RCM RET / RangeNet RET

User Guide

PulsON® 400 RCM 2.8

PulsON® 400 RangeNet 1.3

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1. Introduction

The Ranging and Communications Module Reconfiguration and Evaluation Tool (RCM RET) is a Microsoft Windows-based Graphical User Interface (GUI) program providing an easy, illustrative means of manipulating the ranging and communications configuration parameters on any of Time Domain's PulsON® 400 (P400) series of Ultra Wideband (UWB) platforms. RangeNet is an optional software layer that enhances the basic ranging functionality to support network operation. RangeNet has its own GUI (RangeNet RET).

(Currently the P400 series platforms consist of the P400, P410, and P412, with the potential for additional variants as the technology progresses. For purposes of this discussion, the various P400 series devices will be referred to jointly as a P4xx. Where specific differences exist, the platforms will be referred to by their specific names.)

Because RangeNet RET is built as an add-on to RCM RET and because many users will start with RCM RET and later move to RangeNet RET, this User Guide describes the operation of both tools. Sections 1-14 describe all of the RCM commands while Sections 15-23 describe RangeNet operation. While the documentation describes operation of both tools, RCM users will only have access to RCM commands, while RangeNet RET users will have access to both RCM and RangeNet commands.

The GUI has been designed to emulate as closely as possible the various API commands. RCM RET users can find more information on the RCM-specific API commands in the document *"Ranging and Communications Application Programming Interface (API) Specification".* Similarly, all of the RangeNet-specific API commands are described in the document "*RangeNet Application Programming Interface (API) Specification.*

Because the commands are divided into two groups, the manual will refer to the GUI as RCM or RCM RET when describing operation in RCM mode (Sections 1-14) and RangeNet RET when describing operation in RangeNet mode (Sections 15-23). When connecting to a P4xx, both RCM RET and RangeNet RET will be referred to simply as RET.

Overview: UWB, Ranging, and Networks

UWB: The P4xx modules coherently transmit and receive UWB pulses. These pulses are transmitted between 3 and 5 GHz and have an RF bandwidth of 1.4 GHz. The pulses have a nominal repetition rate of 10 MHz. Because the transmissions are coherent, the energy of multiple pulses can be integrated and used to increase the received signal strength. (SNR will increase by 3 dB each time the integration rate is doubled.) Pseudo-random encoding of transmissions (either by flipping the polarity of the pulse or using pulse position modulation) allows the creation of independent channels. This allows multiple units to be operated on different channels in the same area, at the same time, with a minimum of mutual interference.

Depending on how the pulses are transmitted and received, the units can be used as a range measurement device, a slow speed data link (maximum rate of approximately 600 kbps), an impulse transceiver for channel modeling, a monostatic radar, a bistatic radar, a multistatic radar, or some combination of the above. The device's operating mode is software defined. More information on these capabilities can be found at www.timedomain.com.

UWB Ranging: UWB ranging is normally performed using Two-Way Time-of-Flight (TW-TOF) distance measurement. With this approach, a packet is sent from one UWB platform (the requester) to a second unit (the responder). The responder then transmits a carefully timed response packet which is received by the requester. By knowing the speed of light, the exact time when the request packet was sent, the time it took the responder to send the return packet, and the time when the response packet was received, it is possible to measure the range with 2 cm accuracy. (Using averaging, some customers have reported accuracy of 2 mm.) Such measurements are also called Precision Range Measurements (PRMs).

The P4xx units also measure the signal strength of the first arriving energy. Since the strength of a signal is inversely proportional to the square of the distance, the signal strength can be used to estimate distance. Because signal strength is also a function of other factors, this estimate is rather coarse and is therefore referred to as a Coarse Range Estimate (CRE). A CRE can be calibrated with periodic Precision Range Measurements to form a Filtered Range Estimate (FRE).

Since a transmission from one unit can be heard from many units, CREs are effectively a broadcast in that every transmission will result in a CRE at each receiving unit. This technique can be used to increase the system capacity.

Networks: While it is useful to measure the range between two lone devices, it is often more valuable to take measurements from a system of devices and use that information to compute not just the range between two units but the actual device location in three dimensions.

Control and coordination of such a system of units will require a network. Such a network can be implemented using a wired solution (based on Ethernet or USB) or a wireless solution such as Wi-Fi. However, these types of networks have a serious limitation in that they are designed to maximize data throughput using one-way packets. While that approach is a logical and reasonable approach for handling data, it is not well-suited for handling range measurements. This is due to the way in which range is measured. The range measurement process requires the transmission of two carefully timed packets acting as a single conversation. Therefore, the network must be designed to handle conversations and not simple one-way transmissions. Most, if not all, wireless networks are designed to pass one-way data. Throughput is measured and optimized in terms of one-way data transfers. While acknowledgements are sent and there are handoffs, these networks are not well-suited for handling TW-TOF range measurements.

RangeNet has been specifically designed and optimized to handle networks of ranging UWB devices. While RangeNet can transport data, the associated data rates and throughput are of secondary interest and are normally limited to rates consistent with command and control.

Because RangeNet has been designed for operation with ranging platforms, RangeNet RET includes all the commands needed for configuring an individual P4xx with the necessary ranging parameters and operating P4xx modules as simple pairs of devices or as networks of nodes. RangeNet RET adds several network-specific tabs to the standard RCM tabs shown in RCM RET. These tabs contain commands that allow the user to create and operate systems of devices as a network. RangeNet currently supports both the ALOHA network protocol and TDMA.

Unlike regular data networks, performance of a ranging network is much more tightly coupled with the application for which the ranges are being provided. More specifically, a ranging network needs to be tuned to meet the needs of the specific end application. For example, if one were using the network to monitor and control the location of a few rotorcraft in a confined area where inter-unit distances are very short, then the tuning for that network would be very different from a network intended to keep large mining vehicles from colliding. In the first case, the range measurements are small, all rotorcraft are in view of all of the references, and the maximum range of operation is sacrificed for update speed. In the second case, there are no reference locations, there can be dozens of vehicles, most of the vehicles will not be in range of each other, the range measurements are long, and most updates can be done slowly but occasionally there is a need for very fast updates. RangeNet has been designed with the flexibility to deal with such a wide variety of application requirements.

This brings up an interesting question. Is RangeNet a network or is it a MAC layer? If you are dealing with a relatively simple application, (for example, the sample application demonstrated in the *RangeNet Quick Start Guide*) then RangeNet will have the feel of a complete network. However, as the complexity of the application increases, RangeNet will begin to feel more like a MAC. In any event, RangeNet provides both the convenience of a network and the flexibility of a MAC layer.

RangeNet RET provides the user with the ability to:

- Operate a system of P4xx units as a network optimized for the handling of range measurements
- Measure inter-device range with either Precision Range Measurements (based on Two-Way Time-of-Flight measurements) or Filtered Range Estimates (one-way Coarse Range Estimates updated with periodic Precision Range Measurements)
- Operate P4xx nodes in RCM mode on a standalone basis without the benefit of a network
- Operate P4xx nodes in RangeNet mode as part of a network
- Operate the network either as a random access clock-less ALOHA network or as a synchronized TDMA network
- Transition back and forth between operation as a standalone device or as part of a network
- Define and save configuration parameters
- Enable a node to enter or exit a network
- Define a schedule by which a node will share airtime with other units in the network
- Manually define an average rate at which the node will source a transmission
- Automatically throttle the ranging rate as a function of the total number of system nodes
- Exclude specific units from range requests
- Limit some P4xx nodes such that they cannot initiate a range request
- Allow data to be transmitted between nodes
- Define in each P4xx a Neighbor Database (NDB) which includes, for example, important data such as the ranges to each Neighbor, the rate of approach/withdrawal, and other useful information
- Allow the user to monitor the contents of the NDB, either on a demand basis or as part of a routine schedule
- Allow the user to limit the amount of information transmitted from the P4xx to the user
- Allow the user to monitor communications statistics
- Allow the user to identify a default communications path that does not rely on an established host connection

Installing and Operating RCM RET or RangeNet RET

These two GUIs come as ".msi" installation executables which, when unbundled, will create default directories, load the software, load the default configuration settings, load the USB drivers, and create a link on the user's PC Desktop. Both operate under the following Windows operating systems: Vista (32 and 64 bit), Windows 7 (32 and 64 bit) and Windows 8 (32 and 64 bit).

The default location for RCM RET is in the directory:

C:/Program files (x86)/RCM Reconfig & Eval Tool (RET)

The default location for RangeNet RET is in the directory:

C:/Program files (x86)/Time Domain/RangeNet Reconfig & Eval Tool (RET)

These directories will contain the drivers, Factory Defaults, and the program file. All of the default files are write-protected.

For instructions on the installation and initial use please see either the *RCM Quick Start Guide* or the *RangeNet Quick Start Guide*.

The tabs and data structures of RET closely match those defined in the API. The primary function of both RETs is to provide a graphical representation of these parameters so that the user can develop an intuitive feel for how the API command structures operate. The RETs also provide a real-time display of range measurements, received waveforms, network status, and logging functions. They are intended to help users to develop a feel for how both UWB ranging and UWB ranging networks operate.

The configuration settings and data returned are explained in full detail in the RCM and RangeNet *API Specifications*. We recommend having a copy of these documents close at hand and referring to them for more information on the configuration parameters and returned data.

More than one copy of the RETs can be run on the same PC. Each copy can be connected to a different P4xx module through Ethernet, USB, and serial connections.

2. Before You Begin

Make sure that the P4xx is powered up 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 P4xx 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 *RangeNet Quick Start Guide* for detailed instructions.

The user can also connect through the serial interface. For details on this interface, see the document *Using the USB and Serial Interfaces*.

3. Connecting

When launching either RET, a Connect pop-up window will be displayed querying the user for the local P4xx's IP address and providing the option to connect with either USB or Serial (TTL level RS-232). Users interested in using CAN should contact Time Domain for information. The IP address has no meaning for P4xx modules which do not have Ethernet ports. Example screens are shown in **Figure 1**.

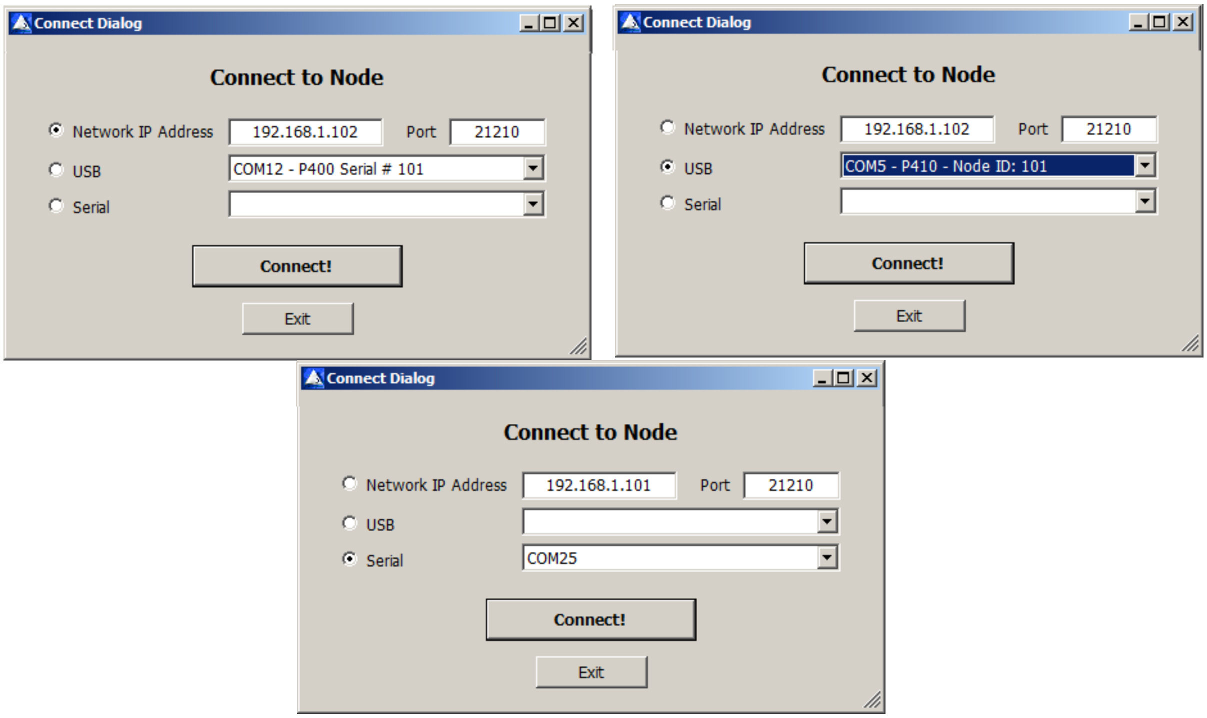


Fig. 1: Ethernet connection screen (upper left), USB connection screen (upper right), Serial (lower center)

Connecting with Ethernet: To verify Ethernet connection to a P400 (currently the only platform with Ethernet), enter the P400 IP Address and click the **Connect!** button. (The IP address is 192.168.1.xxx where "xxx" is the number written on the top of the P400 Ethernet connector).

The RETs will attempt to verify connectivity to the P400 by sending an RCM_GET_CONFIG_REQUEST to that address. This message will be sent up to three times. If RET is successful in connecting with a P400, then RET will transition to the Configuration Tab window (described in **Section 5**). The Configuration window will indicate if the unit is operating in RCM or RangeNet mode, show "Connected" in the bottom left-hand corner and also display the Node ID of the P400. RET controls are now enabled, allowing the user to send commands to the P400.

If the P400 does not respond after the third attempt, then RET will indicate the connection was unsuccessful and the connection status will show "Disconnected." At this point, the user should verify that the network settings are correct and insure that your P400 is powered on and the LEDs are properly illuminated. (See **Section 2** for details.)

Connecting with USB: To verify USB connection to a P4xx, click on the USB button and select the com port/unit serial number from the drop down window. If RET 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 P4xx. RET controls are now enabled, allowing the user to send commands to the P4xx.

Connecting with Serial: To verify Serial connection to a P4xx, click on the USB button and select the com port/unit serial number from the drop down window. If RET 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 P4xx. RET controls are now enabled, allowing the user to send commands to the P4xx.

Issues with USB or Serial: If there are connection issues with either USB or Serial, then open the Device Manager (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 2** confirms that the UWB radio on the COM9 port is actually connected to the computer. The screen shot on the right indicates that no connection exists between the Host and RET. Once these parameters are verified, the user can attempt to connect by selecting the **Connect!** button.

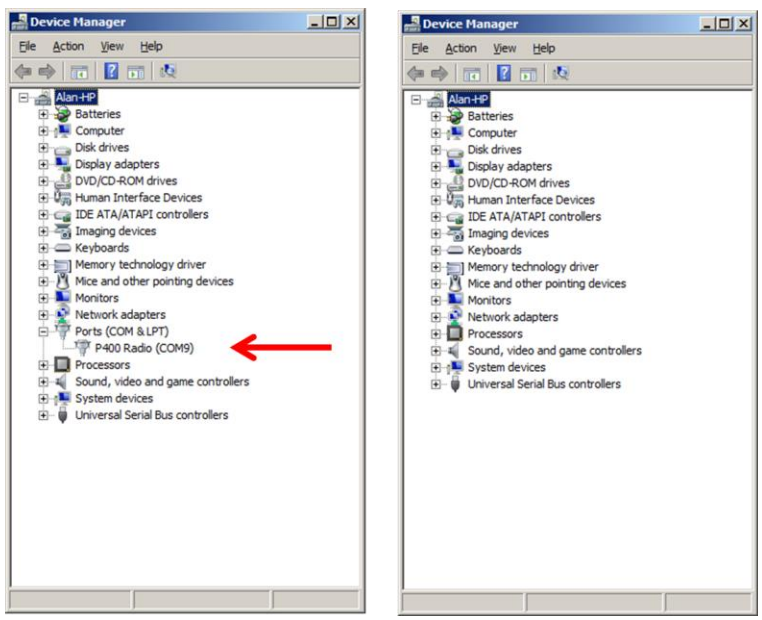


Fig. 2: Successful connection (left), unsuccessful connection (right)

Note: The connection from the P4xx to Host through the USB connector (whether connecting with USB cable or with a Serial cable) is generally very reliable. However, there are times when the Windows operating system can get confused. This can happen if the P4xx is disconnected or power cycled during execution of a RET command. A wobbly USB connector can also cause issues. These issues will manifest themselves in one of two ways. Either (a) RET shows that the P4xx is connected when it is not, or (b) RET shows that the P4xx is not connected when it clearly is. If this should happen, then disconnect the P4xx, cycle its power, and try to reconnect. If this fails, disconnect and power cycle the P4xx and reboot the Host computer. Additional information is provided in **Appendix D "Issues with USB and Microsoft Windows."**

4. Overview & the Action Area

The main RET window is divided into two main areas (see **Figure 3a**). The upper area contains a tab control with selectable tab pages. RCM RET has 10 tab pages while RangeNet RET has 11. The ten on the left are for ranging and communications operation (RCM mode), while the eleventh tab provides access to the network commands and enables the user to switch from RCM mode to RangeNet mode. Each tab page contains controls and/or displays information corresponding to the functionality of that tab. The name of the program is also displayed on the top line of the GUI. These differences are illustrated in **Figure 3b**.

The bottom area contains the Action Area, which contains scrolling text of every message sent to and received from the P4xx and any errors that occur. Errors will be displayed with two time stamps. The left timestamp is in the same time format as the log while the right timestamp (month/day/year) is human readable.

Other areas of interest in the main RCM RET window include:

- The “About RET” dialog, which contains application version information, can be launched by right-clicking on the title bar’s icon.
- A Connection Status Indicator located at the bottom left-hand side of the status pane. This is useful when using multiple RET instances on a single PC and when connected to multiple P4xx devices.
- To the left of the connection status is an indication as to whether the unit is operating as a standalone ranging device (in which case it will say “RCM Mode”) or as part of a network (in which case it will say “RangeNet Mode”). See **Section 17** for details on how one changes the operating mode.
- The Reboot button allows the user to reboot the P4xx. Rebooting will also disconnect the unit and return the user to the Connect screen.
- The Disable Console Window and Only Show Errors check box are used to limit the amount of information show in the Action Area.: Clicking the Only Show Errors button will limit messages displayed to just the errors. Clicking the Disable Console Window will prevent any messages from being shown.
- Sent Statistics
- The Disconnect button located at the bottom right hand side of the window allows the user to switch RET to a different P4xx.
- Finally, the Exit button also located at the bottom right hand side of the window will close the application.

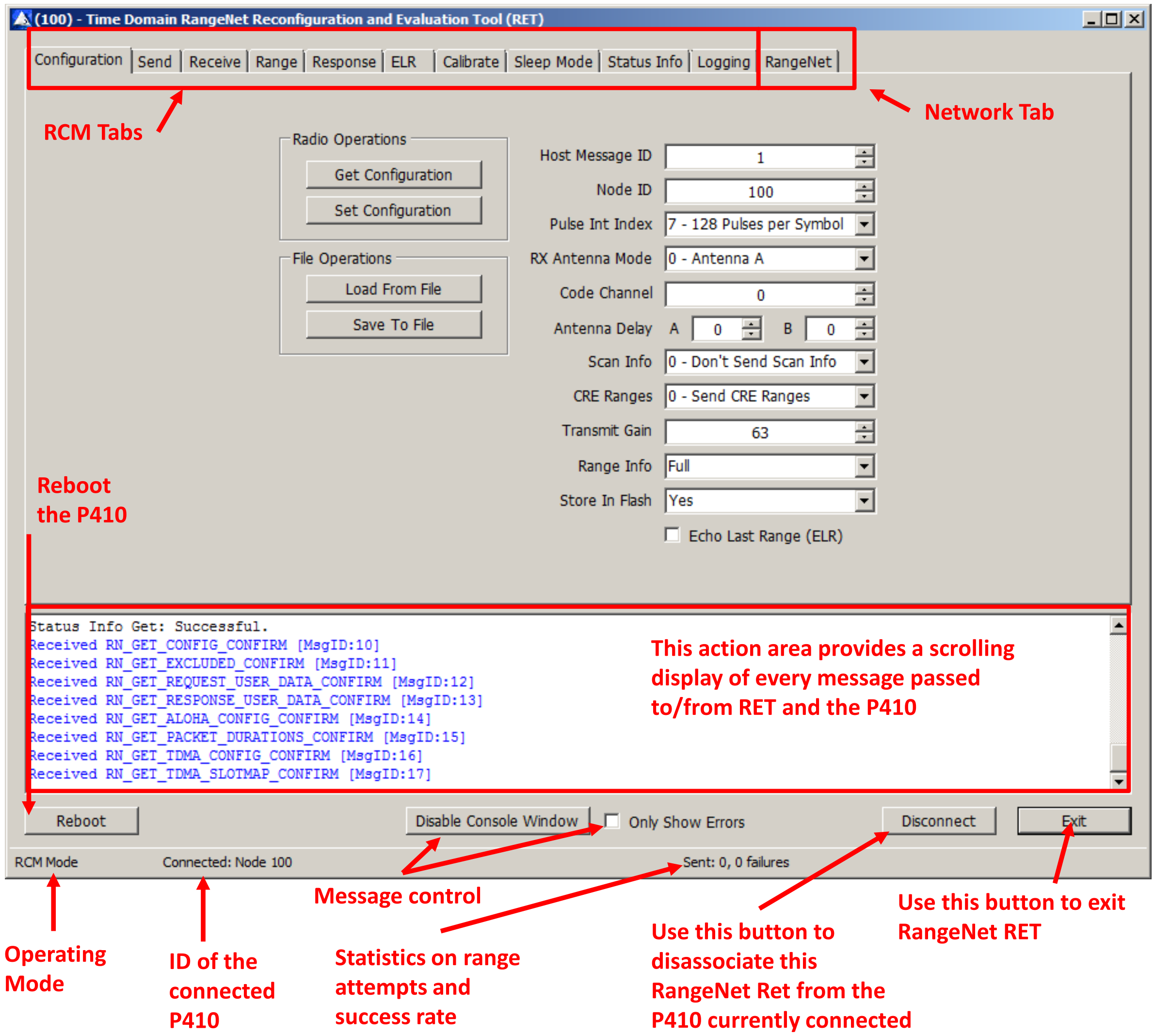


Fig. 3a: Tab layout convention

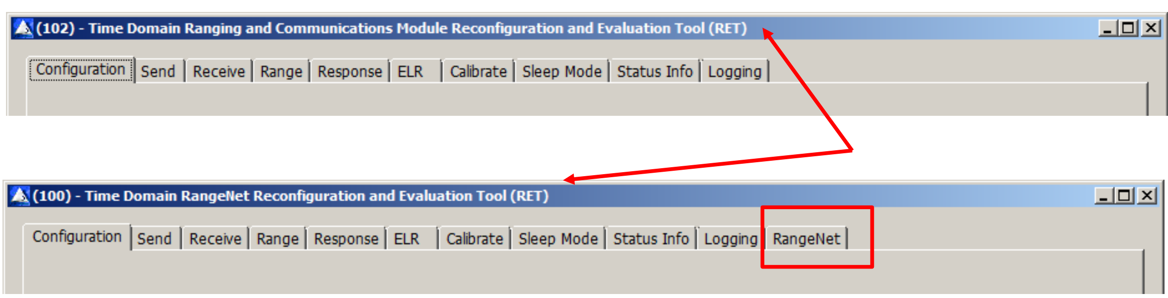


Fig. 3b: Differences between RCM RET (top) and RangeNet RET (bottom)

5. Configuration Tab

Successful connection to a P4xx brings up the Configuration Tab with the P4xx module's currently configured RCM parameters. This tab, shown in **Figure 4**, provides the user with an easy method for reading and writing the eleven essential RCM configuration parameters. This tab implements the RCM API messages RCM_GET_CONFIG_CONFIRM and RCM_SET_CONFIG_REQUEST. These messages get and set the (1) Node ID, (2) Pulse Integration Index, (3) Receive Antenna Mode, (4) Code Channel, (5)Antenna Delay A&B, (6) Scan Info Flag, (7) CRE (Course Range Estimation) flag, (8) Transmit Gain, (9) Range Info Flag, (10) Store in Flash Flag and (11) Echo Last Range flag.

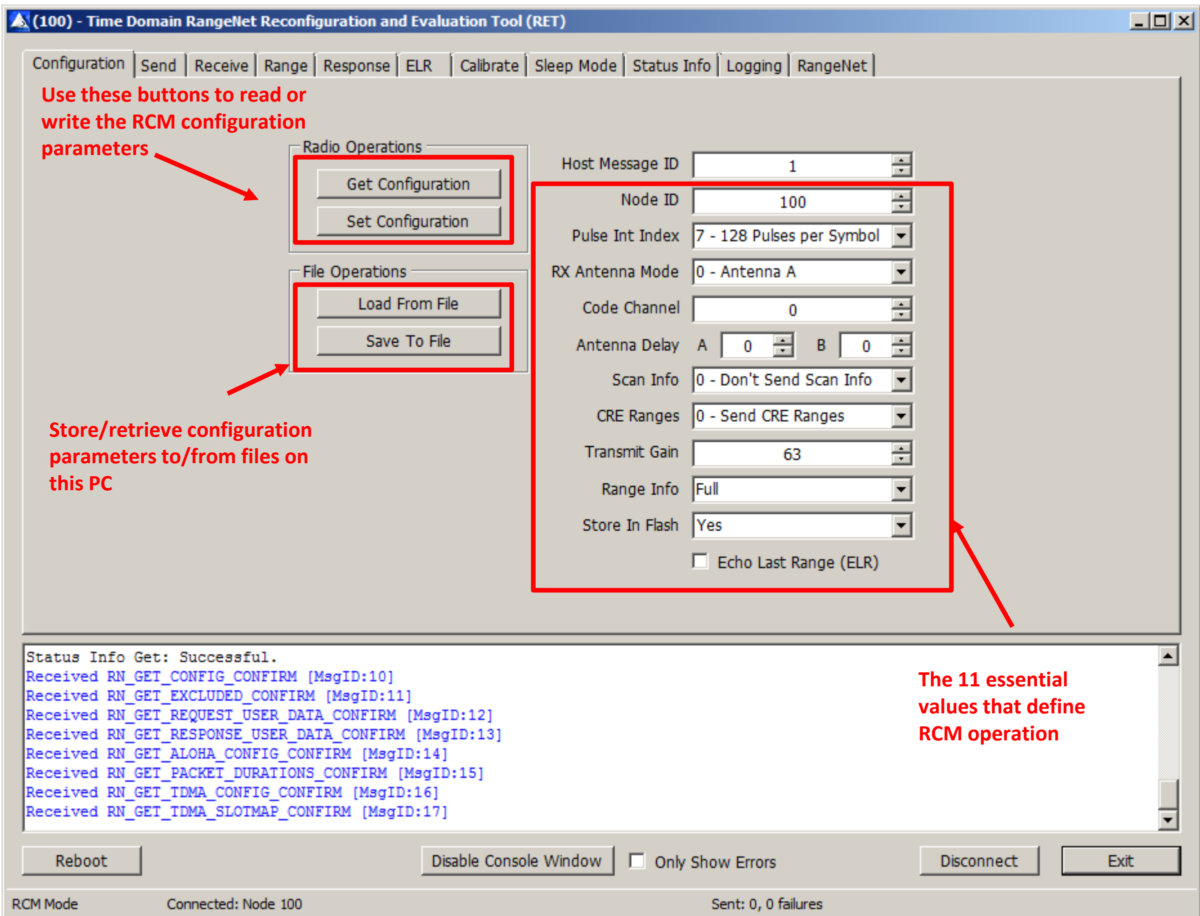


Fig. 4: Configuration Tab featuring the 11 essential configuration parameters

The user can alter the default configuration by adjusting the parameters in the right-hand column and then clicking the "Set Configuration" button on the left. If the user wishes these parameters to persist through a power down of the attached P4xx, then the user must set "Store in Flash" to Yes.

Note: In order for P4xx platforms to communicate with each other, they must all be configured with the same Pulse Integration Index (PII) and Code Channel. Units with different PIIs or operating on different Code Channels cannot communicate with each other.

Clicking the "Get Configuration" button will retrieve the current RCM configuration from the P4xx.

Clicking the "Save to File" button will create an XML file where the configuration data will be saved. The user can also load a configuration from a previously saved file by selecting "Load From File." RCM RET will prompt the user with a standard Windows File-Open dialog window. When in doubt, the user can always load the factory default settings. These are stored as a read-only file in the default installation directory.

Pulse Integration Index, Antenna Mode, Code Channel, Antenna Delay A&B, and CRE Ranges are described in detail in **Appendix B** of the *RangeNet API Specification*.

Node ID: The identification number of the specific P4xx connected to RCM RET.

Scan Info: Allows the user to display some, all, or none of the received waveforms. Each time the P4xx receives a range request or response it will measure the received waveform. This waveform will be measured in increments of approximately 61 ps, starting 90 ns before and ending 10 ns after the waveform lock spot. A total of 1632 measurements will be taken. (The lock spot is normally a zero crossing next to one of the highest amplitude lobes of the received waveform). The user has the option to request that the P4xx report some or all of these measurements to the RCM RET. If the option is selected, then RCM RET will display the waveform on the Receive Tab display and, if desired, log the data. The user's options are: Don't Send Scan Info, Send Scan Info (but only 350 values), or Send Full Scan Info (all 1632 readings).

Transmit Gain: This parameter controls the output RF transmission power level. When set to zero, the P4xx will transmit at the minimum power supported by the P4xx. Setting the transmit gain to a value of 63 will set the unit to maximum transmit power. The default setting for a P410 or P412 is 63. This value has been chosen because it is approximately the maximum transmit power for regulatory certification. When operating a P400 or a P410 equipped with optional power amplifiers, then a value of 0 is approximately equal to the regulatory limit. **Appendix B** documents the relationship between transmit gain setting and transmit power for these three different configurations.

Range Info: This flag determines whether the connected P400 will return range information using the RCM_FULL_RANGE_INFO or the RCM_SMALL_RANGE_INFO messages. Since the "Full" range info is much a much larger packet, it will consume more of the Host-P4xx communcations bandwidth. Some network and slow serial applications are frequently bandwidth-limited and require use of the RCM_SMALL_RANGE_INFO message. We recommend that the user start with Full range info messages and switch to Small if required.

Echo Last Range (ELR): If this box is checked, then the next time the P4xx requests a range measurement, it will also transmit the last range measurement information it has taken. This information includes the range measurement as well as the node IDs of the requestor and responder associated with that range measurement. Any P4xx's that receive this request message and have their ELR box checked will report this last range measurement information on the ELR tab. When multiple units are in use in the same area at the same time, this mechanism will allow RET to display the ranges measured between other units. This increases system capacity. See the API for details.

6. Send Tab

When operating in RCM mode, the P4xx will not send a packet unless commanded by the host. The Send Tab (see **Figure 5**) provides the user with an easy means of commanding the P4xx to send one or more packets. This tab implements the RCM_SEND_RANGE_REQUEST and RCM_SEND_DATA_REQUEST messages of the RCM API. At the end of each REQUEST, the P4xx will send an immediate CONFIRM. This will be noted in the scrolling Action window below.

Packets can be of two types: range request and data-only. Range request packets can optionally contain data, but data-only packets do not result in a range measurement.

Range requests are directed at an individual responder, whose ID is set in the *Responder ID* field. Alternatively, if the responder ID is unknown, the user may select the *Broadcast* checkbox to command any P4xx listening in RCM mode to respond. Note that if multiple P4xx modules respond, they can interfere with each other. (P4xxs that are in range but configured as radar sensors or using the Channel Analysis Tool (CAT) will not respond because they are not in RCM mode.)

The user can define which antenna mode will be used for data transmissions and range requests by selecting the desired configuration from the Antenna Mode drop-down box. Once the data has been sent or the range/response transaction has completed, the antenna mode will revert to the configuration selected on the Configuration Tab.

RCM RET also provides a host-controlled Repeat function. Note that the P4xx does not implement this repeat. The Host individually commands each transmission. RCM RET provides this Repeat control in support of real-time range evaluation and logging (see **Section 13**). When in the repeat mode, RCM RET will display a running count at the bottom of the screen. This count will report the number of range packets that have been sent in the current test, the total number to be sent and the number of transactions that have failed. At the conclusion of the test, RCM RET will summarize these range statistics and display the following:

- Number of ranges successfully completed vs. the number sent
- Success percentage rate
- Mean of the readings
- Standard deviation of the range measurements
- Mean of SNR
- Standard deviation of the SNR

In addition, RCM RET will also filter the readings based on the PRME (Precision Range Measurement Error Estimate) threshold set on the Range Tab. Basically any reading which has a PRME greater than the threshold will be discarded. The statistics for the remaining readings will be then be displayed. This statistics and error reporting feature is illustrated in **Figure 5**.

If the Continuous mode is selected, then this final summary is presented based on the number of readings completed as of the time when range requests were terminated.

Note: the SNR summary values shown in the Action Area are computed based on information sent by the Range Info message. If , on the Configuration Tab, the user sets the Range Info tab “Small” instead of “Full,” then the P4xx will not report the information necessary for computation of SNR and no value will be reported for SNR.

Data can be sent either as part of a regular range request or as a data-only packet. This mode is controlled by the Data flag. Checking the flag will allow the user to enter data into the data buffer. The data in the buffer will be transmitted each time a transmission is sent. In other words, sending a transmission does not reset the buffer. The maximum amount of user data that can be sent in a single message is 1000 bytes.

If the Custom Code Channel button is checked, then the code for the entire requested range conversation will be changed from the code channel indicated on the Configuration Tab to the one indicated in the Custom Code Channel drop-down menu. At the conclusion of the range conversation the code channel will revert to the code selected on the Configuration Tab.

This is useful if the requester needs to range to two separate units as fast as possible. While this function could also be accomplished by making the change on the Configuration Tab, doing so would require the user to execute two API commands. The first would send an API command to set the radio to a new code, and the second would reset it back to the original value. These two steps would take many milliseconds (ms) to execute and will reduce the ranges taken per unit of time. In contrast, using the Custom Code Channel does not add any measureable amount of time to the process and thereby maximizes ranging throughput.

The example shown in **Figure 5** will have the following behavior. When the Send button is clicked, the P4xx will send a range request to unit 104 using Custom Code Channel 3. The range message will also include the data “Message from unit 100.” When the response is received from unit 104, the unit will revert to receiving on the code channel indicated on the Configuration Tab. After 50 ms the unit will then repeat this process. The process will be repeated 200 times. At the conclusion a summary report showing the success rate will appear in the Action Area. As the process is being performed, a running tally of transmissions sent and failures experienced will be shown on the bottom line.

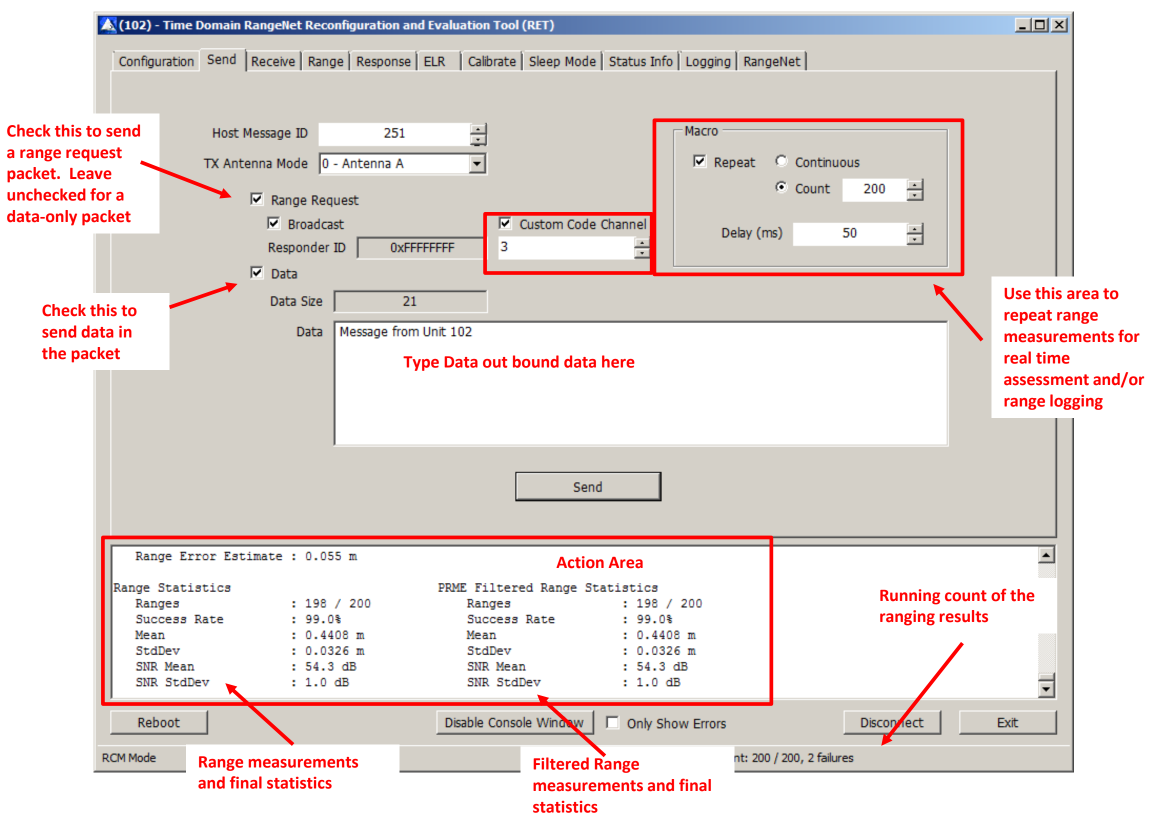


Fig. 5: Send Tab showing results of a 200 measurement test

The summary report has two columns of statistics. Both columns report the following:

- Ranges (number of two-way communications completed with Range Status = 0/total attempts)
- Success rate (successful ranges expressed as a percentage)
- Mean (mean value of the received ranges)
- StdDev (Standard deviation of the received ranges)
- SNR Mean (mean SNR of the received signals)
- SNR StdDev (standard deviation of the SNR of the received signal).

The difference between the two columns lies in the nature of the range measurements being reported.

In the left column, the ranges will be either the Precision Range Measurements or the Filtered Range Measurements as selected on the Range Tab (see **Section 8**).

In the right column, the ranges (either Precision Range Measurements or Filtered Range Measurements) will be filtered according to the Range Error Threshold selected on the Range Tab (see **Section 8**).

7. Receive Tab

The P4xx typically receives two UWB packet types: data-only and range response. Upon receiving either of these packets, it will send received and computed data to the connected Host. This information is displayed by RCM RET in the Receive Tab (see **Figure 6**). Consult the *RangeNet API Specification* for more information on the contents of the RCM_RANGE_INFO, RCM_SCAN_INFO, RCM_FULL_SCAN_INFO, and RCM_DATA_INFO messages.

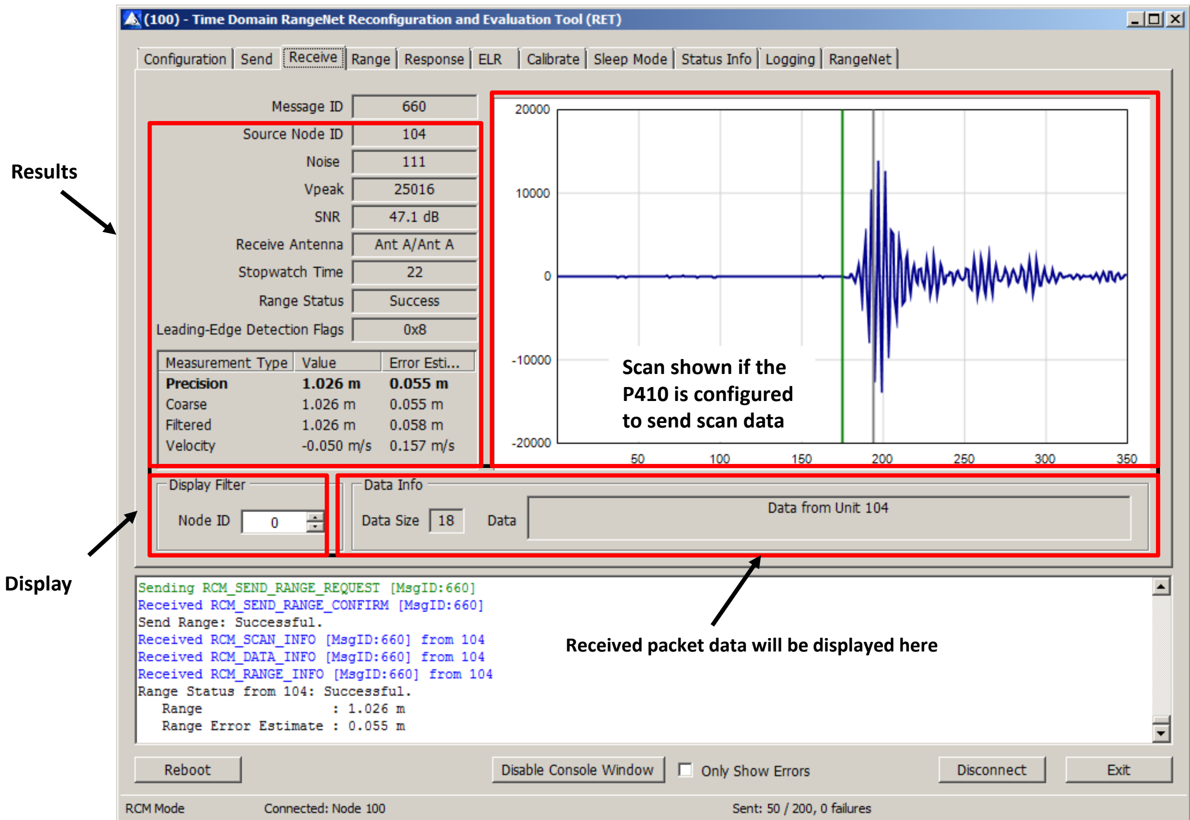


Fig. 6: Receive Tab with data areas shown

The receive display is divided into four areas. These are described below:

Display Area: This control allows the user to select the Node ID whose information is to be displayed. Setting the Node ID to zero will result in the display of response data from any unit that responds. Setting the Node ID to a specific number will result in the display of response data only from the selected unit.

Data Area: This area will contain data received from another unit. In this case, Unit 104 (the responder) has sent 18 bytes of data which spell "Data from Unit 104".

Waveform Scan Area: The plot shows the magnitude of the waveform as a function of time. The vertical axis is the sum of all of integrated analog to digital measurements taken by the radio for the specific measurement point. The horizontal axis is time in increments of approximately 61.0 ps. This is the only measurement time interval supported by RCM RET. The radio lock point is indicated by a light gray line. In this example, the lock point is at approximately point 198. The green line indicates the point on the waveform that the radio believes is the leading edge.

On the Configuration Tab, the user can specify how much Scan Info is to be sent by the radio to RCM RET. The choices are No Data, Scan Info, or Full Scan Info. If Scan Info is selected, then 350 values will be plotted. If Full Scan info is selected, then 1632 values will be plotted. The scan waveform is relative to the point on the waveform to which the radio locked during the packet acquisition. The radio has been programmed to lock on the strongest signal that it finds. That being said, there is no guarantee that the radio will always lock on the strongest signal. In fact, there will be occasions at which the radio will lock to a comparatively weak signal.

Since the ranging measurement is based on finding the leading edge, the waveform capture has been biased to show more of the waveform prior to the lock spot than after. If a "Scan" is selected, then there will be 193 (~11.8 ns) points before the lock point and 157 points (~9.6 ns) after. If a "Full Scan" is selected, then there will be 1475 (~90.0 ns) points before the lock point and 157 (~9.6 ns) points afterward.

Changing Scales: The scales can be adjusted in several ways:

- Double-clicking the right mouse button will auto-scale the magnitude and set the time scale to either 1632 (for "Full Scan") or 350 (for "Scan").
- Holding the left mouse button down and shifting the mouse to the left will move the plot to the left, shifting the mouse to the right will move the plot to the right.
- Holding the right mouse button down and shifting to the right will magnify or expand the scale. Shifting to the left will collapse the scale.
- Holding the right mouse button down and shifting up will increase the scale (make the plot smaller), while shifting down will decrease the scale.

Results Area: This area contains the results of the range measurement and associated statistics.

Source Node ID: This is the ID of the node which responded.

Noise: This is a scaled estimate of the received noise as measured by the P4xx. The unscaled noise can be computed using the following formula:

Unscaled noise = noise * (2^PII)/512

Vpeak: This is the scaled estimate of the maximum received signal in the leading edge as measured by the P4xx. The unscaled signal can be computed using the following formula:

Unscaled signal = Vpeak * (2^PII)/512

SNR: This is an estimate of the Signal-to-Noise Ratio (SNR) of the received signal. It is the SNR of the waveform scan. It is computed using the following formula:

SNR = 20*log10(Vpeak/Noise)

Noise, Signal/Vpeak, and SNR are discussed in greater detail in **Appendix F**.

Receive Antenna: There are two antenna names separated by a slash. The position to the left of the slash indicates the antenna(s) used by the requester and the position to the right indicates the antenna(s) used by the responder.

Stopwatch Time: This is an indication of the amount of time required to take a single range measurement.

Range Status: This field indicates whether or not the range measurement requested was successfully completed. See the API documentation for an enumeration of the possible responses.

Leading-Edge Detection Flags: These flags convey information about the nature of the received signal. If the received signal is a clean Clear Line of Sight (CLOS) channel and the signal was not saturated, then a 08 will be displayed. Any other values indicate an issue with the signal. The flag values are indicated in the API and can be seen by hovering one's mouse over the field. In this case the signal is in CLOS and is not saturated. Normally, at this range the unit would be showing a 0x9 indicating that the signal is so strong that the receiver is saturating. However, in this case the transmit power has been reduced by the addition of a 10 dB attenuator on the antenna ports of both units.

Precision: This is the precision range measurement (PRM) taken using the Two-Way Time-of-Flight (TW-TOF) ranging technique. To the right of that is an estimate of the range accuracy.

Coarse: This is the range measurement taken using the Coarse Range Estimation (CRE) technique. To the right of that field is an estimate of the error in the range accuracy. The error estimate is predicted using an algorithm that has been tuned for predicting range error for use with relatively slow moving vehicles operating in an open environment. When operating in other environments the error estimate can be overly pessimistic. For example, when operating in relatively stationary conditions inside an office (typical of a user's first experience with the RCMs and CRE) the error estimate will be large. It is possible to retune the algorithm for other operating conditions. If doing so would be of interest, please consult Time Domain directly.

Finally, note that the CRE is only valid if the communications channel is determined to be Line of Sight (LOS), the link is not in compression and the range is less than 100 meters.

Filtered: This is an estimate of the range based on a combination of the CRE, PRM, and a linear motion model. To the right of that is an estimate of the range measurement accuracy.

Velocity: This is an estimate of the rate at which the two devices are approaching or receding from each other. A negative value indicates that the units are approaching. A positive value indicates that the units are separating. To the right of that is an estimate of the error associated with the velocity estimate.

8. Range Tab

The Range Tab (see **Figure 7**) provides an alternate, large-character display of the measured distance in large type. This data is also from the RCM_RANGE_INFO message.

Green numbers indicate successful ranges (RangeStatus=0), yellow numbers indicate readings which have range error estimates above the PRME threshold, blue numbers denote CREs, and red numbers indicate unsuccessful ranges (RangeStatus >0). For instance, a RangeStatus=1 indicates a TIMEOUT condition. The responder is either out of range, in an invalid configuration, or inoperable. In the case of a TIMEOUT, the display will indicate a red zero "0."

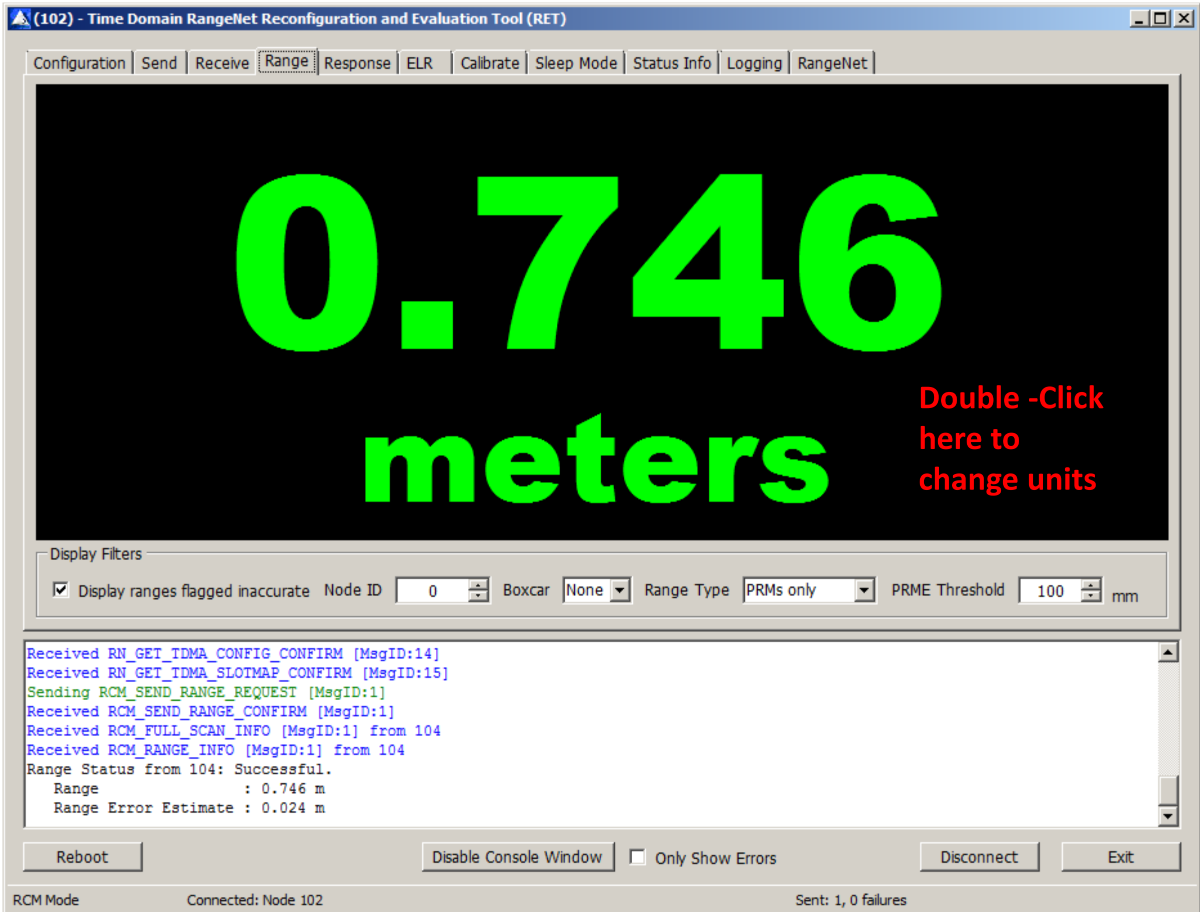


Fig. 7: Range Tab displays current range measurement

The user can change the units by double-clicking in the area indicated above with the red letters. Each time the user double-clicks, the units selected will change. RCM RET supports three units: meters, millimeters, and feet. It is also possible to change the units on the ELR and RangeNet Neighbor DB tabs as well. Changing units on one tab will be reflected on all tabs. Changes to the units will also be reflected in the values reported on the Receive Tab.

There are also four parameters that allow the user to control the nature of the information being presented.

Display range measurements flagged as inaccurate: If this box is checked, then the unit will display any flagged readings in red. If the box is not checked, then RangeNet RET will not display any flagged readings. It will instead display the last valid reading. If no valid readings have been received, then the unit will display the last valid reading it received.

Node ID: When set to 0, the Range Tab will display the range information from any received range conversation. When set to a particular Node ID, the display will only show the range information from that particular node. If the selected node does not respond, then the Range Tab will be entirely blank. This feature is very valuable when operating in RangeNet mode.

Boxcar drop-down menu: This drop-down menu offers four choices as to how the range values can be displayed. The user can select “No filtering” in which the readings will be displayed as they are taken. The user can also average the last N readings using a Boxcar filter. The choices are Boxcar 5, Boxcar 10, and Boxcar 20.

While the box car filters are handy, the user should be careful when using Boxcar filtering when operating in RangeNet mode. In these cases, box car filtering will average ALL of the node ranges and thereby produce the average distance separating the nodes. This is not very useful. The user should either turn Boxcar filtering off, or set Node ID to the node of interest.

Precision Ranges/Filtered Ranges: This drop down menu offers two choices. If the user selects "Precision ranges only," then RangeNet RET will display only Precision Range Measurement ranges. If the user selects "Filtered ranges," then the display will show only Filtered Precision Range Measurements. Once again, note that if the communications channel is in compression or the channel is not line of sight, then CRE measurements (and consequently Filtered ranges) will not be shown.

PRME Threshold: The PRME (Precision Range Measurement Error Estimate) is an estimate of the error of the Precision Range Measurement. This error estimate is determined by a heuristic algorithm that incorporates SNR and the shape of the received waveform. The PRME Threshold is a user-defined threshold against which the errors of Precision and Filtered Precision Range Measurements will be evaluated. If the error estimate is greater than the PRME Threshold, then RCM - RangeNet RET will "mark" the reading as questionable, display it in yellow, and will not include it in the filtered statistics displayed in the Action Area. This "marking" does not affect any data stored in the logs. The PRME threshold is relatively insensitive. Small changes to PRME do not have an appreciable effect. Based on field tests, a value of 100 has proven to be a useful number.

9. Response Tab

Since range response packets are issued by a targeted P4xx immediately upon receipt of a range request, the user can optionally "pre-load" the P4xx with data to transmit in the response packet. The Response Tab (**Figure 8**) does this by sending a RCM_SET_RESPONSE_DATA_REQUEST message to the P4xx as defined in the RCM API.

This message contains 3 fields: Message ID, Data Size (in bytes), and the data block itself. The data block can be a maximum of 1000 bytes. These bytes are actually transferred in 4 byte words. Consequently, the P4xx will up-fill to a 4 byte (word) boundary. For example, if the user loads 3 bytes in the response buffer, the P4xx will actually send four bytes.

The user can type into the Data field and RET automatically counts the number of bytes. The user then clicks Set Response button. This response is added to ALL response packets until changed or deleted. When transmitted, these characters will show up in the Receive Tab of the other P4xx units.

Note: Although RCM RET limits the user keyboard input, users of the direct interface via the API can send any binary sequence.

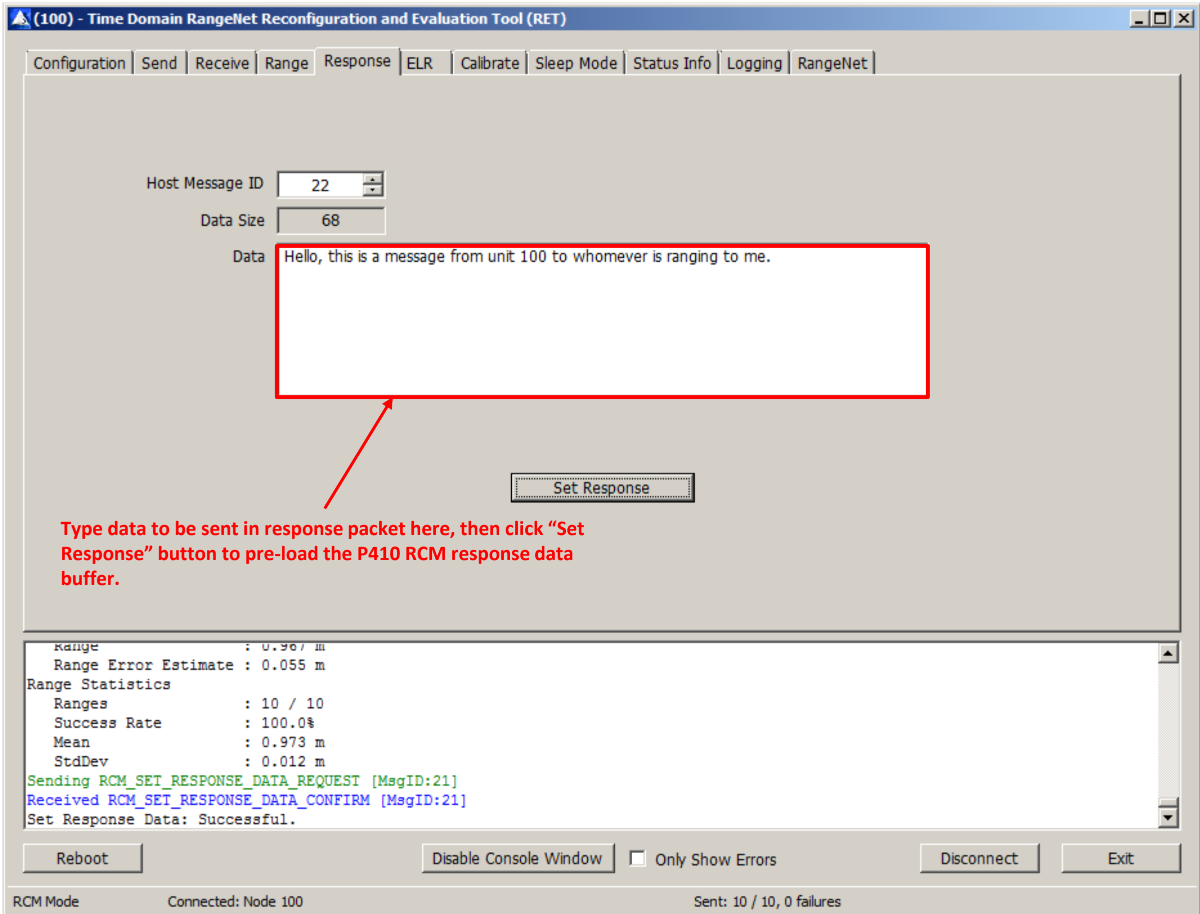


Fig. 8: Response Tab allows user to initialize response data buffer

10. ELR Tab

The Echo Last Range (ELR) Tab is shown in **Figure 9a**. If a unit's ELR flag is set (on the RCM Configuration Tab) then whenever it issues a range request, it will also transmit as data the last range measurement information which it received.

For example, consider the case where unit 100 successfully ranges to unit 101 and subsequently ranges to unit 102. At the conclusion of the first range conversation, unit 100 will have a measurement of the range between it and unit 101. This information will be transferred from unit 100 to unit 102 as part of the range request packet.

This is an excellent tool for automatically distributing range measurement information through a network of units. For example, if unit 102 subsequently ranges to 100 and 101, it will have enough information to locate all three units relative to each other. It will have measured the distance from 102 to both 100 and 101 and will have received the distance between 100 and 101 when the 100 ranged to 102.

Figure 9a shows the ELR Tab for unit 101 which is being ranged to by unit 100. Observe that each time 100 ranges to 101 it will send its last range, which in this case is the range between 100 and 101.

Note that ELR will only be displayed if ***both*** units have their ELR flag set.

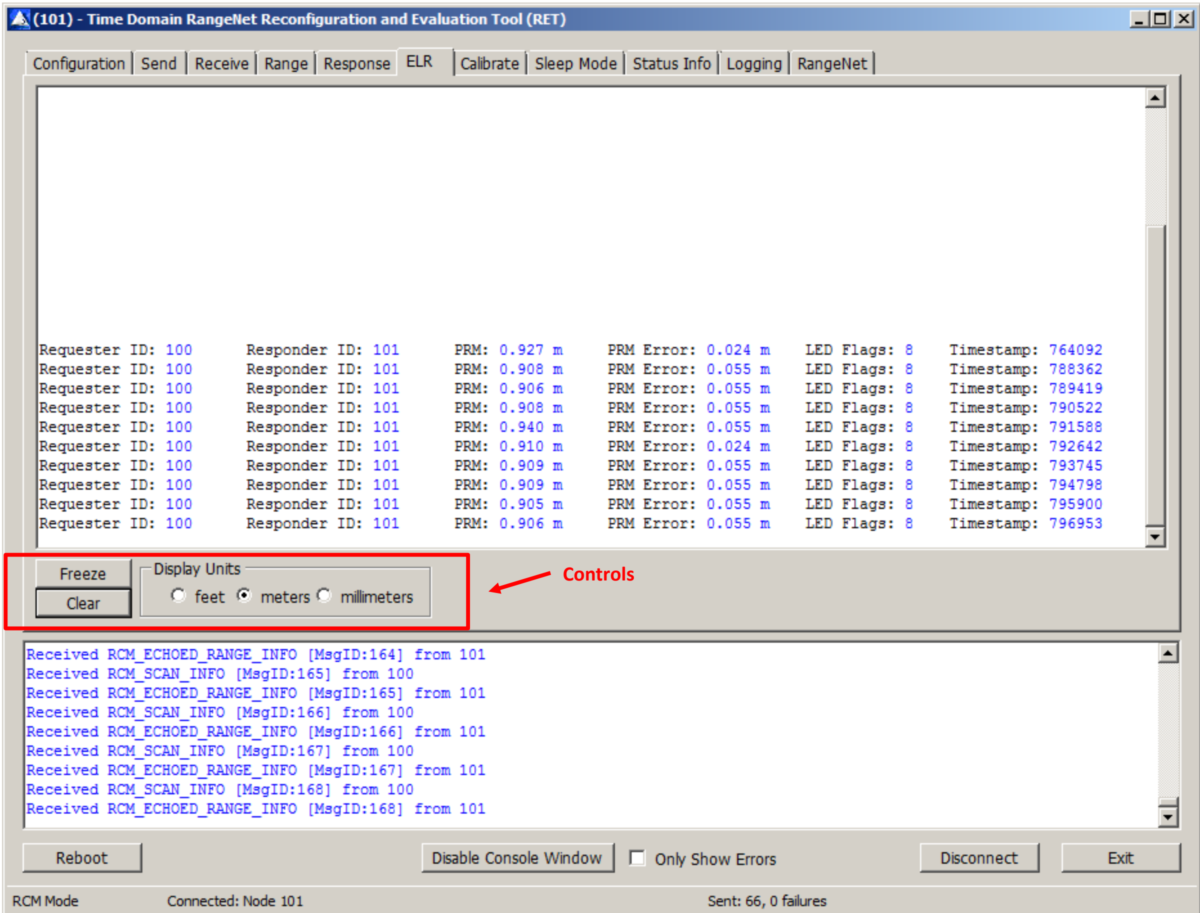


Fig. 9a: Illustration of ELR Tab controls and display of range measurements between unit 100 and 101, as shown at unit 101

The ELR Tab also provides a number of controls. Clicking Freeze will allow the user to stop the display and view the results. Subsequently clicking the Unfreeze button will resume updates. Any information received while the screen is frozen will be lost. The Clear button will clear the screen of entries. The Display Units buttons will allow the user to switch between measurement units. Changes to units on this tab will control the measurement units displayed on any of the RangeNet RET tabs.

This example illustrates how ELR allows unit 101 to receive a range measurement even if it isn't initiating a range request.

Perhaps are more interesting illustration is to look at the result in other units in the area. Consider unit 102 which is in the area, but is not involved with the preceding two way time of flight range measurement. Since all units receive all messages, unit 102 will also receive the range measurement which 100 is broadcasting. The ELR Tab for unit 102 is shown in **Figure 9b.**

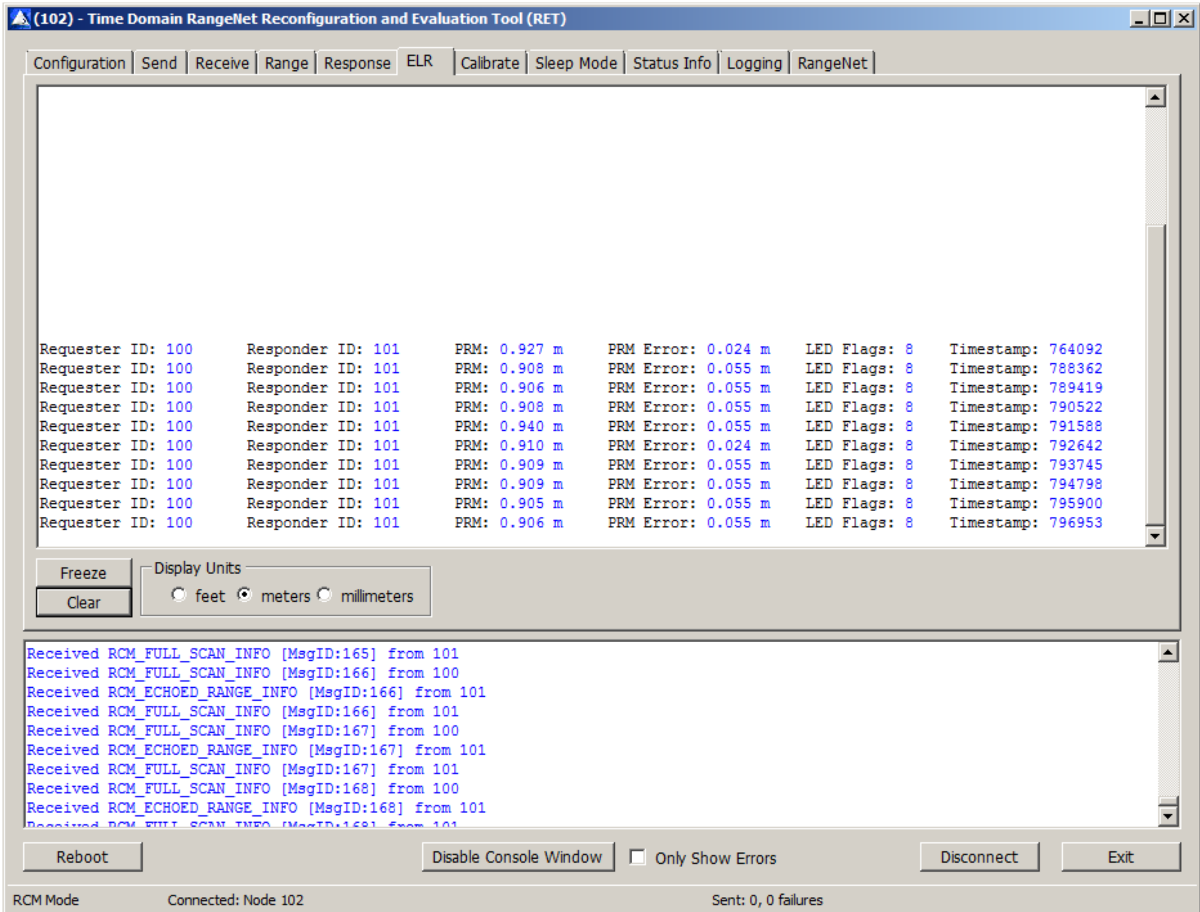


Fig. 9b: Illustration of how ELR can be used to broadcast information (Unit 102 was not involved in the range conversation but it has also received the information on range between units 100 and 101)

11. Calibrate Tab

The Calibrate Tab (see **Figure 10**) provides a simple method of determining antenna (measurement bias) delay due to the antenna and cables/connectors arrangement for either antenna. This antenna delay factor is due to the time required by the electrical RF pulse to travel between the P4xx and the antenna. An antenna delay constant of zero represents the propagation time through a standard Time Domain Broadspec™ antenna connected with the default right-angle SMA connector. This delay is approximately constant for P4xx. One can expect a unit to unit variation on the order of a few centimeters. If the user wishes to use (a) different antennas or cabling, or (b) wants a more exact measurement, then it is best to perform a calibration. The calibration procedure is described below.

Primary Purpose of Calibration: The primary purpose of calibration is to allow a user to deal with operation with non-standard antennas or cables. Any changes to the connection to the RF ports will change the calibration. A longer cable, different SMA connections, or different antennas will all change the effective path length relative to the standard configuration. This change in path length will add an offset or bias to the range measurements. For example, adding an SMA connector or RF attenuation might lengthen the path by a few centimeters, while adding a 2 meter cable will add a few meters of bias. This bias error is referred to as “antenna delay.”

To determine antenna delay for a particular configuration, set up a pair of P4xx units. Configure the P4xx with the unknown antenna delay as the requester, and connect this P4xx to the RET host. The other P4xx, the responder, should have a default antenna configuration or a previously calibrated antenna. The antennas of the two P4xxs should be separated by at least 5 meters (15 feet) to avoid saturation and ensure that they have an unobstructed line-of-sight path to each other.

On the Calibrate Tab, enter the node ID of the responder P4xx. Enter a number of ranges to average (100 is typically a good value). Measure the exact distance between the antennas on the two P4xxs (using a tape measure or a range finder) and enter this “true” value in inches.

Select *Calibrate*. RCM RET will automatically and repeatedly measure distance for the specified number of iterations and produce several statistics from the data. During this time, do not move or walk between the devices. When finished, the required antenna delay bias, in picoseconds, will appear at the bottom of the tab. Select *Write to Flash* to save the value in the P4xx’s non-volatile memory.

After successful antenna delay calibration, the constant range bias will be quite small (less than a couple of centimeters). To confirm the calibration was successful, you may leave the P4xx units in place and select *Calibrate* again. The Distance Difference and Antenna Delay Adjustment should be calculated very close to zero.

Secondary Purpose of Calibration: A secondary goal might be to calibrate the units such that they provide the most accurate reading possible. This would typically be done if one were trying to achieve accuracies of a few millimeters or operate the radios at very close range.

If this is the goal, then one needs to take into consideration the phenomenon of signal compression. The ranging measurement algorithm assumes that the radio link is being operated in its linear range. If the radios are too close to each other, then the receiver will be overwhelmed by the strength of the transmitted signal. It will then compress or saturate. While the radio will still operate, the accuracy of readings taken in compression will be compromised. In compression, the bias of the range readings will change and will become slightly non- linear. These errors total only a few centimeters and generally are of no consequence to most applications.

If these errors are of consequence, then the user should reduce the transmit power such that the units are not compressed, or if max power is still required, the user should characterize the performance and adjust accordingly.

Things to avoid:

- Do not calibrate a unit while in RangeNet mode.
- Since precision is normally important, calibrate the units in an RF-quiet area. In other words, do not calibrate in the immediate vicinity of an active UWB system. Either shut down the network or perform the calibration in a different area of the building, preferably an area with a few walls or 10 meters between the link under calibration and active UWB transmitters. If this isn’t possible, then the system will still calibrate but the standard deviation will be a bit higher.

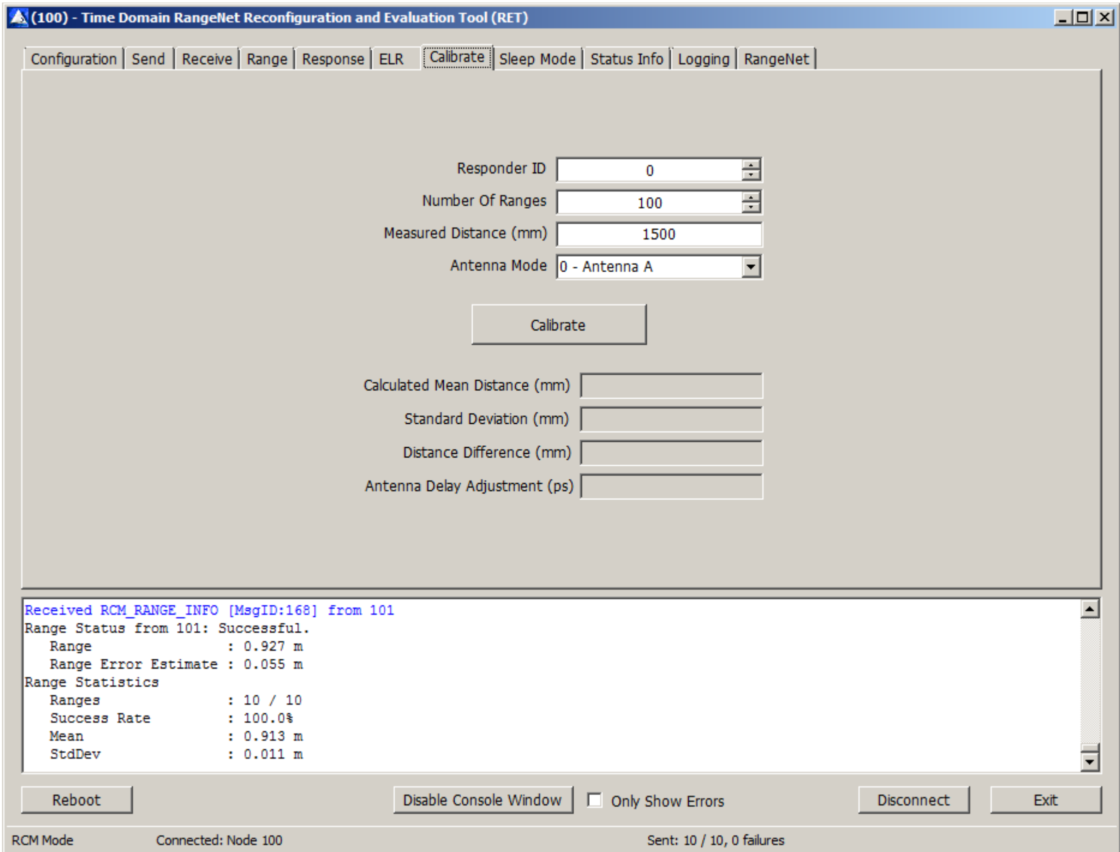


Fig. 10: Calibrate Tab allows the user to calibrate the electrical delay associated with the time it takes a pulse to propagate from the pulse generation circuit through the connectors and cabling to the center of the antenna

P4xx modules are factory-loaded with a default calibration. There is little unit-to-unit variation and the default settings work well in almost all applications. The exception would be situations where very high accuracies are required or non-standard antennas are used. In these cases the user should calibrate the units individually.

12. Sleep Mode Tab

The Sleep Mode Tab (**Figure 11**) is provided by RCM RET to support operation in various sleep modes. These modes are described in the *RCM API Specification*. The desired sleep mode is selected through the “Sleep Mode” drop-down window and set by clicking on the “Set Sleep Mode” button.

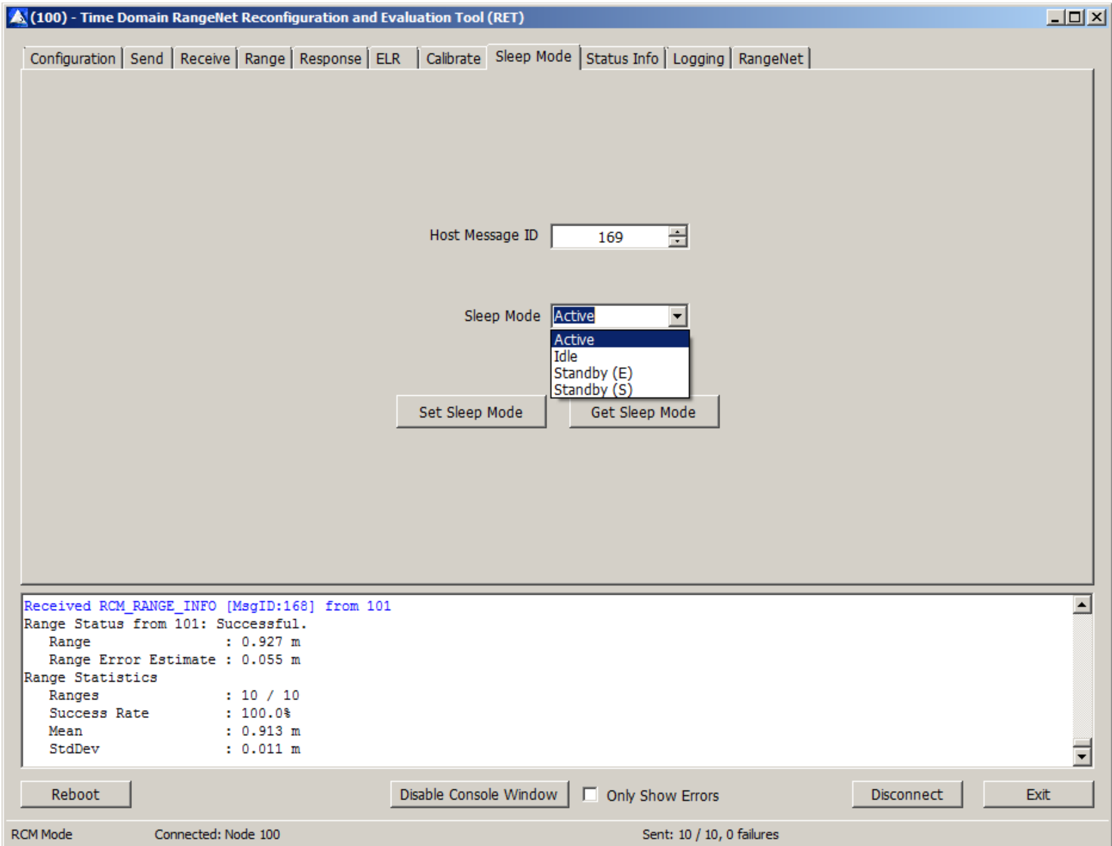


Fig. 11: Sleep Mode Tab allows the user to place the unit in one of several low power sleep states

The P4xx can be either Active or in one of several Sleep states. On power up, the P4xx will boot up in the Active state. When the unit is active, RCM RET will allow the user to change parameters, start or stop ranging, log data, and perform other commands. There are several sleep modes, each of which disables the ability to operate the radio but incrementally reduces the P4xx power consumption. An error message will be generated if the user attempts, while in a sleep mode, to control ranging. Entering and exiting deeper sleep states will also require increasingly more time. In general, the deeper the sleep mode, the longer it takes to exit and enter but the power demand is reduced correspondingly. The P4xx will exit the lowest state only in response to an API command issued through the Serial port (Standby_S). If the user inadvertently enters the lowest state and has no Serial connection, then the unit can be returned to the Active state only by powering the unit off and on.

Different P400 series platforms will have different power down savings. Power savings for the P400 and P410 are shown in **Table 1** and **Table 2**.

Mode	Typical Power (W)	Entry Time (ms)	Exit Time (ms)
Active (transmitting)	5.60		
Active (receiving)	5.37		
Idle	4.26	1.2	1.2
Standby_E	2.08	1.2	2.9
Standby_S	1.75	1.3	2.9

Table 1: Sleep mode characteristics for a P400

Mode	Typical Power (W)	Entry Time (ms)	Exit Time (ms)
Active (transmitting)	3.90		
Active (receiving)	3.88		
Idle	2.60	1.2	1.2
Standby_E	1.10	1.2	2.9
Standby_S	1.10	1.3	2.9

Table 2: Sleep mode characteristics for a P410

13. Status Info Tab

The Status Info Tab (see **Figure 12**) contains version and status information about the P4xx. This information is loaded when RCM RET initially connects to a unit or when the user clicks the "Get Status Info" button. RCM RET accomplishes this by sending a RCM_GET_STATUSINFO_REQUEST message to the connected P4xx. The P4xx responds with a RCM_GET_STATUSINFO_CONFIRM message. RCM RET will then display the version numbers and other unique information pertaining to this P4xx.

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

Software Versions: The P4xx has four different types of software: the overall version number (Package ID), the version of embedded application software (application code running on the P4xx processor), the version of the UWB Kernel (UWB software running on the P4xx processor) and the version of FPGA code (running on the P4xx FPGA). Since RangeNet is an extension to the RCM software, there are two different versions of embedded application software, one for RCM and one for RangeNet. On boot up, if the P4xx is in RangeNet mode, then the version of RangeNet embedded software will be shown. If it is in RCM mode, then the version of RCM embedded software will be shown. If the user changes the operating mode, then the version number of the active application software will be displaced when the user clicks on the Get Status Info button.

Hardware Version: There are three hardware items of note: the board Serial Number, Board Type and Version (400, 410, etc.), and the Pulser Configuration (FCC/EU mask and transmit power range).

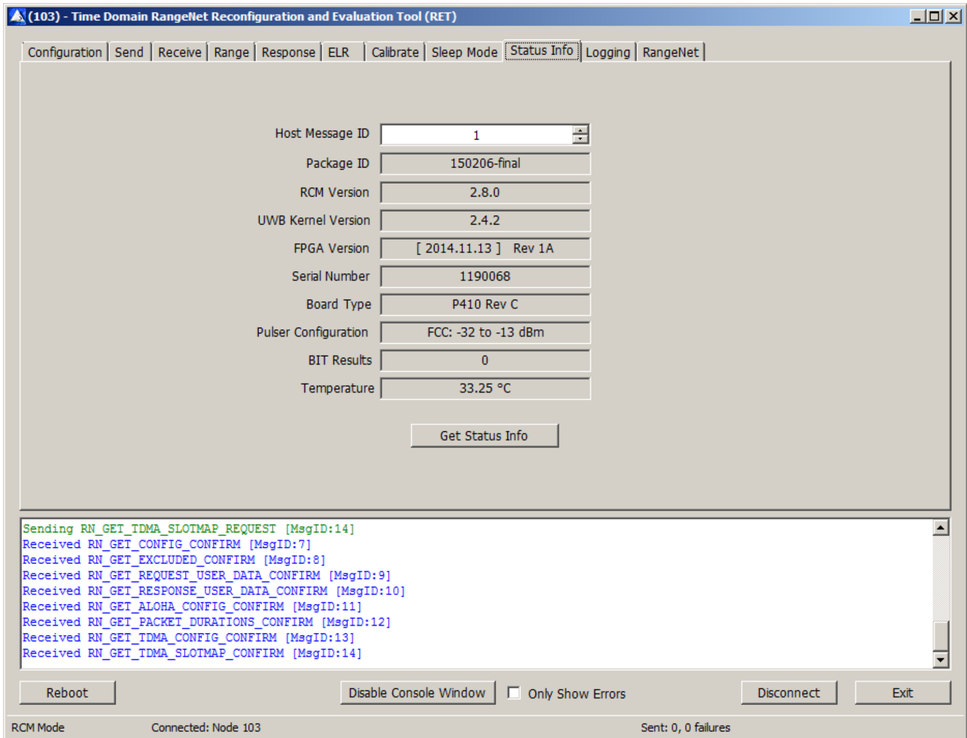
BIT: "BIT" stands for "Built-in Test" and will return "0" under normal operation. A non-zero value indicates some sort of failure. In the event of this failure, please contact Time Domain.

Temperature: This is the temperature of the sensor mounted on the P4xx PCB board. This is *not* the ambient air temperature. Because the P4xx generates heat, the board will run hotter than the ambient. When operated in an office environment the unit will normally run several degrees warmer than the ambient. This is not an issue.

However, if the equipment is used in a heat chamber or some other environment where the temperature can either be very cold or very hot, then the user should check this temperature sensor from time to time to confirm that the unit is operating within its temperature limits. (In fact, it is always a good practice to add a bit of margin and to operate a bit further from the absolute maximum limits.) P4xx platforms that use commercial parts (P400, P410) have an operating range between 0°C and +70°C. The P412 platforms use industrial components which have an operating range of -40°C to +85°C. If the board is operated outside the temperature range, then the worst that will happen is that the units will stop operating. As a practical matter, Time Domain has operated commercial units at temperatures as high as 100°C. Performance becomes erratic, packets are dropped and the noise figure of the LNAs increases by a few dB. At temperatures below -40°C the oscillators typically stop functioning, causing the processors to stop. However, when the temperatures return to operation between the limits, then the radios resume normal operation and show no ill effects. Having said that, it is strongly recommended that the user avoid storing or operating the units for extended periods outside the temperature limits because long periods at low temperatures can crack plastic and long periods at high temperatures can degrade capacitors and reform plastic components.

The information on the Status Info tab (shown in **Figure 12**) is valuable for debug purposes. For example, if the P4xx should malfunction, then Time Domain's product support team will likely ask for a screenshot of this tab.

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



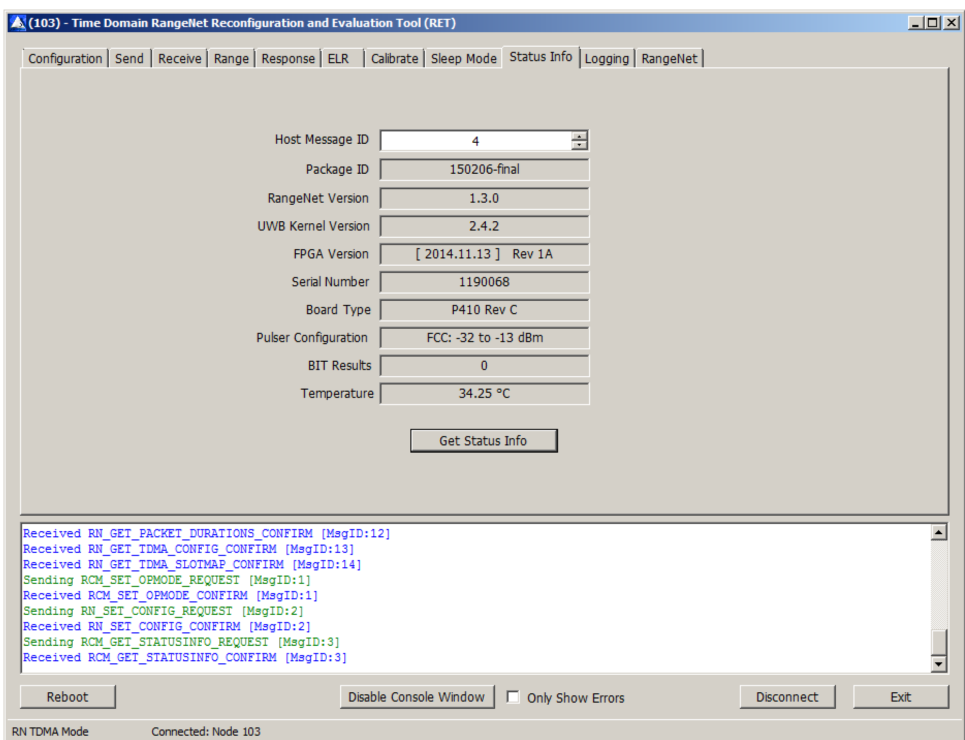


Fig. 12: Status Info Tab provides version, serial number, and status information for the connected P4xx. RCM Mode (top) RangeNet Mode (bottom)

14. Logging Tab

The Logging Tab (see **Figure 13**) is provided by RCM RET to support data collection and post-processing analysis. The logfile will be a comma-separated variable (csv) ASCII text file in the selected folder. (See **Appendix A** for more information on the logfile format.) This tab works in conjunction with the "Repeat" macro in the Send Tab.

The "change" button allows the user to modify the directory on the Host PC where RCM RET stores the logfiles. Each logfile name is in the form of [Logfile Prefix][Increment]. The "Logfile Prefix" can be edited by the user to distinguish logfiles by environment or by the configuration used.

When the user selects "Start Logging", a new file is created in the specified directory with the specified Logfile Prefix followed by the increment (nnn, where nnn is an incremented zero-filled number, i.e. RetLog_000, RetLog_001,etc). At this point the user should transition to the Send Tab and start sending range requests.

Logfiles will keep growing until the user hits "Stop Logging."

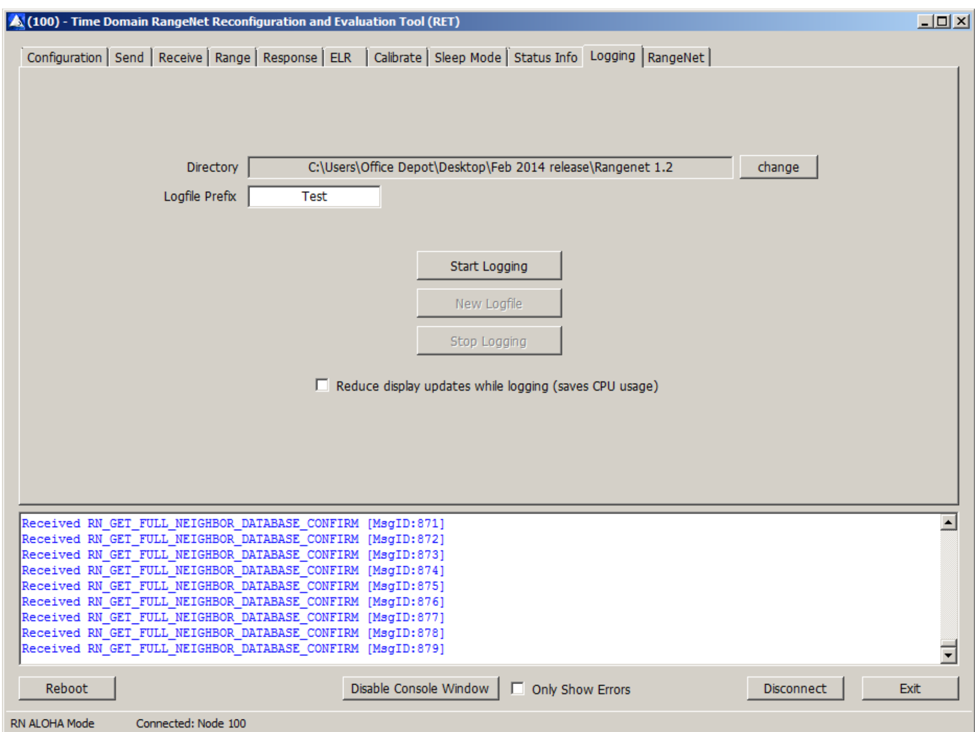


Fig. 13: Logging Tab allows user to log waveforms to CSV files

"Reduce Display…" checkbox: Clicking this button will reduce the rate at which the graphics are displayed. The graphics consume so much of the CPU bandwidth that it can slow down the processor. This is particularly noticeable when you are logging a lot of data from multiple units with multiple copies of RET operating. The problem manifests itself as dropped log entries. If this box is checked then (1) many common messages (Range Info, Scan Info, etc.) will not be displayed in the scrolling Action Area at the bottom of the RET windows and (2) plots of scans will not be displayed. The alternatives to this are (a) use a faster computer or (b) reduce the amount of data you are trying to log.

This concludes the sections describing the RCM RET tabs. The following sections will discuss the tabs and functions associated with RangeNet RET.

15. RangeNet Principles

In principle, networks are simple. In practice, they can be as simple or as complex as the application requires. This section discusses both aspects.

Networks are Simple

RangeNet is a very simple network.

- Each P4xx platform maintains a database of the distances/ranges to neighboring P4xxs. This is called the Neighbor Database.
- The P4xx units each have a scheduler which initiates range requests to neighbors.
- The scheduler operates using your choice of either (a) the ALOHA protocol (random access, simple but relatively inefficient) or (b) a TDMA protocol (time slot setup requires a bit more effort, but is very efficient).
- Both protocols have provisions for dealing with neighbors who leave or join the network.
- With ALOHA, there are provisions for dealing with:
  - neighbors who need less frequent range measurements
  - neighbors to whom one never ranges
  - neighbors who send periodic beacons but do not initiate range conversations
  - neighbors who request that they not be ranged to
  - neighbors who are ranged to based upon a round-robin selection
- With TDMA, the system maintains the network synchronization and the user is able to define and optimize the definitions of which units communicate with which others, when, and how.

That is all there is to RangeNet, two protocol choices, six simple principles and some software knobs with which the user can define operation.

These knobs are accessed through the RangeNet Tab. Clicking that tab will bring up seven control tabs that define network operation:

- RangeNet Configuration Tab allows the user to define the general control parameters
- ALOHA Tab allows the user to configure ALOHA specific network parameters
- TDMA Tab allows the user to configure TDMA specific network parameters
- Data Tab allows the user to load the transmit buffers with data
- Neighbor Database Tab allows the user to monitor the status of the range database
- Health Tab provides statistics on unit operation, network performance, and ranging failure rates
- Comms Tab allows the user to control the host interface on bootup

Networks are Complicated

The complexity in a network becomes apparent when the user attempts to tune or optimize network operation for a particular application. The ideal network would allow a near infinite number of P4xx platforms to operate in a very large area with near instantaneous updates while many existing P4xx platforms exit the network and new ones join. Such a system is difficult to accommodate.

The user will need to balance his applications requirements against the limitation that an individual range request requires a finite amount of time to complete. For example, the shortest duration range measurement is produced with PII 4. At this PII, a range measurement will be produced in 6.5 ms. This 6.5 ms does not include any additional data the user might want to send with the range measurement. PII 4 has a maximum operating range of about 35 meters. This range can be extended by increasing the integration from PII 4 to PII 5. In general, each increase in PII by one will double the amount of time it takes to produce a reading and increase the range distance by 40%. Increasing PII by 2 will double the range and quadruple the measurement time. For details see **Table 3** of the *P410 Data Sheet.*

Most users will likely use PII 7. At this integration rate the system will range to a distance of 125 meters and require 20 ms to complete the measurement. This means that an ideal system would allow approximately 50 range measurements per second. ALOHA is a random scheduling system which does not try to coordinate when units range but rather counts on infrequent operation reducing the number of conflicts/collisions to an acceptable level. At PII 7, the user should not count on more than 18 ranges per second. This range capacity needs to be shared between the neighbors in the system.

For many applications this ranging rate is sufficient and these constraints are manageable. In some cases, capacity can be increased through the prudent use of the CRE feature. However, there will be times when even more capacity is required. For this reason RangeNet has been provided with the ability to exclude certain neighbors. It is also possible to make use of the fact that multiple channels can be used to support multiple networks. While this adds capacity it also adds complexity, operational overhead, and increased (albeit modest) amounts of co-channel interference.

When this isn't enough, then the user can use the TDMA protocol. This protocol divides time into slots and each radio is assigned a specific slot time for ranging. The system automatically synchronizes timing so that all units operate only in the correct time slot. Configuration of the slots requires some effort, but the efficiency of the end result is quite good. The user can expect efficiencies on the order of 90-95%. When the application requires even more capacity, the user can also use multiple channels.

As the complexity of the system grows, the user (or Host application) will take on additional coordination responsibilities. At that point, RangeNet will begin to feel less like a network and more like a MAC layer.

16. RangeNet Tab

Selecting this tab brings up a second row of tabs, all of which are dedicated to network operations. The following is a short summary of these tabs.

Configuration Tab allows the user to:
- Load, set, save, and define defaults

- Switch from RCM mode to RangeNet mode (either ALOHA or TDMA)
- Set the rate at which the Host receives updates from the P4xx Neighbor Database
- Controls the amount of data reported from the P4xx
- Define units to be excluded from the network

ALOHA Tab allows the user to review, modify, set and save ALOHA protocol-specific network parameters.

TDMA Tab allows the user to load a predefined slot map from disk, define/modify a slot map, and save to disk.

Data Tab allows the user to load the request and response data buffers.

Neighbor DB Tab allows the user to display the contents of the neighbor database.

Health Tab shows the temperature of the connected P4xx and provides statistics on the operation the network.

Comms Tab allows the user to define the communications port which the P4xx will initially send messages on boot up.

17. RangeNet Configuration Tab

Selecting the RangeNet Tab will bring up a second row of tabs of which the top tab is the Configuration Tab (see **Figure 14**). The following is a description of each field and command.

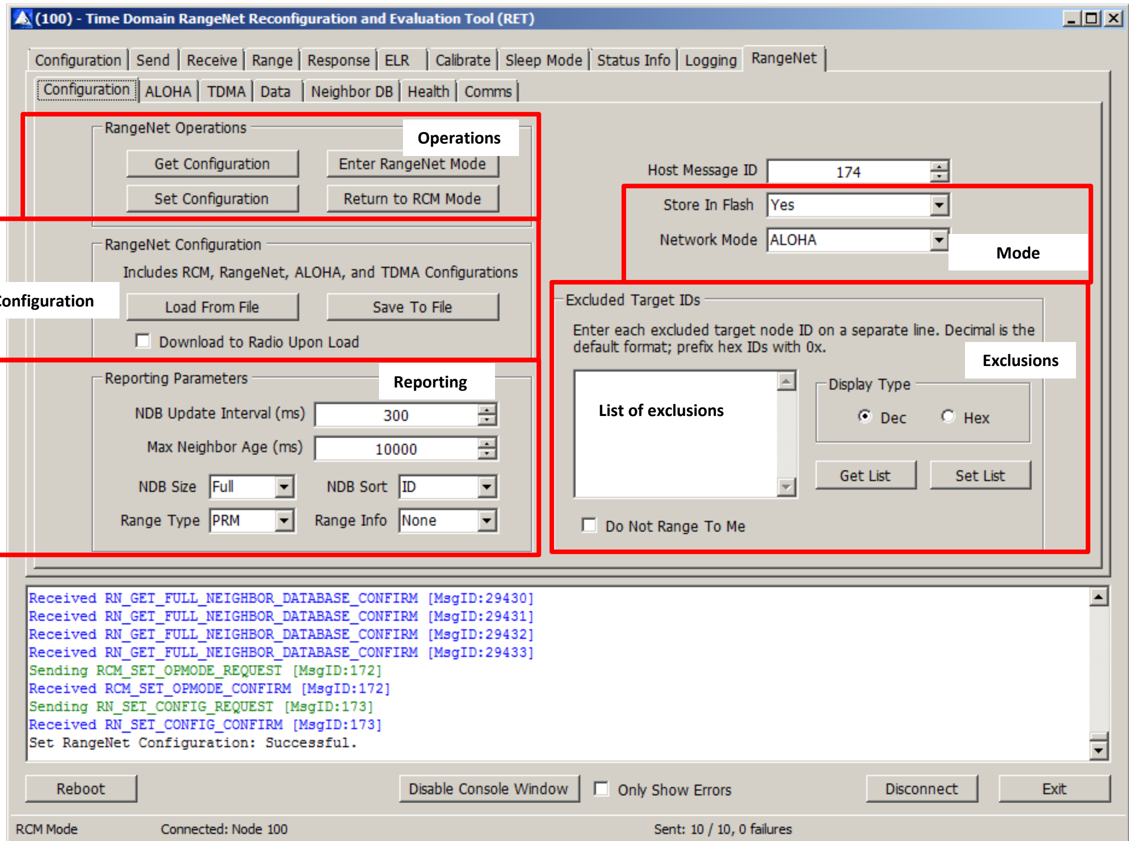


Fig. 13: RangeNet Configuration Tab

RangeNet Operations Commands:

Get Configuration: Clicking this button will retrieve the RangeNet configuration parameters from the P4xx and display them on this screen.

Set Configuration: Clicking this button will download all of the parameters on this screen to the P4xx. Any time one of the parameters on this screen is changed this button will turn yellow as a reminder that the user has made a change and that this change should be downloaded.

There is an exception to this rule. Clicking either the Enter RangeNet Mode or the Return to RCM Mode buttons will immediately turn the Set Configuration button yellow and change the operational state of the connected P4xx. However, this new state will NOT be the new power up default state of the P4xx until the Set Configuration button has been clicked. Even then it will only be the new power up default state if the Write to Flash option is also selected.

Enter RangeNet Mode: Clicking this button will cause the P4xx to join the network. More specifically, RangeNet will now be controlling the P4xx module's behavior. The status bar indicator on the bottom of the page will now show that the unit is operating in RangeNet mode and will indicate if it is in ALOHA or TDMA.

Return to RCM Mode: Clicking this button will disconnect the network and make the user responsible for the units operation. The status bar indicator on the bottom of the page will now show "RCM Mode."

Mode Commands:

Store in Flash Drop-Down: If this is set to "Yes" then each time the user clicks the Set Configuration button, the P4xx will load the RCM and RangeNet parameters to flash memory. This will insure that the parameters to persist through a power down of the P4xx.

Network Mode Drop-Down: This dropdown allows the user to define whether RangeNet will operate using the ALOHA or the TDMA network. If ALOHA is selected, then you will not be able to enter any TDMA parameters. Similarly, if TDMA is selected then ALOHA parameters cannot be changed.

RangeNet Configuration Commands:

Load From File: This command will load RangeNet configuration parameters from file. The factory default configuration parameters can be found in the installation directory:

C:/Program Files (x86)/Time Domain/RangeNet Reconfig & Eval Tool (RET)/RangeNet Factory Defaults.rn

Note that the RangeNet default file contains all of the RangeNet parameters found on the RangeNet screens plus RCM parameters. This default file is different from the RCM default file.

C:/Program Files (x86)/Time Domain/RCM Reconfig & Eval Tool (RET)/RCM Factory Defaults.ret

This allows the user to enter RangeNet and load all of the parameters at one step rather than forcing the user to load twice, once from the RangeNet Config page and then once from the RCM Config page. (The user can still load from the RCM Config page, but this load will be from the RCM Factory Defaults and not the RangeNet Factory defaults.)

In either case, the default values are the ones used in the Quick Start process. All of the factory default files are write-protected.

Download to Radio Upon Load: Clicking this checkbox will not only load the network configuration from file but it will also automatically click the Set Configuration button and download all the parameters to the radio. This is a time saver as it eliminates the need to go to each of the RangeNet tabs and click Set Configuration.

Save to File: Save will download the configuration parameters to a file in a user-specified location. These configuration parameters include the RCM, RangeNet, ALOHA, TDMA and Data parameters. This is useful for saving a complete configuration into a single file.

These commands are very convenient when the user is experimenting with different configurations.

Reporting Parameters:

Neighbor DataBase Update Interval (ms): This is the rate at which the Neighbor Database is uploaded from the P4xx to RangeNet RET. This parameter is passed as a 16-bit binary number and, in principle, can be set to any value between 0 and 2^{16}-1. In practice, the P4xx limits its reporting rate such that it is difficult to overrun the interface. The Ethernet and USB interface update rates have been limited to a 10 Hz update rate, and Serial and CAN interfaces are limited to 5 Hz.

RangeNet RET handles the Update Interval in a similar way. If the user attempts to load the Update Interval with too small a value, then RET will automatically substitute the entered value with the highest rate possible for given interface.

Even so, the user should be aware that the P4xx can produce a lot of data, and it is possible for the user to request enough data to flood the communications port. If this happens, then packets arriving at the Host can be dropped and packets sent from the Host to P4xx may have trouble getting through.

Max Neighbor age (ms): This parameter defines what it means to be a neighbor. If a P4xx has not heard from a specific neighbor P4xx in this number of milliseconds, then that neighbor is dropped from the Neighborhood Database. The P4xx will then no longer attempt to range to the deleted neighbor. This parameter is passed as a 32-bit binary number and can be set to any value between 0 and 2^{32}-1. The units are milliseconds.

NDB Size: This drop-down allows the user to indicate how much information is to be automatically reported on the Neighbor DB page. This capability allows the user to limit the amount of information which might be sent over slow speed serial interfaces such as CAN and TTL/RS232. The choices are:

> **None:** The P4xx will not send any information from the NDB.
>
> **Full:** The P4xx will send all NDB data for display by the GUI.
>
> **Small:** The P4xx will send a limited set of information from the NDB for display by the GUI. The set includes: Node ID, Range, Range Velocity, Range Type, and Measurement Age.

Range Type: This drop-down allows the user to display either PRE (Precision Range Measurements from TW-TOF measurements) or FRE (Filtered Range Measurements from PRE-calibrated and Kalman-filtered CREs).

NDB Sort: This drop-down allows the user to control the order in which data is reported from the Neighbor Database. The data can be sorted by Node ID, by Node ID that is the closest distance to the connected P4xx, or by age (most recent to oldest).

Range Info: Whenever the P4xx takes a range measurement it will normally send the range information to the Host. This is the normal operation when the system is operating in RCM mode. However, when operating in RangeNet mode, it might not be necessary to report each range measurement. After all, this information is already in the Neighbor Database. The Range Info packet also consumes communication bandwidth. This drop-down gives the user freedom to suppress or limit Range Info transmissions from the P4xx. The drop-down options are described below. Note that this setting will also affect the RCM Receive and Range tabs.

None: Range Info packets will be entirely suppressed.

Successful: Only successful PRMs (PRMs with no error messages) will be reported.

All: All information will be displayed, where the nature of "all" is defined by the Range Info drop-down box on the RCM RET Configuration Tab.

Excluded Neighbors Targets:

This capability allows the user to instruct the P4xx to exclude (not range to) a particular Node ID or set of Node IDs. This capability is useful for those cases in which some of the units are located at a fixed and immoveable location. This capability is most useful for ALOHA systems. (It is not particularly useful for TDMA systems because the capability is implicit in the construction of the Slot Map.) For example, consider a system consisting of three fixed references connected together with an Ethernet backhaul to a Host computer and a single mobile node unconnected to the Ethernet. Given that the location of the references is fixed and known, there is no reason for the references to range to each other. In this configuration, each reference could be set up such that all other reference units were excluded and the mobile would be set up in Beacon Only Mode. With this configuration, the references would range to the mobile and would send the measured ranges to the Host such that the Host system would be able to compute the location of the mobile.

List of Exclusions: This field displays the IDs of the P4xxs which are excluded from the scheduler. The maximum number of excluded IDs is 256. The user can use the scroll bar to search the list. IDs can be deleted from the list, edited, and additional IDs can be added to the bottom of the list. Units can be entered in decimal format or with the prefix hex IDs. Making a change to the list will cause the Set Excluded Target IDS to turn yellow. This is a reminder that the changes will not take effect until the Set button is pressed.

Get List: Clicking this button will upload the list of Excluded Target IDs from the P4xx. The list will be displayed in the "list of exclusions" block.

Set List: Clicking this button will download the Excluded Target ID list to the P4xx. If the user edits the list, this button will turn bright yellow. This is a reminder that the changes will not take effect until this button is clicked.

Do Not Range to Me: This flag is sent with every range request and range response. If the flag is set (the box is clicked), then it will prevent any recipient of the message from ever initiating a range request to the flagged node.

18. ALOHA Tab

This tab (see **Figure 14**) allows the user to set up the parameters unique to the ALOHA network protocol. There are two types of ALOHA protocols, Pure and Slotted. Because the P4xx units have been programed with a virtual carrier sense, the ALOHA network acts like a Slotted system and achieves network efficiencies of approximately 40%. In other words, if an ideal, fully synchronized system could maintain 100 range measurements per second, then a Slotted ALOHA system (because of its random nature) will achieve almost 40 readings per second.

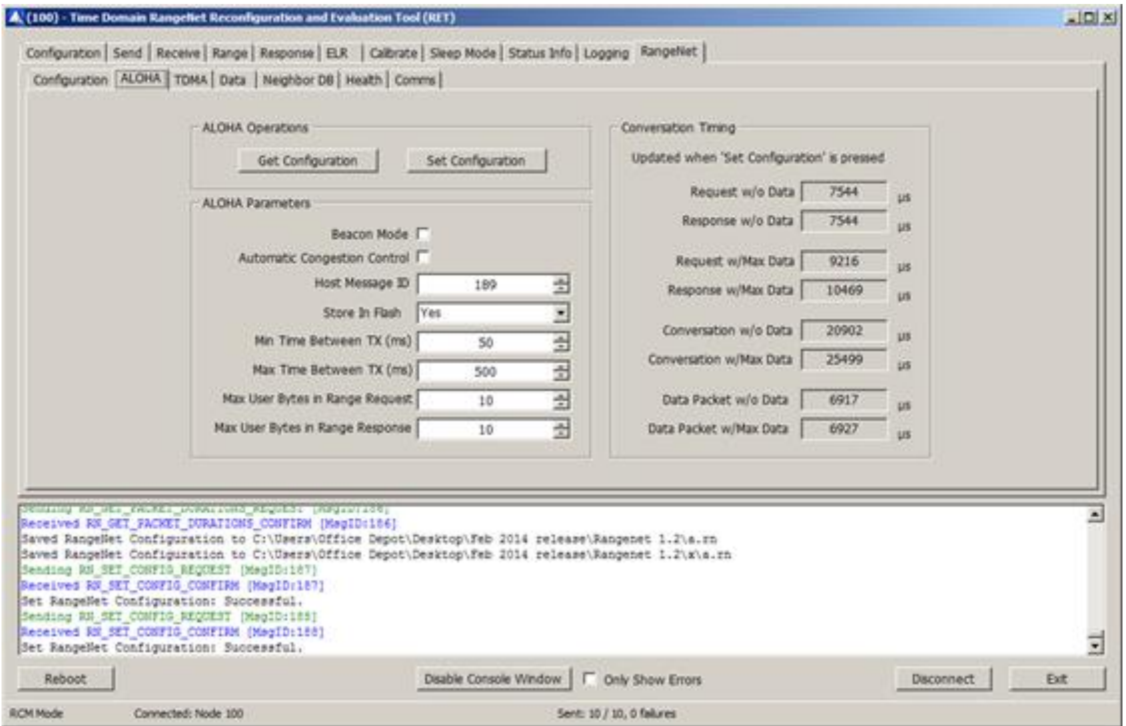


Fig. 14: ALOHA Tab

ALOHA Operations:

Get Configuration: Clicking this button will retrieve the current ALOHA parameters from the P4xx.

Set Configuration: Clicking this button will download all of the parameters currently on this screen to the P4xx. Any changes made to the parameters on this screen will turn the Set Configuration button yellow. This serves as a reminder to the user to click the button when the changes are complete.

ALOHA Parameters:

Beacon-only Mode: When this box is checked the P4xx will act as a Beacon. A Beacon sends out an occasional message as a way of announcing its presence. This occasional message is also called a “beacon” and it contains the Node ID and a few flag bits. This message acts as a seed for the network and its purpose is to prompt other units to range to it. . Beacons will not initiate range requests but will respond to them. Beacons will beacon at an interval determined by the user or if Automatic Congestion Control is selected then RangeNet will establish the beaconing rate. This interval is reset to zero whenever the Beacon responds to a range request. This behavior guarantees that the system will occasionally hear Beacons but also insures that a busy network will not bear the burden of unnecessary Beacon messages.

Unlike RCM data packets, a Beacon will not generate a Data Info Packet.

This capability is useful in a number of instances. For example, given a system consisting of four P4xx nodes in which one node is a mobile and the other three are stationary references, the three references would typically be set in Beacon-only Mode. The mobile uses received beacon messages as a means to discover any references that might be in range. Once a Beacon is discovered it will be added to the mobile's neighbor database . The mobile could range to all of the references but the references would never range to any node. This would allow the mobile to calculate its own location relative to the references.

Automatic Congestion Control: This button allows the user the option to engage or disengage Automatic Congestion Control (ACC).

ACC is a RangeNet algorithm operating in the P4xx which dynamically maximizes the rate at which units range to each other. If the network only has a few neighbor nodes then ACC will set the average request rate to a high rate. If the network has many neighbors then ACC will set the average request rate to a low rate. This rate will be further adjusted as nodes join or leave the network.

If the user disengages ACC then the node will range at the rate defined by the Min Time Between TX and the Max Time Between TX. When ACC is on, these entries are ignored. They will be gray and the user will not be able to change the values.

For additional information see the whitepaper entitled "RangeNet/ALOHA Guide to Optimal Performance."

Host Message ID: This ID is used to number the messages sent from the Host to the P4xx. This number is incremented by RangeNet RET and is independent from the Message ID. In RangeNet mode, Message IDs are used to number the messages sent between P4xx nodes and are incremented by the P4xx. In RCM mode, Host Message ID will not be incremented. Message IDs are provided to all messages and are incremented by RangeNet RET.

Host Message ID and Message ID are normally of use only when debugging system operation. See **Appendix C** of the *RangeNet API Specification* for additional discussion of the use of Host Message and Message IDs.

Store in Flash: If the user wishes these parameters to persist through a power down of the attached P4xx, then the user must set "Store in Flash" to Yes before clicking the Set Configuration button.

Min time between TX (ms) & Max time between TX (ms): These parameters only have meaning when Automatic Congestion Control is off. These parameters allow the user to manually define the limits of when the P4xx-based scheduler will initiate a range request. More specifically, the scheduler will initiate a request at a random time between these minimum and maximum times. RangeNet RET will not allow the user to enter a min time greater than the max time. When using the API directly with C, MATLAB, or some other code, the user must provide his own limit checks.

If the user sets the min and max time to be equal, then the unit will send range requests at exactly this interval.

When setting these limits, the user must be mindful to the fact that a range request takes a finite amount of time to execute. For example, if PII 7 is used, then a range request will take ~20 ms. It would therefore make no sense to set the max time to less than 20 ms. The user can set the minimum time less than 20 ms. If the scheduler attempts to initiate a range request before the previous one has completed, then that range request will be ignored.

The chief advantage of this arrangement is that the user can easily define a mean rate at which range requests will be issued. The mean rate is the average of the min and max. The Conversation Timing block (described below) provides useful information regarding the time required for a given message packet. This is a convenient reference when manually setting Min and Max transmit times.

These parameters are passed as a 16-bit binary number and can be set to any value between 0 and 2^{16}-1. The units are milliseconds.

Max user bytes in range request & in range response: The user has two means of transmitting data. The first way is to load the range request buffer. The second is to load the range response buffer. Anytime RangeNet initiates a range request, the contents of the range request buffer will be transmitted. Similarly, any range response will transmit the contents of the range response buffer. These parameters define the maximum size of the transmit and receive buffers. The user may select any value between 0 and 1000. Any data sent by the user will increase the time it takes to produce a range measurement. Be aware that while the user selects bytes, the P4xx will send 32-bit words. The additional time is added to range request or range response is defined by the following equation:

Additional length (ms) = (Roundup(Number of Bytes/4))*32*(2^PII)*0.0001

At PII 7, a 10 byte data transfer will add 1.2288 ms to the 20 ms required to take a range measurement. This equation is an approximation. It will vary depending on the code channel selected, but the approximation is accurate to within a few percent.

Conversation Timing:

This block provides the user with statistics on the duration of a range conversation. These durations are determined by the integration rate and the amount of additional user data which is transmitted. For convenience, RangeNet will compute the times for the following eight different types of messages.

- Range Request without Data
- Range Response without Data
- Range Request with additional Data (with maximum set by ALOHA parameter)
- Range Response with additional Data (with maximum set by ALOHA parameter)
- Time required for a complete range conversation (without additional data)
- Time required for a complete range conversation (with maximum data)
- Data Packet without additional data (a null message used for announcing presence)
- Data Packet with maximum additional data

This data is recomputed each time the use clicks the Set Configuration button on the ALOHA Tab.

This information is provided as a reference. It is useful when the user is operating in ALOHA, without ACC and it is necessary to manually set Min and Max times between transmissions.

19. TDMA Tab

A TDMA network operates by defining specific time window (slots) in which specific units may communicate with specific units or with all units. This tab allows the user to retrieve the current slot map from the unit, modify an existing slot map, upload a slot map from disk and to download new or modified slot maps to the unit. For each slot, the user can define:

- Which units communicate with each other
- What PII and channel code will be used for the message
- Which antenna configuration will be used
- Whether the transmitted packet is a ranging or data packet
- Whether the data will or will not be sent
- Whether the unit will enter a sleep mode when not in use

The user can manually define the slot times or, alternatively, can allow the system to automatically define the slot time. The user can also define the Maximum number of data bytes which will be sent.

This section is divided into two subsections. The first subsection defines each of the fields. The second subsection illustrates how the user can build a new slot map.

Definitions of the Fields on the Network Tab

Figure 15 shows the TDMA tab and the default Slot Map. This screen has a number of data and control fields. These fields can only be changed if the unit is in Network Mode (see RangeNet Configuration). As a practical matter, changes to the Slot Map are best done when the unit is in RCM Mode or when Sleep Mode is Idle. It is best to insure that all of the P4xx units in the system have the correct Slot Maps before the units are returned to RangeNet Mode.

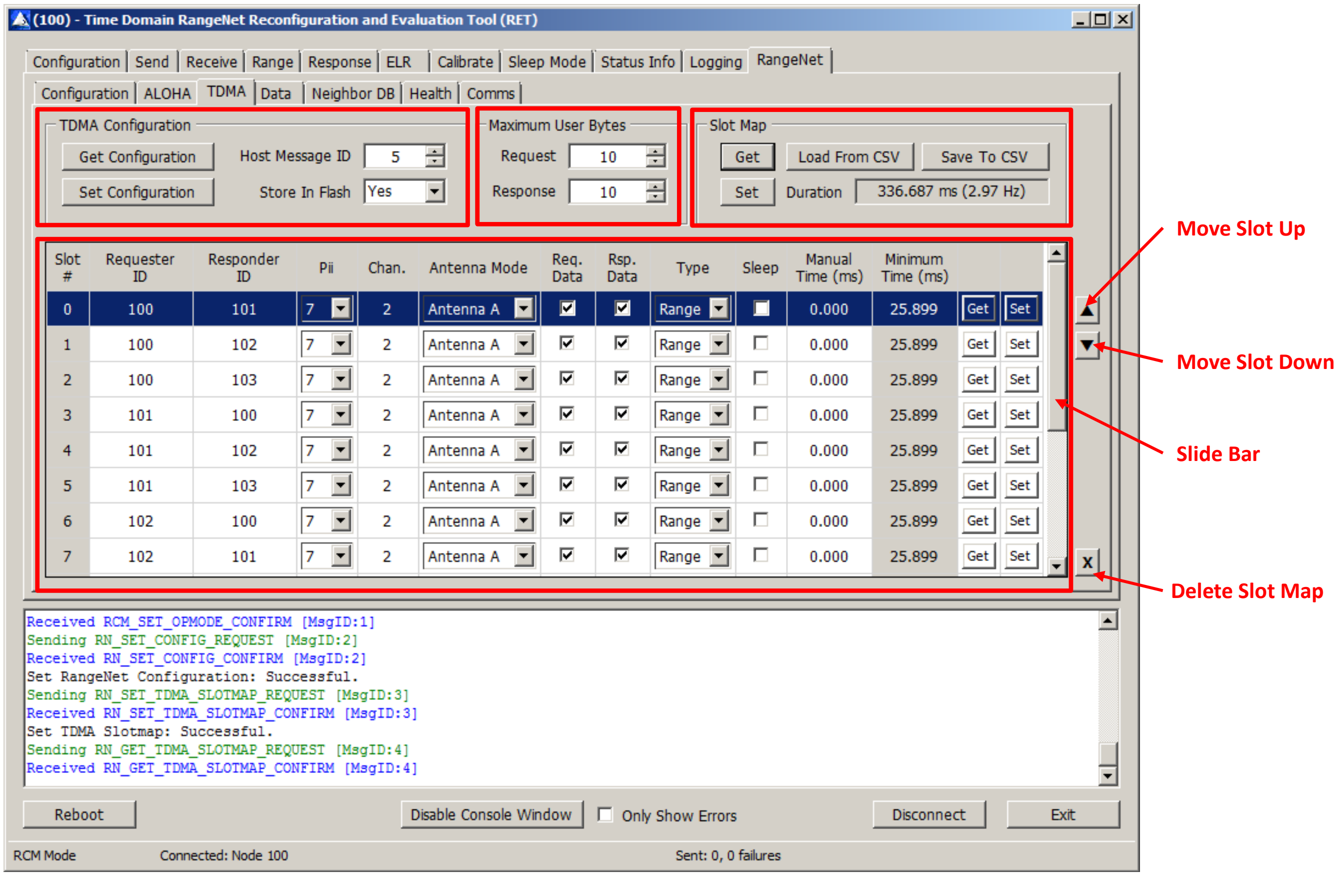


Fig. 15: TDMA Tab and using the Default Slot Map

TDMA Configuration Controls:

Get Configuration: Clicking this button will upload all of the TDMA configuration parameters (Maximum User Bytes) from the connected P4xx.

Set Configuration: Clicking this button will take the current Host based TDMA configuration parameters (Maximum User Bytes) and download them to the unit.

Store in Flash. If this drop-down is set to “Yes” then any changes to the configuration in the P4xx will be saved to non-volatile memory. This will allow the configuration changes to survive a reboot or power cycle.

Maximum User Bytes Controls:

Request: This defines the maximum number of bytes which will be sent by a data only packet or a range request message. Changing this field will change the amount of time required to take a range measurement.

Response: This defines the maximum number of bytes which will be sent in a response message. Changing this field will change the amount of time required to take a range measurement.

Slot Map Controls:

Get: Clicking this button will retrieve the current slot map from the connected P4xx.

Set: Clicking this button will download the current slot map from the Host to the connected P4xx. It will also cause the Get button to turn green. This is to remind the user to click the Get button so that the P4xx will report the updated Minimum Times (slot times) and slotmap Duration.

Load From CSV: This command allows the user to load an existing Slot Map from disk. A default TDMA slot map can be found in the directory:

C:/Program files (x86)/Time Domain/RangeNet Reconfig & Eval Tool (RET)

Save to CSV: This command allows the user to save the current Slot Map to disk.

Duration: This field displays the amount of time which will be required for the P4xx to cycle through the entire Slot Map one time. This field is updated whenever the Get button is clicked.

Slots:

These are the actual slots. Each row is one slot. In this case eight slots are shown in the figure above. The actual number shown is dependent on the size of your display. The user can review any remaining slots by moving the Scroll Bar down. Each slot has twelve fields. Any change to one of the entries will light the Slot map Set button. This is a reminder that the entries have not been downloaded to the attached P4xx.

The fields are described below:

Slot #: The number of each slot. The Requestor in Slot 0 is the master unit and all of the other units in the system maintain synchronization with this unit. This unit is a single point of failure for the entire system, in that if this unit fails or leaves the system, then the units will lose their source of synchronization. See the *RangeNet API Specification* for additional information on slot maps and synchronization. Their oscillators will then start to drift relative to one another and the system will ultimately loose synchronization and the system will collapse. However, because the unit oscillators are very accurate and very stable, it could be many seconds, if not longer, before the network degrades. This will give the operator time to either replace the master or give the system the time to redefine a new master. The redefinition is not performed automatically. The Host computer attached to the P4xx units would need to recognize the situation and then take appropriate action. For example, all of the Host units connected to the various system P4xx units could notice that that master had died and could then delete Slots 0-2, thereby promoting unit 101. Once again, this is only an illustration of a notional response to the loss of the master. The proper response is dependent on the end application and would, in any event, be controlled by the user's Host application.

Requester ID: The ID of the P4xx which has permission to initiate a transmission.

Responder ID: The ID of the P4xx to which a range request will be directed.

PII: The Pulse Integration Index with which the transmission will be made.

Channel: The Code Channel which will be used for the communication.

Antenna Mode: This drop down allows the user to define which antennas will be used for the communication.

Requester Data: Clicking this button will allow the requesting unit to transmit the indicated maximum number of user bytes. If the button is not clicked then the requester will not be able to send additional data.

Responder Data: Clicking this button will allow the requesting unit to respond with the indicated maximum number of user bytes. If the button is not clicked then the requester will not be able to send additional data.

Message Type: This drop-down allows the user to designate this slot as either a ranging or data message. If the slot is reserved for data messages, then the data will be broadcast to all units instead of to just an individual unit. In this case it is not necessary to identify a Responder ID in the third field.

Sleep: Setting this flag will put the attached unit in Sleep Mode “Idle” state for every slot in which the unit is not either a requestor or responder.

Manual Time: The message parameters such as PII and data bytes will define how long a message will take. This is a minimum amount of time and will normally be used to set the duration of a given slot. However, this field allows the user to define a slot duration greater than the absolute minimum.

Minimum Time: This field indicates the amount of time the slot will require. This value is not computed by the RangeNet RET but rather by the P4xx. Consequently, any changes made to the slot parameter that effect duration will not be reported until after the user does a Set and a Get for the slot map.

Get: This field allows the user to retrieve the slot information for this particular slot number from the P4xx. This differs from the Slot Map Get which retrieves the slot information for all of the slots.

Set: This field allows the user to download the slot information for this particular slot number to the P4xx. This differs from the Slot Map Set which downloads all of the slot information to the P4xx.

Other Controls:

Move Slot Up: Selecting a Slot and then clicking this button once will move the slot up one position in the slot map.

Move Slot Down: Selecting a Slot and then clicking this button once will move the slot down one position in the slot map.

Delete Slot Map: Clicking this button will delete the entire slot map.

Creating a New Slot Map

To create a new slot map, first zero out the existing map by clicking the Delete Slot Map button.

Next, click anywhere in the top slot. A new slot will appear populated with the system defaults. See **Figure 16**.

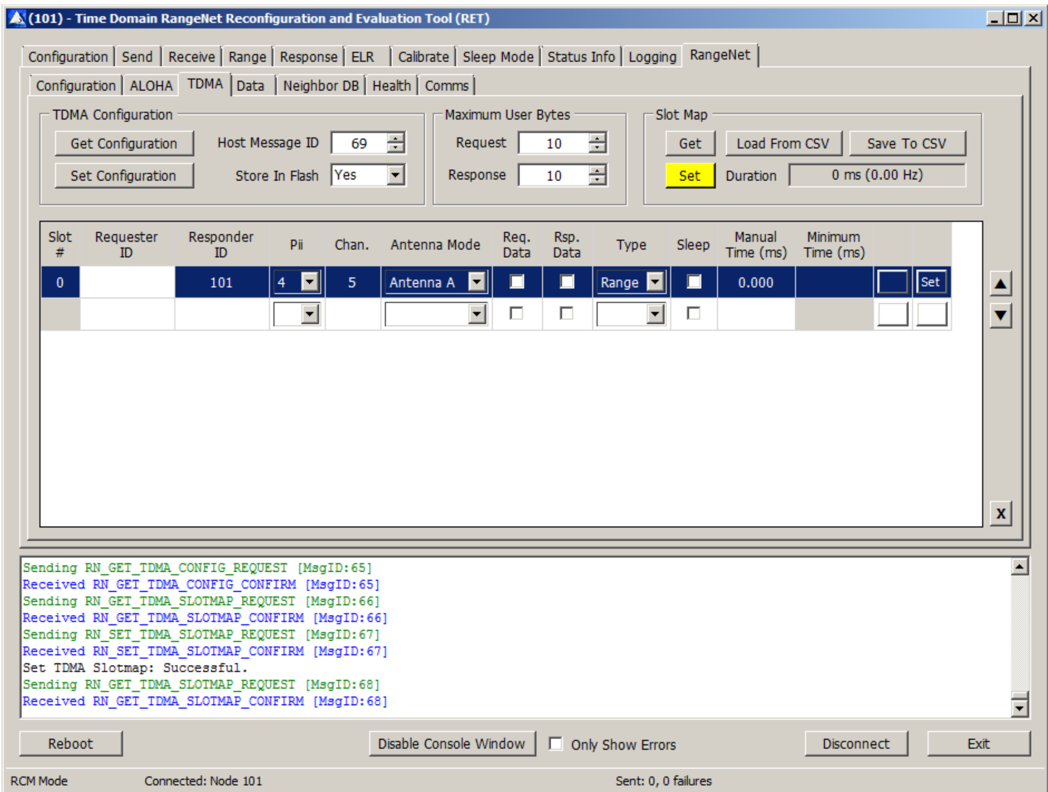


Fig. 16: Example default settings for a new slot

Next, fill in the desired settings and click either the Set button in the Slot Map control or the Set button at the end of the line. Note that the Get button will turn green. This is an indication that the slot duration has changed (see **Figure 17**). (To find out what the duration is, the user can click the Get button.) At this point the first slot is complete and ready to go. Of course, this is a trivial case in that Unit 100 will range to Unit 101 forever.

This slot map is quite similar to doing a point to point range measurement in RCM. It is different in one important regard. With RCM RET, the requests are driven by the Host. RCM will issue a request, wait for response and issue another request. With RangeNet RET, the requests are driven by RangeNet so the ranges are not limited by the polling times and can be driven at almost the maximum rate possible (~90% of the rate specified in the data sheet). As a side note, the only way to range at 100% of the maximum rate on the data sheet is by using custom C code which drives the unit directly.

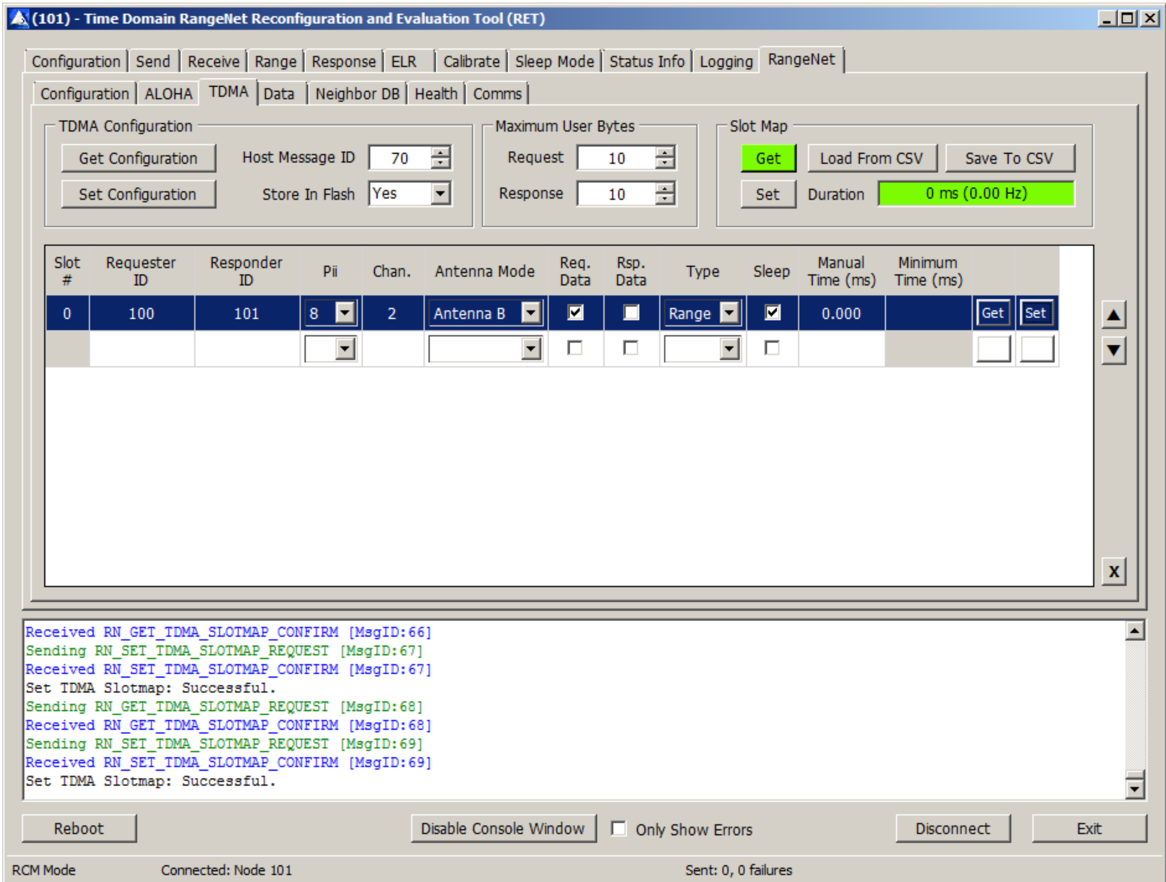


Fig. 17: Example entry with Get highlighted in green.

To add another slot, move the cursor to the next available slot and left click your mouse. This will add a new entry using the previous entries as the defaults. Continue the procedure as before and when you have entered all of the slots of interest and clicked the final pair of Set and Get buttons, the map will be completely downloaded to the attached P4xx. If you want to delete an entire slot, then left click on the slot to be removed and then press the delete key on your keyboard.

Once the slot map is final, the user may or may not want to download the configuration to the attached unit. But in any event, it is a good idea to save this configuration to file. This is accomplished by clicking the Save to CSV button.

20. Data Tab

The Data Tab (shown below in **Figure 18**) allows the user to transmit data either as part of a range request or a range response. The range request buffer contents are shown in the white data box on the left and the range response buffer contents are shown in the white data box on the right. The maximum size of the buffer is indicated above the upper right corner of each box. These sizes are defined on the RangeNet Configuration Tab. The amount of data currently in each buffer is indicated above the upper left corner of the box.

The user can enter any keyboard characters he wishes up to the limit specified by Max Size. Any entry will cause the associated set button to turn yellow. Once the user has finished entering data, the user must click on the associated Set button (Set Request Data for the request buffer or Set Response Data for the response buffer) to actually move the data from the RangeNet RET screen to the connected P4xx. While RangeNet RET limits the user to entering keyboard characters into the buffers, the user can enter any values through the API.

Using the Configuration Tab commands Load from File and Save to File, the user can preload or save the contents of the Request and Response Data buffers. However, unlike other parameters, these values are <u>not</u> saved to Flash in the P4xx memory and will be lost when the P4xx powers down or reboots.

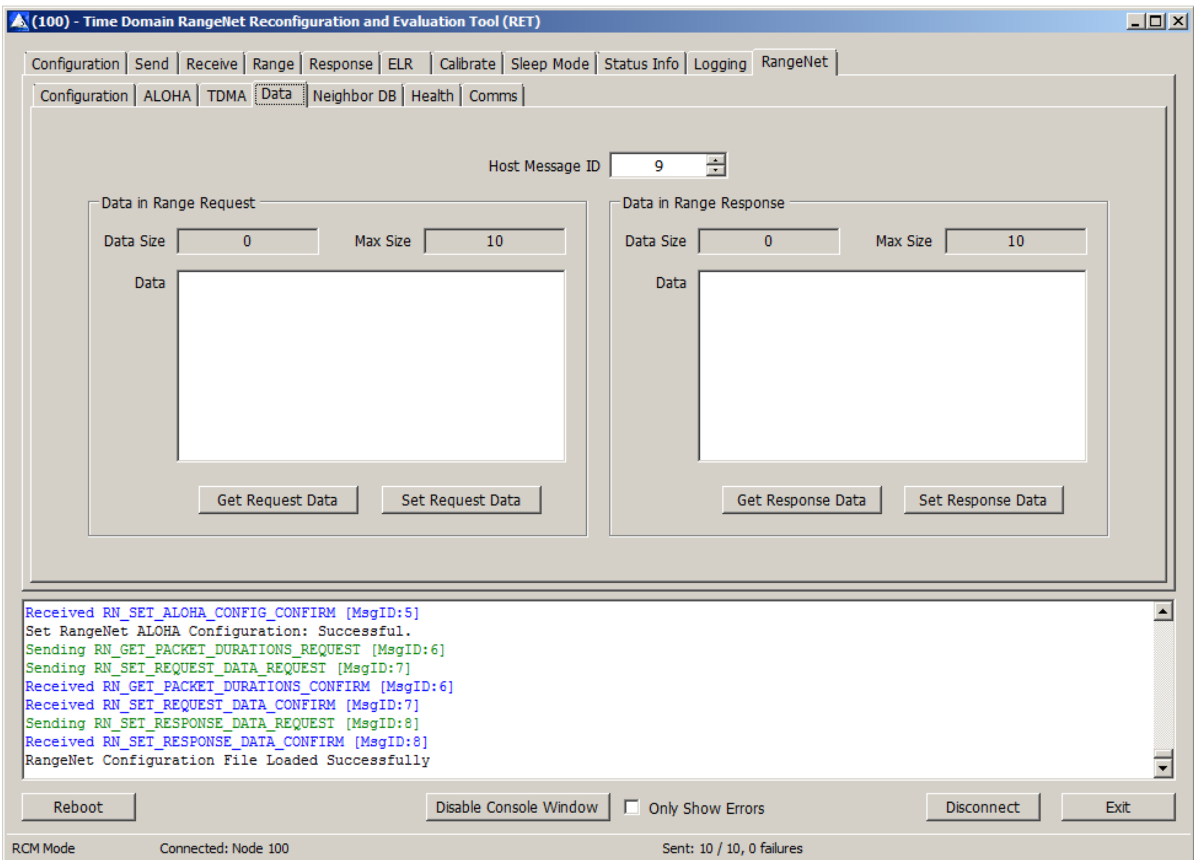


Fig. 18: RangeNet Data Tab

21. Neighbor Database Tab

The Neighbor Database (NDB) Tab provides visibility into the Neighbor Database maintained in the connected P4xx (see **Figure 19)**. More precisely, **Figure 16** shows two versions of the tab, one displaying the leftmost 12 database parameters and second with the right most 13 parameters. The amount of data to be displayed, the rate of display and the order in which the data is displayed is controlled by the settings on the RangeNet Configuration Tab. This section will describe the controls available to the user and meaning of the data being reported.

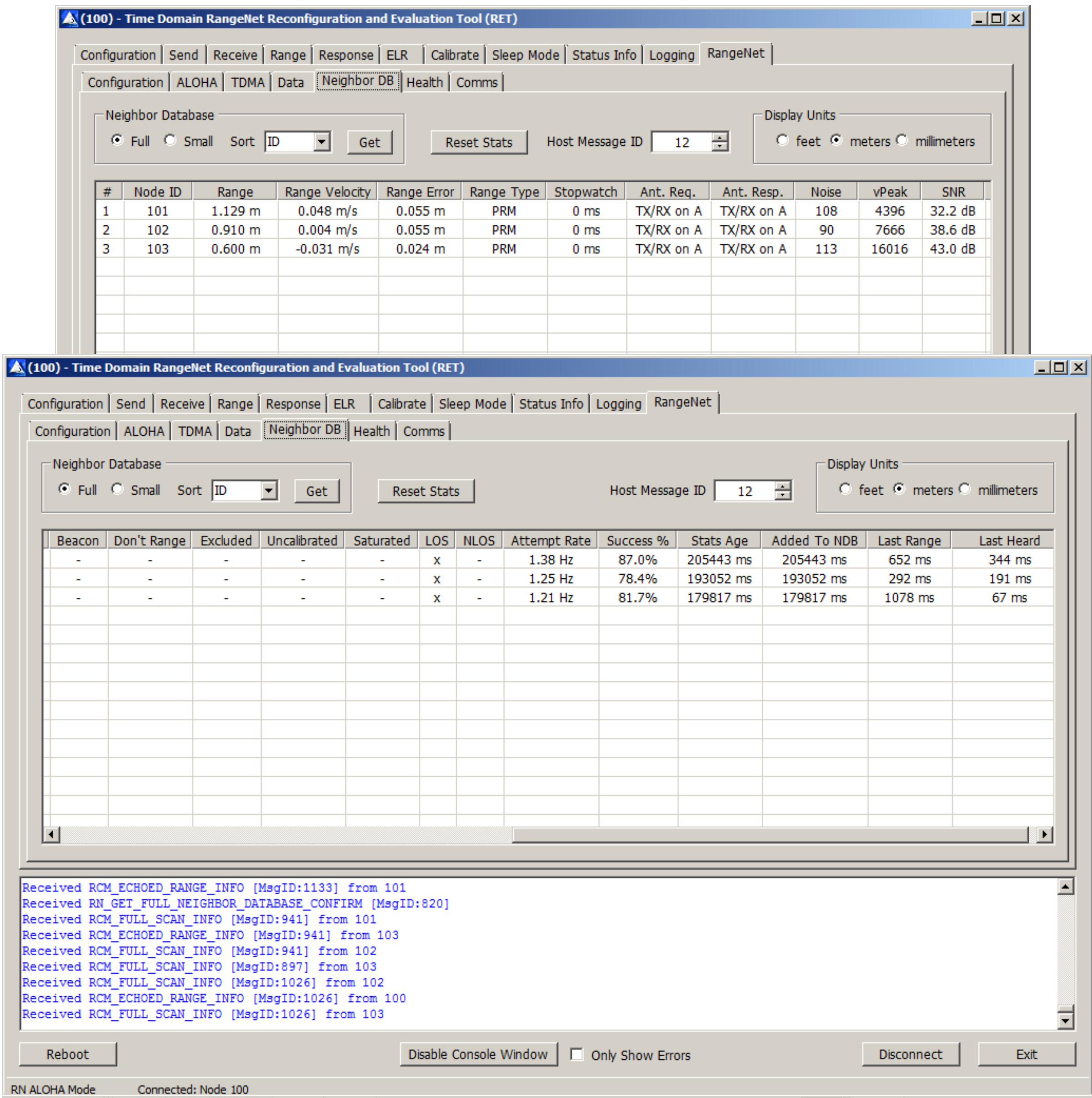


Fig. 19: Neighborhood Database Tab (left-most 12 parameters on top, right-most 13 parameters on the bottom)

Controls:

Neighbor Database Block: If the user has selected "none" for NDB Size on the RangeNet Configuration Tab, then the attached P4xx will not send any update information unless specifically requested to do so. This block of controls gives the user the ability to upload the attached P4xx's Neighbor Database on demand. The user can select how much data he wishes to upload by clicking either the Full or Small buttons. The order in which the NDB is displayed can be selected by choosing one of the methods from the Sort dropdown. Pressing the Get button will cause the data to be uploaded.

Reset Stats: There are a number of statistics which are calculated over time by the system. This button allows the user to reset the statistics on demand.

Display Units: This button allows the user to change the units in which the range measurements are reported. Note that this control will set the units for each of the display tabs (Receive, Range, and Neighbor Database).

Definition of the Data Being Displayed:

The following are the definitions of each field.

#: The row number of the Neighbor Database.

Node ID: The Node ID of the Neighbor.

Range: Range between the connected P4xx and the Neighbor. If PRM is selected on the RangeNet Configuration page as the Range Type of choice then PRMs are reported. If FREs are selected, then FREs are reported.

Range Velocity: Rate at which the Neighbor is approaching (negative value) or retreating (positive value) from the connected P4xx. This value is updated by both CREs and PRMs.

Range Error: An estimate of the error in the range measurement. This value is updated by both CREs and PRMs.

Range Type: Indicates whether the range measurements are Precision Range Measurements (based on TW-TOF) or Filtered Range Estimates. Two types of Filtered Range Estimates are reported: FRE-PRM and FRE-CRE. The first are filtered PRMs. The second are CREs which have been calibrated and filtered based on Precision Range estimates.

Stopwatch: Measurement of the time required for a full two-way range conversation. This value should be close to that predicted by the statistics on the ALOHA Tab. However, it will be different because the measurement is performed using a timer that resolves down the nearest millisecond. As a result, it can be off by 2ms relative to the value reported on the ALOHA Tab. A zero value indicates that the measurement was generated by a CRE.

Ant. Req: Indicates which of the Requester's two antennas was used to transmit and which was used to receive.

Ant. Resp: Indicates which of the Responder's two antennas was used to transmit and which was used to receive.

Noise: This is the scaled estimate of the noise experienced by the P4xx receiver and is identical to the value reported on the Receive Tab. This value is updated by both CREs and PRMs.

VPeak: This is the scaled estimate of the maximum received signal in the leading edge as measured by the P4xx. It is identical to the value reported on the Receive Tab. This value is updated by both CREs and PRMs.

SNR: This is an estimate of the Signal-to-Noise Ratio (SNR) of the received signal. It is computed using the following formula. This value is updated by both CREs and PRMs.

$$SNR = 20*\log10(Vpeak/Noise)$$

Noise, Signal/Vpeak, and SNR are discussed in greater detail in **Appendix F**.

Beacon: An "x" indicates that the unit is a Beacon.

Don't Range: An "x" indicates that the target node does not want to be ranged to.

Excluded: Indicates that this node is specifically excluded from the Neighbor Database.

Uncalibrated: This is a Neighbor node which has been heard, but which has not yet completed a precision range conversation with the attached P4xx. Once the Neighbor node has responded to a range request, then that PRE can be used to calibrate subsequent CREs from the Neighbor node.

Saturated: Indicates that the received signal is so strong that the receiver is starting to saturate. Saturation occurs when the units are closer than approximately 15 ft. (5 meters). Saturation rarely has any impact on range measurement accuracy. A node in saturation will not generate CREs.

LOS: Indicates the ranging link is Line of Sight.

NLOS: Indicates that the ranging link is Non-Line of Sight. A Non-Line of Sight link will not generate CREs.

Attempt Rate: This is the rate in Hertz of the number of successful ranges over a given period of time. The user can reset the period of time by clicking the Reset Stats button.

Success %: This is the number of successful range attempts divided by the total number of attempts over a given period of time. The user can reset the period of time by clicking the Reset Stats button.

Stats Age: This is the number of milliseconds over which the previous rates were calculated.

Added to…: This is the number of milliseconds since the given node was added to the Neighbor Database.

Last Range: This is the amount of time in milliseconds which has elapsed since a successful PRM was measured to the target node.

Least Heard: This is the amount of time in milliseconds which has elapsed since the target node was last heard from either with a Precision Range Measurement or a CRE.

The Neighbor Database has a large number of data fields. Care was taken to arrange the order in a logical sequence. However, there will be times when the user will want to focus on just a few specific fields or perhaps view them in a different order. The user can move a column to a different place by moving the cursor over the header of the field to be moved, holding the left button down and then dragging the column to the desired location. This rearrangement is temporary. Exiting RangeNet will reset the column arrangement to the original state.

22. Health Tab

The Health Tab (see **Figure 20**) provides insight into the operating state of the P4xx and the network to which it is connected. The fields are initially all blank. This is because the fields are only entered on demand. To collect the status, the user must click the Get button. Clicking Reset will reset the statistics.

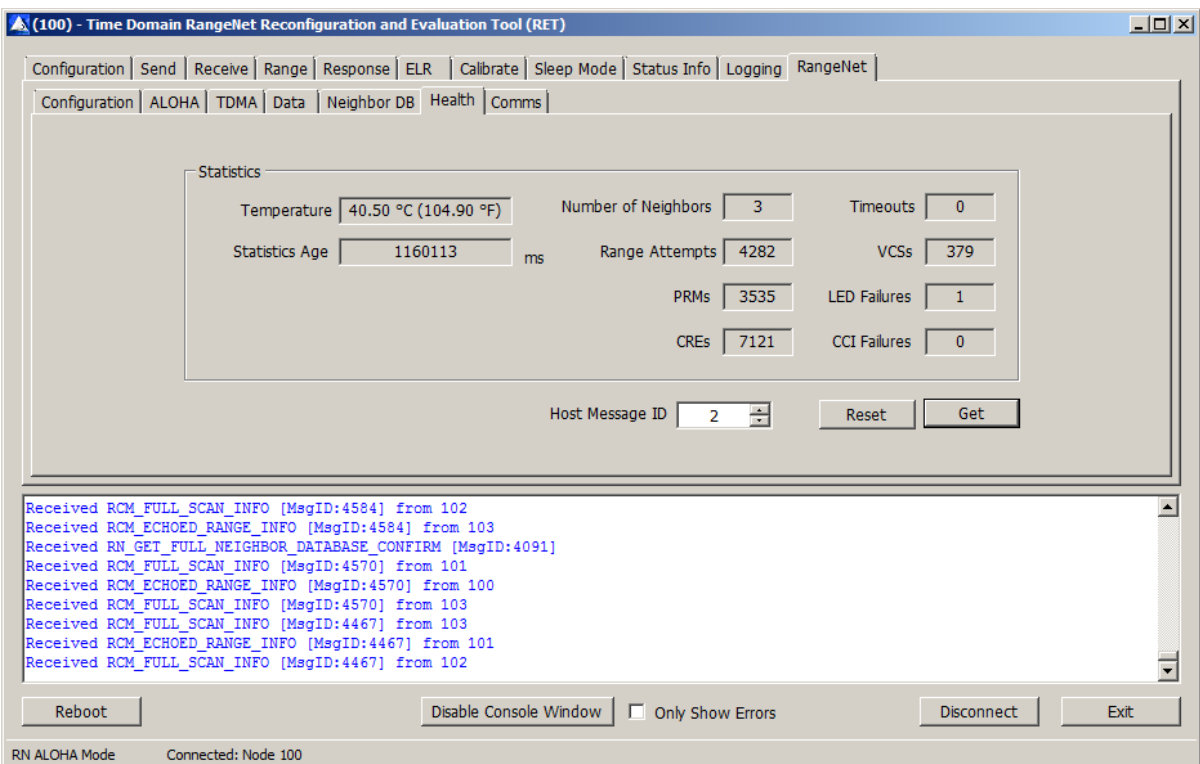


Fig. 20: Health Tab provides information that indicates the health of the P4xx and the network

The following is a description of each of the fields.

Temperature: Temperature of the P4xx as measured by the onboard temperature sensor.

Statistics Age: Amount of time in milliseconds since the Reset button was last clicked.

Number of Neighbors: Number of Neighbors in the database at the moment when the Get button was clicked.

Range Attempts: This is the number of times since the Reset button was last clicked that a precision range was attempted.

PRMs: This is the number of times since the Reset button was last clicked that a precision range was successfully completed.

CREs: This is the total number of CREs received since the Reset button was last clicked.

Timeouts: This is the number of times since the Reset button was last clicked that a precision range measurement failed to successfully complete because the measurement timed out. A large number of Timeouts suggests that one or more nodes are at maximum range.

VCSs (Virtual Carrier Sense): This is the number of times since the Reset button was last clicked that a precision range measurement failed to successfully complete because a Virtual Carrier Sense error occurred. This indicates that there was a communications packet collision. A high number of VCS failures indicate that the number of nodes on the network is starting to exceed capacity. ("High" is a relative term that needs to be assessed on an application basis.)

LED (Leading Edge Detection) Failures: This is the number of times since the Reset button was last clicked that a precision range measurement failed to successfully complete because of an LED failure. While LED will occasionally fail, an unusually high number of such failures indicate that the network is operating in a high multipath environment. ("High," in regard to the number of failures, is a relative term that needs to be assessed on an application basis.)

CCI (Co-Channel Interference) Failures: This is the number of times since the Reset button was last clicked that a precision range measurement failed to successfully complete because of Co-Channel Interference. This interference could have been sensed either at the responder or at the requester. This conversation may produce an actual range measurement, but that measurement will flagged as unreliable and discarded. It will not count as a successful completion. A high number of CCI Failures indicates that there are other RF users in the vicinity and they are interfering with the network. These users might be other UWB devices, extremely powerful transmitters just out of band, or other users in the 3-5 GHz band.

Note: Range Attempts = PRMs + Timeouts + VCSs + LED Failures + CCI Failures

Get Button: Clicking this button will retrieve the statistics from the attached P4xx.

Reset Button: Clicking this button will reset all of the statistics on this page.

23. Comms Tab

The Comms Tab (see **Figure 21**) allows the user to establish a default communications port. This ability bridges an important gap. When operating in RCM mode, the P4xx will never generate a message unless the unit is specifically polled by the Host computer. When operating in RangeNet mode, the P4xx is responsible for initiating conversations and will therefore generate Range Info and Scan Info packets automatically. If the P4xx is operating in RangeNet mode and power fails, it will reboot and resume operation in RangeNet mode. However, the power-down will break the communications link with the Host computer. Therefore, this Tab is used to set the default communications port for the period between boot up and restoration of the P4xx-Host communications link. Once the link is restored, the P4xx will send all Range Info and Scan Info packets to the Host via the restored link.

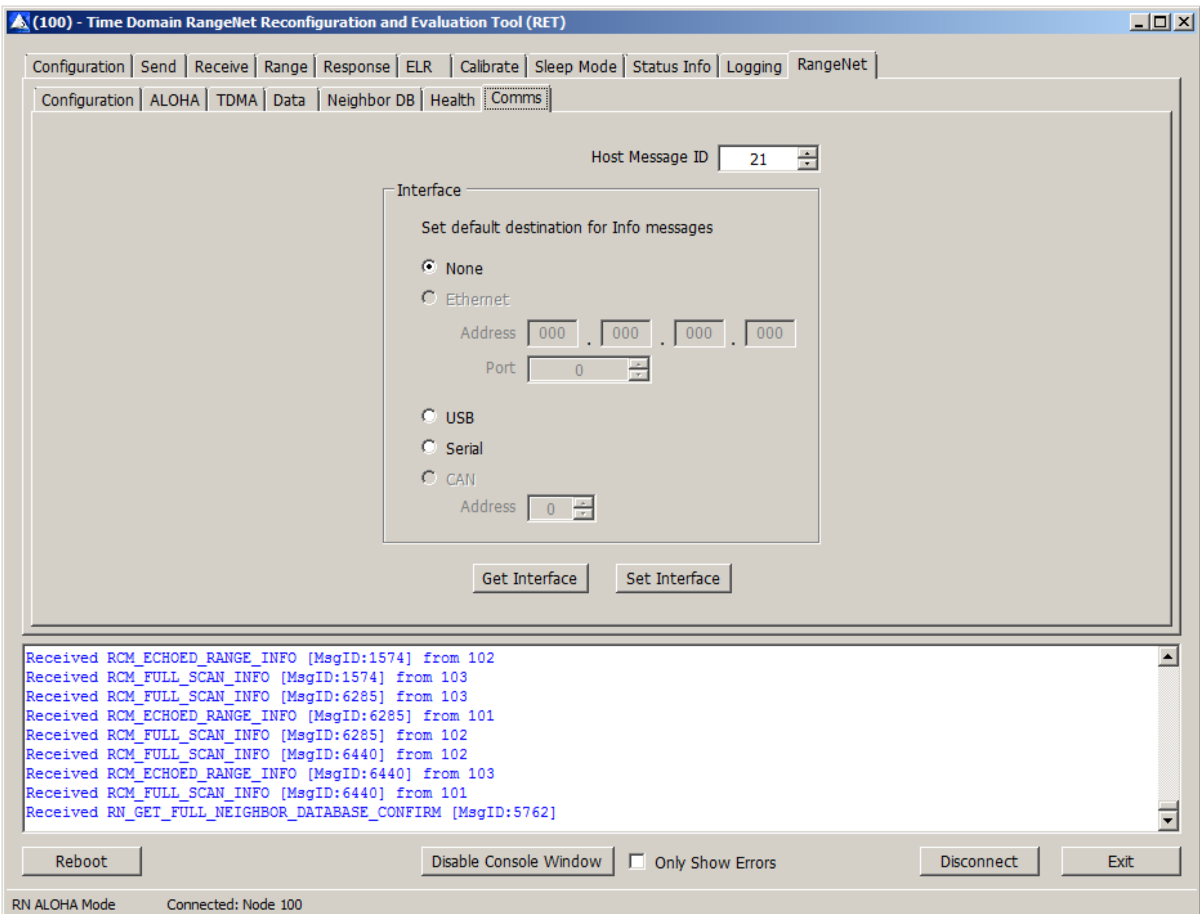


Fig. 21: Comms Tab is used to set the default P4xx Host communications path

This tab will allow the user to select a communications path from among the valid choices. Invalid choices are gray and cannot be selected. The following is a breakdown of valid choices:

P400: Ethernet, USB, Serial
P410: USB, Serial
P412: USB, Serial, CAN

The Get Interface retrieves the current default setting from the P4xx. Clicking the Set Interface buttons will download the new settings to the P4xx. These values are stored directly to Flash memory.

Note that “none” is also a selection. If “none” is selected, then no messages will be issued until the Host initiates a connection.

Appendix A: RET Logfile Format

The RET logfile contains a running account of all interactions between the RET Host application and the connected P4xx. This includes both the RangeNet and RCM API messages. Figure A-1 is an example of part of one such logfile.

Before the FIRST instance of each message type, a header description is provided (illustrated in **red** below). The initial timestamp (always the first parameter in each data line) is a floating point time value, in seconds, provided by the Host PC.

All other parameters are generated and received from the local P4xx. The specifics of the parameters are described in either the *RCM API Specification* or in the *RangeNet API Specification*. (For convenience the RangeNET API Specification contains both the RCM and RangeNet API commands.)

```
Timestamp, Config, PulseIntegrationIndex, AntennaMode, AntennaToggleFlag, CodeChannel, AntennaDelayA,
AntennaDelayB, ScanInfo, DisableCRERanges, TransmitGain
1338055415.281, Config, 7, 0, False, 1, 0, 0, 1, False, 0
Timestamp, RcmSendRangeRequest, MessageId, ResponderId, AntennaMode, DataSize, Data
1338055424.047, RcmSendRangeRequest, 14621, 102, 0, 0,
Timestamp, RcmSendRangeConfirm, MessageId, Status
1338055424.141, RcmSendRangeConfirm, 14621, 0
Timestamp, RcmScanInfo, MessageId, SourceId, AntennaId, LEDFlags, ChannelRiseTime, Vpeak, Timestamp,
LeadingEdgeOffset, LockspotOffset, NumScanSamples, ScanData
1338055424.156, RcmScanInfo, 14621, 102, 0, 0, 1, 42824, 144123, 176, 193, 350, -42, -8, -115, -101, -65, -75,
-26, -108, 126, -3, 50, 23, 65, -32, 5, 65, 12, 2, -14, -37, -125, -61, -43, 3, 53, 6, 67, 75, 38, 65, -27, 96, 3, 42, 22,
59, 18, 43, 9, -10, -5, -24, 54, 116, 59, 36, 51, 73, 68, 7, -49, 90, -51, 26, 73, 0, 48, 21, 38, 128, -40, 86, -78, -31,
1, -68, -26, -41, -18, 11, -31, 15, -36, -47, -28, 93, -54, 63, -3, -66, 21, 44, 92, 32, 14, -39, -74, 82, -21, 128, -5,
-31, -176, 55, -49, 50, 72, -81, -26, 80, -3, 10, -22, 30, 58, 160, 94, 34, -85, -46, 56, 50, -34, -53, -96, 48, 58, 95,
33, -2, -9, 75, 38, -18, 89, 9, 61, 12, 46, 96, 119, 21, -62, 10, -13, 20, -4, -14, -79, 43, 108, 161, 134, -3, 51, 27,
-65, 102, 71, -49, 112, 12, 52, -26, -69, -33, 64, 53, -111, 55, -3, -30, 1, 28, -33, 106, 106, -268, -108, -71, 6, -89,
24, -99, 66, 6, -30, -82, 45, 314, -300, -1078, 1910, 2013, -4799, -3865, 10308, 3935, -16290, -2579, 20683, 524,
-21412, -1214, 19254, 5346, -15182, -8904, 12314, 10191, -7710, -12354, 4190, 11202, 17, -8762, -3595, 7093,
7463, -4982, -9908, 2639, 9805, -1543, -8106, 2350, 5786, -1374, -4395, 1365, 4229, -696, -4888, 352, 6103,
252, -5784, -1076, 4300, 166, -1617, 1457, -818, -2920, 2272, 3647, -2421, -3387, 2425, 2619, -1664, -2508,
1490, 3187, -1872, -4128, 3289, 4684, -3227, -5267, 2637, 5433, -1262, -5407, -611, 5662, 1357, -5862, 150,
4314, -1751, -2739, 3630, 857, -4900, 928, 5572, -996, -5797, 981, 6236, -517, -6300, 235, 5755, -1452, -5192,
1647, 4903, -2228, -4458, 2324, 4834, -1794, -5562, 791, 6306, 1025, -6152, -2753, 4955, 3110, -2853, -3151,
451, 2086, 1017, -1371, -1279, 503, 100, -148, 1238, 94, -2603, -101, 2907, -124, -2741, -32, 2390, 460, -1895,
-1281, 1688, 3192, -1591, -4632, 691, 5152, 420, -4504, -1123, 3305, 2382, -1993, -3041, 1175, 3488, -1393,
-3599, 1370, 3864, -684, -3870, -273, 3905, 1527, -3260, -1575, 2428, 1775, -1198, -1489, 695, 1503, -261,
-1548, 215, 1757
Timestamp, RcmRangeInfo, MessageId, ResponderId, RangeStatus, ReqAntennaMode, RespAntennaMode,
StopwatchTime, PrecisionRangeMm, CoarseRangeMm, FilteredRangeMm, PrecisionRangeErrEstMm,
CoarseRangeErrEstMm, FilteredRangeErrEstMm, FilteredRangeVelocityMmPerSec,
FilteredRangeVelocityMmPerSecErrEst, RangeMeasurementType, ReqLEDFlags, RespLEDFlags,
ChannelRiseTime, Vpeak, CoarseTOFInBins, Timestamp
1338055424.172, RcmRangeInfo, 14621, 102, 0, 0, 0, 20, 3763, 3763, 3763, 55, 55, 3, -1, 322, PCF, 8, 8, 1,
42824, 14254, 144123
```

Fig. A-1: RangeNet RET logfile format

Appendix B: Relationship between Transmit Gain and Transmit Power

The following three P410 configurations are supported: P400, P410 and P410 with optional transmit power amplifiers. (The settings for a P410 and P412 are identical.) The relationship between transmit gain and transmit power delivered to the antenna port for the three configurations is shown below in **Table B-1** and graphically in **Figures B-1 through B-3**. These values are typical and the user can expect minor unit to unit variations.

Transmit Gain	P400	P410	P410 w Amps
63	2.1	-12.64	0.71
59	2.05	-12.88	0.65
55	1.96	-13.2	0.55
51	1.83	-13.62	0.4
47	1.66	-14.12	0.2
43	1.42	-14.78	-0.05
39	1.09	-15.57	-0.36
35	0.65	-16.47	-0.73
31	0.1	-17.43	-1.15
27	-0.75	-18.61	-1.78
23	-2	-20	-2.65
19	-3.57	-21.6	-3.85
15	-5.3	-23.32	-5.4
11	-7.48	-25.35	-7.52
7	-9.94	-27.58	-9.97
3	-12.47	-29.89	-12.47
0	-14.53	-31.6	-14.48

Table B-1: Transmit Gain Setting vs. power delivered to antenna port (dBm) per platform type

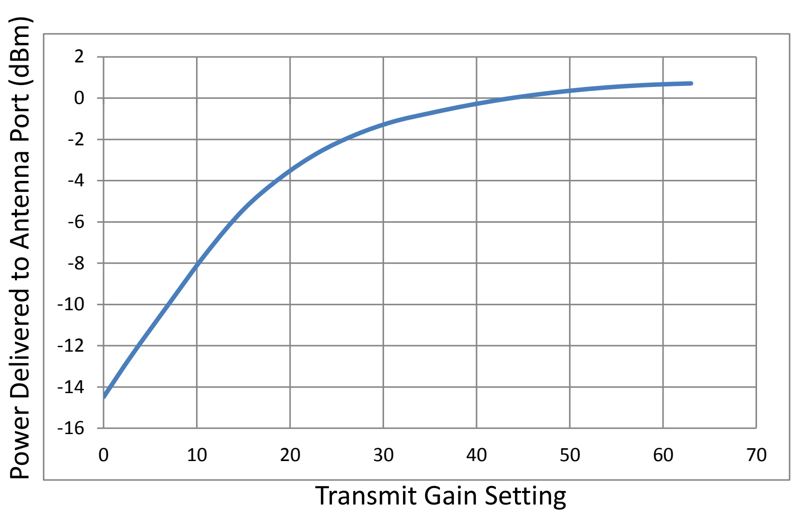


Fig. B-1: P400 - Transmit Gain Setting vs. Transmit Power

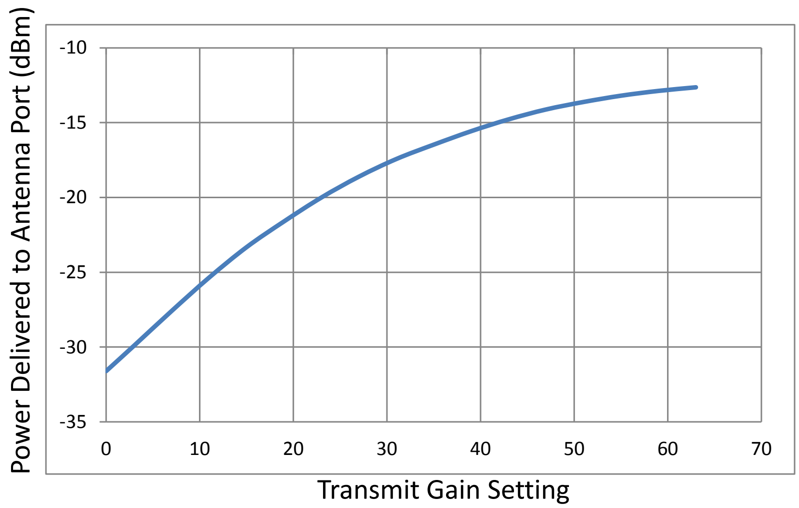


Fig. B-2: P410, P412 - Transmit Gain Setting vs. Transmit Power

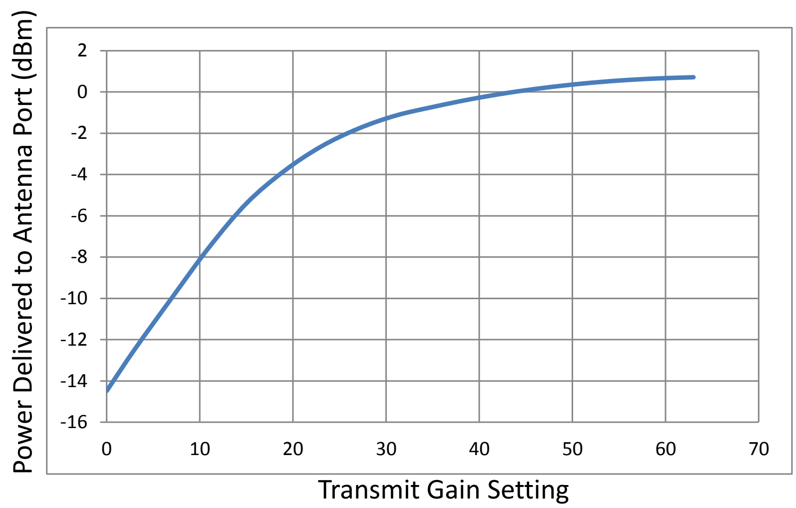


Fig. B-3: P410 with power amp - Transmit Gain Setting vs. Transmit Power

Appendix C: Operation at Elevated Temperatures

The P400 and P410 both use commercial parts rated for operation between 0^{o}C and 70^{o}C. However, this does not translate into an *ambient* operating temperature of 0^{o}C and 70^{o}C. Because the units generate heat in the course of operation, operating them at an ambient temperature of 70^{o}C would result in a board temperature that is significantly higher. Furthermore, the board temperature is also a function of heat load generated by other devices as well as sun loading. Heat buildup can also be reduced through the use of heat sinks and Peltier coolers. As a temperature control aide, the P400s and P410s are provided with an on board temperature sensor. Readings from the sensor are available through the API. The user should use this to evaluate the need for temperature control. In any event, the temperature sensor measures the board temperature and the user should insure that the temperature reading never exceeds 70^{o}C. Operation of the units at temperatures above 70^{o}C will exceed the temperature ratings of many of the parts and should be avoided. Having said that, it should be noted that Time Domain has successfully operating the units at temperatures as high as 100^{o}C. Also, there does not appear to be any reduction in system performance due to temperature cycling (even if that temperature is as high as 100^{o}C). In other words, the system might stop working at elevated temperatures, but once the temperature falls below the upper limit, the user should expect that operation would return to normal. Regardless, extended operation at temperatures in excess of the design limits is a very bad practice as some components may physically deteriorate over time in a manner that is neither obvious nor well documented by the component vendor.

At temperatures above 50^{o}C the user will also see a slight degradation (approximately 3-4 dB) in the performance of the receive channel. This is largely due to heating of the Low Noise Amplifiers. As the temperature of an amplifier increases, its noise figure will also increase thereby reducing the SNR of the receiver.

Appendix D: Issues with USB and Microsoft Windows

Microsoft Windows doesn't handle USB interfaces particularly robustly. The allocation of COM port assignments is not predictable (at least not by mere mortals) and is not robust. It can be particularly frustrating if the user is attempting to monitor a network of several P4xx which are all connected back to multiple USB ports on a single PC. In such a configuration, the PC will intermittently and randomly disconnect individual P4xx units from the PC. Reconnecting the P4xx to the PC may require rebooting of the P4xx or even the host PC. This problem can be addressed by connecting the units under test to a USB hub and then connecting the hub to the PC.

This is just an example of a Windows/USB issue. There are likely other such traps.

Note that this issue has not been seen on Host machines that operate under Linux.

Appendix E: Noise, Signal, and SNR

The SNR reported by RangeNet RET is based on an estimate of the signal and noise made by the P4xx and reported through the API. SNR is 20*Log10(Vpeak/Noise) where Vpeak is a measure of the largest signal near the leading edge of the scan and noise is an estimate of the noise prior to the leading edge. Note that the Noise and Vpeak values reported by the P4xx are scaled. These numbers are scaled identically. To get the unscaled values, multiply the value returned by the Scan Info message and multiply by (2^pii)/256. While both of these estimates are close, neither estimate is exact. Consequently the measure of SNR is close, but not exact.

First, SNR is actually computed from the scan measured during waveform generation after the receiver has acquired lock. Given that, SNR is not the SNR the radio sees when it acquires, but rather the SNR it sees during waveform scan. However, these SNRs are believed to be close to each other. Note also that Time Domain's Channel Analysis Tool (CAT) computes SNR a bit differently. It reports the SNR of the data not the scan. As a result it will be exactly 3 dB lower.

Noise and Signal are also imperfect estimates in the following senses. For example, the "proper" way of calculating noise might be based on computing the standard deviation of the N readings which occur prior to the leading edge. For processor computation reasons a much simpler estimation process was used. This noise estimate has proven to be adequate and we believe it is within 1-2dB of being accurate. In addition, Vpeak is the magnitude of the absolute value of the largest lobe. However, if the radio is not locked on the largest lobe then the receiver will be experiencing a smaller magnitude signal. In those cases, the SNR reported can be a few dB higher than the SNR which the receiver is actually experiencing.

As a practical matter this SNR estimation process has proved to be a useful and repeatable, if slightly inaccurate, tool for describing radio performance. Users wishing more exact estimates of SNR can log scan waveforms and develop custom algorithms that yield more accurate results.

As suggested earlier, a more rigorous value of noise can be calculated directly from scan readings provided in Scan Info. An example is offered below. It is more computationally intensive but still produces results within a dB of those produced by the P4xx. In this example Vpeak is taken straight from the value reported in the Full Scan packet.

1) Compute the standard deviation of the first N entries in a Full Scan packet. This standard deviation will be used to compute a more rigorous value for noise than is reported in Full Scan info packet. N must be selected such that you have sufficient values to have a stable estimate of standard deviation but not so large as to risk including energy associated with the first arriving energy. When operating in high multipath environments the leading energy can occur within the first 500 or so entries. In general, a value of 100 has proven to yield good results.
2) Noise = 2*(Standard Deviation of the first N readings in the full scan packet)^2
3) SNR = 10*log10(Vpeak^2/Noise)