AVR2002: Raven Radio Evaluation Software

Features

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1 Introduction

The Radio Evaluation System Software (RES) supports Range/Packet Error Rate (PER), Radio Frequency signal (RF) and Direct Current (DC) characterization testing for the ATAVRRZRAVEN kit.

RES comprises of both hardware and firmware to provide an environment that the customer can use as a basis for understanding Atmel AVR Wireless System performance. This document briefly describes each of these components and how they function together to accomplish these tests.

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Application Note

2 Hardware

RES is developed for evaluation of the AT86RF230 2.4 GHz radio transceiver found on the ATAVRRZRAVEN Evaluation and Starter kit. References [5] and [6] provide in-depth detail about this kit. The kit contains three different boards: two AVRRAVENs (LCD module) and one RZUSBSTICK (USB dongle). Only two of these boards are used at the time when running RES tests, since all tests are done peer-to-peer.

Figure 2.1 Overview of ATAVRRAVEN Hardware Components
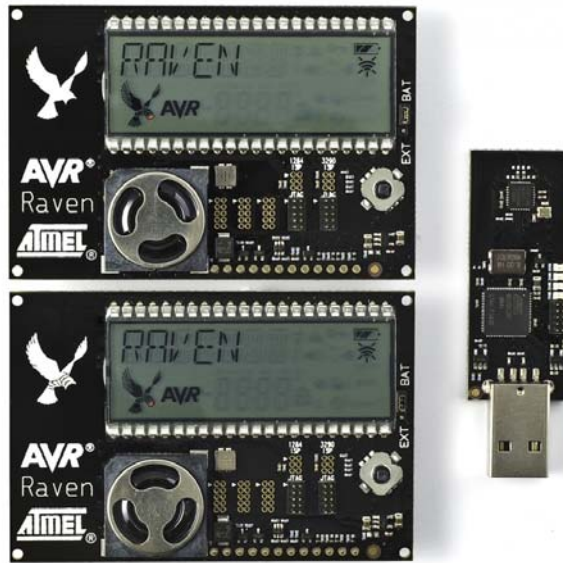
3 Firmware

As mentioned above, RES is a test environment that runs on top of the Transceiver Access Toolbox (TAT). A brief description of each firmware component follows.

3.1 Transceiver Access Toolbox

TAT provides support for low-level access of the AT86RF230 radio chip to RES during testing. RES depends on TAT for easy access to the radio registers, frame, and SRAM with read and write capabilities. References [2] and [3] provide in depth information about TAT.

3.2 Radio Evaluation Software

RES provides the API and infrastructure necessary to facilitate testing of the AT86RF230 radio transceiver. Additionally, a user interface was designed for the LCD on board the AVRRAVEN in which to control RES.

The RZUSBSTICK uses a Communication Device Class (CDC) creating a Virtual COM Port. This will allow for simple communication between the host PC and the RZUSBSTICK in which to control RES.

RES consists of three major test categories. These are:

1. Packet Error Rate (PER) and Range Testing - This will operate a PER test as a TX or RX device in which both are required to run a full test. This will allow the user to evaluate transceiver performance on range and receiver sensitivity.

2. RF Characterization Testing - This will operate a series of RF tests that will allow a user to characterize the RF performance of the transceiver. The available tests are:

   a. Continuous Transmission (CW)

      i. -500kHz - The transmitter emits a continuous wave at 500KHz below the center frequency of the channel selected.

      ii. +500kHz - The transmitter emits a continuous wave at 500KHz above the center frequency of the channel selected.

      iii. Modulated - The transmitter continuously transmits pseudo random data modulated at the channel frequency selected.

   b. Fast Transmission Mode - Transmits IEEE 802.15.4 frames as fast as possible based on frame length selected.

3. DC Characterization Testing - This will operate a single example of sleep operation. The system will wake-up, analyze any necessary data, send frame, listen for acknowledge frame, and return to sleep. This cycle is set for 5 second intervals allowing a user to evaluate current consumption measurements over time.

These three tests are fully described below.

3.2.1 Packet Error Rate (PER) and Range Characterization for AT86RF230 Based Systems

This is a system specification for the Range and PER system using the AT86RF230 radio transceiver and AVR microcontroller. It describes the requirements for a range test hardware platform and the associated firmware to be used to demonstrate the unique RF performance of the AT86RF230. Range of a wireless system is a critical performance parameter and one that is often the primary concern of an end customer. It is heavily dependent on a number of variables external to the transceiver itself such as; antenna, firmware, and transmission environment.

The firmware is architected and implemented in such a way as to provide easy field modifications to demonstrate unique features and performance as needed by the user.
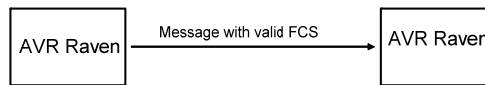
3.2.1.1 Operational configuration

One way range testing is configured where a hardware platform such as the AVRRAVEN is the data originator and another AVRRAVEN is the data receptor.

Figure 3.2.1.1 PER/Range Test Configuration


```
┌───────────┐   Message with valid FCS   ┌───────────┐
│ AVR Raven │ ─────────────────────────► │ AVR Raven │
└───────────┘                            └───────────┘
```

One way range evaluation test

For all range tests the originator will send a predefined number of messages for a specific amount of time. This way the receiving device can do measurements on the stream of messages.

A test is typically initiated by a button press and there should be no ambiguity in these measurements even if no packets are received. At the receive end the display system indicates the end of a test, and if no packets have been received the PER is defined as 100%. This is the only test that will work for determination of PER to the 100% point.

3.2.1.2 Operator Selectable Options

All user selectable configuration settings are input via the AVRRAVEN's user interface at each test node. The joystick is used to maneuver through the menu and set the available parameters for each test.

At a minimum the range test platform supports the following options:

1. Channels - The IEEE 802.15.4 defined channels that the range test operates in is 11 - 26.

2. Frame Lengths - Each message is selectable to contain variable length payloads, exclusive of the SFD.

3. Frame Count – The number of frames that will be transmitted during the test.

4. Output Power Level Setting - This option provides a means to set the transceiver output power. Valid settings are +3dBm to -17.2dBm inclusive.

3.2.1.3 Hardware Platform

Battery operation and portability are key aspects of this range test platform. An AVRRAVEN provides both nodes with a user interface and data display capabilities while mobility is also achieved.

The AVRRAVEN uses a Printed Circuit Board (PCB) trace antenna that was designed for and has demonstrated a significant range capability. In addition, the AVRRAVEN can be configured to provide a 50 Ohm output for alternate antenna testing see reference [6]). Note that range results are highly dependant on antenna configuration.

The use of the RZUSBSTICK with the onboard compact PCB antenna will reduce the achievable range compared to the AVRRAVEN slightly. This will provide a PC to AVRRAVEN test platform which will allow for quick evaluation of the antenna differences between the AVRRAVEN and the RZUSBSTICK.

3.2.1.4 Packer Error Rate Calculation

IEEE 802.15.4-2006 defines PER as "Average fraction of transmitted packets that are not detected correctly". For this application the following is used to calculate results:

PER = (Number of failed messages / Number of attempted measurements) x 100

All attempts are triggered by human interaction so precise control of the test is achieved. The Frame Check Sequence is used to validate if a message is detected correctly or not. RSSI summary data is available for all measurements.

3.2.1.5 Data Display

Collection and display of as much meaningful data as possible is a key requirement for this application. This data report is managed and updated on the AVRRAVEN LCD in which quantitative Packet Error Rates and RSSI metrics are key components. The user interface will communicate the status of testing and test results as they are available.

The interface is updated after each test interval is complete. The default frame refresh rate is set to every 50 frames until the test is finished based on the user selected frame count. RSSI is also displayed in real time to allow for evaluation of received signal strength during the test. RSSI values and LQI values are obtained during the test and stored locally to calculate the test max, min, and mean values. These final test results are stored for reference at a later time in the RESULT screen. This data will be overwritten after the next test. The current firmware does not allow the user to dump the stored data automatically. This will need to be recorded manually between each test.

3.2.2 RF Characterization for AT86RF230 Based Systems

This is a system specification for the RF (Modulation and carrier frequency) test system for the AT86RF230 radio transceiver and AVR microcontroller. It defines the requirements for an RF evaluation platform used to demonstrate the RF characteristics of Atmel's AVR Wireless radio transceivers. The primary intent of this capability is to evaluate the transmitter output for regulatory agency compliance testing. Agencies that typically require compliance are ETSI and the FCC.

The RF test system provides the user a pre-programmed firmware package with an easy means to demonstrate and examine the performance of the Atmel AVR Wireless system.

The firmware is architected and implemented in such a way as to provide easy field modifications to demonstrate unique features and performance as needed by the user.

The firmware builds upon the TAT (see references [2] and [3]).

3.2.2.1 Operational Configuration

This application allows the RF spectral content of the transceiver to be evaluated for regulatory agency compliance. Atmel's AVR Wireless radio transceivers are designed to be compliant with IEEE 802.15.4 physical layer requirements that specify a mode of transmission where the RF output is off unless an active message packet is being sent. This non-continuous mode of transmission makes it more difficult to capture the output on a measuring device (such as a Spectrum Analyzer). In an effort to make measurements more consistently available, the firmware associated with this test

sends messages as frequently as possible. When a message transmission is complete, the next message starts as soon as possible.

The spectral content of the transmitter output is also affected by the data pattern contained within the message. For this reason the data content of the messages in this application are, to the maximum extent possible, random data values. It is critical that, while messages are to be repeated as quickly as possible, these messages do not contain the same data but contain random data that changes from message to message.

The firmware supports Fast TX mode, for transmission of properly formatted data frames as quickly as possible, as well as CW and modulated continuous modes.

Complete configuration of the system will be made available via the LCD user interface on the AVRRAVEN.

3.2.2.2 Operator Selectable Options

All user selectable configuration settings are input via the AVRRAVEN user interface at each test node.

At a minimum the RF test platform supports the following options:

1. Channels - The IEEE 802.15.4 defined channels that the range test operates in is 11 - 26.

2. Frame Lengths - Each message is selectable to contain variable length payloads, exclusive of the SFD.

3. Output Power Level Setting - This option provides a means to set the transceiver output power. Valid settings are +3dBm to -17.2dBm inclusive.

The type of RF mode for testing is also user selectable:

1. Continuous Transmission (CW)

    a. -500kHz - The transmitter emits a continuous wave at 500KHz below the center frequency of the channel selected.

    b. +500kHz - The transmitter emits a continuous wave at 500KHz above the center frequency of the channel selected.

    c. Modulated - The transmitter continuously transmits pseudo random data modulated at the channel frequency selected.

2. Fast Transmission Mode - Transmits IEEE 802.15.4 frames as fast as possible based on frame length selected.

3.2.2.3 Measurement

RF energy is measured on applicable lab equipment, such as spectrum analyzers, while the test is being performed. It is considered to be beyond the scope of this document to describe RF laboratory measurement procedures.

3.2.3 DC Characterization for AT86RF230 Based Systems

This is a system specification for the DC test system for the AT86RF230 radio transceiver and AVR microcontroller. It defines the requirements for a DC evaluation platform used to demonstrate the DC characteristics of Atmel's AVR Wireless radio transceivers. The primary intent of this capability is to evaluate the power consumption over time.

The DC test system provides the user a pre-programmed firmware package with an easy means to demonstrate and examine the performance of the Atmel AVR Wireless system.

The firmware is architected and implemented in such a way as to provide easy field modifications to demonstrate unique features or performance.

The firmware builds upon the TAT (see references [2] and [3]).

3.2.3.1 Operational Configuration

The DC characterization firmware provides system selectable test options to the user. The following figure shows a typical test setup:

Figure 3.2.3.1 DC Test Configuration
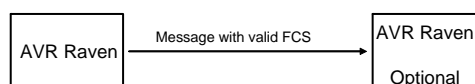
One way DC test

To properly analyze the DC characteristics of the system, a testing platform is required that can be configured. The AVRRAVEN can be configured via its LCD user interface and with modifications, provides easy access to signals for lab measurement (see reference [6]). This allows for accurate analysis and measurements during operation of a system under test. Understanding the relationships between voltage and current in the system provides detailed data that is collected from the measurement equipment. The collected data is then analyzed and supplied to the end user.

3.2.3.2 Operator Selectable Options

All user selectable configuration settings are input via the AVRRAVEN user interface at each test node.

At a minimum the DC test platform supports the following options:

1. Channels - The IEEE 802.15.4 defined channels that the range test operates in is 11 - 26.

2. Frame Lengths - Each message is selectable to contain variable length payloads, exclusive of the SFD.

3. Output Power Level Setting - This option provides a means to set the transceiver output power. Valid settings are +3dBm to -17.2dBm inclusive.

While the test is active, the AVRRAVEN LCD is turned off for minimal current consumption during testing. This test will run as long as the user allows it. There is no preset DC test duration.

3.2.3.3 Hardware Platform Options

Specific hardware setups are required to make proper system measurements. The AVRRAVEN platform provides test pin mounting holes for connection of lab

equipment and accurate measurements of voltage, current, clock etc. This is described in detail in the hardware manual for the AVRRAVEN (see reference [6]).

3.2.3.4 DC Characteristics Test Use Case

Using the available APIs (TAT, RES, DC, etc.) test cases are constructed to begin DC characterization.

One–Way Test
1. Use an AVRRAVEN, with test pins added, to provide connection points for voltage, current, clock etc. to capture measurements.
2. Make all measurement connections necessary to hardware platforms
    a. A Digital Multi Meter (DMM) is required for voltage measurements.
    b. An Ammeter is required for current measurements.
    c. An oscilloscope is required to capture the controller clock frequency, etc.
3. Use the RES API to set up the system for DC test and measurement.
4. Use the RES API to initiate DC characterization testing.
5. Allow process to run for a user defined period of time.
Collect data for characteristic analysis

An example test case for DC characterization using the AVRRAVEN could be described as:
1. Using a 2000mAh battery cell (typically a AA 1.5V)
2. System Scenario: Sleep for 30 seconds, Wake-up and read temperature data, Transmit one data packet, Receive one Acknowledgement packet, Return to sleep within 3-5 milliseconds.
3. System Sleep: 600nA (20nA for the AT86RF230 + 500nA for a picoPower AVR + some margin)
4. System Active: 20mA (16/17mA for the AT86RF230 at full TX power + 3-4mA for picoPower AVR + some margin).
The above scenario should yield more than 8 years battery lifetime with safe margin.

4 Programming RES for RZRAVEN

In order to operate RES tests on the ATAVRRZRAVEN kit, the user will need to become familiar with the hardware of the kit described in reference [6]. Included in the kit are 50mil 6-pin and 10-pin headers that will need to be soldered for programming the boards. To program the AVRRAVEN board, the AVRISP 6-pin header or the JTAGICE mkII 10-pin header can be used. To program the RZUSBSTICK, the JTAGICE mkII 10-pin header can be used.

The preferred programmer is the JTAGICE mkII which will also allow full debugging capabilities. The other option would include the AVRISP programmer with no debug capabilities. These programmers are available from www.atmel.com. Also included in the ATAVRRZRAVEN contents is a 50mil to 100mil 10-pin JTAGICE mkII adaptor.

Familiarity with programming and debugging microcontrollers with AVR Studio® and Starter Kits is assumed. Refer to the AVR Studio help files to program a target microcontroller using Atmel tools. AVR Studio is available free at www.atmel.com.

Programming the AVRRAVEN and RZUSBSTICK will be required as the RES firmware is not programmed at the factory during build.

4.1 RES Microcontroller Fuse Settings

The bulk of RES protocol and testing process are run on the AVRRAVEN ATmega1284P device. The fuse settings for the ATmega1284P are:

0xFF, **0x99**, **0xE2**.

The user interface functions (display, joystick) that run on the AVRRAVEN board are handled by the ATmega3290P device. The fuse settings for the ATmega3290P are:

0xFF, **0x99**, **0xE2**.

The USB/CDC interface for RES is handled on the AT90USB1287 device. The fuse settings for the AT90USB1287 using the external 8MHz crystal are:

0xFB, **0x99**, **0xDE**.

4.2 RES Firmware Installation

RES for the RZRAVEN project folder *res_raven* is defined with an image *bin* folder, *res_raven_lcd* project and a *res_raven_usb* project. Internal to \res_raven_lcd are a *res_1284* project and a *res_3290* project.

Loading the pre-compiled images found in the *bin* folder can be done with AVR Studio and the programmer of choice. The required image files to run RES are:

1. res_1284.hex (ATmega1284P)
2. res_3290.hex (ATmega3290P)
3. res_raven_usb.hex (AT90USB1287)

The source code is available in the project release folder under the respective folders. In order to compile the source code provided, WinAVR GCC compiler is a required plug-in to AVR Studio. This is available free at www.sourceforge.net.

There are three AVR Studio projects available to build, load, and debug RES on the RZRAVEN using the provided source code. The AVRRAVEN supports two projects. One is the RES System firmware itself for the ATmega1284P and the second is the LCD User Interface firmware for the ATmega3290P. The LCD firmware provides a menu system to guide the user through the various RES setup and test configurations. Located in their respective project folders, these projects are:

1. res_1284.aps
2. res_3290.aps

The RZUSBSTICK supports the third project for the USB/CDC interface for the AT90USB1287. Located in its respective project folder, this project is:
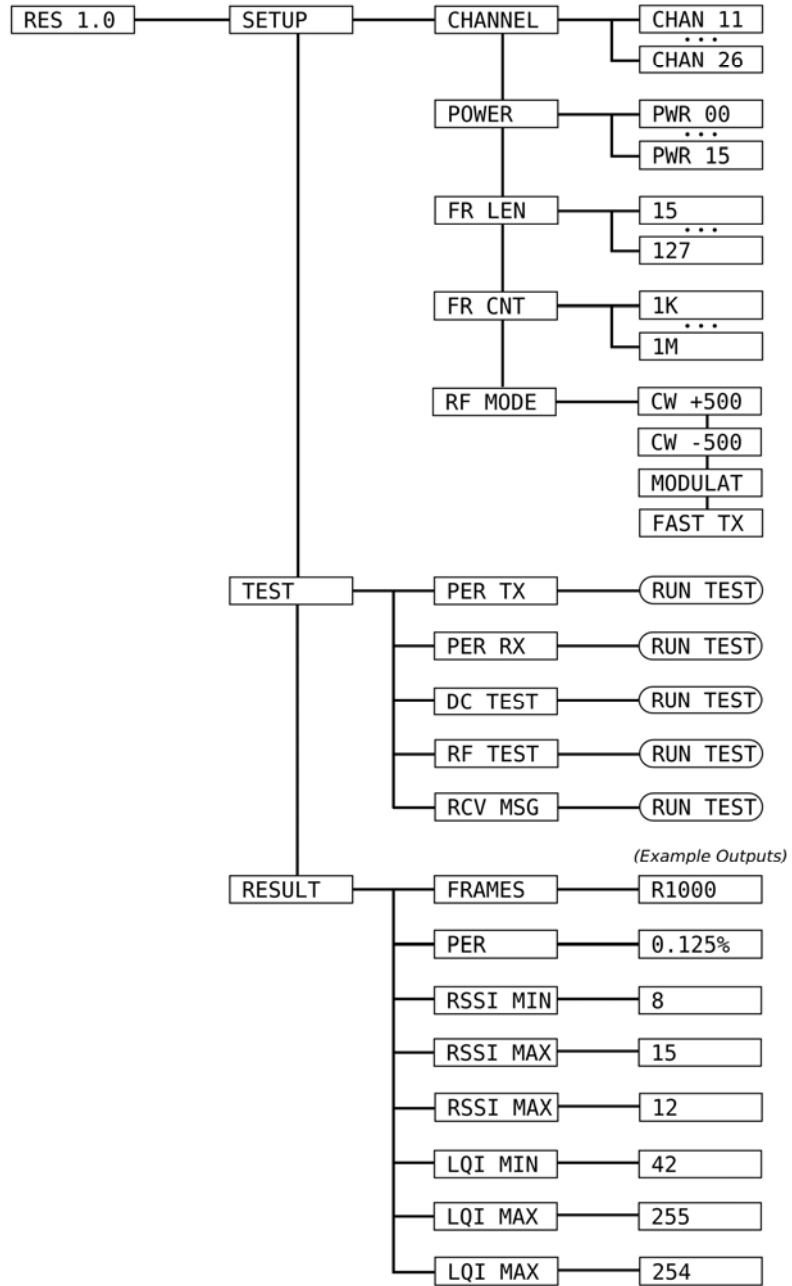
1. res_raven_usb.aps

4.3 RES Menu Overview

The flowchart depicted in Figure 4.1 describes the complete menu sequence for all test settings and test initiation on board the AVRRAVEN. The menu selections are accessed via the joystick on the AVRRAVEN.

Full operation of the AVRAVEN is described in section 5.1 while the full operation of the RZUSBSTICK is described in section 5.2.

Figure 4.1 RES Menu

```
RES 1.0 ──── SETUP ──── CHANNEL ──── CHAN 11
                                      ...
                                      CHAN 26

                        POWER ──────── PWR 00
                                      ...
                                      PWR 15

                        FR LEN ─────── 15
                                      ...
                                      127

                        FR CNT ─────── 1K
                                      ...
                                      1M

                        RF MODE ────── CW +500
                                      CW -500
                                      MODULAT
                                      FAST TX

            TEST ────── PER TX ─────── (RUN TEST)
                        PER RX ─────── (RUN TEST)
                        DC TEST ────── (RUN TEST)
                        RF TEST ────── (RUN TEST)
                        RCV MSG ────── (RUN TEST)

                                      (Example Outputs)
            RESULT ──── FRAMES ─────── R1000
                        PER ────────── 0.125%
                        RSSI MIN ───── 8
                        RSSI MAX ───── 15
                        RSSI MAX ───── 12
                        LQI MIN ────── 42
                        LQI MAX ────── 255
                        LQI MAX ────── 254
```

5 Getting Started

The following sections provide step-by-step instructions to perform the Range/PER, RF, and DC tests using the RZRAVEN system. Both the AVRRAVEN and the RZUSBSTICK will have a default of channel 19. This can be manually configured in both devices.

5.1 Testing With AVRRAVEN

The following sections describe step-by-step how to perform the three tests with the AVRRAVEN platform. The AVRRAVEN LCD is the preferred user interface platform, especially when the Range/PER test is performed in the field.

The AVRRAVEN is a joystick operated device. Pushing the joystick up or down takes the user through the various menu choices. Pushing the joystick to the right when a choice is highlighted takes the user to the next step in a series of steps. Pushing the joystick to the left takes the user back one step. To make a selection from a range of available choices, first highlight the default value, then push the joystick up or down to view the available choices and once the desired value is highlighted, press straight down (Enter) on the joystick to select that value – or press the joystick right one more time.

Upon power up of the device, the following screen appears which displays the current version of RES.

Figure 5.1.1 AVRRAVEN Power Up Screen
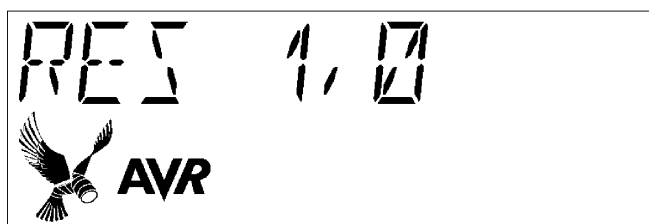
To begin testing, push the joystick to the right when "RES -»" is displayed.

5.1.1 Range/PER Test Setup

To begin Range/PER setup push the joystick to the right to access the "Setup" menu. Then configure the parameters desired for the test. The following figures show examples of setting the channel and selecting the TX power level.

Figure 5.1.1.1 AVRRAVEN Setup Screen
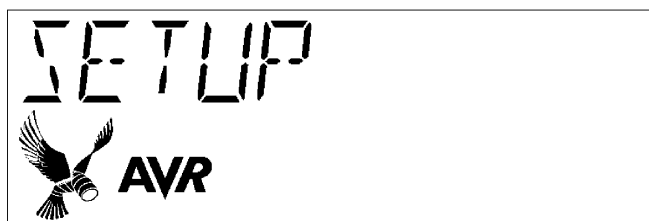
When the "Setup" menu is displayed, push the joystick to the right again to get to the channel setting menu. The next screen to be displayed is "Channel" and is shown below (Figure 5.1.1.2).

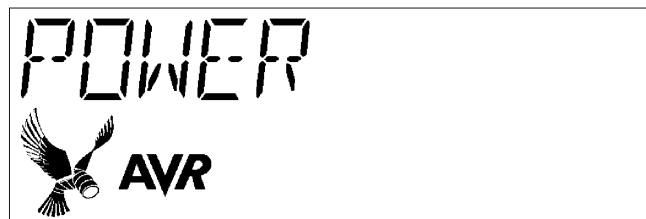**Figure 5.1.1.2 Channel Setup on the AVRRAVEN**

Pushing the joystick right again gets to the screen where actual channel settings can be made. Pushing the joystick up or down will increment or decrement the channel number. The following figure (Figure 5.1.1.3) shows Channel 19 selection. Once the desired channel is displayed a center push on the joystick will set it and the channel screen (Figure 5.1.1.2) will again be displayed.

Figure 5.1.1.3 Selecting Channel 19 on the AVRRAVEN
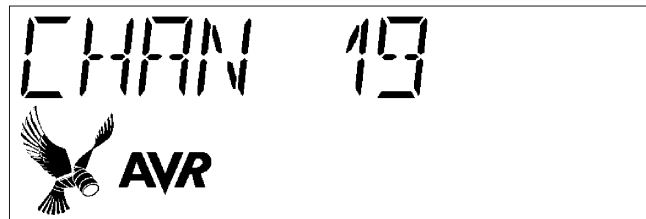
To set the transmit power, starting from the setup menu, push the joystick to the right. The first setup parameter is the channel setting (Figure 5.1.1.2). When the channel screen is shown, push the joystick down to enter the "Power" setup mode. This screen is shown below (Figure 5.1.1.4).

Figure 5.1.1.4 Power Setup on the AVRRAVEN

Pushing the joystick right again gets to the screen where actual transmit power settings can be made. Pushing the joystick up or down will increment or decrement

through the available power selections. Once the desired power level is found a center push on the joystick will set if and return to the power screen (Figure 5.1.1.4).

The power settings correspond to the AT86RF230 register value TX_PWR. The typical power mapping for the power settings is defined in the following table (Table 5.1.1.1). Figure 5.1.1.5 shows an example power level selection.

Table 5.1.1.1 Power Mapping

TX Power Setting	Output Power[dBm]
0	3
1	2.6
2	2.1
3	1.6
4	1.1
5	0.5
6	-0.2
7	-1.2
8	-2.2
9	-3.2
10	-4.2
11	-5.2
12	-7.2
13	-9.2
14	-12.2
15	-17.2

Figure 5.1.1.5 Selecting Power Level 03 (1.6dB) on the AVRRAVEN
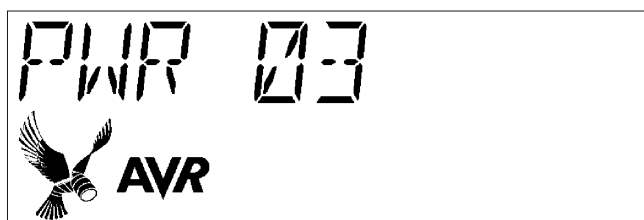
The Channel, Transmit (TX) Power, and Frame Size choices contain discrete values to choose from. Scroll through the value choices to see the specific value ranges. The default setting for Frame Count is 1000. The Report Rate is fixed at 50 and not user changeable. Setting a frame count of 1000 is shown below in Figures 5.1.1.6 and 5.1.1.7.

Figure 5.1.1.6 Frame Count Setup on the AVRRAVEN

```
FR CNT
AVR
```
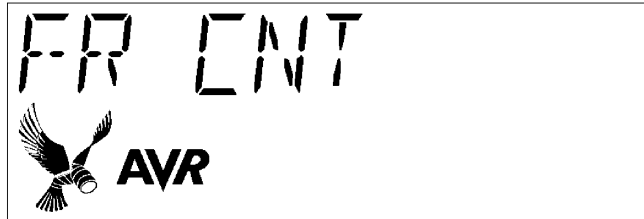
Figure 5.1.1.7 Selecting a Frame Count of 1000

```
1K
AVR
```
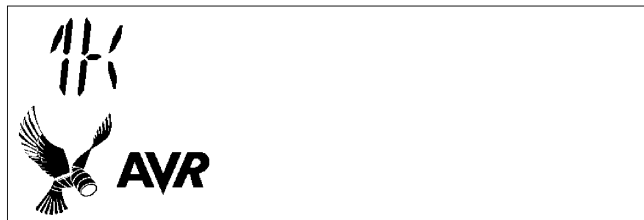
5.1.2 Range/PER Testing

Once all setup values are chosen, testing can begin by highlighting the "Test" choice and pushing the joystick to the right. For instance, when the "Setup" menu is displayed (Figure 5.1.1.1), pushing the joystick down gets to the "Test" menu shown below in figure 5.1.2.1. Then the user can select the type of test the AVRRAVEN will perform.

Figure 5.1.2.1 AVRRAVEN Test Screen

```
TEST
AVR
```

Pushing the joystick to the right enables the user to select the test of choice. For example, the "PER TX" test is selected with a right press, Figure 5.1.2.2 shows this.

Figure 5.1.2.2 AVRRAVEN PER TX Test Screen

```
PER TX
AVR
```

14   AVR2002
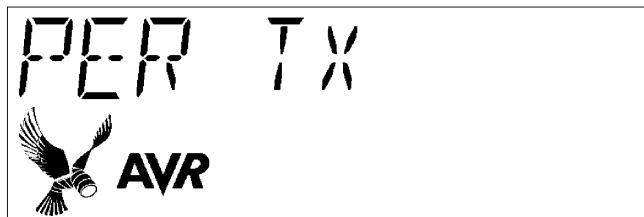
When the user wishes to start the test the joystick is simply pushed to the right and the node immediately begins to transmit frames according to the setup selections previously made. The LCD will show the count of frames sent in increments of 50.

When the selected number of frames has been transmitted, the test stops and the LCD will display the final count of the frames transmitted. Figures 5.1.2.3 and 5.1.2.4 show an active PER TX test and the final frame count of 1000 frames transmitted.

Figure 5.1.2.3 Frames Transmitted during active PER TX test

Figure 5.1.2.4 PER TX Test Final Count
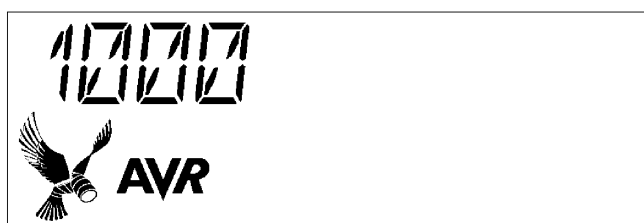
The "PER RX" test is selected by pushing the joystick right from the "Test" screen and then pushing it down. This is shown in Figure 5.1.2.5 below.

Figure 5.1.2.5 AVRRAVEN PER RX Test Screen
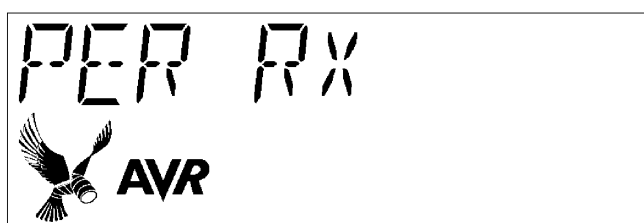
When the user wishes to start the node in PER RX test mode the joystick is pushed to the right.

Range/PER test results are collected and displayed on the receiver node. The receiver node should be configured and started before the test is started on the transmitter node to receive all frames and report accurate test results. During the test and after the transmitter node has started, an intermediate frame count will be shown on the receiver node LCD which will also include a real time RSSI value. This value is represented in dBm based on the following equation:

Received Power (dBm) = (RSSI * 3) – 94

The RSSI range varies from 0 to 28 allowing the Received Power value to range from -94dBm to -10dBm. This value does not reflect the actual receiver sensitivity during the test, but gives a simple conversion of how much RF power was received from the outside world based on the RSSI value.

Figures 5.1.2.6 and 5.1.2.7 below show an active PER RX test and the final received frame count of a receiver node.

Figure 5.1.2.6 Frames Received during active PER RX test
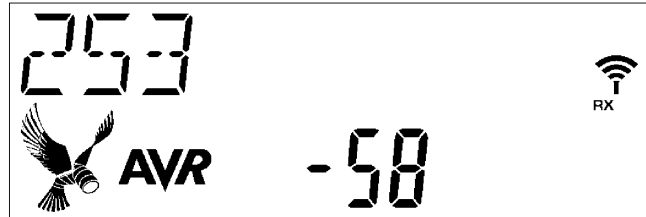
Figure 5.1.2.7 Frames Received on RX Node
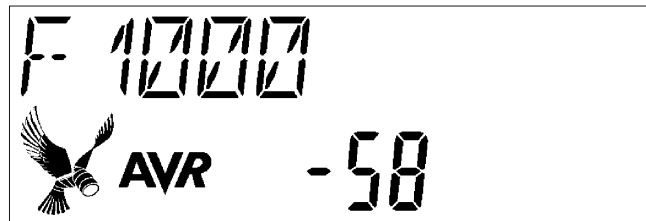
5.1.3 Range/PER Test Results

When a test has concluded the total frame count is displayed on the transmitter node (Figure 5.1.2.4) and the total received frames are displayed on the receiver node (Figure 5.1.2.7). To view the complete test results the receiver node can select the "Results" menu by pushing the joystick to the left until the "Test" mode screen is displayed (Figure 5.1.2.1) and then pushing the joystick down two times. This moves to the "Results" screen (Figure 5.1.3.1) and enables the user to examine the number of frames received versus expected, PER, RSSI (Min, Max and Avg) and LQI (Min, Max and Avg).

A sampling of screen shots is shown below.
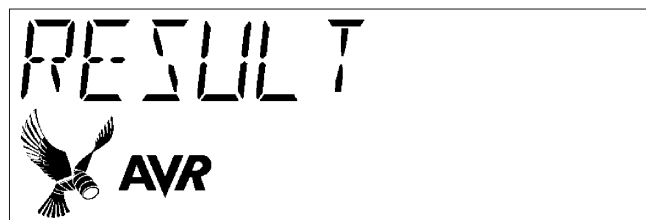
Figure 5.1.3.1 AVRRAVEN Results Screen

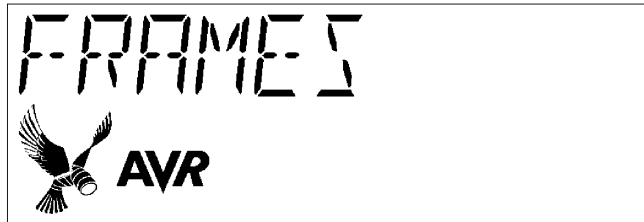**Figure 5.1.3.2 Frame Results Screen**

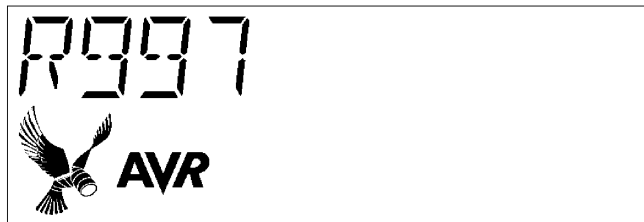**Figure 5.1.3.3 Example of Frames Received Results**

Figure 5.1.3.4 PER Result Screen

Figure 5.1.3.5 Example 0.3% PER Results

The next result screens give the user a report of Min, Max, and Avg values received of both RSSI and LQI.
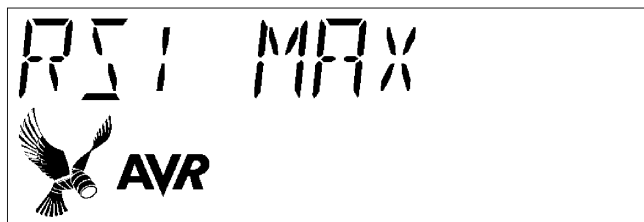
Figure 5.1.3.6 RSSI MAX Results Text
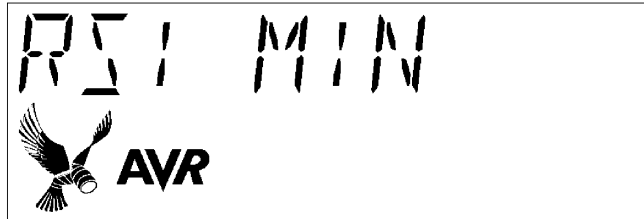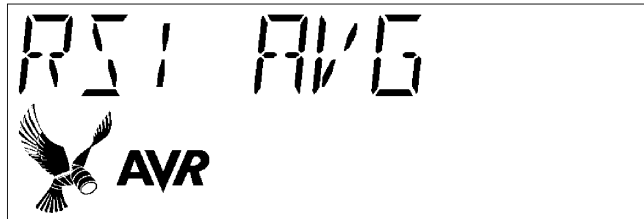
Figure 5.1.3.7 RSSI MIN Results Text

RSI MIN
AVR

Figure 5.1.3.8 RSSI AVG Results Text

RSI AVG
AVR

For each RSSI value (Min, Max, Avg) the results are viewed by pushing the joystick right.
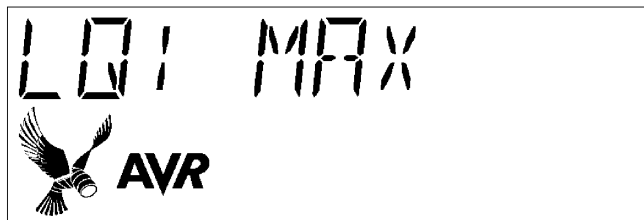
Figure 5.1.3.9 LQI MAX Results Text

LQI MAX
AVR

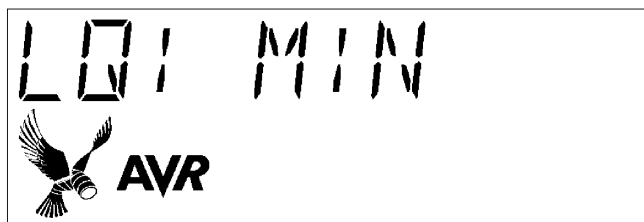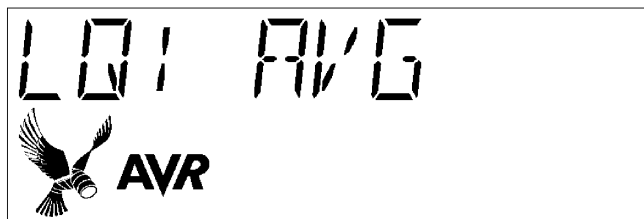**Figure 5.1.3.10 LQI MIN Results Text**

LQI MIN
AVR

Figure 5.1.3.11 LQI AVG Results Text

LQI AVG
AVR

For each LQI value (Min, Max, Avg) the results are viewed by pushing the joystick right.

5.1.4 RF Setup and Testing

The primary intent of the RES RF testing capability is to evaluate the transmitter output for regulatory agency compliance. Agencies that typically require compliance are European Telecommunications Standards Institute (ETSI) and the Federal Communications Commission (FCC).

The AVRRAVEN is equipped to direct RF energy to the onboard PCB trace antenna. To get the most accurate RF laboratory measurements the AVRRAVEN can be populated with a balun and an SMA connector to allow direct coaxial connection to laboratory equipment such as a spectrum analyzer. For more information please see reference [6].

To run an RF test, the desired test must be configured from the "setup" menu. From the "Setup" screen (Figure 5.1.1.1), push the joystick to the right. Then push the joystick down until the "RF Mode" screen is selected. This screen is shown below in Figure 5.1.4.1.

Figure 5.1.4.1 AVRRAVEN RF Setup Screen

Pushing the joystick to the right will allow the user to select between four different active transmitter modes. These modes are:

1. CW -500 – The transmitter emits a continuous wave at 500KHz below the center frequency of the channel selected.

2. CW +500 – The transmitter emits a continuous wave at 500KHz above the center frequency of the channel selected.

3. CW Modulated – The transmitter continuously transmits pseudo random data modulated at the channel frequency selected.

4. Fast TX – In this scenario a complete IEEE 802.15.4 data frame, of length selected from earlier setup configuration, with a pseudo random payload is transmitted as quickly as possible. The payload is altered for each frame sent.

To make the RF mode selection, push down on the center of the joystick and the menu will return to RF Mode shown in Figure 5.1.4.1. The following figures show a couple examples of these settings.
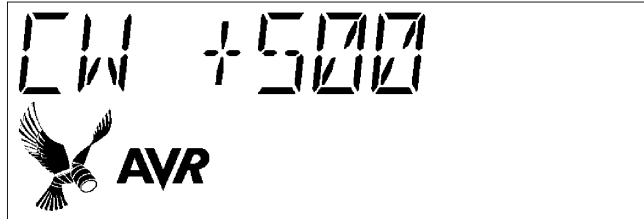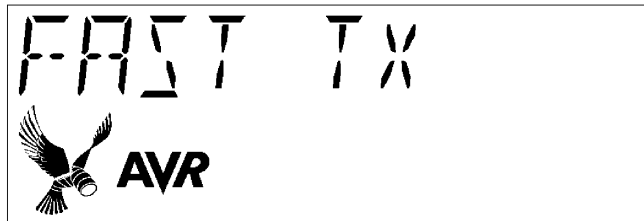
Figure 5.1.4.2 CW Mode at +500KHz

```
CW +500
```

Figure 5.1.4.3 Fast TX Mode

```
FAST TX
```

To run the RF test that was selected, return to the "Test" screen (Figure 5.1.2.1) and move the joystick to the right and down three times displaying "RF Test" on the display. Pushing the joystick to the right from this screen will start the RF test. The figures below give an example of starting a test.

Figure 5.1.4.4 AVRRAVEN RF Test Screen

```
RF TEST
```

Figure 5.1.4.5 Active RF Test

```
CW ON                    TX
```
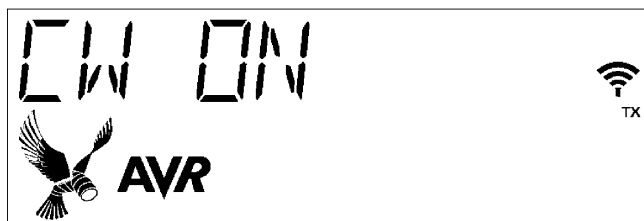
When the test has run for an appropriate amount of time, the joystick is pushed to the left to manually stop the test. The AVRRAVEN system will return to the previous menu item.

5.1.5 RF Test Results

Typically, a spectrum analyzer is used to collect data while the RF test is performed. The following figures show sample spectrum analyzer output from two separate RF tests.

Following are two sample outputs from an RF test. Figure 5.1.5.1 shows results for an RF test with RF Mode set to CW -500KHZ and Figure 5.1.5.3 shows an RF Test with RF Mode set to FAST_TX and frame size of 127.

Note that the spectrum analyzer images show tests that occurred on Channel 25 (2.475 GHz Center Frequency).

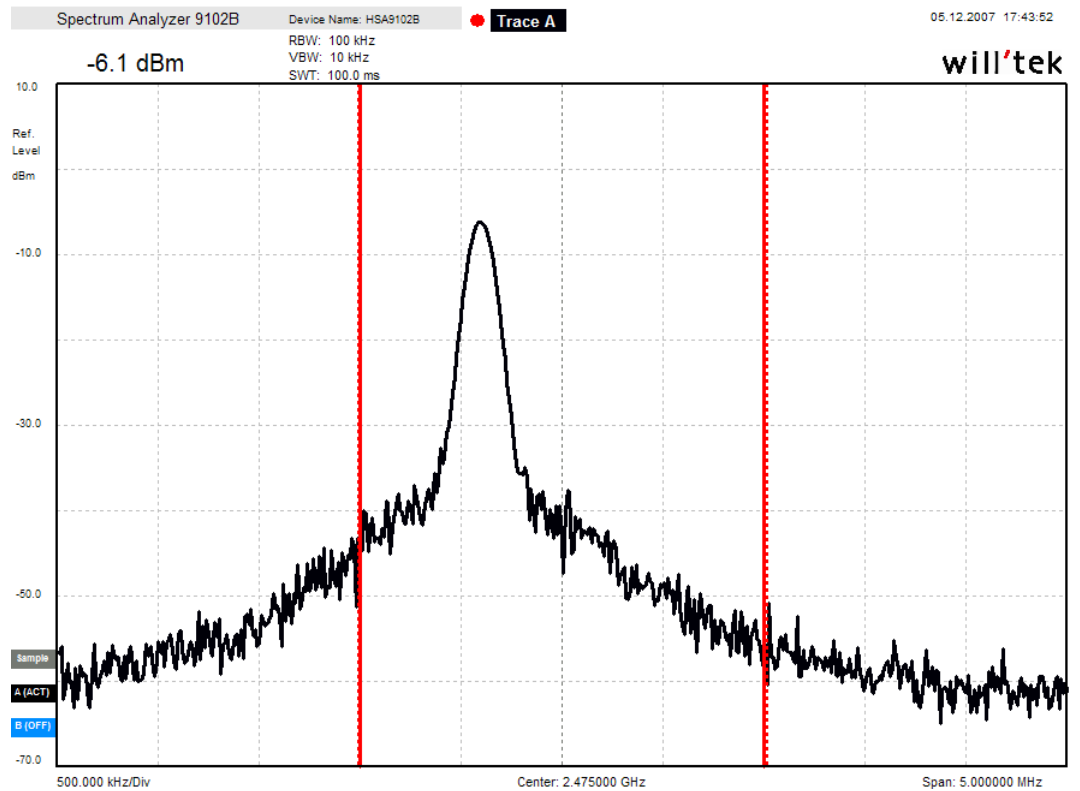## Figure 5.1.5.1 Sample Spectrum Analyzer Output During CW RF Testing

Figure 5.1.5.2 Spectrum Analyzer Settings for Figure 5.1.5.1

Figure 5.1.5.3 Sample Spectrum Analyzer Output During Fast TX RF Testing
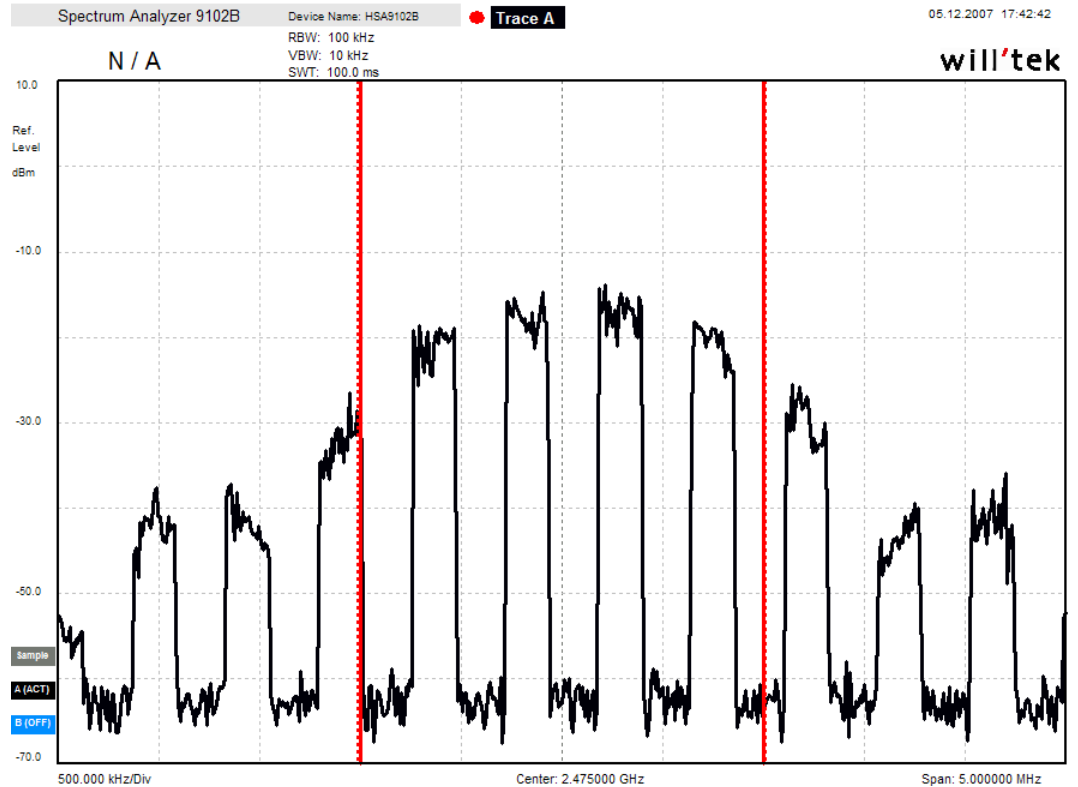
Figure 5.1.5.4 Spectrum Analyzer Settings for Figure 5.1.5.3

Level		
Impedance	:	50 Ohm
Ext. Device Comp.	:	–
Ref. Level	:	10.0 dBm
Attenuation	:	40 dB
Scale	:	10.0 dB/div

Status		
Mode:	Spectrum Analysis	
Center	:	2.475000 GHz
Span	:	5.000000 MHz
Start	:	2.472500 GHz
Stop	:	2.477500 GHz
Measure Mode	:	Channel Power
Trigger	:	OFF
Single Count	:	1

Trace/Detector		
Detect	:	Sample
Trace A	:	(ACT)
Trace B	:	(OFF)
Average Count	:	5

Instrument		
SW Version	:	5.01.0000
Boot Version	:	4.00
Serial Number	:	0604269
Cal. Date	:	12.02.2007
Last Check	:	12.02.2007
by		Willtek
Next Check	:	12.02.2008

5.1.6 DC Setup and Testing

The primary intent of RES DC testing is to provide accurate metrics to evaluate power consumption over time.

To run a DC test, select "DC Test" by pushing the joystick right while at the "Test" screen (Figure 5.1.2.1). During sleep testing the microcontroller is placed into power down mode and the radio is placed into sleep mode for a period of 5 seconds. Then the system is brought into active transmit mode and a frame is transmitted. The frame that is transmitted contains a pseudo random payload and the length is based on the user choice that was entered in the "FR LEN" setup selection.

Once all parameters are set to the desired value for the test and the "DC Test" test screen (Figure 5.1.6.1) is shown, pushing the joystick to the right will immediately start the test.

**Figure 5.1.6.1 DC/Sleep Test Start Screen**

Sleep time is fixed at 5 seconds and not configurable from the AVRRAZEN user interface. It is configurable within the source code to create longer system sleep periods.

During the test the ATmega3290P driving the LCD and the LCD itself are put into Power Down sleep mode which will only wakeup from an external interrupt. This can be achieved by pressing the joystick center push button. This allows for minimal current consumption during the DC test.

Once the test has run for a sufficient amount of time to obtain the desired lab measurements, it is stopped manually by pressing the joystick center push button. The following figure (Figure 5.1.6.2) shows the display while waking up and starting the wake up process for the RES system. Once the system is awake, the menu will return to the "DC Test" screen (Figure 5.1.6.1)

Figure 5.1.6.2 DC Test Wakeup
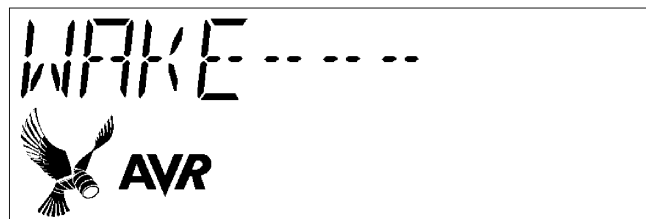
The DC/Sleep test is a laboratory test where results are to be obtained with separate measuring equipment further.

5.1.7 DC Test Results

Typically, an Ammeter is used to record data during DC testing. Radio performance is measured over time and the power consumption calculated. Utilizing this real average, battery lifetime can be accurately predicted. For illustration purposes see the figure below showing a system duty cycle that will sleep, wakeup, enter RX mode, enter TX mode, build and transmit a sensor data packet, and return to sleep.

Figure 5.1.7.1 Sleep Duty Cycle
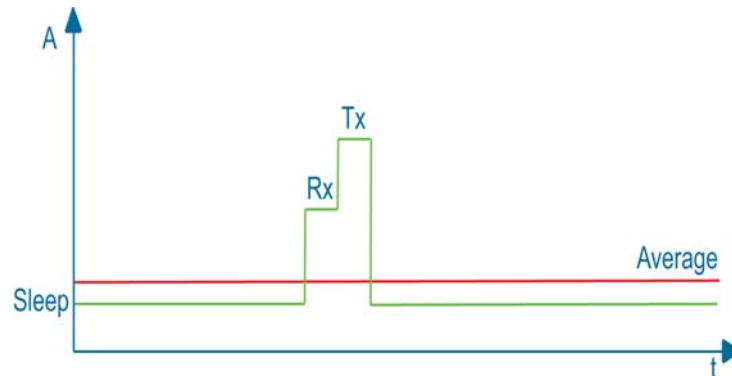
It is recommended to use an Ammeter that keeps track of the average current over the entire test, rather than one that just displays the instantaneous current, to more easily facilitate the calculations necessary to accurately predict battery life span. The Ammeter used for illustration purposes for this document measures and displays time elapsed since test start, milliamp-hours of battery life consumed since start of test, average current since start of test, average current of the last 1 second, and battery voltage.

5.1.8 AVRRAVEN Receive Message

When using the AVRRAVEN, there is a "RCV MSG" option that will allow the AVRRAVEN to receive and display a text message sent from the RZUSBSTICK in Terminal Mode. Once the message is received, the LCD is immediately updated with the information that was sent in the data packet. If the text message is more than 7 characters long, the LCD will scroll the data until the end of the message and then restart the message again. The RZUSBSTICK will only send up to 14 characters of data in each message to the AVRRAVEN. This can be manually adjusted within the source code if more data is needed to be sent.

The following figures show beginning a "RCV MSG" option and receiving "Hello" from the RZUSBSTICK.

From the "Test" screen (Figure 5.1.2.1), press down on the joystick until the "RCV MSG" screen is displayed in Figure 5.1.8.1.

**Figure 5.1.8.1 AVRRAVEN Receive Message Screen**

By pushing the joystick to the right from the "RCV MSG" screen, the mode will become active and the AVRRAVEN will display the screen shown in Figure 5.1.8.2. This mode can be manually stopped by pushing the joystick to the left from this screen.

Figure 5.1.8.2 Hello Message Received from RZUSBSTICK

Upon receiving a message from the RZUSBSTICK, the text data from the message will be displayed. This example shows the text "Hello" received from the message.

Figure 5.1.8.3 Hello Message Received from RZUSBSTICK
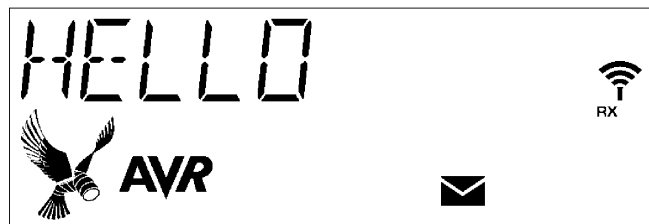
5.2 Testing With RZUSBSTICK

The following sections describe step-by-step how to perform the three tests with the RZUSBSTICK platform. The USB device uses a Communication Device Class (CDC) creating a Virtual COM Port. This will allow for simple communication between the host PC and the RZUSBSTICK in which to control RES.

5.2.1 RZUSBSTICK Installation

After loading the *res_raven_usb.hex* binary into the AT90USB1287 microcontroller as described in section 4, the USB device is now ready for installation to the local PC. If the device was previously connected to the USB port of the local PC during

programming, then the device may need to be disconnected and reconnected to initialize the installation process. Assuming the RZUSBSTICK is programmed; follow these steps to install the device:

1. Attach the RZUSBSTICK to one of the PC's unused USB ports.
2. After a few seconds the "Found New Hardware Wizard" will pop up.
3. Check the "No, not this time" option.
4. Click the Next button.
5. Verify that "Install from a list or specific location" option is checked. Press the Next button.
6. Select the "Search for the best driver in these locations" option.
7. Be sure that the "Include this location in the search:" option is selected and add the *..\res_raven* to the path.
8. Press the Finish button when the installation has completed.
9. Done.

If this installation process did not work for your PC system, be sure that the *at90usbxxx_cdc.inf* driver is the selected driver during installation. This file can be found in the folder *..\res_raven\res_raven_usb\driver.*

In order to verify proper installation, open System Properties and enter the Device Manager. Expand the Ports(COM & LPT) option which should now have the device "AT90USBxxx CDC USB to UART MGM (COMxx)". This also provides the virtual COM port number that was created.

Using the RZUSBSTICK as a virtual COM port device allows the user to operate RES with any custom GUI or simple terminal program. In order to control RES with a COM port user interface, there are two modes titled Terminal Mode and Binary Command Mode. These modes are fully described in the following sections.

NOTE: When using the RZUSBSTICK as a virtual COM port, advanced serial functionality is not supported as this is a USB device. An example of this advanced functionality would be SERIAL_BREAK_ON or SERIAL_BREAK_OFF commands. These commands will not be acknowledged by the RZUSBSTICK which may cause some instability with various terminal programs.

5.2.2 RZUSBSTICK Hardware Description

The RZUSBSTICK supports the AT90USB1287 and the AT86RF230 devices. This system is powered from the USB port from the local PC. The onboard PCB trace antenna has a peak gain of 0dB. There is a full hardware description on the RZUSBSTICK in the RZRAVEN hardware guide (see reference [6]).

Figure 5.2.1 RZUSBSTICK with active LED's
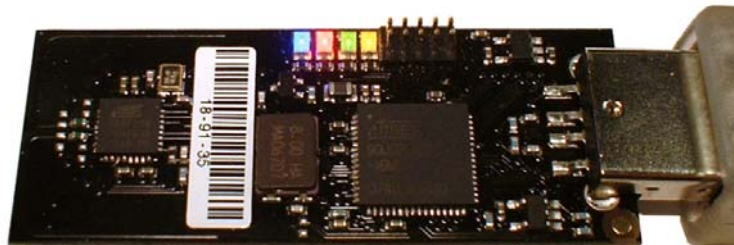
Four LED's have been provided as a visual to the user during proper RES operation. Each LED has a different color which has been described in the table 5.2.1 below.

Table 5.2.2.1 RZUSBSTICK LED Description

LED Color	Functionality
Blue	When RF data is received via the AT86RF230, this LED is flashed.
Red	When RF data is transmitted via the AT86RF230, this LED is flashed.
Green	When USB data is transmitted to the local PC, this LED is flashed.
Yellow	When USB data is received from the local PC, this LED is flashed.

When connecting to the USB/CDC interface it is recommended to use the following parameters when opening the virtual COM port:

1. Baudrate: **38,400**

2. Data bits: **8**

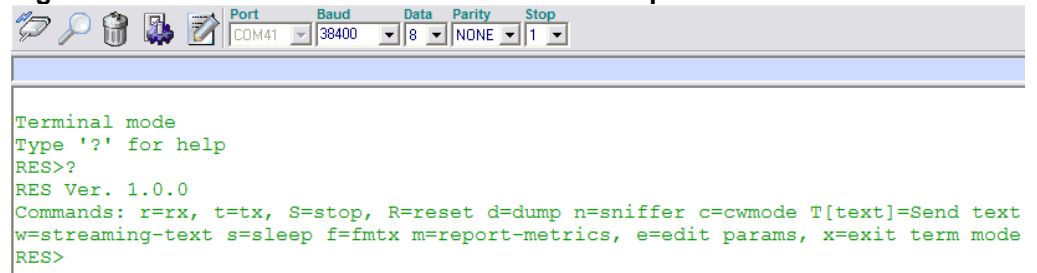3. Parity Bits: **None**

4. Stop Bits: **1**

To demonstrate the USB/CDC interface of the RZUSBSTICK, the terminal program SimpleTerm Gold v5.0 developed by Ptronix was selected for the following sections.

5.2.3 RZUSBSTICK Terminal Mode for RES

Terminal Mode offers a simple user interface for RES operation. This mode is entered by opening the CDC virtual COM port with the terminal program of choice. Configure the terminal program to ASCII mode and type "**Ctrl-T**" in the terminal window. The RZUSBSTICK will respond with an "**RES>**" prompt. This will allow the RZUSBSTICK to bypass the Binary Mode operation and pass each typed character in as ASCII data.

By typing a "**?**" at the "**RES>**" prompt, a help menu is displayed. Figure 5.2.3.1 shows the initialization of Terminal Mode and a help menu request.

Figure 5.2.3.1 Terminal Mode Initialization with Help Menu


```
Terminal mode
Type '?' for help
RES>?
RES Ver. 1.0.0
Commands: r=rx, t=tx, S=stop, R=reset d=dump n=sniffer c=cwmode T[text]=Send text
w=streaming-text s=sleep f=fmtx m=report-metrics, e=edit params, x=exit term mode
RES>
```

5.2.3.1 Terminal Mode Operation

The basic functionality of each terminal command is described in the help menu; however, there are some commands that are fully described below.

> **r** - Begin a PER/Range Characterization Test as an RX_NODE.

> **t** - Begin a PER/Range Characterization Test as a TX_NODE.

> **S** - Stop the current test in progress.

> **R** - Reset the RES system (Software Reset).

d - Report the current settings of AT86RF230 registers. (see reference [4])

n - Enable an ASCII based Sniffer node which reports the raw RF frame data with the current timestamp.

c - Begin an RF Characterization CW Test based on the CW mode of choice.

T[text] - Send text message to AVRRAVEN LCD (i.e. THello will send Hello).

w - Enter Streaming Text mode (Second RZUSBSTICK required for this mode). This will send ASCII data between two RZUSBSTICK's configured as Streaming Mode devices.

s - Begin DC/Sleep Characterization Test (Sleep mode currently not enabled on the RZUSBSTICK).

f - Begin an RF Characterization Fast Mode TX Test based on the selected frame parameters.

m - Report last TX or RX metrics from a PER/Range Characterization Test.

e - Edit the RES system parameters for testing options.

x - Exit Terminal Mode and return to Binary Command Mode

5.2.3.2 Terminal Mode PER/Range Characterization

Operating a PER/Range Characterization Test is a simple command in Terminal Mode. The user can configure the RZUSBSTICK as a TX_NODE or an RX_NODE for the One-Way test. The "**t**" or "**r**" commands can be entered at the "**RES>**" prompt to begin the test as the desired device.

When a test is run as a TX_NODE ("**t**"), the device will immediately begin transmitting frames based on the parameters setup in the Edit option ("**e**"). An example test that transmits 1000 frames based on a 20 byte frame length is shown in Figure 5.2.3.2.

Figure 5.2.3.2 Terminal Mode TX_NODE PER/Range Test

```
RES>t
Tx Mode
................................................................
................................................................
.............................................................200
................................................................
................................................................
.............................................................400
................................................................
................................................................
.............................................................600
................................................................
................................................................
.............................................................800
................................................................
................................................................
............................................................1000
.
1000 frames tx'd

RES>
```

During the PER/Range Test as a TX_NODE, RES will update the terminal program with frame interval data. This data represents the number of transmitted frames as the test is in progress. At the end of the test, a final transmit count is updated.

When a test is run as an RX_NODE ("r"), the device will immediately enter receive mode based on the parameters setup in the Edit option ("e"). An example test that receives 1000 frames based on a 20 byte frame length is shown in Figure 5.2.3.3.

Figure 5.2.3.3 Terminal Mode RX_NODE PER/Range Test

```
RES>r
Rx Mode
1ooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooo
ooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooo
ooooooooooooooooooooooooooooooooooooooooooooooooooooooo
206 RSSI   16    16    17
ooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooo
ooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooo
oooooooooooooooooooooooooooooooooooooooooooooooooo
406 RSSI   16    16    17
ooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooo
ooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooo
oooooooooooooooooooooooooooooooooooooooooooooo
607 RSSI   17    18    19
ooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooo
ooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooo
oooooooooooooooooooooooooooooooooooooooooo
808 RSSI   18    18    18
ooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooo
ooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooo
ooooooooooooooooooooooooooooooooooooooooo$
1000 RSSI   18    18    19

1000 frames rec'd
PER = 0.00%
RSSI Val -  Count
  16 - 190
  17 - 236
  18 - 547
  19 - 27

RES>
```

During the PER/Range Test as an RX_NODE, RES will update the terminal program with frame interval data. This data represents the number of received frames and the current RSSI values as the test is in progress. The RSSI values represent Min, Avg, and Max (in order) for each interval received. At the end of the test, a final receive count is updated with the calculated PER percentage along with an array of RSSI values. This array represents the number of frames that were counted for each RSSI value acquired over the testing period.

This receive data also provides an analysis tool for how many missed and bad frames were counted. During a test, the following symbols may appear throughout the test.

Table 5.2.3.1 Received Frame Symbol Description

Receive Symbol	Description
O	Good frame received with CRC check passed
1	First received frame in series
$	Last received frame in series
@	Missed Frame (Out of order sequence Number)
X	CRC check failed

5.2.3.3 Terminal Mode RF Characterization

There are four different RF characterization modes for the RZUSBSTICK when using Terminal Mode. These modes have been separated into two different RF tests. The first RF test is CW Mode ("**c**") which supports three CW Mode options. In order to change between any of the three options, enter the Edit Menu ("**e**"). After choosing the CW Mode of choice, leave the Edit Menu ("**0**"). To start the CW Mode test, type "**c**" at the "**RES>**" prompt and the terminal window will be updated with the CW Mode that was chosen in the Edit Menu. Figure 5.2.3.4 gives an example for configuring CW Modulated Mode and operating the test. To stop the CW Mode test, press "Enter" to send a carriage return to stop the test.

Figure 5.2.3.4 CW Modulated Mode Configuration and Test

```
RES>e
1. Channel = 19
2. Power = -0.2dBm
3. Packets/test = 1000
4. Packet size = 20
5. SFD = 0xA7
6. CWMode = Minus
0. Exit
Select an item:6
Enter CW Mode (m/p/r)r
1. Channel = 19
2. Power = -0.2dBm
3. Packets/test = 1000
4. Packet size = 20
5. SFD = 0xA7
6. CWMode = Rand
0. Exit
Select an item:0


RES>c
CW Modulated Mode
```

The second RF test is Fast Mode TX. In this mode, the AT86RF230 radio transceiver will transmit IEEE 802.15.4 compliant data frames as fast as possible based on the frame length listed in the Edit Menu. To start the Fast Mode TX, type "**f**" at the "**RES>**" prompt and the test will begin transmitting frames. To stop the Fast Mode TX test, press "Enter" to send a carriage return to stop the test. At the end of the test, RES will update the terminal window with the total frame count that was transmitted. Figure 5.2.3.5 shows the operation and completion of a Fast Mode TX test.

Figure 5.2.3.4 Fast Mode TX Test and Results

```
RES>f
Fast Mode TX

Stop

18912 frames tx'd

RES>
```

5.2.3.4 Terminal Mode DC Characterization

DC Characterization has been disabled on the RZUSBSTICK as this device cannot perform a sleep operation for current analysis over time. The USB/CDC interface must be active at all times and therefore would produce inaccurate results during current measurement.

The platform of choice for DC characterization is the AVRRAVEN.

5.2.4 RZUSBSTICK Binary Command Mode for RES

In order to use the Binary Command set developed for communication with RES, a proper Command Frame needs to be formatted with the Binary Command data. This Command Frame requires the following structure for RES to properly understand the requested command:

1. 1 Start of Frame Byte (hex **0x01**)

2. 2 Length Bytes for Payload only

3. 1 Binary Command Byte

4. n Payload Bytes

5. 1 End of Frame Byte (hex **0x04**)

Once this message is received by RES in the proper format, RES will send an Acknowledgement Frame in the following format:

1. 1 Start of Frame Byte (hex **0x01**)

2. 1 Binary Command Byte that was Received

3. 1 End of Frame Byte (hex **0x04**)

RES will also update the user with data throughout the testing process without any request. These commands are formatted with the same Command Frame structure; however, there will not be a requirement for an acknowledgement from the terminal program.

The full list of Binary Commands has been provided in Table 5.2.4.1.

Table 5.2.4.1 Terminal to RES Binary Command Set

Binary Command	Value (hex)	Payload Bytes	Description
NULL_CMD	(0)	0	Empty command
SET_CHANNEL	(0x80)	1	Integer Channel
SET_TX_POWER	(0x81)	1	Integer Power Level
SET_FRAME_RATE	(0x82)	2	TX Frame Rate (ms)
SET_FRAME_LENGTH	(0x83)	1	15 - 127 byte Frame Size
SET_FINITE_FRAMES	(0x86)	4	Number of Frames TX'd
TX_NODE	(0x87)	0	Set TX_NODE
RX_NODE	(0x88)	0	Set RX_NODE
START	(0x89)	0	Start current test
STOP	(0x8A)	0	Stop current test
FRAME_REPORT_INTERVAL	(0x8B)	4	Report interval (# frames)
RES_SLEEP	(0x8C)	0	Set sleep mode
FAST_MODE_TX	(0x8D)	0	Set Fast Mode TX
CW_MINUS_2MHZ	(0x8E)	0	Set CW -2MHz Mode
CW_MINUS_500KHZ	(0x8F)	0	Set CW -500kHz Mode
CW_PLUS_500KHZ	(0x90)	0	Set CW +500kHz Mode
CW_MODULATED	(0x91)	0	Set CW Modulated Mode
NO_TX *	(0x92)	0	Disable TX
CYCLE_THRU_PLL_ON *	(0x93)	0	No state change
CYCLE_THRU_TRX_OFF *	(0x94)	0	TRX_OFF to PLL_ON
CYCLE_THRU_RX_ON *	(0x95)	0	RX_ON to PLL_ON
CYCLE_THRU_ALL *	(0x96)	0	TRX_OFF to RX_ON to PLL_ON
SNIFFER_NODE	(0x97)	0	Set sniffer mode
SET_SFD	(0x98)	1	Change SFD byte
RES_STREAM	(0x99)	0	Set streaming text mode
SLEEP_ACK	(0x9A)	0	Wakeup Ack command
DISPLAY_TEST	(0xB0)	0	Binary command test
RF230_REG_DUMP	(0xB1)	0	AT86RF230 register read
RES_RESET	(0xBF)	0	RES software reset

* Binary Commands Specific to Fast Mode TX and AT86RF230 state changes

Table 5.2.4.1 shows the RES to terminal Binary Command automatic updates while a test is in progress or a test has finished.

Table 5.2.4.1 RES to Terminal Binary Command Set

| Binary Command	Value (hex)	Payload Bytes	Description
REPORT_ONE_WAY	(0xC0)	1148	Final PER test summary
REPORT_RX_INTERVAL	(0xC1)	14	RX_NODE PER interval
REPORT_TX_INTERVAL	(0xC2)	4	TX_NODE PER interval
REPORT_SNIFFER	(0xC3)	n	Raw over the air data
REPORT_REG_DUMP	(0xC4)	39	Raw AT86RF230 register values

5.2.4.1 Binary Command Operation

In order to operate the three tests, each test will need to be configured with the proper binary commands. This will allow for custom configurations for each test giving the user the flexibility to test the AT86RF230 is several ways.

The common method for operating these tests is described in the sections below.

This is the proper method for sending and receiving Binary Commands to and from the RES system on the RZUSBSTICK. The terminal program is configured for Hexadecimal display. Figure 5.2.4.1 shows the configuration of Binary Command mode and sending a Binary Command Frame to set the AT86RF230 to MAX TX_POWER.

Figure 5.2.4.1 Binary Command Mode Operation
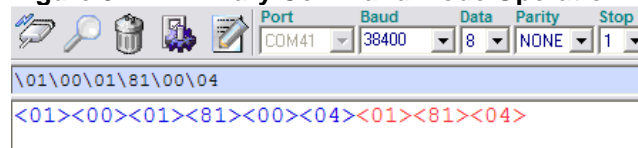
The first six bytes of data is the Command Frame sent to the RZUSBSTICK. This data is decoded below:

0x01,0x00,0x01,0x81,0x00,0x04 - Set MAX TX_POWER of AT86RF230

    0x01 - Start of binary command frame

    0x00 - Length of binary command payload (high byte)

    0x01 - Length of binary command payload (low byte)

    0x81 - RES binary command SET_TX_POWER

    0x00 - Payload value (raw register setting of AT86RF230)

    0x04 - End of binary command frame

The last three bytes of data is the Acknowledgement Frame sent from the RZUSBSTICK. This data is decoded below:

0x01, 0x81, 0x04 – Acknowledge the setting of MAX TX_POWER of AT86RF230

    0x01 - Start of binary command frame

    0x81 - Binary command byte that was acknowledged

    0x04 - End of binary command frame

NOTE: Once any test is in progress, the only Binary Command that RES will respond to is a STOP Binary Command. This prevents improper function changes while a test is in progress.

5.2.4.2 Binary Command PER/Range Characterization

In order to operate a PER/Range Test using the RZUSBSTICK in Binary Command mode, the device will need to be properly configured as a TX or RX node. The list of recommended commands is listed below.

    1.   SET_CHANNEL

    2.   SET_TX_POWER (TX_NODE only)

3. SET_FINITE_FRAMES

4. SET_FRAME_LENGTH

5. TX_NODE or RX_NODE

6. START

This will configure the proper channel, TX power level, number of frames to be transmitted, frame length, and what type of node the RZUSBSTICK is configured as. Once the START command is sent, a TX_NODE device will begin transmitting frames and an RX_NODE device will enter receive mode.

During the test, RES will automatically update the user with test metric information. This data is captured by the terminal program in the same Command Frame structure.

An example test that transmits 1000 frames based on a 20 byte frame length is shown in Figure 5.2.4.2 along with the interval data received from the RZUSBSTICK.

Figure 5.2.4.2 Binary Mode PER/Range TX_NODE & REPORT_TX_INTERVAL

```
<01><00><01><80><13><04><01><80><04>
<01><00><01><81><00><04><01><81><04>
<01><00><04><86><00><00><03><E8><04><01><86><04>
<01><00><01><83><14><04><01><83><04>
<01><00><00><87><04><01><87><04>
<01><00><00><89><04><01><89><04>
<01><00><04><C2><00><00><00><C8><04>
<01><00><04><C2><00><00><01><90><04>
<01><00><04><C2><00><00><02><58><04>
<01><00><04><C2><00><00><03><20><04>
<01><00><04><C2><00><00><03><E8><04>
```

Each REPORT_TX_INTERVAL contains 4 bytes of payload data representing the total number of frames transmitted at the interval update rate. These values are accumulated while the test is in progress until the total number of frames transmitted meets the end of test frame count.

An example test that receives 1000 frames based on a 20 byte frame length is shown in Figure 5.2.4.3 along with the interval data received from the RZUSBSTICK.

Figure 5.2.4.3 Binary Mode PER/Range RX_NODE & REPORT_RX_INTERVAL

```
<01><00><01><80><13><04><01><80><04>
<01><00><01><81><00><04><01><81><04>
<01><00><04><86><00><00><03><E8><04><01><86><04>
<01><00><01><83><14><04><01><83><04>
<01><00><00><88><04><01><88><04>
<01><00><00><89><04><01><89><04>
<01><00><0E><C1><00><00><00><00><00><00><00><CC><FF><FF><FF><10><10><12><04>
<01><00><0E><C1><00><00><00><00><00><00><01><94><FE><F4><FF><10><10><11><04>
<01><00><0E><C1><00><00><00><00><00><00><02><5C><FF><FF><FF><10><10><11><04>
<01><00><0E><C1><00><00><00><00><00><00><03><24><FF><FF><FF><11><11><12><04>
<01><00><0E><C1><00><00><00><00><00><00><03><E8><FF><FF><FF><11><11><11><04>
```

Each REPORT_RX_INTERVAL contains 14 bytes of payload data that is broken out below.

  4 bytes - Place holder for TX frame count
  4 bytes - RX frame count
  3 bytes - LQI values (Avg, Min, Max)
  3 bytes - RSSI values (Avg, Min, Max)

The final report after a PER/Range test as an RX_NODE is REPORT_ONE_WAY. This report is automatically sent after the last REPORT_RX_INTERVAL Command Frame. This Command Frame contains 1148 bytes of payload data that is broken out below.

     4 bytes - Place holder for total TX frame count
     4 bytes - Total RX frame count
     1024 bytes - Total LQI values
     116 bytes - Total RSSI values

LQI is represented by a range of 0 to 255 while RSSI is represented by a range of 0 to 28. For each LQI and RSSI value, there are 4 bytes of total frames received within that value.

5.2.4.3 Binary Command RF Characterization

There are five different RF characterization modes for the RZUSBSTICK when using Binary Command Mode. These modes have been separated into five different Binary Command RF tests while also providing 5 different transmit modes for Fast Mode TX.

To enable any of the four CW Modes, simply select the proper Binary Command for the preferred CW Mode and send the Command Frame. Once this CW command has been sent, send the START Binary Command Frame. An example of configuring CW Modulated Mode and starting the test is shown in Figure 5.2.4.4.

Figure 5.2.4.4 Binary Mode CW Modulated Mode Test

```
<01><00><00><91><04><01><91><04>
<01><00><00><89><04><01><89><04>
```

The Fifth RF test is Fast Mode TX which will transmit IEEE 802.15.4 data frames as fast as possible. Within Binary Command Mode, there are also Cycle options where each Cycle option will change the state of the AT86RF230 between frames transmitted. An example of changing the AT86RF230 from PLL_ON to RX_ON and back to PLL_ON to transmit another 20 byte frame is shown in Figure 5.2.4.5.

Figure 5.2.4.4 Binary Mode Fast Mode TX with CYCLE_THRU_RX_ON Test

```
<01><00><00><8D><04><01><8D><04>
<01><00><00><93><04><01><93><04>
<01><00><01><83><14><04><01><83><04>
<01><00><00><89><04><01><89><04>
```

Having the ability to Cycle through AT86RF230 states during an RF Characterization test allows the user to fully evaluate the RF performance of the system. Some agencies require that all regulatory agency compliance requirements have been met including transceiver state change. There is also a NO_TX Binary Command that can be used to disable any RF data from being transmitted from the AT86RF230 while in Fast Mode TX.

5.2.4.4 Binary Command DC Characterization

DC Characterization has been disabled on the RZUSBSTICK as this device cannot perform a sleep operation for current analysis over time. The USB/CDC interface must be active at all times and therefore would produce inaccurate results during current measurement.

The platform of choice for DC characterization is the AVRRAVEN.

6 References

[1] IEEE 802.15.4™-2006 standard

[2] AVR2001: AT86RF230 Software Programmer's Guide

[3] AVR2009: AT86RF230 - Software Programming Model

[4] AT86RF230 ZigBee™/IEEE 802.15.4™ Radio Transceiver Datasheet, Revision D

[5] AVR2015: RZRAVEN Quick Start Guide

[6] AVR2016: RZRAVEN Hardware User's Guide

7 Definitions, Acronyms and Abbreviations

7.1 Definitions

Node	A system consisting of a microcontroller, an AT86RF230 radio transceiver and system firmware – Typically an AVRRAVEN.
Display System	The user interface, usually AVRRAVEN.

7.2 Acronyms and Abbreviations

DB	Display Board
DMM	Digital Multi Meter
DUT	Device Under Test
ETSI	European Telecommunications Standards Institute
FCC	Federal Communications Commission
FCS	Frame Check Sequence
GUI	Graphical User Interface
LQI	Link Quality Indication
PCB	Printed Circuit Board
PER	Packet Error Rate
RES	Radio Evaluation System Software
RF	Radio Frequency
RSSI	Receive Signal Strength Indication
RX	Receive
SFD	Start of Frame Delimiter
SMA	Sub Miniature Version A
TAT	Transceiver Access Toolbox
TX	Transmit

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