Atmel AT03188: Performance Test EVK with External FEM

Atmel MCU Wireless

Features

- Getting started with Performance test EVK application
- Adding support for external Front End Modules
- FEM logical control checklist
- Usage and significance of menu driven Performance test EVK application
- Using script to run Performance test EVK application

Description

Scope of the application note is to guide customers in designing and validating their wireless products using Atmel wireless software solutions.

Targeted audience includes product designers, embedded programmers and hardware engineers.

For validating RF performance and power consumption, customers can use Performance test EVK example application in IEEE 802.15.4 MAC stack [1]. This document includes getting started guide for performance test EVK application, along with software and hardware modification required for supporting custom board with external Front End Module (FEM).

Example custom board considered in this document contains Atmel's RCB256RFR2 [3] on Sensor Terminal Board platform (STB) [4] and Skywork's SE2431L–EK1 board [5]. And MAC stack version 2.8.0 is used for demonstrating the required software modifications.

SE2431L [6] FEM chips supports both LNA/PA and Antenna diversity features.

This application note can also be extended to custom boards based on other external FEM modules as well, like SE2438T [7], RC6505 [8], RC6575 [9], RC6555 [10] etc.

Table of Contents

1.   Introduction

This document shall guide the user through the usage of default performance test example application in Atmel IEEE 802.15.4 MAC stack [1] and along with example procedure for modifying the default Performance test EVK application to support a custom board with ATmega256RFR2 and SE2431L [6] chip.

As Performance test is a menu driven application it is must to have a serial interface for communicating with the terminal window in the custom boards.

With the help of Performance test EVK application customer can carry out the following list of validation tests,

- Continuous transmission mode for certification
- Packet error rate for Receiver Sensitivity measurement
- Power consumption at various transceiver states
- Energy scan of all channels
- Maximum achievable application throughput

Getting started with default Performance test application is covered in section 2. Hardware connectivity and software modifications required for adding new external FEM modules is covered in section 3 and 4 respectively.

2.   Getting started with Performance test EVK

The Performance_Test_EVK is a terminal-based TAL level example application used extensively for Range measurement and Packet Error Rate measurement. Download and install IEEE 802.15.4 MAC stack version 2.8.0 [1]. By default it will be get installed in location C:\Atmel\MAC_v_2_8_0\.

The application is targeted to demonstrate the capabilities of Atmel Transceivers such as,

- Range of the Transceiver for peer-to-peer communication (using Range measurement mode)
- Robust Link Quality (using PER Measurement mode)
- Packet Error Rate measurement (using PER Measurement mode)
- Evaluate features like, (with UART connection only)
    - Antenna Diversity
    - Rx Sensitivity
    - CSMA-CA Transmission
    - Read / Write Transceiver Registers
    - TX Power of radio
    - Continuous transmit test modes
    - Reduced Power consumption mode

Let us consider RCB256RFR2 and Sensor Terminal Board (STB) as an example hardware platform for getting started with Performance test application. RCB256RFR2 mounted over STB is shown in Figure 2-1.You can find more informations about two boards in the below documents,

- AVR2063: Sensor Terminal Board - Hardware User's Manual [4]
- AVR10004: RCB256RFR2 – Hardware User Manual [3]

Figure 2-1. RCB256RFR2 and Sensor Terminal Board
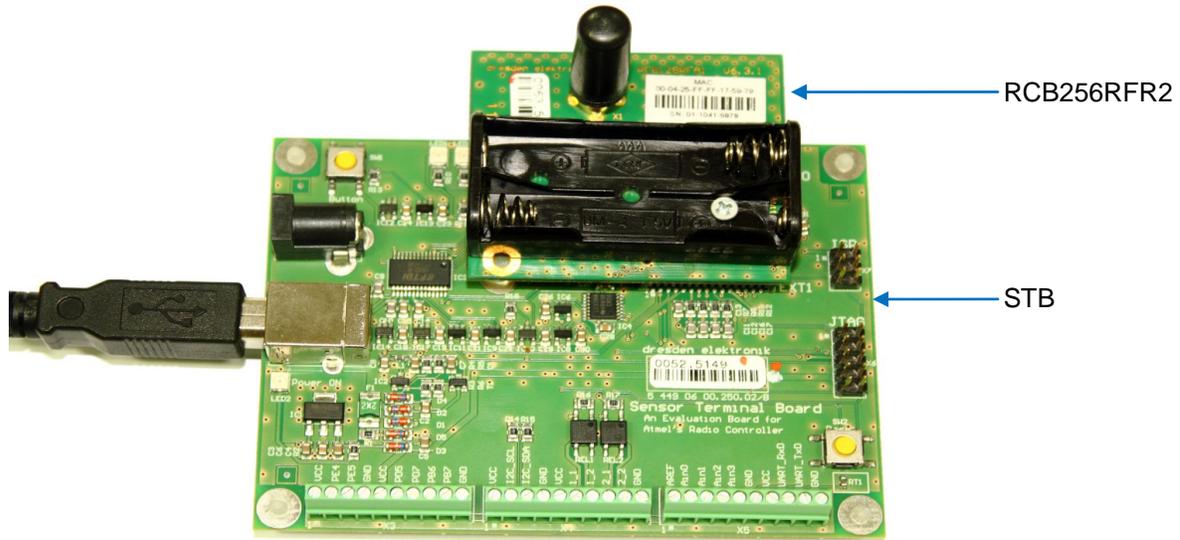
2.1 Serial interface

Using STB it is possible to configure either USB0 or UART1 for serial interface. Default Performance test EVK application based on STB platform has USB0 interface enabled for serial communication.

Please follow the below steps for installing the STB driver,

- Once the STB is connected "Found New Hardware wizard" will pop up. If it is not happening then update the driver manually by going to Computer Management -> Device Manager -> on the right panel Select the new Device -> Right Click Update Driver.
- Select the radio button for Install from a list or specific location (Advanced), as shown in Figure 2-2.
- After connecting the STB board to PC it asks for driver. Please point to the directory MAC_v_2_8_0\PAL\Board_Utils\STB_USB_Driver, as shown in Figure 2-2.
- In the Hardware Installation dialog click Continue Anyway and the installation will proceed, refer Figure 2-3.
- It might ask for second time, please click Continue Anyway again.
- Once the driver installation is completed check whether it is enumerated as SensTermBoard in the Computer Management -> Device Manager -> Ports, refer Figure 2-4.
- Steady glow of LED2 besides the USB port indicates the successful installation of the STB driver.
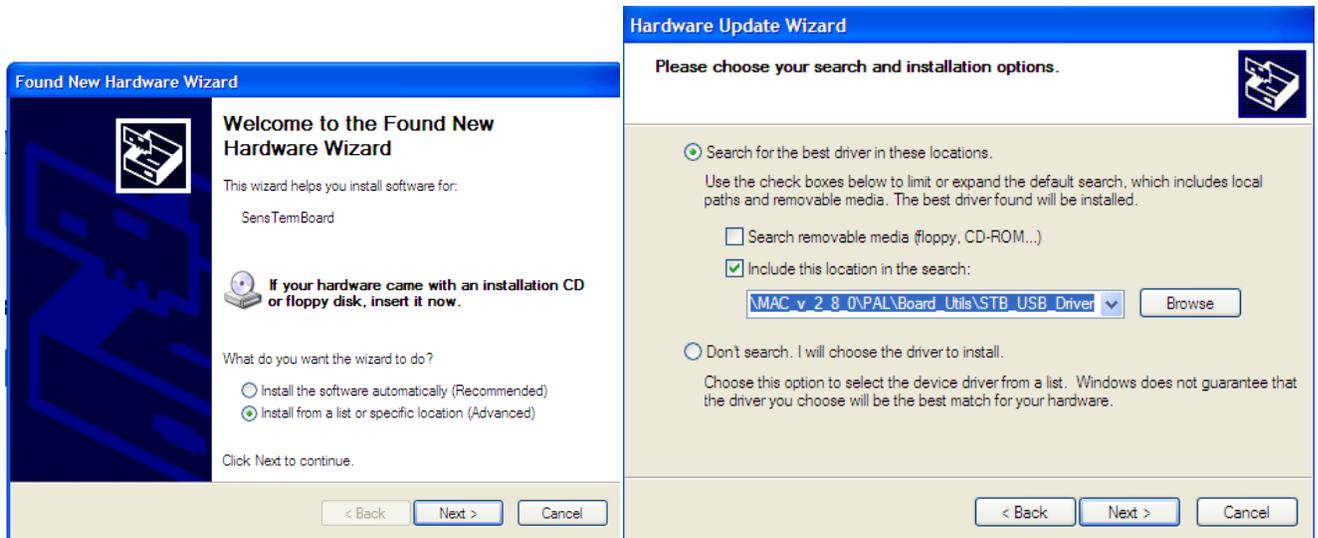
Figure 2-2. STB Driver path selection

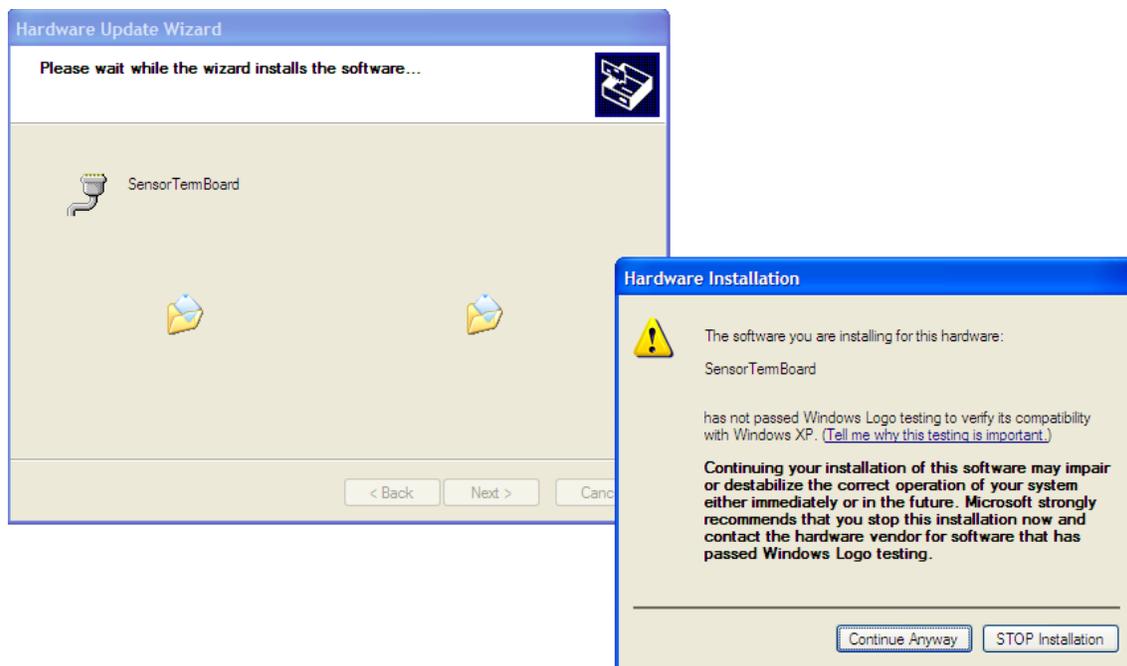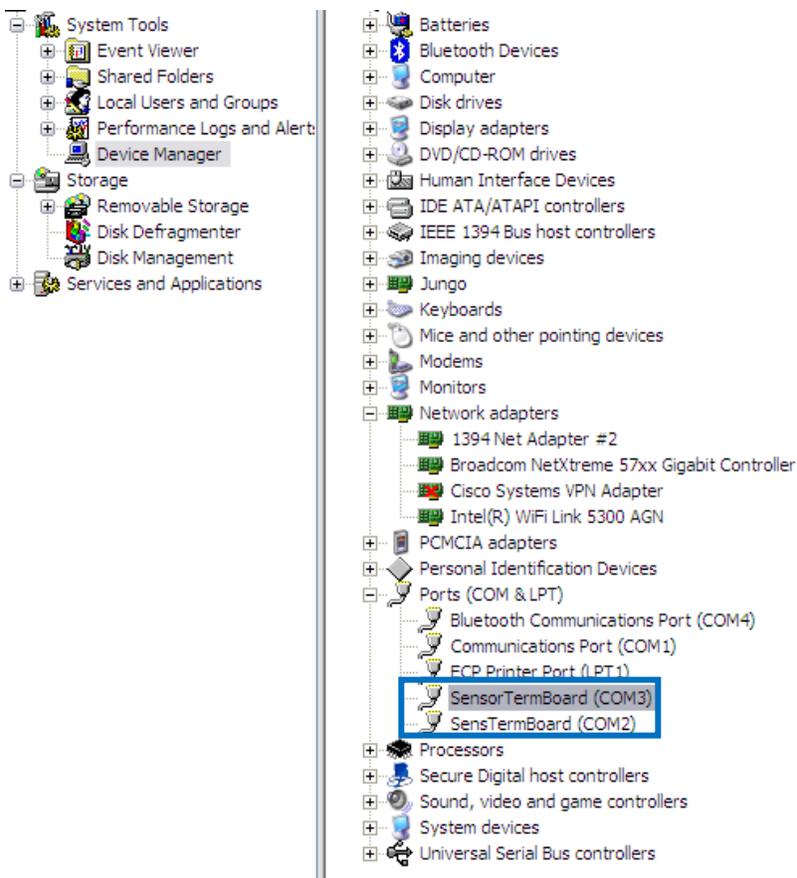**Figure 2-3. Hardware installation**

Figure 2-4. Check the Enumerated STB board

Tera Term [16] is used as example for terminal interface. And configure the Baud Rate: Data: Parity: Stop: Flow control settings as 9600:8: None: 1: None respectively for the enumerated COM port.

Note: Open Tera Term -> Setup -> Serial port

2.2 Programming interface

The firmware has to be loaded using JTAG interface. As RCB256RFR2 board does not have on board JTAG interface we need to have Sensor Terminal Board (STB) for programming the firmware as shown in Figure 2-5.

Note: Custom board can also be designed to have this programming header on the same base board itself.
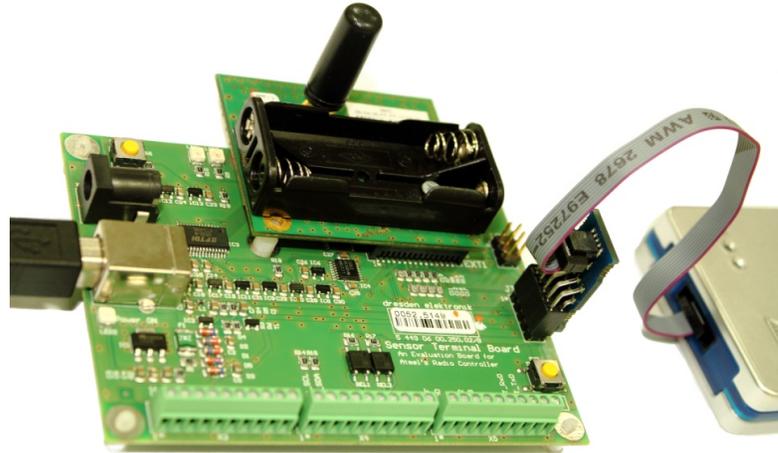
Default Binary image:
\MAC_v_2_8_0\Applications\TAL_Examples\Performance_Test_EVK\ATMEGA256RFR2_RCB_6_3_2_SENS_TERM_
BOARD\GCC\ Performance_test_evk.hex

Fuse settings: 0xFF 0x91 0xE2

Notes: Fuse settings can be changed as per the application requirement.

Figure 2-5.   JTAG programming interface on STB

2.3   Running default Performance test application

Performance test EVK example application flow chart is shown in Figure 2-6 and it has two operation modes,

1.   Range measurement mode
2.   Packet Error Rate measurement mode

Section 2.2 and 2.3 explains the procedure for entering these modes.

Figure 2-6.   Performance Test EVK Application State Diagram
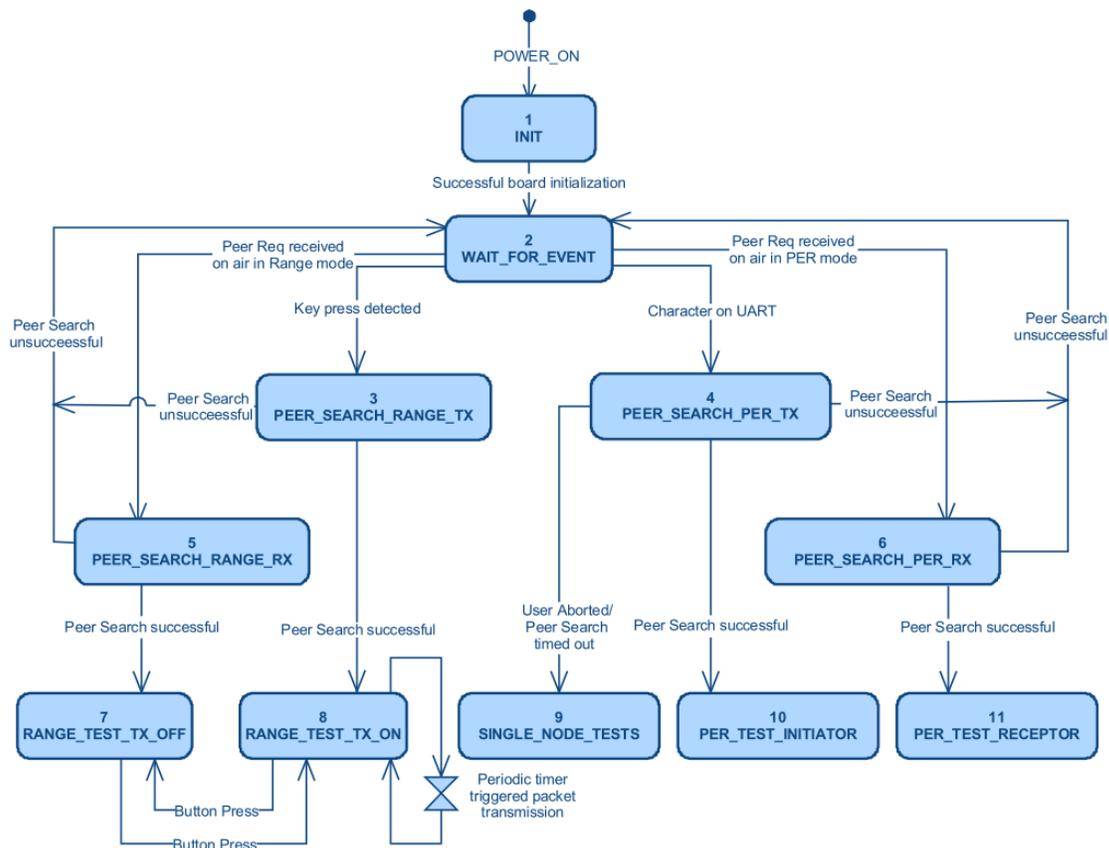
2.4 Range test mode

After initializing the board, the Performance test EVK application waits either for a character on UART event or for a key press event as shown in Figure 2-7

During Range measurement, the transmitter node will initiate a sequence to find a peer node. Once peer node is found, packet transmission is initiated by the transmitter to the receiver. And the Receiver node acknowledges each packet received.

Press button SW1 on Sensor Terminal Board to initiate peer search for Range Measurement Mode. Sequence diagram for Range Measurement Mode is shown in Figure 2-8.

Note: Code implementation is available in wait_for_event_task() function in wait_for_event.c file. Pin definition for sensing button press is available in pal_config.h file.

**Figure 2-7.   Sequence diagram of Range measurement**
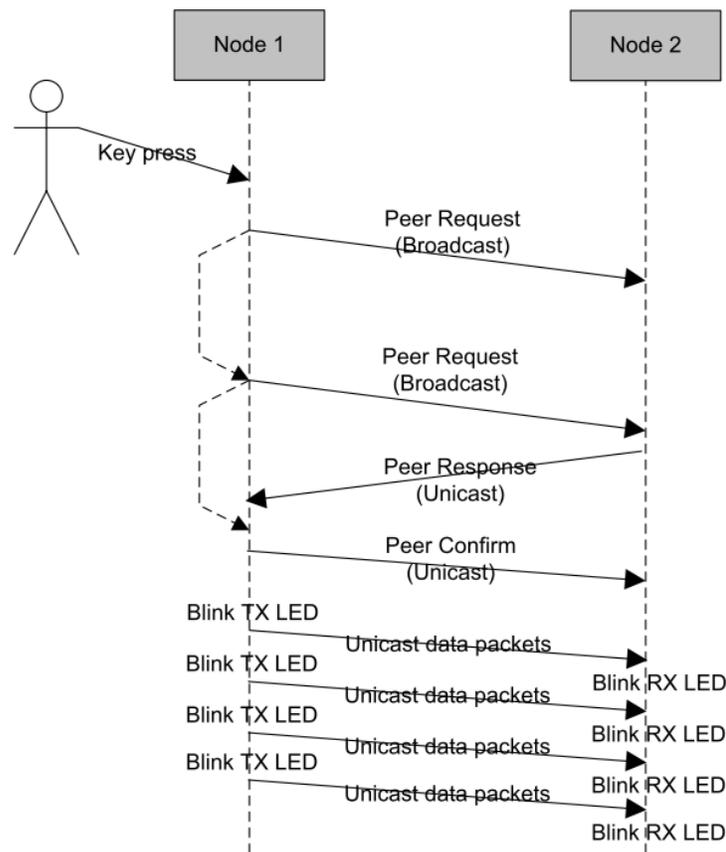
Debug prints can be viewed if the node is connected to a serial interface (but it is not mandatory). The node on which the key was pressed will display a print as shown in Figure 2-8 This node initiates the transmission and calls itself the TX node.

Figure 2-8. Initializing Range measurement – transmitter
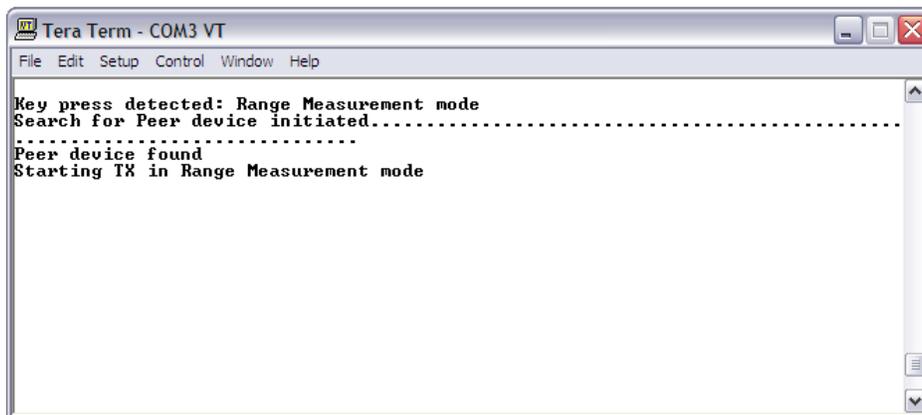
The node connected to the TX node over RF link will display print as shown in Figure 2-9. This node receives the packets and calls itself the RX node.

Figure 2-9. Initializing Range measurement – receiver
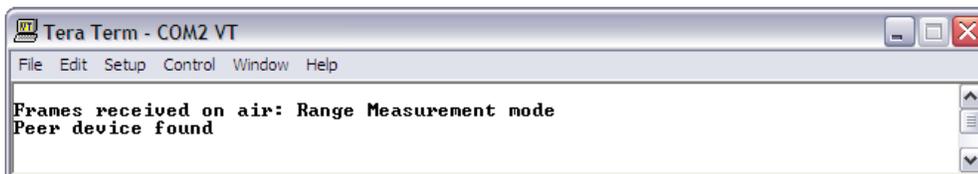
On input of any character in the serial interface prints the statistics of the frames received and frames sent as shown in Figure 2-10. And the frames from RX node are zero always, because frames are sent only by the TX node.

But two way communications can be activated if the button is pressed on both the RX node. Now any input of character in serial interface prints the statistics of the frames sent by both TX node and RX node as shown in Figure 2-11.

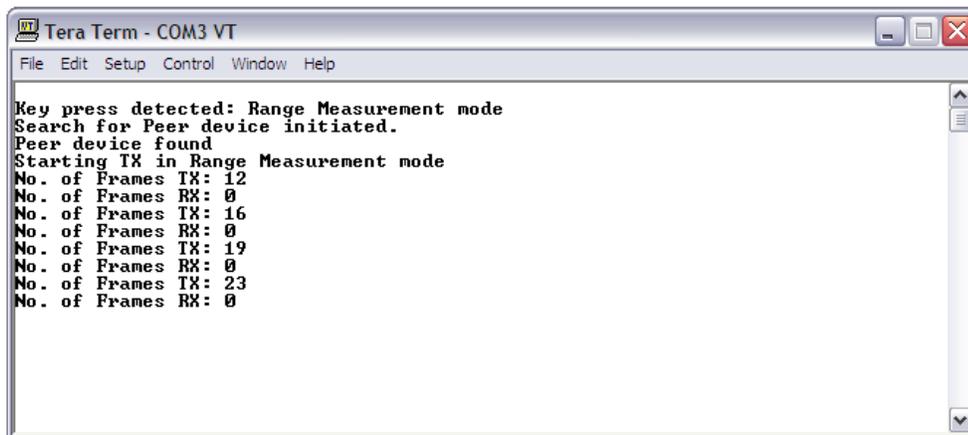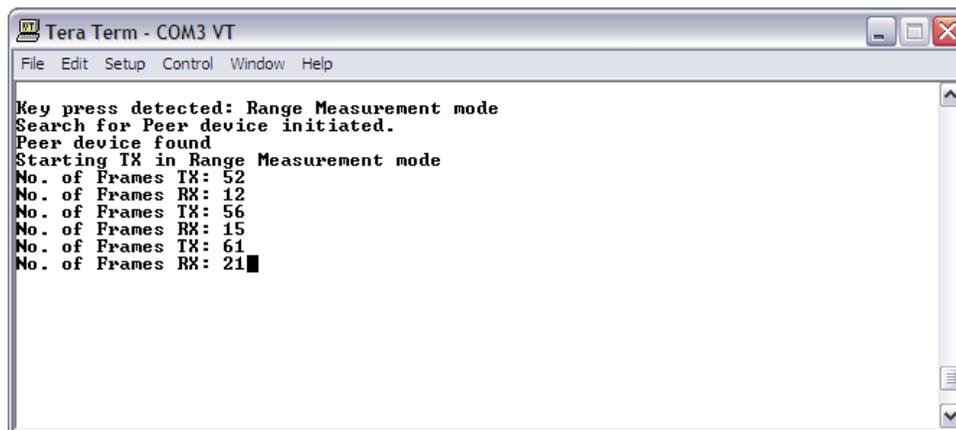**Figure 2-10. One way communication for Range measurement**

Figure 2-11. Two way communication for Range measurement

LED0 on STB indicates frame is sent from the node and LED1 on STB indicates frame is received by the node. For two way communications both LED0 and LED1 shall blink, because each node send and receive frames simultaneously.

It shall be possible introduce mobility for both TX and RX nodes in Range Measurement mode by disconnecting the serial interface. From the LED indicates customer can get a rough estimate of RF link between two particular nodes for the given environment. For example, if blinking of LED1 is not periodic, then we can interpret that the RF link is not proper. Cause of the problem can be due to one of the below reasons,

1. Lower output transmit power on transmitting node
2. Poor Receiver Sensitivity on receiving node
3. Nodes might be located at the null points of antenna radiation pattern
4. Environment of test.

In order to understand the reason or cause of the issue, it is required to run PER Measurement mode tests, refer section 2.6.

2.5 PER measurement mode

In PER measurement mode one of the nodes should be connected to the terminal program through serial interface. The node connected to the terminal is referred as transmitter and other node (need not be connected to the terminal or remote node) is referred as receiver.

So PER measurement mode has limited mobility because one node has to be permanently connected to serial interface for configuration and testing.

● After the boards are turned on if any character is received on the serial interface then the node (transmitter) tries to find its peer node (i.e. receiver) as shown in Figure 2-12.

● If the peer node is found then a menu appears as shown in Figure 2-13.

● And if search for peer node is aborted / failed then a minimal set of test can be performed with only single node as shown in Figure 2-14.

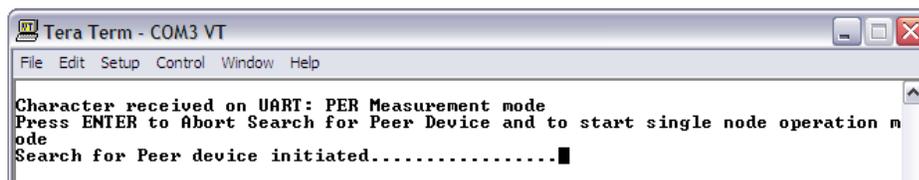**Figure 2-12. Initializing PER measurement**

Figure 2-13. Main Menu after Peer Search Process in PER mode is successful
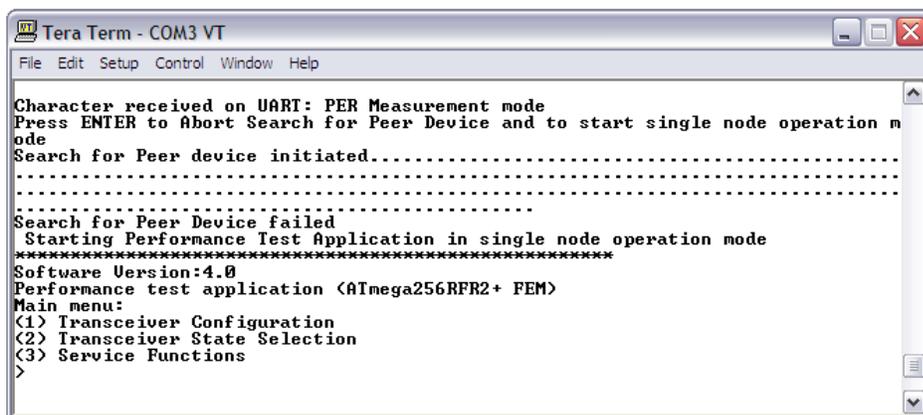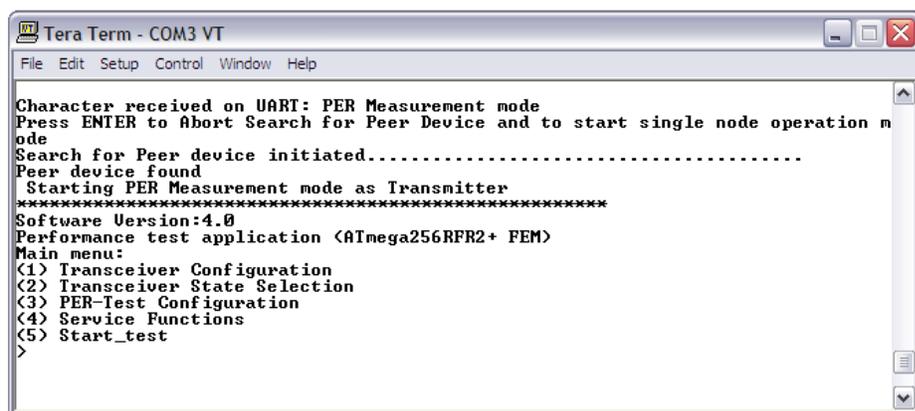

Figure 2-14. Main menu after Peer Search process aborted/failed

2.6 PER measurement mode configuration options

Below Table 2-1, Table 2-2, Table 2-3 and Table 2-4 gives a quick overview on the list of options available in Performance test EVK application. Additional description and importance of parameters are provided in section 5.

Table 2-1.   Description for Sub menu – Transceiver Configuration (1)

Menu Option	Functionalities	Default Value	Comment
C	Channel	20	User can change channel Allows the user to enter ISM frequencies also in case of AT86RF233 transceiver
P	Channel Page	0	User can change channel page
R	RPC	Enabled	Toggling RPC (Reduced Power Consumption) .Only available in AT86RF233
X	Desensitization	Disabled	Toggling Receiver Desensitization
W	TX Power	3 dBm (depends on Transceiver)	For changing TX power of the radio transceiver. Allows the user to enter TX power in absolute dBm values or TX_PWR register values.

A	Auto-ACK	Disabled	To enable / disable auto ACK request
F	Retransmission	Disabled	To enable / disable auto re-transmission for no ACK packet
M	CSMA	Enabled	To enable / disable CSMA functionality for TX
Y	Antenna Diversity	Enabled	To toggle the antenna diversity mode on the node connected to the PC
#*	FEM control	Enabled	To enable/disable external FEM

* Option added in this example for controlling external FEM

Table 2-2.   Description for Sub menu – Transceiver State Selection (2)

Menu Option	Functionalities	Default Value	Comment
X	Desensitization	Disabled	Toggling Receiver Desensitization
S	RESET	--	Allow the user to reset the transceiver
B	DEEP_SLEEP	--	Put the transceiver in DEEP SLEEP (Only available in AT86RF233)
T	SLEEP	--	Put the transceiver in SLEEP
G	TRX_OFF	--	Put the transceiver in TRX_OFF state
J	PLL_ON	--	Put the transceiver in PLL_ON state
K	RX_ON	--	Put the transceiver in RX_ON state
U	Continuous Transmission	--	To enable / disable continuous transmission on the current channel
Y	Antenna Diversity	Enabled	To toggle the antenna diversity mode on the node connected to the PC
#*	FEM control	Enabled	To enable/disable external FEM

* Option added in this example for controlling external FEM

Table 2-3.   Description for Sub menu – PER-Test Configuration (3)

Menu Option	Functionalities	Default Value	Comment
N	Test Frames	100	No. of test frames to be transmitted. Max value = 4,294,967,295
L	Frame length	20	The length of frame inclusive of headers limits are (12 - 127)
Q	Diversity	Enabled	To enable / disable the antenna diversity on the remote node
Z	CRC	Disabled	To enable/disable the CRC settings on remote node

Table 2-4.   Description for Sub menu – Service functions (4)

Menu Option	Functionalities	Default Value	Comment
I	Peer Identify	--	Peer node identifies itself by blinking its LEDs
E	Energy Scan	--	To do energy scan for all channels
U	Continuous Transmission	--	To enable / disable continuous transmission on the current channel
D	Continuous Wave Pulse	--	To enable / disable continuous wave pulse mode from the radio transceiver
V	Sensor Data	--	To read the sensor data in voltage and temperature
H	Read / Write	--	To read or write any register set from the radio transceiver

3. Hardware setup for adding external FEM

This section describes the hardware mapping required for controlling external FEM module.

Example custom board considered in this document includes Atmel's RCB256RFR2 [3] on Sensor Terminal Board platform (STB) [4] and Skywork's SE2431L–EK1 board [5].

Both the RCB256RFR2 and SE2431L-EK1 boards are powered by the PC through USB interface on Sensor Terminal Board.

3.1 Logical control checklist

Table 3-1 provides the list logical controls options available in the SE2431L [6] chip. It is always recommended to refer the logical control table available on the other external FEM datasheet.

ATmega256RFR2 chip has DIG1/2/3/4 control lines which are automatically switched to control Antenna selection and RX/TX selection based on the transceiver state.

DIG1 and DIG2 are differential pin pair used to feed the antenna switch signal for controlling Antenna diversity switching, refer section 9.8.3 Antenna Diversity in ATmega256RFR2 datasheet [11].

The control of an external PA is done via the differential pin pair DIG3 and DIG4. DIG3 = H / DIG4 = L indicates that the transmission starts and can be used to enable an external PA, refer section 9.8.4 RX/TX Indicator in ATmega256RFR2 datasheet [11].

So CTX and ANT_SEL pin on SE2431L can be connected directly to these DIG lines of ATmega256RFR2. For other controls (like CPS and CSD) any of the free GPIO pins can be used. Example pin mapping between ATmega256RFR2 and SE2431L is provided in section 3.2.

Table 3-1.   Logical controls available on SE2431L

State	CPS	CSD	CTX	ANT_SEL
Tx mode	1	1	1	x
Rx bypass mode*	0	1	0	X
Rx LNA mode	1	1	0	X
All off (sleep mode)	0	0	0	x
Antenna_1 selected	x	x	x	0
Antenna_2 selected	x	x	x	1

*RX bypass mode option is out of scope of this application note.

3.2 External FEM interface

Refer Figure 3-1 and Figure 3-2 for connecting RCB256RFR2 +STB with SE2431L-EK1 board. Due to the GPIO limitations on the STB we have chosen PD0 and PD1 lines for controlling CSD and CPS. Example reference pin mapping between RCB256RFR2 and SE2431L-EK board is given Table 3-2.

Table 3-2.   Pin mapping between RCB256RFR2 and SE2431L-EK1

RCB256RFR2	SE2431L-EK1	Quick reference on STB
PD0[(1)]	CSD	On STB pin I2C_SCL, X4 connector
PD1[(1)]	CPS	On STB pin I2C_SDA, X4 connector

DIG3/PG0	CTX	On STB pin PB6, X3 connector
DIG1/PG1	ANTSEL	On STB pin PB7, X3 connector
VCC	VCC	On STB pin VCC, X3 connector
GND	GND	On STB pin GND, X3 connector
VCC	VCC2	On SE2431L-EK1 board use jumper between VCC and VCC2
VCC	VDD	On SE2431L-EK1 board use jumper between VCC and VDD

(1) Please note that GPIO controls pins (PD0 and PD1) chosen for this example have the alternate function as I2C interface. Please choose different GPIO control pins if the design requires I2C interface.

For this example reference board, it shall required to have wires for connecting between the RCB256RFR2 and SE2431L-EK1 board and atleast two SMA RF cable, **part number: R284C0351054** [12].

● One RF cable for connecting the RF output from RCB256RFR2 to the RF input of SE2431L-EK1, refer Figure 3-2.

● And another RF cable for performing conducted measurement tests using RF instruments like Spectrum analyzer.

Also it might be required to have two SMA antennas for ANT1 and ANT2 connectors.

Figure 3-1.   RCB256RFR2 + STB board and SE2431L-EK1 board
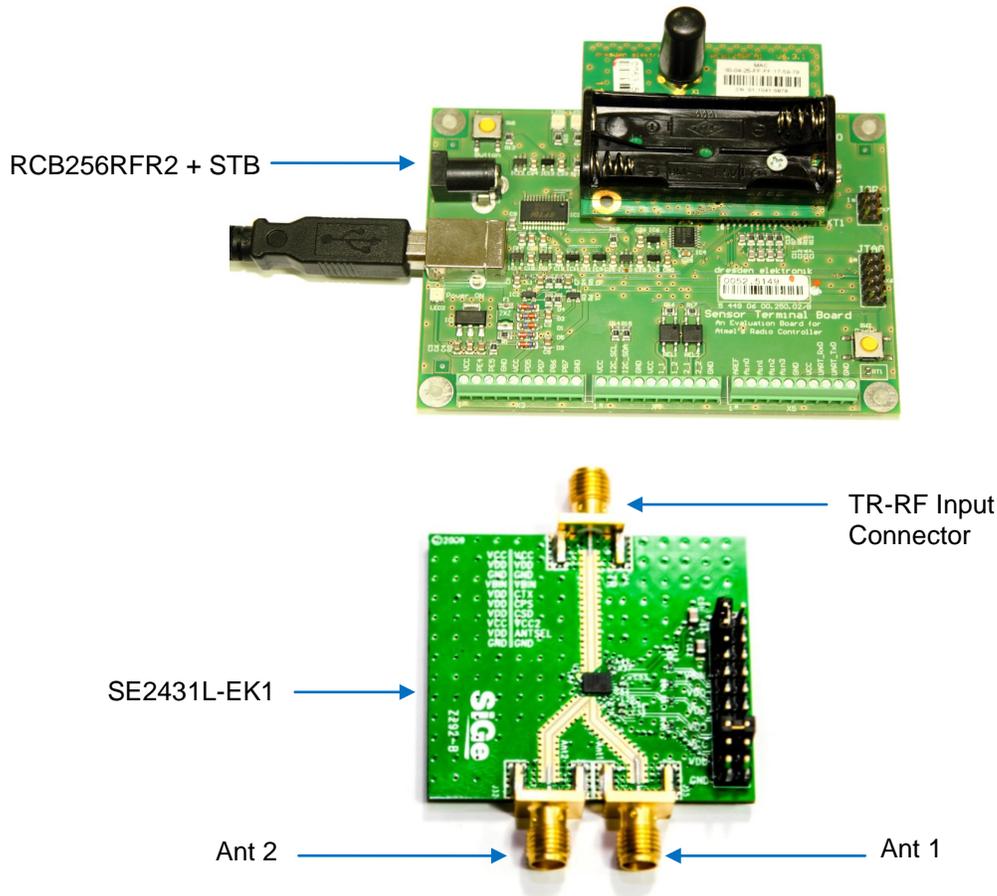
Figure 3-2. Hardware setup of RCB256RFR2 + STB + SE2431L-EK1
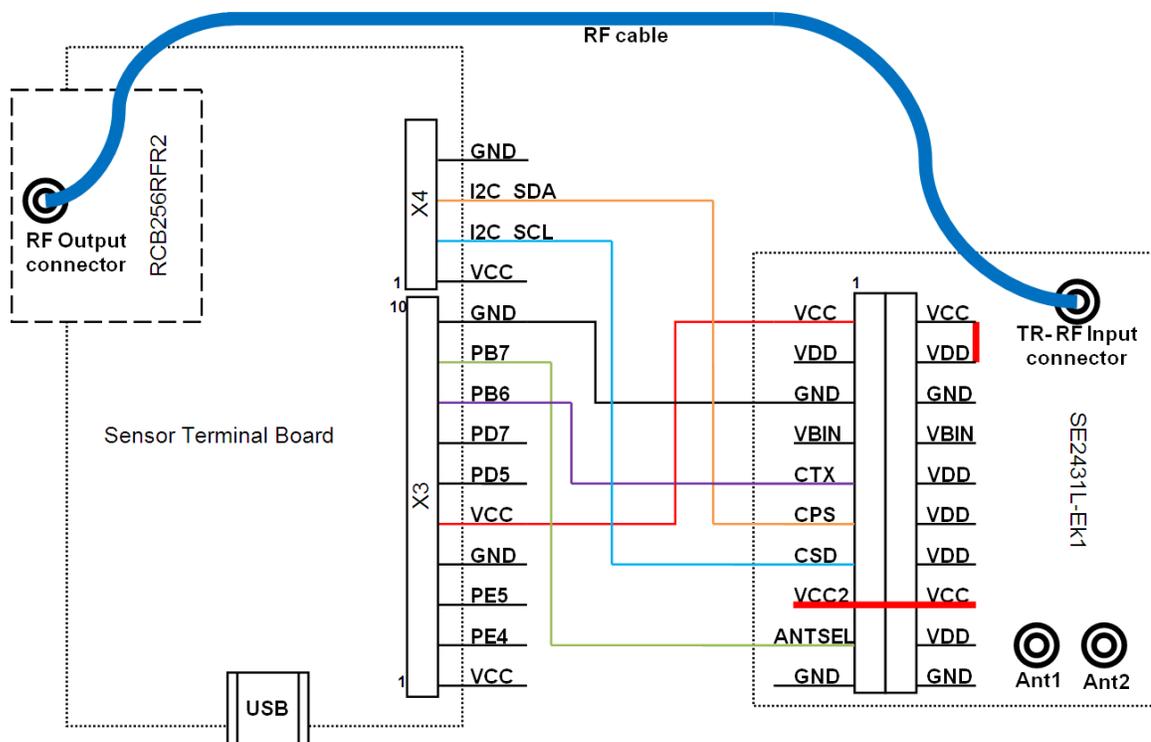
4. Software modifications for adding external FEM

Choose an example project which is best suited for the custom board. Before starting the actual porting below terms need to be defined:

- Target MCU: MCU that is not yet supported and shall be utilized within a new platform
- Base MCU: MCU that is already supported within the MAC package and it's PAL implementation is used as base code for the target MCU
- Target board: Board based on the target MCU that is not yet supported and shall be utilized within a new platform
- Base board: Board that is already supported within the base MCU PAL directory and is used as base code for the target board
- Target platform: Platform consisting of target MCU and target board
- Base platform: Platform consisting of base MCU and base board

As this application note concentrates only on adding external FEM support on existing platform, detailed procedure for adding new platform support is provided in section11, Platform Porting in MAC AVR2025: IEEE 802.15.4 MAC Software Package - User Guide [2]. Once the basic porting is completed, please continue reading following sections for adding support for external FEM module.

Example project refered in the application note is based on the below target platform,

- Target MCU: ATmega256RFR2
- Target Board: RCB256RFR2
- Target Platform: RCB256RFR2 + Sensor Terminal Board
- Chosen project: \MAC_v_2_8_0\Applications\TAL_Examples\Performance_Test_EVK\ ATMEGA256RFR2_RCB_6_3_2_SENS_TERM_BOARD\

4.1 Application layer

Open the example project in Atmel AVR Studio® or IAR Embedded Workbench® IDE.

Add:

Compile time switch EXT_RF_FRONT_END_CTRL in the project for enabling external FEM support.

For example,

- Open AVR Studio project -> Makefile -> Add CFLAGS += -DEXT_RF_FRONT_END_CTRL
- Open IAR project -> General options -> C/C++ Compiler -> Preprocessor -> Defined symbols -> Add EXT_RF_FRONT_END_CTRL

Please refer the code modification given below for supporting external FEM. Below file changes are common for both IAR and GCC compilers.

File: C:\Atmel\MAC_v_2_8_0\Applications\TAL_Examples\Performance_Test_EVK\Src\init_state.c

Function: `void init_state_init(void *arg)`

Add:

```
#ifdef EXT_RF_FRONT_END_CTRL
    /* Initialize FEM GPIO controls */
    FEM_INIT();
#endif
```

Note: Add next to pal_button_init();

File: C:\Atmel\MAC_v_2_8_0\Applications\TAL_Examples\Performance_Test_EVK\Src\peer_search_initiator.c

Function: `void peer_search_initiator_init(void *arg)`

Add:

```
/* Disable external FEM */
FEM_DISABLE();
```

Note: Add before pal_trx_bit_write(SR_PA_EXT_EN, PA_EXT_DISABLE); and within #ifdef EXT_RF_FRONT_END_CTRL

File: C:\Atmel\MAC_v_2_8_0\Applications\TAL_Examples\Performance_Test_EVK\Src\peer_search_receptor.c

Function: `void peer_search_receptor_init(void *arg)`

Add:

```
  /* Disable external FEM */
  FEM_DISABLE();
```

Note: Add before pal_trx_bit_write(SR_PA_EXT_EN, PA_EXT_DISABLE); and within #ifdef EXT_RF_FRONT_END_CTRL

File: C:\Atmel\MAC_v_2_8_0\Applications\TAL_Examples\Performance_Test_EVK\Src\per_mode_initiator.c

Add:

```
/* Declare the FEM status flag and function for toggling FEM */
#ifdef EXT_RF_FRONT_END_CTRL
static bool fem_status = true;
static void toggle_fem(void);
#endif
```

Note: Add in Globals section of the file

File: C:\Atmel\MAC_v_2_8_0\Applications\TAL_Examples\Performance_Test_EVK\Src\per_mode_initiator.c

Function: `void per_mode_initiator_init(void *parameter)`

Add:

```
 /* Enable external FEM */
  FEM_ENABLE();
```

Note: Add before pal_trx_bit_write(SR_PA_EXT_EN, PA_EXT_ENABLE); and within #ifdef
         EXT_RF_FRONT_END_CTRL

File: C:\Atmel\MAC_v_2_8_0\Applications\TAL_Examples\Performance_Test_EVK\Src\per_mode_initiator.c

Function: `static void print_HW_version_details(void)`

Add:

```
#ifdef EXT_RF_FRONT_END_CTRL
    printf("+ FEM");
#endif
```

Note: Add before printf(")");

File: C:\Atmel\MAC_v_2_8_0\Applications\TAL_Examples\Performance_Test_EVK\Src\per_mode_initiator.c

Function: `static void print_trx_config_menu(void)`

Add:

```
/************************External FEM ******************************/
#ifdef EXT_RF_FRONT_END_CTRL
    {
      printf("    (#) : Toggle FEM control - ");

      fem_status = pal_trx_bit_read(SR_PA_EXT_EN) ? true : false;
          if (fem_status)
          {
              printf("enabled\r\n");
          }
          else
          {
              printf("disabled\r\n");
          }
    }
#endif /* #ifdef EXT_RF_FRONT_END_CTRL*/
```

Note: Add after #endif /* #if (ANTENNA_DIVERSITY == 1) */ and before printf("   (0) : Leave sub-menu\r\n");

File: C:\Atmel\MAC_v_2_8_0\Applications\TAL_Examples\Performance_Test_EVK\Src\per_mode_initiator.c

Function: `static void print_trx_config_menu(void)`

Add:

```
#ifdef EXT_RF_FRONT_END_CTRL
        case '#':
            toggle_fem();
            break;
#endif
```

Note: Add within switch (input) next to case 'Y': for toggle_antenna_diversity();

File: C:\Atmel\MAC_v_2_8_0\Applications\TAL_Examples\Performance_Test_EVK\Src\per_mode_initiator.c

Function: static void print_trx_state_sel_menu(void)

Add:

```
/***********************External FEM *******************************/
#ifdef EXT_RF_FRONT_END_CTRL
{
    printf("    (#) : Toggle FEM control - ");

    fem_status = pal_trx_bit_read(SR_PA_EXT_EN) ? true : false;
        if (fem_status)
        {
            printf("enabled\r\n");
        }
        else
        {
            printf("disabled\r\n");
        }
    }
#endif /* ifdef EXT_RF_FRONT_END_CTRL */
```

Note: Add after #endif /* #if (ANTENNA_DIVERSITY == 1) */ and before printf("   (0) : Leave sub-menu\r\n");

File: C:\Atmel\MAC_v_2_8_0\Applications\TAL_Examples\Performance_Test_EVK\Src\per_mode_initiator.c

Function: static void print_trx_state_sel_menu(void)

Add:

```
#ifdef EXT_RF_FRONT_END_CTRL
        case '#':
            toggle_fem();
            break;
#endif
```

Note: Add within switch (input) before case '5':

File: C:\Atmel\MAC_v_2_8_0\Applications\TAL_Examples\Performance_Test_EVK\Src\per_mode_initiator.c

Function: static void toggle_trx_sleep(void)

Add:

```
#ifdef EXT_RF_FRONT_END_CTRL
    /* Disable FEM module */
    FEM_DISABLE();
    printf("\r\n FEM in sleep mode : Controls disabled");
#endif
```

Note: Add next to printf("\r\n TRX in sleep mode 1 : Options disabled");

File: C:\Atmel\MAC_v_2_8_0\Applications\TAL_Examples\Performance_Test_EVK\Src\per_mode_initiator.c

Function: static void print_trx_state_sel_menu(void)

Add:

```
#ifdef EXT_RF_FRONT_END_CTRL
    /* Enable FEM module */
    FEM_ENABLE();
    printf("\r\n FEM woke up");
 #endif
```

Note: Add next to printf("\r\n TRX woke up");

File: C:\Atmel\MAC_v_2_8_0\Applications\TAL_Examples\Performance_Test_EVK\Src\per_mode_initiator.c

Function: `static void start_cw_transmission(void)`

Add:

```
#if (ANTENNA_DIVERSITY == 1)
    uint8_t antenna_temp;
      /* Check which antenna has been selected */
    antenna_temp = pal_trx_bit_read(SR_ANT_CTRL);
#endif
```

Note: Add next to uint8_t input;

File: C:\Atmel\MAC_v_2_8_0\Applications\TAL_Examples\Performance_Test_EVK\Src\per_mode_initiator.c

Function: `static void start_cw_transmission(void)`

Add:

```
#ifdef EXT_RF_FRONT_END_CTRL
            if(fem_status)
            {
              /* Enable RF front end control after tal_reset */
              FEM_ENABLE();
              pal_trx_bit_write(SR_PA_EXT_EN, PA_EXT_ENABLE);
            }
#endif
#if (ANTENNA_DIVERSITY == 1)
        if (antenna_temp == 1)
        {
            /* Enable A1/X2 */
            pal_trx_bit_write(SR_ANT_CTRL, ANT_CTRL_1);
        }
        else
        {
            /* Enable A2/X3 */
            pal_trx_bit_write(SR_ANT_CTRL, ANT_CTRL_2);
        }
#endif
```

Note: Add next to tal_reset(false);

File: C:\Atmel\MAC_v_2_8_0\Applications\TAL_Examples\Performance_Test_EVK\Src\per_mode_initiator.c

Function: `void save_all_settings(void)`

Add:

```
#ifdef EXT_RF_FRONT_END_CTRL
  fem_status = pal_trx_bit_read(SR_PA_EXT_EN);
#endif
```

Note: Add anywhere within this function

File: C:\Atmel\MAC_v_2_8_0\Applications\TAL_Examples\Performance_Test_EVK\Src\per_mode_initiator.c

Function: `void recover_all_settings(void)`

Add:

```
#ifdef EXT_RF_FRONT_END_CTRL
if(fem_status)
  {
    /* Enable FEM module */
    FEM_ENABLE();
```

```
       pal_trx_bit_write(SR_PA_EXT_EN, PA_EXT_ENABLE);
    }
    else
    {
        /* Disable FEM module */
      FEM_DISABLE();
      pal_trx_bit_write(SR_PA_EXT_EN, PA_EXT_DISABLE);

    }
#endif
```

Note: Add anywhere within the function

File: C:\Atmel\MAC_v_2_8_0\Applications\TAL_Examples\Performance_Test_EVK\Src\per_mode_initiator.c

Add:

```
#ifdef EXT_RF_FRONT_END_CTRL
static void toggle_fem(void)
{
if(fem_status)
  {
    fem_status = false;
      /* Disable external FEM */
    FEM_DISABLE();
    pal_trx_bit_write(SR_PA_EXT_EN, PA_EXT_DISABLE);
  }
  else
  {
    fem_status = true;
      /* Enable external FEM */
    FEM_ENABLE();
    pal_trx_bit_write(SR_PA_EXT_EN, PA_EXT_ENABLE);
  }
}
#endif
```

Note: Add the function definition within the file

File: C:\Atmel\MAC_v_2_8_0\Applications\TAL_Examples\Performance_Test_EVK\Src\per_mode_receptor.c

Function: `void per_mode_receptor_init(void *parameter)`

Add:

```
    /* Enable external FEM */
    FEM_ENABLE();
```

Note: Add before pal_trx_bit_write(SR_PA_EXT_EN, PA_EXT_ENABLE); and within #ifdef
         EXT_RF_FRONT_END_CTRL

4.2   PAL layer

File: C:\Atmel\MAC_v_2_8_0\PAL\MEGA_RF\ATMEGA256RFR2\Boards\RCB_6_3_2_SENS_TERM_BOARD
\pal_board.c

Add:

```
#ifdef CUSTOM_PWR_TABLE
/*
 * Update definitions for TX Pout and RX Gain in case of FEM usage
 */


/*
 * Mapping table for FEM TX Pout (dBm).
 *      based on board characterization
 */
```

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```
FLASH_DECLARE(int8_t tx_pwr_table[16]) =
{
    /*PA*/ /* ATmega256RFR2 */  /* TX_PWR */ /* EVDD 3V0 */
    21,  /*  3.0  */  /*  0x00  */
    22,  /*  2.8  */  /*  0x01  */
    22,  /*  2.3  */  /*  0x02  */
    21,  /*  1.8  */  /*  0x03  */
    21,  /*  1.3  */  /*  0x04  */
    21,  /*  0.7  */  /*  0x05  */
    21,  /*  0.0  */  /*  0x06  */
    21,  /*  -1   */  /*  0x07  */
    20,  /*  -2   */  /*  0x08  */
    20,  /*  -3   */  /*  0x09  */
    19,  /*  -4   */  /*  0x0A  */
    17,  /*  -5   */  /*  0x0B  */
    16,  /*  -7   */  /*  0x0C  */
    13,  /*  -9   */  /*  0x0D  */
    9,  /*  -12  */  /*  0x0E  */
    4,  /*  -17  */  /*  0x0F  */
};
#endif
```

Note: Add in Globals section of the file. The power table values have to be modified based the actual measured output power levels of the board.

File: C:\Atmel\MAC_v_2_8_0\PAL\MEGA_RF\ATMEGA256RFR2\Boards\RCB_6_3_2_SENS_TERM_BOARD
\pal_config.h

Add:

```
/**
 * This board supports antenna diversity.
 */
#define ANTENNA_DIVERSITY               (1)


/**
 * For this example we have chosen PD0 and PD1 GPIOs for controlling CSD and CPS
logics
 * User can choose different GPIOs based on their actual board design
 */

/* CSD is used to enable the FEM module */
#define CSD    PD0

/* CPS is used to enable LNA during reception */
#define CPS    PD1



/* Define FEM_DDR value based GPIO selection */
#define FEM_DDR DDRD

/* Define FEM_PORT value based GPIO selection */
#define FEM_PORT PORTD
/*
 * External FEM controls
 */
#define FEM_INIT()       FEM_DDR = _BV(CSD) | _BV(CPS);
#define FEM_ENABLE()      FEM_PORT = _BV(CSD) | _BV(CPS);
#define FEM_DISABLE()    FEM_PORT = ((0<<CSD) | (0<<CPS));


/**
 * Example application uses a custom power table
 */
```

```
#ifdef EXT_RF_FRONT_END_CTRL

#define CUSTOM_PWR_TABLE
#define CUSTOM_DEFAULT_TX_PWR

#endif

/*
 * Value of an external LNA gain.
 * If no external LNA is available, the value is 0.
 */
#define EXT_LNA_HIGH_GAIN    (14)

/**
  * RSSI BASE VAL based on External LNA Gain.
  */
#define PAL_RSSI_BASE_VAL      (RSSI_BASE_VAL_DBM - EXT_LNA_HIGH_GAIN)


#ifdef CUSTOM_DEFAULT_TX_PWR
/*
 * Default value of transmit power of transceiver: Preset
 *     - definition acct. IEEE802.15.4 PHY PIB attribute phyTransmitPower
 *     - TX Pout init value based on validation
 */
#define TAL_TRANSMIT_POWER_DEFAULT       (TX_PWR_TOLERANCE | 0x14)
#endif

/*
 * Default tx power for Ch26 to meet FCC compliance
  */
#define DEFAULT_TX_POWER_CH26             (0x80 | 0x0d)
```

Note: Values defined in this section vary based on the specification of external FEM. So refer to the FEM datasheet and choose the values accordingly.

4.3   TAL layer

File: C:\Atmel\MAC_v_2_8_0\TAL\ATMEGARFR2\Inc\atmega256rfr2.h

Add:

```
/* Constant PA_EXT_enable for sub-register SR_PA_EXT_EN */
#define PA_EXT_ENABLE   (1)
/* Constant PA_EXT_disable for sub-register SR_PA_EXT_EN */
#define PA_EXT_DISABLE   (0)
```

Note: Preferably next to #define SR_PA_EXT_EN   0x144, 0x80, 7

Add:

```
/* Constant ANT_CTRL_0 for sub-register SR_ANT_CTRL in register RG_ANT_DIV */
#define ANT_CTRL_0               (0)
/* Constant ANT_CTRL_1 for sub-register SR_ANT_CTRL in register RG_ANT_DIV */
#define ANT_CTRL_1               (1)
/* Constant ANT_CTRL_2 for sub-register SR_ANT_CTRL in register RG_ANT_DIV */
#define ANT_CTRL_2               (2)
/* Constant ANT_CTRL_3 for sub-register SR_ANT_CTRL in register RG_ANT_DIV */
#define ANT_CTRL_3               (3)
```

Note: Preferably next to #define SR_ANT_SEL   0x14D, 0x80, 7

File: C:\Atmel\MAC_v_2_8_0\TAL\ATMEGARFR2\Inc\tal_constants.h

Add:

```
#ifndef CUSTOM_DEFAULT_TX_PWR
/*
 * Default value of transmit power of transceiver: Use highest tx power
 */
#define TAL_TRANSMIT_POWER_DEFAULT          (TX_PWR_TOLERANCE | 0x04)
#endif
```

Note: Enclose #define TAL_TRANSMIT_POWER_DEFAULT within the #ifndef CUSTOM_DEFAULT_TX_PWR condition

File: C:\Atmel\MAC_v_2_8_0\TAL\ATMEGARFR2\Src\tal_init.c

Function: `retval_t tal_reset(bool set_default_pib)`

Add:

```
#ifdef EXT_RF_FRONT_END_CTRL
    /* Re-initialize FEM GPIO controls after reset */
    FEM_INIT();
#endif
```

Note: Add before return MAC_SUCCESS;

File: C:\Atmel\MAC_v_2_8_0\TAL\ATMEGARFR2\Src\tal_pib.c

Add:

```
#ifdef CUSTOM_PWR_TABLE
/*
 * If a customized powr table is used, the power table gets defined within the
 * pal_board.c file.
 */
extern FLASH_DECLARE(int8_t tx_pwr_table[16]);
#else
/*
 * Translation table converting register values to power levels (dBm).
 */
FLASH_DECLARE(int8_t tx_pwr_table[16]) =
{
    4,  /* 3.5 */
    3,  /* 3.3 */
    3,  /* 2.8 */
    2,  /* 2.3 */
    2,  /* 1.8 */
    1,  /* 1.2 */
    0,  /* 0.5 */
    -1, /* -0.5 */
    -2, /* -1.5 */
    -3, /* -2.5 */
    -4, /* -3.5 */
    -5, /* -4.5 */
    -7, /* -6.5 */
    -9, /* -8.5 */
    -12,/* -11.5 */
    -17 /* -16.5 */
};
#endif
```

Note: Enclose FLASH_DECLARE(int8_t tx_pwr_table[16]) with #ifdef CUSTOM_PWR_TABLE condition

If the custom board uses other external FEM module, then customer shall be required to change the FEM specific defines on the PAL Layer files.

5. PER measurement mode EVK

After the software modification, build the project (press F7) and flash ATmega256RFR2 new binary image. Refer section 2.6 for getting started with PER measurement mode test

Below sections addresses the significances of various options in Single node and Peer mode tests.

5.1 Single node test

Single node tests can be used during FCC [13] / ETSI [14] certification tests, current consumption measurement at various transceiver states and for validating RF output power of the board.

5.1.1 Channel selection

IEEE 802.15.4 channels from 11 to 26 can be individually chosen using the following procedure,

1. From the main menu, type '1' to display transceiver configuration options.
2. Type 'c' to select channel selection sub-menu.
3. Enter the required channel number and press ENTER.
4. To return back to main menu type '0'.
5. Example screenshot is shown in Figure 5-1

5.1.2 Transmit power selection

Transmit power can be varied in 16 steps by configuring the PHY_TX_PWR register value. Transmit power can be configured using the following procedure,

1. From the main menu, type '1' to display transceiver configuration options.
2. Type 'w' to select TX power selection sub-menu.
3. Type 'a' or 'r' to select either absolute or register value.
4. Enter the required transmit power value and press ENTER.
5. Example screenshot is shown in Figure 5-1

Note: **Absolute power values are derived from the tx_pwr_table [16] in pal_board.c. So it is responsibility of the customer to enter correct absolute values for each PHY_TX_PWR register settings based on the actual transmit power measurement. If the absolute transmit power values are not known, then it is always recommended to configure output power via PHY_TX_PWR register values.**

5.1.3 Antenna selection

Antenna selection option is used to choose either antenna_1 or antenna_2 or enable antenna diversity algorithm. For RCB256RFR2 + SE2431L-EK1 board we have options to choose either antenna 1 or 2 or enable antenna diversity algorithm.

1. From the main menu, type '1' to display transceiver configuration options.
2. Type 'y' to select antenna diversity sub-menu.
3. Type '1' or '2' to select either antenna 1 or antenna 2.
4. Example screenshot is shown in Figure 5-1

Note: **If #define ANTENNA_DIVERSITY is set to '0' in pal_config.h file then this option will not be available because the board does not support antenna diversity.**

5.1.4 Enabling/Disabling FEM

By default external FEM will be enabled. For toggling this feature use the following procedure.

1. From the main menu, type '1' to display transceiver configuration options.
2. Type '#' to toggle external FEM control.

Note: **This option will be available only if EXT_RF_FRONT_END_CTRL build switch is enabled in the project.**

Figure 5-1.   Single node test

5.1.5 Continuous transmission selection

Continuous transmission option shall be helpful during FCC [13] / ETSI [14] certifications. With continuous transmission option it shall be possible to start continuous transmission on the configured channel and transmit power level. For more details refer section 9.9 in ATmega256RFR2 [11].

Two modes are available in continuous transmission mode,

● Continuous Wave mode – Pure carrier wave

● Pseudo Random Binary Sequence mode (PRBS) – Random payload modulated and continuously transmitted.

For choosing these modes refer the following procedure,

1. From the main menu, type '3' to display service functions.
2. Type 'u' to select continuous transmission sub-menu.
3. Type 'c' or 'p' to select either continuous wave or PRBS.
4. Continuous transmission will be observed until any key is pressed on the keyboard.
5. Example screenshot is shown in Figure 5-2.

Figure 5-2.   Continuous transmission using Single node test

Note: **If #define ANTENNA_DIVERSITY is set to '1' in pal_config.h file and EXT_RF_FRONT_END_CTRL build switch is enabled in the project then additional codes described in page 19 for function start_cw_transmission() has to be added. These modifications are required for saving the configurations of external FEM and antenna selection.**

5.1.6 Transceiver state selection

It is possible to navigate to various transceiver states for measuring current consumption,

1. From the main menu, type '2' to select transceiver state.
2. Type the required character for choosing the required state.
3. Example screenshot is shown in Figure 5-3.

Note: **Only transceiver and external FEM are put to sleep in Performance test EVK application. Please note that MCU is in active state.**

Figure 5-3. Transceiver state selection using Single node test

5.1.7   Energy scan on all channels

Energy scan option is useful to understand which frequency channel is noisy / busy. Larger the negative value indicates lower noise on the channel. It can also be used to study the environment during wireless network deployment.

1. From the main menu, type '4' to service functions options.
2. Type 'e' to select energy scan sub-menu.
3. Enter the required duration of energy scan and press ENTER.

Note: **While using external FEM modules, the EXT_LNA_HIGH_GAIN parameter in pal_config.h file have to be configured with the datasheet LNA gain or receiver gain value of that FEM module.**

5.2   Peer mode test

5.2.1   Channel page selection

Channel page selection is not applicable for single node operation mode. Channel page is required to configure the transceiver to proprietary high data rate modes (500kbps, 1Mbps and 2Mbps). For more details please refer to section 9.8.2 in ATmega256RFR2 [4].

1. From the main menu, type '1' to display transceiver configuration options.
2. Type 'p' to select channel page sub-menu.
3. Enter the required channel page and press ENTER.

Note: **At high data rate modes, the maximum achievable coverage distance of the node decreases with respect to 250kbps mode under the same environmental conditions due to reduced spreading factor.**

5.2.2   Number of test frames

For PER test, it is possible to configure the number of test frames based on the following procedure.

1. From the main menu, type '3' to PER test configuration options.
2. Type 'n' to select number of test frames configuration sub-menu.
3. Enter the required number of test frames and press ENTER.

5.2.3   Frame length selection

For PER test, it is possible to configure the test frame length based on the following procedure.

1. From the main menu, type '3' to PER test configuration options.
2. Type 'L' to select test frame length configuration sub-menu.
3. Enter the required frame length and press ENTER.

5.2.4   Diversity settings on remote node

For PER test, it is possible to configure the antenna diversity settings on the remote node using the following procedure,

1. From the main menu, type '3' to PER test configuration options.
2. Type 'q' to get the current antenna diversity settings from remote node.
3. Type 'c' in order to change the current settings.
4. Enter '1' to enable antenna diversity algorithm or '2' to select antenna 1 or '3' to select antenna 2 or press key to exit configuration.

5.2.5   CRC settings on remote node

For PER test, it is possible to enable or disable CRC checking on the remote node using the following procedure,

1. From the main menu, type '3' to PER test configuration options.
2. Type 'z' to get the current antenna diversity settings from remote node.
3. Type 'c' in order to change the current settings.
4. Enter '1' to enable counting of frames with wrong CRC on remote node or '2' to enable counting of frames with wrong CRC on remote node or press key to exit configuration.

5.2.6   Starting test

Before starting PER test, please make sure that the transceiver configuration like channel number, channel page, TX power, etc and PER-test configurations are configured correctly.

For starting the test type '5' and wait for the test results as shown in Figure 5-4 and Figure 5-5. If the board supports LEDs then the ongoing transmission is indicated.

5.2.7   Analyzing results

PER test can be used to validate the link quality between the nodes, Receiver sensitivity of the receiving node and Net data rate of the application.

Following informations are provided as the result of PER test,

1. Number of frames successfully transmitted.
2. Number of frames received by the remote node.
3. Frames without acknowledgement
4. Number of channel access failures caused during the test.
5. Number of frames with wrong CRC
6. Test Duration

7. Net data rate achieved

8. Link Quality Indicator (LQI)

9. Received Signal Strength Indicator (RSSI)

10. Example screenshot is shown in Figure 3-25.

Figure 5-4.   PER Measurement mode results on Transmitter node

**Figure 5-5.   PER Measurement mode results on Reflector node**

5.2.7.1 Maximizing throughput

It shall be possible to configure different settings for maximizing application level throughput.

Below example result was configured for the below settings,

1. ACK request – Disabled

2. Frame retries – Disabled

3. CSMA – Disabled

4. Configure maximum Frame length, i.e 127 bytes

5. Test results are shown in Figure 5-6.

Refer the FAQ - Achieving maximum throughput using High data rate modes [16] for detailed test results.

Figure 5-6. Increasing data rate on PER Measurement mode
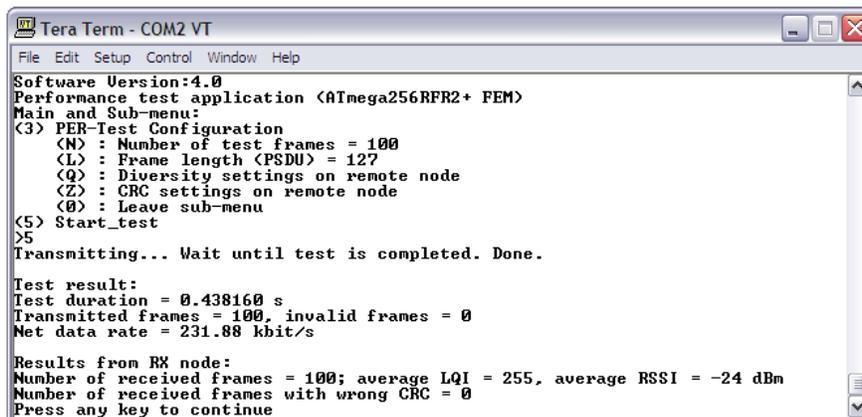
```
Tera Term - COM2 VT
File  Edit  Setup  Control  Window  Help
Software Version:4.0
Performance test application (ATmega256RFR2+ FEM)
Main and Sub-menu:
(3) PER-Test Configuration
     (N) : Number of test frames = 100
     (L) : Frame length (PSDU) = 127
     (Q) : Diversity settings on remote node
     (Z) : CRC settings on remote node
     (0) : Leave sub-menu
(5) Start_test
>5
Transmitting... Wait until test is completed. Done.

Test result:
Test duration = 0.438160 s
Transmitted frames = 100, invalid frames = 0
Net data rate = 231.88 kbit/s

Results from RX node:
Number of received frames = 100; average LQI = 255, average RSSI = -24 dBm
Number of received frames with wrong CRC = 0
Press any key to continue
```

Note: **Above configured settings may not be suitable for real world applications because acknowledgement, frame retires and CSMA/CA algorithm are required for guaranteed frame delivery. So choosing a particular configuration purely depends on the requirement of the end application.**

5.2.7.2 PER calculator

As per the IEEE 802.15.4 specification, Packet Error Rate [15] is defined as the average fraction of transmitted packets that are not correctly received.

And receiver sensitivity [15] is defined as the threshold input signal power measure at antenna terminals that yields a 1% PER for a PSDU length of 20 bytes in a controlled environment where external Interference is not present.

- If counting of frames with wrong CRC on remote node is enabled then Packet Error Rate (PER) calculation is,

  PER = Number of frames received with Wrong CRC / Number of received frames

- If counting of frames with wrong CRC on remote node is disabled and CSMA is enabled on transmitter node then Packet Error Rate (PER) calculation is,

  PER = ((Number of transmitted frames - Number of channel access failures) - Number of received frames) / Number of received frames

- If counting of frames with wrong CRC on remote node is disabled and CSMA is disabled on transmitter node then Packet Error Rate (PER) calculation is,

  PER = (Number of transmitted frames - Number of received frames) / Number of received frames

6.   Scripting

Small example scripting file is attached along with the application note for running performance test application. It is based on Tera Term [16] serial interface on PC. Open Tera Term and select the COM port on with STB is enumerated.

Open tera term -> Control -> Macro -> Open the "performance_test_evaluation_script.ttl" file.

This script will set the device on channel 11, configure TX_PWR register to 0x0F and start continuous transmission mode as shown in Figure 6-1.

Please go to Tera Term -> Help for additional information on scripting.

Figure 6-1. Tera Term output on running the example script.

7. References

1. IEEE 802.15.4 MAC stack – (www.atmel.com/tools/IEEE802_15_4MAC.aspx)
2. AVR2025: IEEE 802.15.4 MAC Software Package - User Guide
   (www.atmel.com/tools/IEEE802_15_4MAC.aspx?tab=documents)
3. Atmel AVR10004: RCB256RFR2 – Hardware User Manual
   (www.atmel.com/Images/Atmel-42081-RCB256RFR2-Hardware-User-Manual_Application-Note_AVR10004.pdf)
4. Atmel AVR2063: Sensor Terminal Board - Hardware User's Manual (www.atmel.com/Images/doc8359.pdf)
5. SE2431L-EK1 (www.skyworksinc.com/Product.aspx?ProductID=933)
6. SE2431L (www.skyworksinc.com/uploads/documents/SE2431L_202410B.pdf)
7. SE2438T (www.skyworksinc.com/uploads/documents/SE2438T_202476A.pdf)

8. RC6505 (www.rfmd.com/CS/Documents/RF6505DS.pdf)

9. RC6575 (www.rfmd.com/CS/Documents/RF6575DS.pdf)

10. RC6555 (www.rfmd.com/CS/Documents/RF6555DS.pdf)

11. ATmega256RFR2 datasheet, revision B, updated: 02/2013 (www.atmel.com/Images/Atmel-8393-MCU_Wireless-ATmega256RFR2-ATmega128RFR2-ATmega64RFR2_Datasheet.pdf)

12. RF cable (www.farnell.com/datasheets/80711.pdf)

13. FCC Code of Federal Register (CFR); Part 47; Section 15.35, Section 15.205, Section 15.209, Section 15.231, Section 15.247 and Section 15.249. United States.

14. ETSI EN 300 328, Electromagnetic Compatibility and Radio Spectrum Matters (ERM); Wideband Transmission Systems; Data transmission equipment operating in the 2.4GHz ISM band and using spread spectrum modulation techniques; Part 1-3.

    IEEE Std 802.15.4™-2006: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (LR-WPANs).

15. FAQ (www.support.atmel.no/bin/customer.exe?=&action=viewKbCategory&id=144)

16. Tera Term version 4.77 (http://ttssh2.sourceforge.jp/)

8. Revision History

Doc. Rev.	Date	Comments
42140A	06/2013	Initial document release

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