

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**



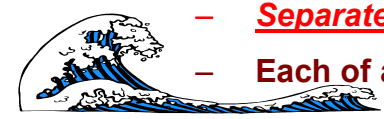
70's & 80's Journal Publications on HF Radar

- Long, A.E. & D.B. Trizna, *Mapping of North Atlantic winds by HF radar sea backscatter interpretation*, IEEE Trans. Ant. & Prop, AP-21, pp.. 680-685, 1973.
 - 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.
- Ahearn, J.L, et al, *Tests of remote skywave measurements of ocean surface conditions*, Proceeding of the IEEE, 62, pp. 681-687, June 1974.
 - Several examples of mapping of movement of storms through the Atlantic
- Trizna, D.B., J.M. Headrick, R.W. Bogle, J.C. Moore, *Directional sea spectrum determination using HF Doppler radar techniques*, IEEE Trans. Ant. & Prop, AP-25, pp. 4-11, 1977.
 - 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
- Trizna, D.B., J.M. Headrick, R.W. Bogle, J.C. Moore, *Observation of the Phillips resonance mechanism for generation of wind waves*, JGR, 85, pp. 4946-56, 1980.
 - 2-30 MHz SCI Radar 1st order Bragg line amplitudes vs azimuth
 - Phillips resonances at angles relative to wind direction vs wave number
- Trizna, D.B., *Mapping ocean currents using over-the-horizon radar*, Int'l Journal of Remote Sensing, 3, pp. 295-301, 1982.
 - First time OTH radial current components used to locate major current field: the Gulf Stream



B. Introduction to the Octopus Radar Transceiver PCI Card

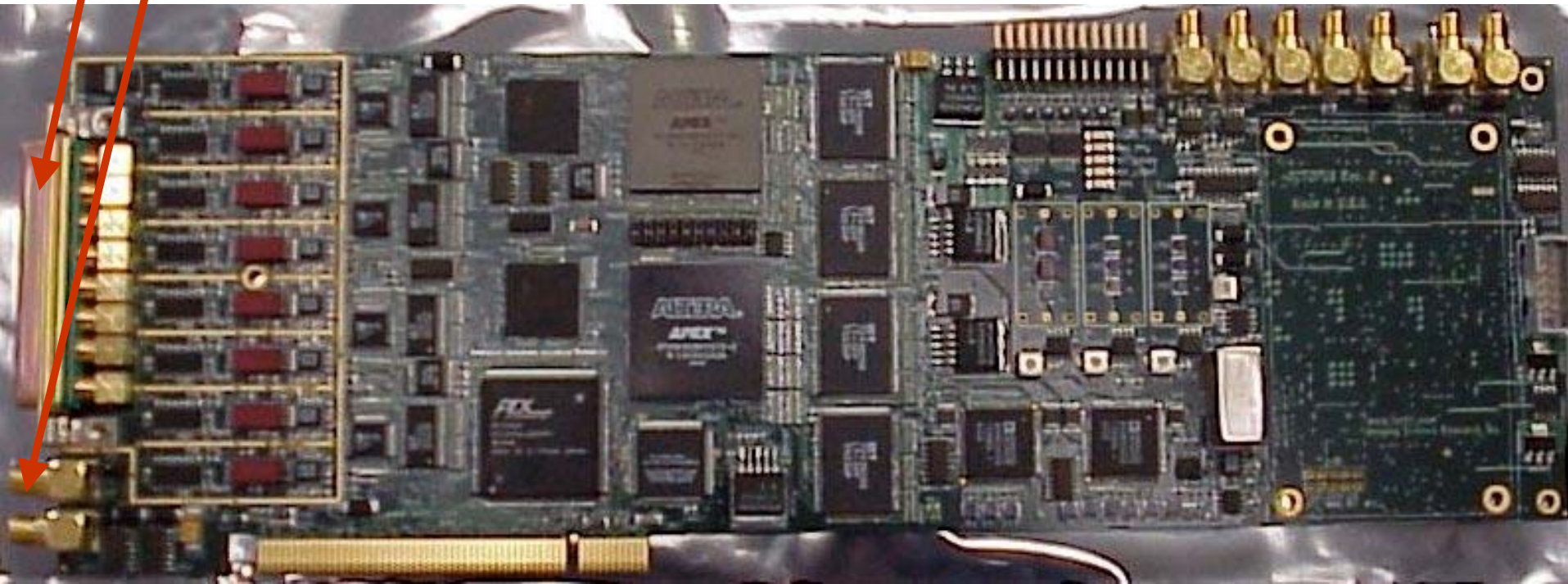
- **Windows Environment, Programmable waveform generation**
 - coupled DDS pair for (1) waveform and (2) coherent A/D clock generation
 - Programmable Frequency set & pulse envelope with onboard mixer for spectrum control:
 - Simple Pulse - envelope programmable (all waveforms)
 - FM Chirp or FM CW
 - 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 I 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



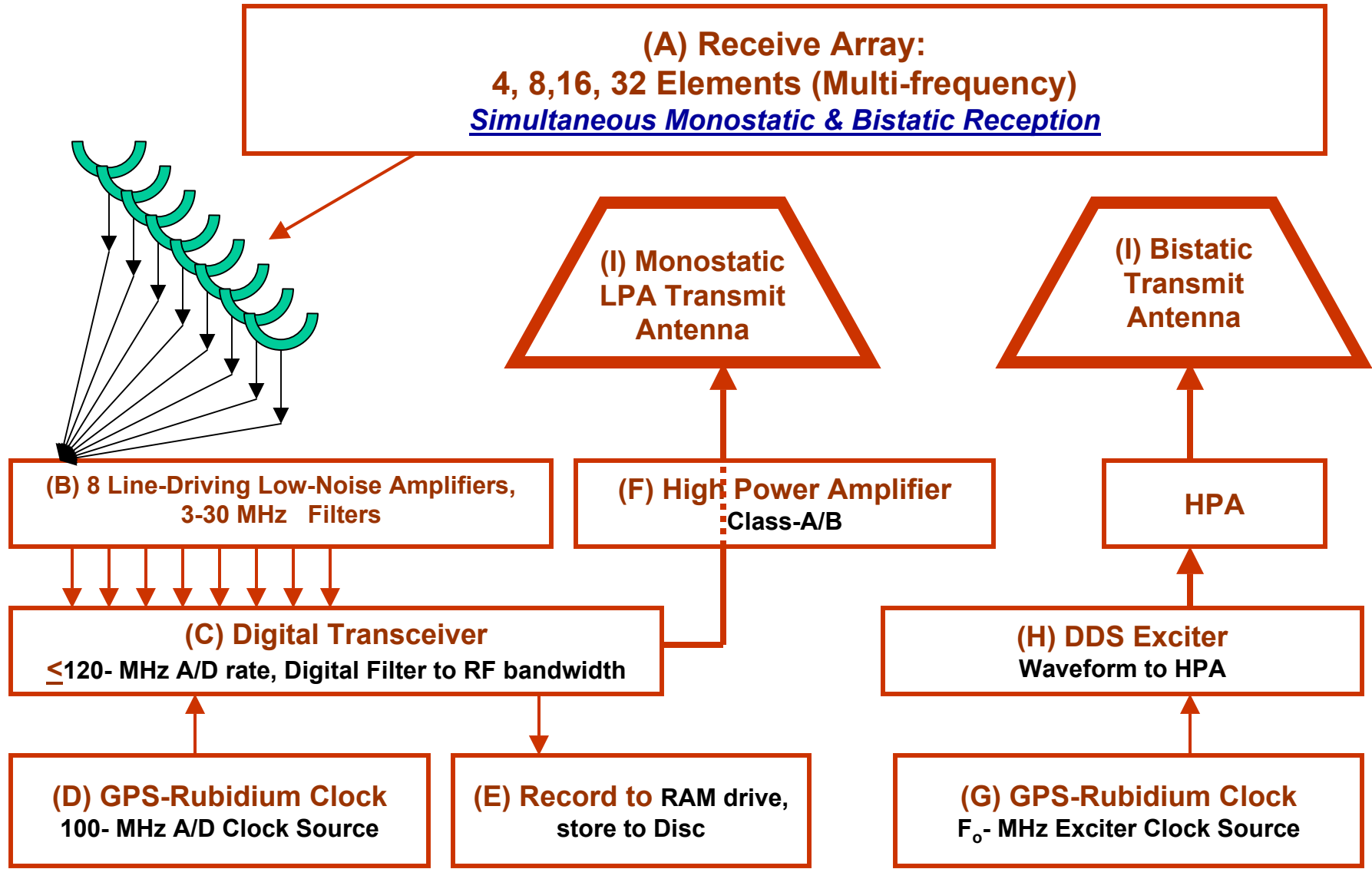


8-channel *Octopus* Digital Radar Transceiver

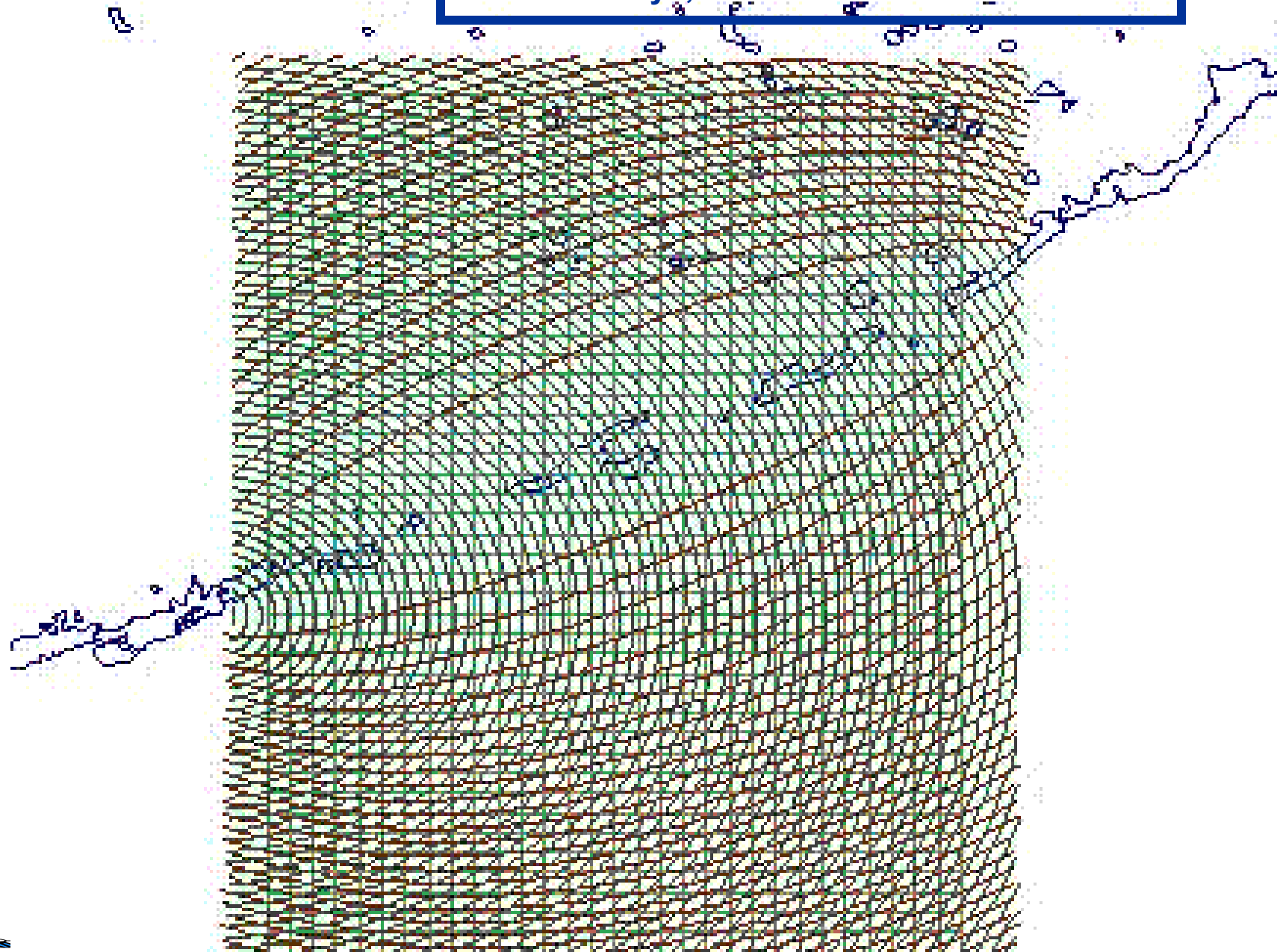
- **Variety of output signal available from Top Auxiliary SMA/Bracket**
 - Pulse Envelope, DSS output direct & mixed, receiver blanking pulse, trigger, GPS 1-PPS
- **Inputs to 8 100-MHz A/D converters**
- **SMA connector pair for clock & trigger input/output**



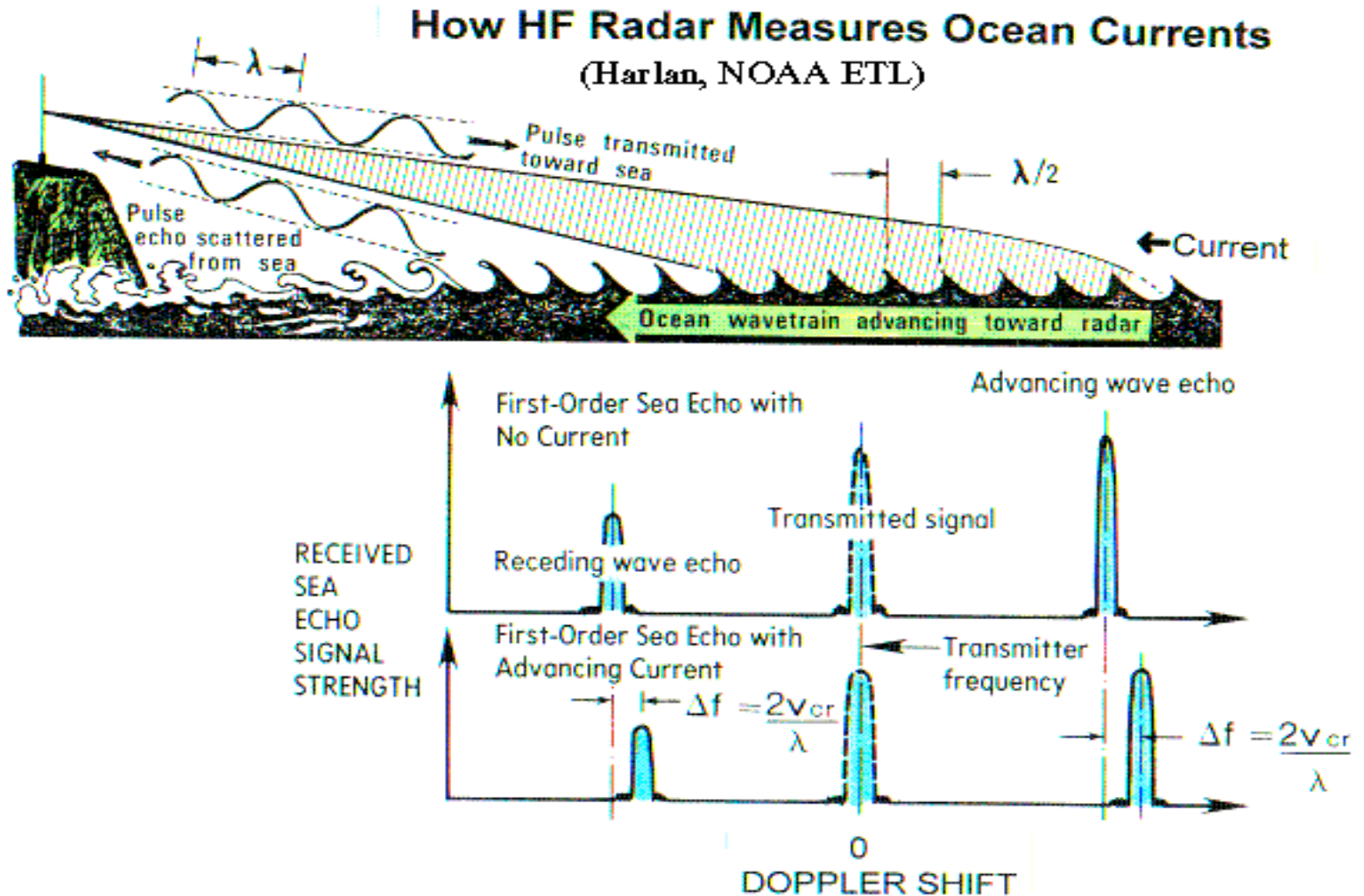
Octal-1 Series HF Radar System Design



2-Site Bistatic Coverage Example: Florida Keys, 1-km Monostatic Resolution

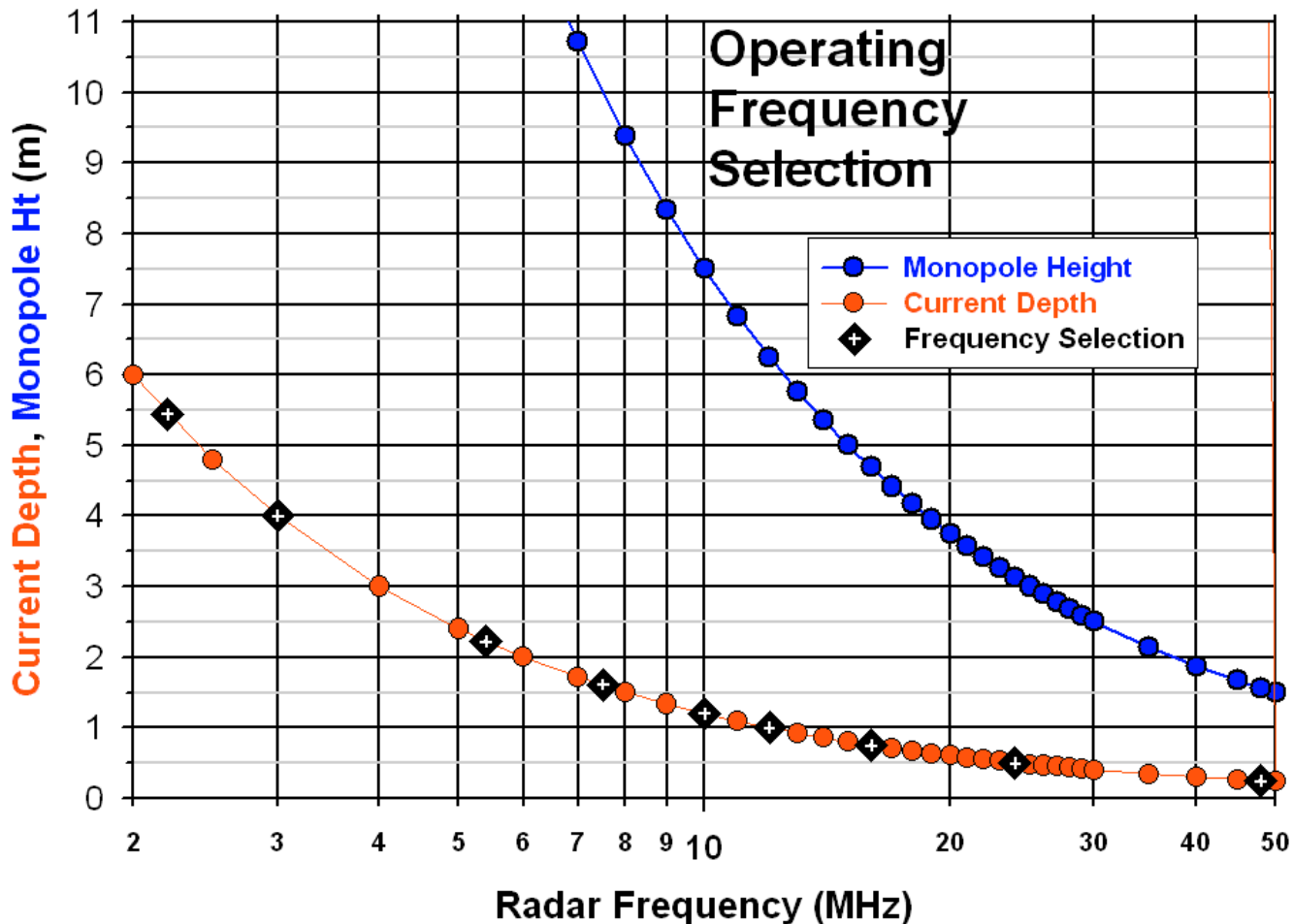


C. HF Radar Ocean Current Measurement



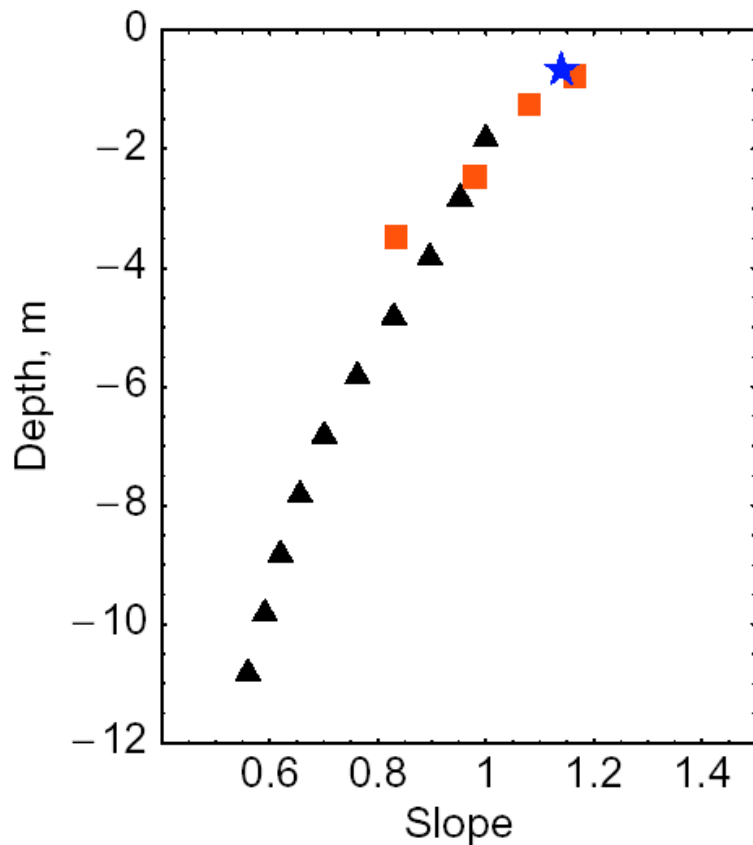
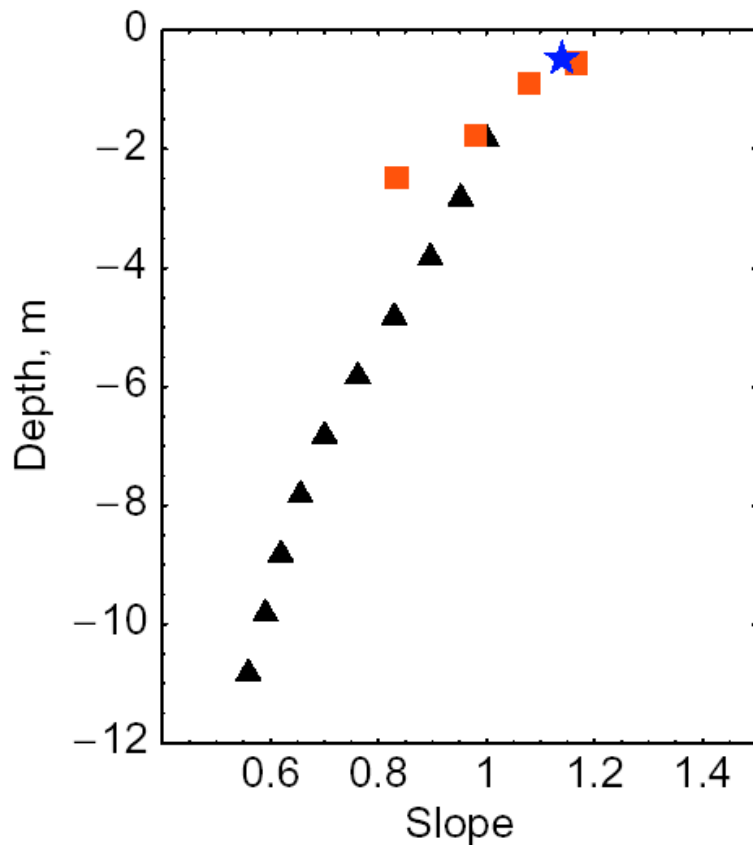
D. Vertical Current Shear Measurement

- 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



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

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

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:

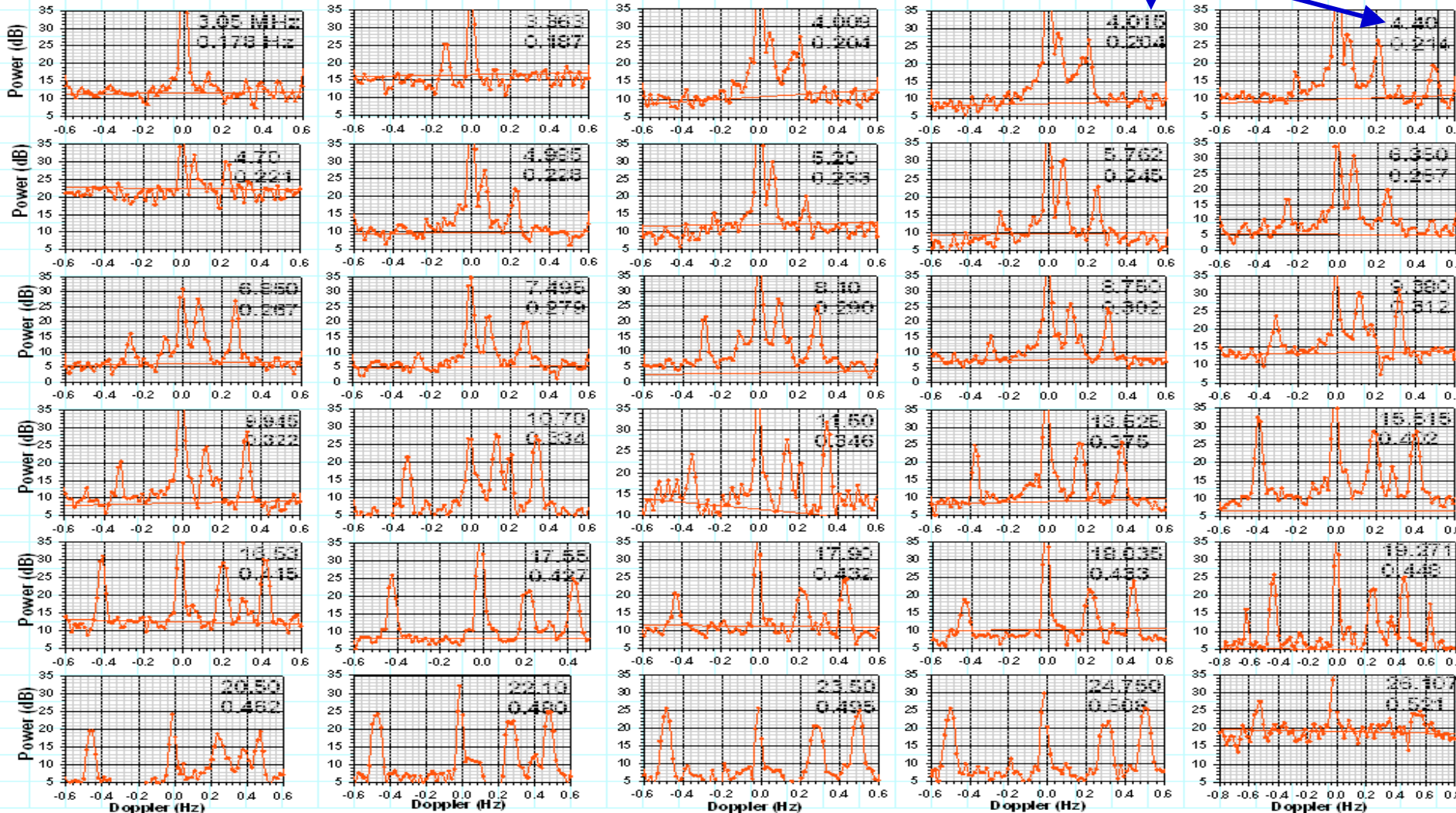
Spectra shown for 30 of 32 RF frequencies used, 3.05 - 30 MHz

Demonstration of simultaneous multiple frequency ability, digital receiver approach.

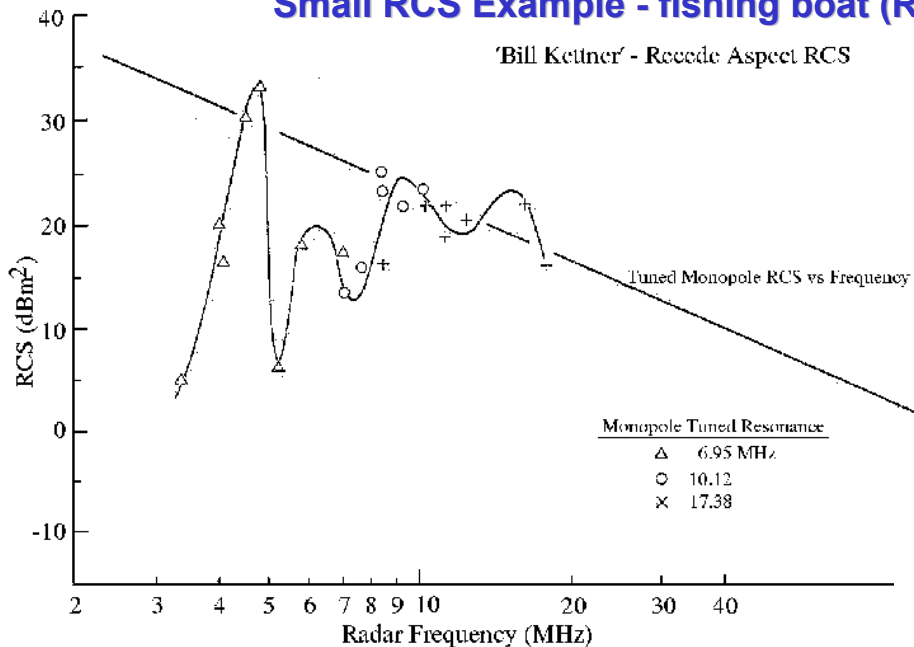
Radar Frequency (MHz)

Bragg Doppler (Hz)

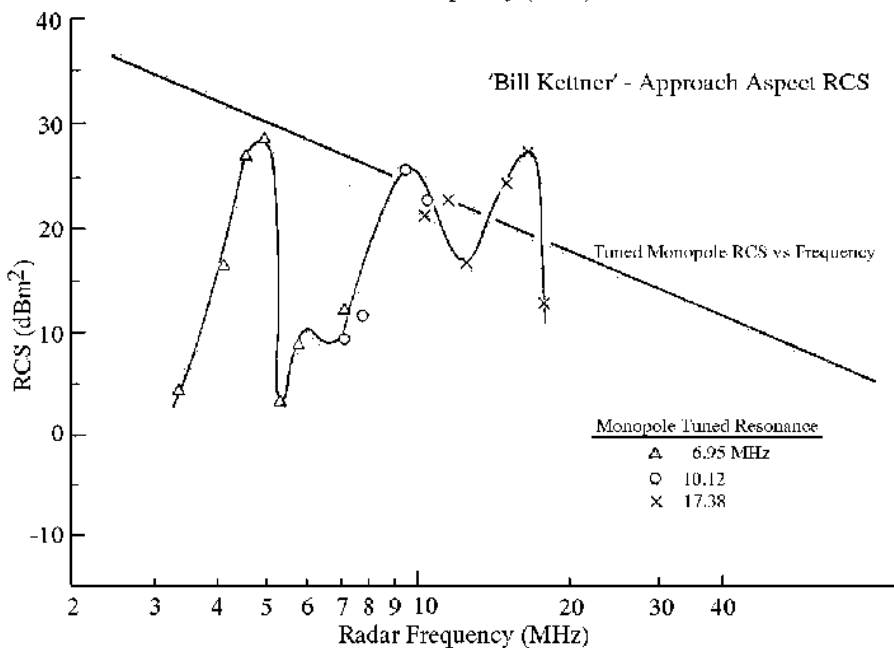
Skip 10x5, Filter Spec: 512/2048 Samp, 1-32 Frqs, 20 Nov 02, JD324 10:04.000, SpecAvg=4, RB Samp1 @768, 128-pt FFT Dop FFT (~.016 Hz Res), Bore-Site Beam



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

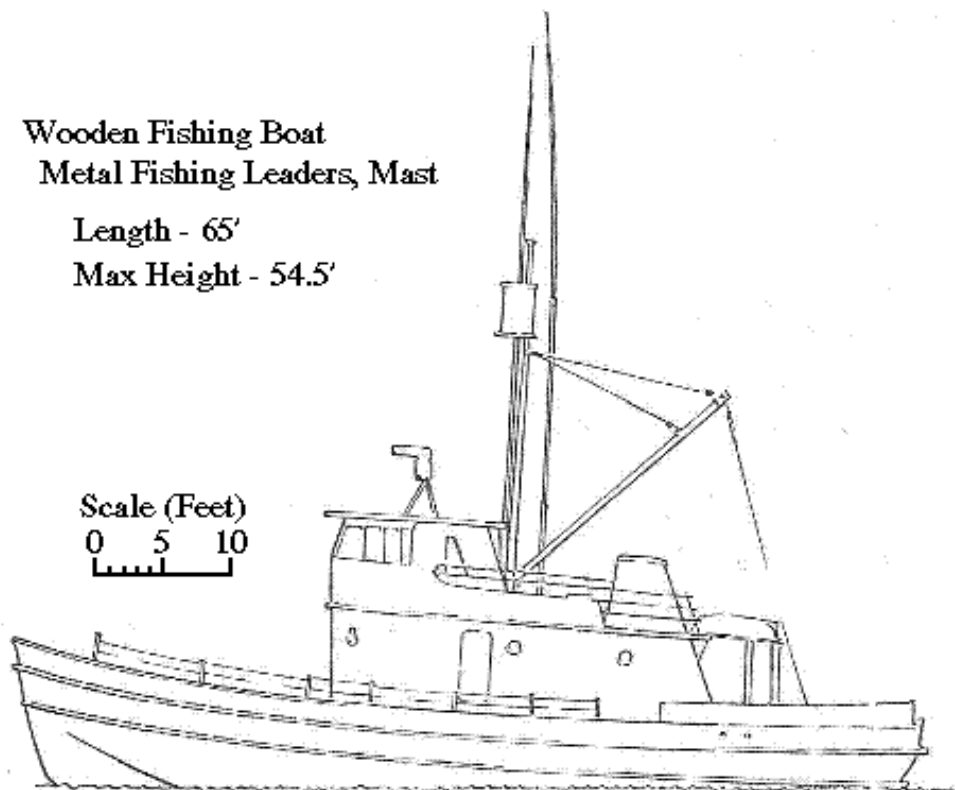


Metal Mast = 54.5 ft = 16.6 m
 $= \lambda/4$ @ 4.5 MHz



Wooden Fishing Boat
 Metal Fishing Leaders, Mast

Length - 65'
 Max Height - 54.5'



Multi-frequency HF Radar

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

