AT12459: FCC Test for IEEE 802.15.4 Transmitters

802.15.4

Introduction

This test suite is designed primarily for FCC testing of Atmel® IEEE® 802.15.4 transmitters. This test is initiated over-the-air with remote start. Regulatory tests of wireless products are usually performed in retail enclosures that do not offer access to test ports. Additionally remote start is convenient for characterizing designs with modified I/O pin assignments. This test supports Modulated Carrier mode which is used to demonstrate compliance with CFR 49 Part 15.247. Additional modes like Carrier Wave (CW) and Pulsed Packet are supported for characterization. This version of the test supports several Atmel transmitters including ATmega256RFR2, ATSAMR21 and AT86RF212B.

Features

- Designed for FCC Testing and Transmitter Characterization
- Configure and Activate Transmitter Remotely
- Continuous Modulated Carrier Output (PRBS)
- Continuous Wave Output (CW)
- Pulsed Packet Output
- Duty Cycle Reduction Factor mode (DCRF)
- Channel and Power Configuration
- No wires to DUT required.
- Tx LED indicator
- Crystal Trim Adjustment
- Configuration Storage (PIB)

1 Overview

Developers of wireless products need to exhibit regulatory compliance of Radio Frequency (RF) emissions. This tool was developed to assist in Federal Communications Commission (FCC) and Industry Canada (IC) testing programs. Wireless consumer products need to be tested as they are sold to the public including antennas and enclosures. Typically industrial designers omit external connections for conducted testing, debugging and external control on retail enclosures.

Using this tool Test Engineers can initiate RF emissions from the Device Under Test (DUT) using a remote Commander (CDR) device. The CDR can be built from an Atmel development board plus laptop computer. Once the DUT transmission has started, the CDR system can be completely removed from the test chamber.

Figure 1-1.   Test Set-up Diagram
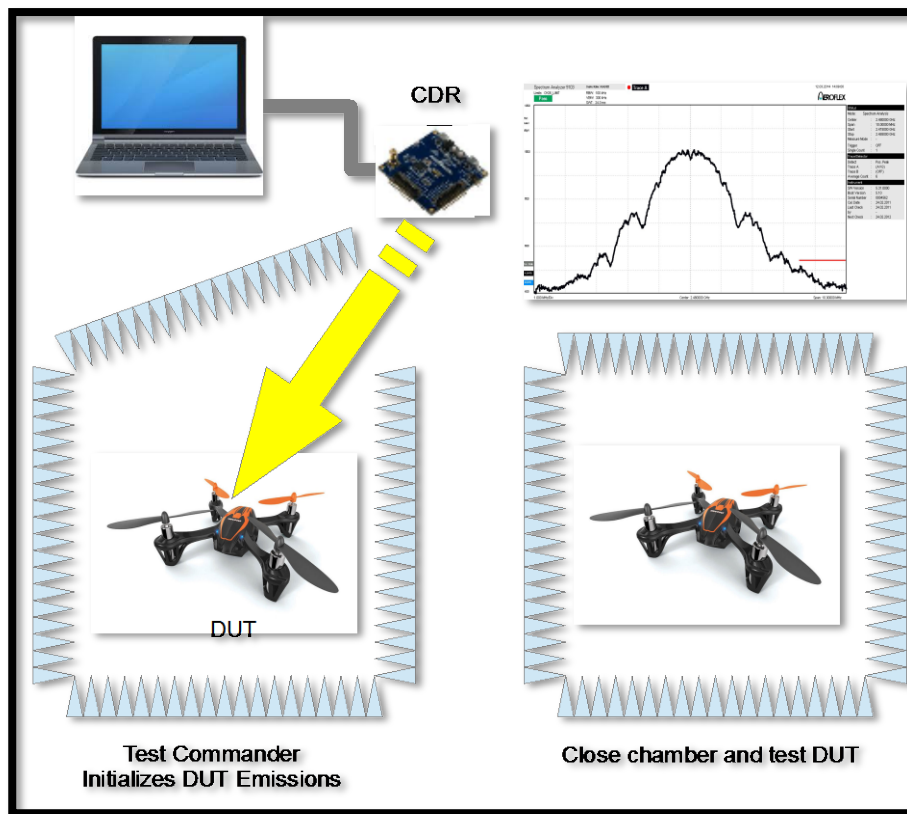
Typically IEEE 802.15.4 devices are certified under CFR 49 Rule 15.247 which measures the occupied bandwidth and power spectral density of modulated carrier signals. For testing, this is achieved with a continuous Pseudo-Random Binary Stream (PRBS) of data. Using the CDR interface, Test Engineers can adjust the frequency and the RF output power. In addition to the PRBS mode, Continuous Wave (CW) mode is also supported. This is commonly used to measure transmitter power and frequency with basic instruments like RF power meters. Other modes include Pulsed Packet for use with RF Automated Test Equipment (ATE) And DCRF mode for measuring the effects of packet size and padding delays on spurious emissions.

The test suite provides controls for frequency, RF output power and antenna path. Additionally a handful of controls are included for trimming the local oscillator and configuring the radio for extended operations.   And finally ATmega256RFR2 users can enable this part's special band-edge filter feature that improves compliance when

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operating in channels 25 and 26. Test configurations can be saved. There are four Configuration Caches (PIBs) on the CDR. These can be used to save and recall frequently used test parameters.

2   Operation

To use this tool the Test Engineer will need two wireless devices; a DUT and a CDR. For the purposes of this app-note we will use two SAMR21 Xplained Pro (ATSAMR21-XPRO) evaluation kits. In practice the DUT will most likely be a new creation.   Alternately this demo can be evaluated using the ATmega256RFR2-XPRO, or AT86RF212B Extension + ATSAMD20/21-XPRO, or AT08973 (Ramen) platforms. The AT86RF212B has some special features that will be explained later in this app-note.

To start the reader will need two ATSAMR21-XPRO evaluation kits, a windows computer with Atmel Studio 6 (AS6), a terminal application such as PuTTY or Tera Term, a USB micro-B cable, a 3.3 VDC power source (ATBATTERY-CASE-2AAA) and a instrument capable of measuring radiated RF emissions in the 2400-2480 MHz ISM band.

Use AS6 to load `fcc_test_r21.hex` on the ATSAMR21-XPRO boards. Both CDR and DUT use the same binary image. Once the XPROs are programmed connect the CDR to the terminal application and find a power source for the DUT. The UART settings for the CDR are Baud 38400, Data 8, Stop 1, Parity N, Flow N. The Atmel EBDG Embedded debugger allows connection to the UART and AS6 simultaneously however it is recommended users halt the AS6 debugger as it is not needed to run the test. Resetting the CDR should show the intro line, build timestamp and ">" prompt. Entering in "help" will summon the Help Menu.   This menu outlines the available functions.

Figure 2-1.   Intro Line and Help Menu


```
FCC Remote Test, built Feb 24 2015 11:52:38


> help
help      [<comamnd>]

list
save      [<config>]
load      [<config>]
reset     [<config>]
show      [<config>]

local
remote

ch        <channel>
pwr       <tx_power>
ant       <antenna>
trim      <value>
ccnum     <value>
ccband    <value>
txflt     <value>

set       [<duration>] [<side>]
pulse     <on_time> <off_time>

cw        [<side>] [<duration>]
prbs      [<duration>]
data      [<size>] [<interval>]
stop

>
```
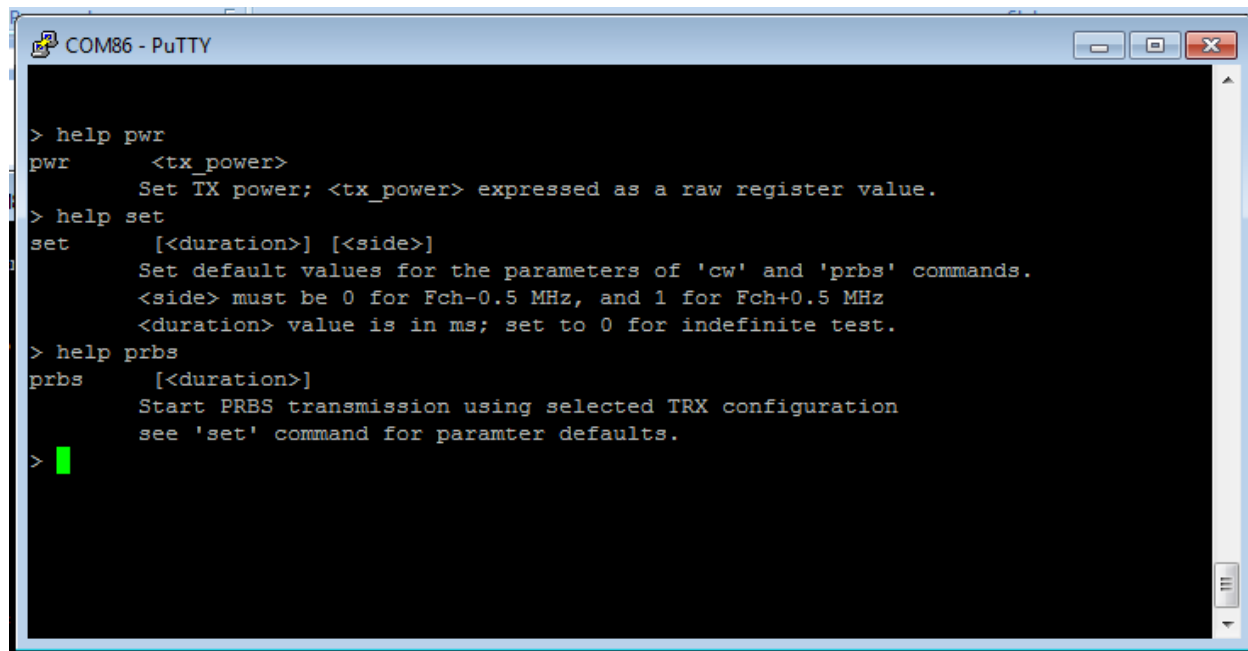
Each function has its own help topic. Some examples are show below.

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Figure 2-2.   Expanded Help Topics

3   A Basic Test

To start a basic test, follow the steps shown below. This sets the transmitter to ch 18 (2440 MHz), sets the transmitter power to maximum and selects ant 2 (chip). We can verify the settings with the "show" command. If all is well, we can start the transmission with the "prbs" command.
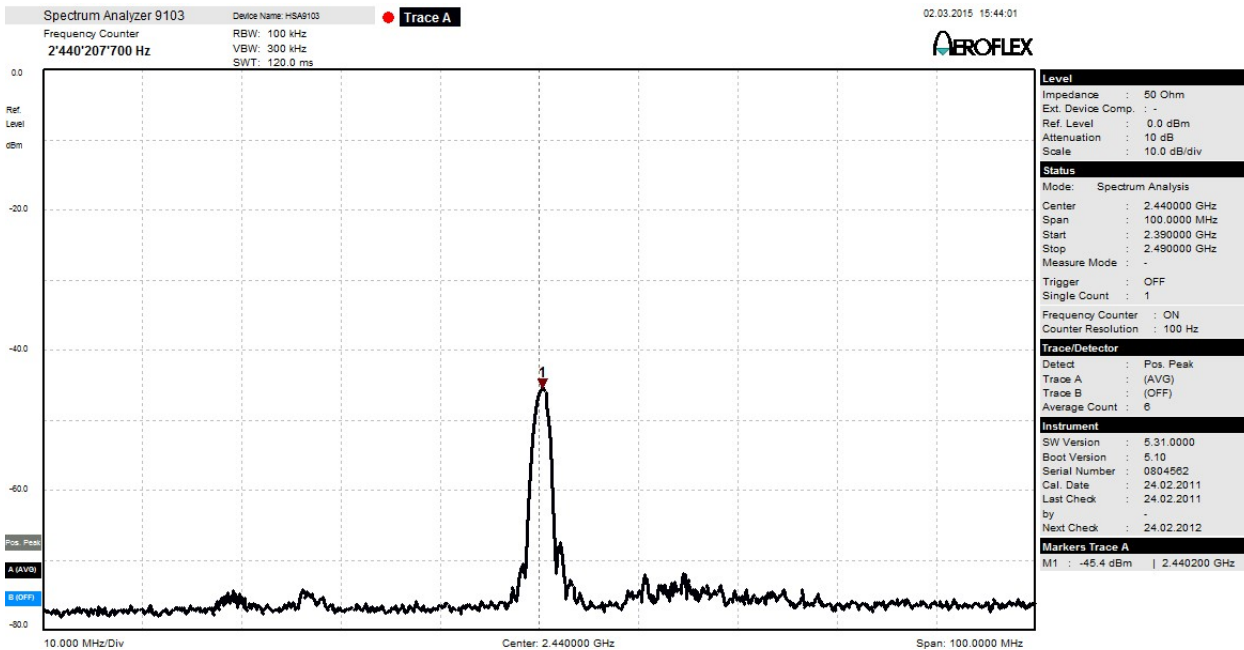
Figure 3-1. **Basic Test Command Sequence**


```
COM83:38400baud - Tera Term VT

File  Edit  Setup  Control  Window  KanjiCode  Help

FCC Remote Test, built Mar  2 2015 14:38:23


> ch 18

> pwr 0

> ant 2

> show
        remote, ch = 18 (0x12), TX power = 0 (0x0), antenna = 2
        Xtal Trim = 0, CC_NUMBER = 0, CC_BAND = 0, PLL_TX_FLT = 0
        duration = 0 ms, side = 0
        pulse: On time = 0 ms, Off time = 0 ms
> prbs

>
```

Figure 3-2. **Output from Basic Test, PRBS on Ch 18 (2440 MHz)**

When the transmitter is active, LED0 on the DUT will be lit. LED0 is amber.   When the DUT is continuously transmitting it is not able to receive any commands over-the-air. Therefore when the measurement is complete, we must reset the DUT by either asserting the reset signal, or power cycling it.

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4   Using the Configuration Caches

There are four Configuration Caches (PIBs). These can be used to save and load frequently used test parameters. In remote mode the caches are saved on the CDR device in flash memory. When a test is initiated, the CDR copies PIB 0 to the DUT and then starts the DUT transmitter.

As an example, we will create and save transmitter settings for High, Middle and Low channels in the ISM band. These three settings are commonly used to exhibit compliance with FCC rule 15.247. Using the sequence below, we program caches for High, Middle and Low channels. The original PIB 0 is modified using the "ch" command and stored using the "save" command. For the highest channel we will also attenuate power to meet the regulatory limits. The Low Channel configuration is stored in PIB1. The Middle is in PIB2.   PIB3 has the High channel with full-power. PIB4 is the highest channel, but with attenuated power to meet the band-edge restrictions.   The content of the caches can be displayed using the "list" command.

Figure 4-1.   Setting up PIB Caches
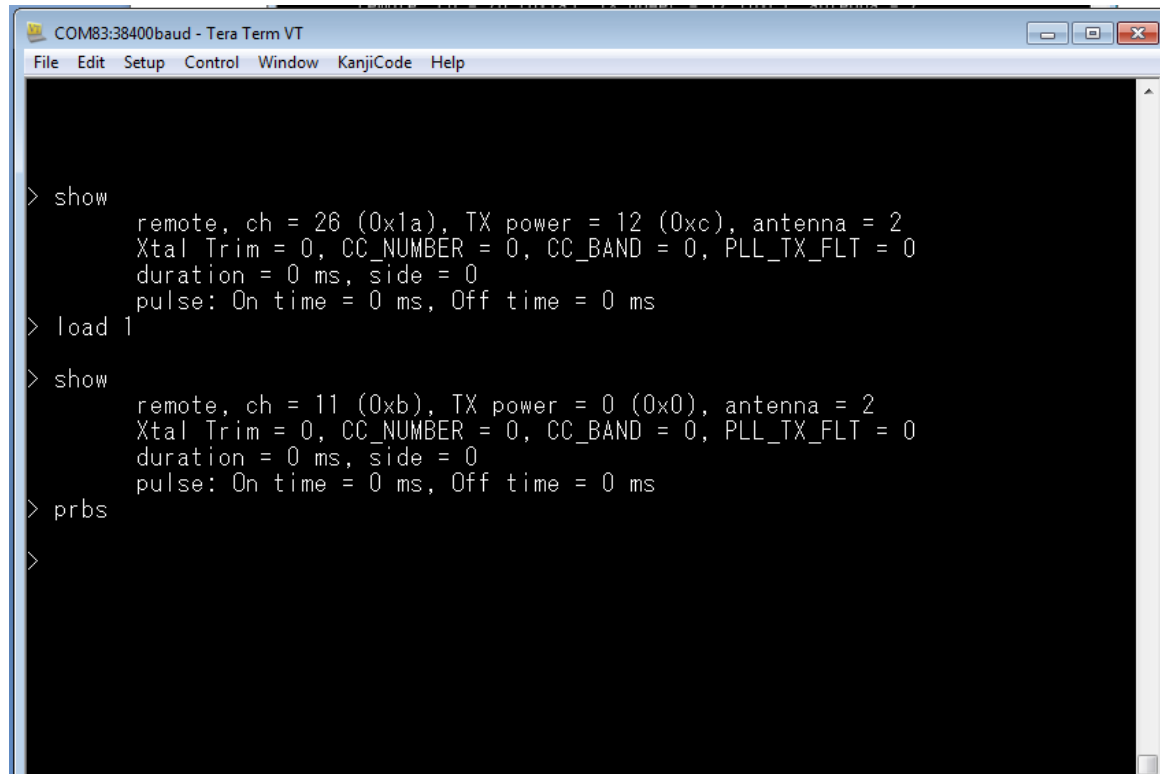

```
COM83:38400baud - Tera Term VT

File  Edit  Setup  Control  Window  KanjiCode  Help

> show
        remote, ch = 15 (0xf), TX power = 0 (0x0), antenna = 2
        Xtal Trim = 0, CC_NUMBER = 0, CC_BAND = 0, PLL_TX_FLT = 0
        duration = 0 ms, side = 0
        pulse: On time = 0 ms, Off time = 0 ms
> ch 11

> save 1

> ch 18

> save 2

> ch 25

> save 3

> ch 26

> pwr 12

> save 4

> list
--- 0 ---
        remote, ch = 26 (0x1a), TX power = 12 (0xc), antenna = 2
        Xtal Trim = 0, CC_NUMBER = 0, CC_BAND = 0, PLL_TX_FLT = 0
        duration = 0 ms, side = 0
        pulse: On time = 0 ms, Off time = 0 ms
--- 1 ---
        remote, ch = 11 (0xb), TX power = 0 (0x0), antenna = 2
        Xtal Trim = 0, CC_NUMBER = 0, CC_BAND = 0, PLL_TX_FLT = 0
        duration = 0 ms, side = 0
        pulse: On time = 0 ms, Off time = 0 ms
--- 2 ---
        remote, ch = 18 (0x12), TX power = 0 (0x0), antenna = 2
        Xtal Trim = 0, CC_NUMBER = 0, CC_BAND = 0, PLL_TX_FLT = 0
        duration = 0 ms, side = 0
        pulse: On time = 0 ms, Off time = 0 ms
--- 3 ---
        remote, ch = 25 (0x19), TX power = 0 (0x0), antenna = 2
        Xtal Trim = 0, CC_NUMBER = 0, CC_BAND = 0, PLL_TX_FLT = 0
        duration = 0 ms, side = 0
        pulse: On time = 0 ms, Off time = 0 ms
--- 4 ---
        remote, ch = 26 (0x1a), TX power = 12 (0xc), antenna = 2
        Xtal Trim = 0, CC_NUMBER = 0, CC_BAND = 0, PLL_TX_FLT = 0
        duration = 0 ms, side = 0
        pulse: On time = 0 ms, Off time = 0 ms
```

Next to run the test we use the "load" command then the "prbs" command to start the DUT transmitter.

Figure 4-2.   Loading and Starting Modulated Carrier Transmission on 2405 MHz.

To halt transmission we must reset, or power cycle the DUT. The CDR is still active, after resetting the DUT, we can use "load 2" to load the Middle channel configuration and take another measurement.   The spectrograph below shows all four settings superimposed with the MAX_HOLD feature of the spectrum analyzer. The PIB Caches are handy to save commonly used test configurations.

Figure 4-3.   Low-Middle-High signals
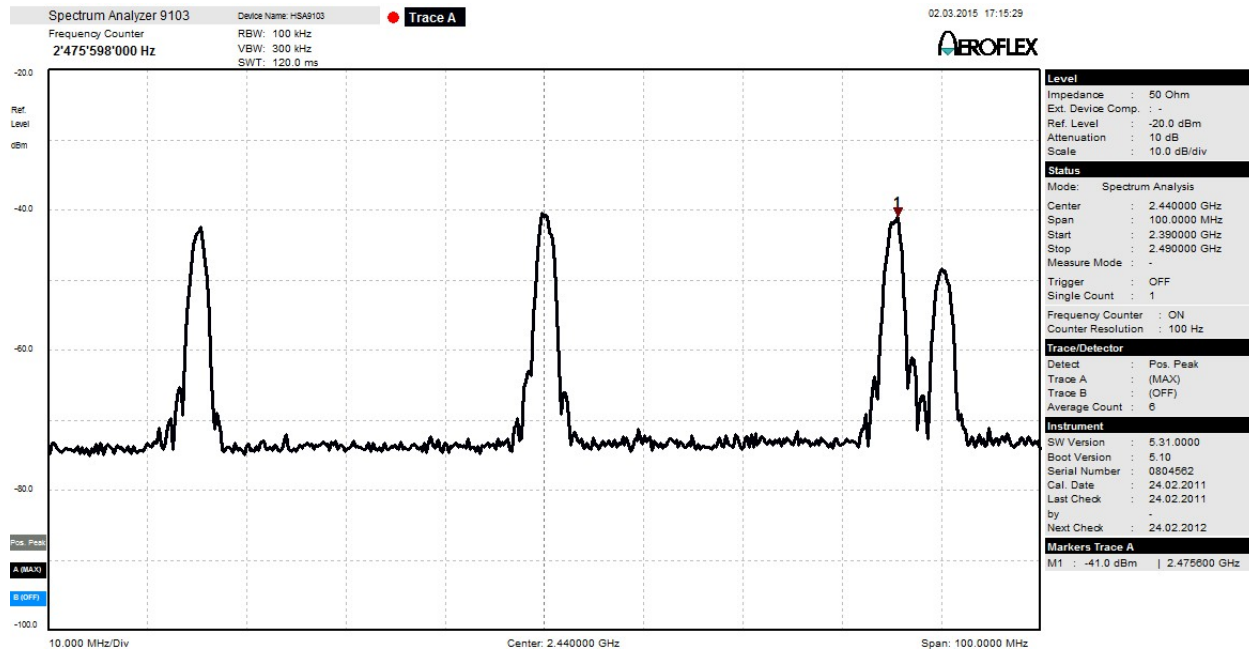
5   Transmitter Power

The transmitter RF power level can be adjusted using the "pwr" function. Arguments for the "pwr" function are identical to the values used in the TX_PWR register of the device. For the 2.4 GHz products the values range from 0 to 15 (0x0F). The value is really an attenuation coefficient: 0 is maximum power output and 15 is the minimum.   The UHF products have additional values to cover a broader range of settings. Note; either decimal values or hexadecimal values can be used. Hexadecimal values must be preceded with the classic 0x prefix. Please review the PHY_TX_PWR table in your transmitter's datasheet for complete details.

Table 5-1.   TX_PWR Settings

TX_PWR Value	ATSAMR21 dBm	AT86RF233 dBm	ATmega256xRFR2 dBm
0	4	4	3.5
1	3.7	3.7	3.3
2	3.4	3.4	2.8
3	3	3	2.3
4	2.5	2.5	1.8
5	2	2	1.2
6	1	1	0.5
7	0	0	-0.5
8	-1	-1	-1.5
9	-2	-2	-2.5
10	-3	-3	-3.5
11	-4	-4	-4.5
12	-6	-6	-6.5
13	-8	-8	-8.5
14	-12	-12	-11.5
15	-17	-17	-16.5

6   CW mode and Crystal trim

This tool also supports Carrier Wave (CW) mode. This is not included in the IEEE802.15.4 specification however it is commonly used to verify transmitter power and carrier frequency using low-cost test instruments like RF Power meters. Atmel IEEE 802.15.4 transmitters are designed for O-QPSK modulation and achieve CW mode by moving all the symbols to one sideband. The Test Engineer will have to select a sideband and factor the ± 500 kHz offset into their carrier frequency measurements.

A related feature is the Crystal Trim adjustment. Atmel IEEE802.15.4 transmitters have on board trim capacitors that can slightly pull the carrier. For complete details read the XOSC_CTRL and XTAL_TRIM sections in the transmitter datasheets.   The trim function has a small range of approximately 60 kHz and is provided to correct for manufacturing tolerances in the PCB, crystals and bias components. See Atmel Application Note AVR2067 for more details.

7   Transmission Outside the ISM Band

CC_BAND and CC_NUMBER registers are exposed in this tool .These can be used to configure the Transmitter for frequencies outside the ISM band. This is useful for laboratory work and licensed bands.   As an example the command sequence below shows the R21 configured to transmit CW at 2360 MHz. This could be useful as an intermediate frequency (IF) or Local Oscillator (LO) in a licensed radio system.
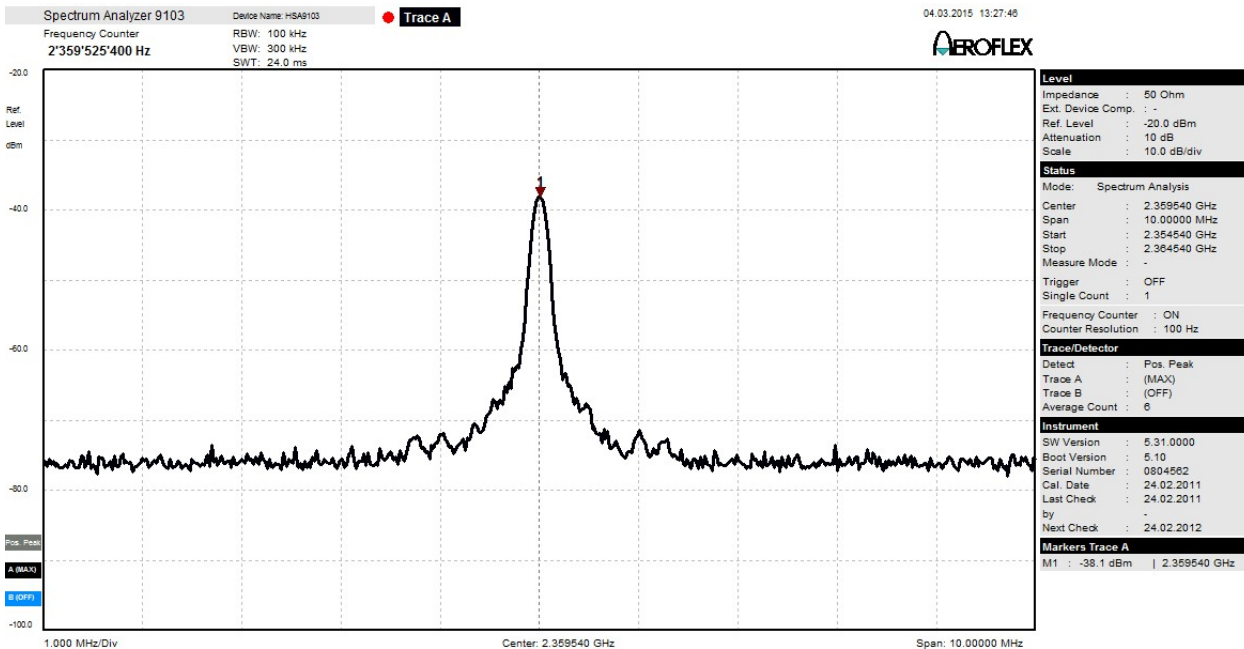
**Figure 7-1.   Configuring for use outside the ISM bands**

Figure 7-2.   CW at 2360 MHz

8 Pulsed Packets

This mode provides the ability for the DUT to generate repetitive pulses of modulated carrier signal. This is a non-linked transmission, the modulated data is not packetized and AACK is disabled. The Test Engineer can control the pulse and gap periods. This is handy for use with Automated RF Test Equipment (ATE) that need wave-fronts to trigger. The measurement below shows the time-domain (zero span) output of a ">pulse 10 40" setting followed by a "prbs" command. The results are 10 mS wide pulses of pseudorandom O-QPSK symbols interleaved with 40 mS gaps.

Figure 8-1.   Pulses of Modulated Carrier Signals
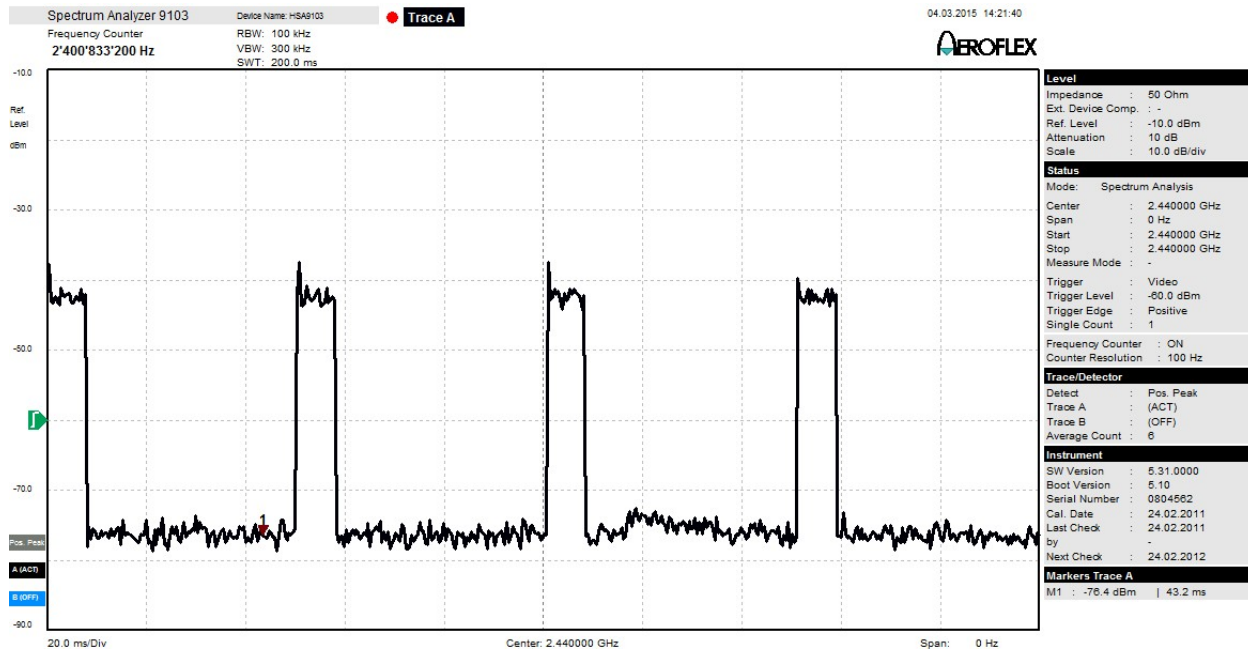
9 Duty Cycle Reduction Factor

Many users are interested in measuring the effects of Duty Cycle on spurious emissions and determining the Duty Cycle Reduction Factor (DCRF). DCRF can be used to give a more accurate estimate of a transmitters radiated energy in real-world operation. DCRF can be calculated, or empirically measured. In IEEE 802.15.4 networks the DCRF is a product of MAC/PHY and Network interaction. Network activity is unpredictable and makes calculation virtually impossible. This tool provides control of the MAC/PHY layer so it can be used to measure baseline DCRF and the effects of payload size and delay intervals.

Arguably one of the worst cases of transmitter chatter is the IEEE 802.15.4 retry mechanism. When Auto-Acknowledgement (AACK) is enabled the transmitter will automatically re-send a packet if it does not receive an Acknowledgement (ACK) from the intended recipient. Usually the burst of retries is limited to four attempts in rapid succession. If all four attempts fail the MAC returns a fault flag in the data confirmation callback. The number of retries and interval between retries is set when the network is initialized and are immutable. For the purposes of adjustment at the application-level, programmers can delay the initiation of subsequent data transmission requests to pad the transmitter activity and thereby reduce the duty cycle. This can be implemented with a temporary transmitter-busy flag set in the data confirmation callback.

The zero-span time domain capture below shows this type of activity. This transmission is a result of a "data 20 100" command. The data packet is 20 bytes and the delay between packets is 100 mS. The AACK is enable and we can see the retry activity. The scale is 20 mS per division. By visual inspection, the Duty Cycle is roughly 5 mS on-time in 100 mS.   This results in a Duty Cycle of 5% or DCRF -13 dB.
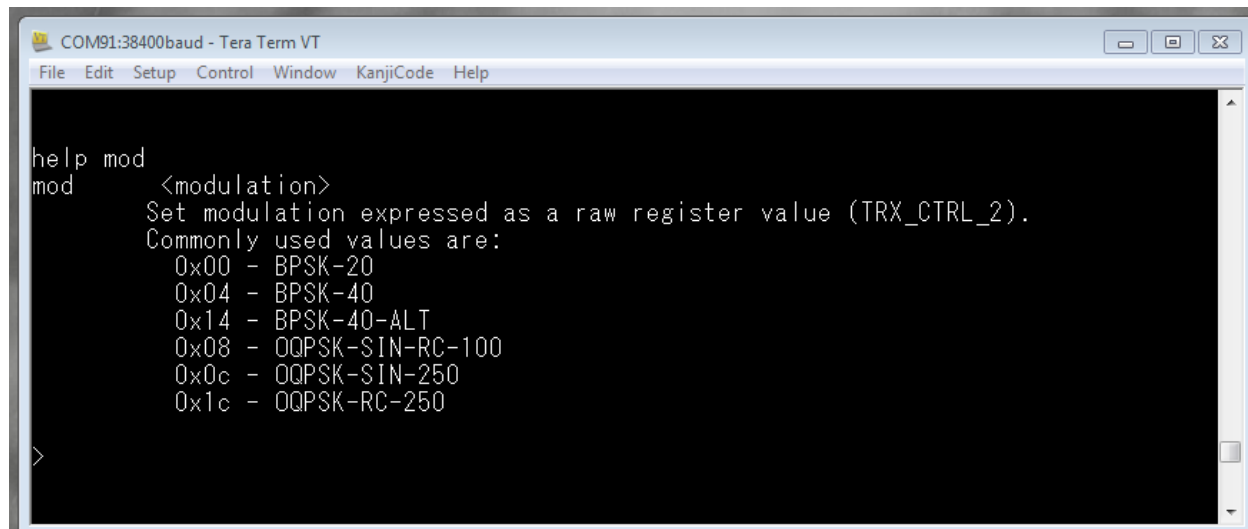
Figure 9-1. **Measurement of -13 dB DCRF within 100 mS window**
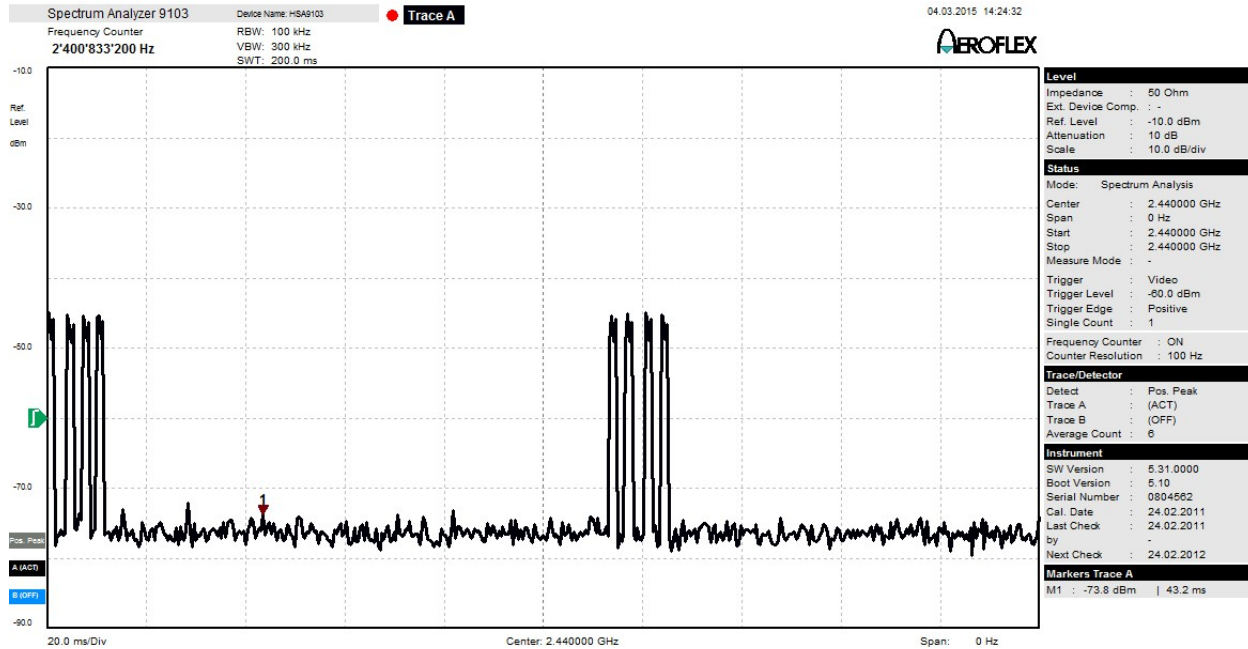
10 AT86RF212B Support

This tool supports the AT86RF212B and ATSAMD20/21 combination. Several modulation modes are available for this chipset.   The commonly used modes are visible using the help function.

Figure 10-1. **Modulation Modes for AT86RF212B**

11 BPSK-40-ALT mode

The BPSK-40 mode is desirable for long-range applications. Unfortunately, implementation of BPSK-40 per the IEEE 802.15.4 specification does not meet the 500 kHz Occupied Bandwidth requirement of the FCC "wideband" rule (15.247). Users can certify under the FCC 'narrowband' rule (15.249) however the narrowband rule has significantly lower power limits. Atmel has developed an alternate BPSK modulation scheme with more spreading to satisfy the

FCC wideband rule. The BPSK-ALT mode is compatible with the legacy IEEE BPSK-40 mode with minor losses in processing gain.

12   Antenna Path

The ATSAMR21 XPRO and ATMEGA256RFR2 XPRO demo boards have two antennas to evaluate diversity. One is an SMA connector for an external antenna and the other is a Chip antenna. The table below shows the mapping between the physical antennas and the "ant" command arguments.

Table 12-1.   Antenna Selections for XPRO Evaluation Boards

ANT	R21 XPRO	PA12/RFCTRL2	PA09/RFCTRL1	ATMEGA XPRO	DIG1	DIG2
ant 0	DISABLED	0	0	DISABLED	0	0
ant 1	SMA	0	1	SMA	0	1
ant 2	Chip	1	0	Chip	1	0
ant 3	Auto	0	1	Auto	0	1

13   Limitations and Caveats

- This test cannot be used in a conducted set-up. A conducted connection between the DUT and test instrument will attenuate signals from the CDR. Test Engineers will either have to start the DUT transmitter before connecting or use the 'local' mode.
- This test does not measure receiver sensitivity. Use the Performance Analyzer in Atmel Studio, or the Performance Test to characterize receiver sensitivity.
- When using the ATSAMD20/21-XPRO and ZigBit® Extension boards, local reset is not connected to the transmitter. Users will have to power cycle the system to halt transmission.
- The antenna is disabled by default. Be sure to select a functional antenna path.

14   Conclusion

This test is handy for evaluating new IEEE 802.15.4 designs and regulatory testing. The user interface is human readable and does not take in-depth software knowledge to use. Common transmitter functions like modulated carrier, CW, channel and power are supported. The Remote Start feature allows in-the-enclosure testing required to exhibit regulatory compliance. Advanced features like Pulsed Packet, Crystal Trim and DCRF can be quickly evaluated on the RF test bench. This tool will simplify test programs and accelerate time-to-market during one of the most critical phases of wireless product development.

15   Bibliography

AVR®2067 crystal Characterization for AVR RF

IEEE 802.15.4 Specification

FCC CFR 49 Part 15

16   Revision History

Doc Rev.	Date	Comments
42424A	03/2014	Initial document release.