The SeaWinds Scatterometer instrument using a pulse compression radar

C. Wu, J. Graf, M. Spencer, C. Winn
Jet Propulsion Laboratory, California Institute of Technology
Pasadena, CA, 91109 U.S.A.

ABSTRACT

The SeaWinds scatterometer instrument is currently being developed by NASA/JPL, as a part of the NASA EOS Program, for flight on the Japanese ADEOS II mission in 1999. This Ku-band radar scatterometer will infer sea surface wind speed and direction by detecting the normalized radar backscatter cross-section over several different azimuth angles. This paper presents the design characteristics of and operational approach to the instrument itself. The SeaWinds pencil-beam-antenna conical-scan design is a change from the fixed fan-beam antennas of SASS and NSCAT. The purpose of this change is to develop a more compact design consistent with the accommodation constraints of the ADEOS II spacecraft. The SeaWinds conical-scan arrangement has a 1-m reflector dish antenna that provides a time shared dual-antenna beam at 40 and 46 degree look angles. The dual-beam operation provides up to four azimuth look directions for each wind measurement cell. At an orbit height of 803 km, the conical scan provides a broad and contiguous wind measurement swath of about 1800 km for each orbit pass. The radar has a linear frequency modulation, or chirp, encoded transmitter waveform. The bandwidth of modulation is 375 KHz nominal. For each transmitted pulse, an onboard pulse compression processor will produce 12 measurement cells of 6 km resolution in range and about 26 kn in azimuth. Key specifications of the SeaWinds instrument and associated tradeoffs and performance will be described.

Keywords: scatterometer, chirp radar, ADEOS, SASS, pencil beam, wind velocity.

I. INTRODUCTION

This paper provides a summary of the National Aeronautics and Space Administration (NASA) SeaWinds Scatterometer Experiment. The SeaWinds instrument is a part of NASA's Earth Observing System (EOS), which comprises a family of instruments that will provide long-term monitoring of the Earth's global environment and processes. The SeaWinds Experiment will measure wind speed and direction over the ocean surface, which affects global heat transport and weather changes. It will be the latest in a series of spaceborne scatterometers, that includes the Seasat-A Spaceborne Scatterometer (S ASS)[1] launched in 1978, the Earth Resource Satellite (ERS-1) scatterometer in orbit since 1991, and the NASA Scatterometer (N SCAT) [2] which was launched in 1996 aboard the Advanced Earth Observation System (ADEOS) satellite of the National Space Development Agency (NASDA) of Japan. The SeaWinds Scatterometer[3], [4] is scheduled to be flown on the ADEOS II satellite in 1999, along with a complementary set of passive and active sensors for Earth observation. They include the Advanced Microwave Scanning Radiometer (AMSR), the Global Imager (GLI), the Improved Limb Atmosphere Spectrometer (ILAS), and the Polarimetric and Directional Earth Reflectance (POLDER).

An overview of the SeaWinds instrument and the associated performance was reported by C. Wu[4]. This paper updates the SeaWinds radar design which was enhanced in 1996 to include a modulated transmitter and onboard processor to produce range compressed radar response.

II. SEAWINDS DESIGN APPROACH

A scatterometer is an active radar that measures the normalized radar backscatter coefficient, or sigma-O, of the ocean surface from azimuth look angles, and thereby to infer the wind speed and direction of that measurement cell. The SeaWinds science objective is to map sea-surface winds to a spatial resolution of 50 km, a wind measurement accuracy within 2 meters per second or 1070 of the wind speed (whichever is greater) for wind speeds from 3 to 30 meters per second, and 20 degrees in direction. The frequency of coverage should be such that more than 90% of ocean surface will be covered every two days. The mission should last for three years or more to monitor seasonal and annual change of global atmospheric and weather phenomena.

The SeaWinds instrument contains three major subsystems. The conical scanning SeaWinds Antenna Subsystem (SAS) developed by Honeywell Inc. in Phoenix, Arizona, the SeaWinds Electronics Subsystem (SES) by Raytheon/E-System in St. Petersberg, Florida, and the Command and Data Subsystem (CDS) developed inhouse at JPL. The three subsystems have a total mass of about 200 kg, and a power consumption of about 250 Watts. While the flight unit is being integrated, a picture of an Engineering Model of the SeaWinds instrument is shown in Figure 1. Specific features of the instrument subsystems and the associated key parameters are discussed in subsequent sections.

2.1 The Pencil Beam Scanning Radar Scatterometer

Recent spaceborne scatterometers, SASS, ERS-1, and NSCAT have employed a "fan-beam" measurement technique. The SeaWinds scatterometer uses conically scanning "pencil-beams" produced by a rotating dish antenna of about 1 meter diameter. The dish has two center feeds and rotates at a rate of 18 rounds per minute. The single-aperture antenna is relatively compact in physical dimension compared with the fro-beam design of NSCAT, therefore better accommodates the configuration of the ADEOS 11 satellite. The elevation or look angles of the two antenna beams are 40 and 46 degrees with respect to nadir. At the planned orbit height of 803 km, the incidence angles of the beams are about 46 and 55 degrees, respectively. The rotation rate of the conical scan antenna is nominally 18 revolutions-per-minute (rpm). The beams are electrically polarized in the horizontal (perpendicular to the incidence plane) direction for the inner or the 40-degree beam, and in the vertical direction for the outer, or the 46-degree beam. The antenna beamwidths produces a surface footprint response of approximately 26 by 36 km in size. The scanning radii of the two beams are about 700 and 900 km. The dual-beam design allows most of the surface cells in the primary radar mapping swath of 200 to 700 km on both sides of nadir to be viewed from up to four azimuth look directions to detect the wind vectors. The radar acquired sigma-O over several azimuth angles shall be tested against a wind model function[5], [6], which characterizes the sea surface backscattering coefficient as a function of wind speed and direction relative to the viewing angle. The result of this processing is a wind velocity map over ocean surface. Wind performance near nadir and the edge of the 900 km swath tend to produce inferior wind vectors for the lack of diversity in azimuth look angles from sensor to the wind cell. However wind cells of lower spatial resolution than the 50 km objective may still be formed in those less favorable locations to produce full coverage swath of 1800 km per orbit track.

2.2 The Pulse Compression Approach to enhance the Beam Resolution

The radar timing includes a transmitter pulse width of 1.5 ms and a pulse repetition interval of 5.4 ms. Pulses for the two beams operate in an interleaved manner, and the echo delay is about 1.5 times of the pulse interval. The antenna scan rate and the pulse interval lead to a beam spacing of 22 km along-track, and 15 or 18 km in azimuth for the inner or outer beam. The beam sample space provides proper overlap of the beam footprints, of dimension about 26 by 36 km, to facilitate subsequent beam resampling operations.

The NSCAT experiment of 1996 to 1997 has shown a great potential of science return with a sigma-O resolution, to the order of 10 km to map local wind features and to monitor sea ice over the pole areas. To serve such applications, the radar specifications of SeaWinds was revised in 1996 to add a modulated transmitter waveform and a corresponding onboard pulse compressor. A linear FM chirp modulation of 375 KHz over the 1.5 msec pulse was applied. The dechirp pulse compressed range elements are integrated into 12 cells of a nominal 6 km each in sulfate range. Data of each cell is encoded in a (4,8) pseudo floating point format. The beam or cell resolution in the cross-range, or azimuth, of about 26 km, is unchanged.

2.3 Operation Control and Telemetry

To accommodate for the Doppler frequency shift over the conical scan, the onboard Control and Data Subsystem, CDS, reads the azimuth encoder in SAS and then computes the expected range delay and Doppler shift in real time to command the timing gate and the transmitter frequency of the radar to compensate for the time delay and frequency shift effect. The CDS also sends the packetized telemetry to the host spacecraft to be downlinked to earth. The instrument datarate is within 40 kbits per second.

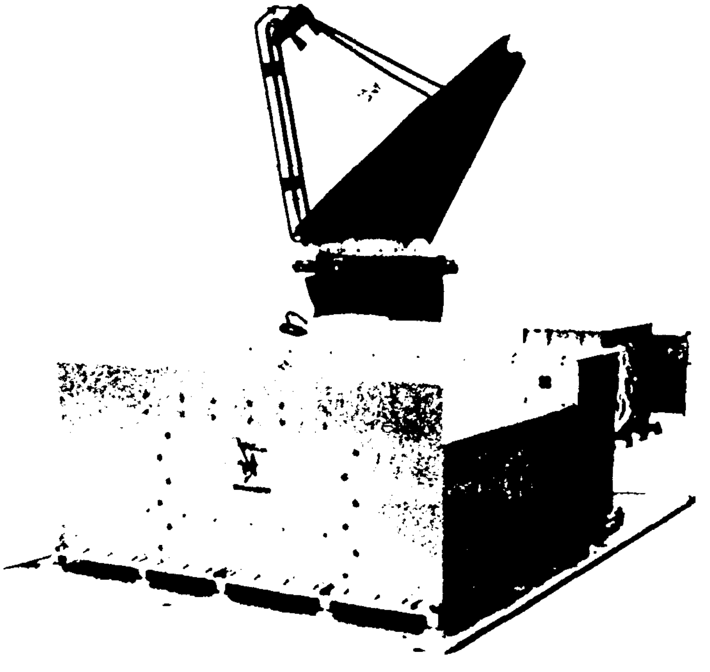

Figure 1 The Engineering Model of the SeaWinds Instrument

2.4 Key Parameters

Table 1 summarizes the key radar parameters of the SeaWinds instrument.

Table 1. SeaWinds Instrument Key Parameters

Parameter	Value
Instrument frequency	13.402 +/- 0.5 GHz
Expected sigma-O range	-37 to -2 dB
Number of Beams	2
Look angle to nadir	40 deg (Beam A) and 46 deg (B)
Antenna beam width	1.6 deg (cl) x 1.8 deg(az), Beam A 1.4 (cl) x 1.7 (az), Beam B
Two- way Footprint	30 km (rg) x 24 km (az), Beam A 36 km (rg) x 26 km (az), Beam A
Polarization	Hat 40 deg beam, Vat 46 deg
Antenna spin rate	18 rpm
Antenna gain	>39 dB
Antenna peak sidelobe	-15 dB or below
Transmitter power	11 OWTWTA
Transmitter pulse width	1.5 ms
Transmitter modulation	linear FM chirp at 250 kHz/msec
Transmitter pulse period	5.4 msec nominal
Transmitter Doppler tracking	+/-500 kHz in transmitter
Receiver sensitivity	< -135 dBmW
Receiver dynamic range	>45 dB
Receiver noise Figure	4.5 dB or less
Echo detection filter bandwidth	1 MHz for noise filter 100 KHz nominal up to 150 KHz for echo filter
Echo filter pulse compression	FM dechirp with 12 echo cells over the selected echo bandwidth
Receiver data format	(8,4) pseudo real for each echo cell (12,4) pseudo real for noise sample
Absolute prelaunch gain knowledge	<1 dB
Gain uncertainty and drift (6 month)	<0.5 dB
Engineering Telemetry accuracy	< 2 %
Absolute calibration pre-launch	<1 dB
Instrument radiometric stability	0.15 dB

III. ECHO ESTIMATION & CALIBRATION

3.1 Echo Resolution Cells

Rayleigh noise is associated with narrow-band scattering from distributed scatters, which randomize the amplitude and phase of the return echo. Smoothing of the echo into resolution cells is a routine practice in remote sensing radar. For SeaWinds design, a transmitter modulation of 375 KHz for a 1.5 msec pulse width is specified. The dechirped impulse responses is approximately 0.5 km on the surface. These elements are integrated into 12 cells of 6 km resolution of each cell. The effective echo gate width, which is the difference between the echo gate width and the pulse width, may be commanded to take a value between 0.1 and ().6 msec. The system design keeps the number of cells per radar pulse in telemetry to be a constant value of 12. The spatial resolution and the amount of integration for Rayleigh noise reduction of each cell can change according to the echo gate selected.

To obtain an unbiased echo estimation, the noise interference in the detected echo should be removed. The noise may come from several sources, such as thermal noise and background radiation. To estimate the noise level, the SeaWinds radar receiver contains two echo power detection channels of different frequency bandwidth. The first one is the pulse compression multi-cell echo filter channel, and the second one is the single cell broadband filter (or briefly the noise filter) which detects the power of echo plus a 1 MHz noise band. The net total echo power can then be estimated from output of the two filters. The noise component within each of the 12 echo cells can then be subtracted to produce an unbiased echo power estimate for each integrated range cell.

3.2 Radiometric Gain Calibration, Data Verification and Products

To produce the normalized radar back-scattering cross-section, or sigma-O, the echo estimate shall be normalized by factors including the transmitter power, the range effect, the receiver gain, the effective area of the range cell, etc., according to a standard radar equation.

Calibration of the radar sigma-O of the 12 cells depends most critically on accurate knowledge of 1) the product of the radar transmitter power and the receiver gain, and 2) the center of the antenna gain when projected on the surface. The SeaWinds electronics has a loop-back calibrator in the transmitter and receiver waveguide assembly. The loop-back power of the transmitter pulse through receiver and processor is monitored periodically to serve as calibration reference for ground data processing. The location of the center of the beam depends on the orbit and attitude knowledge, and may be refined by tracking the echo power profile over the 12 range cells over one or more scan circles.

IV. GROUND DATA PROCESSING SYSTEM

The absolute calibration of the radar system and the formation of an accurate sea wind scattering model function will be made after the instrument is launched and is put into operation. Distributed nature targets and wind statistics will be important data sources for such in-flight calibration and verification.

SeaWinds standard data products are summarized in the following categories: Level 1 B, global sigma-O map over sea, land, and ice, radiometrically calibrated based on engineering telemetry and radiometer derived atmospheric attenuation, and estimated beam center; Level 2, chosen wind vectors and the associated set of ambiguous solutions, Level 3, wind vector field. Special data products, such as the intermediate coregistered sigma-O cells, may also be available(Level 2A).

VI. SUMMARY

The SeaWinds instrument is being developed now according to the architectural design described herein. The implementation approach has strong heritage from the current NSCAT and other related satellite programs. The expected performance meets the science requirements, and the extended data acquisition swath indeed offers a potential for global wind mapping on a nearly daily basis. The pulse compression mode of radar also allows spatial resolution approaches to be less than 10 km.

ACKNOWLEDGEMENTS

This research described in this paper was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under a Contract with the National Aeronautics and Space Administration. The authors wish to thank the colleagues in JPL, Honeywell, and Raytheon E-System for collaboration, and especially the E-System Team on their most recent effort to incorporate linear FM pulse modulation and the associated onboard compression.

Reference

[1] Jones, W.L. L. Schroeder, D. Boggs, E. Bracalente, R. Brown, G. Dome, W. Pierson, and F. Wentz, "The Seasat-A satellite scatterometer", J. Geophysical Research, Vol. 87, C5, 3297-3317, April 1982.
[2] Naderi, F. M., M.H. Freilich, and D. Long, "Spaceborne radar measurement of wind velocity over the ocean - an overview of the NSCAT scatterometer system", Proc. IEEE, 79, 850-866, 1991.
[3] Freilich, M.H., D. Long, and M. W. Spencer, "A scanning Scatterometer for ADEOS II -Science overview", IGARSS'94 Proceedings, August 1994.
[4] Wu, C., J. Graf, M. Freilich, D. Long, M. Spencer, W. Tsai, C. Winn, D. Lisman, "The SeaWinds Scatterometer Instrument" IGARSS'94 Proceedings, August 1994.
[5] Wentz, F. J., S. Peteherych, and L.A. Thomas, "A model function for ocean radar cross-sections at 14.6 GHz", J. Geophys. Res., 89, 3689-3704, 1984.
[6] Young, J. D., and R.K. Moore, "Active microwave measurement from space of sea-surface winds", IEEE J. Ocean. Eng., OE-2, 309-317, 1977.