Monostatic Radar Module Reconfiguration and Evaluation Tool (MRM RET) User Guide

TDSR UWB Radios

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1. Introduction

The Monostatic Radar Module Reconfiguration and Evaluation Tool (MRM RET) is a Microsoft Windows-based Graphical User Interface (GUI) program that provides an easy and illustrative means for (a) manipulating the configuration parameters of either TDSR's P400 series of UWB modules and (b) demonstrating their operation as Ultra Wideband (UWB) monostatic radar sensors. For convenience, this document will refer to P400s, P410s, P440s, and P452s interchangeably as Monostatic Radar Modules or MRMs. Any platform-related differences are specifically identified.

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

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

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

The tabs and data structures of MRM RET closely match those defined in the *MRM API Specification*. The primary function of MRM RET 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. MRM RET also provides a real-time display of the raw radar returns, filtered data, detections, and logging functions. This allows a user to develop a feel for how the radar works.

The configuration settings and data returned are explained in full detail in the *MRM API Specification*. We recommend having a copy of this document close at hand and referring to it for more information on the configuration parameters and return data.

More than one copy of MRM RET can be run on the same PC. Each copy can be connected to different MRMs through an Ethernet hub or through multiple USB and serial connections. At the user's option, each MRM RET can use an MRM Server process to provide additional radar signal processing.

2. Before You Begin

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

When using the USB interface, simply connect the USB cable to both the MRM 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 *MRM Quick Start Guide* for detailed instructions. Next, connect to the MRM with a crossover Ethernet cable or use an Ethernet hub. If the LEDs are ON and initial connection does not work, try sending a PING command to the MRM IP address from a terminal window. (The IP address is initially set at the factory to 192.168.1.100.) This will confirm that the MRM can communicate with the PC.

3. Connecting

When launching MRM RET, a Connect pop-up window will be displayed querying the user for the local MRM's IP address or USB connection. The actual display shown will depend on whether the connection is made to the MRM using an Ethernet or USB connection. Example screens for both are shown in **Figure 1**.

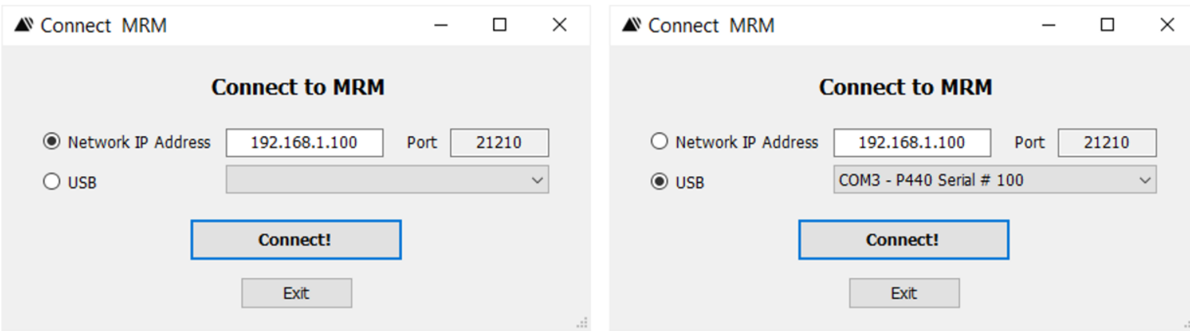


Fig. 1: Ethernet connection screen (left) and USB connection screen (right)

Connecting with Ethernet: To verify Ethernet connection to an MRM, enter the MRM IP Address and click the **Connect!** button. (New units will have their IP address configured as 192.168.1.100 at the factory.) MRM RET will attempt to verify connectivity to the MRM by sending a MRM_GET_CONFIG_REQUEST (see *MRM API Specification*) to that address. This message will be sent up to three times. If MRM RET is successful in connecting with an MRM, then MRM RET will transition to the Configuration Tab window (described in **Section 5**). The Configuration window will show "Connected" in the bottom left-hand corner and also display the Node ID of the MRM. MRM RET controls are now enabled allowing the user to send commands to the MRM.

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

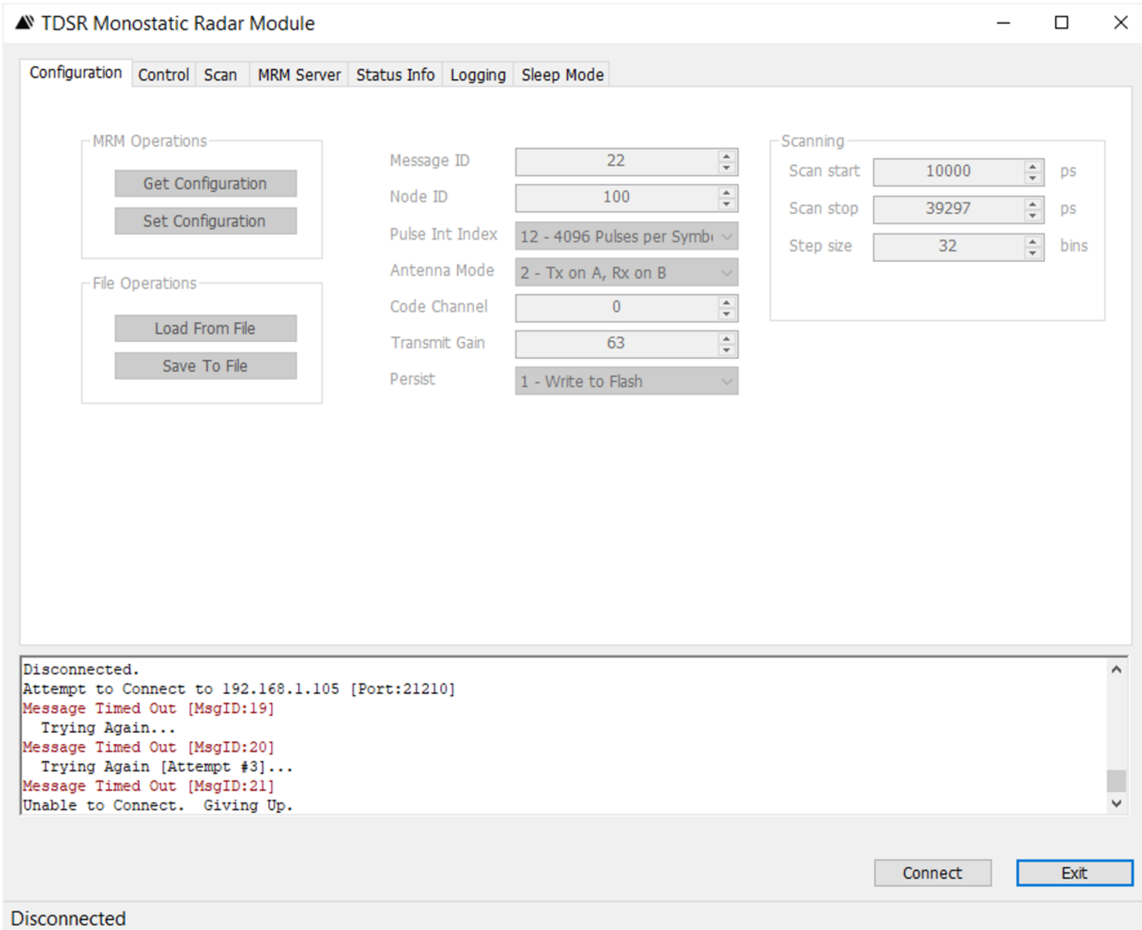


Fig. 2: This window will appear if the MRM fails to connect

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

If there are connection issues, then open the Device Manager (Windows Start Button/Control Panel/Device Manager) and confirm that the computer actually registers connection to your USB Host Port. The screen shot shown on the left side of **Figure 3** confirms that the COM8 is actually connected to the computer. The screen shot on the right indicates that no connection exists between the Host and MRM. Once these parameters are verified, the user can attempt to connect by selecting the "Connect" button.

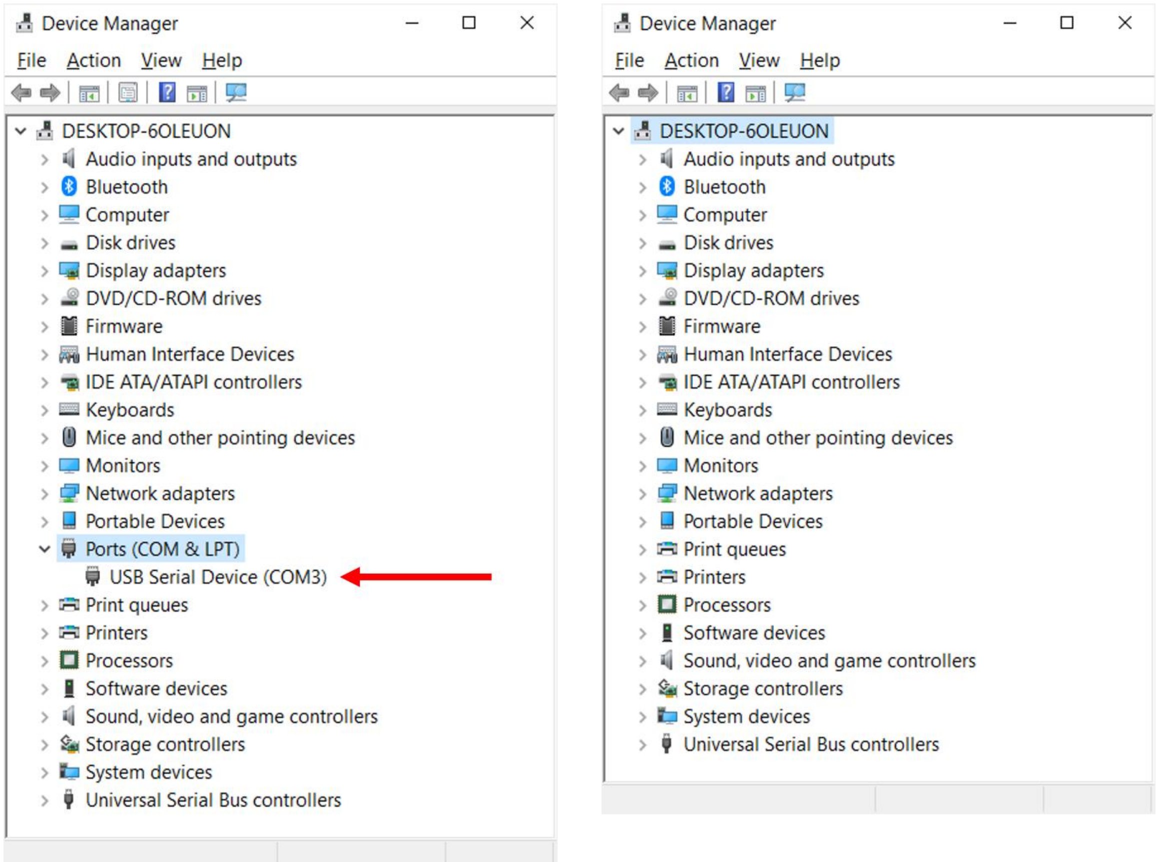


Fig. 3: Successful connection (left), unsuccessful connection (right)

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

4. Overview: Tabs & Action Area

Each MRM RET window is divided into two main areas: Tab Control and Action Area. See **Figure 4**.

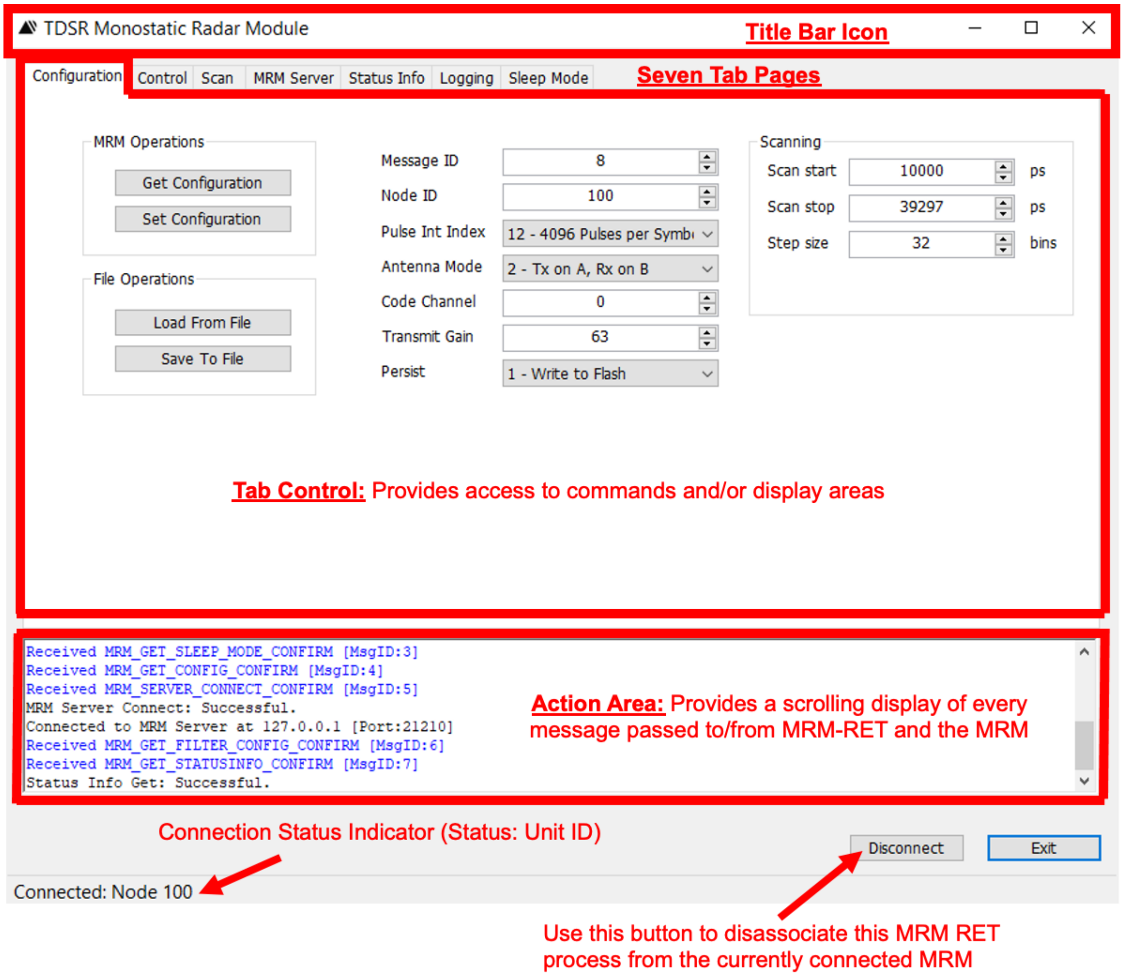


Fig. 4: Configuration screen with indication of the main areas

Tab Control is the upper area and provides access to seven selectable tab pages. The function of each tab is summarized below. A complete description is provided in the following sections.

- **Configuration:** Defines various parameters including integration rate, antenna configuration, and radar scan windows
- **Control:** Starts and stops radar scanning
- **Scan:** Displays a live plot of the radar scans including filtered response and detections
- **MRM Server:** Allows the user to connect to a Windows Service that converts raw radar scans from the MRM into filtered radar scans
- **Status Info:** Displays software & hardware version numbers as well as MRM board temperature
- **Logging:** Allows the user to record radar scan data to log files
- **Sleep Mode:** Allows the user to reduce the power consumption of the radar when it is not in active use.

The bottom part of the window contains the Action Area, which provides scrolling text indication of every message sent to and received from the MRM.

Other areas of interest in the MRM RET window include:

- Right-clicking on the Title Bar Icon will produce the "About RET" dialog box. This box will show the MRM RET version number.
- A Connection Status Indicator located at the bottom left-hand side of the status pane indicates connection status and the ID of the connected MRM. This field is useful when using multiple copies of MRM RET on a single PC to connect to multiple MRMs through an Ethernet hub.
- The **Disconnect** button located at the bottom right-hand side of the window allows the user to switch MRM RET connection to a different MRM.
- The **Exit** button, also located at the bottom right-hand side of the window, will close the application and stop MRM scanning. The MRM will also halt scans if the user exits MRM RET by using the red X in the upper right-hand corner of the GUI or by killing the task with Windows Task Manager. However, the MRM will continue scanning if the Ethernet or USB cables are disconnected.
- The Message ID field appears on most, if not all, of the screens. MRM RET will define a message number for any command that is sent and its associated response message. This number serves as a tracking number and is of great value to a system engineer during the development and debug of a network of multiple MRMs. Note that this field can be manually incremented, decremented, or set to an arbitrary value. Subsequent message numbers will be incremented. Similarly, when the MRM sends radar data to MRM RET each transmission will have a unique scan message number. This number is incremented each time a new radar data message is sent. The command/response message numbers are incremented separately from the radar data scan message numbers.

5. Configuration Tab

Successful connection to an MRM brings up the Configuration Tab showing the MRM's current configuration parameters (see **Figure 5**). This tab provides the user with an easy method for reading and writing the seven essential MRM configuration parameters: Node ID, Pulse Integration Index, Antenna Mode, Code Channel, Transmit Gain, Radar Scan Start point, and Radar Scan Stop point. This tab implements the MRM API messages MRM_GET_CONFIG_CONFIRM and MRM_SET_CONFIG_REQUEST.

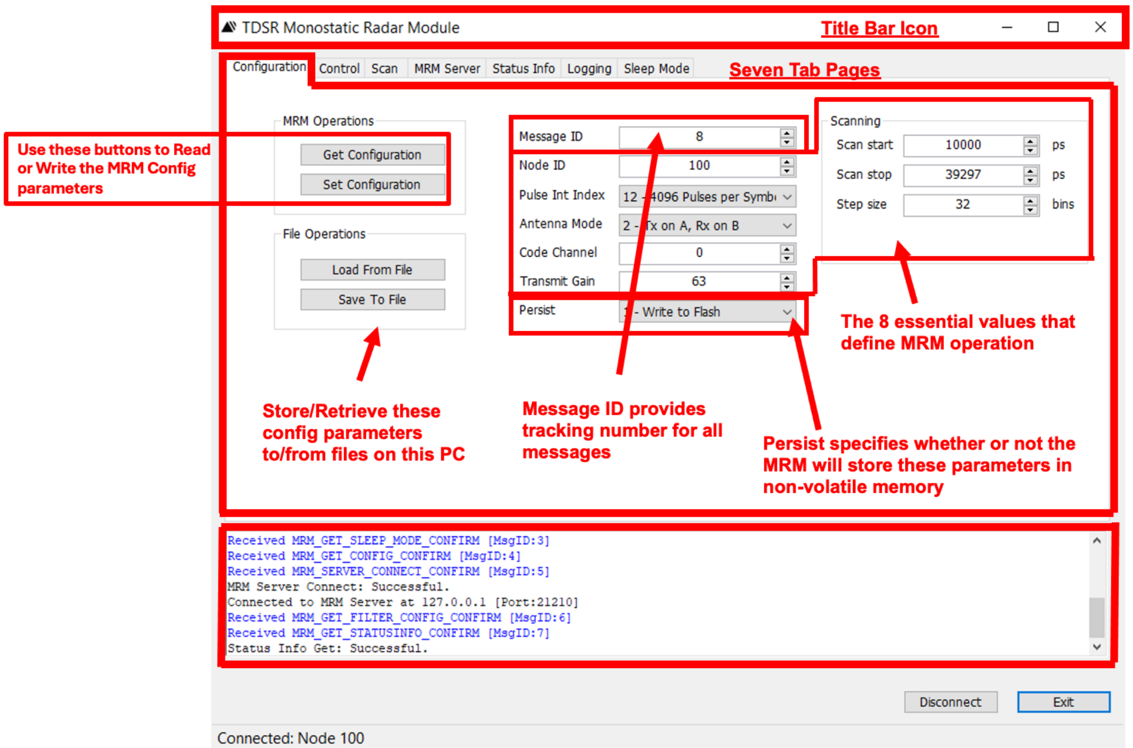


Fig. 5: Configuration Tab

Figure 5 shows the default factory settings. The factory default settings can be loaded by clicking on "Load From File" and then browsing to the file "MRM Factory Defaults.ret." (This file is located in the default MRM RET directory selected at installation.)

The user can alter the default configuration by adjusting the parameters and then clicking the **Set Configuration** button on the left. To make these changes last through the next time the MRM is powered down, the user must also set the Persist flag to "1-Write to Flash" (this is the default position). If the Persist Flag is set to a 1, then any time the **Set Configuration** button is clicked, the current values will be set to last through power-down. If the user does not want the changes to last through a power-down, then the user must be sure to set "Write to Flash" to a zero.

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

To save the current settings for future use, click on the **Save to File** button. MRM RET will prompt the user with a standard Windows File-Open dialog window. To load the settings from an existing file, click on the **Load From File** button.

The eight essential values are defined in the API. Node ID and Antenna Mode are reasonably obvious but the other fields warrant a bit of discussion.

Pulse Integration Index: Since the MRM has been designed for coherent operation, it is possible to integrate multiple scans and thereby improve the received Signal-to-Noise Ratio (SNR). Each time the integration is doubled, the SNR of the received signal will improve by 3dB. Consequently, doubling the integration also doubles the amount of time it takes to produce a scan. The minimum integration the user can set is 64:1 or 2^6. TDSR refers to this as a Pulse Integration Index (PII) of 6. A PII setting of 6 will increase the received SNR by 18 dB. Similarly a PII of 15 (the maximum allowed by MRM) will integrate 32,768 scans and thereby provide an SNR improvement of 45 dB.

Set Configuration: Clicking **Set Configuration** will stop radar scanning, set the radar scan message ID number equal to the current message ID number, and download the newly requested configuration information.

Code Channel: When operating two or more MRMs in the same vicinity, the user must take care to insure that the units are operating on different code channels. Code channels are numbered from 0-255. The user should limit his selection to values between 0 and 10 inclusive. Code channel values greater than 10 are reserved for special applications. Use of code channel numbers greater than 10 should only be done at the recommendation of TDSR's technical support team. Using an invalid code channel number can cause unpredicable results.

Transmit Gain: When set to zero, the unit will transmit at the minimum power supported by the MRM. Setting to transmit gain to a value of 63 will set the unit to maximum transmit power. The default setting is 63. This value has been chosen because it is approximately the maximum transmit power for a standard P4xx equipped with the standard BroadSpec antenna which the FCC allows for commericial products. When operating a P4xx equipped with optional power amps, then this value should be set to 0 to approximate FCC-compatible power.

Scan Start: While this field is entered in increments of picoseconds (ps), the MRM converts the input values into "bins," where each bin is 1.907 ps. This conversion takes place when the **Set Configuration** command is executed. When the **Get Configuration** command is executed, the MRM will convert the bin value used into ps. Because this conversion involves rounding, the value shown in Scan Start may not match the value originally entered by the user. For example, setting a Scan Start value to 5000 will actually result in the Scan Start value being set to 4999.

Scan Stop: While this field is entered in increments of ps, it is constrained in two ways.

First, the MRM converts the input values from ps into "bins," where each bin is 1.907 ps. Because the process may involve rounding, the value loaded and stored with a **Set Configuration** command may be off by a ps when it is recovered with a **Get Configuration** command.

Second, the Scan Stop entry is further constrained by the Scan Start point and the MRM rake receiver architecture. The MRM produces a radar scan using several samplers acting in parallel as a rake receiver. Because of this architecture, the difference between Scan Start and Scan Stop must be in even multiples of 5859.36 ps. This quantizes the radar scan data into blocks of 96 readings covering 5859.36 ps. As a convenience, the MRM will automatically convert the Scan Stop value entered by the user into an integer number of quanta. This conversion follows two rules. (1) If the user requests a fraction of a single quanta, then Scan Stop will be set to a full quanta. (2) If the user requests several quanta plus a fractional quanta, then Scan Stop will be rounded to the nearest number of quanta (e.g., requests for scans having a duration of 2.3 quanta will be rounded to 2.0 quanta, while 6.53 quanta will be rounded to 7 quanta). To demonstrate this, enter an arbitrary value for Scan Start and Scan Stop, then execute **Set Configuration**. Next, execute a **Get Configuration** and compare the difference between the entered value and the reported value. If the user subsequently changes the Scan Start value, then the Scan Stop value will also be automatically adjusted such that the Scan Stop is approximately in the same location.

To minimize potential confusion, the user is advised to execute a **Get Configuration** command whenever the Scan Start or Scan Stop values are changed.

Step size: This parameter controls the resolution with which the radar waveaform is captured. The default value is 32 bins. This is equivalent to 1.907*32 ps. In other words with a step size of 32, the received radar waveform will be measured every 61ps. The user can produce this waveform with a minumum resolution of 1bin or 1.907ps. However, doing so will deactivate the rake reciever and scans will be taken 12 times slower. This factor of 12 does not include the increased time associated with the ratio of 32/selected step size. In other words if the user selectes a step size of 1 then the radar waveform will be produced with excellent resolution, but it will take 12*32/1 times longer to generate. Changing from 32 to any other value will also have an unpredictable effect on the motion filter and detection processing algorithms. The user is strongly encouraged to leave the step size set to 32.

Antenna Mode: The MRM RF (Radio Frequency) front-end hardware supports the following antenna configuration: Transmit on A, Receive on B. The MRM is currently limited to operation with two antennas.

6. Control Tab

The Control Tab (**Figure 6**) is used to initiate and stop radar scans. To perform this work, MRM RET uses the following API messages:

- MRM_CONTROL_REQUEST (0x1003)
- MRM_CONTROL_CONFIRM (0x1103)

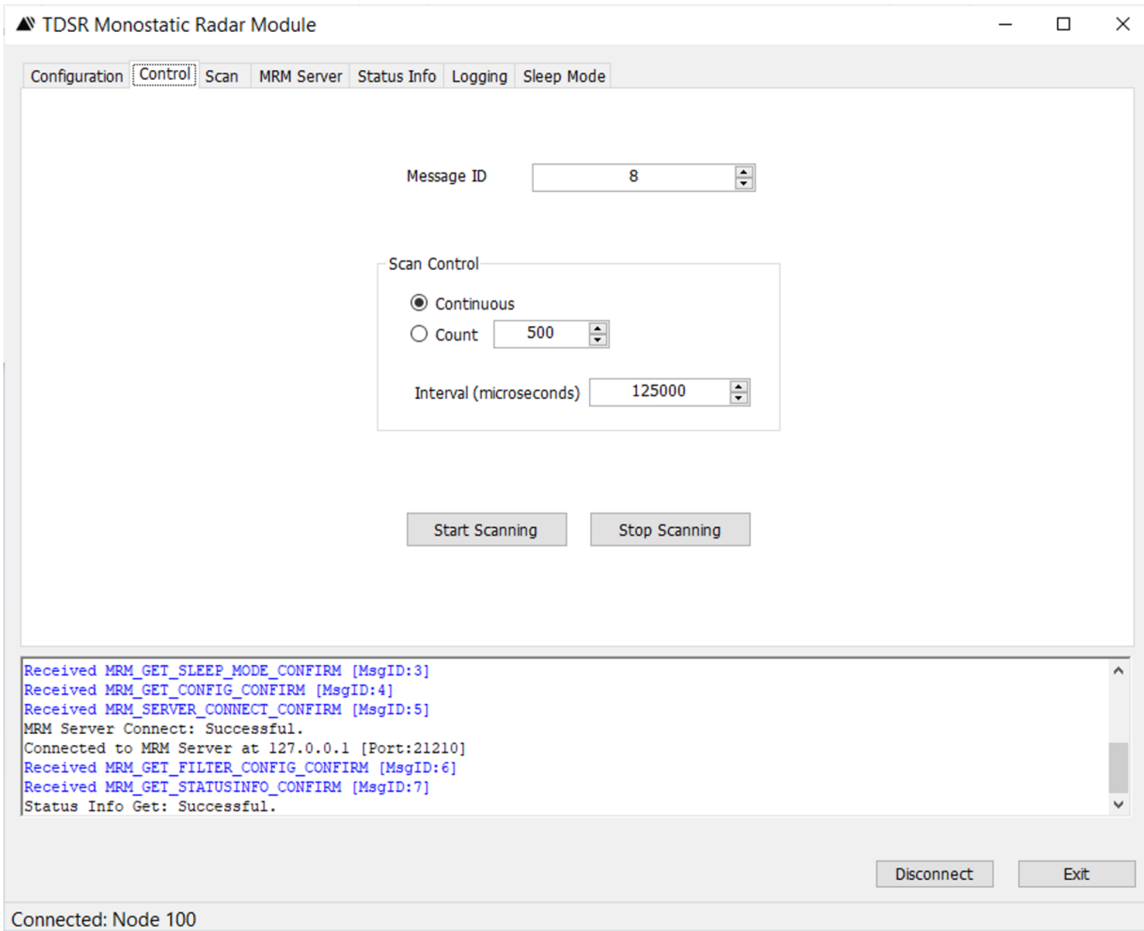


Fig. 6: Control Tab

Radar scans can be started and stopped by clicking on either the **Start Scanning** or **Stop Scanning** buttons. When **Start Scanning** is selected, the Scan Message ID number will be set equal to the present Message ID number and scanning will begin. Scanning will be executed based on the contents of the Scan Control box. Clicking on **Stop Scanning** will stop the scans and will reset the Scan Message ID number to the current value of the Message ID number.

By selecting the **Continuous** option, the user is requesting that scans be generated indefinitely at an interval defined by the contents of the "Interval (microseconds)" box.

By selecting the **Count** option, the user is requesting that MRM produce the number of scans indicated in the Count field at an interval defined by the contents of the "Interval (microseconds)" field. The maximum allowed interval is 2,000,000 microseconds.

Each scan requires a certain amount of time to complete. This time is a function of the integration rate and the size of the scan window (difference between the Scan Start and Scan Stop times). The time required is determined by the following equations.

Scan time (μs) = (# of quanta in scan window) * (0.792 μs) * (2^(Pulse Integration Index))

Where a quanta (i.e., the rake sampler size) = 5859 ps

For the user's convenience, this has been summarized in **Table 1**.

Pulse Integration Index (PII)	Quanta 1	2	3	4	5	6	7	8
	Swath (m) 0.88	1.75	2.63	3.51	4.38	5.26	6.14	7.02
6	51	101	152	203	253	304	355	406
7	101	203	304	406	507	608	710	811
8	203	406	608	811	1,014	1,217	1,419	1,622
9	406	811	1,217	1,622	2,028	2,433	2,839	3,244
10	811	1,622	2,433	3,244	4,055	4,867	5,678	6,489
11	1,622	3,244	4,867	6,489	8,111	9,733	11,355	12,977
12	3,244	6,489	9,733	12,977	16,222	19,466	22,710	25,955
13	6,489	12,977	19,466	25,955	32,444	38,932	45,421	51,910
14	12,977	25,955	38,932	51,910	64,887	77,865	90,842	103,819
15	25,955	51,910	77,865	103,819	129,774	155,729	181,684	207,639

Table 1: Minimum Scan Intervals as a function of PII and Quanta

For example, selecting a Scan Start value of 10,000 ps and a Scan Stop value of 21,000 ps results in a requested swath size of 11,000 ps. Dividing 11,000 by 5859 gives a value of 1.87 quanta. The MRM will round this up to 2 quanta. If the user requests a PII of 13, then the minimum scan time (or fastest update rate) will be 12,977 μs (77 Hz). If the operator enters an Interval higher than this, then the radar will idle between scans. If the operator enters an Interval smaller than this, then the radar will operate as fast as possible. The Interval is maintained by the custom UWB silicon and is stable and accurate such that scans are coherent.

The radar scan data will be reported from the MRM to the MRM RET Host PC as a serial data stream. However, the user should be aware that the Host PC must have the communications and processing bandwidth to receive all of the packets. Otherwise, packets will be dropped. Furthermore, the display shown on the Scan Tab has an update limit as well. If this limit is exceeded, then the display will update only occasionally.

For example consider **Table 1A**. The upper part presents the data shown in **Table 1** not in microseconds of duration but rather in terms of update rate in Hertz. As an experiment, the author tried to operate the radar and log data for each of the settings in **Table 1** using a low end laptop. All of the entries marked in green completed successfully with no dropped packets. The entries marked in red all experienced dropped packets.

Furthermore, the tranfer rates indicated in **Table 1** are for an ideal system. An actual system will also have communications overheads which further limit the transfer rate. This is demonstrated in the lower part of **Table 1A**. With PII set to 11 and a scan size of 5 quanta the predicted transfer rate was 123 Hz while the actual measured rate was 109 Hz.

PII	Quanta 1	2	3	4	5	6	7	8
6	19,727	9,863	6,576	4,932	3,945	3,288	2,818	2,466
7	9,863	4,932	3,288	2,466	1,973	1,644	1,409	1,233
8	4,932	2,466	1,644	1,233	986	822	705	616
9	2,466	1,233	822	616	493	411	352	308
10	1,233	616	411	308	247	205	176	154
11	616	308	205	154	123	103	88	77
12	308	154	103	77	62	51	44	39
13	154	77	51	39	31	26	22	19
14	77	39	26	19	15	13	11	10
15	39	19	13	10	8	6	6	5

Scans sent	10000	5000	10000	10000	10000	10000	10000	10000
Time (Sec)	76	38	58	142	92	110	126	143
predicted rate (hz)	154	154	205	77	123	103	88	77
actual rate (Hz)	132	132	172	70	109	97	79	70
predicted bit rate	473,088	946,176	1,889,280	946,176	1,889,280	1,898,496	1,892,352	1,892,352

Table 1A: Maximum Scan Rates (Green - no dropped packets, Red – dropped packets)

To maximize the scan rate the user should use the fastest Windows machine available. It is also possible to improve the transfer rate by eliminating the overhead associated with the MRM RET and drive the interface with C code directly. Sample C code can be found on the software delivery CD or USB flash drive.

Users interested in further maximizing the transfer rate should contact TDSR directly.

7. MRM Server Tab

The MRM Server is a separate and independent Windows Service that is installed by the .msi loader when MRM RET is installed. It will be available whenever the PC is booted. When MRM RET is connected to this service, the MRM Server will intercept raw data being sent by the MRM to MRM RET, filter the data, and produce a detection list. While the user can connect and disconnect MRM RET from this service, by default this service is normally connected. If the MRM Server task is not connected, then MRM RET will receive only the raw data scans. If the MRM Server is connected to MRM RET, then MRM RET will receive the raw data and all the selected filtered and detection data.

While the MRM Service normally runs on the same PC on which MRM RET is operating, it is possible to run the MRM Service from a different PC. To cause the service to operate on a different machine, the user should click the “Disconnect” button, enter the IP address of the target PC, and then click the “Connect” button. If the user enters an invalid IP address, then MRM RET will return an error message. This capability can be useful if the user’s host PC is underpowered or overloaded. For example, if the user attempts to run multiple copies of MRM RET on one PC, then each copy will put an additional load on the service. At some point the capacity of the PC to handle both the demands of MRM RET as well as the service will be exceeded. This capacity issue can be addressed by operating the service remotely.

This tab implements the following MRM API messages:

- MRM_SERVER_CONNECT_REQUEST (0x1004)
- MRM_SERVER_CONNECT_CONFIRM (0x1104)
- MRM_SERVER_DISCONNECT_REQUEST (0x1005)
- MRM_SERVER_DISCONNECT_CONFIRM (0x1105)

When the user clicks on the MRM Server Tab, then the screen shown in **Figure 7** will appear.

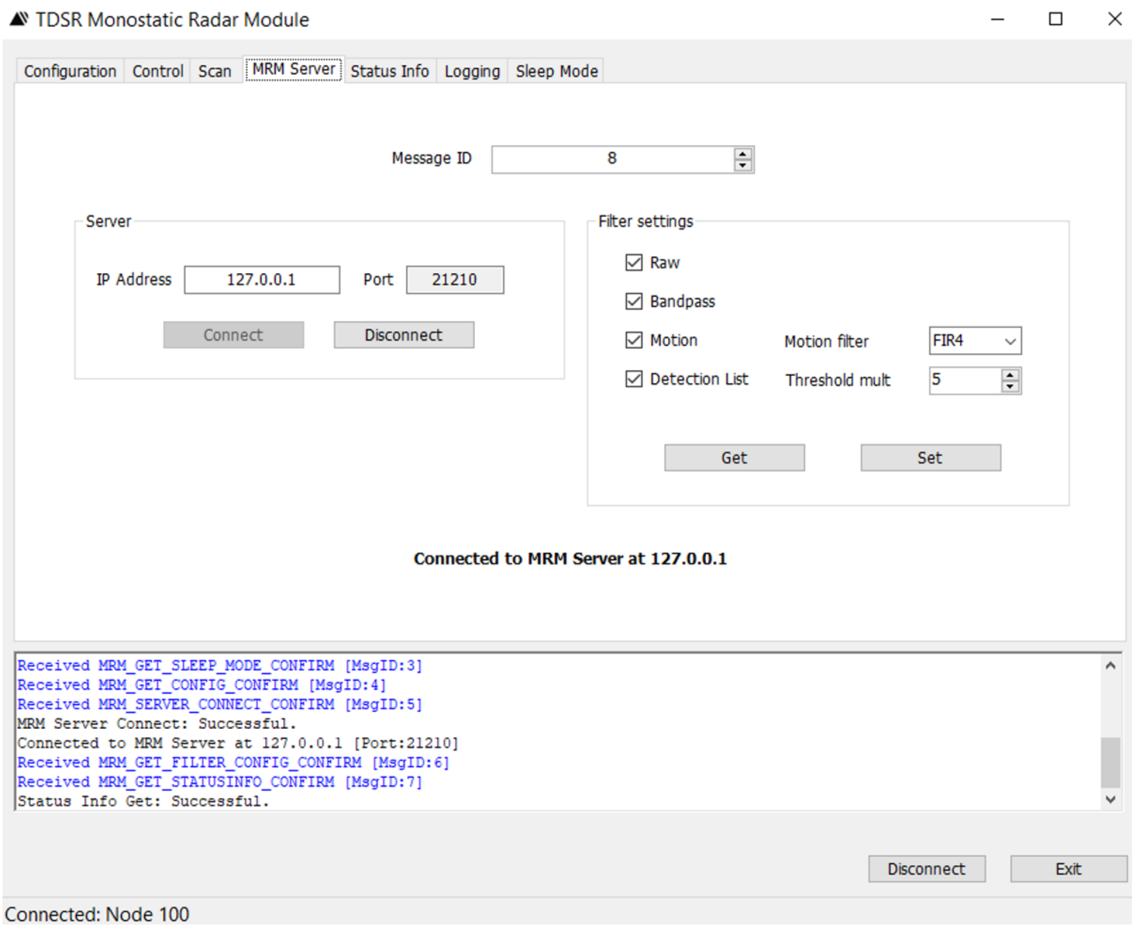


Fig. 7: MRM Server Tab

The MRM Server has two boxes of information: one for the Server and the other for the Filter Settings. These are described below.

Server Box:

IP Address: This is the IP address of the computer on which the MRM Server is being run.

Disconnect: Clicking on this button will disconnect the MRM RET from this service.

Connect: Clicking on this button will connect the MRM RET to the service operating on the machine indicated by the current IP Address.

Filter settings:

If MRM RET is not connected to the MRM Server, then only raw radar scan data will be displayable on the Scan Tab. If MRM RET is connected to the MRM Server, then the user will be able to select the type of filters to be employed. Only the selected filter data streams will be available for display in the Scan Tab or logging to a .csv file. **Appendix A** provides a detailed description of the filter operation.

Raw: Clicking this box will pass raw scans from the MRM Server to MRM RET, enabling the display of MRM raw radar scan data.

Bandpass: Clicking this box will pass bandpass filtered scans from MRM Server to MRM RET, enabling the display of MRM bandpass filtered scan data.

Motion: Clicking this box will pass motion filtered scans from the MRM Server to the MRM RET, enabling the display of MRM motion filtered scan data. The computation of the motion filtered data is independent of whether or not the Bandpass box is checked. The data will be filtered using the filter selected in the Motion Filter drop-down window. Four motion filter options are provided: FIR2, FIR3, FIR4, and IIR3. The FIR filters are Two, Three, and Four Tap difference filters. The IIR3 is a length 3 order 2 IIR filter.

Detection List: Clicking this box will pass detection data from the MRM Server to MRM RET, enabling the display of MRM detection lists. The detection list is produced based on the motion filtered data using the currently selected bandpass filter, motion filter, and Threshold Multiple. Note that the detection list is produced independent of whether the Bandpass and Motion boxes are checked.

Threshold Mult: The value selected will set the sensitivity of the detector. This sensitivity is based on the results of a “100 scan training period.” The detection processor begins by measuring the standard deviation of the first 100 scans. This standard deviation is computed on a per bin basis and constitutes the nominal value for each bin. The Threshold Multiple is the number of standard deviations that a received signal must deviate from nominal in order to generate a detection. Consequently, setting the Threshold Multiple to 1 will generate detections that are very sensitive to changes in the radar scan. Using a large number will make the system very insensitive to changes. The user may enter values between 1 and 255. Entries higher than 255 will be set to 255 and entries lower than 1 will be set to 1. Once the first 100 scans have been computed, the nominal values will be updated each scan using a 100-element box car filter. MRM RET will not display every individual detection on the Scan screen. Instead, it will plot a single red dot for every cluster of three adjacent detections reported by the MRM Server.

Note that if the Detection List box is checked, then the detection list will be produced regardless of whether or not the Bandpass and Motion filter boxes are checked. Also, detections will not be reported until 100 scans have been processed. If the sampling interval is 125000 µs then it will take 12.5 seconds before any detection can be produced. If no detections are detected, then none will be reported.

Get: Clicking on this button will display the filter settings currently being used by the MRM Server.

Set: Clicking on this button will set the MRM Server to the currently displayed filter settings.

It is worth taking a moment to discuss the use of filters and detection processing in general. The objective of filtering and detection is to allow the user to sense items or motions of interest. These targets of interest can have startlingly different characteristics. For example, one could be interested in detecting the heartbeat of an individual as opposed to the presence of a large military vehicle. One could be interested in measuring small objects moving at speeds of millimeters per second, or the application might be trying to detect large targets moving at hundreds of km/hour. One could be more interested in detecting items in an indoor environment, as opposed to under rubble or outside in the open.

For each of these cases one needs to optimize the filter and detection process for the application of interest.

The filters and detection algorithm provided with MRM RET are very basic and are intended to provide the user with

- A means to demonstrate radar functionality
- The ability to experiment with a few simple algorithms
- An example of how raw data scans can be captured and processed

While some users might find these algorithms sufficient, we would expect that many users will quickly discover that the needs of their particular application will require that the filter and detection strategy be optimized. If so, these users may choose to develop their own version of an MRM Server. To help address that need, TDSR has provided sample C and MATLAB code which interfaces directly to the MRM and bypasses the MRM server filter. This code is provided on the USB flash drive containing the software release.

8. Scan Tab

The Scan Tab (see **Figure 8**) is used to view scan parameters as well as raw and processed data. To perform this, MRM RET uses the following API messages:

- MRM_SCAN_INFO (0xF201)
- MRM_DETECTION_LIST_INFO (0x1201)

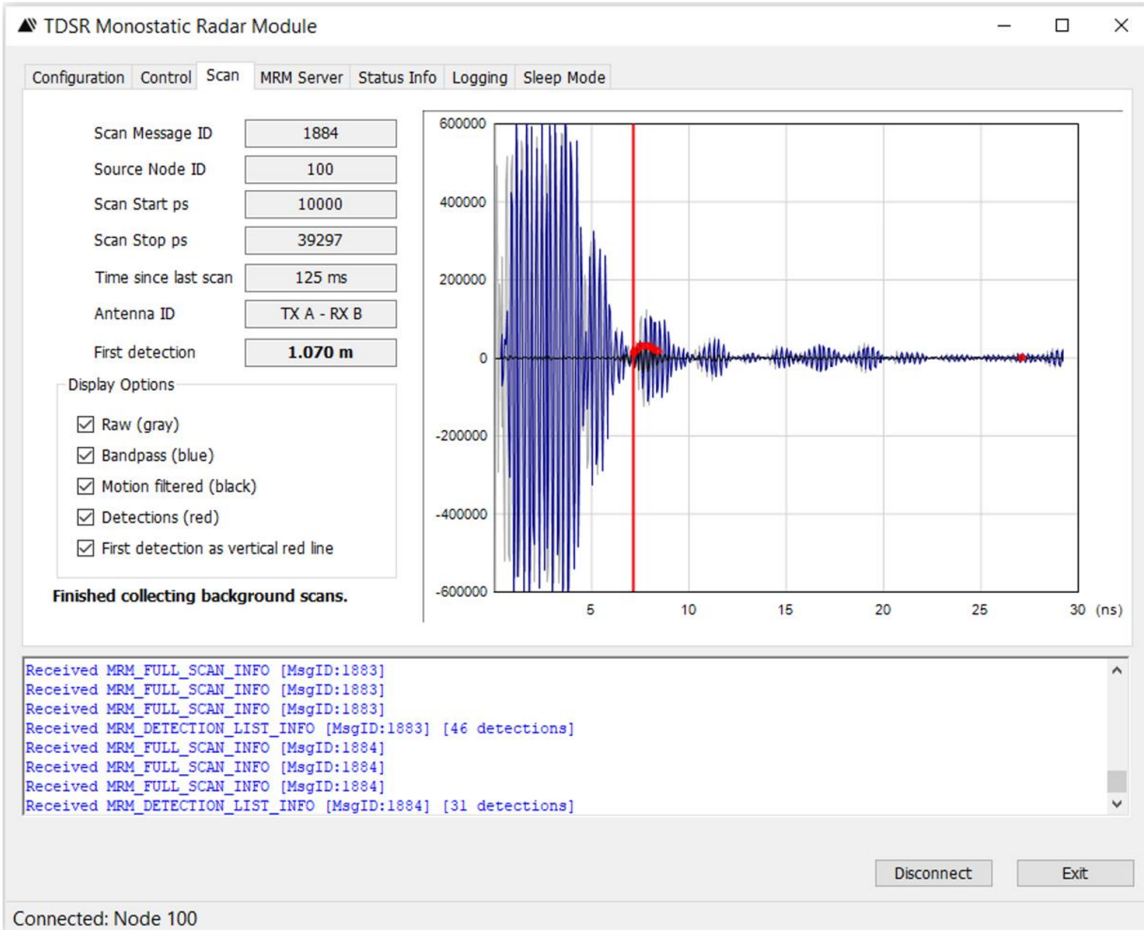


Fig. 8: Scan Tab

The tab display is divided into three unique areas: parameter info (upper left), display options (lower left), and the data plot. These areas are discussed below.

Parameter Information:

Scan Message ID: This is the ID of the raw scan and filtered scans currently being displayed. In other words, the raw scan data, bandpass filtered data, motion filtered data, and detection list data all share the same scan message ID because they are all using the same raw data.

Source Node ID: This is the ID of the MRM that produced the scan data.

Scan Start ps: This is the starting time in picoseconds of the first data point in the scan.

Scan Stop ps: This is the ending time in picoseconds of the last data point in the scan.

Time since last scan: This is the difference in time between this scan and the previous scan. This value is computed by MRM RET by subtracting the Timestamp value reported by the previous MRM_SCAN_INFO message from the current MRM_SCAN_INFO message. The Timestamp value is actually generated by the MRM processor based on its operating system clock interrupts. These interrupts have an accuracy tolerance of a few microseconds at best.

However, this is not the actual time when the scan was produced, rather it is the best approximation that the interrupt can make. The actual time is controlled by the FPGA and the UWB chipset. These devices are responsible for all scan timing and maintain the intra-scan and inter-scan timing accuracy to within a few picoseconds.

The user should occasionally monitor this value and compare it to the Interval defined on the Control Tab. The two numbers should match. If they do not, then either the Host is dropping packets or the user has requested an interval that is smaller than the requested scan duration.

Antenna ID: Indicates the current antenna configuration.

First Detection: This is an approximate measurement of the distance, in meters, from the Scan Start point to the First Detection. If the Scan Start point is set to 10,000 then the measurement is the approximate distance of the supplied BroadSpec antenna (with the associated with elbow connectors) to the target.

This distance is computed using the following equation:

Distance = (Detection0_ps – ScanStart_ps)*(Seconds/picoseconds)*C/2

Where:

Distance:	distance from target to the face of the BroadSpec antenna
Detection0_ps:	detection time in picoseconds
ScanStart_ps:	value entered for Scan Start on Configuration Tab (normally 10,000)
Seconds/picoseconds:	seconds to picoseconds conversion factor
C:	speed of light 299,792,458 m/s

Display Options:

The user can select which waveform scans are to be displayed by putting a check mark in the indicated box. Note that it is only possible to display those scans provided by the MRM Server. The scan parameters provided are selected on the MRM Server tab. The screen shown in **Figure 8** was taken with all five waveforms selected.

Scan Data Plot:

This is a plot of radar scan amplitude or reflectivity (y-axis) as a function of time in nanoseconds (ns) (x-axis). (The API reports the reflectivity as an integer value and time in ps.) The vertical scale is set when the Scan Tab is selected. The horizontal scan uses the Scan Start value as the origin and sets that maximum so that it includes the Scan Stop value. The mouse buttons are used to change scales in the following fashion:

- To change the vertical scale, hold the right mouse button down and move the mouse up or down.
- To change the horizontal scale, hold the right mouse button down and move to the left or right.
- To change the origin, hold the left mouse button down and move to the left or right.
- To return to default plot setting, double-click the left mouse button.

Note that the first ~5 ns of the raw signal is subject to a great deal of "chatter." During this time energy is coupling from the transmit antenna directly to the receiver. This produces regular, repeating saturated pulse images. This chatter is static and can be reduced by motion filtering, integration, or scan template calibration. However, since the chatter region has high amplitude, slight deviations in sample time (jitter) can cause significant noise.

Odd Behaviors: There are three relatively common behaviors that the user might occasionally see and may interpret as a hardware or software bug. In the interest of reducing confusion, the following is an explanation for these behaviors.

No detections are being produced. The radar is scanning, the motion filter shows obvious targets, and all the proper buttons are checked, but no detections are being reported. Remember that all the following conditions must exist for detections to be displayed:

- The Detection List box on the MRM Server Tab must have a check mark.
- The Threshold Mult on the MRM Server Tab must be set to a low enough value to sense detections.
- The Detections box on the Scan Tab must be checked.
- The user should not expect any detections to be reported until after the "100 Scan Training Period" has concluded. During this period a message, printed in red, will warn the user that the background measurements are being taken to establish a baseline. Once the 100 scan training period has elapsed, a message, printed in black, will alert the user that background measurements have been completed and that detections, if any, will be reported.
- There must be a target moving within the bounds of the Scan Start and Scan Stop points (a range of approximately 0.1 and 4 meters from antenna when using the factory default settings.
- If the target oscillates in a very regular fashion, then over the course of 100 scans the oscillation will be averaged into the nominal. This may reduce the sensitivity of the detection algorithm such that a threshold that initially worked might no longer have sufficient sensitivity to produce detections.

If this does not resolve the problem, then please contact TDSR for assistance.

The scan screen display is flickering. If the scans are being produced at a reasonable rate (i.e., the "Time since last scan" matches the interval set on the Control Tab) and the plot seems to be "flickering," then it is likely that the flow of information from the MRM to the PC exceeds the capability of the processor or the display driver to keep up with the flow of information. In these cases one can improve the situation by reducing the amount of information being displayed. This can be accomplished by one or more of the following:

- Unchecking the Raw and Bandpass boxes on the Scan Tab
- Increasing the scan interval
- Reducing the scan size
- Using a faster PC
- Implementing a custom MRM Server using the standard API

If these steps do not resolve the problem, then please contact TDSR for assistance.

The Detections clip. The raw and filtered data has an absolute magnitude that is limited by the transmit power, the target proximity, the radar cross-section (RCS) of the target, and the amount of integration that has been selected. The raw and filtered data are reported as 32-bit values while the detections are reported at 16-bit values. TDSR has yet to observe signals strong enough to exceed 32-bit value. However, the 16-bit detections sometimes will clip or flatline. This is illustrated in **Figure 9**. If there is a need to recover this clipped information, the simplest approach is to extract the missing information from the corresponding bandpassed filtered data stream. If this proves to be an issue for your application, then please contact TDSR for assistance.

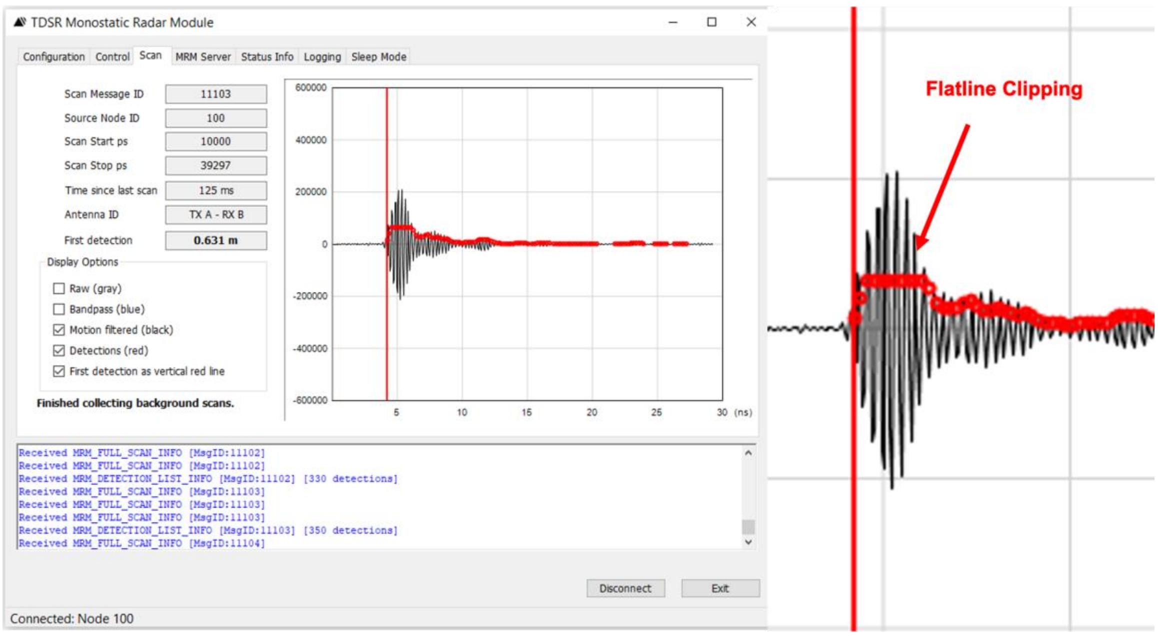


Fig. 9: Example of clipped or flatlined detections

9. Status Info Tab

MRM RET uses the following messages to report the MRM status information:

- MRM_GET_STATUSINFO_REQUEST
- MRM_GET_STATUSINFO_CONFIRM

When the Status Info tab is selected, MRM RET will issue an MRM_GET_STATUSINFO_ REQUEST and update the table with hardware and software version information.

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

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

<u>**Software Versions:**</u> The MRM has four different software designations:

- The software Package ID is the overall build version for the P4xx and encompasses all types of software on the P4xx. When reporting issues to the factory, please reference this one number. If

N/A is displayed, then the other three designations should be reported. Otherwise the other three are irrelevant and at some time in the future they will likely be deleted from the display and possibly the API.

- The version of MRM embedded application software (application code running on the MRM processor).
- The version of the UWB Kernel (UWB software running on the MRM processor).
- The version of FPGA code (running on the MRM FPGA).

Hardware Version: There are three hardware items of note: the board Serial Number, Board Type, and Version (440, 452, etc.), and the Pulser Configuration (FCC/EU mask and Tx power range).

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

Temperature: This is the temperature of the sensor mounted on the PCB board. This is not the ambient air temperature. Because the MRM generates heat, the board will run hotter than the ambient.

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

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

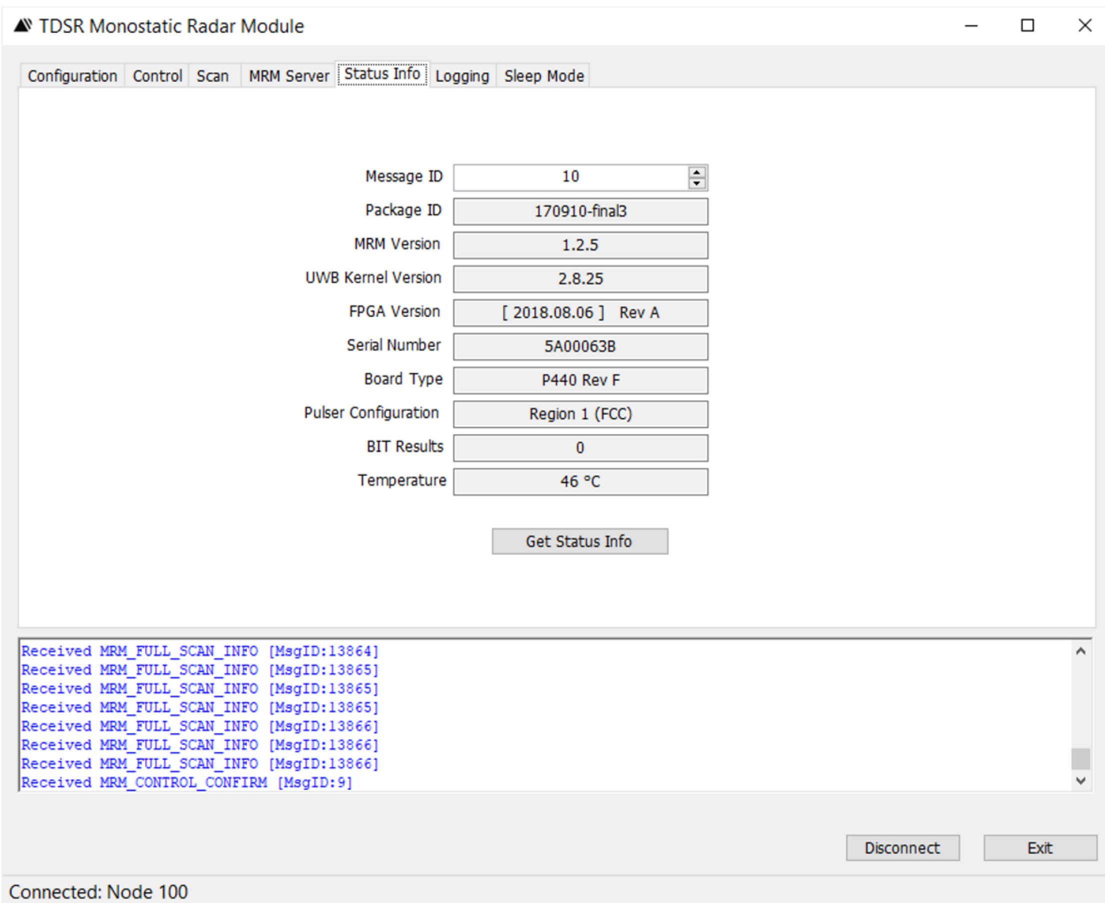


Fig. 10: Status Info Tab

10. Logging Tab

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

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

When the "Start Logging" button is clicked, MRM RET will add a three-digit suffix number to the file name. This name will be displayed on the screen. Each time the log is stopped and started, this suffix number will be incremented. The Start Logging button can be clicked at any time. If no scans are currently requested, then a logfile will be opened, logging will start, and it will standby for scan data. If scans have already been requested, then logging will start with the next scan.

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

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

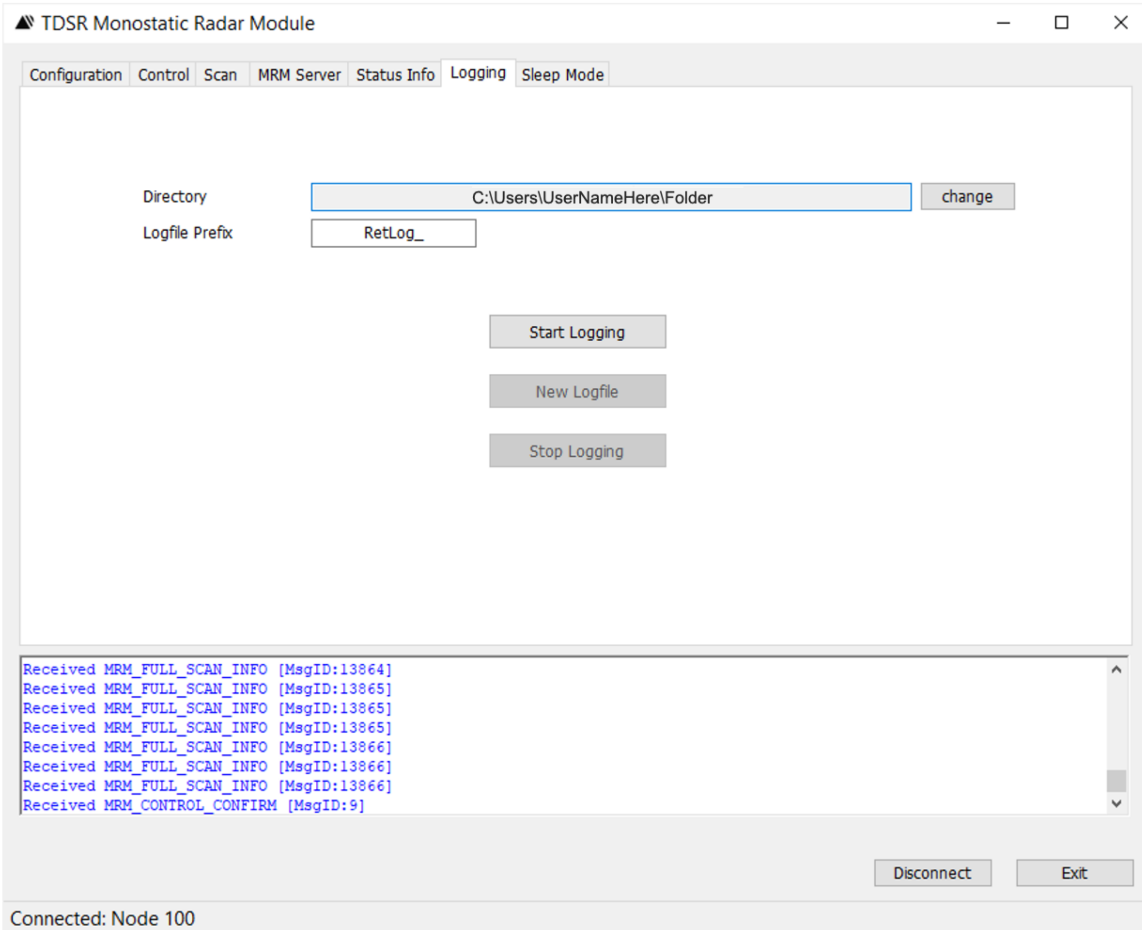


Fig. 11: Logging Tab

11. Sleep Mode Tab

The Sleep Mode Tab (see **Figure 12**) is provided by MRM RET to support operation in various sleep modes. These modes are described in the *MRM 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.

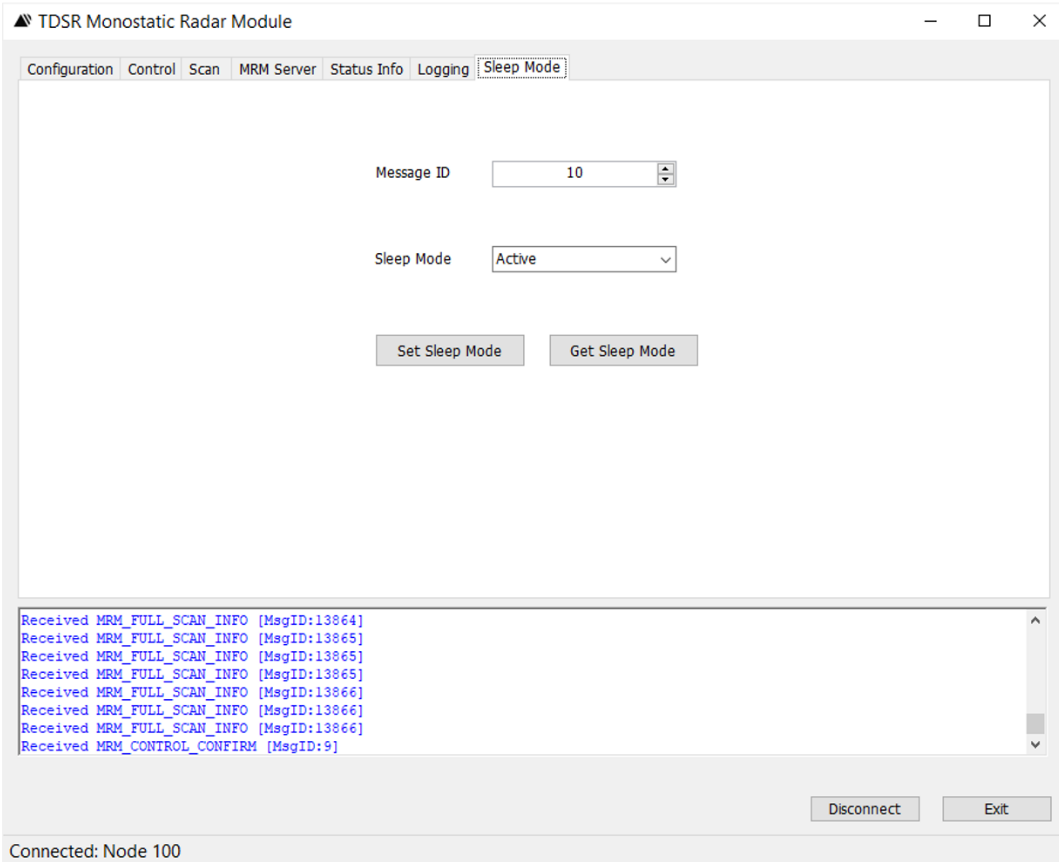


Fig. 12: Sleep Mode Tab

The MRM can be either Active or in one of several Sleep states. On power up, the MRM will boot up in the Active state. When the unit is active, MRM RET will allow the user to change parameters, start or stop scanning, log data, and perform other commands. There are several sleep modes, each of which disable the ability to operate the radar but incrementally reduce the MRM power consumption. An error message will be generated if the user attempts, while in a sleep mode, to control the radar. 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 MRM will exit the lowest state only in response to an API command issued through the Serial port (Standby_S). If the user inadvertently enters either of the lowest states and has no Serial connection, then the unit can be returned to the Active state by powering the unit off and on. The characteristics of the different modes are summarized in **Table 2**.

Mode	Typical Power (W)	Entry Time (ms)	Exit Time (ms)
Initial Boot	4.82		
Active (scanning)	6.90		
Active	3.94		
Idle	3.94	1.2	1.2
Standby_E	2.08	1.2	2.9
Standby_S	1.75	1.3	2.9

Table 2: Sleep mode characteristics

Appendix A: MRM Server Filters

The MRM Server filters were implemented using MATLAB and then instantiated in the MRM Server in C. These filters are relatively basic and are intended to illustrate operation of the radar and implementation of a sample filtering strategy. While they are illustrative and useful, they have not been optimized for any particular application. The user will likely need to tailor a custom filtering strategy to meet the performance requirements of a target application.

Bandpass Filter: The bandpass filter has been implemented as a third order filter. The MATLAB code for the filter and the associated coefficients are shown below in **Figure A-1** and **Figure A-2**. This filter is run across a single scan. (Some refer to this as a fast time filter).

```
function y = iir_filt_ord3(x,b,a)
% IIR_FILT_ORD3
%
% NOTES
% Filter order is 3 so length of b and a are 7 = 2*3 + 1.
% MATLAB array indices begin with 1.
% a(1) = 1 is the coefficient of y(n) so it is not used.
% b(4) = 0 so it is not included in the summation.
% y(1:6) must be initialized to 0.

N = length(x);
y = zeros(1,N);

for n = 7:N
  y(n) = ...
    + b(1)*x(n) ...
    + b(2)*x(n-1) ...
    + b(3)*x(n-2) ...
    + b(5)*x(n-4) ...
    + b(6)*x(n-5) ...
    + b(7)*x(n-6) ...
    - a(2)*y(n-1) ...
    - a(3)*y(n-2) ...
    - a(4)*y(n-3) ...
    - a(5)*y(n-4) ...
    - a(6)*y(n-5) ...
    - a(7)*y(n-6);
end
    %+ b(4)*x(n-3) ...
```

Fig. A-1: Order 3 Bandpass Filter

```
function [b,a] = filt_coefs
% FILT_COEFS

b(1) =  0.058918593549;
b(2) =  0.003704122993;
b(3) = -0.130605206968;
b(4) =  0;
b(5) =  0.130605206968;
b(6) = -0.003704122993;
b(7) = -0.058918593549;

a(1) =  1;
a(2) =  0.339893240317;
a(3) =  1.247471159638;
a(4) =  0.315004577848;
a(5) =  0.752494992039;
a(6) =  0.094346011045;
a(7) =  0.145214408359;
```

Fig. A-2: Coefficients for Order 3 Bandpass Filter

<u>Motion Filters:</u>

Four motion filters are supported: FIR2, FIR3, FIR4, and IIR3. These filters are implemented for each scan on each range bin. (Some refer to this as a slow time filter.)

FIR2 is a Two Tap Difference Filter that uses the following equations:

$$w = [1\ -1]$$
$$y(n) = w(1)*x(n) + w(2)*x(n-1) = x(n) - x(n-1)$$

FIR3 is a Three Tap Difference Filter that uses the following equations:

$$w = [1\ -0.8\ -0.2]$$
$$y(n) = w(1)*x(n) + w(2)*x(n-1) + w(3)*x(n-2)$$

FIR4 is a Four Tap Difference Filter that uses the following equations:

$$w = [1\ -0.6\ -0.3\ -0.1]$$
$$y(n) = w(1)*x(n) + w(2)*x(n-1) + w(3)*x(n-2) + w(4)*x(n-3)$$

IIR3 is a length 3, order 2 IIR filter. The MATLAB code used to implement the filter and the associated coefficients are shown in **Figure A-3** and **Figure A-4**.

```
function y = iir_filt_ord2(x,b,a)
% IIR_FILT_ORD2
%
% NOTES
% Filter order is 2 so length of b and a are 3 = 2 + 1.
% MATLAB array indices begin with 1.
% a(1) = 1 is the coefficient of y(n) so it is not used.
% y(1:2) must be initialized to 0.

N = length(x);
y = zeros(1,N);

for n = 3:N
  y(n) = ...
    + b(1)*x(n) ...
    + b(2)*x(n-1) ...
    + b(3)*x(n-2) ...
    - a(2)*y(n-1) ...
    - a(3)*y(n-2);
end
```

Fig. A-3: IIR3 filter

```
function [b,a] = filt_coefs
% FILT_COEFS

% 0.245 Hz -3 dB cutoff at 8 Hz update rate
a(1) =  1.000000000000;
a(2) = -1.729249571742;
a(3) =  0.761764999239;

b(1) =  0.872753642745;
b(2) = -1.745507285491;
b(3) =  0.872753642745;
```

Fig. A-4: IIR3 filter coefficients

<u>Detection Filter:</u> Detections are determined through the following procedure.

1. Each scan is bandpass-filtered as described above.
2. Each scan is motion-filtered as described above.
3. A scan envelope is computed by
   a. Multiplying the scan by 2*Pi*cos(F_0t)
   b. Low pass filtering the result using the filter shown in **Figure A-6** and **Figure A-7**
      I=lpf(scan*2*Pi*cos(F_0t))
   c. Multiplying the scan by 2*Pi*sin(F_0t)
   d. Low pass filtering the result using the filter shown in **Figure A-6** and **Figure A-7**
      Q=lpf(scan*2*Pi*sin(F_0t))
   e. Taking the square root of the sum of the squares of I and Q
      Envelope = SQRT(I^2 + Q^2)
4. A 100-element moving box car average is computed by taking each measurement in the scan and averaging it with the corresponding measurements in the previous 99 scans. The

standard deviation for each measurement position in this 100-element box car filter is computed.

5. Each measurement in the enveloped waveform is compared with the average measurement in the 100-element moving box car filter. A detection is reported if the measurement is greater than the 100-element average measurement by more than Threshold Mult * standard deviation of the 100-element average measurement.
6. Each of these detections is reported by the MRM Server both to the logfile and to MRM RET.
7. The MRM RET Scan screen reports detections in a slightly different manner. MRM RET will report a detection (plot a red dot on the Scan Tab plot) if there are three adjacent detections. This simplification reduces the false alarm rate, thereby making the detection process more robust. This is illustrated in **Figure A-5**. In this figure, a measurement that constitutes a detection is marked as an “X”, otherwise it is an “O.”

```
MRM Server Detection:   OOOOXOOXXXXOXOXXOXXXOOOOXOXOX
MRM-RET Plot:           OOOOOOOXOOOOOOOOOXOOOOOOOOOOO
                               1  2      3
```

Fig. A-5: Example of how MRM RET further filters the detections

MRM RET will report point #1 as a detection because it is the first of three Xs. Point #2 is an X, but it is followed by an O and an X, so it doesn’t qualify. Point #3 is the first of three Xs, so MRM RET will report a detection at that point.

```
function y = iir_filt_ord6(x,b,a)
% IIR_FILT_ORD6
%
% NOTES
% Filter order is 6 so length of b and a are 7 = 6 + 1.
% MATLAB array indices begin with 1.
% a(1) = 1 is the coefficient of y(n) so it is not used.
% y(1:6) must be initialized to 0.

N = length(x);
y = zeros(1,N);

for n = 7:N
  y(n) = ...
    + b(1)*x(n) ...
    + b(2)*x(n-1) ...
    + b(3)*x(n-2) ...
    + b(4)*x(n-3) ...
    + b(5)*x(n-4) ...
    + b(6)*x(n-5) ...
    + b(7)*x(n-6) ...
    - a(2)*y(n-1) ...
    - a(3)*y(n-2) ...
    - a(4)*y(n-3) ...
    - a(5)*y(n-4) ...
    - a(6)*y(n-5) ...
    - a(7)*y(n-6);
end
```

Fig. A-6: MATLAB code for implementing the detection filter

```
function [b,a] = filt_coefs
% FILT_COEFS

b(1) =  0.010312874763;
b(2) =  0.061877248576;
b(3) =  0.154693121440;
b(4) =  0.206257495253;
b(5) =  0.154693121440;
b(6) =  0.061877248576;
b(7) =  0.010312874763;

a(1) =  1.000000000000;
a(2) = -1.187600680176;
a(3) =  1.305213349289;
a(4) = -0.674327525298;
a(5) =  0.263469348280;
a(6) = -0.051753033880;
a(7) =  0.005022526595;
```

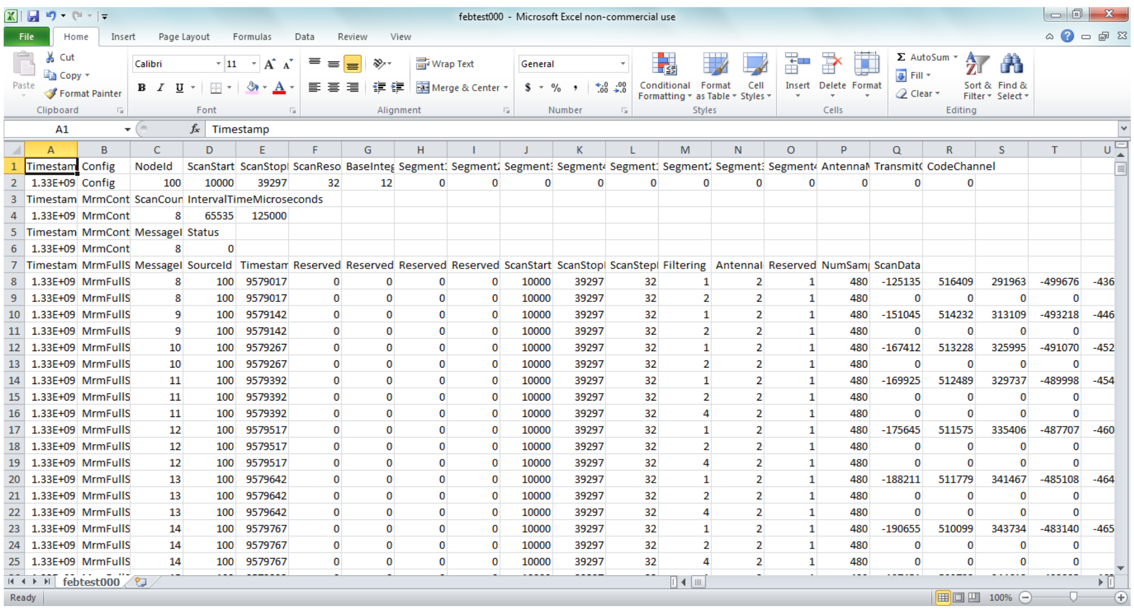
Fig. A-7: Detection filter coefficients

Appendix B: MRM RET Logfile Format

The MRM RET logfile captures in a .csv file all of the messages sent to, and received from, the MRM or MRM Server. If MRM RET is connected directly to the MRM (bypassing the MRM Server), then the only data logged will be the raw scan data. If MRM RET is connected to the MRM Server, then the filter parameters set in the MRM Server Filter Settings will determine which data is logged.

Before the FIRST instance of each message type, a header description will be provided. The initial timestamp (always the first parameter in each message line) is a floating point time value, in seconds, provided by the Host PC. All parameters for all messages are described in the *MRM API Specification.*

Figure B-1 shows an example .csv logfile as viewed in MS Excel. This figure does not show the final 474 columns.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
1	Timestam	Config	NodeId	ScanStart	ScanStopI	ScanReso	BaseInteg	Segment1	Segment2	Segment3	Segment4	Segment1	Segment2	Segment3	Segment4	AntennaM	TransmitG	CodeChannel			
2	1.33E+09	Config	100	10000	39297	32	12	0	0	0	0	0	0	0	0	0	0	0			
3	Timestam	MrmCont	ScanCoun	IntervalTimeMicroseconds																	
4	1.33E+09	MrmCont	8	65535	125000																
5	Timestam	MrmCont	MessageI	Status																	
6	1.33E+09	MrmCont	8	0																	
7	Timestam	MrmFullS	MessageI	SourceId	Timestam	Reserved	Reserved	Reserved	Reserved	ScanStart	ScanStopI	ScanStepI	Filtering	AntennaI	Reserved	NumSam	ScanData				
8	1.33E+09	MrmFullS	8	100	9579017	0	0	0	0	10000	39297	32	1	2	1	480	-125135	516409	291963	-499676	-436
9	1.33E+09	MrmFullS	8	100	9579017	0	0	0	0	10000	39297	32	2	2	1	480	0	0	0	0	
10	1.33E+09	MrmFullS	9	100	9579142	0	0	0	0	10000	39297	32	1	2	1	480	-151045	514232	313109	-493218	-446
11	1.33E+09	MrmFullS	9	100	9579142	0	0	0	0	10000	39297	32	2	2	1	480	0	0	0	0	
12	1.33E+09	MrmFullS	10	100	9579267	0	0	0	0	10000	39297	32	1	2	1	480	-167412	513228	325995	-491070	-452
13	1.33E+09	MrmFullS	10	100	9579267	0	0	0	0	10000	39297	32	2	2	1	480	0	0	0	0	
14	1.33E+09	MrmFullS	11	100	9579392	0	0	0	0	10000	39297	32	1	2	1	480	-169925	512489	329737	-489998	-454
15	1.33E+09	MrmFullS	11	100	9579392	0	0	0	0	10000	39297	32	2	2	1	480	0	0	0	0	
16	1.33E+09	MrmFullS	11	100	9579392	0	0	0	0	10000	39297	32	4	2	1	480	0	0	0	0	
17	1.33E+09	MrmFullS	12	100	9579517	0	0	0	0	10000	39297	32	1	2	1	480	-175645	511575	335406	-487707	-460
18	1.33E+09	MrmFullS	12	100	9579517	0	0	0	0	10000	39297	32	2	2	1	480	0	0	0	0	
19	1.33E+09	MrmFullS	12	100	9579517	0	0	0	0	10000	39297	32	4	2	1	480	0	0	0	0	
20	1.33E+09	MrmFullS	13	100	9579642	0	0	0	0	10000	39297	32	1	2	1	480	-188211	511779	341467	-485108	-464
21	1.33E+09	MrmFullS	13	100	9579642	0	0	0	0	10000	39297	32	2	2	1	480	0	0	0	0	
22	1.33E+09	MrmFullS	13	100	9579642	0	0	0	0	10000	39297	32	4	2	1	480	0	0	0	0	
23	1.33E+09	MrmFullS	14	100	9579767	0	0	0	0	10000	39297	32	1	2	1	480	-190655	510099	343734	-483140	-465
24	1.33E+09	MrmFullS	14	100	9579767	0	0	0	0	10000	39297	32	2	2	1	480	0	0	0	0	
25	1.33E+09	MrmFullS	14	100	9579767	0	0	0	0	10000	39297	32	4	2	1	480	0	0	0	0	

Fig. B-1: Example logfile

As described previously, Line 1 contains the column names for all of the fields associated with the message shown in Line 2. The message shown on Line 2 shows the following:

- Time stamp (4.1E-06 seconds, expanding the field will show a PC-generated timestamp of 4163152)
- Message name (Config, an abbreviation for MRM_SET_CONFIG_REQUEST (0x1001 in the API)
- Subsequent parameters on line 2 map directly to the headers on line 1 and to the parameters defined in the MRM_SET_CONFIG_REQUEST.

Similarly, Line 3 contains the column names for all of the fields of the message shown in Line 4. Line 4 is the MRM API command that initiates the taking of radar scans. Lines 5 and 6 are the API confirmations for the previous API request. Lines 7 and 8 are radar scan messages. Columns A through P contain header information. Column P indicates the number of data points that follow. In this case, there are 480 data points in each scan. The first point corresponds to the reading taken at Scan Start Point

10000, with the subsequent 479 data points being taken at 32 bin increments up to the Scan Stop Point. (Each bin is an increment of 1.907 picoseconds.)

While raw scan data, bandpass data, motion filtered data, and detections all share the same message number, they are easy to distinguish based either on the contents of the Filtering field (column M in Excel) or the message type. (See **Table B-1**.) Note that the detections will only be produced if the Detection List Flag is set on the MRM Server page and there are detections present.

Data Type	Message Type	Column M
Raw Scan Data	MrmFullScanInfo	1
Bandpass Data	MrmFullScanInfo	2
Motion Filtered Data	MrmFullScanInfo	4
Detection Data	MrmDetection ListInfo	Number of Detections (1-350)

Table B-1: Example logfile

Finally, a scan can be very long and can consist of thousands of measurements. In theory, every measurement could generate a detection. However, the MRM Server will only report the earliest 350 detections in a scan.