SeaWinds on QuikSCAT Calibration Using a Calibration Ground Station

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Abstract— In order to achieve highly accurate calibration of the SeaWinds scatterometer, a calibration ground station (CGS) was constructed by Jet Propulsion Lab (JPL) at White Sands, New Mexico, in association with the QuikSCAT mission. This receive-only system precisely measures the time, frequency, and power of the SeaWinds transmit signal as it passes overhead. From the CGS data, key instrument and spacecraft parameters can be estimated. Since the launch of QuikSCAT in June of 1999, several key calibration results have been obtained, including a one second GPS error, and determination of instrument attitude, timing, frequency, and power.

INTRODUCTION

Like its predecessor, NSCAT, SeaWinds on QuikSCAT has employed the use of a Calibration Ground Station (CGS) to assist in the calibration and validation of its operation. However, the SeaWinds CGS is completely different in its design and operation from the NSCAT ground station. Unlike the NSCAT CGS, which both transmitted and received, the SeaWinds CGS is a receive-only system designed to accurately measure the power, frequency, and timing of the SeaWinds signal as it passes overhead. The SeaWinds CGS has been developed using a simplified hardware design which provides it greater accuracy than the previous system.

This paper will describe the hardware and operation of the SeaWinds CGS. It will then overview some of the methods used in analysis of the data and associated results.

CGS OPERATION

The SeaWinds CGS was constructed to provide a high level of measurement accuracy and stability, while operating autonomously. It is able to measure instrument timing, power, and frequency with great accuracy. Prior to each pass it calculates the predicted location of the instrument and when the pass will occur. It then records the instrument transmissions and stores the data.

SeaWinds operates by transmitting alternately polarized pulses from a circularly rotating antenna. The outer beam, which is vertically polarized, has an elevation angle of 46 degrees. The inner beam, which is horizontally polarized, has an elevation angle of 40 degrees. Operating at a nominal elevation of 800 km, the outer beam covers a swath of 1800 km in diameter, the inner beam covers about 1400 km in diameter, as shown in Figure 1. Thus, the CGS might observe all four beams or only the outer beam on a given pass, depending upon the nadir track of the satellite.

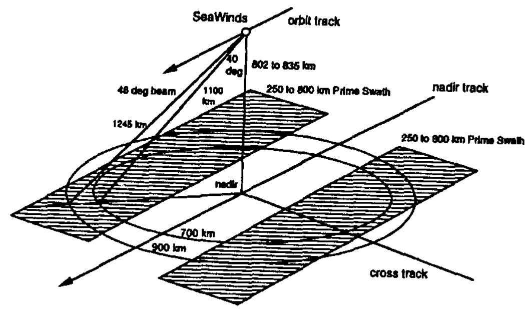

Figure 1: Figure showing the ground coverage of Seawinds.

Just before the satellite travels overhead, the CGS positions its antenna in the appropriate direction. The position is held constant during data reception of each beam. The constant antenna position is made possible due to a wide main lobe, which minimizes sensitivity to pointing errors. With a wide beam antenna, multipath of the signal is a concern. Using data collected in a careful survey of the site a numerical study concluded that multipath is not a concern in CGS data analysis.

Once the pass has been completed the recorded data is then processed and stored. Each pass typically consists of 40 seconds of data which is segmented into files of 0.1 seconds in length. Since the CGS operates autonomously, the data is then posted to a web and ftp server for remote access.

HARDWARE DESCRIPTION

The SeaWinds CGS employs a circularly polarized corrugated horn antenna mounted on an el/az mount. The antenna and pedestal mount are encased by a radome which protects the hardware from outside debris as well as temperature fluctuations. When a signal is received it is downconverted from the transmitted 13.4 GHz to 35 MHz. It is then sampled by the A/D converter and decimated for a

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final sample rate of 5.1875 MHz; the expected bandwidth of the signal is approximately 375 kHz. A block digram of the CGS is shown in Figure 2. Figure 3 shows the antenna and associated RF circuitry.

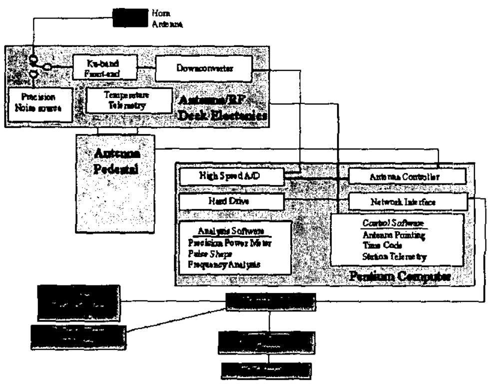

Figure 2: Block diagram of the SeaWinds calibration ground station.

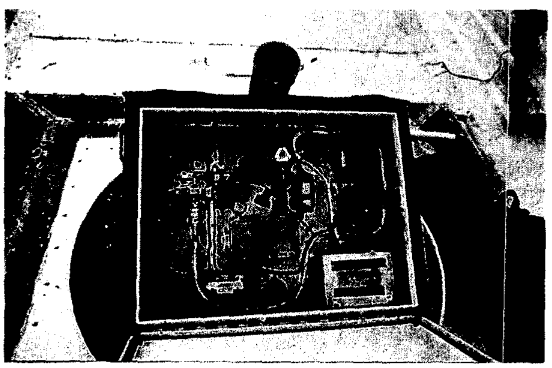

Figure 3: Figure showing the receive antenna and RF hardware at the CGS.

ANALYSIS METHODS

One method of CGS based calibration uses a model to simulate satellite transmissions. A software model has been developed which uses SeaWinds Level 1A telemetry data to emulate the operation of the instrument. When the actual spacecraft passes over the CGS the transmitted microwave pulses are captured and stored; the model emulates these capture files. A comparison of the two data sets analyzes timing, power, and frequency to determine discrepancies between the model and the data. The model is then rerun, perturbing parameters until the difference between the model and CGS data is minimized. The resulting simulation parameters then match the actual data and are used to compute the system calibration.

The data received at the CGS goes through several procesing steps as part of the analysis effort. The digitized signal, which is stored as a voltage, is first converted to a received power, removing the gain of each stage of CGS processing. The recieved pulses and their associated time of occurence are found by windowing the data with a 1.5 ms rect, the approximate envelope of a received pulse. The windowing creates a spike at the location of each pulse, leading to an accurate measurement of pulse timing. Excluding an unresolved long term time bias of about 2.0 ms, accuracy between actual data and the model is within $\pm 50\mu s$.

Figure 4 shows a sample of the received power at the CGS over a time of 0.2 seconds. It shows the receive pulses of both the inner and outer beams. The windowed waveform is super-imposed on the data.

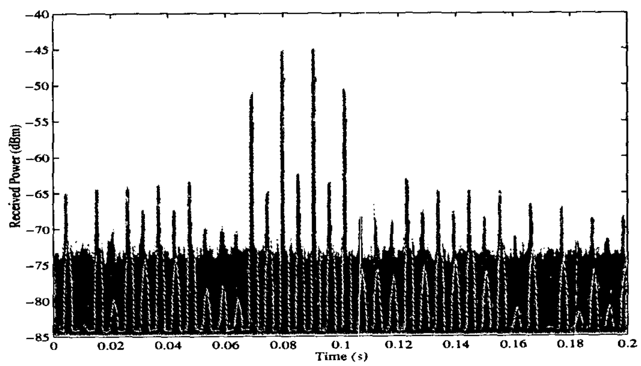

Figure 4: Plot of the windowed triangle waveform superimposed over the CGS received power. The peak of each triangle occurs exactly at the end of each pulse.

Once the locations of the pulses are identified, each pulse is extracted for frequency analysis. The center frequency is found by computing the FFT of each pulse. The FFT is then filtered by convolving it with a 375 kHz wide rect, which is the bandwidth of the linearly chirped pulse, as shown in Figure 5.

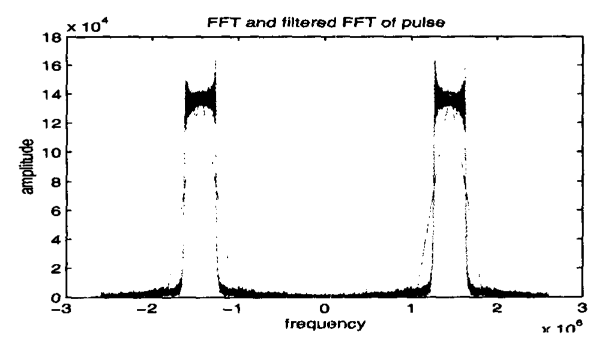

Figure 5: Pulse bandwidth of received CGS data.

From the center frequency, the carrier and the Doppler frequency due to the velocity of the spacecraft relative to the CGS are removed. This leaves only the commanded

Doppler. The commanded Doppler is a frequency bias added by the instrument before the signal is transmitted, designed to compensate for the Doppler shift of the pulse. This commanded Doppler varies sinusoidally with time; a result of the helical pattern which the instument's footprint traces along the surface of the earth.

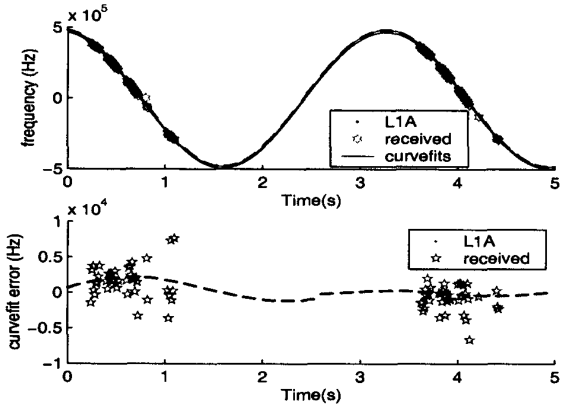

Figure 6: Sample results of the frequency analysis. The small dots represent the Level 1A data, the stars represent the actual received data. The top graph shows the commanded Doppler frequency with a sinusoid fit to the data. The bottom graph shows the curvefit errors.

Fitting a sinusoid through the center frequencies of the received data and the transmitted commanded Doppler as recorded in the Level 1A data allows for timing (phase shift) and frequency (amplitude shift) analysis. Example results are shown in Figure 6.

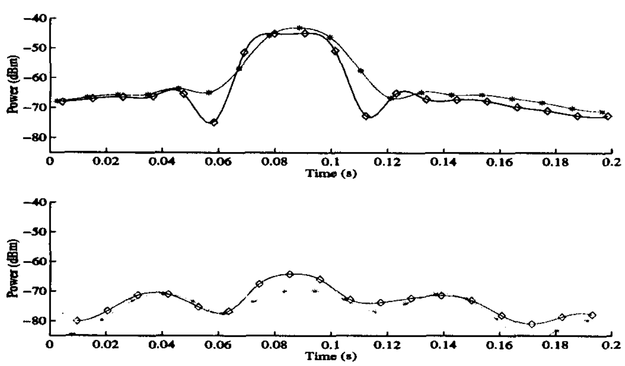

Figure 7: Comparison between CGS received power and model based power. The stars represent model predicted power, the diamonds are CGS determined power. The top subplot is the outer beam (V pol), the lower subplot the inner beam (H pol). The plots show the model curves before the error minimization.

The final analysis is to estimate the power of each pulse received at the CGS and compare it to the model prediction. The power is estimated by finding the its mean-square value of each pulse. Figure 7 shows a comparison between the pulse power for each pulse received at the CGS and the model predicted pulse power. Once pulse power has been determined, the model is then re-run, perturbing attitude parameters to find the best fit; that which minimizes the difference between the two power curves. By minimizing the error calibration of the spacecraft attitude is able to be determined.

RESULTS

The calibration ground station has proven effective in determining satellite and instrument calibration. The following is a list of major accomplishments:

Discovered a 1 second GPS / satellite timing error. When QuikSCAT was launched it initially received reference time incorrectly from the GPS receiver. Time reported to the satellite was in error by one second; the error was quickly corrected.

Verified a PRI of 5.3895 ms and pulse width of 1.49495 ms. By tuning the rectangular window a refined value for the pulse width and pri was obtained.

Verified correct operation of the instrument Doppler Tracking tables. The commanded Doppler, or the instrument Doppler precompensation, is calculated using lookup tables. Analysis of pulses received at the CGS showed the correct operation of the compensation.

Observed STALO drift. Comparison of the frequency of pulses over a long time period showed a small drift of the instrument STALO. The drift has been found to be within specifications.

Verified spacecraft attitude to within ±0.3°. By using the minimization techniques, the roll, pitch, and yaw of the spacecraft have been determined to within 0.3° for each axis. Further refinement is in process.

SUMMARY

The Calibration Ground Station is a valuable asset in ground based calibration for Seawinds on QuikSCAT.
Through its precision design it has provided accurate calibration results. By accurately measuring timing, frequency, and power, a model based analysis has been successful in detecting errors and refining calibration parameters. Further investigation is ongoing, including increased resolution of mentioned parameters, as well as other CGS based results.