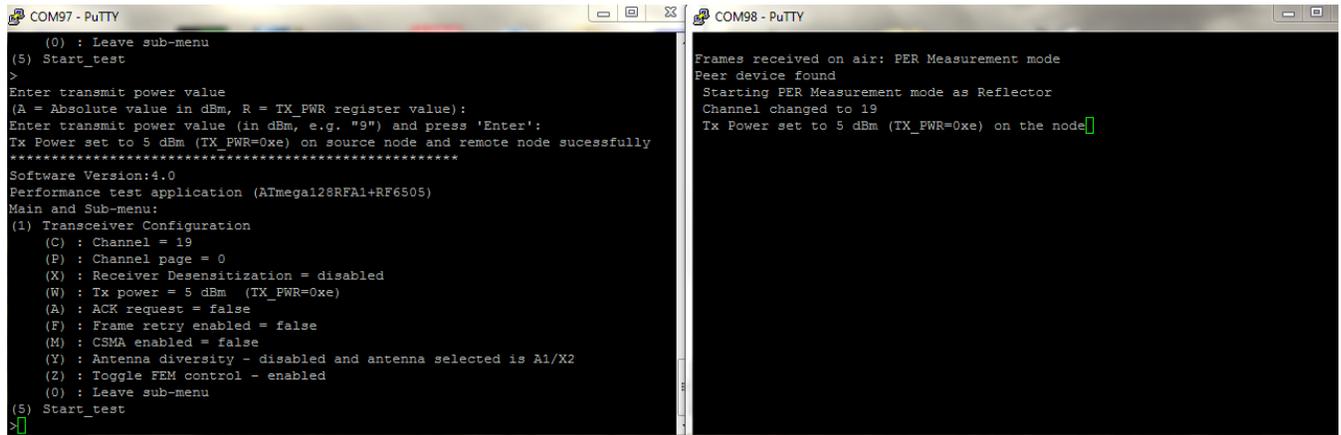
8. Press 'O' to return to Main menu. Then press '3' to enter the 'PER-Test Configuration' menu.

9. Set the number of packets (frames) for transmission. The default number is 100. To change the number of packets, press 'N', type number, and press 'Enter'.

10. Select the antenna for reception by pressing 'Q', then 'C', and then '2' or '3'.
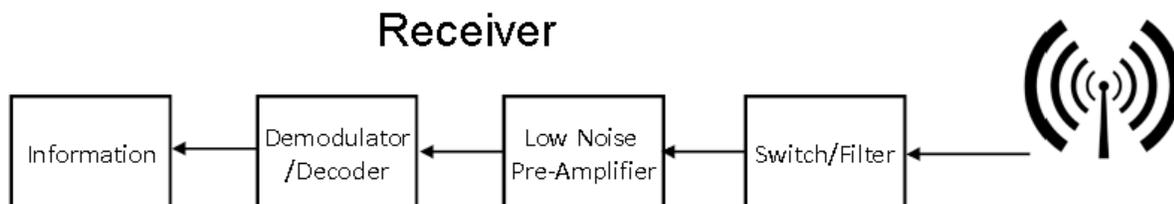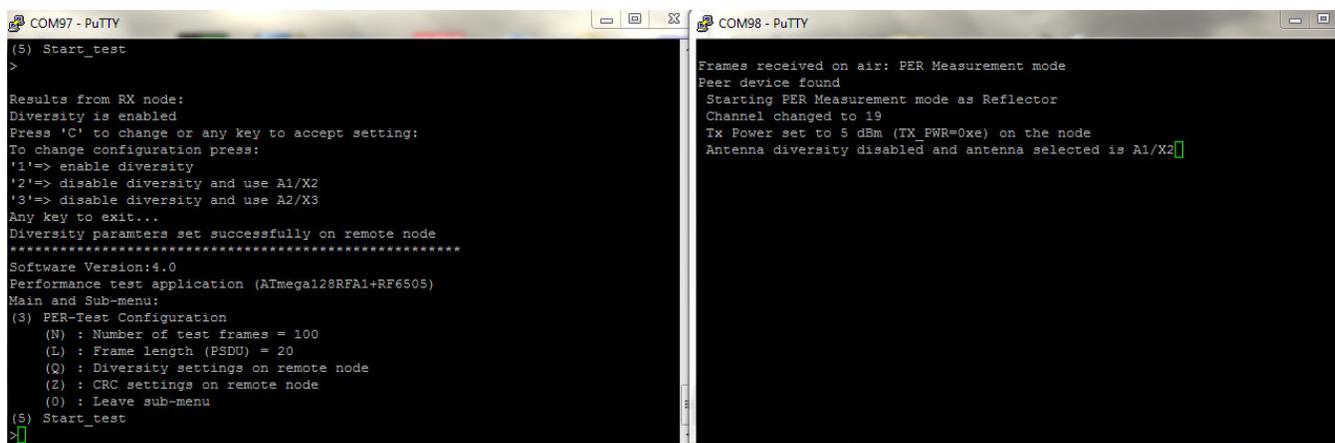
Figure 4-13. Receiver

Figure 4-14. Terminal Screens After Receiver Configuration

11. In the main menu, press '5' and you will see "Transmitting… Wait until test is completed". The main screen will display the number of packets (frames) received. See Figure 4-14 for reference. This will define your PER value. For example 1000/1000 equates to a 0% PER… 990/1000 equates to 1% PER. Average PER <1% at -102.5dBm.

4.6 Simple Sensitivity Calculation

A very simple way to determine the expected sensitivity of a radio system is that the external LNA should improve the radio by approximately the noise figure of the transceiver minus the noise figure of the external LNA.
I.e. = Sensitivity – (TXVR N.F. – FEM N.F. – Filter Loss).

Example: The noise figure of the ATmega128RFA1 is 6dB and the sensitivity is -100dBm at <1% PER. The noise figure of the RF6505 is 2.5dB. The loss of the LPF is ~0.9dB. The new sensitivity of the radio is expected to be -100 - (6.0 – 2.5 – 0.9) = -102.6dBm. This shows that the sensitivity of the RF6505RC128RFA1 can be improved by replacing the SMD LPF with a discrete one that has a very low insertion loss at 2.4GHz.

4.7 PER Radio to Radio Manual Station Setup

Note: The average, peak power level of the packets being transmitted should be measured for your records. It may be needed as a base line for calculating the attenuation level between the transmit RF6505RC128A-410 and the receive RF6505RC128A-410 board.

For instance, for radio to radio conducted PER measurements; first set the board that is going to transmit packets to its minimum power level. This to insure the EVM is at a low level and to minimize the number of attenuators needed. Next, start transmitting packets and use either a power meter or a spectrum analyzer to measure the amplitude of the packets.

4.7.1 Using Power Meter

If using a ROHDE & SCHWARZ NPR power meter, the amplitude can be recorded by going into the Mode menu and then select the Burst Average option. Once there set the Trigger and increase or decrease the Level until the packet amplitude is located. Record this as the baseline measurements. See Figure 4-15.

Another way to record this while using the NRP is to enter the Mode menu and select the Trace and Statistics option. Once there go to Gates and set both gates to capture the on burst and record the Average and Peak power levels. Do this for each channel being measured.

Figure 4-15. Power Meter Setup for PER Measurements
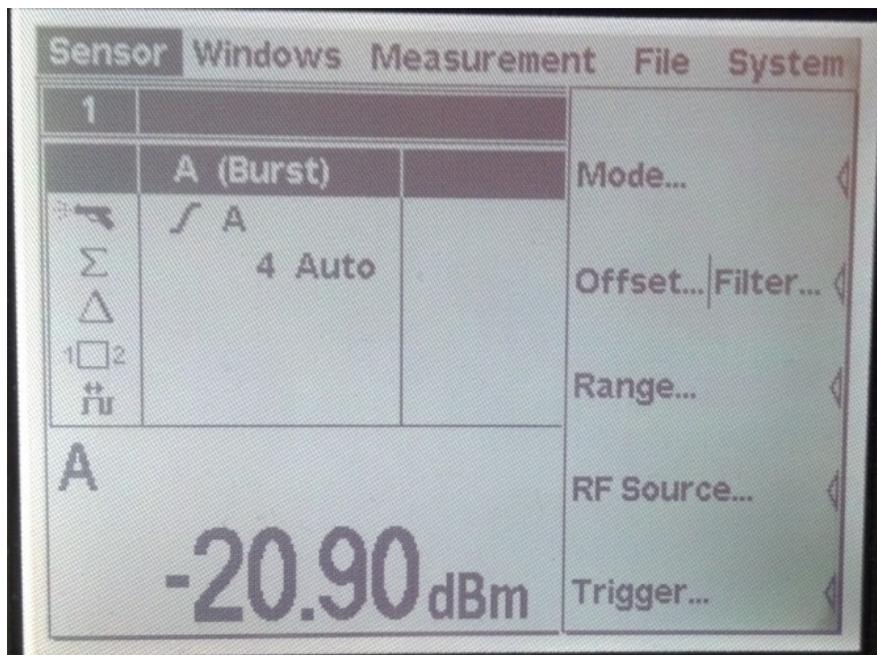
4.7.2 Using Spectrum Analyzer

If using a spectrum analyzer, be sure to use a wide RBW i.e. 3MHz, and set detector to average. Do this for each channel being measured. See http://cp.literature.agilent.com/litweb/pdf/5989-4746EN.pdf.

Next, record the insertion loss at 2.4GHz of each coaxial cable being used and the value of the attenuator(s). Record this value. Refer to Figure 4-8 as it shows a cable outside of the screen room and cables inside the screen room. The board inside the screen room should be one meter from the wall of the screen room where the outside cable is connected. Add up all of the losses from the cables and attenuator(s) and subtract it from the power level of the packets being transmitted. Record this number as the power level of the received packets. Adjust the attenuator while receiving packets on the board inside the screen room and record the percentage of packets received at the different attenuation levels. This will give you the PER. See Table 4-1 for example of PER derivation.

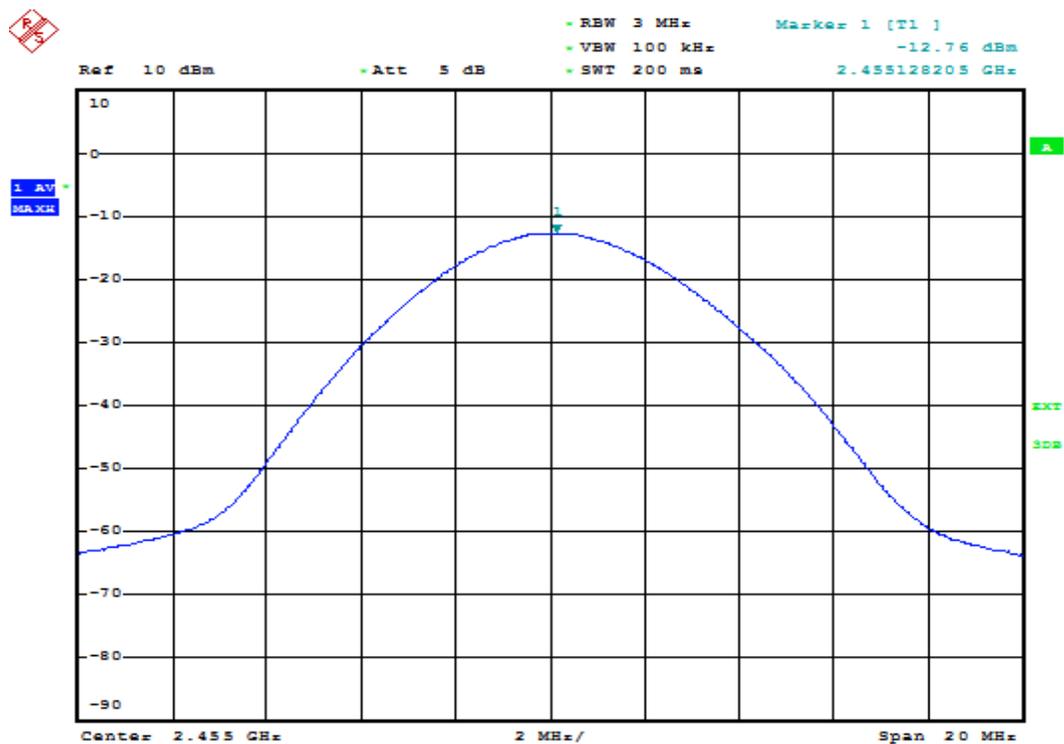**Figure 4-16. Spectrum Analyzer Setup for PER Measurements**

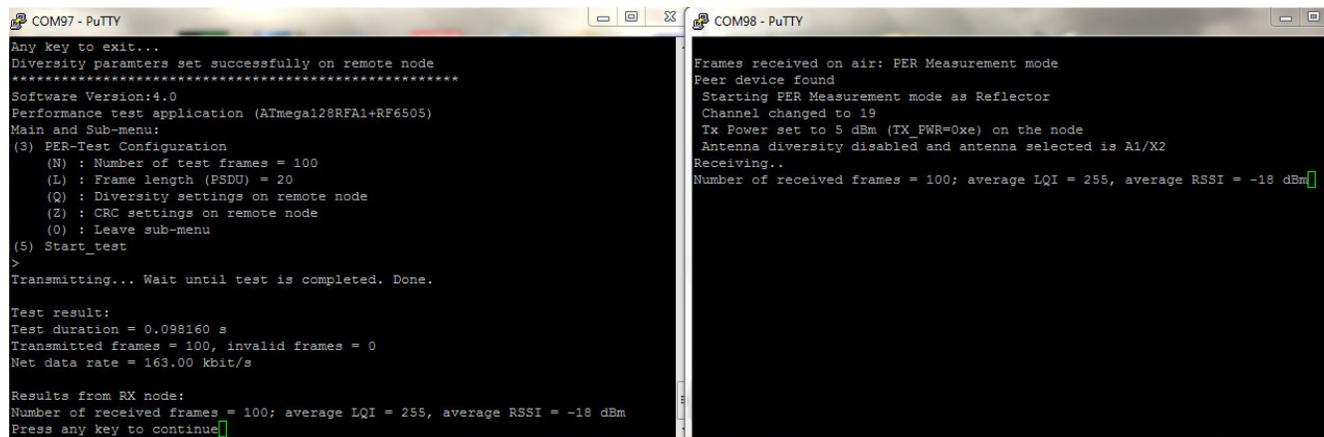**Figure 4-17. Terminal Screens After PER Test Transmission**

Table 4-1.   Example of how PER Values are Derived

Numbers of packets transmitted	Transmitter packet strength measured [dBm]	Static or variable attenuation [dB]	Coaxial cable loss [dB]	Trace loss of Rx board from antenna connector to LPF [dB]	Power at receiver board LPF [dBm]	Number of packets lost or not decoded out of 1000	%PER
1000	-20.9	-79	-2.5	-0.2	-102.6	10	1
1000	-20.9	-78	-2.5	-0.2	-101.6	3	0.3
1000	-20.9	-77	-2.5	-0.2	-100.610	0	0

Table 4-2. Typical Sensitivity Performance of RF6505ATmega128RFA1/ATmega256RFR2

Packet error rate ≤1%, packet size 20 octets, T = 25°C			
Channel	11	19	26
Average(dBm)	-102.9	-102.5	-102.7

5. Transmission Performance

Table 5-1 provides information about the harmonic performance of the reference design with respect to temperature and supply voltage.

Table 5-1. Typical Transmission Power and Conducted Harmonic(AVG DET) Performance over Voltage and Temperature

Temp -40°C	Channel	P_{OUT} [dBm]	H2 [dBm/MHz]	H3 [dBm/MHz]	H4 [dBm/MHz]	H5 [dBm/MHz]	H6 [dBm/MHz]	H7 [dBm/MHz]	H8 [dBm/MHz]
3.0V	CH19	26.6	-52	-53.2	-53.5	-55.5	-47.5	-46.6	-55.9
3.3V	CH19	27.5	-50.4	-54.1	-52	-55	-46.3	-43.6	-56.4
3.6V	CH19	28.2	-50	-52.3	-52.3	-55	-46.8	-45.9	-55.9
4V	CH19	29	-50	-50	-52.3	-54.4	-47.7	-50.5	-55

Temp +25°C	Channel	P_{OUT} [dBm]	H2 [dBm/MHz]	H3 [dBm/MHz]	H4 [dBm/MHz]	H5 [dBm/MHz]	H6 [dBm/MHz]	H7 [dBm/MHz]	H8 [dBm/MHz]
3.0V	CH19	25.1	-54.5	-50.3	-56.6	-50.2	-57.5	-57.7	-60
3.3V	CH19	26.1	-53.5	-50.8	-55.7	-57.9	-54.1	-56.7	-59.6
3.6V	CH19	26.5	-53.4	-49.1	-56.5	-57.4	-55.6	-53.8	-60.1
4V	CH19	27	-54.3	-48.9	-58.4	-58.1	-57.9	-51.9	-61.2

Temp +85°C	Channel	P_{OUT} [dBm]	H2 [dBm/MHz]	H3 [dBm/MHz]	H4 [dBm/MHz]	H5 [dBm/MHz]	H6 [dBm/MHz]	H7 [dBm/MHz]	H8 [dBm/MHz]
3.0V	CH19	22.5	-58.35	-52	-60	-60.3	-60	-59.2	-62.3
3.3V	CH19	23.5	-57.7	-51.1	-59.8	-60.1	-59.5	-58.5	-62.1
3.6V	CH19	23.7	-57.7	-51.9	-59.6	-61.2	-59.9	-58.8	-62.2
4V	CH19	24	-57.7	-52.8	-59.8	-62.1	-60.5	-59	-62.5

Variation of transmit output power of the reference design across the operating channels is given in Figure 5-2.

Figure 5-2. Typical TX Output Power(dBm) per TX_PWR, CW, Settings

VDD 3.6

Max of f0

CH	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
11	26.7	26.7	26.5	26.2	25.8	25.5	25.1	24.5	23.8	23.1	22.2	21.1	19.9	17.8	14.3	8.8
19	26.9	26.6	26.2	26	25.5	25.1	24.6	24	23.2	22.4	21.4	20.2	18.4	15.9	11.8	6.6
26	26.2	25.9	25.5	25.1	24.7	24.2	23.7	23.1	22.4	21.5	20.4	19	17.2	14.2	10.1	5.1

TX_PWR
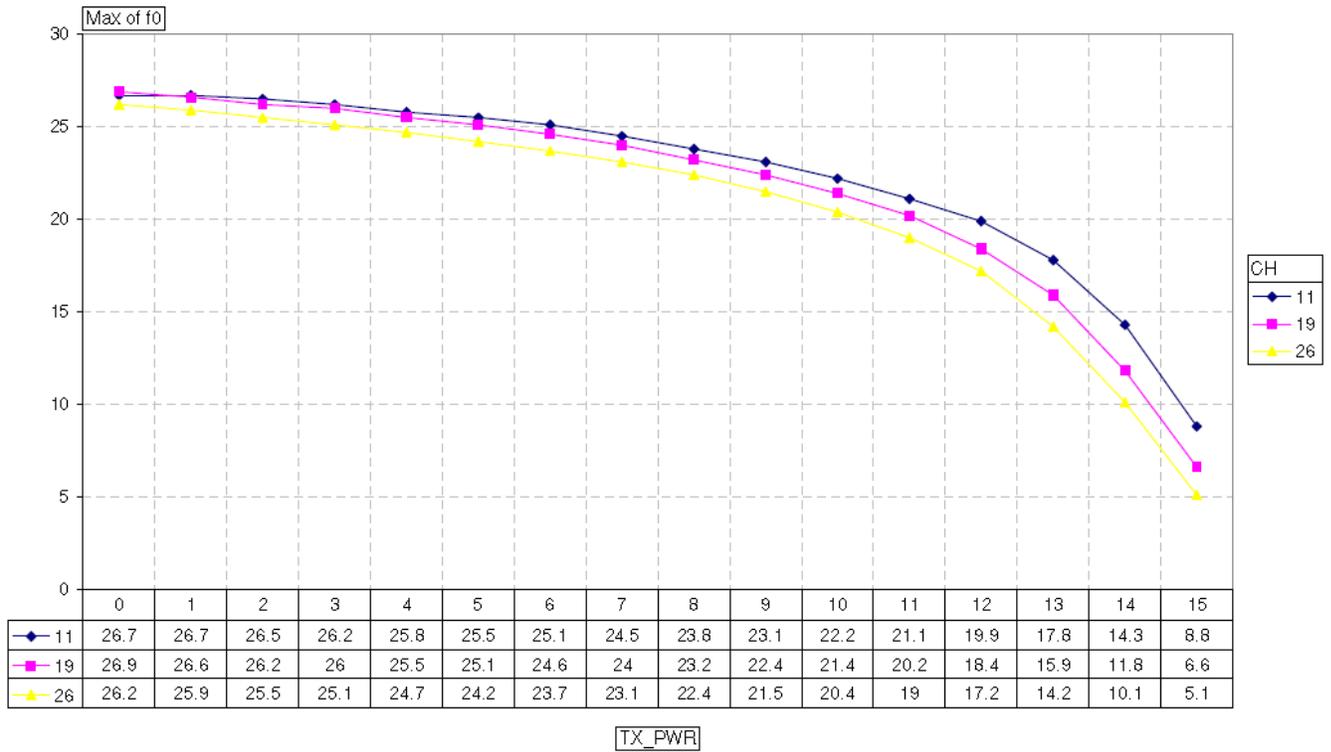
6. FCC Compliance Measurements

Figure 6-1. Second Harmonic Conducted
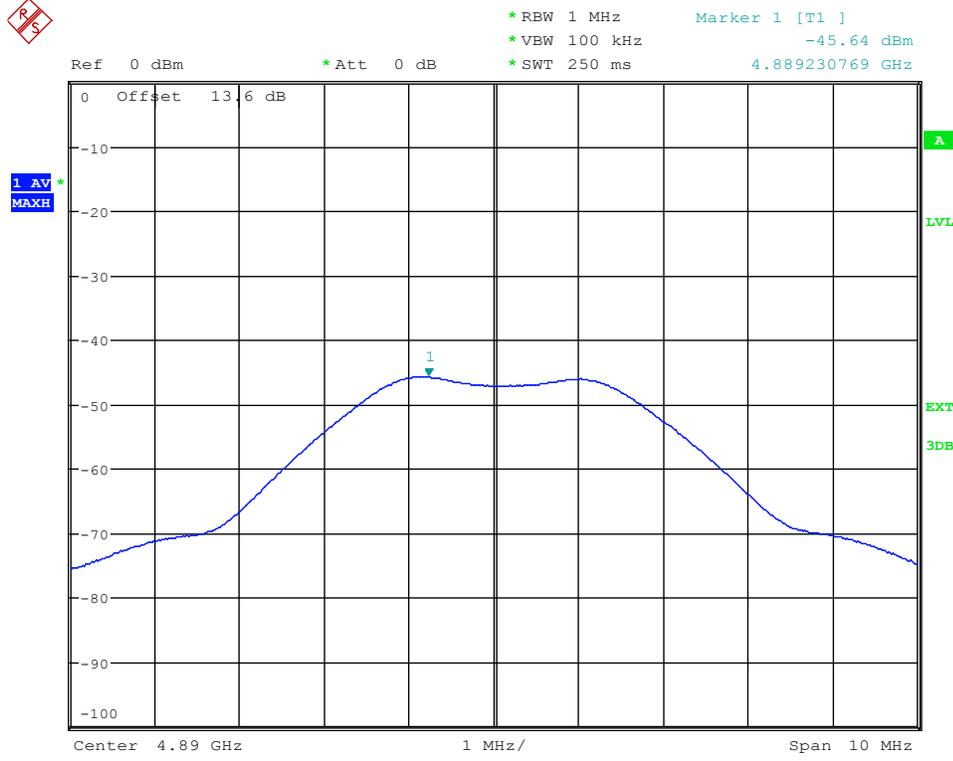
Figure 6-2. Third Harmonic Conducted
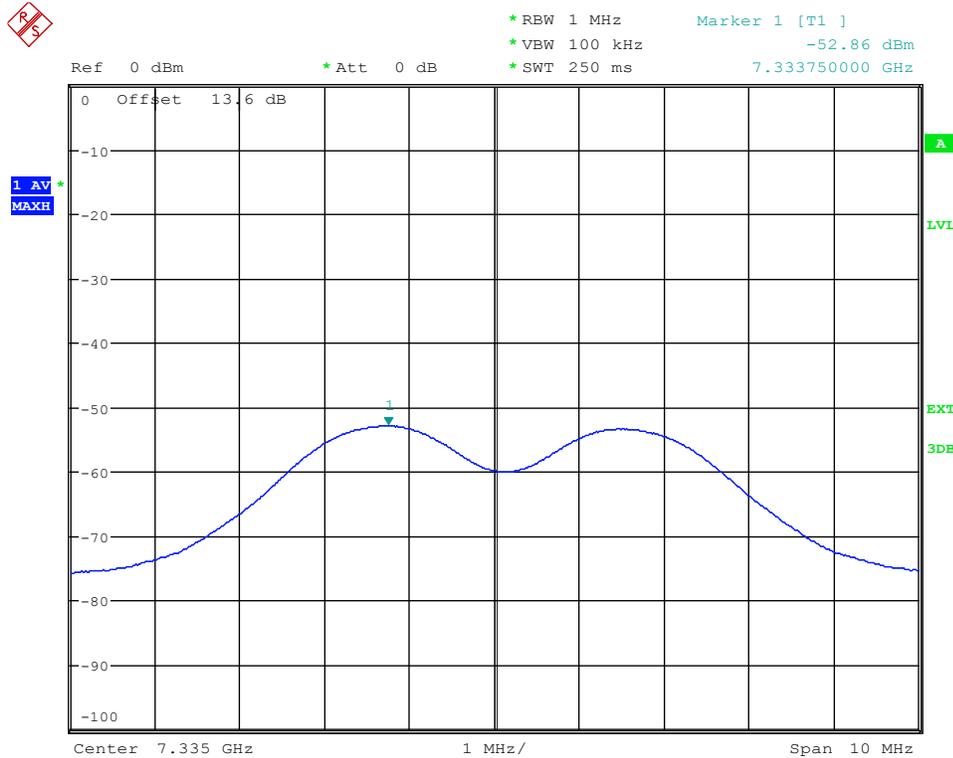
Figure 6-3. Fourth Harmonic Conducted



```
  R                              *RBW 1 MHz       Marker 1 [T1 ]
  S                              *VBW 100 kHz             -64.36 dBm
       Ref   0 dBm       *Att   0 dB    *SWT 250 ms      9.778221154 GHz

       0  Offset  13.6 dB                                              A

        -10
  1 AV*
  MAXH  -20                                                           LVL

        -30

        -40

        -50                                                           EXT

        -60                                                           3DB
                          1
        -70

        -80

        -90

       -100

       Center  9.78 GHz              1 MHz/              Span  10 MHz
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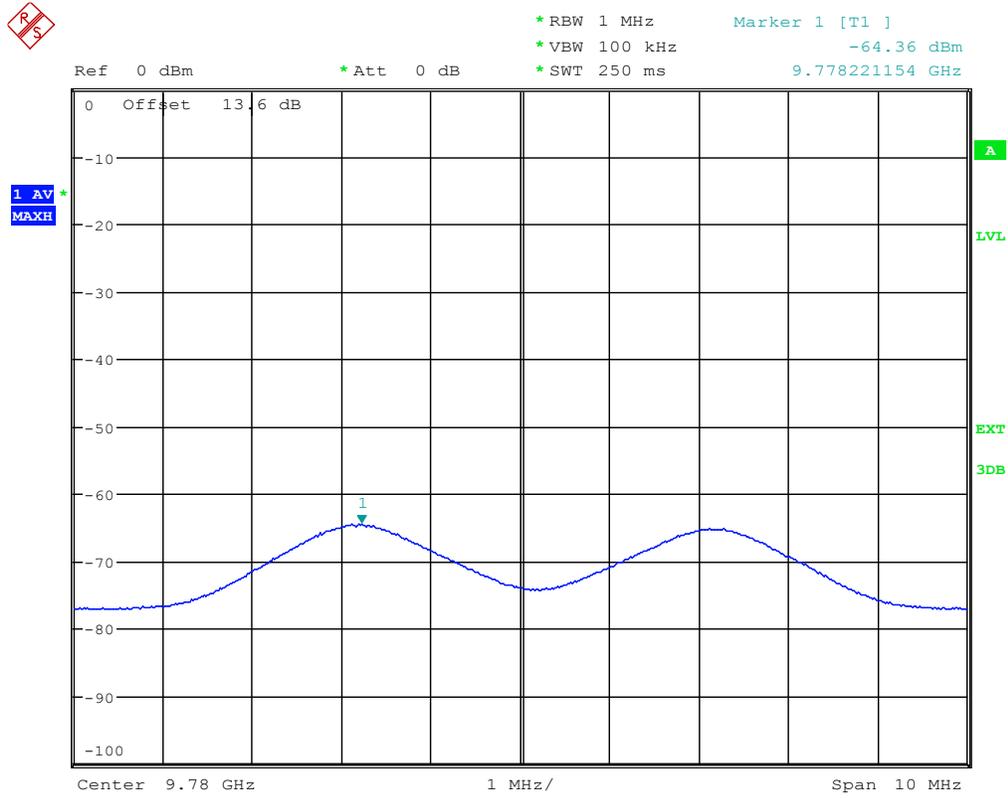
Figure 6-4. Power Spectral Density at CH 11 P$_{OUT}$ = 27dBm


```
  R                              *RBW 3 kHz        Marker 1 [T1 ]
  S                              *VBW 30 kHz              7.48 dBm
       Ref   28.6 dBm    *Att   10 dB   *SWT 250 ms      2.445021635 GHz

          Offset  13.6 dB                                             A

         20
  1 AV*
  MAXH  10                         1                                  LVL

          0

        -10

        -20                                                           EXT

        -30                                                           3DB

        -40

        -50

        -60

        -70

       Center  2.445 GHz            150 kHz/            Span  1.5 MHz
```
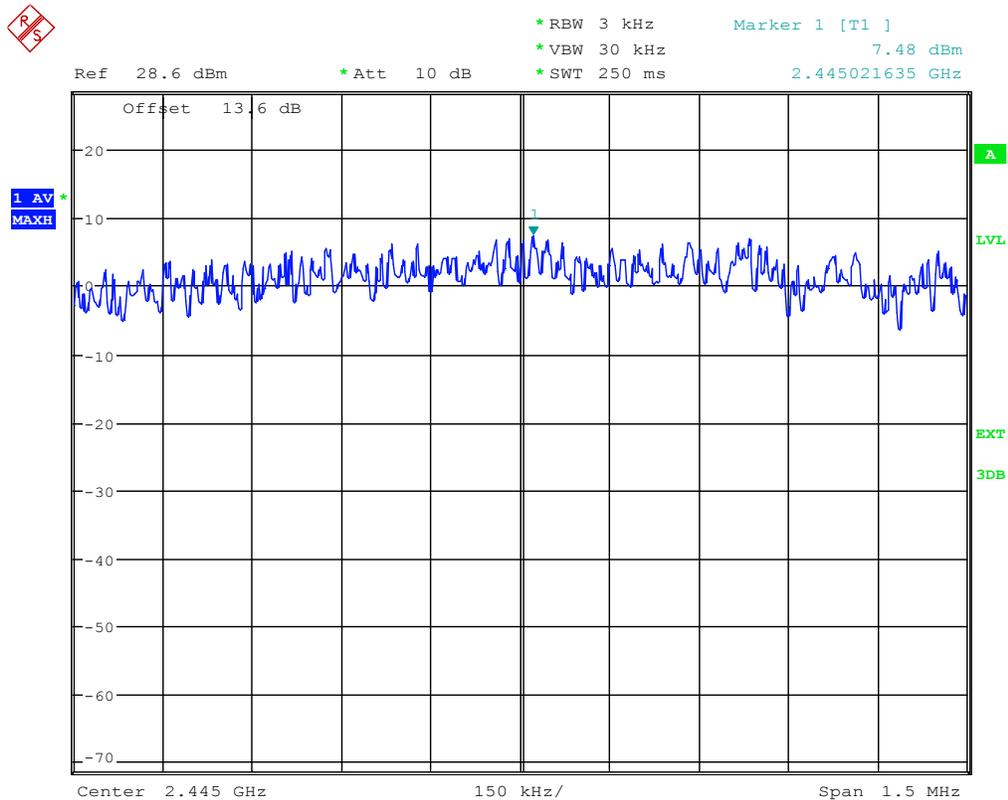
Figure 6-5. Power Spectral Density at CH 25 P$_{OUT}$ = 27dBm
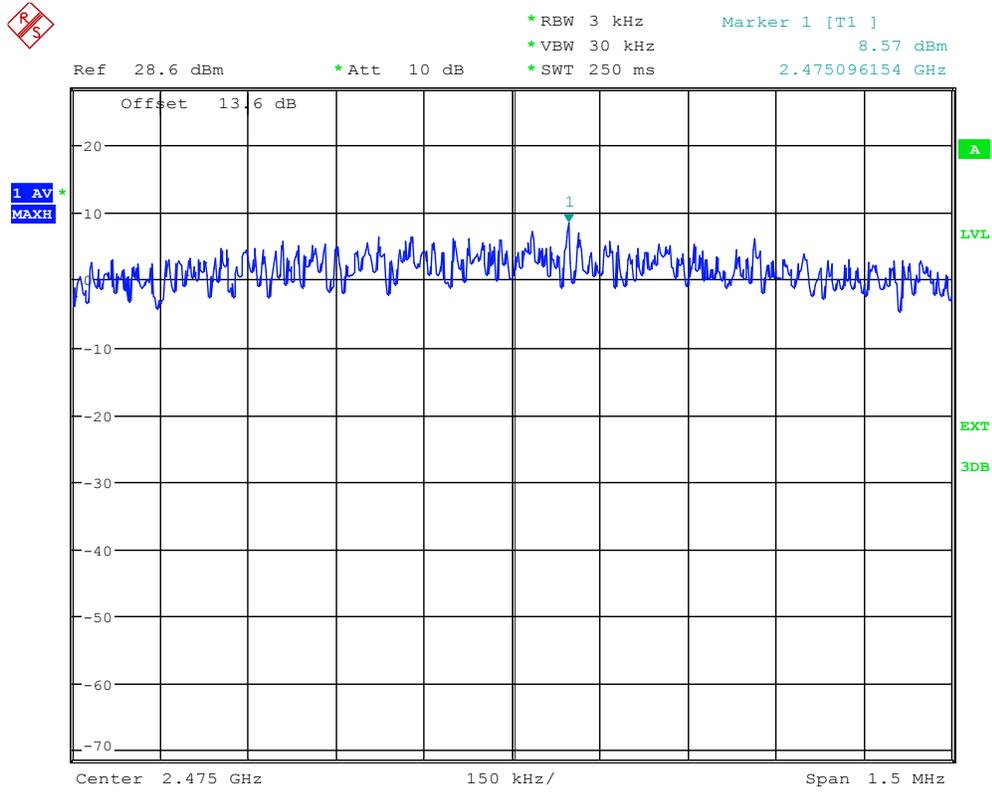
Figure 6-6. Power Spectral Density Mask, CW
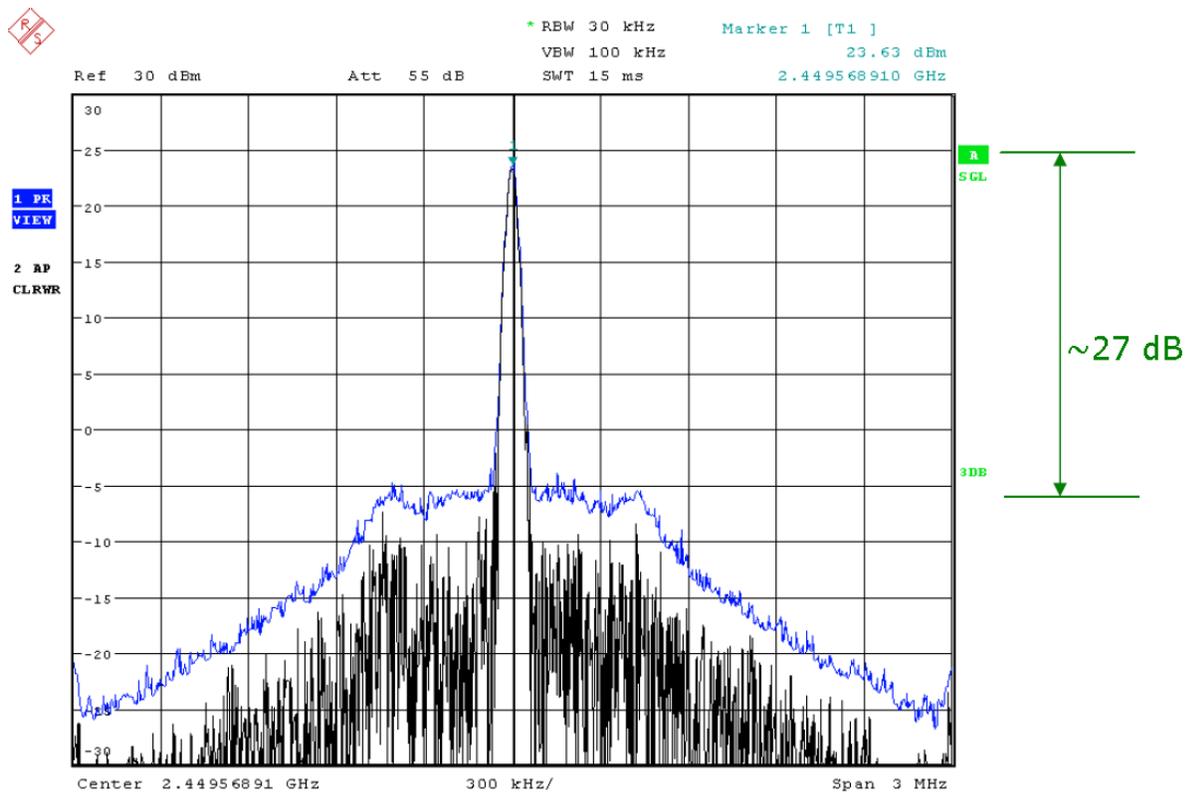
7. ETSI_EN 300 Compliance Testing

Figure 7-1. Second Harmonic Conducted
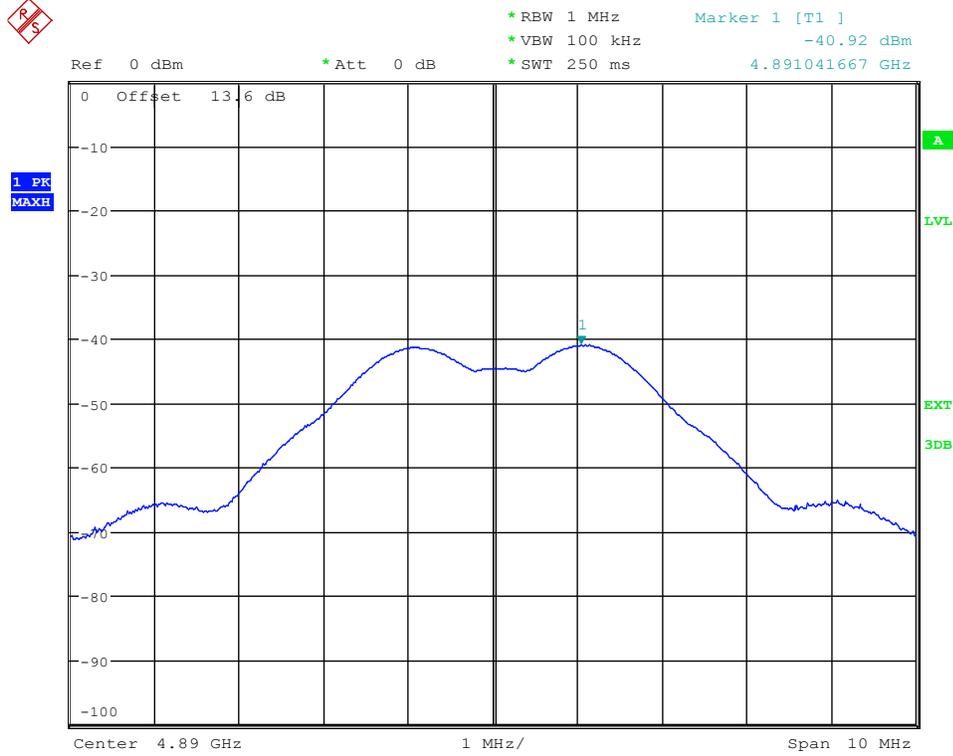
Figure 7-2. Third Harmonic Conducted
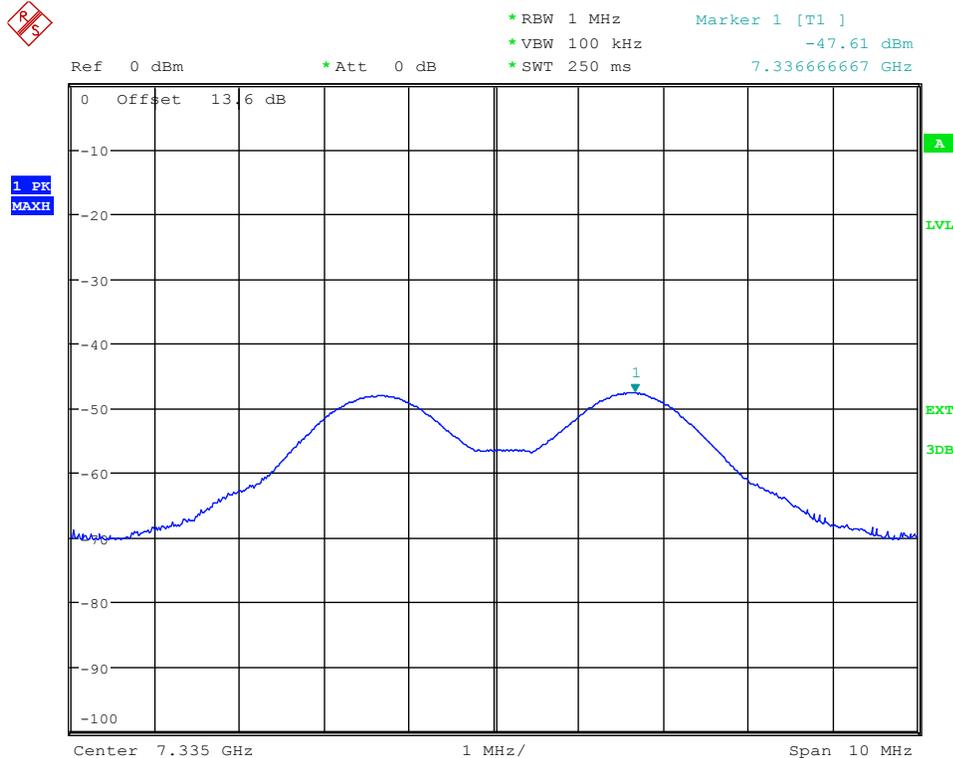
Figure 7-3. Fourth Harmonic Conducted
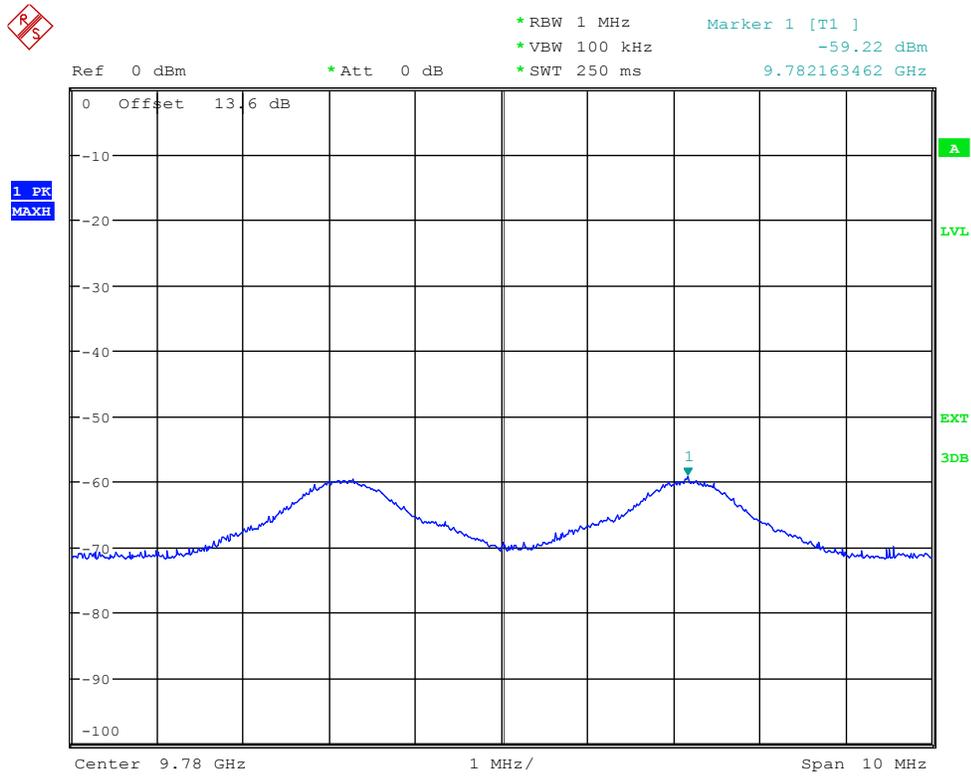
Figure 7-4. PSD per ETSI, at 23dBm Conducted EIRP
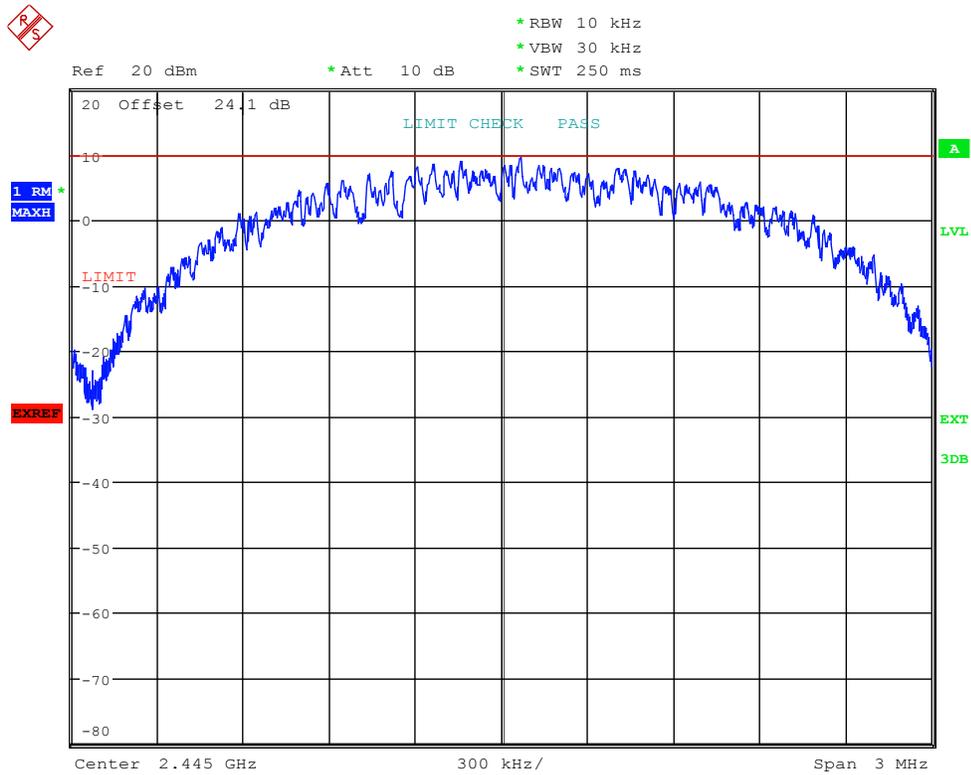
8. References

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9. Revision History

Doc. Rev.	Date	Comments
42219A	02/2014	Initial document release

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