Quonset Microwave
www.quonsetmicrowave.com

315 Commerce Park Road
North Kingstown, RI 02852
Tel: 401-267-8750
Fax: 401-667-2912

QM-RDK Lesson Guide

Introduction to Radar

A radar system uses beams of radio waves or microwaves, also known as signals, to measure distance and/or movement.

To determine distance, the system measures the time it takes for a transmitted (TX) signal to reach an object, reflect off of it, and return (RX signal). This time will be called the round trip time in this document. Since the signals travel at the speed of light (which is about 670 million mph [300 million meters per second]), an object at a distance of 100 miles [160 thousand meters] could be detected in just over one millisecond under favorable conditions. The following equation is used for determining range using radar round trip time:

Half the speed of light × Round trip time = Range

It is important to note that there may be a delay within the radar equipment itself. This will result in a longer round trip time and cause objects to appear to be farther away than they really are. Fortunately, this delay is predictable and, once the value of the error is known, it can be subtracted from the round trip time or range.

To measure movement (velocity) with radar, the frequency of the TX signal is compared to the frequency of the RX signal. A lower RX frequency means that the round-trip time for the signal is increasing. This indicates that the object is moving away from the radar. If the object is moving towards the radar, the opposite is true and the frequency of the RX signal is higher than the TX signal frequency. If the object is neither moving towards nor away from the radar, the frequency will not change. In this case, the object may still be moving, but if it is, it is maintaining a constant distance from the radar system. This frequency change due to movement is known as the Doppler Effect.

The amount of change between the TX and RX frequencies relates to how fast the object is moving, which can be calculated with the equation listed below:

(Received frequency–Transmitted frequency)×Speed of light ÷Transmitted frequency=Velocity

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Using this equation, the units used for the speed of light will match the units of the resulting velocity. The speed of light is equal to either 670 million miles per hour, or 300 million meters per second. A positive result indicates the object is approaching the radar, while a negative result indicates an object moving away from the radar. As a side effect of the measurement method used by the QM-RDK, it cannot determine whether an object is moving towards or away from the radar. This is described in more detail in the next section.

FMCW

When using Radar for range finding, the simplest method is to send a pulse (a brief signal) out and wait for the pulse to return. Since the beginning of the RX pulse is easy to recognize, it is easy to determine the round trip time of the signal. There are, however, some drawbacks to this method. For example, at short ranges, the round trip time could be too short to measure accurately. Also, if the radar is operating over long ranges, the time between each measurement could be too long for some applications. In situation like these, an alternative to pulsed radar is needed.

FMCW (Frequency Modulated Continuous Wave) radar constantly sends out a predetermined pattern of frequencies with easily recognizable reference points (often the maximum and/or minimum frequencies) which can be located in both the TX and RX signals to determine the round trip time of the signal without stopping the transmission, which is helpful in the long range case described above.

The method used by the QM-RDK for FMCW range finding measures the beat frequency to determine round trip time indirectly, which helps most at short ranges when the round trip time is very small. The beat frequency is the difference between the TX and RX frequencies. It is called a ‘beat frequency’ because, in the audio range, one can hear a beat (a periodic change in intensity level) when two acoustic waves with a small frequency difference are played together. The frequency of the beat is equal to the difference between the two frequencies that caused it. For example, if a 200Hz tone and a 202Hz tone are played together, a 2Hz beat will be heard. The QM-RDK uses the beat frequency because it is slower than either the transmitted frequency or the received frequency, which makes it easier to measure and allows for less complicated and less expensive hardware to be used without significant loss in performance.

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Since the frequency change is steady, the system can easily determine how long ago it transmitted a frequency that differed from the current TX frequency by an amount equal to the beat frequency. This time is assumed to be the round trip time and range is calculated normally. If only the beat frequency and the values given as input to the software were known, the following calculation would have to be done to determine round trip time:

(Beat frequency × Ramp Time) ÷ (Stop frequency – Start frequency) = Round trip time

The units used for ramp time will be the same as the units of the resulting round trip time. The graph below is taken from the QM-RDK manual and it shows both the *Round trip time* (**T_p**) and the *Beat frequency* (**f_b**) for a TX and RX signal ramp pair similar to what would be produced by the QM-RDK. In this diagram, **Δf** is the difference between the *Start frequency* and the *Stop frequency*, and **T** is the *Ramp time*.

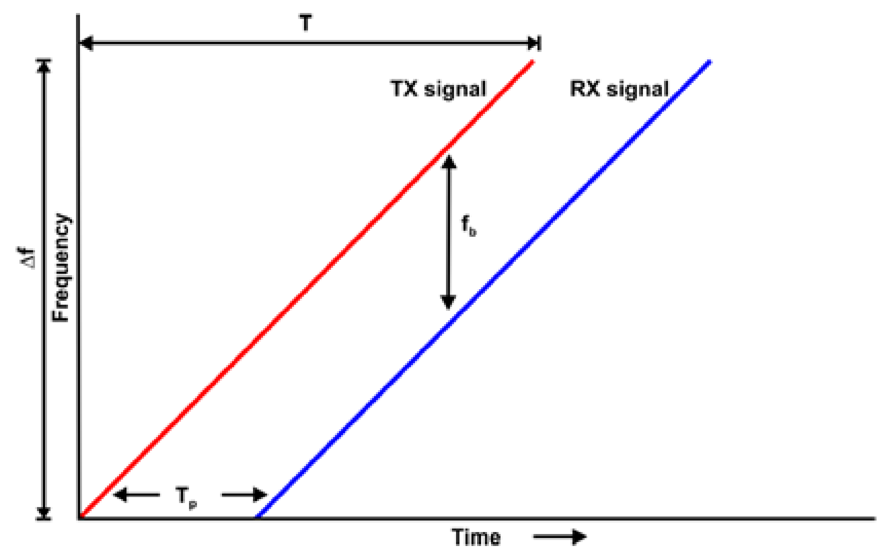

Figure 1 - *FMCW Radar frequency and timing diagram*

The primary disadvantage to this technique is that it is most useful for relatively still targets. As the Doppler frequency shift increases, the range error does as well. In more complex systems, this can be handled by measuring the difference between the maximum RX frequency and the maximum TX frequency and using the result as a reference Doppler frequency to compensate for the range error. Even more complex

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systems can look for abnormalities in the shape of the RX signal ramp for even better compensation.

Modern FMCW radar systems can simultaneously track the positions and velocities of many targets within the regions they monitor.

QM-RDK GUI

The QM-RDK GUI is included with the QM-RDK hardware and provides the user with a pre-built interface to the QM-RDK system with no programming required from the user. More application specific software can be developed by the user. Details for doing this are in the Programming section of the QM-RDK User Manual.

The GUI window contains 2 major sections. On the left side is the input area and on the right side is the output area. The input area has 2 tabs for inputs and one containing a small collection of user tips. Additionally input area can be used to save numeric data to files from either a single capture or a series of captures using the “Radar setup” tab or the “Data Collection” tab respectively. The Output area has six tabs for different graphical output options.

In the “Radar Setup” tab of the input section, there are many input fields which are shown below:

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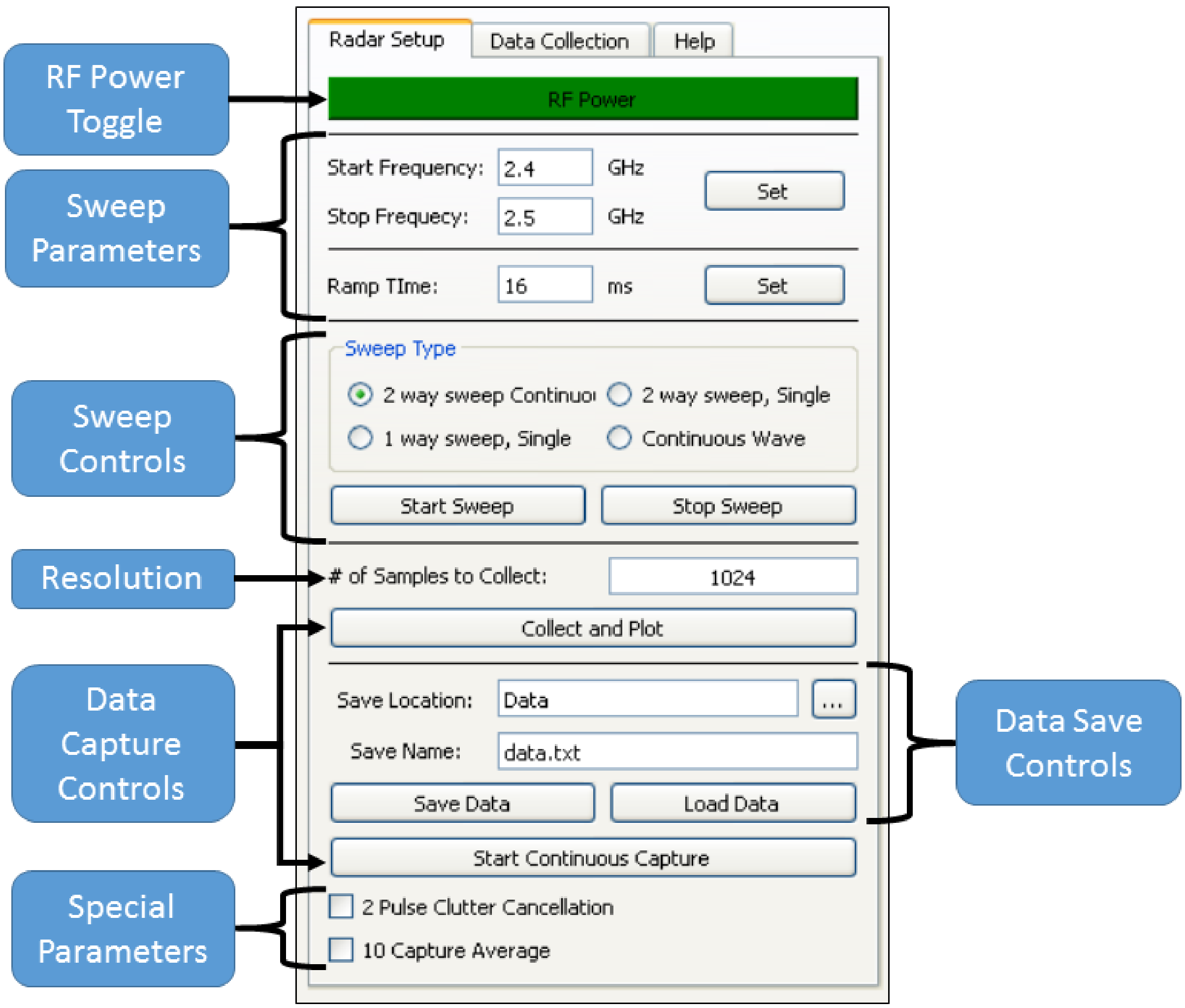

***Figure 2 -** GUI Data Collection Tab*

Table 1 - *GUI Data Collection Tab Definition*

Radar Setup Tab Features

RF Power Toggle: Switch transmitter power ON or OFF. Also indicates current state, appearing GREEN when transmitter is ON and RED if OFF

Sweet Parameters: Determine the highest and lowest frequency used in the sweep and the time it takes to get from one to the other. The default settings will work for most situations.

Sweep Controls: Select one of the sweep modes for range finding. Select “Continuous Wave” for velocity measurement. “Start Sweep” and “Stop Sweep” perform the same task as RF Power Toggle.

Resolution: This value should be increased if the data output looks too round with only a couple dozen peaks (this will be visible in “spectrum”, “range”, or “Doppler” modes). If individual peaks are not visible or it updates too slowly, then this value should be reduced.

Data Capture Controls: These controls allow you to start data capture events. The “Start Continuous Capture” button will trigger new capture events periodically until it is pressed again. The “Collect and Plot” button will only run a single data capture event.

Data Save Controls: This section allows for data from the most recent capture only to be saved. If saved data from multiple successive plots for these sections are desired, the “Data Collection” tab should be used.

Special Parameters: “2 Pulse Clutter Cancellation” is used to suppress stationary objects in range finding data and is useful for finding new or moved objects. “10 Capture Average” will average the current collection event with the 0 preceding it to suppress random noise, however it will also reduce sensitivity to moving objects.

The output area is fairly simple. The ‘Raw Data’ tab displays the RX signal amplitude in volts. The ‘Spectrum’ tab gives the spectrum plot of the beat frequencies between the TX and the RX signals. This is the data used to calculate range and distance in its

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unprocessed form. 'Range' shows the return strength of beat frequencies corresponding to the ranges shown on the axis. And 'Doppler' shows the return strength for various Doppler frequencies.

The last 2 tabs use color to represent amplitude and the horizontal axis corresponds to the capture number. They perform the same function as their corresponding single capture tabs, but they allow for multiple captures to be displayed simultaneously, which can be useful.

To change the axis limits, make sure only the check boxes for the axis or axes you wish to change is/are checked. Then, scroll up to zoom in and down to zoom out. Hovering over a certain value will keep that value where it is on the axis and rescale around it. You can also click with the left mouse button and drag to pan to different regions of the plot. On Graphs with color bars, make sure continuous capture is stopped before adjusting the axis limits. The reference bar on the right can also be adjusted to improve contrast and change the range of values which can be differentiated. It is useful to try to move the values such that all noise is below the bottom of the reference bar.

Example Tests

Range Finding 1

This test is best conducted in a large (relatively) open space such as a warehouse, a hanger, or a parking lot. Large metal objects with solid surfaces (not open scaffolding or lattice structures) make good targets. For this example, metal shipping containers and a large metal object (steel plate, at least 10 feet by 5 feet) were used. The QM-RDK hardware was connected to a laptop and mounted to a tripod 4 to 5 feet off the ground with the cantennas horizontally attached.

The First target was a pair standard shipping containers. They were side by side, about 3 feet apart, and the QM-RDK was aimed at the doors of the containers (so the smallest face of each container was ‘visible’ to the radar). The ‘Range’ tab was used and the ‘Radar Setup’ parameters used can be seen on the following pages. The actual distance to the containers was measured to be 14.5 meters. (**Figure 3**)

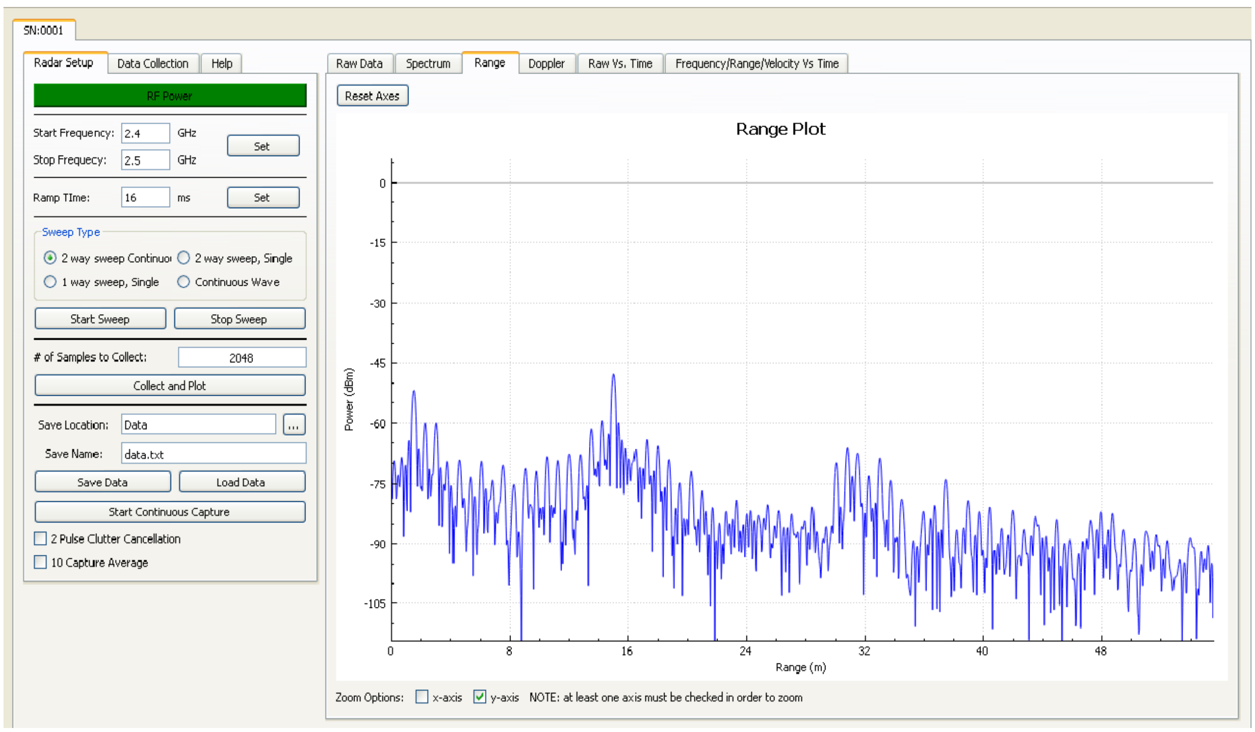

Figure 3 - *Full window view of range data for 2 shipping containers at 14.5 meters*

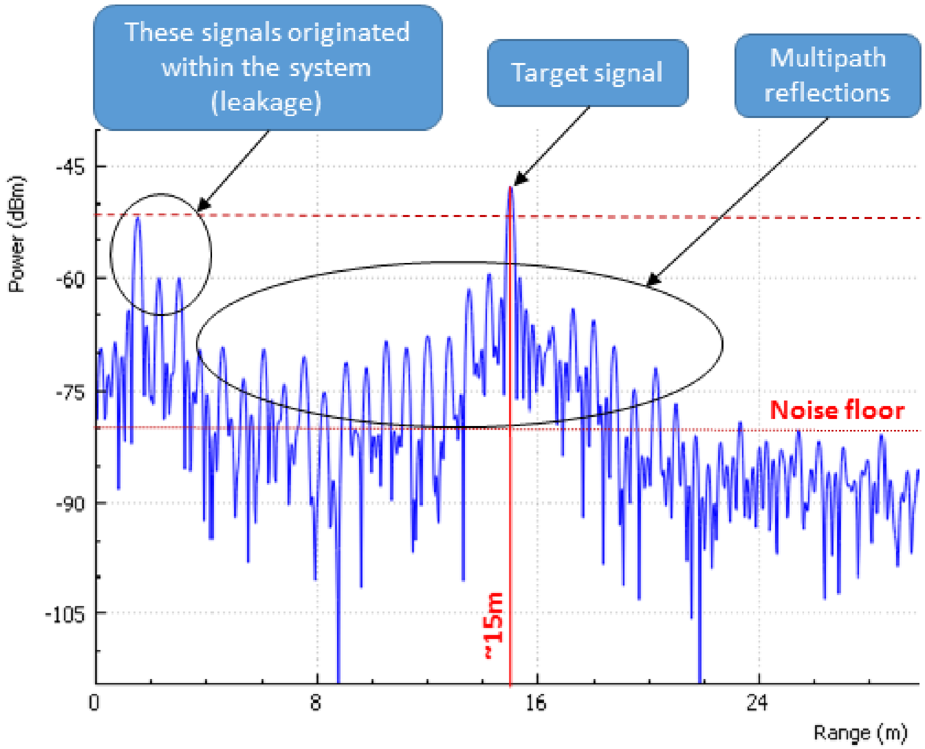

Figure 4 - *Annotated detail of* ***Figure 3***

Figure 5 - *View of target from cantennas' perspective*

Range Finding 2

The second target was a large metal object. It was about a foot beyond the chain link fence that bordered the test area. The face presented to the radar was a thick, oxidized steel plate measuring at least 10 feet wide by 5 feet high, with a semicircular cutout, about 24 - 30 inches in radius, centered on the top edge. The distance to the fence was measured to be 31 meters from the QM-RDK system (**Figure 6**). Due to the larger distance used for this test, the cantennas had to be elevated to the maximum height allowed by the tripod (over 5 feet) to reduce the strength of the noise reflecting off the ground so that the signal was more visible. The GUI parameters used for this target were the same as those used for the first target.

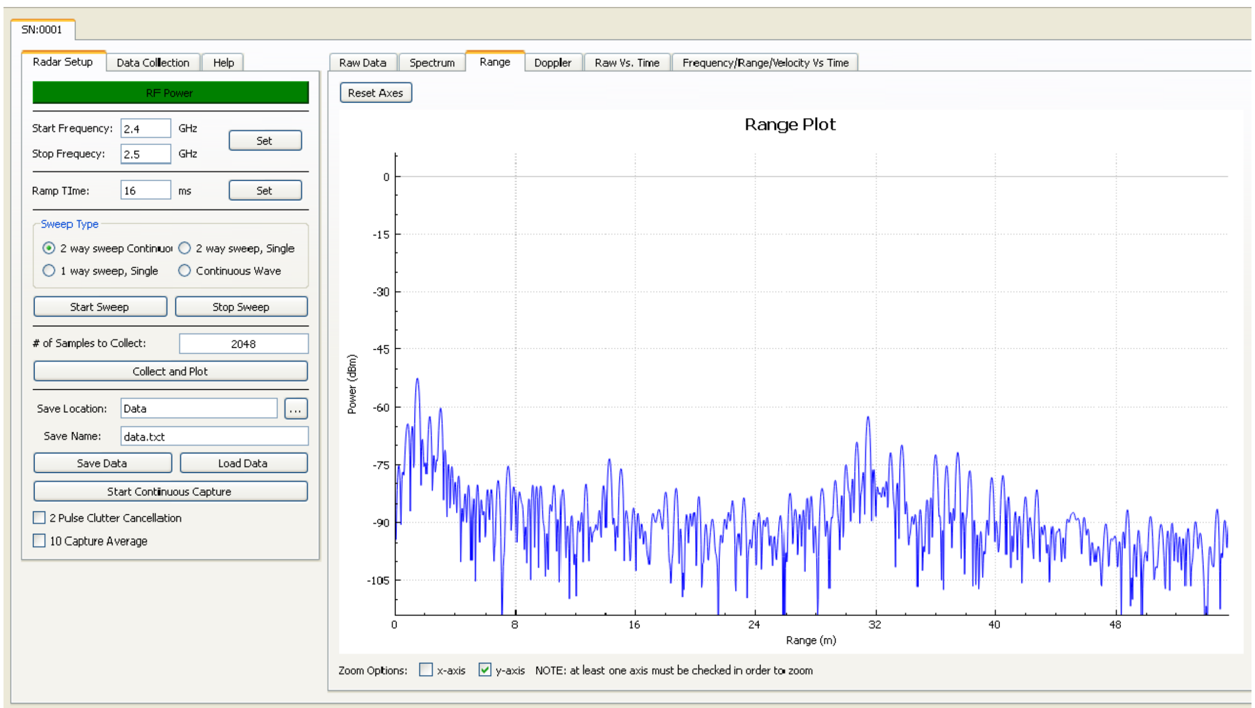

Figure 6 - *Full window view of range data for 5 foot by 10 foot steel object at 31 meters*

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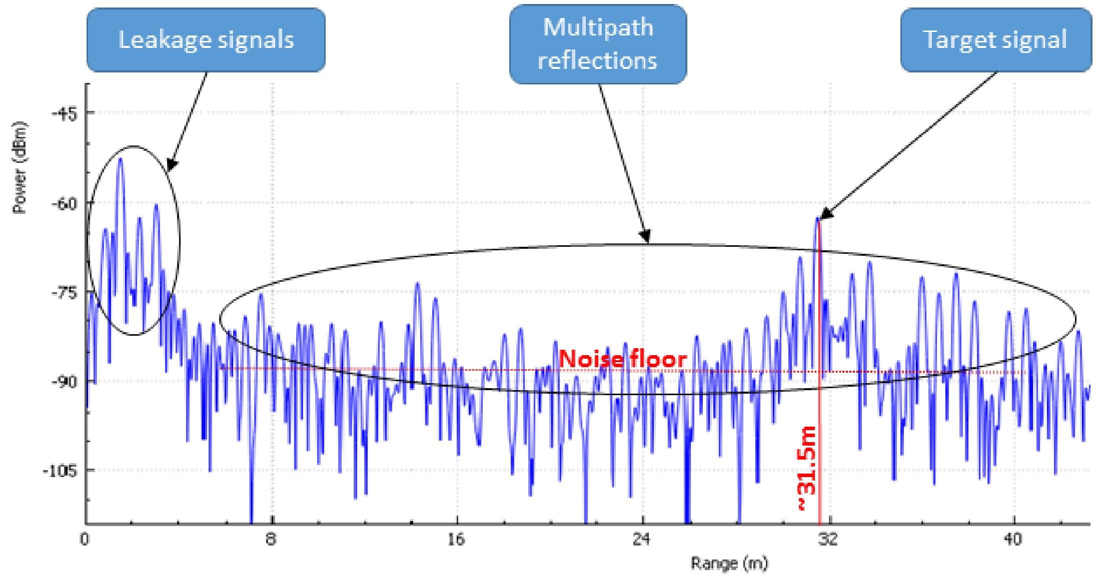

Figure 7 - *Annotated detail of **Figure 6***

Figure 8 - *Target (outlined) from cantennas' perspective*

Doppler 1

This test can be performed with relatively limited space. It requires a 1 foot square (±6 inches) sheet of light metal. The “Continuous Wave” sweep type must be selected and the rightmost tab of the output area is used. The “Velocity” option must be set within this tab. To prepare the test, start by pressing “Collect and Plot” once so the axis limits and color scale can be set; alternatively, you can let the continuous capture run for a few iterations. Make sure continuous capture is off before adjusting the axis limits.

Once the limits and color scale have been set to reasonable initial values, click “Start Continuous Capture” once to begin. Have the cantennas mounted at about chest level with a reasonable amount of open space around them. While standing off to the side, quickly but carefully swing the sheet of metal at and/or away from the cantennas such that one of the faces of the sheet is always aimed directly at the cantennas. Try to keep at least 3 inches away from the cantennas to avoid hitting them. After a few swings, stop the continuous capture and adjust your color scale to isolate the desired signals.

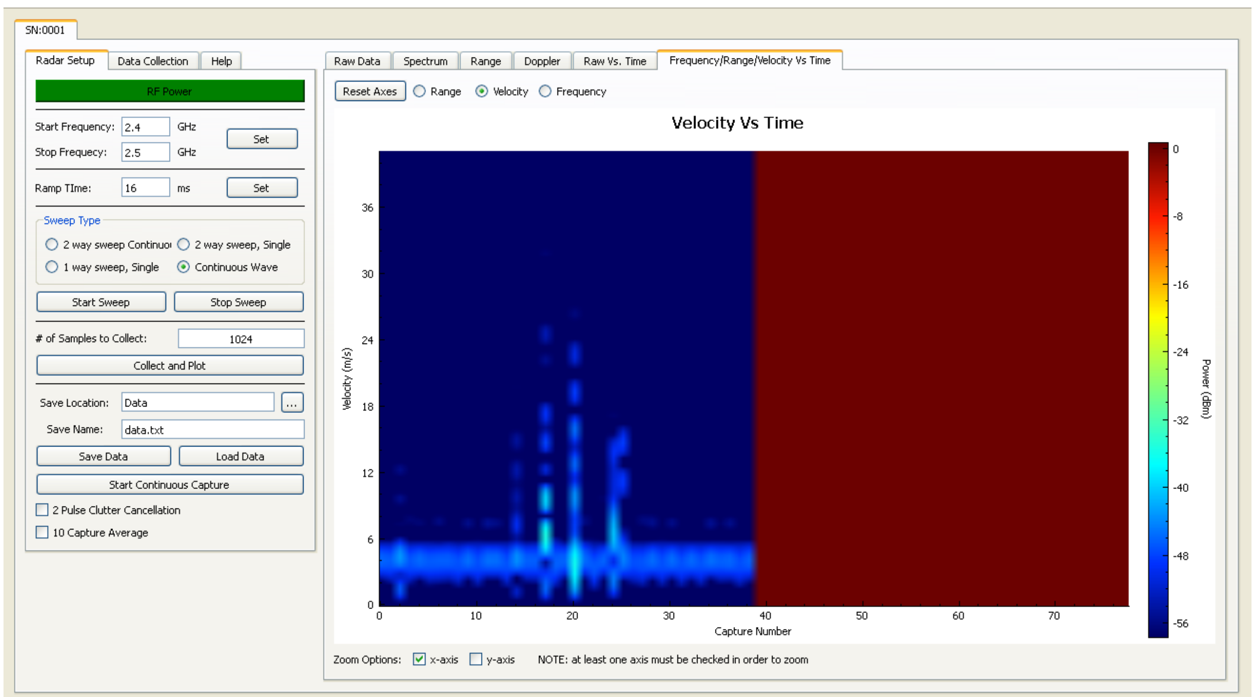

Figure 9 - *Initial limits and scaling show data, but it is not very easy to read*

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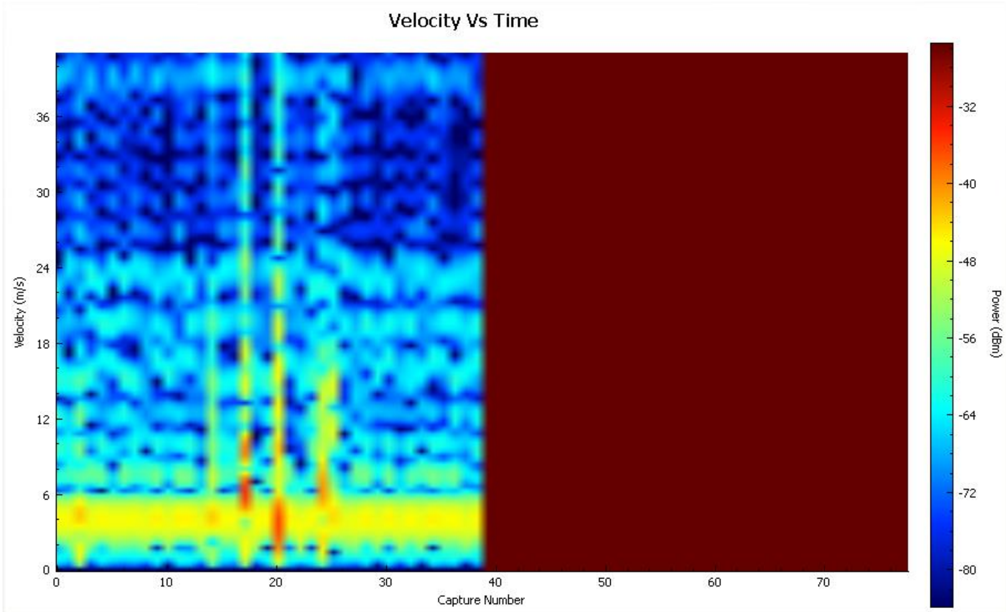

Figure 10 - *By shifting the color scale, the data becomes slightly easier to read*

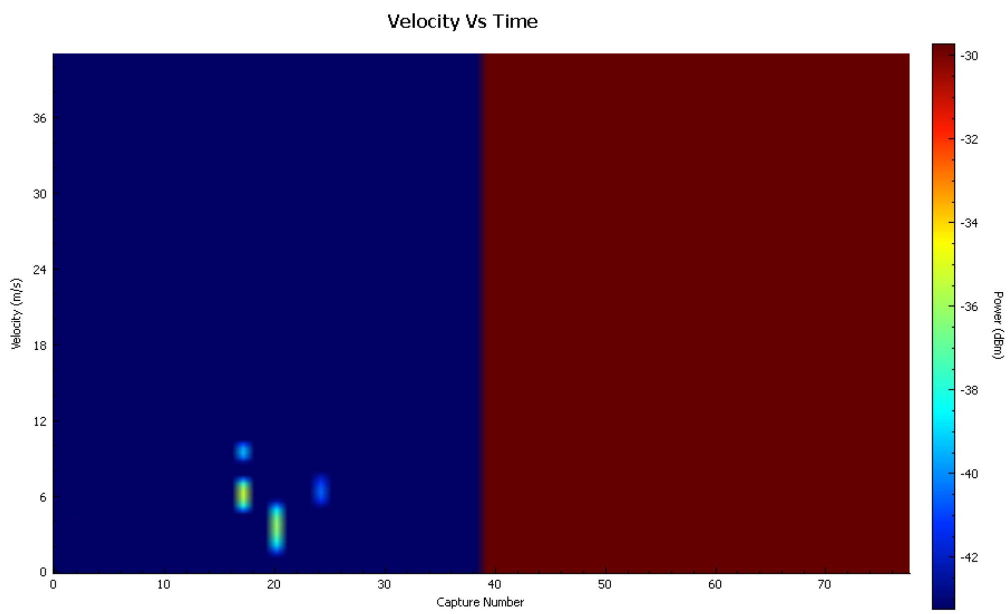

Figure 11 - *Narrowing the range of the scale eliminates most of the noise allowing for easy interpretation of the data*

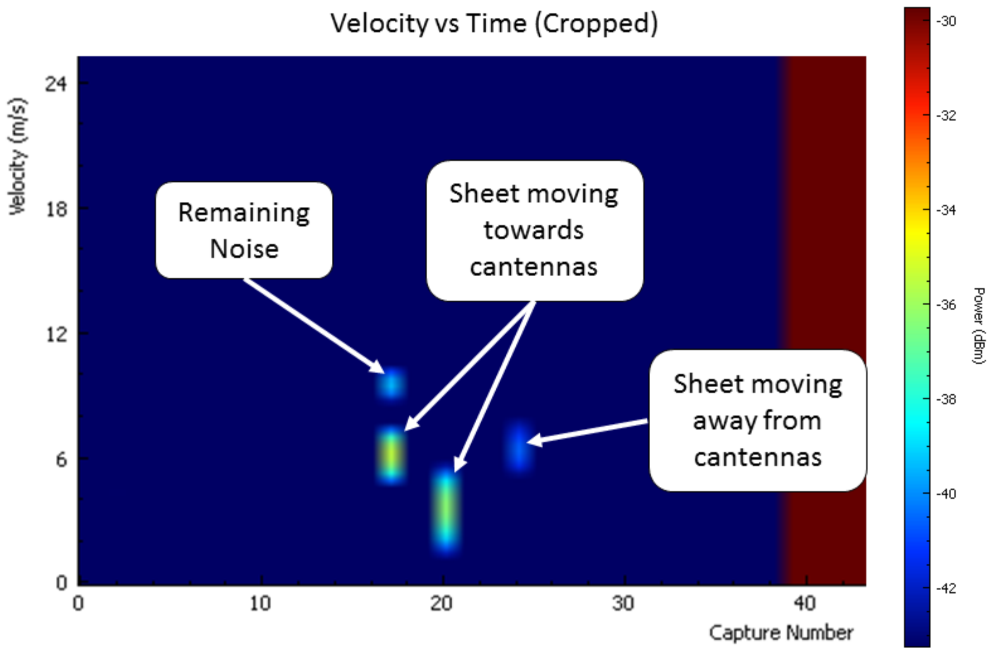

Figure 12 - *Annotated detail of* ***Figure 11***

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Doppler 2

This test can better show how a Doppler radar can track changes in velocity over time. To do this, a car is driven at the cantennas, which are mounted at about grill level, and data is collected as the car accelerates past the cantennas. Asphalt reflections are not an issue with this test, but moving objects in the periphery of the system can cause extra signals to appear. This test uses the same output settings as the Doppler 1 test. As before, a capture or captures must be collected before the axis limits and color scale can be adjusted and adjustments should not be made to these while captures are in progress. The axis limits used in the previous test should be acceptable, but the color scale may need to be adjusted.

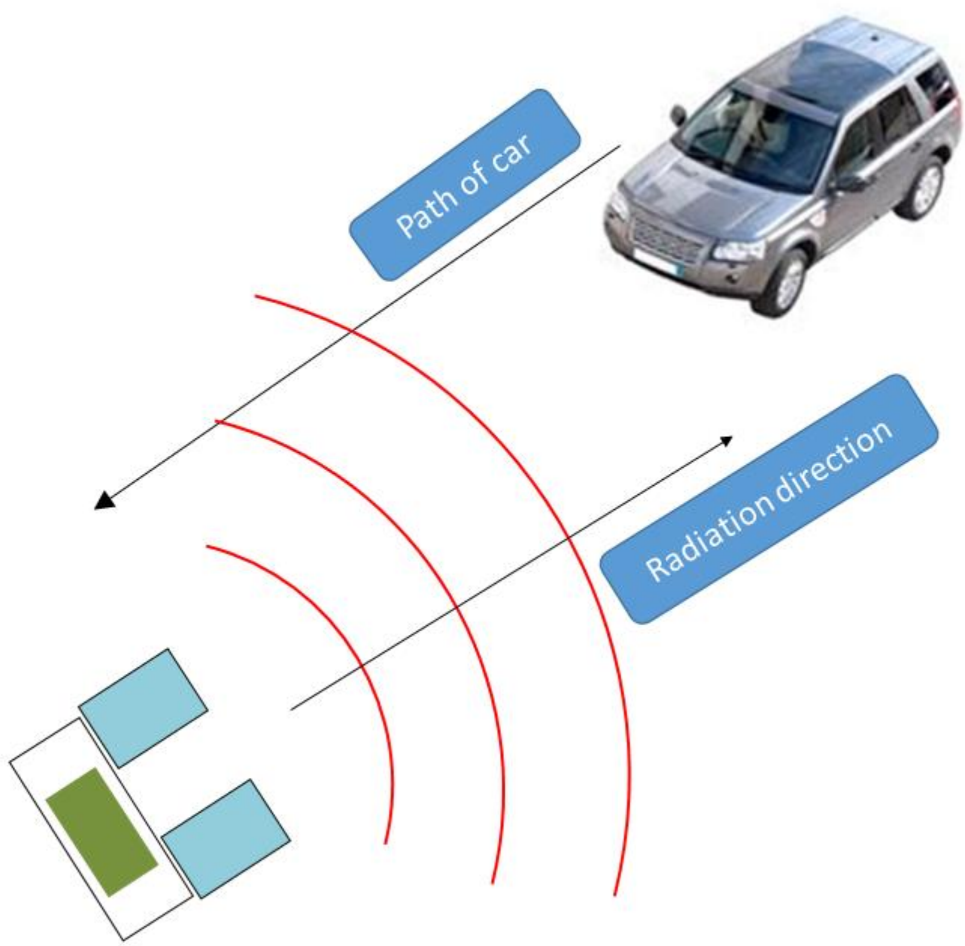

Figure 13 - *Experimental setup diagram*

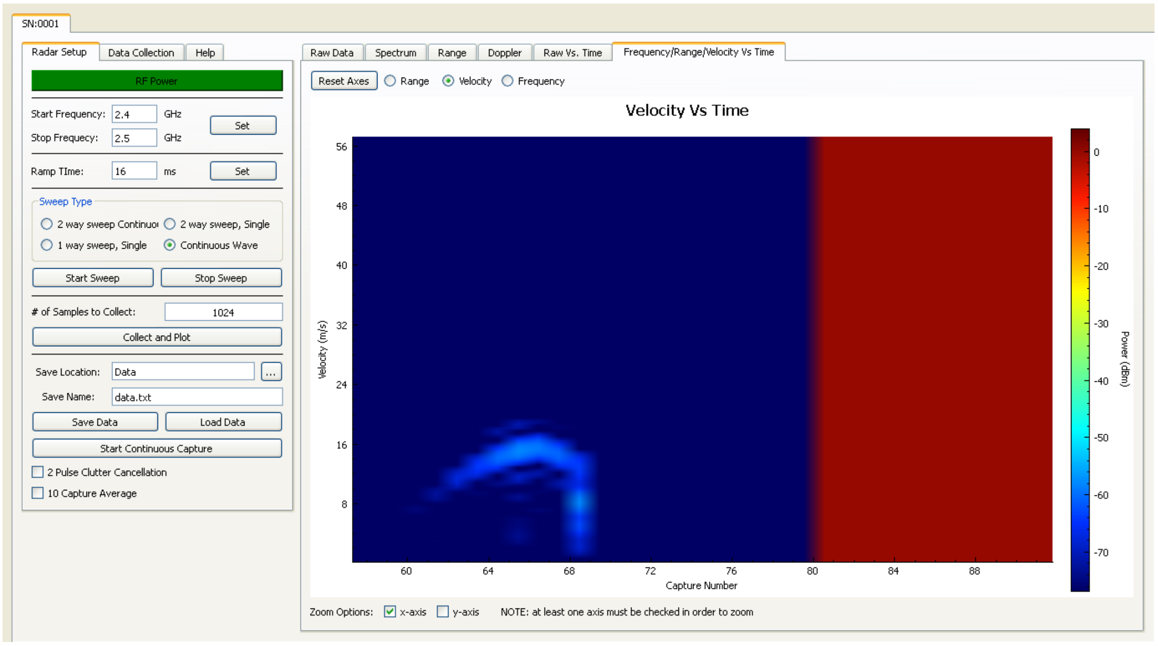

Figure 14 - *Full window view of Doppler data of car accelerating towards and passing cantennas*

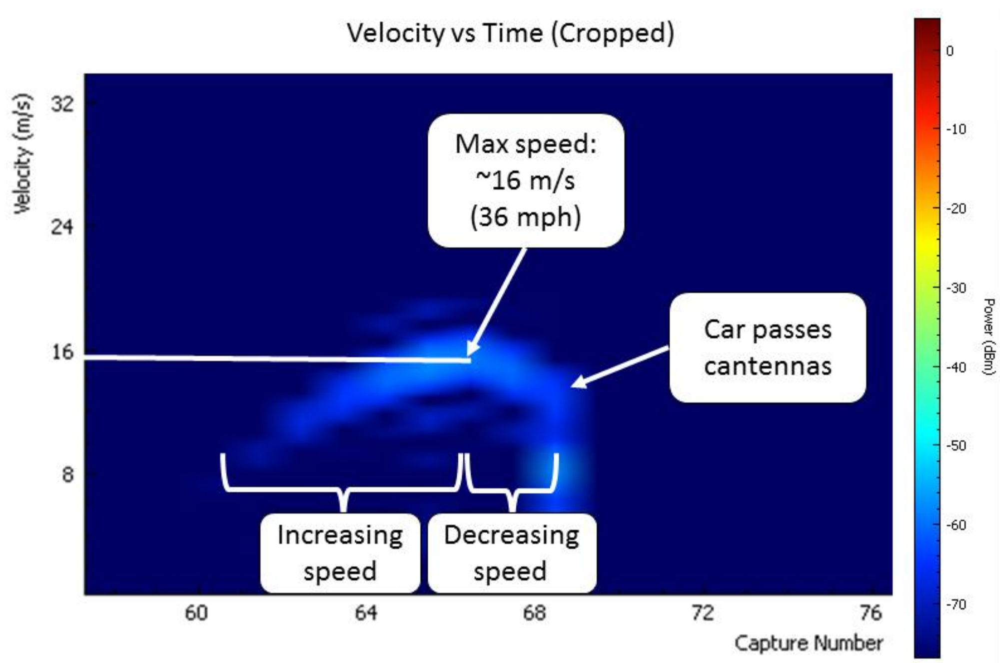

Figure 15 - *Annotated detail of* ***Figure 14***