# Initial Results from the Deployment of an Ultra-Wide Band Scatterometer

Ryan Reed, David G. Long, David V. Arnold, and R. Scott Collyer
Brigham Young University
Electrical and Computer Engineering Department
459 Clyde Building, Provo, UT 84602

*Abstract* - An ultra-wide band scatterometer (Y-Scat) has been developed to support tower based studies of the air-sea interface. These studies are designed to improve the present understanding of the relationship between the normalized radar cross section ($\sigma^0$), local wind speed, wave height, and wave slope. The scatterometer utilizes an ultra-wide band design (2-18 GHz), which provides complete and essentially simultaneous coverage over this frequency band. The antenna system used on Y-Scat is designed to produce a frequency independent illumination pattern over this operating range. The positioning system allows the radar to rotate 360° in azimuth and from nadir to above horizontal in elevation. The system also includes an integral weather station which collects relevant environmental data. Preliminary analysis of results obtained from initial engineering deployments are used to study the dependence of the wind exponent on Bragg wavelength.

## INTRODUCTION

Microwave radars have been used to probe various aspects of the ocean's surface for several decades. Practical applications, such as spaceborne measurements of surface conditions, depend heavily on our understanding of the physical processes that produce the microwave scattering observed by radars.

Single frequency radar systems are limited in the portions of the ocean wavelength spectrum that can be probed. This limits the aspects of the geophysical model function that they can investigate. This limitation is compounded by the fact that the region of the ocean wavelength spectrum probed by most microwave radars (approximately 0.5 to 20 cm) is in the transition region between capillary and capillary-gravity waves, where the dependence of $\sigma^0$ on local wind speed varies significantly with other parameters such as stability, and possibly, long wave field. A multi-frequency, variable incidence angle scatterometer can provide essentially complete coverage of the ocean spectrum over this range and, hence, provides valuable insight into new aspects of the geophysical model function.

The Y-Scat radar system was developed in order to expand current studies of ocean microwave scattering. This paper describes the system and presents preliminary results from an engineering deployment. The first section covers the physical details of the radar systems, while the next section covers the control, signal processing, and data acquisition systems. The final section presents some preliminary data collected during our initial deployments.

## RF SUBSYSTEMS

### Transmitter

Y-Scat is an ultra-wide band radar with an operating frequency that can be varied continuously from 2 to 18 GHz. The heart of the RF sub-system is an HP-83590A microwave generator and a variable YIG filter (see Fig. 1). The generator is controlled via an HPIB link to an embedded controller. The generator can be rapidly switched to any frequency from 2-18 GHZ.

From the RF generator, the signal is split between the transmitter and the receiver using a 3 dB power splitter. The transmitter signal is amplified to 23 dBm and either routed through the antenna or through the internal calibration circuit. If the calibration circuit is selected, the signal is attenuated by 60 dB and then split evenly and coupled into the receiver using 10 dB directional couplers.

The transmit antenna is a custom designed 36" elliptical figure reflector that gives a nearly constant 5 degree beam width over most of the operating bandwidth from 4 - 18 GHz of the radar system (see Fig. 2). The feed is a dual polarization, sinuous feed in order to minimize VSWR changes over the large frequency range. This special antenna design is crucial to making broad spectrum measurements of the same size surface patch.

The receive antenna is a quad-ridge, dual-polarization rectangular horn with an aperture of 10 x 10 cm. This provides a broader pattern than the transmit antenna to help minimize the effects of pointing alignment errors.

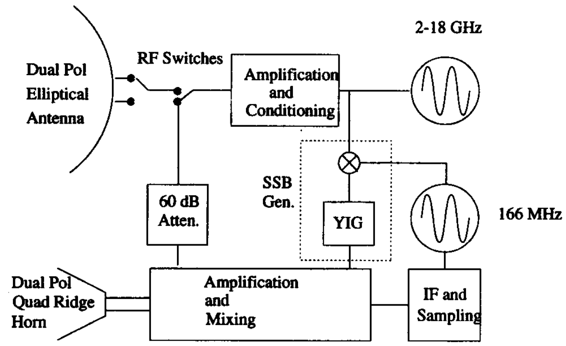


Figure 1: Y-Scat block diagram.

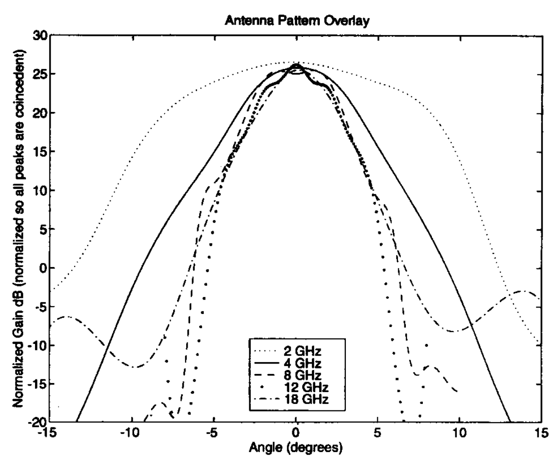


Figure 2: Two way antenna patterns.

### Receiver

The receiver is a dual pol system designed to maximize the system SNR. After each polarization is received and amplified using low noise amplifiers, both channels are mixed down to the IF in a single side band mixing operation.

The SSB LO is generated by mixing the RF carrier with the desired IF signal in a normal double sideband mix, and then filtering off one of the sidebands using a voltage controlled YIG filter. The YIG filter has a 30 MHz 3 dB bandwidth that can be varied continuously from 2 to 18 GHz. This provides about 60 dB of carrier and sideband suppression over the entire operating range.

0-7803-1497-2/94 $4.00 © 1994 IEEE

### IF Circuit

The IF sub-system is designed to operate at a constant frequency regardless of the operating mode of the RF sub-system. The IF signal source is an HP-86568B signal generator which can be remotely set. Under normal operation the IF is 166 MHz.

The horizontal and vertical signals are received from the RF system, split into I and Q signals, and mixed down to baseband. The baseband signal is high pass filtered at 1 Hz to eliminate antenna feed through and any returns from stationary targets, and then amplified from 0-60 dB using a programmable filter-amplifier. The signal is then digitized by the computer/controller. The entire SSB IF circuit provides an image rejection of more than 40 dB.

## CALIBRATION, CONTROL, AND PRE-PROCESSING SUBSYSTEM

### Calibration

The ultra-broadband nature of the radar system presents a formidable calibration challenge. Not only do the various system gains drift with temperature, but this drift is frequency dependent. Temperature drift is minimized by a temperature control system that can maintain the RF components at $25° \pm 5°$ C under normal operating conditions. The residual system drift requires that the Y-Scat system be continuously calibrated while in operation.

The internal calibration is accomplished by routing a portion of the transmit signal through the entire transmit-receive chain. This is done at each frequency of operation just before and just after each $\sigma^0$ measurement, and thus allows the true transmit power for each measurement to be determined with great precision.

Absolute calibration is accomplished before and after deployment on the BYU antenna range. The entire radar system is assembled and the two way antenna patterns are measured along with the absolute system gain. The calibration target is a 4" aluminum sphere mounted on a device to that moves the sphere back and forth in order to cause a Doppler shift in the received signal. This information, along with the internal calibration measurements from the field deployment allows the absolute system gain to gain to be determined to within 0.5 dB and relative gain to within 0.1 dB.

### Control

Since Y-Scat is designed for long unattended deployments, the control and data processing sub-system is crucial. Y-Scat is controlled by a 486 PC, which can be remotely controlled via a 9600 baud telephone link.

The PC controls all of the signal generators, switches, and programmable filters in the IF subsystem and can be reconfigured on the fly to perform many different measurements. The RF system is controlled by an embedded Kila v80 microprocessor card which receives instructions from the PC via an RS-232 serial link. The Kila also monitors system parameters, controls the digital switches and provides the analog control signal for the YIG filter via a D/A. This frees the main PC controller to do data pre-processing and other control functions in a real time manner.

The PC also controls the positioning of the radar. A customized two axis mounting system allows the radar to be pointed in almost any direction from $\pm 180°$ in azimuth and from $+30°$ to $-90°$ (nadir) in elevation. Two digitally controlled stepping motors are used to position the radar system. Pointing control is accurate to 0.1 degrees. Direction is measured using twelve bit absolute encoders mounted directly to the support shafts.

### Data Processing and Storage

Under normal conditions, baseband signals produced by the IF subsystem are sampled via sample and hold circuitry at 2 kHz on each of four signal lines (in phase and quadrature phase for both h and v pol returns.) Since this data rate is unsuited for extended unattended deployments, it is reduced by pre-processing the data.

First and second moment estimation methods are used to calculate and store signal power, Doppler centroid, and Doppler bandwidth at 10 Hz. This reduces the total data rate from +50 MBytes per hour to about 1 MByte per hour. Although under normal operating conditions, the radar data will be collected weekly on tape, an onboard 1.2 GByte hard drive and 2 GByte Digital tape drive will hold up to 4 weeks worth of data.

### Environmental System

Y-Scat is designed to support data intensive studies of ocean scattering and the air/sea interface in general. It includes a full complement of environmental sensors. The most crucial measurement for interpreting the radar data is the surface wind speed. This is assured by the use of two anemometers that return 30 second averages of direction and speed to the computer/controller. The system also measures air temperature, humidity, and water temperature at 30 second intervals.

## PRELIMINARY RESULTS

Ocean surface anemometry is one of the most important applications of ocean scatterometery. In order to maximize the sensitivity of the scatterometer to surface winds, it is necessary to determine the operating frequency which best responds to wind speed. It has been demonstrated that at moderate incidence angles, $\sigma^0$ is dependent on the surface spectral component that is in Bragg resonance with the incident electromagnetic radiation (Wright, 1966):

$$\sigma^\circ = 16k_m^4 \langle G(\phi)\left[\Psi(k_B,\theta) + \Psi(k_B,\theta+\pi)\right]\rangle \tag{1}$$

where $\Psi(k)$ is the spectral density of the surface displacement, $G(\phi)$ depends on polarization and incidence angle, $k_m$ is the incident microwave number, and $k_B$ is the wavenumber of the Bragg resonant ocean wave.

Therefore, the problem is one of finding the response of the capillary waves to the wind speed. A scatterometer can probe various surface wavelengths by varying incidence angle and frequency.

Y-Scat was deployed from November 11 to December 18, 1993 at Utah Lake, a local fresh water lake in Provo, Utah. Measurements were designed to measure the wind speed sensitivity of the wavenumber spectrum. Measurements were made at 3, 7, 11, and 15 GHz at 40, 50, 60, and 70 degree incidence angles. For purposes of the sensitivity study, only measurements at 40 and 50 degrees were considered in order stay in the predominantly Bragg scattering regime (see Fig. 3).

Wind speed sensitivity is defined by assuming a power law relationship between wind speed and $\sigma^0$

$$\sigma^\circ = AU^\gamma. \tag{2}$$

Thus, in log-log space, $\gamma$ is the slope of the $\sigma^0$ verses windspeed plot. As shown below, $\gamma$ is strongly dependent on frequency and incidence angle, and therefore, on surface wavelength.

Many different forms have been proposed for $\gamma$ (Long et al., 1991). Almost all of them fix $\gamma$ to some value around 1. However, there is experimental data (Colton, 1989, Unal et al., 1991) that suggests $\gamma$ is a function of wavenumber, with a peak around 3 cm (see Fig. 4) and an asymptotic value between 0.5 and 1 for long wavelengths.

When the wind exponent, as computed from Y-Scat data and from Unal et. al., is plotted against the Bragg wavelength (see Fig. 4), it suggests using the computational form

$$\gamma(\lambda) = \alpha\lambda e^{-\lambda/\vartheta} + \nu \tanh\lambda \tag{3}$$

in scatterometer models. There is some physical justification for the wavelength dependence of $\gamma$ given by Eq. (3). At small wavelengths, turbulence and viscous dissipation effects become large in compared to wave height. At longer wavelengths, energy is transferred from the wind primarily through nonlinear wave interactions from smaller waves. Further investigation is continuing.

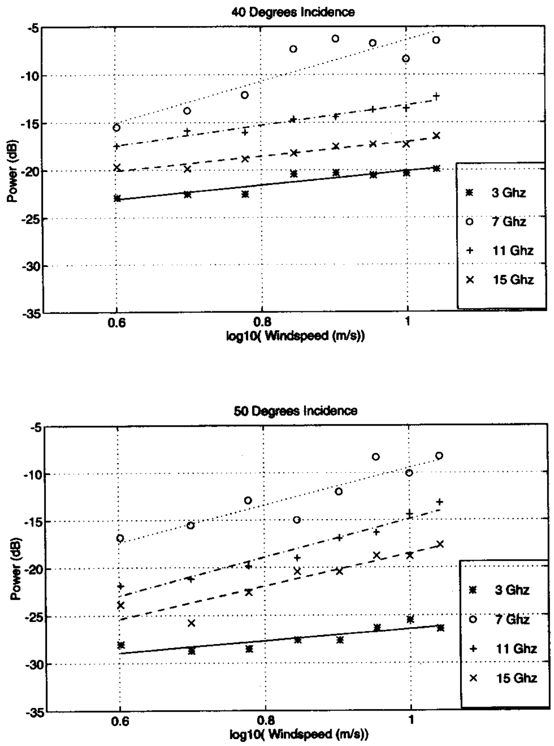


Figure 3: Return power versus windspeed for 3, 7, 11, and 15 Ghz at 40 and 50 degrees incidence. Some of the lines have been moved vertically for clarity.

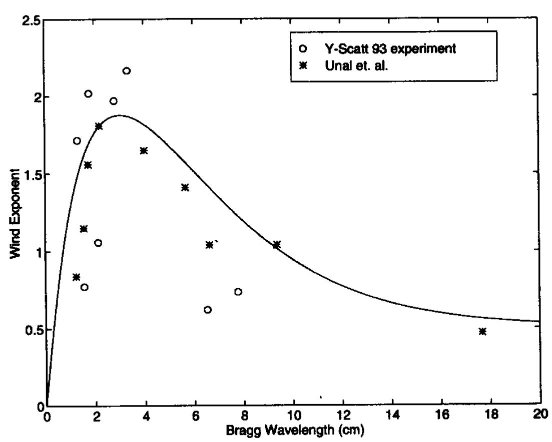


Figure 4: Windspeed exponents verses Bragg wavelength. The solid line is Eq. (3) using $\alpha = 1.25$ , $\nu = 0.5$, and $\vartheta = 3$.

## SUMMARY

The Y-Scat scatterometer is capable of probing a large range of the ocean spectrum. It will be used for comprehensive studies of the ocean-electromagnetic interaction. Its frequency and directional agility will make it very useful in better understanding the physical phenomena associated with the geophysical model function that relates $\sigma^0$ with surface conditions including wind speed, wind direction, surface stability, etc. In order for spaceborne radar anemometry and other remote sensing applications over the ocean to be of practical use, this relationship must be better understood. The results from Y-Scat will be useful in the design of future remote sensing devices as well as in the interpretation of data collected from those currently in operation.

## REFERENCES

Colton, M.C.,"Dependence of Radar Backscatter on the Energetics of the Air Sea Interface," Dissertation, Naval Research Laboratory, Monterey, CA, 1989.

Long, S.R., L.F. Bliven, Q. Zheng, and X. Yan,"On the Ocean Surface Microscale Features and Remote Sensing of the Oceanic Surface Wind," tech. rep., Laboratory for Hydrospheric Processes, NASA Goddard Space Flight Center, Wallops Flight Facility, Wallops Island, VA, September, 1991.

Unal, C.M., P. Snoeij, and P.J.F. Swart,"The Polarization Dependant Relation Between Radar Backscatter from the Oceans Surface and Surface Wind Vector at Frequencies Between 1 and 18 GHz," *IEEE Transactions on Geoscience and Remote Sensing*, Vol 29 (1991):621-626.

Wright, J.W.,"Backscattering from Capillary Waves with Application to Sea Clutter," *IEEE Transactions on Antennas and Propagation*, Vol 14 (1966):749-754.