NROSS SCATTEROMETER -- AN INSTRUMENT FOR GLOBAL OCEANIC WIND OBSERVATIONS

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Abstract

In 1983, a study for a scatterometer to be flown on the Navy Remote Ocean Sensing System was initiated. This mission will be launched in the late 1980's and will operate for a period of 3 years. This paper briefly describes the design of the scatterometer instrument and discusses some of the technical issues involved.

Introduction

The Navy Remote Ocean Sensing System (NROSS) is a spaceborne ocean remote sensing mission to be launched in 1989 with a planned mission life of three years.[1] There will be four instruments onboard: a microwave scatterometer, a microwave altimeter, a special sensor microwave/imager (SSM/I) and a low frequency microwave radiometer. This paper provides a brief description of the NROSS scatterometer flight instrument and discusses some of the technical issues involved. The details will be deferred to a future paper.

The prime goal of the NROSS scatterometer is to obtain accurate measurements of global oceanic winds that can be useful in oceanography and meteorology. A similar scatterometer flown on SEASAT (SASS) clearly demonstrated that such oceanic wind vector data can be obtained.[2,3] The NROSS scatterometer operates in a manner similar to SASS. It measures the ocean normalized radar cross section (NRCS), σ_o , by illuminating the ocean's surface with microwave pulses and measuring the return signal power. The NRCS is computed using the radar return signal power and the radar equation.[2] A wind retrieval algorithm is then used to compute the wind speed and direction from the measured NRCS. The retrieval algorithm, in general, utilizes a geophysical model that relates NRCS to wind velocity. For example, the SASS-I geophysical model function was employed in the wind retrieval of SASS data.[4]

Due to the biharmonic dependence of NRCS on the relative angle between the wind direction and the antenna illumination angle, the wind direction retrieved is generally not unique for a limited set of σ_o measurements. These multiple solutions are called directional ambiguities.

The SASS wind vector data has been applied to only a limited number of scientific problems because the three-month duration of the data set is not sufficiently long for many studies. Furthermore, most of the wind vectors retrieved by SASS had four directional ambiguities. This limits the application of the data because most studies require unique vector solutions. The NROSS scatterometer is designed to alleviate these problems.

NROSS scatterometer requirements

The mission requirements for the NROSS scatterometer (SCATT) were put forth by the NASA Satellite Surface Stress working group and the Navy.[5,6] The SCATT is to provide accurate, global measurements of the ocean wind field for a nominal 36 month period. Winds over at least 90% of the global, ice-free ocean will be observed at least once every two days.

For NASA users, the SCATT system will retrieve winds with a wind speed accuracy of ± 2 m/s or 10%, whichever is greater, for wind speeds ranging from 3 to 30 m/s. In addition, the instrument design will not preclude measuring wind speeds up to 100 m/s, assuming that the geophysical model function can be extended to such wind speeds. At least 90% of the vector wind retrieved will have no more than 2 directional ambiguities which are approximately 180 degrees apart. The wind direction rms accuracy will be 20 degrees or better for the ambiguity closest to the true wind direction. The wind cell resolution will be 50 km or smaller. The absolute and relative accuracies for the wind cell location will be better than 50 km and 10 km, respectively. In addition, a "rain flag" will be required for any vector wind solution which has excessive atmospheric absorption, and, therefore, may not meet the wind vector accuracy requirements.

For Navy applications, the wind cell resolution requirement will be 25 km or smaller. The rms wind speed and direction accuracies required are 4 m/s and 22.5 deg., respectively.

NROSS scatterometer description

The design of the NROSS scatterometer system is heavily based on the SASS design and the results from several previous studies of spaceborne scatterometers.[7] Table 1 provides a comparison of the nominal system parameters of the NROSS and SEASAT scatterometers. A block diagram of the NROSS scatteometer is shown in Figure 1.

Table 1

A Comparison of the Nominal System Parameters for the NROSS and SEASAT Scatterometers

	NROSS	SEASAT
Orbit Altitude	830 Km	800 Km
Orbit Inclination	98.7°	108°
Operation Frequency	13.995 GHz	14.599 GHz
Receiver Noise Figure	4.0 dB	5.7 dB
Transmitter Pulse Length	5.0 ms	4.8 ms
Transmitter Duty Cycle	31 %	17 %
Peak RF Power Output	110 W	110 W
Antennas	6	4
Number of σ_0 Measurement Cells	26	12
σ_0 Measurement Cell Resolution	25 Km	50 Km
Doppler Filtering	Digital	Fixed-Frequency

The nominal SCATT operation frequency will be 13.995 GHz, compared to the SASS frequency of 14.599 GHz. This change in frequency is in response to the reallocation of the frequency spectrum available for remote sensing.

The NROSS Scatterometer will use six fan-beam antennas with surface illumination patterns shown in Figure 2. The SASS antenna illumination pattern was similar, but without the center antenna beams. The center antennas are used to reduce the nominal number of directional ambiguities to two which are approximately 180 degrees apart. In the baseline design, two of the six antennas will be dual-polarized while the other four will be singly polarized. Therefore, there will be eight antenna beams (see Fig. 1). The baseline antenna configuration and polarization was selected based on extensive system performance simulation study results.

The antenna illumination pattern will be subdivided in the along-beam dimension into measurement cells by Doppler filtering. The NROSS scatterometer will have 26 measurement cells with a sampling size of 25 km. It is envisioned that the σ_0 cells will be combined in retrieving winds at 50 km resolution for the NASA users and will be used to retrieve winds

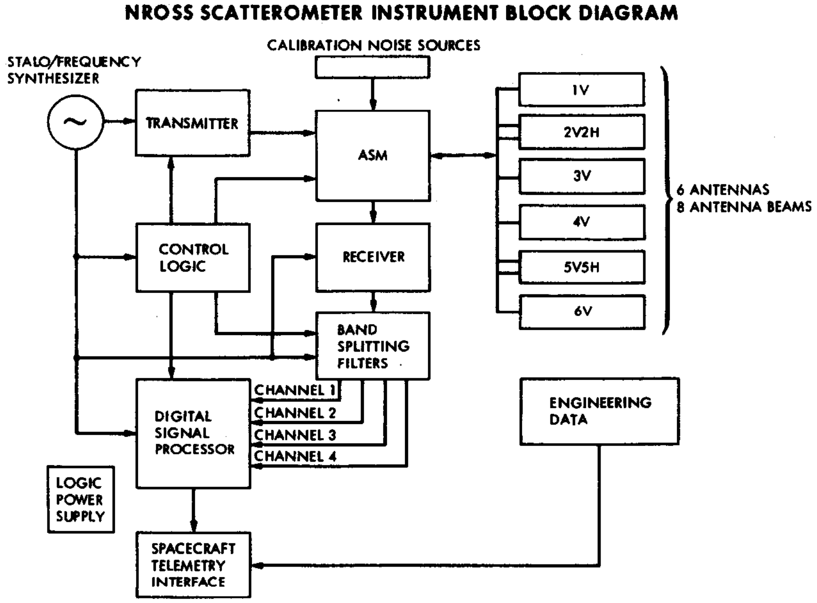

Figure 1. Block Diagram for the NROSS Scatterometer Instrument.

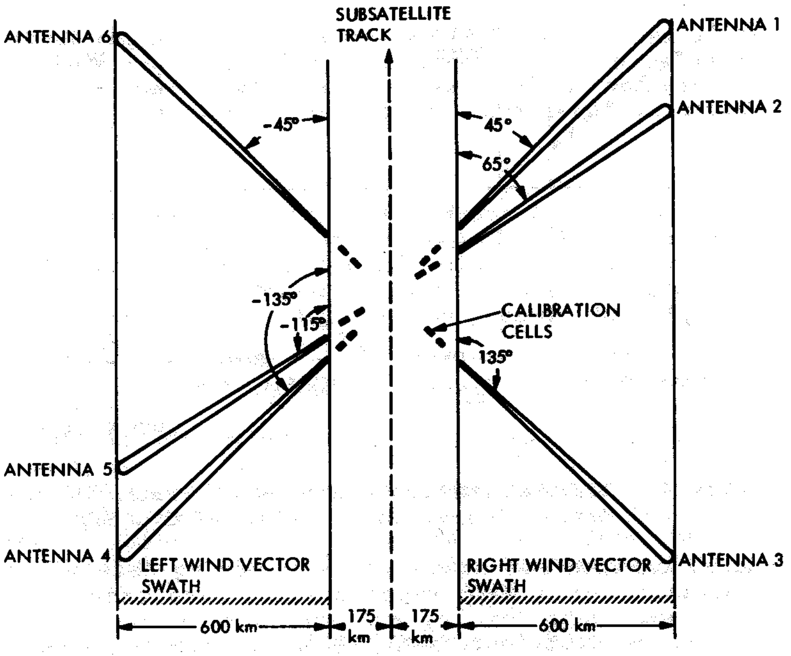

Figure 2. Antenna Illumination Patterns for NROSS Scatterometer.

at 25 km resolution for Naval applications. Two of the measurement cells will have incidence angles of about 11 degrees. The data obtained from these cells will be used for monitoring the instrument[4] performance since at these incidence angles, σ_0 is relatively insensitive to wind speed.[4]

A stable local oscillator (STALO in Figure 1) will provide a stable reference frequency for the transmitter, receiver, and digital processor. The transmitter section is designed with redundant travelling-wave-tube-amplifier units in order to meet the mission lifetime requirements. The transmitter will provide 110 W peak pulses with a 31% duty cycle. The antenna switching matrix (ASM) will sequencially cycle through the eight antenna beams in aproximately 3.75 s to achieve the desired along-track resolution of 25 km. In the baseline design, for each antenna beam, 25 pulses will be transmitted and the return signal powers averaged. An additional set of 4 measurement intervals for each antenna beam, during which pulse transmission is inhibited, will be used to measure system noise.

A GaAsFET receiver will be used to amplify the return signal. The improvement in the receiver technology provides a lower overall system noise temperature relative to SASS (refer to Table 1). The receiver output will be split into 4 channels of different, partially overlapping bandwidths by the band-split filters. The channel splitting will be used to reduce the amount of computation required in the digital signal processor (DSP).

In SASS, the Doppler filtering was achieved through the use of fixed-frequency Doppler filters.[2] The fixed-frequency filters do not take into account the additional Doppler shift caused by the Earth's rotation. This additional doppler shift distorted the pattern of the measurement cells between the fore and aft beams so that one pattern was compressed and the other expanded as illustrated in Figure 3. This led to misregistrations between the measurement cells of the fore and aft beams and the loss of measurement swath width.

In the NROSS scatterometer, Doppler filtering will be performed using an onboard digital Fast Fourier Transform (FFT) processor. The processor will also perform data windowing and power detection. The output of the FFT will be digitally summed over the frequency range of each measurement cell. The DSP will adjust the frequency ranges of the measurement cells in order to compensate for the latitudinal dependence of Doppler effects due to the Earth's rotation. The DSP will model these effects as two half sine waves on a pedestal. A set of parameters for the cells, as well as the orbital period, will be stored in RAM which may be changed as the orbital parameters are varied. The orbital position computation will be synchronized with the equator crossing times. This compensation for the Earth's rotation will ensure that the measurement cells from the diffferent antenna beams will be corregistered and will reduce the loss of swath width.

In order to obtain accurate measurement of the overall system gain, two reference noise sources will be used. The noise power from these sources will be input to the receiver periodically to calibrate the system gain.

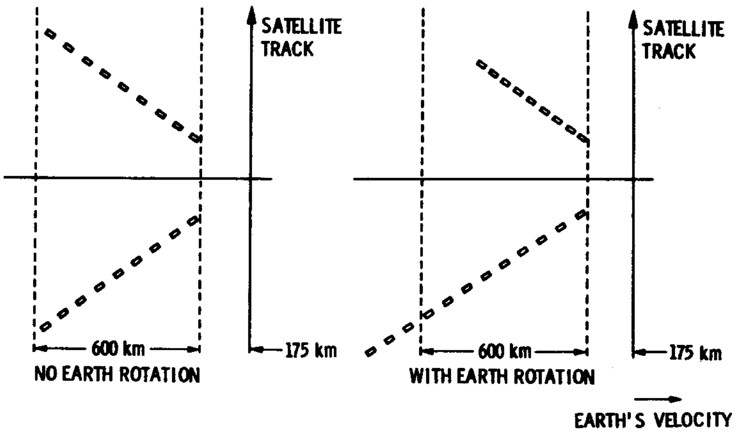

Figure 3. Misregistration and Loss of Swath Due to Earth's Rotation for Fixed-Frequency Filter.

The radar return data, calibration data, and engineering data will be telemetered to the ground for further processing by a NASA research-mode data processing system. The ground system will convert the radar data into σ_0 and then into winds. The wind data, as well as other processed data, will be distributed to the NASA science investigator team via a data management system. The plan is to process these data into winds within two weeks of data reception from the NROSS project. It is envisioned that there will also be a Navy-sponsored operational ground processing system that will process the scatterometer data in a real-time manner for various Naval applications. We will describe the NASA research-mode data system in more detail in a forthcoming paper.[8]

Digital filter performance evaluation

The use of a digital signal processor in the instrument design leads to a number of interesting performance analysis issues. For example, when an FFT is used, spectral leakage will cause interference between measurement cells. This cell-to-cell interference can be reduced by data windowing. It is planned that SCATT will use a generalized Hamming window, applied by convolution in the frequency domain. Windowing, however, increases the variance of the σ_0 estimates (see below). This effect may be reduced by time-overlapped processing of the data at the expense of additional computation.

The performance of a scatterometer is usually characterized by the nomalized standard deviation of the σ_0 measurements, which is the so-called Kp parameter.[9] A comparison of the Kp equation applicable to the analog filters used on SASS and the digital filtering used on SCATT are shown in equations (1) and (2). These equations are discussed in the Appendix.

ANALOG K_p EQUATION

$$K_p = \frac{1}{\sqrt{T_s B_s}} \left[1 + \frac{2}{SNR} + \frac{1}{(SNR)^2} \frac{T_g}{T_s} \left(1 + \frac{T_g B_s}{T_n B_n} \right) \right]^{1/2} \tag{1}$$

DIGITAL K_p EQUATION

$$\begin{aligned} K_p = \frac{1}{\sqrt{T_g B_s}} \frac{1}{MU_s^*} \Bigg\{ & \frac{1}{K_1} \sum_{m=-K_s}^{K_s} \sum_{i=j}^{K_1} \sum_{j=i}^{K_1} \left| \Gamma_{ij}(m) + \frac{1}{SNR} W_s(i-j, m) \right|^2 \left(1 - \frac{|m|}{K_s} \right) \\ & + \frac{1}{(SNR)^2} \frac{T_g B_s (MU)^2}{\left(\sum_{i=1}^{N_c} T_n^{(i)} B_n^{(i)} \right)^2} \Bigg[\sum_{i=1}^{N_c} \frac{T_n^{(i)} B_n^{(i)}}{K_2^{(i)}} \left(\frac{1}{N^{(i)} \overline{U}^{(i)}} \right)^2 \\ & \sum_{m=-K_v^{(i)}}^{K_v^{(i)}} \sum_{j=-K_2^{(i)}}^{K_2^{(i)}} \left| W_n^{(i)}(j, m) \right|^2 \left(1 - \frac{|m|}{K_v^{(i)}} \right) \left(1 - \frac{|j|}{K_2^{(i)}} \right) \Bigg] \Bigg\}^{1/2} \end{aligned} \tag{2}$$

We have verified these equations by Monte Carlo simulations. From these equations, tradeoff studies have been conducted to determine the effects of design parameters on instrument performance. In particular, the trade-offs in processor speed and complexity versus the need for windowing and its effects on Kp have been evaluated.

Summary

This paper provides a brief description of the NROSS Scatterometer system and some of the issues associated with the instrument. It is expected that the NROSS scatterometer will provide accurate, global observations of oceanic winds for a period of three years. These wind data will undoubtedly have significant impact on many studies in marine forecasting of weather and waves, in ocean circulation studies and potentially in climatological studies of the ocean-atmosphere feedback system.

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