

# A FREQUENCY ANALYSIS OF THE QUIKSCAT CALIBRATION GROUND STATION

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*Abstract*— To insure the accuracy of the Seawinds scatterometer measurements, BYU is analyzing the signal of the Seawinds on QuikSCAT instrument as received by a Ground Station. Both the power and the frequency of the received signal are analyzed and compared to the power and frequency of the expected, or ideal, signal. The frequency analysis of the ground station data has helped to confirm key satellite operation parameters, including the local oscillator offset between the satellite radar and the ground station. Timing offsets between the satellite and the ground station have also been determined. The analysis in its present state, however, needs further improvement to determine the timing offset to the desired precision.

## Introduction

BYU is aiding in NASA and JPL's efforts to calibrate the Seawinds scatterometer aboard the QuikSCAT satellite. It is doing so by analyzing the frequency and power of the satellite's signal received by a special ground station. This paper describes the satellite and the calibration ground station. It then discusses the frequency analysis, its contributions and its limitations.

## QuikSCAT Satellite

June 19, 1999 saw the successful launch of the QuikSCAT satellite (See Figure 1). Aboard was Seawinds, NASA's pencil beam scatterometer created to replace NSCAT, NASA's original scatterometer which had prematurely ceased operation in 1997. The Seawinds on QuikSCAT mission is a precursor to the Seawinds on ADEOS II mission, which is scheduled to launch in 2002. The basic operation of a scatterometer is to send out chirped pulses at microwave frequencies and receive the reflected pulses after they have been scattered off the surface of the earth.

The primary purpose of Seawinds, is determining the speed and direction of the winds over the surface of the earth's oceans. Scatterometer data has been used in other applications, such as polar ice monitoring and classification, vegetation classification and deforestation detection. Recently, it has even been used for iceberg tracking.

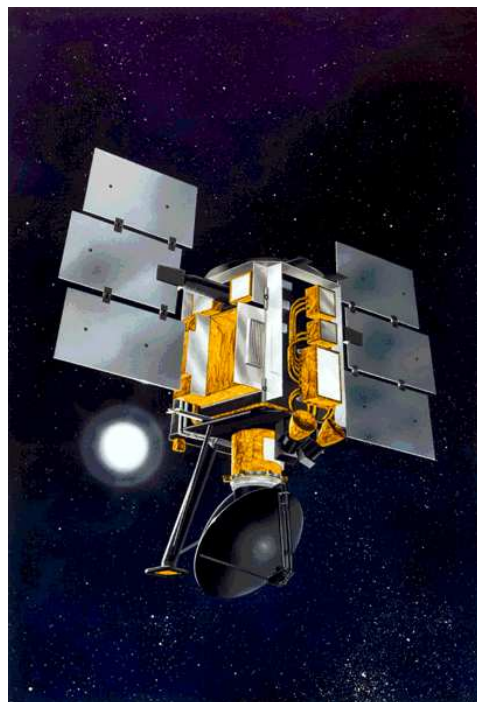


Figure 1: Artist's depiction of QuikSCAT

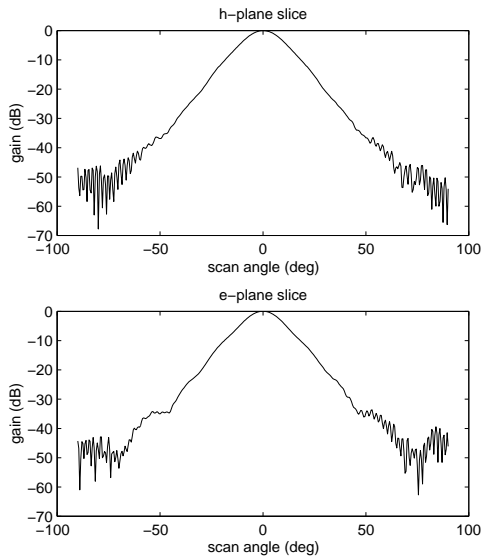
## CGS Description

Scatterometers, by nature, are high accuracy instruments. In order to ensure the accuracy of Seawinds on QuikSCAT operation, NASA Jet Propulsion Laboratory (JPL) designed, built and currently operates a Calibration Ground Station (CGS), located at the NASA White Sands Testing Facility in White Sands, New Mexico.

The CGS is a receive-only system designed to accurately measure the power and frequency of the Seawinds signal as it passes overhead. From these measurements, key instrument and spacecraft parameters, such as attitude and timing can be estimated. Careful attention was paid during the design and construction to ensure highly accurate CGS measurements.

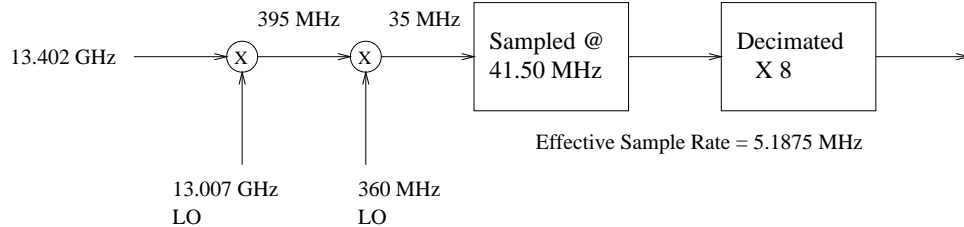
The CGS employs a circularly polarized corrugated horn antenna mounted on an el/az mount which is steered to point toward the spacecraft as it passes through the

ground station's field of view. Just before the anticipated signal reception, the CGS antenna is steered to the calculated direction. The position is then held constant during reception of the data. A wide main beam antenna (see Figure 2) minimizes sensitivity to CGS pointing errors.



**Figure 2:** Azimuth and elevation slices through the CGS antenna gain pattern

In operation, the CGS captures 10 to 20 seconds of data at a time. The frequency plan of the CGS is shown in Figure 3. The 13.402 GHz carrier is mixed down to 35 MHz, at which point it is sampled at an effective rate of 5.1875 MHz. The resulting 200-400MB data per Sea-winds pass is stored locally to disk at the CGS. It is later made available via the Internet for download and analysis. Approximately 4-6 captures are collected every three days at the mid-latitude site of the CGS. Data are analyzed at both JPL and BYU.



**Figure 3:** Frequency plan of the Ground Station

### Frequency Analysis

Along with the power analysis, which compares the power of the signal received at the CGS, BYU conducts a frequency analysis. This compares the frequency of the received signal to that of the expected signal. The frequency analysis begins by finding the precise starting time of the received pulses. First, a datafile in which the amplitude of the received signal is estimated to be fairly large, i.e. captured at a time when the main beam of the instrument antenna passed over the CGS, is selected. A 20 msec window of the data is then extracted and convolved with a 1.5 msec square wave. The result is a series of triangle waves, the peaks of which indicate the centers of the pulses. The maximum of the convolved data then indicates the center of a desired pulse which represents a known point in time from which the start times of all other pulses in the data can be deduced.

Knowing the start times of the pulses, the next step in the frequency analysis is to process the data in 200 msec pieces (2 consecutive raw datafiles) at a time. From each of these 200 msec pieces, 12 consecutive pulses are extracted, each with a buffer of approximately 1000 samples on either end to assure that the pulse is not cut off. The number 12 was selected so as to extract the majority of pulses in the 200 msec of data, but to definitely avoid pulses at the end of the section of data, which might be cut off.

The frequency analysis finds the center frequency of each pulse by first taking the FFT of each pulse. The FFT is then filtered by convolving it with a 375 MHz (the bandwidth of the chirp) wide rect. This, like the determining of the pulse center, produces a triangle wave, the center or maximum of which indicates the center frequency of the chirp i.e. the pulse (see Figure 4).

From the center frequency, the carrier frequency and the doppler frequency due to the velocity of the spacecraft relative to the CGS are removed at this point. This leaves only the commanded doppler, a frequency bias designed to compensate for the doppler frequency caused by the satellite's velocity relative to the footprint of the scatterometer. This commanded doppler varies sinusoidally with time, a result of the helical pattern which the instrument's footprint traces along the surface of the earth.

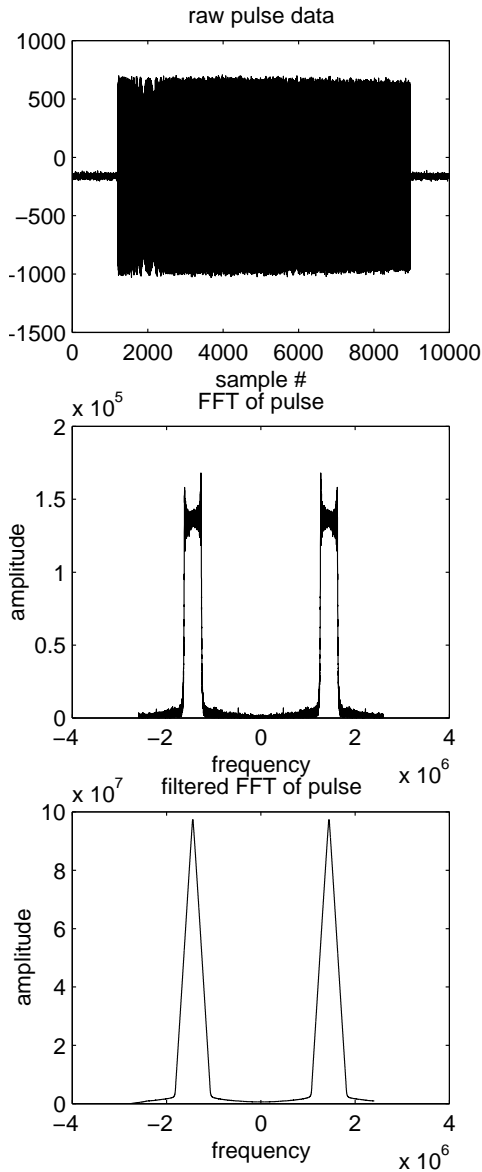


Figure 4: Pulse analysis of received CGS data

The commanded doppler of the transmitted pulse is recorded in a satellite dataset called L1A data, made available by JPL. The L1A data contains all important information about the satellite and the scatterometer, such as transmit frequency, transmit time, estimated position and velocity of the spacecraft, etc. In order to plot the center frequencies and compare them to the actual transmitted frequencies, the indices within the L1A data at which the pulses occur are determined. The frequency analysis finally plots the center frequencies of the pulses versus time, as well as the commanded doppler versus time. Fitting a sinusoid through each of the mentioned sets of points allows for quick and accurate comparison of DC offset, amplitude and phase. A DC offset of the fitted sinusoids indicates a frequency offset in the local oscillators of the instrument and the ground station. A phase difference indicates a timing offset between the instrument and the L1A data. Figure 5 shows the results for data collected in the afternoon of the 19th of december, 1999. Analysis of this data returns a frequency offset of 12 KHz and a time shift of -3 msec.

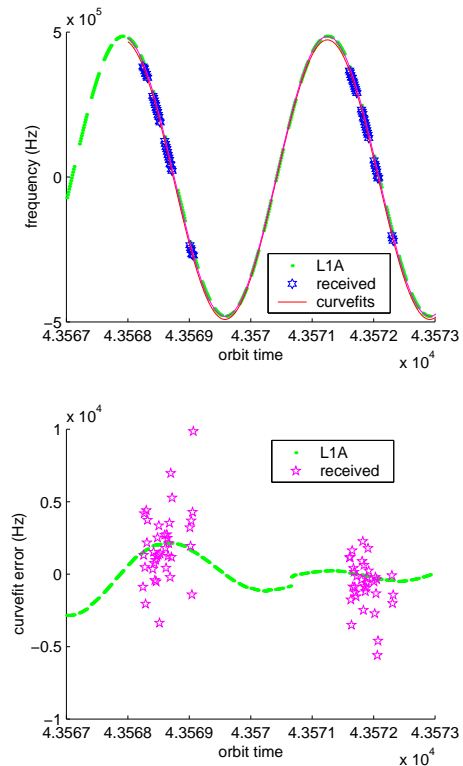


Figure 5: Example results of the frequency analysis. The small dots represent the L1A data, the stars represent the actual received data. The top graph shows the commanded doppler frequency with sinusoids fit to the data. The bottom graph shows the curvefit errors.

### Contributions

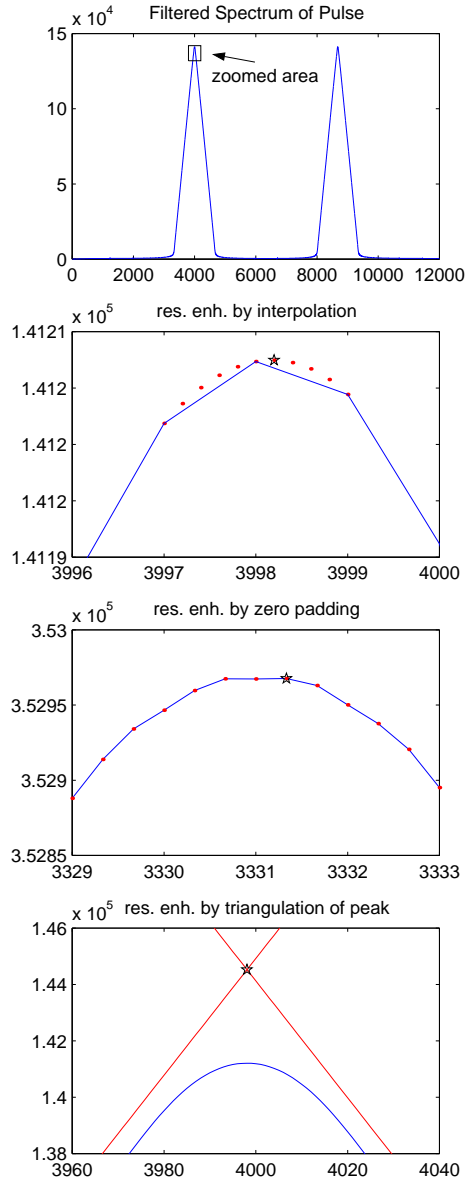
The frequency analysis of the QuikSCAT CGS has provided a confirmation that the Seawinds local oscillator (LO) and the CGS LO are offset by approximately 15 KHz. It has also verified QuikSCAT's timing to within less than 3.0 msec. The frequency analysis has also allowed BYU to confirm the PRI of Seawinds to be 5.3895 msec.

Determining the precise frequency of the CGS will also facilitate matched filtering of the received signal. This involves convolving the received signal with a simulated ideal received signal having the correct frequency. The matched filter will help to pinpoint the timing of the scatterometer.

### Limitations

The frequency analysis in its present state can only determine the timing of the received signal to an accuracy of 3 msec. Current algorithms to infer the attitude of the spacecraft from the ground station signal require knowledge of the instrument timing to within the  $\mu\text{sec}$  range. thus, it is necessary to improve the timing resolution of the frequency analysis. One cause of inaccuracy which was investigated is its limited frequency resolution. The 1.5 msec pulse and the 5.1875 MHz sample rate result in a frequency resolution of around 600 Hz.

A number of techniques were investigated to enhance the frequency resolution. The first was simply to zero-pad the extracted and analyzed pulses. This improved the frequency resolution roughly by the same factor as the zero padding lengthened the extracted pulse data. The second improvement technique was that of interpolating the filtered spectrum of the pulse around the peak. This improved the frequency resolution roughly by the interpolation factor. A third technique was investigated. It involved using the sides of the triangle created by the filtered spectrum to estimate the location of the peak. Examples of the frequency resolution enhancement methods are shown in Figure 6.



**Figure 6:** Frequency Resolution Enhancement Examples. Index of center frequency is marked by the star

### Conclusions

The QuikSCAT CGS frequency analysis has proved useful in confirming important parameters of the Seawinds scatterometer. Although it can determine frequency and timing discrepancies between the satellite and the ground station, further improvement is necessary. The timing accuracy needs to be increased in order to aid in determining the attitude of the spacecraft. This is an area of immediate future research.