Multi-frequency HF Radar Measurements of Ocean Current Shear Using a Digital Transceiver

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Outline:

• A. HF Radar Project Background
• B. Octopus 8-channel PCB General Purpose Transceiver
• C. HF Radar Surface Current Measurement
• D. Multi-frequency Vertical Current Shear
• E. Wind-Speed Estimates from Current Shear
A. Background : ISR HF Radar Projects

- **NEW HF RADAR FOR REMOTE SENSING - ONR 32: SBIR**
  - *Wind speed mapping from multi-frequency HF radar ocean current shear measurements*

- **ONR 31: Digital radar transceiver PC Card design**
  - Based on Rubidium clock for multiple site simultaneous ops
  - Supporting bistatic HF sea scatter model validation

- **NSWC: Multiple-frequency ship RCS measurements**
70’s & 80’s Journal Publications on HF Radar

  – Use of Approach/Recede 1st-order Bragg ratio to determine wave/wind direction in OTH mode
  – First unclassified paper featuring OTH HF data collected using ionospheric propagation.

  – Several examples of mapping of movement of storms through the Atlantic

  – First 2nd-Order Doppler sea scatter published model using E.M. 2nd order effects only
  – Allows retrieval of directional components of wave spectrum, est. of RMS wave height

  – 2-30 MHz SCI Radar 1st order Bragg line amplitudes vs azimuth
  – Phillips resonances at angles relative to wind direction vs wave number

  – First time OTH radial current components used to locate major current field: the Gulf Stream
B. Introduction to the Octopus Radar Transceiver PCI Card

- **Windows Environment**, Programmable waveform generation
  - coupled DDS pair for (1) waveform and (2) coherent A/D clock generation
  - Programmable Frequency set & pulse envelope with onboard mixer for spectrum control:
    - Simple Pulse - envelope programmable (all waveforms)
    - FM Chirp or FM CW
    - Phase Coded
    - Random Noise - repeated pulse to pulse for FIFO averaging or variable
      - Record transmitted signal option using 1 of 8 channels, important for Noise Radar
- 8-channel 100-MHz A/D receive capability
- FPGA Pair for housekeeping & real-time processing (2 pair of 4 parallel channels)
- Direct Digital Down conversion Pair for programmable digital filtering
  - Pair of DDC l chips, increases sampled dynamic range by ratio of SR/DDC-BW
- FIFO pair for averaging digitized waveforms
  - additional increase in dynamic range and reduction in recording volume, to PRF desired
- DMA transfer to PC memory currently for storage
- Onboard GPS receiver for TC Oscillator lock or external ISR Rubidium Clock
  - *Separate ISR Exciter card option for bistatic multi-site operation*, interleaved pulse ops on GPS time
  - Each of a sequence of sites has its own UT transmit time slot
8-channel *Octopus* Digital Radar Transceiver

- Variety of output signal available from Top Auxiliary SMA/Bracket
  - Pulse Envelope, DSS output direct & mixed, receiver blanking pulse, trigger, GPS 1-PPS
- Inputs to 8 100-MHz A/D converters
- SMA connector pair for clock & trigger input/output
Multi-frequency HF Radar

(A) Receive Array:
4, 8, 16, 32 Elements (Multi-frequency)

Simultaneous Monostatic & Bistatic Reception

(B) 8 Line-Driving Low-Noise Amplifiers, 3-30 MHz Filters

(C) Digital Transceiver
≤120-MHz A/D rate, Digital Filter to RF bandwidth

(D) GPS-Rubidium Clock
100-MHz A/D Clock Source

(E) Record to RAM drive, store to Disc

(F) High Power Amplifier
Class-A/B

(G) GPS-Rubidium Clock
F_o-MHz Exciter Clock Source

(H) DDS Exciter
Waveform to HPA

(I) Monostatic LPA Transmit Antenna

(I) Bistatic Transmit Antenna

HPA
2-Site Bistatic Coverage Example: Florida Keys, 1-km Monostatic Resolution
C. HF Radar Ocean Current Measurement

How HF Radar Measures Ocean Currents
(Harlan, NOAA ETL)

First-Order Sea Echo with No Current
Transmitted signal
Receding wave echo
First-Order Sea Echo with Advancing Current
Transmitter frequency

\[ \Delta f = \frac{2v_{cr}}{\lambda} \]

DOPPLER SHIFT

Multi-frequency HF Radar
D. Vertical Current Shear Measurement

- Currents measured represent average over ~4% of Radar wavelength
- Multiple frequencies probe deeper, providing depth dependence, shear
Vesecky, et al, HF current shear vs. ADCP (IGARSS 2001)

- Currents measured at 4 radar frequencies (red squares): **1-km spatial average**
- Acoustic Doppler Profiler (black) *point measure* compares reasonably well

![Graphs showing depth vs. slope comparisons between HF radar and ADCP measurements.](image)
E. Wind Speed estimates from Current Shear

Ocean Current Coupling to the Atmosphere

- Both atmosphere and water horizontal velocity profiles (winds and currents) satisfy log profile according to MO theory =>

- \( u(z) \) is wind friction velocity in atmosphere, current velocity in water

- Assume that all current shear is induced by wind and independent of bottom effects and other flows (e.g., Gulf Stream)

- Stress is constant across the water interface, so velocities at the surface behave as: \( u_a(0) \rho_a = u_w(0) \rho_w \)

- Wind speed can thus be estimated by inversion of stress continuity equation.

\[
u(z) = \frac{u_*}{k} \left[ \ln \left( \frac{z}{z_0} \right) - \psi \left( \frac{z}{L} \right) \right]
\]

where

- \( u_* \) is the friction velocity
- \( k \) is the von Karman constant 0.4
- \( z_0 \) is the roughness length
- \( L \) is the Monin - Obukhov length

\[
L = \frac{T_0 \cdot c_p u_*^3}{kg \cdot H_0}
\]

where

- \( T_0 \) is the surface absolute temperature
- \( H_0 \) is the surface heat flux
- \( c_p \) is the heat capacity of air at constant pressure
- \( u_* \) is the friction velocity
- \( k \) is the von Karman constant 0.4
- \( g \) is the acceleration due to gravity
ISR Data, Sea Scatter Experiment:
Spectra shown for 30 of 32 RF frequencies used, 3.05 - 30 MHz
Demonstration of simultaneous multiple frequency ability, digital receiver approach.
Multi-frequency HF Radar

Small RCS Example - fishing boat (RW Bogle, DB Trizna, NRL Report 3322, July 1976)

Metal Mast = 54.5 ft = 16.6 m
=λ/4 @ 4.5 MHz

Ship Classification
Summary

• New *Digital Radar Transceiver technology* makes multi-frequency HF radar measurements straightforward and relatively inexpensive.

• HF Radar multi-frequency current measure allows *current shear mapping*.

• Current shear mapping capability allows inversion to maps of *wind stress estimates*.

• Preliminary experimental results using 32 frequencies demonstrates digital radar measurement capabilities, *ship target classification potential*.

• *New radar recently deployed* at FRF Pier at Duck, NC, under ONR SBIR.

• Measurements to proceed over summer as a wind measure demonstration from our FRF monostatic site.

• *Bistatic capability to be installed* in FY04, Bistatic Sea Scatter model validated.
Plans

• Log-periodic antenna to be extended
  – two additional elements to provide 2.2-50 MHz transmit capability.

• Test of new ISR High Power Amplifier will be made at FRF for 3-30 MHz coverage capability.

• Channel occupancy testing in August
  – determine set of frequencies to request from the FCC.

• Data will be collected at low power for short ranges
  – accumulate additional evidence for wind-current coupling and
  – show ability to extract winds from multi-frequency current shear
Vesecky, et al, (IGARSS 02) Wind-Current Correlation

- HF radar observations of buoy winds and HF current speeds at 6.8 MHz
- Correlation are strong for sea-breeze conditions when the currents can be expected to be dominated by air-sea interaction
- At IGARSS ‘03, this group reported current shear observations and deduced wind speeds and compared with buoy winds to validate MO predictions discussed previously