Channel Analysis Tool (CAT) User Guide

P400 CAT 1.1.4

TDSR UWB Radios

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Table of Contents

1. Introduction

The Channel Analysis Tool (CAT) is a Microsoft Windows-based Graphical User Interface (GUI) that allows the users to configure and operate TDSR's P400, P410, P412, P440 and P452 Ultra Wideband (UWB) RF platforms such that the user can generate, capture, display, and log UWB RF waveforms as they propagate through an RF Channel. In the process, CAT will also calculate, display, and log a variety of communications statistics associated with the transmissions. Logged waveforms are stored as .csv files compatible with a variety of software tools such as Excel and MATLAB. A sample waveform, or scan, captured by CAT is displayed below in **Figure 1**. CAT will run on Windows 7, Windows 8, Windows 10 and Windows 11.

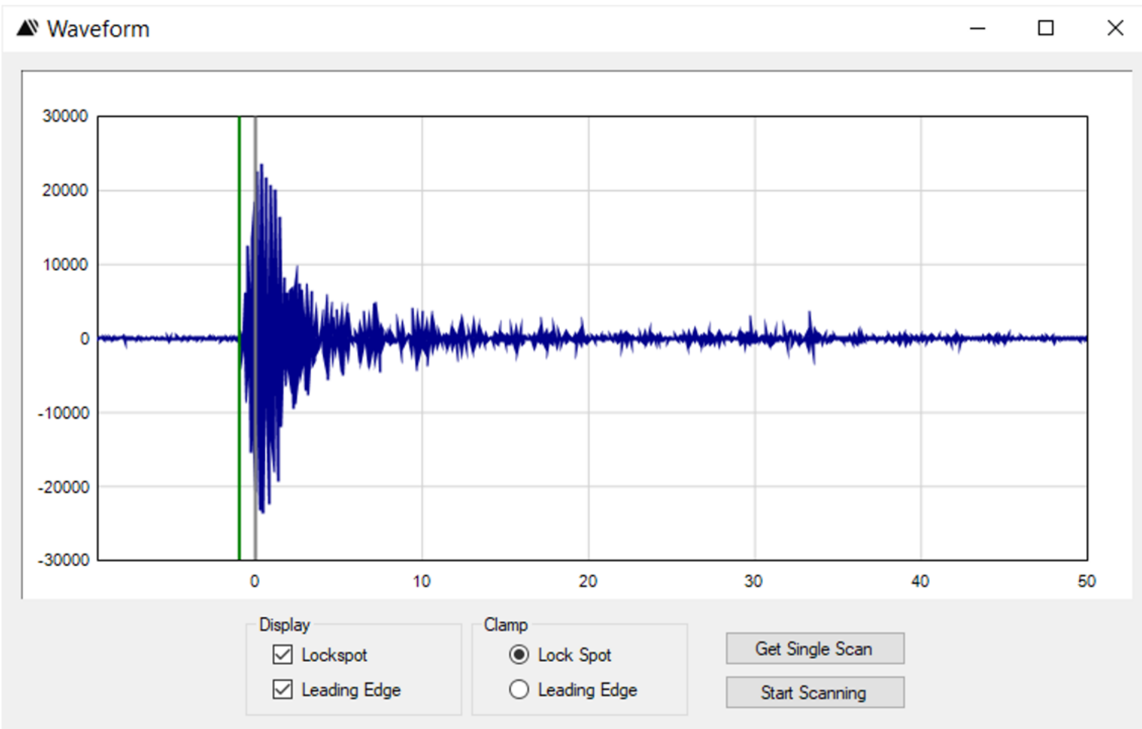


Fig. 1: Sample waveform captured using CAT (relative strength vs. time in nanoseconds)

These waveforms typically have two main uses:

- One can capture a large body of waveforms in a wide variety of environments and use that data base to create communications channel models.
- By analyzing the received waveforms in real time, one can implement a bistatic or multistatic radar.

CAT has been designed to operate with any of the P400 family of UWB RF platforms. As of this date the family consists of the P400, P410, P412, P440 and P452. These platforms can be used as radios that measure range or as radars. Consequently, users may be accustomed to referring to the UWB platform as a P400, a P410, a P4xx, a radio, a ranging radio, or radar. Some users are familiar with the platform as a Monostatic Radar Module (MRM) or as a Ranging and Communications Module (RCM). This wealth of names can be confusing. With that in mind, this document will refer to the UWB RF platform as a "radio" or occasionally, a "node."

To aid in the development of channel models, TDSR provides sample MATLAB code (CATCIR) which can be used to convert the logged waveforms into Channel Impulse Response (CIR) information. This conversion is accomplished using the CLEAN algorithm. Basically, CATCIR deconvolves the received waveform with a template transmitted waveform. The process for generating CIRs from logfiles is described in **Appendix A**.

To aid in the development of bi- and multistatic radars, CAT enables the user to capture, log, and post-process bistatic radar scans.

While CAT is a fine aid for developing models and multistatic radars, it is likely that at some point the user may need to develop a custom interface for driving the UWB platform and monitoring results. TDSR enables customization by providing a published definition of the command structures, messages and responses that govern operation of the interface. The document is called the *CAT API Specification*. Furthermore, TDSR offers sample C and MATLAB code to drive the interface from a Host computer.

CAT comes as an ".msi" installation executable which, when unbundled, will load the software and USB drivers and create a link on the Desktop. The default location for CAT is in the directory:

C:/Program files (x86)/Time Domain/Channel Analysis Tool (CAT)

For instructions on the installation and initial use of CAT, see the CAT *Quick Start Guide*.

More than one copy of CAT can be run on the same PC. Each copy can be connected to a different radio through an Ethernet hub or through multiple USB and serial connections.

2. Before You Begin

Make sure that the Radio is powered up and that the LEDs on the Ethernet connector (if present) are illuminated and that the board-mounted LEDs are blinking properly. (The light green LED should be blinking at approximately 10 Hz and the yellow LED should be blinking at 1 Hz.)

When using the USB interface, simply connect the USB cable to both the Radio and the Host computer.

When using Ethernet, you should first verify the TCP/IP properties of your PC. The PC is typically configured with static IP 192.168.1.1, subnet mask 255.255.255.0. Please see the CAT *Quick Start Guide* for detailed instructions. Next, connect to the Radio with a crossover Ethernet cable or use an Ethernet hub. If the LEDs are ON and initial connection doesn't work, try sending a PING command to the Radio IP address from a terminal window. The IP address is initially set at the factory to 192.168.1.100. This will confirm that the Radio can communicate with the PC.

3. Connecting

To launch CAT, double-click on the desktop CAT icon shown in **Figure 2-A**. When launching CAT, a Connect pop-up window will be displayed querying the user for the local Radio's IP address, USB connection, or serial connection. The actual display shown will depend on whether the connection is made to the Radio using an Ethernet, USB, or serial connection. Example screens are shown in **Figure 2-B**.

Fig. 2-A: CAT Icon installed on Desktop

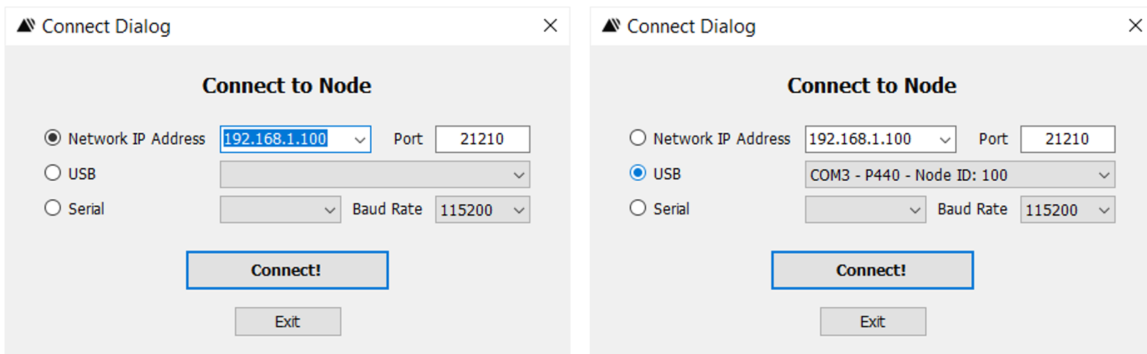


Fig. 2-B: Ethernet connection screen (left) and USB connection screen (right)

Connecting with Ethernet: To verify Ethernet connection to the Radio, enter the Radio's IP Address and click the **Connect!** button. (New units from the factory will be set to the IP address 192.168.1.100) CAT will attempt to verify connectivity to the Radio by sending a CAT_GET_CONFIG_REQUEST (see *CAT API Specification*) to that address. This message will be sent up to three times. If CAT is successful in connecting with a Radio, then CAT will transition to the Configuration Tab window (described in Section 4). The Configuration window will show "Connected" in the bottom left-hand corner and will also display the Node ID of the Radio. CAT controls are now enabled allowing the user to send commands to the Radio.

If the Radio does not respond after the third attempt, CAT will indicate the connection was unsuccessful by reporting the connection status as "Disconnected" and indicating a "Timeout Error." This is illustrated in **Figure 3.** At this point, the user should verify that the network settings are correct and ensure that your Radio is powered on and the LEDs are properly illuminated. (See Section 2 for details).

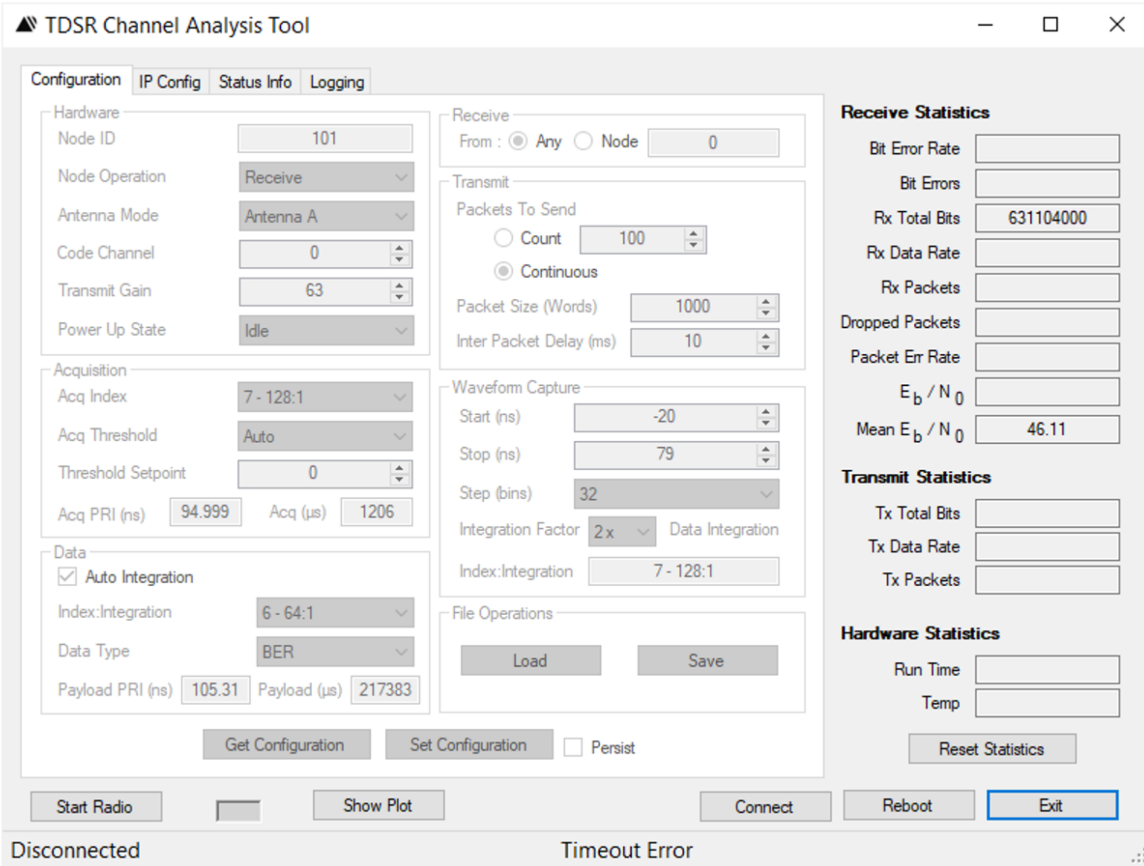


Fig. 3: This window will appear if the Radio fails to connect

Connecting with USB: To verify USB connection to a Radio, click on the USB button and make note of the com port/unit serial number from the drop-down window. If CAT is connected, then clicking on "Connect" will transition to the main window with the Configuration Tab selected. The Configuration window will show "Connected" in the bottom left-hand corner and also display the Node ID of the Radio. CAT controls are now enabled allowing the user to send commands to the Radio.

Connecting with Serial: While CAT does support communications with a P4xx, the communications rate using this link is very slow. Unless there is a special need to use a serial interface, this communications method should be avoided.

To verify Serial connection to a P4xx, click on the Serial button and select the com port/unit serial number from the drop down window. If CAT is connected through a serial cable to the P4xx, then clicking on **Connect!** will transition to the main window with the Configuration Tab selected. The Configuration window will show "Connected" in the bottom left-hand corner and also display the Node ID of the P4xx. CAT controls are now enabled, allowing the user to send commands to the P4xx.

If there are connection issues, then open the Device Manager (Windows Start Button/Control Panel/Device Manager) and confirm that the computer actually registers connection to your USB Host Port. The screen shot shown on the left side of **Figure 4** confirms that the COM3 is actually connected to the computer. The screen shot on the right indicates that no connection exists between the Host and the Radio. Once these parameters are verified, the user can attempt to connect by selecting the "Connect" button.

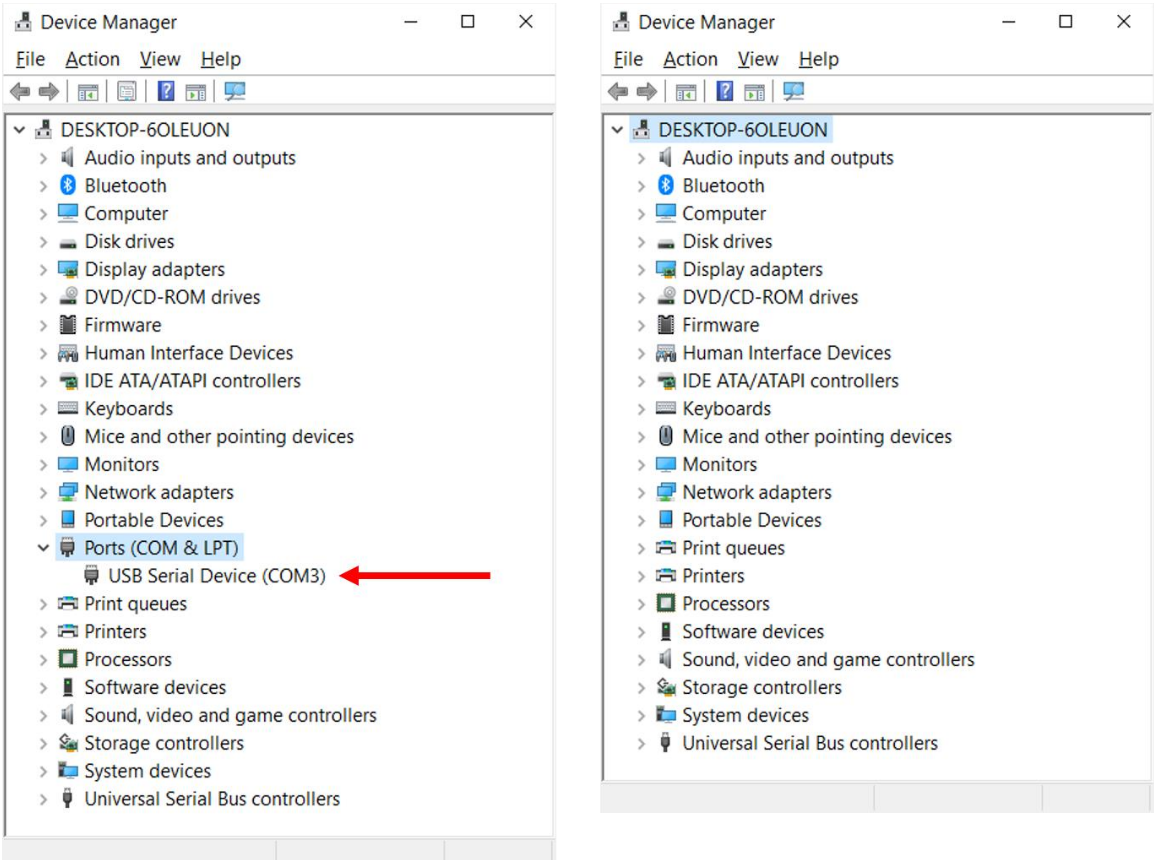


Fig. 4: Successful connection (left), unsuccessful connection (right)

Note: The connection from the Radio to Host through the USB connector is generally very reliable. However, there are times when the connection can get confused. This can happen if the Radio is disconnected or powered during execution of a CAT command. A wobbly USB connector can also cause issues. These issues will manifest themselves in one of two ways. Either (a) CAT shows that the Radio is connected when in fact it is not, or (b) CAT shows that the Radio is not connected when in fact it clearly is. If this should happen, then disconnect the Radio, cycle its power, and try to reconnect. If this fails, disconnect and power cycle the Radio and reboot the Host computer.

4. Configuration Tab

Successful connection to a Radio brings up the Configuration Tab showing the device's current configuration parameters. The parameters are divided into three general groupings: Commands, Parameter Settings, and Communications Statistics (See **Figure 5**). This tab provides the user with an easy method for reading and writing the configuration parameters.

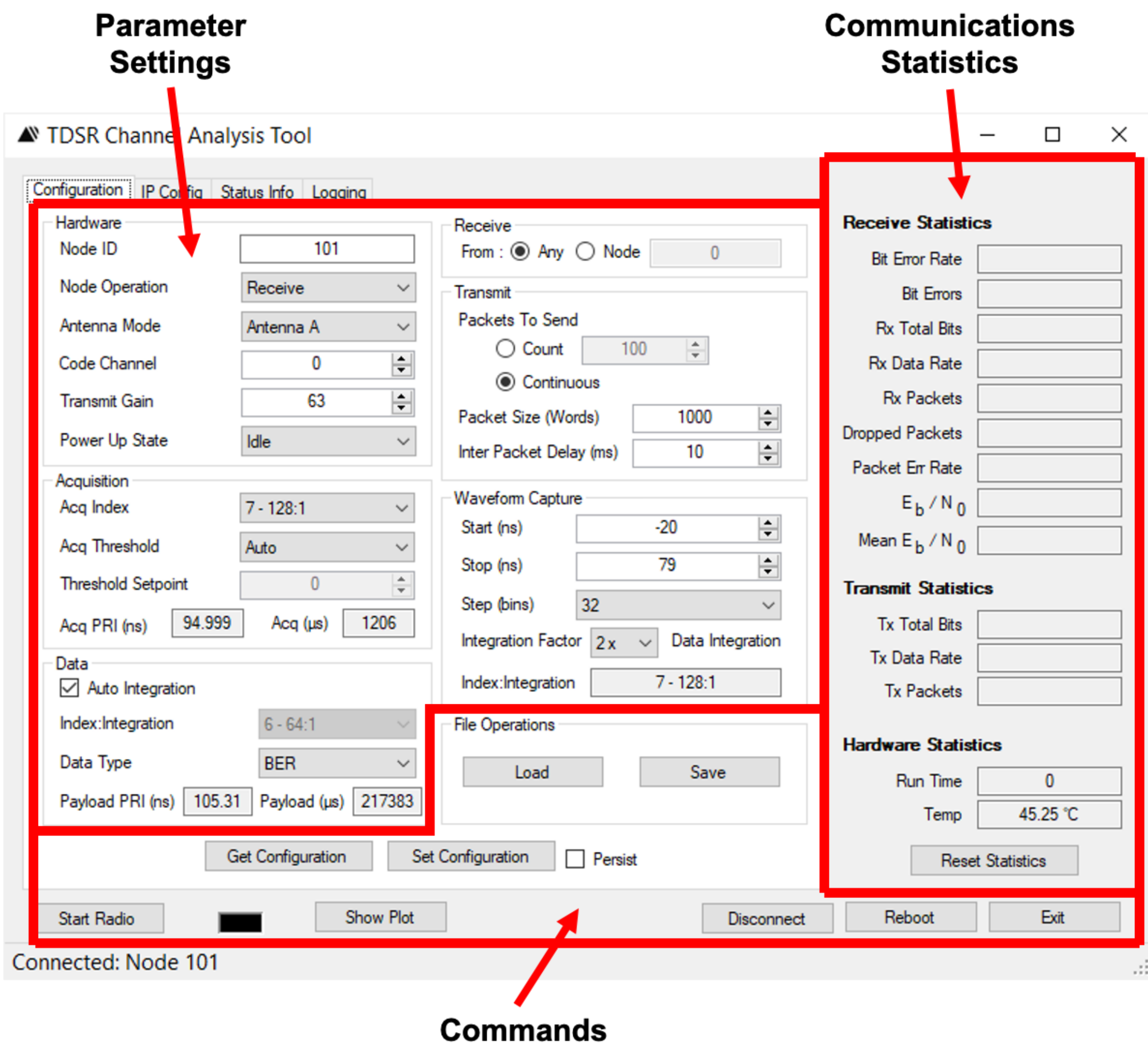


Fig. 5: Configuration Tab showing the default factory settings

To determine the current version of CAT, right click on the upper title bar and select "About CAT." A popup window will appear displaying the current CAT version.

4.1 Commands Section

<u>Set Configuration</u>: The user can alter the default configuration by adjusting the parameters and then clicking the **Set Configuration** button. In order for the new values to be downloaded to the Radio, the user *MUST* click the **Set Configuration** button. Otherwise, the parameters used by the Radio will not match the parameters on the screen. This will lead to confusion and frustration. As a reminder, any time the user changes a parameter value, the **Set Configuration** button will turn yellow. It will remain yellow until the button is clicked.

Persist Flag: To make these changes last through the next time the Radio is powered down, the user must also set the Persist flag to "1-Write to Flash." If the Persist Flag is set to a 1, then any time the **Set Configuration** button is clicked, the configuration parameters will be stored in non-volatile memory. The parameters will then be saved if the Radio is powered down. If the user does not want the changes to last through a power down, then the user must be sure to set "Write to Flash" to a zero.

Get Configuration: To view the current Radio values or to confirm that the requested changes were made, click on **Get Configuration**.

File Operations - Load: To load the settings from an existing file, click on the **Load** button and then browse to the directory that contains the desired file.

File Operations - Save: To save the current settings for future use, click on the **Save** button. CAT will prompt the user with a standard Windows File-Open dialog window.

Start/Stop Radio: This button and the colored Status Indicator Light to the right of the button are linked. The button allows the user to start and stop the Radio and the Status Indicator Light reports the Radio's state of operation. When **Start Radio** is clicked, it will cause the Radio to perform the action requested in the Node Operation field and will then change the button's name to **Stop Radio**. Clicking the button will also disable all of the parameter entry fields. If the user wishes to change parameters, it will be necessary to stop the radio. **Table 1** indicates the relationship between the Start/Stop Radio button, the Node Operation setting, the Radio's Activity state, and Status Indicator Light.

Start Radio Button Indicates	Node Operation Parameter	Radio Activity	Status Indicator Light
Start Radio	Not relevant	Not connected	Gray
Start Radio	Not relevant	Connected but neither transmitting or receiving	Black
Stop Radio	Transmit	Transmits packets	Green
Stop Radio	Receive	Searching for packets but unable to detect any	Yellow
Stop Radio	Receive	Receiving packets	Green
Stop Radio	Ambient Sampling	Receive is measuring background receive level	Green

Table 1: Relationship between Start Button, Radio Activity, and Status Indicator Light

Finally, the Node Operation may also show Idle. This means that the unit is neither Transmitting or Receiving. Clicking Start Radio when Idle is showing has no meaning.

Show Plot: This button brings up the plot screen shown in **Figure 1**. The procedure to capture and display waveforms is described in Section 5.

Disconnect: Clicking this button will disconnect CAT from the Radio and bring up the Connect window (see **Figure 2-B**), thereby allowing the user to connect to a different Radio.

Exit: Clicking this button will exit CAT. Alternatively one can exit CAT by clicking on the X button in the upper right corner of the window.

4.2 Parameter Settings

This subsection describes the various CAT parameter settings and is subdivided into the following categories: Hardware Settings, Acquisition Settings, Data Settings, Receive Settings, Transmit Settings, and Waveform Capture Settings. It is important to note that any settings that define transmission characteristics (such as Acquisition Index, Waveform Capture Start location, etc.) *MUST* be common to both the transmit unit and the receive unit. If there is a mismatch between the two, then the receiver will not be able to properly acquire the transmissions, process the received information, or produce waveforms.

One easy way to avoid mismatches is to load the same default configuration file information into both units and then modify the setting such that one unit transmits and the other unit receives.

Hardware Settings

Node ID: The unit's Node ID is typically the last three digits of the IP address. (New units from the factory are configured with IP address 192.168.1.100.) The user can change the Node ID by entering a new value in the Node ID field and clicking on **Set Configuration**. Once this is accomplished, the user is advised to properly record this change on the hardware.

Node Operation: This indicates the operating state of the radio. The user can set this field to one of the following three states: Transmit, Receive, or Ambient Scan. When the user subsequently clicks the **Start Radio** button, the Radio will then enter this identified state.

Antenna Mode: **Table 2** indicates the three supported antenna modes.

Field Entry	Result
Antenna A	Transmit and Receive on Antenna A
Antenna B	Transmit and Receive on Antenna B
TX on A, RX on B	Transmit on Antenna A, Receive on Antenna B

Table 2: Antenna Configuration

Code Channel: Selects the Code Channel used for transmitting or receiving. To properly communicate, both the transmitting and receiving Radios must be operating on the same Code Channel. When operating two or more Radios in the same vicinity, the user must take care to ensure that different pairs of units are operating on different code channels, otherwise they can interfere with each other. Code channels are numbered from 0-255. The user should limit his selection to values between 0 and 10 inclusive. Code channel values greater than 10 are reserved for special applications. Use of code channel numbers greater than 10 should only be done at the recommendation of TDSR's technical support team. Using an invalid code channel number can cause unpredicable results.

<u>Transmit Gain:</u> When set to zero, the unit will transmit at the minimum power supported by the Radio. Setting the transmit gain to a value of 63 will set the unit to maximum transmit power. The default setting is 63. This value has been chosen because it is approximately the maximum FCC transmit power for a standard P4x. When operating a P4xx equipped with optional power amps, a Transmit Gain setting of zero will approximate the maximum FCC transmit power. For additional information on transmit powers consult the relevant data sheet.

<u>Power Up State:</u> This is the state in which the Radio will operate when it is powered up. Three choices are possible and are summarized in **Table 3**.

Power Up State	Action on Power Up
Transmit	The unit will boot and immediately start transmitting using the parameters that were last downloaded.
Receive	The unit will boot and immediately start receiving using the parameters that were last downloaded.
Idle	The unit will boot, it will be in the requested transmit or receive state but the radio will not be started. It will then await user instructions.

Table 3: Power Up States and resultant action

Acquistion Settings

<u>Acq Index:</u> Acquisition Pulse Integration Index (PII) determines the operating range at which transmissions can be acquired. The higher the value, the longer the operating range. Available values are 5 through 11. For a complete discussion of Pulse Integration, see **Appendix C**.

<u>Acq Threshold:</u> This button has two values: Auto and Manual. If set to Auto, the Radio will determine the threshold for receiving signals. This is the preferred operating condition and the user should routinely use this setting.

If set to Manual, then the user can select a threshold setpoint. Because the current thresholding algorithm is quite good, there is little value in the user selecting a threshold. However, there might be occasional reasons for the user to set a threshold. To set the threshold, the user should select a value that is a fraction of the largest signal in the scan. For example, the waveform shown in **Figure 6** has a maximum value of about 15,000. Setting the threshold to a number greater than 15,000 will result in no packets ever being received because the largest received signal is less than the threshold. Setting the threshold to a value less than 15,000 will guarantee that some of the packets are acquired. The higher the threshold, the higher the probability that the received signal will have a high Signal to Noise ratio (SNR). However, the probability of dropped packets will increase. Setting the threshold to a low value will guarantee that the packet rate will be high, but the SNR of the received packet could be quite low.

<u>Threshold Setpoint:</u> This is the threshold setting used if Acq Threshold is set to Manual. The user will very rarely have need to use this capability.

Acq PRI (ns): This is the pulse repetition interval (PRI), measured in nanoseconds, between individual RF pulses transmitted in the acquisition portion of the transmitted packet. This parameter is a function of the selected Code Channel and typical has a value of approximately 100 ns.

Acq (µs): This is the amount of time, in microseconds (µs), allocated for the packet acquisition header. It is a function of the selected Acq Index and Code Channel. This duration constitutes most, but not all, of the communications overhead.

Data Settings

Auto Integration: This button determines if the Data Index: Integration (or Data Pulse Integration Index) will be determined automatically or by the user. If auto is selected, then CAT will automatically set the integration to one PII index value lower than the Acquisition Index. If Auto Integration is not set, then the user can selected a Data Index less than or equal to the Acq Index. This capability allows the user to reliably acquire packets but then send the data with lower integration, such that it reliably and repeatably generates bit errors for determination of Bit Error Rate (BER) vs E_b/N_o. For additional details on integration, see **Appendix C**.

Index:Integration: This is the Data Pulse Integration Index (PII) selected automatically by CAT or defined by the user. See previous discussion of Auto Integration for additional details.

Data Type: This drop-down window determines if the data sent will be all ones, all zeros, or will be sent with a predefined pattern for computation of BER.

Payload PRI (ns): This is the pulse repetition interval, measured in nanoseconds, between individual RF pulses transmitted in the payload portion of the RF packet. This parameter is a function of the selected Code Channel and typically has a value of approximately 100 ns.

Payload (µs): This is the amount of time, in microseconds, allocated for the payload portion of the transmitted RF packet. It is a function of the selected Data Index: Integration (Data PII), the size of the data to be sent, and the Payload PRI.

Receive Settings

From Buttons (Any or Node): This button determines whether the receiver will process packets received from any transmitting node or only from a specifically designated node.

Node Number: If the Node button is selected, then this numeric field will be accessible to the user. The user should enter the node number of the Radio from which packets are to be received. The Radio will then acquire packets as usual, but will terminate acquisition for any packet not sent from the intended source. (Note: this feature is not enabled at this time. The radio is currently always in the "Any" state regardless of the state of the Node button or the node selected. This will be enabledin the next release.)

Transmit Settings

Packets to Send (Count & Continuous Buttons): By using these buttons the user can determine whether (a) a specific number of packets will be transmitted, or (b) packets will be sent continously.

Count Field: If the user selects Count, then the field immediately to the right of the Count button will become available and the user can select a number between 1 and 10,000.

Packet Size (Words): This is the number of 32 bit data words that will be sent in a transmitted packet. Available values are 0-1000.

Inter Packet Delay (ms): This is the delay in milliseconds between the transmissions of a packet. Available values are 0 to 10,000.

Waveform Capture Settings

The Radio can capture, display, and log waveforms. These waveforms will have a starting and ending point relative to the radio lock spot. The lock spot is a specific point on the received waveform. Any zero crossing is a candidate lock spot. The Radio has been designed to find a zero crossing close to one of the largest amplitude signals. For example, any of the points marked in **Figure 6** with a red circle are likely (and desirable) lock points. However, it is possible that the Radio will occasionally lock on a signal distant from the leading edge (for example, the green point at 3.5 ns). While this is a very unusual occurrence, it does happen from time to time. Unless the signal is unusually strong, the radio will have difficulty maintaining lock on such a weak signal and will likely drop the packet.

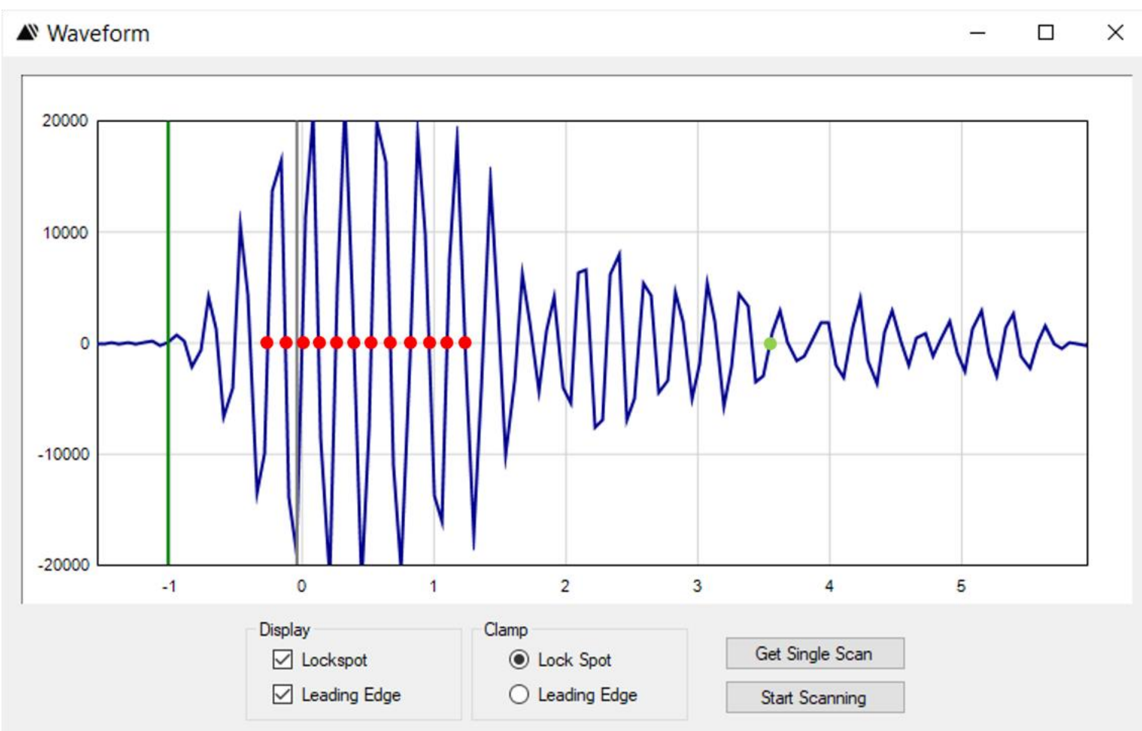


Fig. 6: Sample captured waveform showing potential radio lock spots

There are two ways in which the lock spot can be immediately located. The lock spot is always at nanosecond #0 and it is marked with a vertical gray line.

Start (ns): Beginning point of a captured waveform in nanoseconds relative to the Radio lock spot. A negative value will start the waveform prior to the lock spot. A positive value starts the waveform after the lock spot. The maximum number of measurement points in a scan is 4094. When using a step size of 32 (one measurement every 61 ps), the user may select Start and Stop values between -100 ns and +100 ns. For a step size of 64, the Start and Stop values can be between -200 ns to + 200 ns. Similary, for step sizes smaller than 32, the Start and Stop values will be reduced by half each time the step size is reduced by half. The user should take care to ensure that the starting point is smaller/earlier than the ending point.

Stop (ns): Stopping point of a captured waveform in nanoseconds relative to the Radio lock spot. A negative value will set the stopping point on the waveform prior to the lock spot. A positive value stops the waveform after the lock spot. The maximum number of measurement points in a scan is 4094. When using a step size of 32 (one measurement every 61 ps), the user may select Start and Stop values between -100 ns and +100 ns. For a step size of 64, the Start and Stop values can be between -200 ns to + 200 ns. The user should take care to ensure that the starting point is smaller/earlier than the ending point.

Because of the manner in which the receiver works, the time between the starting and stopping point will be in increments of 5.8 ns. The Radio will round the user's Stop point to reflect this limitation.

Step (bins): This is the amount of time between measurements in a scan. A bin is approximately 1.9073 ps in duration. The standard amount of time between readings is 32 bins, or approximately 61.035 ps. This setting is rather coarse, but should be sufficient for most applications because the sampling rate is approximately twice the Nyquist rate. Alternate step sizes can be selected from the drop-down menu.

It is important to note that the receiver architecture has been optimized to take waveform measurements at the 61 ps (32 bin) spacing. Selecting an alternate spacing will dramatically increase the amount of time necessary to collect a given scan. Selecting 64, 128, or 256 will reduce the rake efficiency by 50% and double the time required to collect a scan. Selecting any other value will reduce the rake efficiency by about 88% and thus increase the time required to collect a scan by a factor of 12.

Integration Factor : This value defines the Pulse Integration Index (PII) to be used in collecting the waveforms. For a discussion of PII, see **Appendix C**. This value is shown as a factor of Data Integration. For example, if Data Integration is set to PII 6, and Integration Factor is set to 2x, then the Waveform Capture Integration Index will be set to PII 7.

Index:Integration: This field is computed by CAT and shows the Waveform Capture Integration Index selected by the user.

4.3 Communications Statistics

CAT will compute and report a variety of communications statistics. These include Receive Statistics (such as BER), Transmit Statistics (such as the number of Transmitted Packets), and Hardware Statistics (such as Run Time). All of these statistics can be be reset by the user by clicking on the **Reset Statistics** Button. CAT will automatically reset all of these statistics whenever the Start Radio Button is clicked.

These statistics are described below.

Receive Statistics

Bit Error Rate: This is the total number of bit errors divided by the number of bits that were received. It is expressed in scientific notation.

Bit Errors: The total number of bit errors that have occurred since the statistics were last reset. This computation assumes that the transmitted Data Type is set to "BER." Bit errors are computed based on a comparison of the received bits with the BER pattern. Bits associated with totally missed packets are not included in the total. However, a partially received packet will be considered completely received if it is successfully acquired. If the packet is subsequently dropped in the middle of the data packet, the radio will continue to demodulate the "received" signal. Since the "signal" received after the packet is dropped is entirely noise, the receiver will report a large burst of errors.

Rx Total Bits: The total number of bits that were received since the statistics were last reset.

Rx Data Rate: This is the total number of bits that have been received since the statistics were last reset divided by the time since the statistics were reset. Note that time includes: packet acquisition time and packet overhead; Inter Packet Delay; time associated with packets that were dropped; and time when the receiver was receiving but the transmitter had not yet been started.

Rx Packets: The total number of packets that have been received since the statistics were last reset.

Dropped Packets: The total number of packets that have been missed since the statistics were last reset.

Packet Error Rate: The packet error rate (PER) is the number of incorrectly received data packets divided by the total number of received packets. A packet is declared incorrect if it is either missed in its entirety or at least one bit is in error.

E_b/N_o: The ratio of the energy per bit to the noise power spectral density expressed in dB. TDSR will sometimes refer to this as SNR (Signal to Noise Ratio).

There are four important considerations when interpreting E_b/N_o.

First, E_b/N_o is calculated based on the measured noise and the measured signal strength. More specifically, the noise and signal are calculated by measuring the 90 ns of signal prior to the lock spot and the maximum signal within 9 ns after the lock spot. This means that E_b/N_o only has meaning if the User sets Start = -90 and the Stop = 9. If other values are used, then E_b/N_o will still be reported but will not be meaningful.

Second, since E_b/N_o is a function of integration and since the integration can be set differently for Acquisition, Data, and Waveform Capture, each can have a different E_b/N_o. The reported E_b/N_o is for the Data. E_b/N_o for Acqusition and Scanning can be calculated from the PII. Each difference in PII is 3 dB. For example, if E_b/N_o is 18.0, Data integration is 6, Acquistion Integration is 9, and Waveform Capture Index:Integration is 10, then:

Data E_b/N_o:	18.0
Acquisition E_b/N_o:	27.0 =3*(9-6)+18.0
Waveform Scan E_b/N_o:	30.0 =4*(10-6)+18.0

Third, the strength of the signal is based on the measurement of the peak signal within 9 ns of the lock spot. The lock spot is at a zero crossing and the signal demodulation point is the 64 ns (or one step) to the right of the lock spot. If the lock spot is not adjacent to the peak lobe, then the demodulated signal strength will be overstated.

Finally, RangeNet and RCM also report E_b/N_o. However, this value is associated with the Acquisition PII, not Data. Therefore, an RCM link set identically to a default CAT link will report 3 dB higer E_b/N_o.

Mean E_b/N_o: The running average of E_b/N_o since the start of the transmittion or since the last time the statistics were reset.

Transmit Statistics

Tx Total Bits: Total number of bits sent since the Start Radio button was last clicked.

Tx Data Rate: Total number of bits sent since the Start Radio button was last clicked divided by the Run Time (see *Hardware Statistics*: Run Time). Note that Run Time includes acquistion time, packet overhead, and the Inter Packet Delay time. Consequently, this is effective throughput and not the raw data rate. Since Run Time is determined by the Windows OS, it could have an error of as much as a second or two. To get an accurate Tx Data Rate, the user should run the test long enough that errors in Run Time estimation are trivial compared to the desired data rate accuracy.

Tx Packets: The total number of packets sent since the Start Radio button was last clicked.

Hardware Statistics

Run Time: The number of seconds that have elapsed since the statistics were reset.

Temp: This is the temperature of the sensor located on the Radio printed circuit board (PCB). It is updated approximately three times a second. This temperature is normally between 30-40^o C.

5. Waveform Plotting

Clicking Show Plot will cause the window shown below in **Figure 7** to appear. The window will appear regardless if the unit is transmitting or receiving. However, no further actions are possible unless the window is associated with a Radio that is receiving.

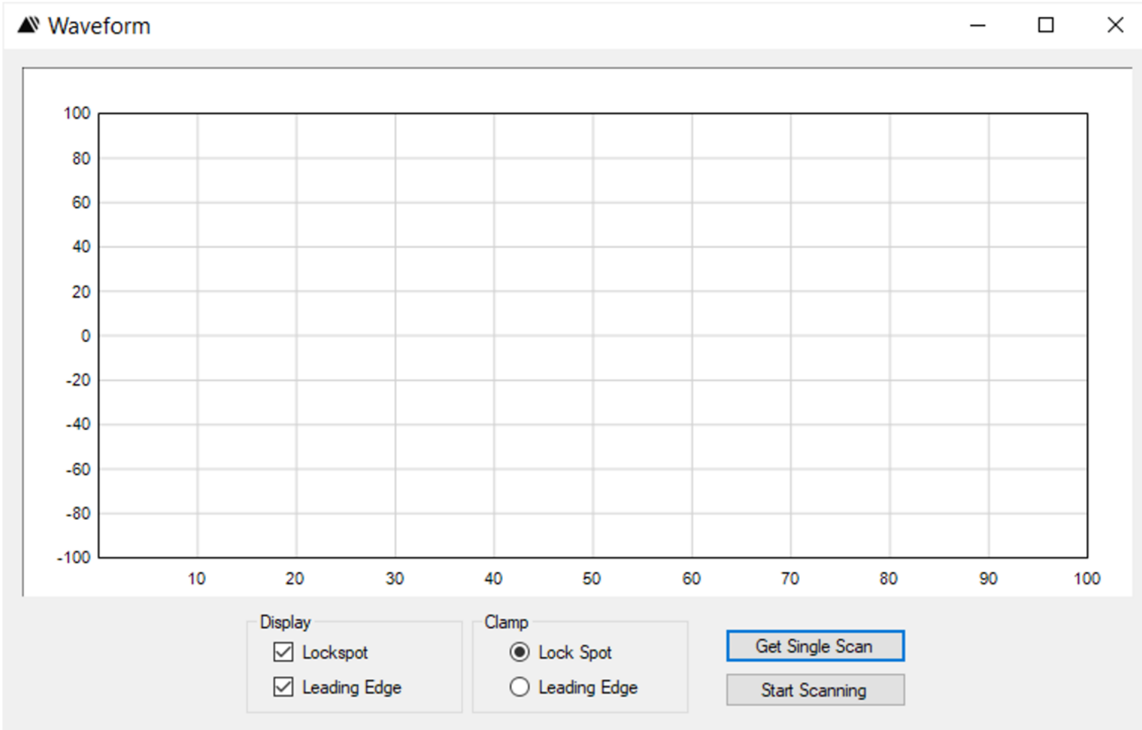


Fig. 7: Basic waveform plot screen

If the window is assocated with a Radio that is receiving, then the waveforms can be viewed in one of two ways. Clicking on the Get Single Scan button will cause one (and only one) waveform scan to appear. Clicking on Start Scanning will cause waveform scans to appear as fast as possible. See **Figure 8** for an example waveform scan. The actual speed will be limited by the rate at which scans are produced, the ability of the USB (or Ethernet, if present) communications link to transport the signal from the Radio to the Host and the ability of the PC display software to update the screen. While it is possible to overdrive any of these potential bottlenecks, operation of the system is normally robust.

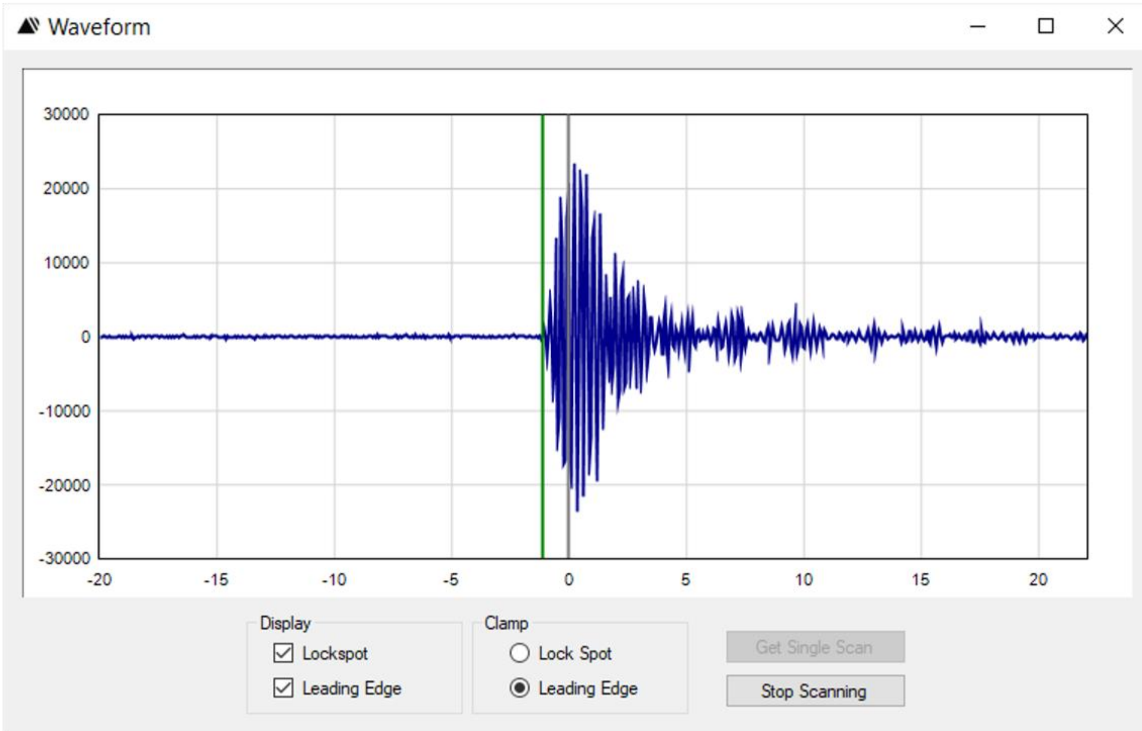


Fig. 8: Typical waveform scan

Display Options

Display: Lockspot: Clicking this button will cause the lock spot to be marked with a vertical gray line that extends from the bottom of the scale to the top.

Display: Leading Edge: Clicking this button will cause the leading edge of the waveform to be marked with a vertical green line that extends from the bottom of the scale to the top. The leading edge is an approximate measure of the leading edge of the received waveform and does not mark the leading edge with the same accuracy that one would get using TDSR's RangeNet software.

Clamp Button (Lock Spot or Leading Edge): The user may choose to "clamp" the displayed waveform either by the Lock Spot or by the Leading Edge. If the user chooses Lock Spot, then the x-axis frame of reference will be fixed and subsequent waveforms will appear to "dance" as a function of what lock spot the Radio selected. If the user choses Leading Edge, then the waveform and leading edge will appear steady and both the scale and lock spot will dance as a function of thelock spot the Radio selected.

Plot Controls

The scales are controlled using the left and right buttons on the mouse.

To vary the portion of the waveform in view, position the cursor anywhere in the plotting area, hold the left button down, and move the cursor to the left or right.

To change the x-scale, position the cursor anywhere in the plotting area, hold the right button down and move the mouse to the left (compresses the scale) or the right (expands the scale).

To change the y-scale, position the cursor anywhere in the plotting area, hold the right button down and move the mouse up (compresses the scale) or down (expands the scale).

6. IP Config Tab

The IP Config tab gives the user the capability to change the IP Address, Netmask, Gateway and or change from static to DHCP. If changes are made an information box will show up below the “Get” and “Set” buttons that will say “IP Settings changed. Must reboot the radio for the changes to take effect”.

The user should be aware that changing the Netmask or Gateway from the original setting will cause the radio to be unreachable via Ethernet and will need to be connected over USB. This is also true if any of the first 7 numeric characters (example from 192.168.1.101 to 192.168.2.101) of the IP Address is changed from the original. Changing the last three numeric characters (other than .000, .001 or .254 or 255, which are usually set aside for the computer Gateway) will still keep the device reachable on the network.

If DHCP is selected the user will need to have a DHCP server running on the host computer/network so the radio will get it’s allotted IP Address. This number will change over time instead of being a static IP Address.

Once a change is made select the “Set” button and select “Reboot.”

See the IP Config example **Figure 9** below.

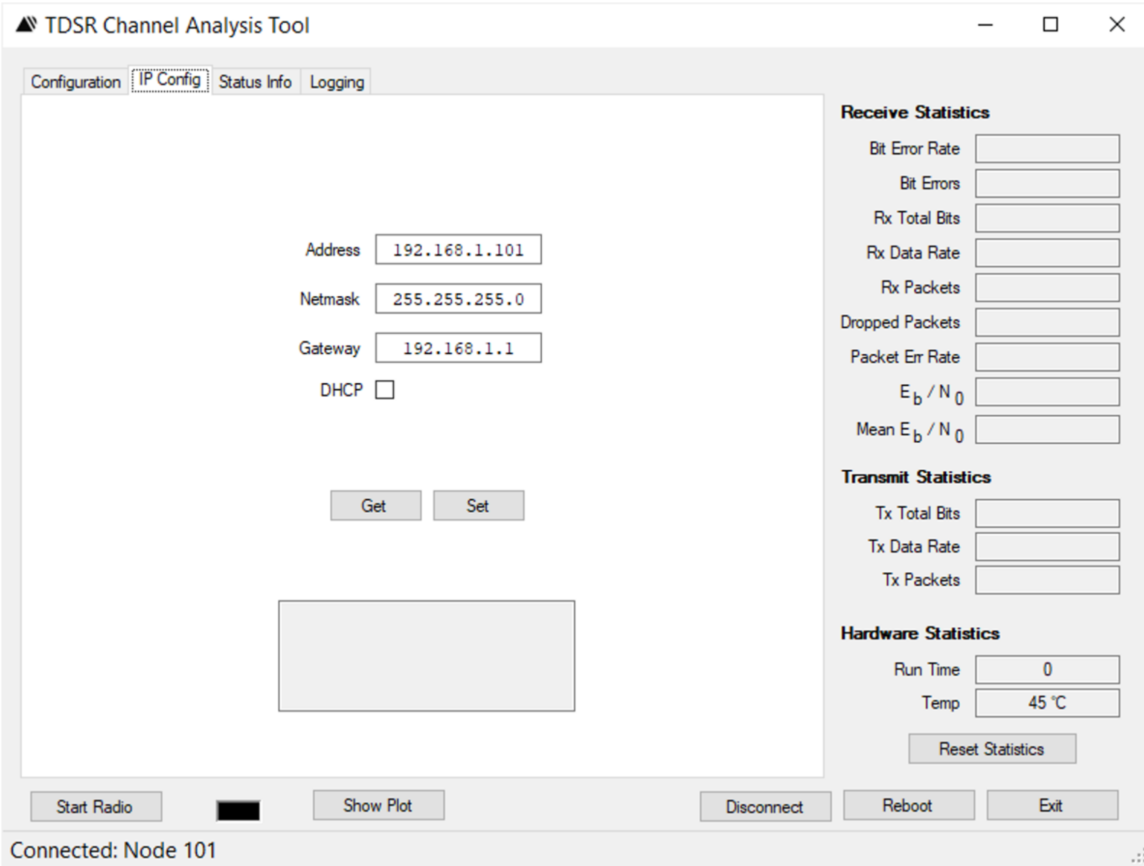


Fig. 9: IP Config Tab

7. Status Info Tab

When the Status Info tab is selected, CAT will issue a CAT_GET_STATUSINFO_ REQUEST and update the table with hardware and software version information.

To update the information, the user can click the **Get Status Info** button. This is useful for uploading software and hardware version numbers as well as measuring the Radio's board temperature.

The following is a short description of the key parameters. For more information, see the *CAT API Specification*.

Software Versions: Radios have four different software designations:

- The software Package ID is the overall build version for the P4xx and encompasses all types of software on the P4xx. When reporting issues to the factory, please reference this one number. If N/A is displayed, then the other three designations should be reported. Otherwise, the other three are irrelevant and at some time in the future they will likely be deleted from the display and possibly the API.
- Embedded Software Version: The version of Radio application code running on the Radio processor.
- UWB Kernel Version: The version of the UWB software running on the Radio processor.

- FPGA Version: The version of FPGA code running on the Radio.

Hardware Version: There are four hardware items of note: the Radio Model (P4xx), Board Serial Number, Board revision, and Pulser Configuration (FCC/EU mask and TX power range).

BIT: "BIT" stands for "Built-in Test" and will return "0" under normal operation. A non-zero value indicates some sort of failure. In the event of this failure, please contact TDSR.

Temperature: This is the temperature of the sensor mounted on the PCB. This is not the ambient air temperature. Because the Radio generates heat, the board will run hotter than the ambient. The maximum operating temperature of many key components is 70º C. However, these boards have been successfully run at temperatures approaching 100º C. No physical damage to the radio has been observed when operating up to 100ºC. While the unit may or may not function above 70ºC, our experience to date indicates that when the temperature falls below 70ºC the equipment will work normally. Operating the equipment above 70ºC cannot be guaranteed, is not recommended and should be avoided.

The information on this tab (shown in **Figure 10**) is valuable for debugging purposes. For example, if the P4xx should malfunction, then the TDSR product support team will likely ask for a screenshot of this tab.

As embedded software/firmware is upgraded, this version info is used to assure host code compatibility.

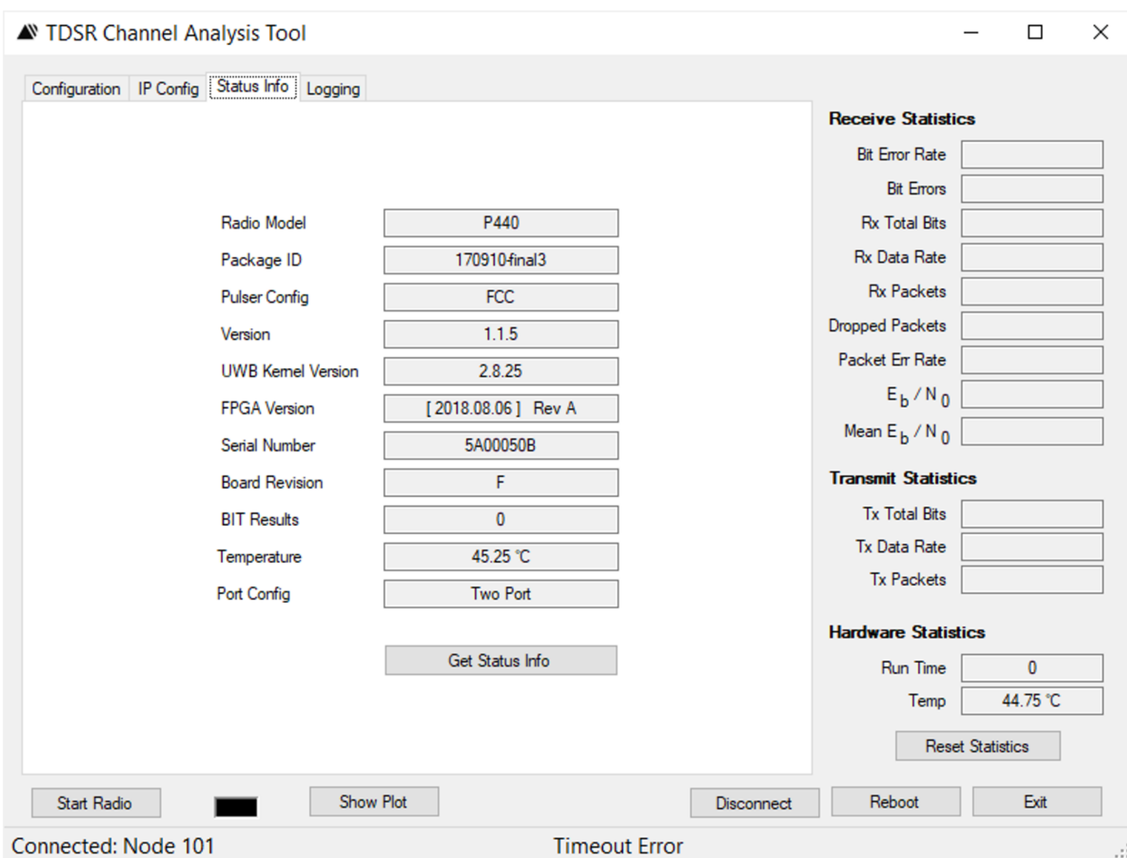


Fig. 10: Status Info Tab

8. Logging Tab

The Logging Tab (see **Figure 11**) is provided by CAT to support data collection and post-processing analysis. The logfile is a comma-separated variable ASCII .csv text file. See **Appendix B** for more information on the logfile format. Logfiles will be stored in the directory indicated in the "Directory" field. The user may change the target directory by using the "Change" button to browse to the desired location.

The logfile names are designated by the "Logfile Prefix" field. The user can change the name by entering the desired prefix name in the 'Logfile Prefix" field.

When the "Start Logging" button is clicked, CAT will add a three digit suffix number to the file name. This name will be displayed on the screen. Each time the log is stopped and started, this suffix number will be incremented. The Start Logging button can be clicked at any time. Once the button has been clicked, all messages will be logged.

IMPORTANT: While logging will record all messages, no waveform scans will be logged unless the **Show Plot** button on the Configuration Tab has been clicked *AND* the **Start Scanning** button is clicked.

When the "Stop Logging" button is clicked, CAT will stop logging and the logfile will be closed.

Clicking the "New Logfile" button will close the existing file, open a new logfile with an incremented number, and continue logging. This can be accomplished in the middle of a scanning sequence because clicking this button does not stop and restart the Radio; it merely redirects that data flow to a new file.

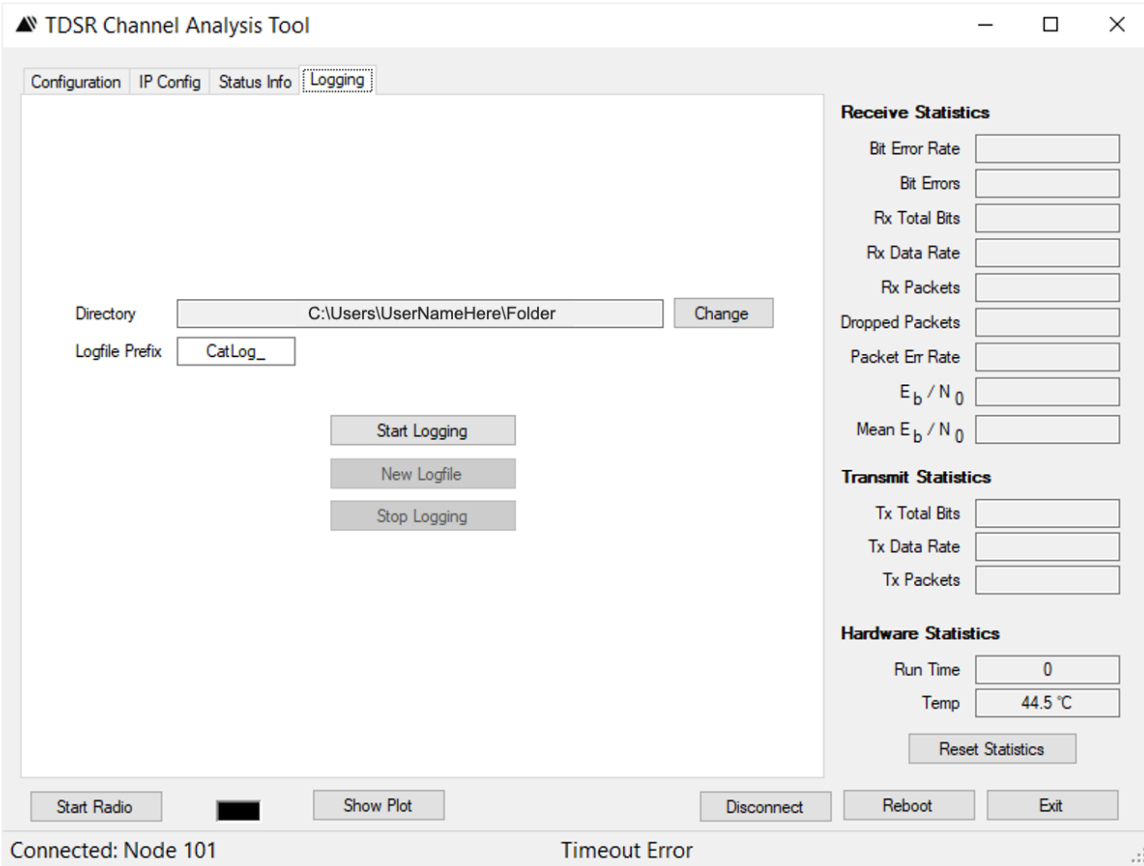


Fig. 11: Logging Tab

Appendix A: Using CAT and MATLAB to Compute Channel Impulse Responses

CAT is provided with MATLAB code which can take logfiles collected by CAT and process the results into Channel Impulse Responses (CIRs). The MATLAB code will use the CLEAN algorithm to deconvolve the received signal with a reference or template waveform. All these operations are performed in a batch process. The user collects waveform scans with CAT and then separately runs the MATLAB script CATCIR. The host machine must have MATLAB Version 2011B and be equipped with the Signal Processing Toolbox. Versions of MATLAB more recent that 2011B are not able to process these files. They process up to a point and then stop. We believe that the problem is due to a format change introduced in more recent versions of MATLAB. To run the program, the user must either downgrade to the earlier version or locate and fix the MATLAB bug.

The MATLAB source code has been provided as it is assumed that the user will likely wish to make modifications. The source code has good and bad characteristics. The key drawback is that the code was originally developed 12 years ago and was modified by several different developers over the course of 10 years. These programmers developed the code for a wide variety of unrelated analysis tasks. Much of the inline documentation is scant. Some of the developers are no longer available. As a result, the code is not at all clean. Besides this document and the embedded comments in the code, the MATLAB is currently not supported. No effort has been made to delete irrelevant or unused code. In fact, the actual code used to produce the CIRs is only a small percentage of the total code delivered with CAT.

On the positive side, the code was extensively used for propagation analysis and was both exercised and validated. Furthermore, the code specifically used to produce the CIRs was reviewed and revalidated, and the inline documentation was improved. The CIR code is well tested, and the user should not have issues either using the code as-is or in modifying the core CIR code. While there is a great deal of unused code, much of it is actually very useful for computing delay spread and other important parameters. It is our expectation that the user will find the base code useful, easy to work with, and that the excess code will prove to be a valuable resource library.

The following sections describe how the user:

- Installs CATCIR
- Collects waveforms
- Runs CATCIR
- Interprets the results

Process Steps

1. Installing CATCIR

The CATCIR code is delivered on the installation disk and can be found in the folder entitled "CATCIR Delivery Files". The user should copy this directory to a place of his choosing on his computer.

This directory has two sub-folders called "CATCIR" and "Log Files". CATCIR contains a zip file called CATCIR.ZIP. This file contains all of the MATLAB used to convert log files into CIRs. As a convenience to the user, the contents of the .ZIP file have already been moved into the CATCIR folder. The folder “Log Files” contains some sample log files which the user can use to exercise CATCIR for the first time.

2. Collecting waveforms

Before collecting waveforms or exercising the CATCIR program, it is recommended that the user practice with and become proficient with the use of CAT and the Radios. In doing so, the user will become familiar with how waveforms are captured and logged.

Once familiar with CAT and the hardware, the next step is to collect waveforms for a test. As a reminder, while it is easy to collect hundreds of waveforms in a given location, there is generally no reason to collect more than a few waveforms per location as waveforms collected at the same time and in the same conditions are quite similar.

CATCIR makes some assumptions about the parameters used when collecting waveforms.

I. It assumes that the waveforms are collected using the following parameters:
   - Step Size: 32
   - Start (ns): -20
   - Stop (ns): 80

   Note that these values correspond to the factory defaults.

II. When run, CATCIR will ask the user to point to the directory that contains the logfiles to be processed into CIRs. The user will then be asked if the user wants all the files in the directory processed or just the first one. The “first” file is the one that appears alphabetically first. All of the waveforms captured in the logfile must have been collected using the same parameters. If the user indicates that all files are to be processed, then all waveforms in all of the files need to have been taken using the same parameters and the same type of radios. There are three types of radios: P400, P410, and P410 with power amplifiers.

III. All files in the directory must contain at least one waveform scan. A logfile that contains no scans will likely generate an error.

IV. All files in the directory must have been collected using the same parameters and with the same type of radios.

3. Running MATLAB

When CATCIR runs, it will process the logfiles and generate graphics of the waveforms. The speed at which CATCIR runs is a function of the processing capacity of your particular computer as well as the capabilities of the video processor. If you ask to process “too many” logfiles, then the machine could take a long time to finish or it may be overwhelmed and terminate improperly. This limit is a function of your computer processing horsepower. You should have no trouble processing several dozen, if not a few hundred, scans. Just be aware that there is a limit, and it is important to be prudent in the amount of files processed at one time.

Steps to run the MATLAB script CATCIR:

I. Open MATLAB

II. In MATLAB, navigate to the directory where you have placed the CATCIR directory.

III. Select CATCIR and run it. You will be asked to navigate to the directory where the logfiles to be processed are located. The following example was taken using the file "final catcir test000.csv" located in the folder "Log Files" provided with CATCIR.

IV. Once you have selected the logfile directory, CATCIR will examine the logfiles in the directory and confirm that they were all produced using the same parameters. It will then ask if you wish to combine them. See **Figure A-1**. If you click on Yes, CATCIR will process all of the waveforms in all of the logfiles. If you click on No, then CATCIR will process only the first logfile. Note that the "Do not show this dialog again" box has been disabled. Clicking or unclicking it has no effect on the program operation.

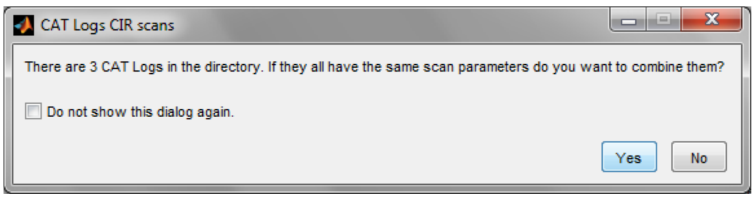


Fig. A-1: Combine screen

V. Once you have made your selection, CATCIR will prompt you to indicate what sort of radio you were using to generate waveforms. See **Figure A-2**. This is important because each of the radio transmit waveforms have slightly different shapes. Since the CIRs produced are done so by deconvolving the received waveform with the transmitted waveform (or "template" waveform), this step insures that the deconvolution is performed with the correct transmit waveform.

Fig. A-2: Selection transmit waveform shape

Once again, the "Do not show this dialog again" button has no effect on the program's operation.

VI. Once a selection has been made, CATCIR will run the selected the logfiles and will produce the following figures:

Figure A-3 shows MATLAB Figure 1. It is blank and can be ignored.

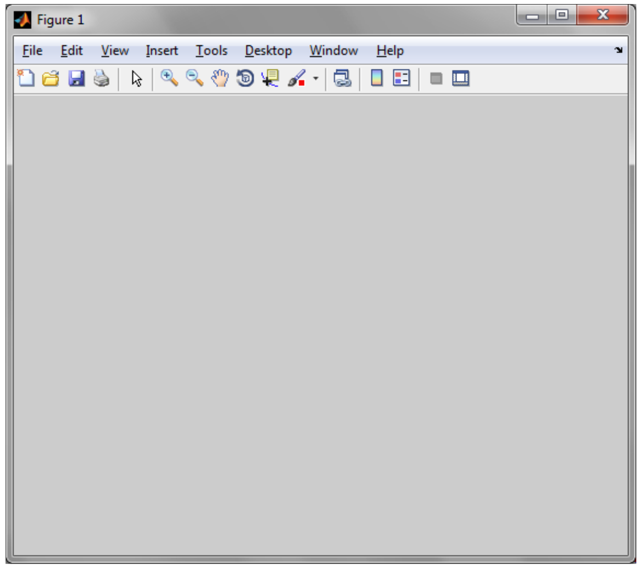


Fig. A-3: MATLAB Figure 1

Figure A-4 shows MATLAB Figure 2 entitled "Scan 1". The graph on top shows the template waveform used in the deconvolution process. It is shown in the same scale as the subsequent CIRs. The plot on the bottom is the CIR for that template waveform. Since the CIR of a template is the deconvolution of a waveform with itself, the resulting CIR is an impulse. The various scales and axes will be described shortly in the section entitled "Interpreting Results."

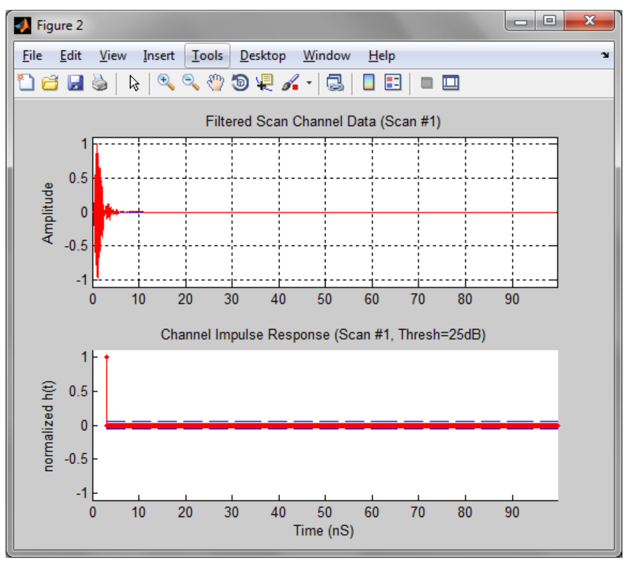


Fig. A-4: MATLAB Figure 2 - Template used to compute the CIR

Figure A-5 is MATLAB Figure 3 entitled "Scan 2". The graph on top shows the first collected waveform in the selected logfile. The plot on the bottom is the CIR for the collected waveform. If there are more multiple waveforms in the logfile, then subsequent waveforms will be called Scan 3, Scan 4, etc.

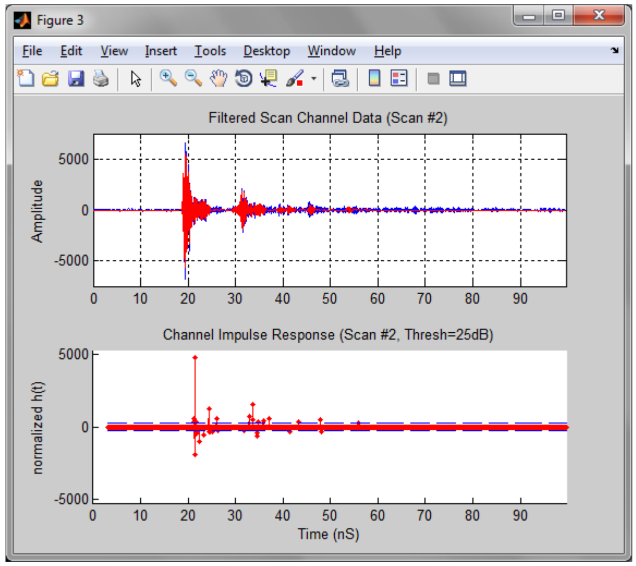


Fig. A-5: MATLAB Figure 3 - CIR of the first captured waveform

The final MATLAB figure shown will be of the template waveform. This is the same waveform shown in **Figure A-4** except it is shown using a higher resolution time scale. See **Figure A-6**. In this case the example data was taken using a P400 as a transmitter. **Figures A-7** and **A-8** show the templates for a P410 and a P410 with power amps.

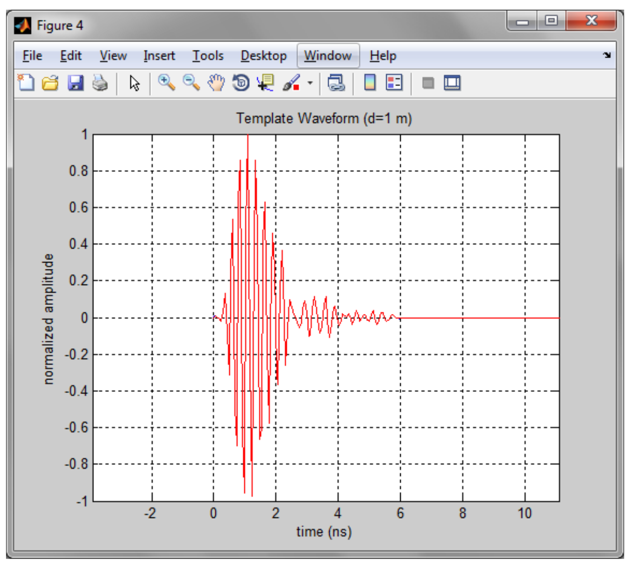


Fig. A-6: Template waveform for a P400 with power amp

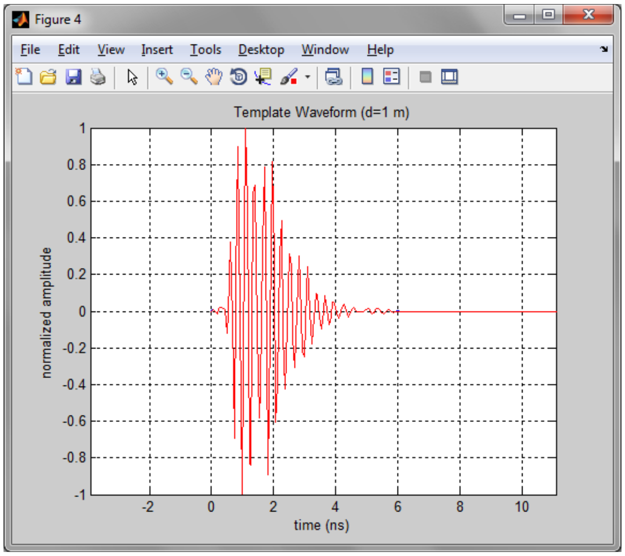


Fig. A-7: Template waveform for a P410 without power amp

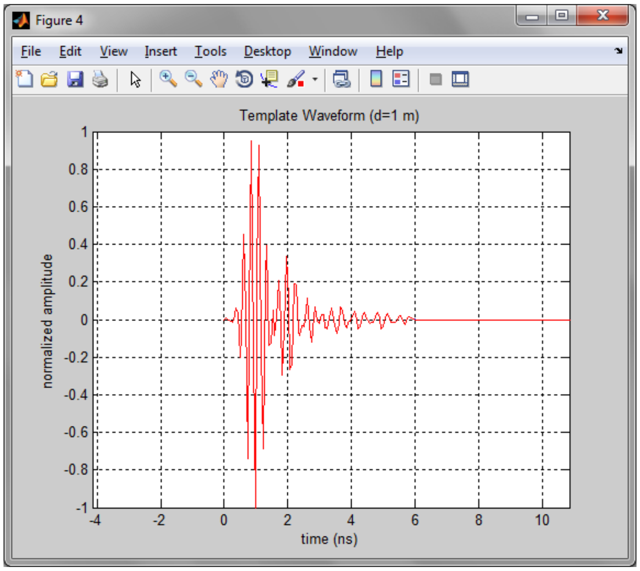


Fig. A-8: Template waveform for a P410 with power amp

VII. Once MATLAB has produced the final plot, then a dialog box will appear prompting the user to indicate whether or not the CIRs are to be saved in a text file. If yes is selected, then CATCIR will store the CIRs in a single ".out" file. See **Figure A9** below. As before, the "Do not show this dialog again" button has no effect on program operation.

The ".out" file is a text file. It can be opened by any number of programs including MATLAB and Excel. When opening in Excel, be sure to use the Text Import Wizard and select "Fixed width." Before converting the file, check the fixed width alignment of each column to insure that they are properly parsed.

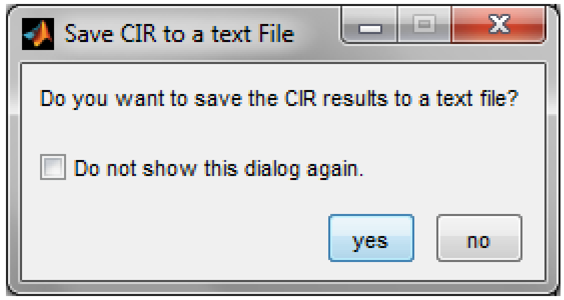


Fig: A-9: Template waveform for a P410 with power amp

4. Interpretation of the results

Consider again **Figure A-5**, reproduced below as **Figure A-10**.

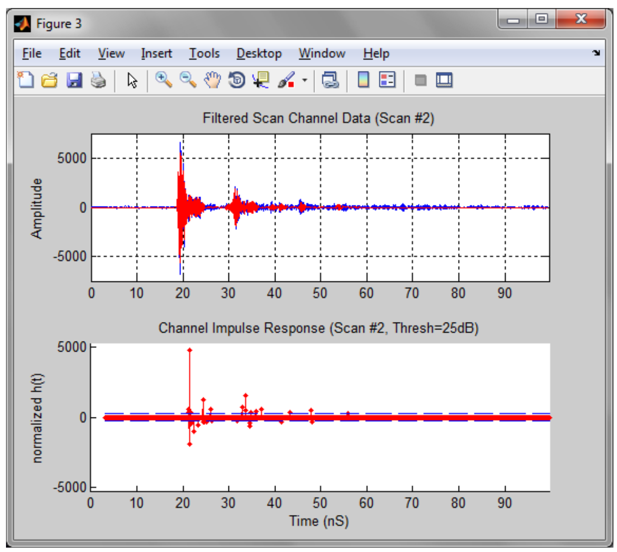


Fig. A-10: Example Channel Impulse Response (CIR)

The upper plot shows two traces, one in blue and the second in red. The blue trace is the original raw data. We will discuss the red trace more in a moment.

The lower plot shows the resultant CIR plot. The x-axis is time in nanoseconds, while the vertical scale shows the magnitude of the CIR relative to the first arriving signal. A negative magnitude indicates that the received signal has been inverted relative to the template. Note that one can clearly see the reflections at 20 and 32 ns as well as a relatively large number of smaller ones. The deconvolution process is not applied to every data point in the received scan. Instead the deconvolution process has a 10% threshold. If the input signal is less than 10% of the main signal then it is considered too small for reliable analysis and is ignored. This threshold is shown on the lower plot as a dashed blue line.

Let us return now to the upper plot. The red line was created by convolving the channel impulse response from the lower plot with the original template waveform. From this we can see that the reconstructed waveform matches the original waveform. This serves as a quick visual confirmation that the computation was executed properly. Any differences are likely an indication of the imperfections in the signal processing. Perhaps an improved CLEAN algorithm would further improve the match. Then again, much of the difference between the red and the blue line might also be the result of random noise variation.

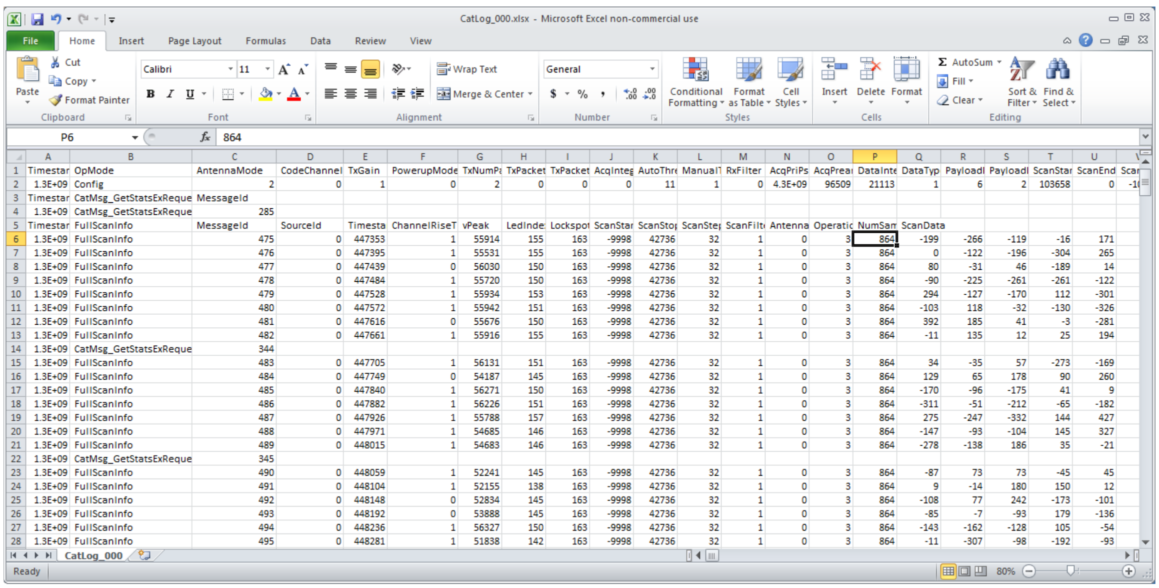
Note also that the red line does not completely cover the blue line. These gaps are the result of the +/- 10% threshold imposed on the deconvolution process.

Appendix B: CAT Logfile Format

The CAT logfile captures in a .csv file all of the messages sent to, and received from, the P4xx module. Before the FIRST instance of each message type, a header description will be provided. The initial timestamp (always the first parameter in each message line) is a floating point time value, in seconds, provided by the Host PC. All parameters for all messages are described in the *CAT API Specification.*

The scans are associated with the "FullScanInfo" messages. For example, column P ("NumSamp…" indicates that there are 864 measurements in this scan and the next 864 fields are the scan readings. All of the other key features of the waveform including location of leading edge, location of lock spot, waveform start point, waveform stop and step size can be found in the following fields: LedIndex, Lockspot, ScanStart, Scanstop, and ScanStep. See *CAT API Specification* for details.

Figure B-1 shows an example .csv logfile as viewed in MS Excel. This figure does not show the final 859 columns.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
1	Timestar	OpMode	AntennaMode	CodeChannel	TxGain	PowerupMode	TxNumPa	TxPacket	TxPacket	AcqInteg	AutoThre	ManualT	RxFilter	AcqPriPs	AcqPreai	DataInte	DataTyp	Payloadl	Payloadl	ScanStar	ScanEnd	Scar
2	1.3E+09	Config	2	0	1	0	2	0	0	0	11	1	0	4.3E+09	96509	21113	1	6	2	103658	0	-1
3	Timestar	CatMsg_GetStatsExReque	MessageId																			
4	1.3E+09	CatMsg_GetStatsExReque	285																			
5	Timestar	FullScanInfo	MessageId	SourceId	Timesta	ChannelRiseT	vPeak	LedInde	Lockspot	ScanStar	ScanStop	ScanStep	ScanFilt	Antenna	Operatic	NumSam	ScanData					
6	1.3E+09	FullScanInfo	475	0	447353	1	55914	155	163	-9998	42736	32	1	0	3	864	-199	-266	-119	-16	171	
7	1.3E+09	FullScanInfo	476	0	447395	1	55531	155	163	-9998	42736	32	1	0	3	864	0	-122	-196	-304	265	
8	1.3E+09	FullScanInfo	477	0	447439	0	56030	150	163	-9998	42736	32	1	0	3	864	80	-31	46	-189	14	
9	1.3E+09	FullScanInfo	478	0	447484	1	55720	150	163	-9998	42736	32	1	0	3	864	-90	-225	-261	-261	-122	
10	1.3E+09	FullScanInfo	479	0	447528	1	55934	153	163	-9998	42736	32	1	0	3	864	294	-127	-170	112	-301	
11	1.3E+09	FullScanInfo	480	0	447572	1	55942	151	163	-9998	42736	32	1	0	3	864	-103	118	-32	-130	-326	
12	1.3E+09	FullScanInfo	481	0	447616	0	55676	150	163	-9998	42736	32	1	0	3	864	392	185	41	-3	-281	
13	1.3E+09	FullScanInfo	482	0	447661	1	55916	155	163	-9998	42736	32	1	0	3	864	-11	135	12	25	194	
14	1.3E+09	CatMsg_GetStatsExReque	344																			
15	1.3E+09	FullScanInfo	483	0	447705	1	56131	151	163	-9998	42736	32	1	0	3	864	34	-35	57	-273	-169	
16	1.3E+09	FullScanInfo	484	0	447749	0	54187	145	163	-9998	42736	32	1	0	3	864	129	65	178	90	260	
17	1.3E+09	FullScanInfo	485	0	447840	1	56271	150	163	-9998	42736	32	1	0	3	864	-170	-96	-175	41	9	
18	1.3E+09	FullScanInfo	486	0	447882	1	56226	151	163	-9998	42736	32	1	0	3	864	-311	-51	-212	-65	-182	
19	1.3E+09	FullScanInfo	487	0	447926	1	55788	157	163	-9998	42736	32	1	0	3	864	275	-247	-332	144	427	
20	1.3E+09	FullScanInfo	488	0	447971	1	54685	146	163	-9998	42736	32	1	0	3	864	-147	-93	-104	145	327	
21	1.3E+09	FullScanInfo	489	0	448015	1	54683	146	163	-9998	42736	32	1	0	3	864	-278	-138	186	35	-21	
22	1.3E+09	CatMsg_GetStatsExReque	345																			
23	1.3E+09	FullScanInfo	490	0	448059	1	52241	145	163	-9998	42736	32	1	0	3	864	-87	73	73	-45	45	
24	1.3E+09	FullScanInfo	491	0	448104	1	52155	138	163	-9998	42736	32	1	0	3	864	9	-14	180	150	12	
25	1.3E+09	FullScanInfo	492	0	448148	0	52834	145	163	-9998	42736	32	1	0	3	864	-108	77	242	-173	-101	
26	1.3E+09	FullScanInfo	493	0	448192	0	53888	145	163	-9998	42736	32	1	0	3	864	-85	-7	-93	179	-136	
27	1.3E+09	FullScanInfo	494	0	448236	1	56327	150	163	-9998	42736	32	1	0	3	864	-143	-162	-128	105	-54	
28	1.3E+09	FullScanInfo	495	0	448281	1	51838	142	163	-9998	42736	32	1	0	3	864	-11	-307	-98	-192	-93	

Fig. B-1: Example logfile

Appendix C: Acquisition, Data, and Waveform Pulse Integration Index

Pulse integration is a key characteristic of TDSR's RF transmissions. This ability is used to increase operating range, minimize error rate, and capture high SNR waveform scans. This Appendix describes pulse integration, TDSR's definition and its effect on performance.

Since the Radio has been designed for coherent operation, it is possible to transmit a single bit of information over multiple pulses and then receive that bit of data by integrating multiple pulses to recover the original bit of information. Each time integration is doubled, the SNR of the received signal will improve by 3 dB. Consequently, doubling the integration also doubles the amount of time it takes to collect that bit of data and thereby reduces that data rate by half.

The user can set the integration increments in powers of two. For example, the user can set integration to 64:1 or 2^6. TDSR refers to this as a Pulse Integration Index (PII) of 6. A PII setting of 6 will increase the received SNR by 18 dB. Similarly a PII of 16, the maximum allowed by CAT (accomplished for Scans by setting Data Index: Integration to 11 and Integration Factor to 32x) will integrate 65,536 scans and thereby provide an SNR improvement of 48 dB.

"Bit of information" could be (but is not necessarily) referring to bits of data. It could also relate to the energy needed to acquire/receive an RF packet or the energy needed to capture a waveform. By increasing the PII and consequently the signal SNR, the user can increase the range of performance, improve the signal BER and PER, and improve received scans. However, increasing PII will increase the time required to accomplish a given function.

In general, it will take 3 dB more to acquire a packet that to demodulate data. Therefore the PII for Acquisition is normally set to one PII setting higher than that used for data demodulation. Similarly, the PII used for generating a scan is normally set to one PII higher than data. These are the normal settings, all of which the user can override. The following table indicates the effect PII settings will have on maximum operating range and raw data rate.

Acquisition PII	DATA PII	Max Range (meters)	Raw Data Rate: (bps)
5	4	35	632k
6	5	60	316k
7	6	88	158k
8	7	125	79k
9	8	177	39.5k
10	9	250	19.7k
11	10	354	9.86k

Table C-1: Data and ranging performance characteristics @ -14.5 dBm transmit power