**DESK NUMBER: ___________**

# RF WIRELESS FOUNDATION COURSE BOOK ONE

## Overview

This course book comes as the lab manual of the "Wireless Foundation Course" for use in the practical sessions. It is assumed that the student has completed the lecture sessions prior to attempting this lab section.

In this foundation course, students will use the EZRadio® wireless product line from Silicon Laboratories to calculate variables, generate code, and create a simple wireless link. Using EZRadio technology, students will come to understand RF basics by implementing simple tasks using the Si4421 Universal FSK transceiver on an EZLink™ platform.

RF basic lessons:

- Lesson 1: Optimizing the RF parameters
- Lesson 2: CW link between two EZLink modules
- Lesson 3: Sending packets

## Introducing the Hardware Platform

During these lab sessions the EZLink platform will be used for code development. The firmware pre-loaded onto the EZLink platforms is not the standard firmware, it is specific to this foundation course. The firmware image should be available on the course CDROM or pre-installed onto the course PCs (if provided). When pre-installed, the image typically can be found in the following folder:

C:\Silabs\SRW\RF Basic Lesson\ (assuming C: is the local Hard Disc)

In the event that your PC is setup differently then your course leader will be able to re-direct you to the correct location.

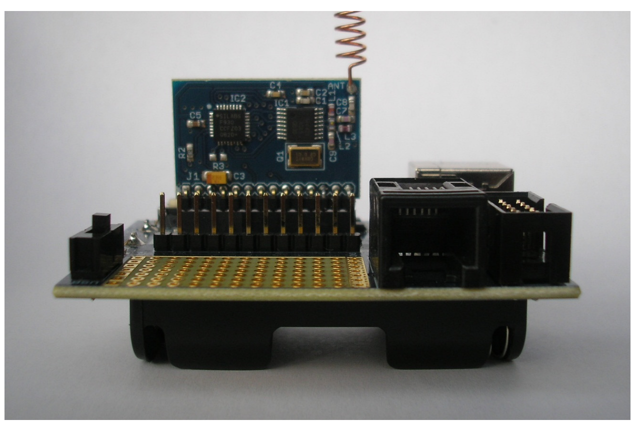

**Figure 1. EZLink**

EZLink's development hardware can be connected to a PC via a standard USB cable. The PC will recognize the hardware as a serial device since the hardware comes equipped with a USB to UART converter on the EZLink peripheral board.

The serial settings used for communication are as follows:

- Data rate: 9.6 kbps
- Bits: 8
- Parity: NO
- Stop bit: 1
- Handshake: NONE

# LESSON 1: OPTIMIZING THE RF PARAMETERS

## Exercise 1—How to Calculate RF Link Parameters

One of the earliest tasks to perform when developing a wireless system is to work out the main RF characteristics that the system will work with. These RF characteristics often define many of the other system characteristics. A typical example of this is RF frequency which defines the size of the antenna, and that in turn may define the size of the housing that the system may be mounted in.

Once you have selected the basic RF characteristics, it is a simple mathematical procedure to optimize the additional RF parameters.

Required RF Characteristics:

- Frequency :________________________ [MHz] (typically driven by the market)
- Crystal :________________________ [ppm] (typically driven by the cost)
- Data Rate :________________________ [kbps] (typically driven by the range & battery life)

This lesson helps to practice optimizing the RF link parameters through a calculation based on a real life example.

What is the recommended deviation and baseband bandwidth if the data rate of the RF communication is 9.6 kbps, the accuracy of the selected crystal is 20 ppm and the frequency band is 915 MHz?

1. Calculate the frequency error if selected crystal is used:

$$f_{e\_xtal} = xtal\_acc[ppm] \times \frac{freq\_band}{1000000} = 20 \times \frac{915000}{1000000} = \underline{\hspace{4cm}}[kHz]$$

2. Calculate the recommended deviation:

$$deviation = data\_rate + 2 \times f_{e\_xtal} + 10 = 9.6 + 2 \times \underline{\hspace{2cm}} + 10 = \underline{\hspace{3.5cm}}[kHz]$$

3. What is the closest available deviation?

$$\underline{\hspace{4cm}}[kHz]$$

(Tip: Use either the data sheet or WDS to look up what deviation values the Si4421 has available)

4. Calculate the baseband bandwidth:

$$BBBW = 2 \times deviation - 10 = \underline{\hspace{4cm}}[kHz]$$

5. What is the closet possible baseband bandwidth?

$$\underline{\hspace{4cm}}[kHz]$$

6. Calculate the center frequency based on your desk number:

$$f_0 = 910.2 + desk\_number \times 0.63 = \underline{\hspace{3.5cm}}[MHz]$$

## Exercise 2—Entering Parameters into WDS

The wireless development suite (WDS) contains a software module written for the PC called "Chip Configurator". This software module is designed to help engineers develop with Silicon Lab's wireless radio ICs. This software module is designed to generate the register settings for a given RF configuration using a simple-to-use GUI. This allows the engineer to quickly calculate the required register values without the need to work with a complex multi-page data sheet and application notes.

Using the RF parameter values calculated in the previous exercise, use WDS to generate the register settings. These register settings will be used during the class with the EZLink firmware.

1. Run WDS selecting the Si4421 control panel:

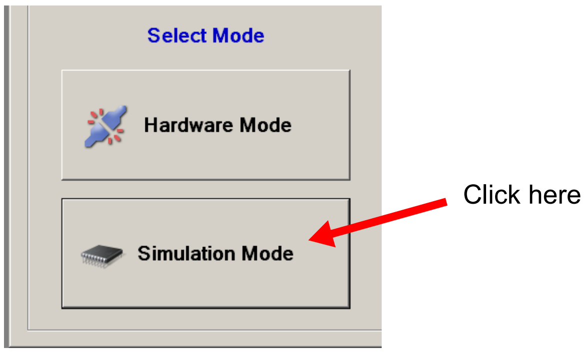


**Figure 2. Select Mode**

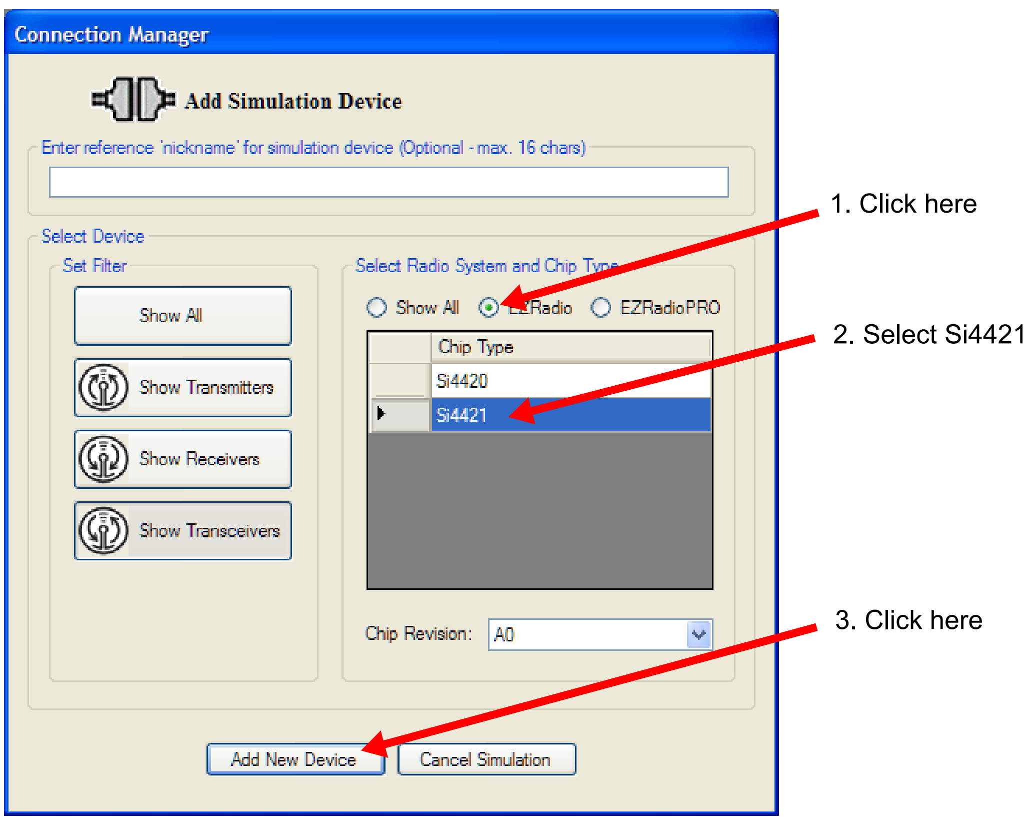


**Figure 3. Select Si4421 Transceiver**

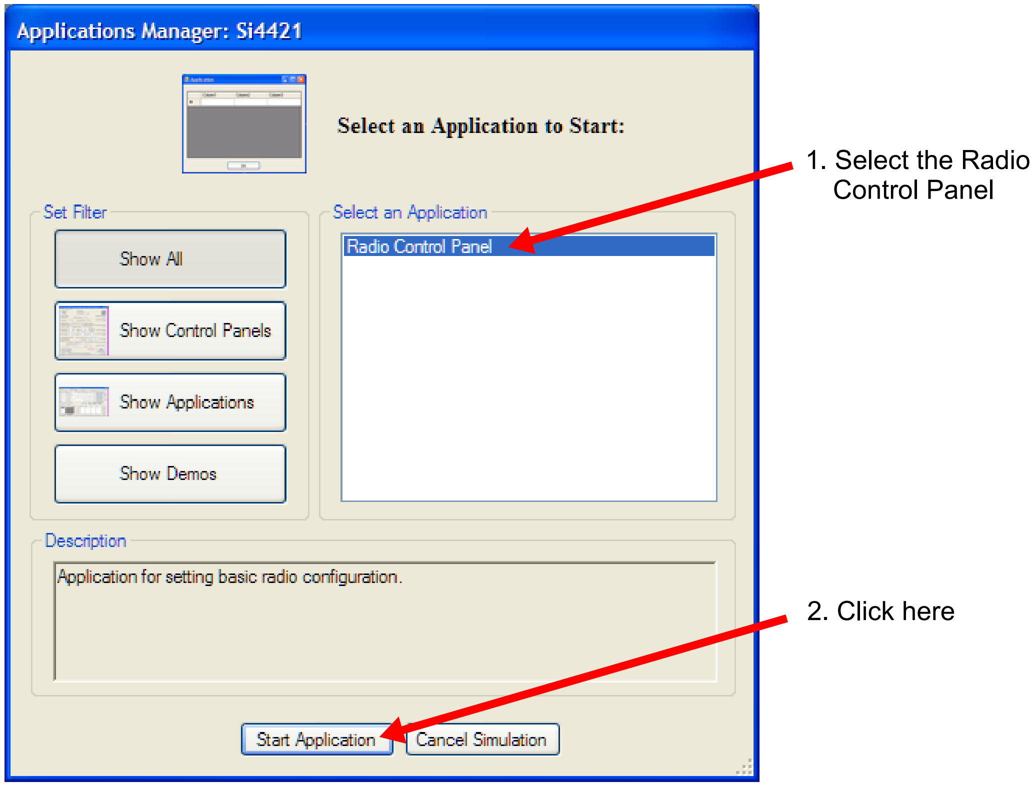


**Figure 4. Start Radio Control Panel**

2. Load the "Si4421_Configuration.swc" configuration file
   (the location of the file is: C:\Program Files\Silabs\WDS3\Project_Configurations\).

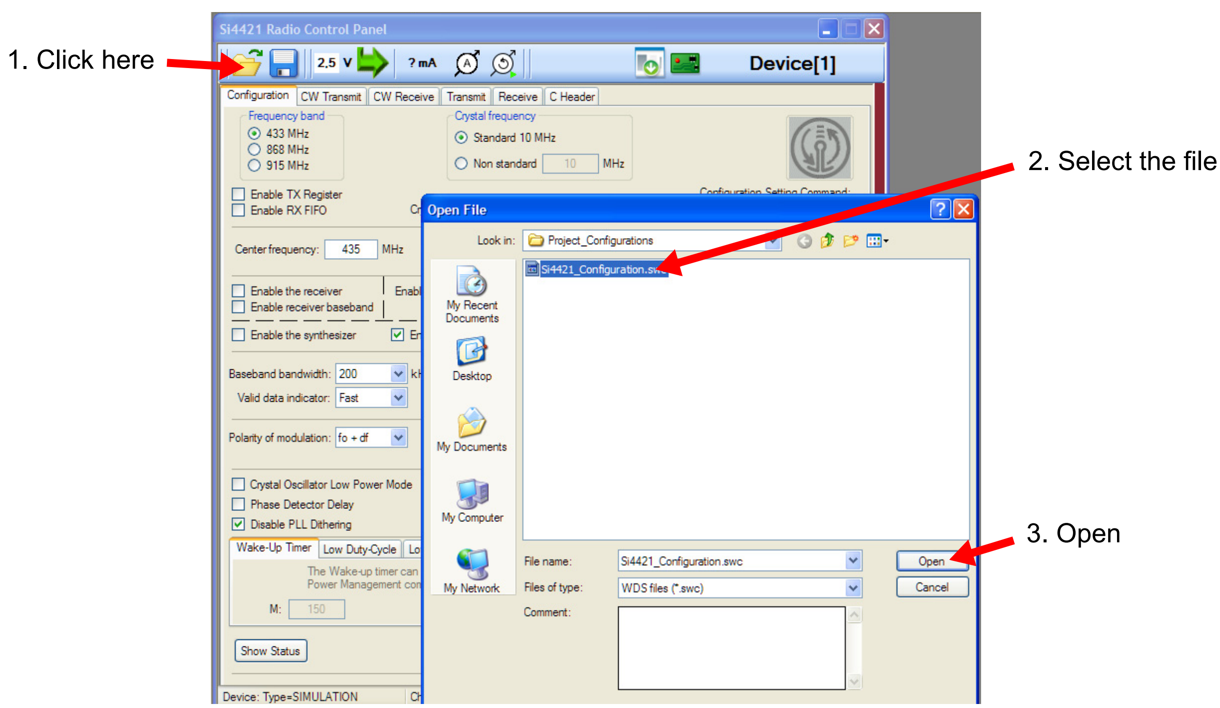


**Figure 5. Load Si4421 Configuration File**

3. Set Center Frequency, Baseband Bandwidth, and Deviation according to your calculations.

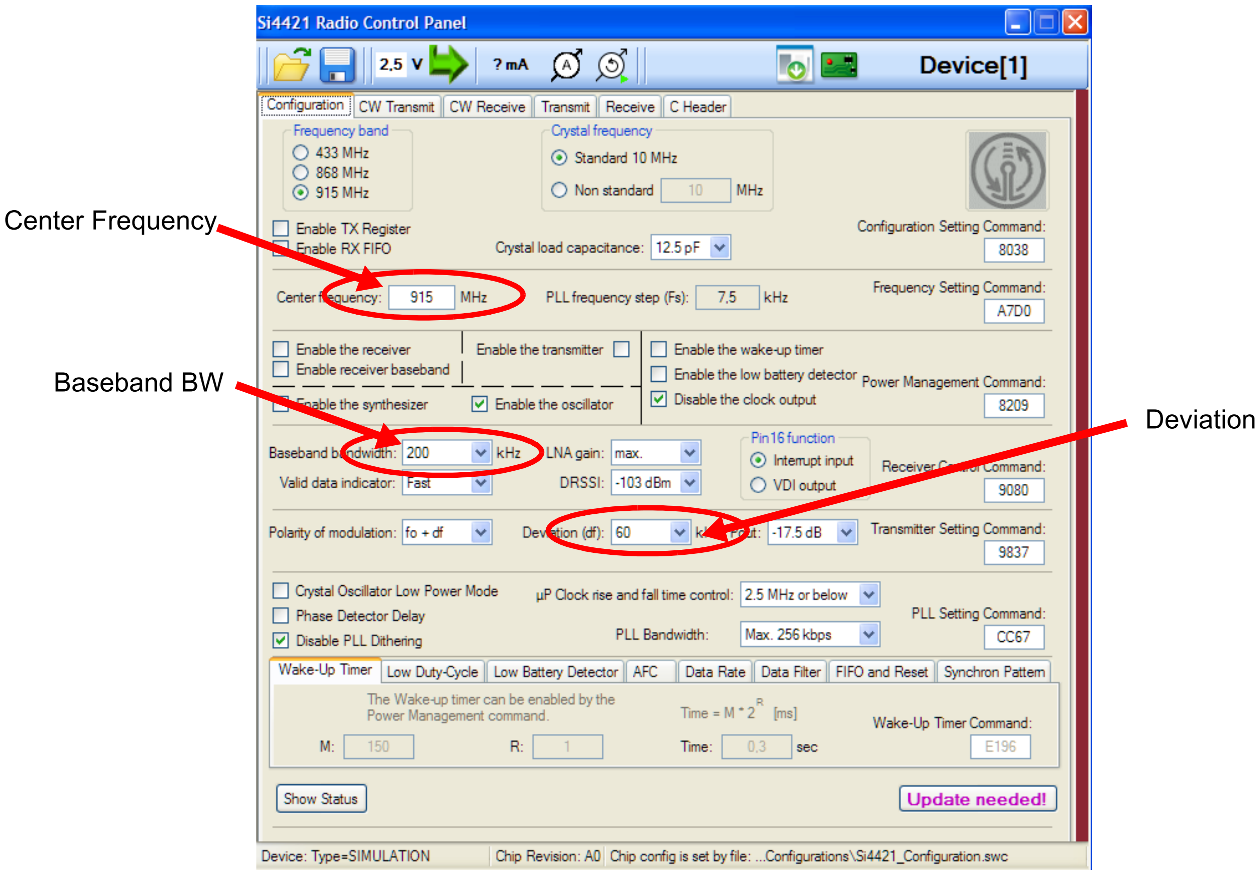


**Figure 6. Set Center Frequency, Baseband BW, and Deviation**

## Exercise 3—How to Generate a Header File for Our Software

At the top level, the WDS Chip configurator is a useful tool for swiftly generating register settings, but in lab environments the WDS chip configurator is also capable of loading the register values directly into the Silicon Labs RFIC. During the code development stages of a project, this tool also is useful for developing header files. This header file can be directly included into the compilation of the source code as the control commands of the RF chip are available as a definition.

1. Start the “ANSI C header generator tool” from the “Tools” menu
2. Generate the header file with the “Generate Header” button
3. Save the header file (if it already exists, just overwrite the existing file) “C:\Silabs\SRW\RF_Basics_Lesson\Setup_Si4421.h”

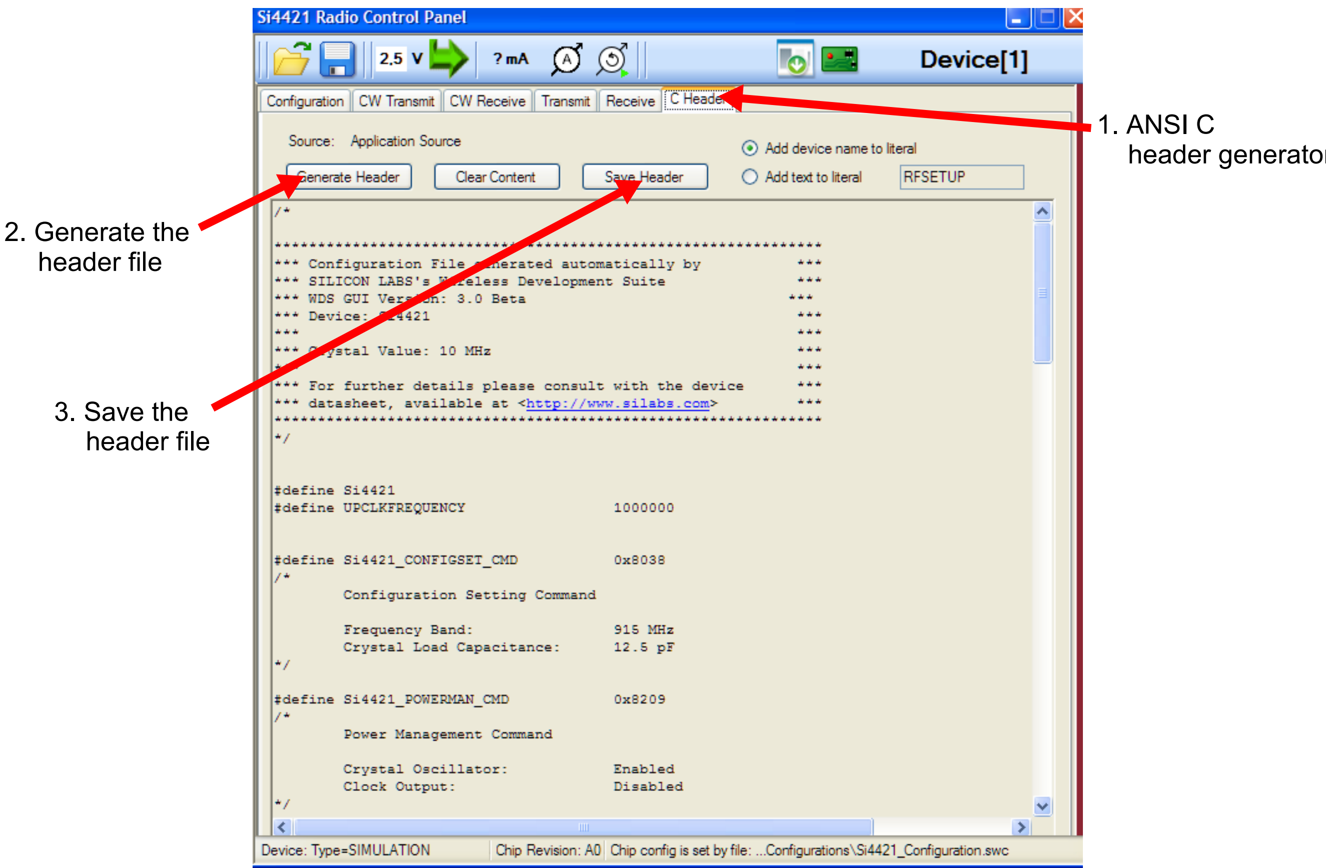


**Figure 7. ANSI C Header Generator Tool**

Example from the header file:

```
#define IA4421_CONFIGSET_CMD                 0x8038
/*
     Configuration Setting Command

     Frequency Band:                    915 MHz
     Crystal Load Capacitance:          12.5 pF
*/
```

# LESSON 2: CW LINK BETWEEN TWO EZLINK MODULES

In review of the lecture portion of this course, this lesson will help in the understanding of FSK modulation and the RF link parameters such as deviation and baseband bandwidth.

What is happening in the transmitter side?

- Without modulation, the RF chip provides a continuous wave signal (called a CW signal).
- If 0 is sent, the CW signal is shifted in frequency by the deviation, so the frequency will be $f_0 - \Delta f_{FSK}$, where $f_0$ is the center frequency and $\Delta f_{FSK}$ is the deviation.
- If 1 is sent, the CW signal is shifted in frequency by the deviation, so the frequency will be $f_0 + \Delta f_{FSK}$.

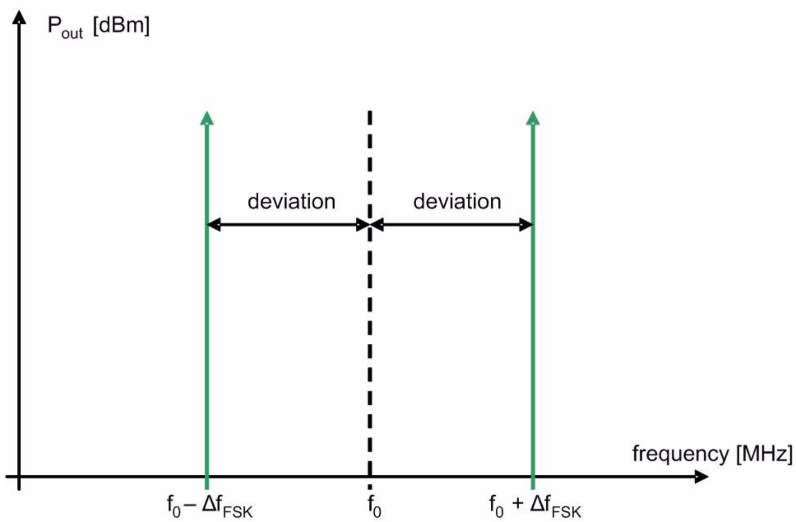


**Figure 8. FSK Modulation**

### *Tips & Tricks*

"How does this work with EZRadio Universal ISM band FSK radio ICs?"

EZRadio FSK transceivers do not provide a CW signal at frequency, however you can set this frequency by the Frequency Setting Command. The ICs provide only the $f_0 - \Delta f_{FSK}$ or $f_0 + \Delta f_{FSK}$ frequencies, because if the power amplifier is switched on it is always modulated with 0s or 1s, depending on the actual value of the nFFS/DATA pin (and the modulation polarity, or mp control bit).

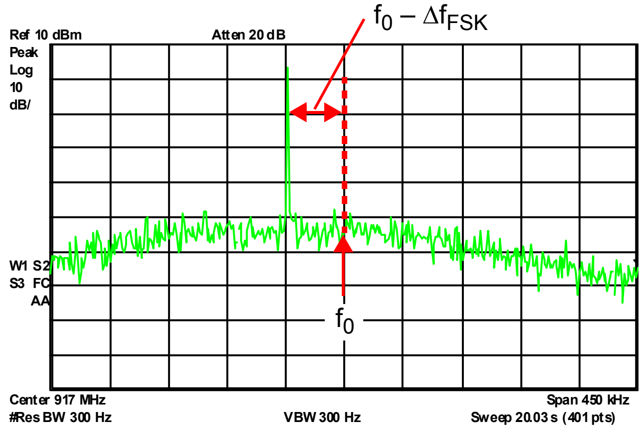


**Figure 9. Output Spectrum (CW), if FSK = 0 and mp = 0 (Positive Modulation)**

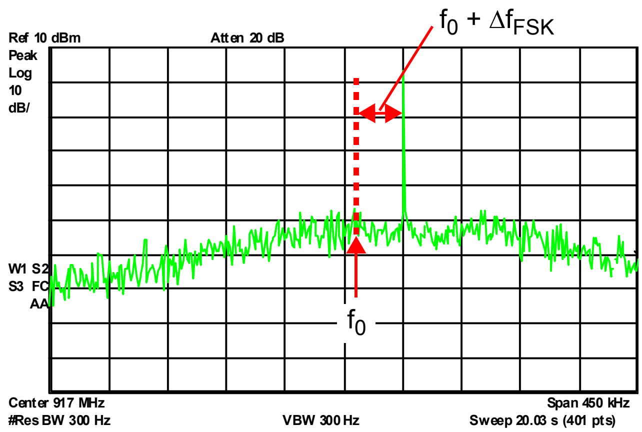


**Figure 10. Output Spectrum (CW), if FSK = 1 and mp = 0 (Positive Modulation)**

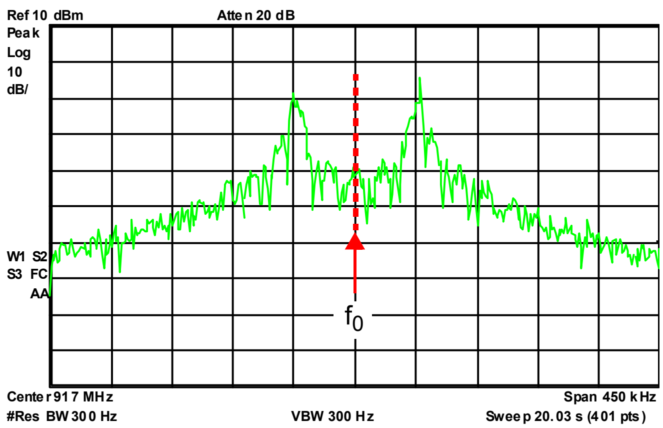


**Figure 11. Output Spectrum Modulated by PN9 Random Data**

## Exercise 1—How to Set Up an EZLink Si4421 Module as a CW Transmitter

This example project modulates the output power of the transmitter IC according the state of the push button on the EZLink main board:

- If the SW2 button is pressed then the output is modulated through the FSK pin of the transmitter by 1, the RC LED will be illuminated.
- If the SW2 button is not pressed, the output is modulated through the FSK pin of the transmitter by 0 and the TR LED will be illuminated.

To run this project on the EZLink Si4421 module, please follow the following steps:

1. Run Silicon Laboratories IDE and load the project from: "C:\Silabs\SRW\RF_Basics_Lesson\Lesson2".
2. Uncomment the "#define CW_TRANSMITTER_MODE" and comment the "#define CW_RECEIVER_MODE" definition for compiling the source code as a transmitter.
3. Compile the project and program it into an EZLink module.
4. Disconnect the programmer from the board, then by pressing the SW2 button the RC LED should illuminate instead of TR LED. For further testing please follow the steps in Exercise 2.

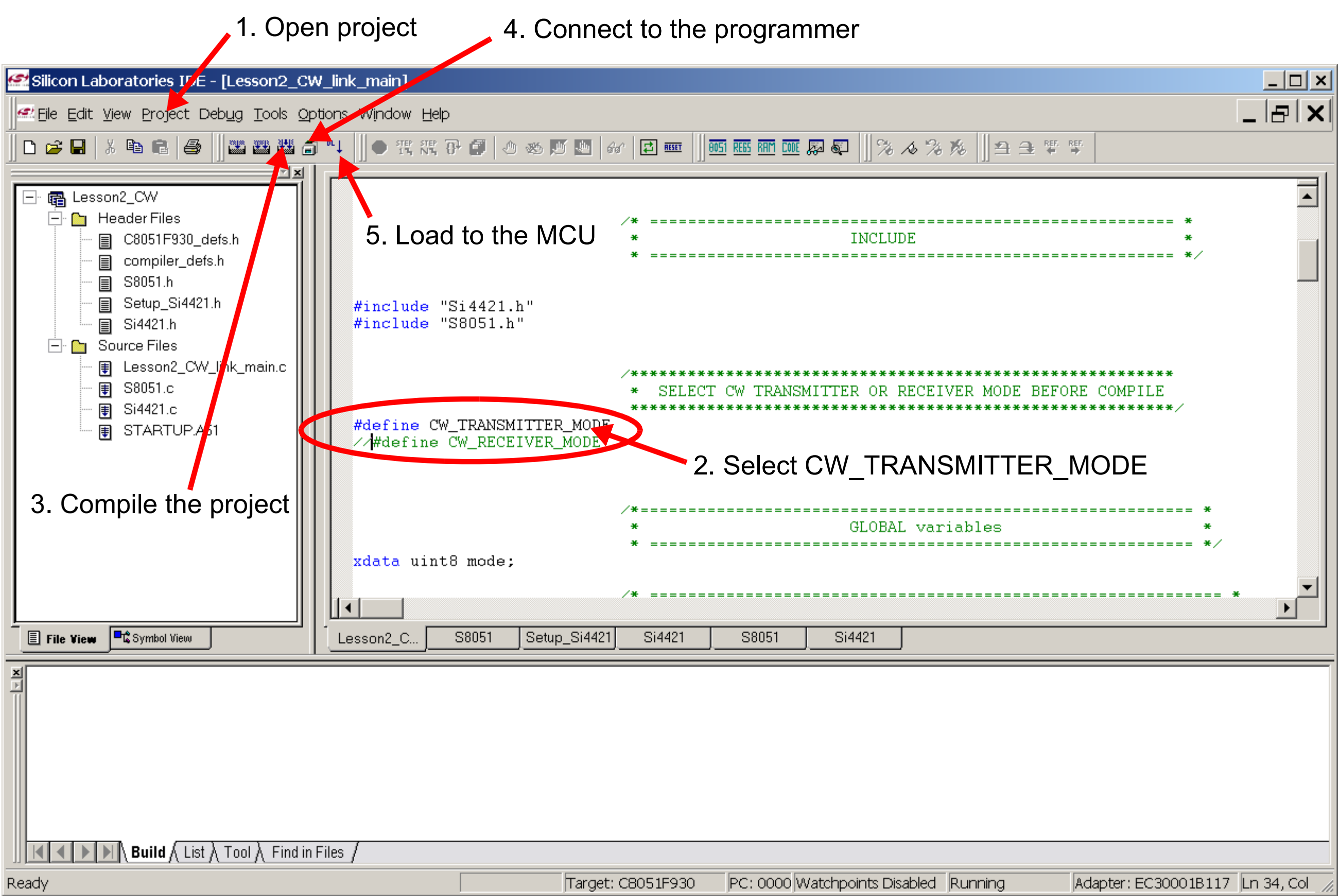


**Figure 12. Lesson 2 Project in Silabs IDE**

### *What is Happening on the Receiver Side?*

The modulated data is represented by two frequencies: $f_0 - \Delta f_{FSK}$ and $f_0 + \Delta f_{FSK}$, where $f_0$ is the center frequency and $\Delta f_{FSK}$ is the deviation. The receiver should focus on this information and should filter it out from the noise. One of the parameters that is configurable on the RFIC is the bandwidth of the baseband filter. This circuit filters out real information from the air, so this parameter has to be set properly. If the filter is set to too narrow, it filters out the real data as well. If the filter is set to too wide, then it allows in too much noise, affecting the receiver sensitivity.

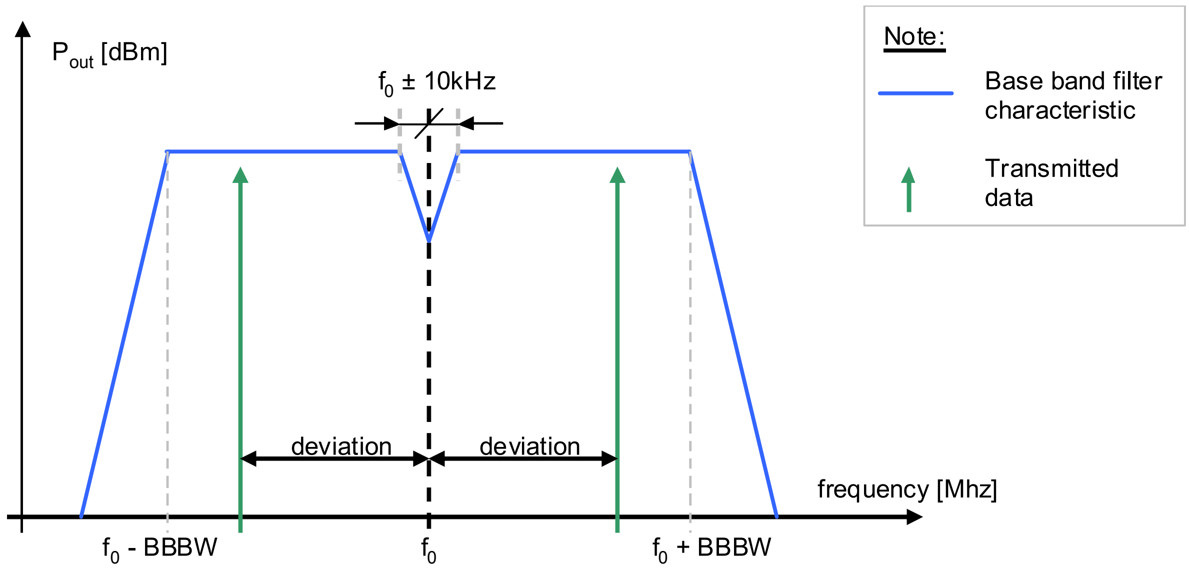


**Figure 13. FSK Modulation**

### *Tips & Tricks*

"How does this work with EZRadio Universal ISM band FSK radio ICs?"

Silicon Labs' EZRadio FSK transceiver chip has a zero IF architecture, so the baseband filter of them has a high pass filter for dc cancelation. The corner frequency of it is at 10 kHz! This has to be kept in mind when defining the deviation for the transmitter.

In raw data mode (if the FIFO is not used), the transceiver IC provides the received and demodulated data on the DATA pin. They can also provide the recovered clock on the DCLK pin, which helps to get samples from the DATA pin while using the right timing, according to a given data rate.

## Exercise 2—How to Set the Second EZLink Module as a CW Receiver

The example project shows a very simple application: the receiver chain of the transceiver chip on the EZLink Si4421 module is continuously enabled in raw data mode (FIFO is not used: only the DATA pin is used for receiving the data). The software switches the LEDs according the received bits:

- If it receives 1 it illuminates the RC LED.
- If it receives 0 it illuminates the TR LED.

This project provides the ability to check the CW transmitter application if the modules are configured to the same center frequency.

To work with this example, please follow the following steps:

1. Use the same project as in Exercise1: "C:\Silabs\SRW\RF_Basics_Lesson\Lesson2".
2. Uncomment the "#define CW_RECEIVER_MODE" line and comment the "#define CW_TRANSMITTER_MODE" definition for compilation of the source code as a CW receiver.
3. Compile the project and program it to a second EZLink Si4421 module.
4. If there is no transmitted data on the given center frequency, then the receiver receives only noise, which is represented randomly changing 0 and 1. This can be easily identified, because both LEDs blink at the same time (this is because the signal is changing so often that it appears that both LEDs are on).
5. If the previously programmed CW Transmitter board is also switched on, then pressing and releasing the SW2 push button will result in the LEDs blinking accordingly on the CW receiver board also.

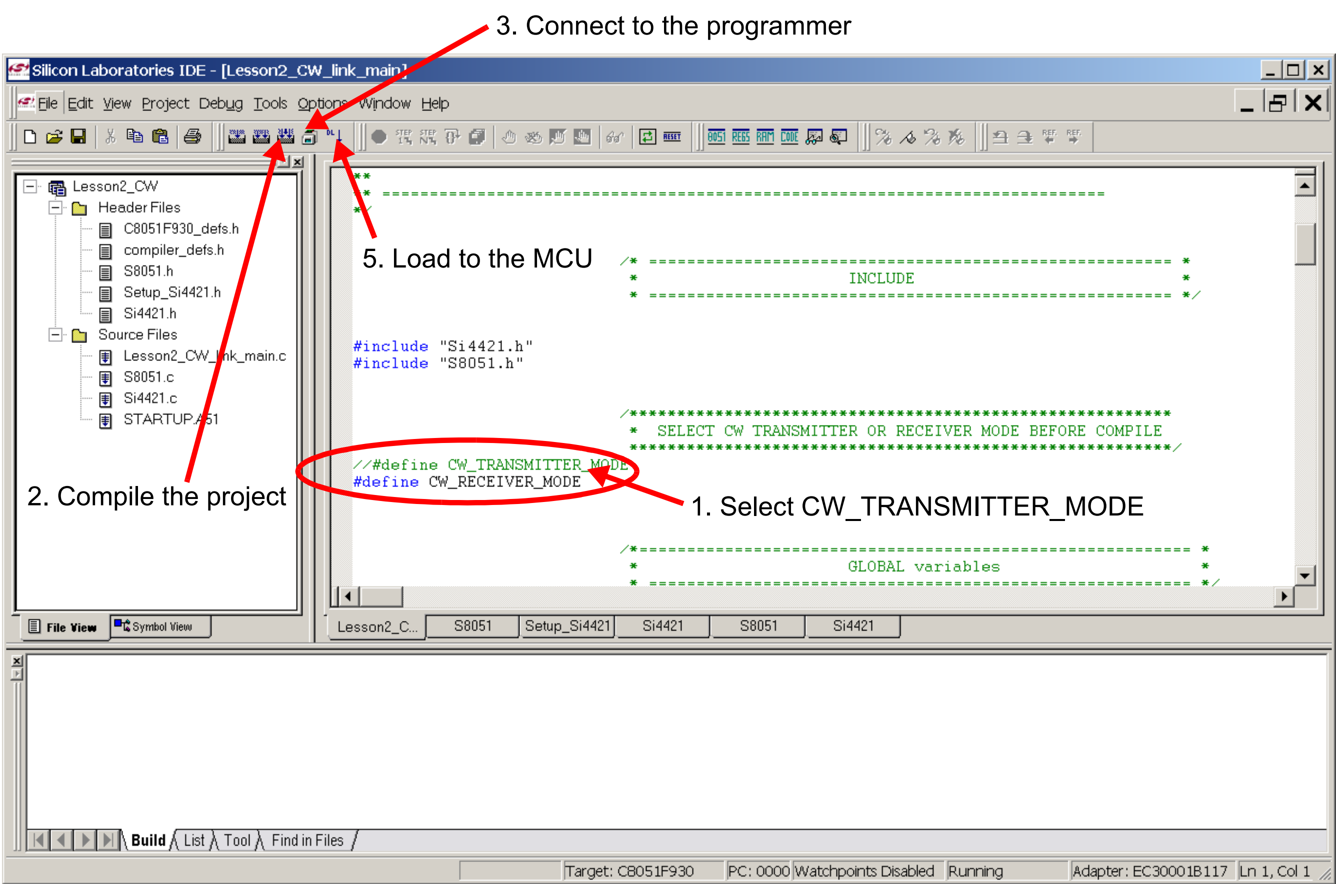


**Figure 14. Lesson 2 (CW Receiver)**

## LESSON 3: SENDING PACKETS

There are few rules which are needed when sending data through an RF link; however, there are some differences compared to a typical wired link. After enabling a receiver, data is received even if there is nothing in the air. The receiver receives noise (random data). In a wireless environment, the real data has to be found somehow in the noise. To help a receiver, the transmitted packet should start with a preamble and a synchron pattern:

- The preamble is a continuous 0101 sequence. It helps the receiver synchronize with the transmitter. The preamble is a known sequence with continuous edge changes in the data so during that period the demodulator and clock recovery circuit of the receiver node can be settle easily, which means that the receiver finds out where the sample from the data has to be taken.
- After the transmitter and receiver node synchronize, the receiver has to find out where the real data in the packet starts. For that purpose the transmitter sends some data with a known bit pattern. This is called the synchron word.

The receiver also needs to know how long the transmitted packet is. Remember: if there is no transmitted signal, the receiver receives noise which is seen as 1s and 0s, so even if the transmitter node finishes sending a packet, the receiver does not realize this without knowing how long the packet is! There are a few possibilities of how to solve this issue:

- Wait for a special end character.
- Always send a fixed length message.
- Include the length information into the packet.

In the RF physical layer, the transmitted packet can be easily disturbed by another node, or another RF system also of noise. To solve this issue it is highly recommended to use a form error checking. Error checking will confirm whether the received data is valid or contains bit error(s).

Unfortunately, if the communication is disturbed it causes not only a bit error, but usually causes burst bit errors which can usually be identified by using a CRC check only (a simple checksum can recognize bit errors and but not burst errors).

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| AA | AA | 2D | D4 | Length | Source ID | Dest. ID | Payload | CRC16 |

**Figure 15. Typical RF Packet with Addressing**

### *Tips & Tricks*

"What do EZRadio Universal ISM band FSK receivers and transceivers do to help in realizing packet reception?"

By using FIFO mode in the EZRadio receiver or transceiver ICs, the RF chip can be configured in such way that it will automatically recognize the preambles and synchron words (16bits: 0x2DD4 is used by Silicon Labs) and only the real data (after synchron word) will be filled into the FIFO.

## Exercise 1—How to Send Packets with Addressing Fields

This exercise uses a project which sends and receives packets where the source and destination addresses are included into the header of the packet. The packet is received only if the destination address is identical with the self address of the node which intended to receive the packet. If the packet ID is incorrect, the packet is dropped.

The packet structure of the packet is shown in Figure 15.

1. Open the following project: "C:\Silabs\Srw\RF_Basics_Lesson\Lesson3".
2. Open the Si4421.h header file and change the DESK_NUMBER definition according to your number.
3. Uncomment BOARD1 definition (while keeping BOARD2 definition commented), compile the code, and load it into one of the EZLink board.
4. Uncomment BOARD2 definition (while keeping BOARD1 definition commented), compile the code, and load it into the second EZLink board. These definitions swap the self and destination addresses.
5. If the push button of one of the EZLink unit is pressed, then the TR LED should blink (showing it is sending a packet) and the second EZLink should blink the RC LED (showing that the packet is received).

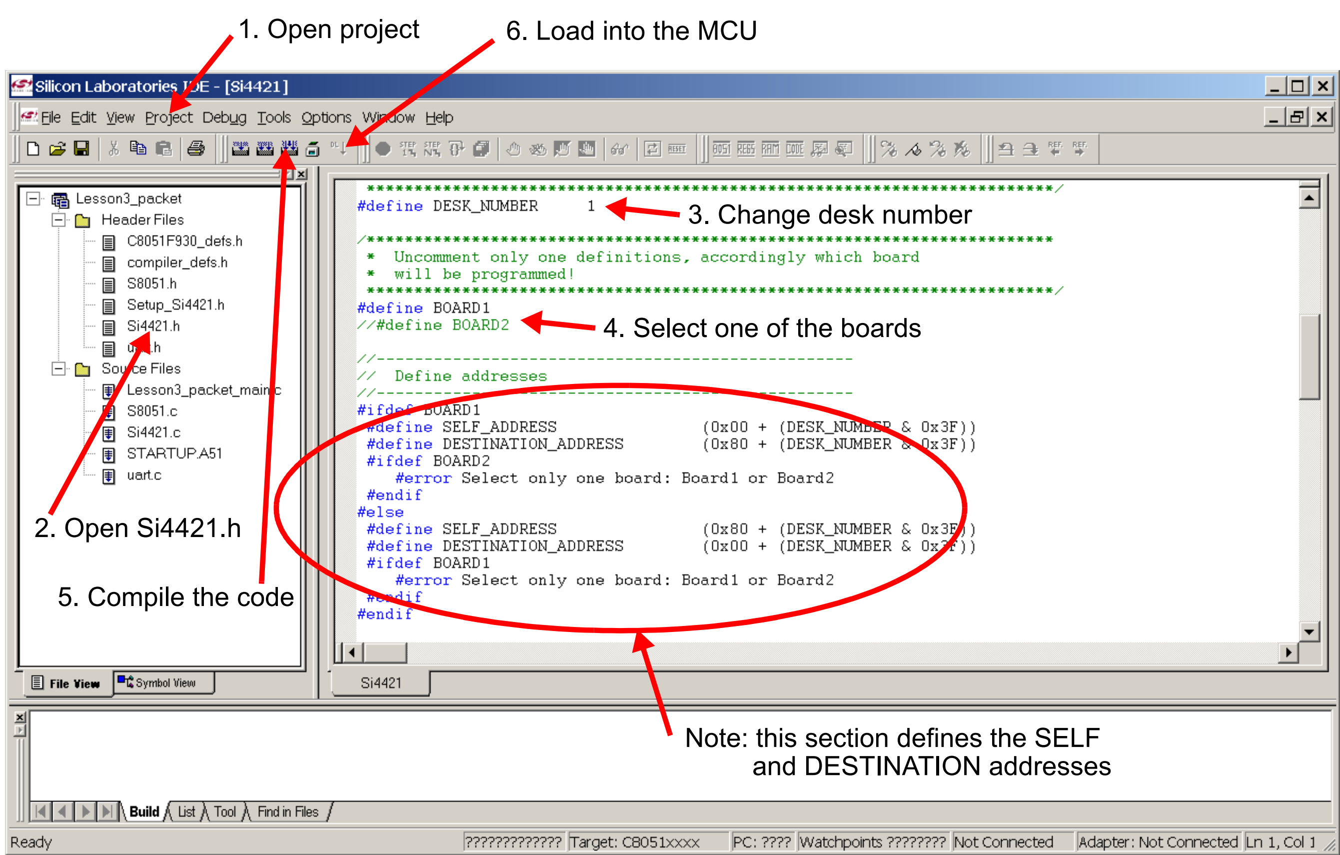


**Figure 16. Packet Transmission**

6. The receiver board also reports the payload to the USB port. If the board is connected to the USB port, using a simple terminal program (like "WDS Terminal Emulator"), the result can be confirmed:
   a. Run WDS Terminal Emulator: "C:\Program Files\Silabs\WDS Terminal Emulator\TE.exe".
   b. Wait until the program find the used com ports.
   c. Set 9600 bps data rate, 8-bit, no parity and no handshaking.
   d. Press Open Port.

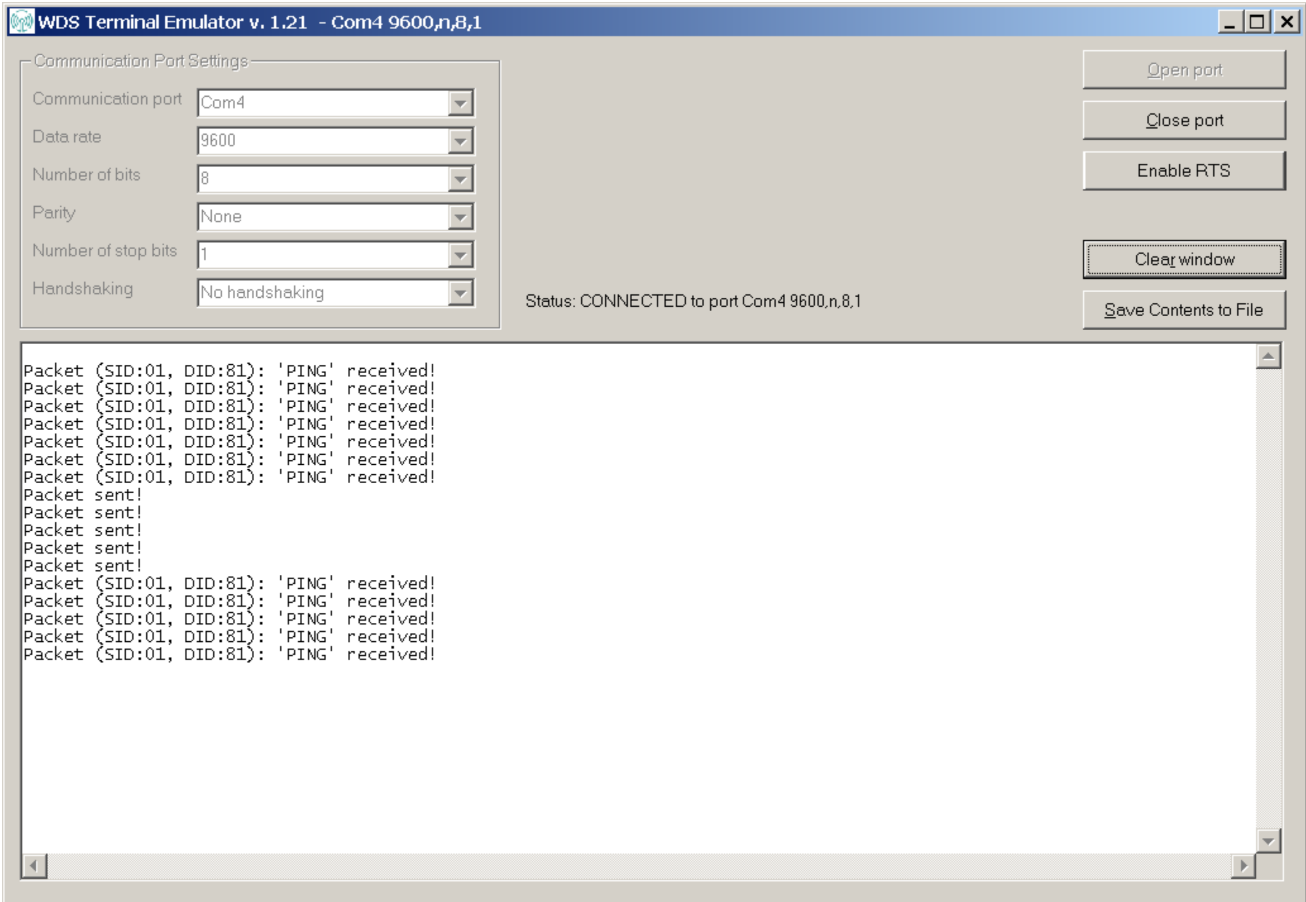


**Figure 17. WDS Terminal Emulator**

## NOTES:

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