

***Multi-Frequency HF Radar
For Mapping Current Shear and Vector Winds***

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ISR Navy SBIR Phase-1 contract in progress:

- **develop a multi-frequency HF radar for mapping vertical ocean current shear and vector winds @ km scales**

Objectives:

- ***Define Technology*** required for multi-frequency HF radar
 - **Bistatic capable - lower site costs, all processing centralized**
 - **Wide-band transmit antenna, 3-30 MHz potential**
 - **Incorporate state of the art digital transceiver technology**
 - **developed under second ONR program**
 - **Interleaved frequency operation, pulse-to-pulse switching**
- ***Measure current shear*** using multi-frequency HF Radar
- ***Infer wind speed*** estimate from corresponding wind shear



The radar development is based on fully digital HF transceiver built on a PC card begun in FY02:

- **Windows operating environment**
- **Digitally programmed transmit waveform - to Hi Power Amp**
- **8 receive channels, 16 or 32 bit word capable**
- **GPS time for bistatic operation**



Features of the Octopus Radar Transceiver PCI Card

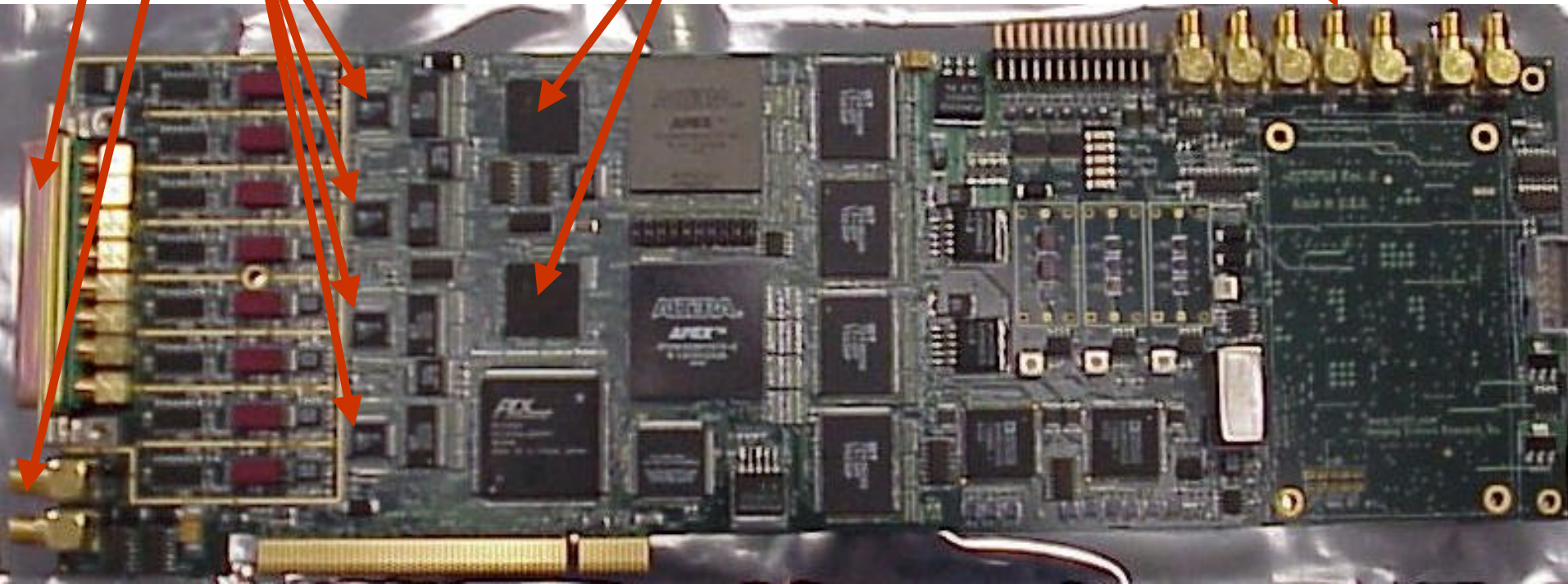
- **Programmable waveform generation**
 - coupled DDS pair for (1) waveform and (2) coherent A/D clock generation
 - Programmable Frequency set & pulse envelope with onboard mixer for spectrum control
 - 32 frequencies used in Navy RCS application
 - Variety of wave forms:
 - Simple Pulse - envelope programmable (all waveforms)
 - FM Chirp (Codar-like) or FM CW (WERA-like) pulse compression capable
 - Phase Code pulse compression capable
 - Random Noise - Repeated Code pulse-to-pulse for FIFO averaging, or Variable Code
- **8-channel 100- MHz A/D receive capability per card (capable of up to 4 cards, 32 antennas)**
- **FPGA Pair for housekeeping & real-time processing (2 pair of 4 parallel channels)**
- **Direct Digital Down conversion Pair for programmable digital filtering**
 - 8 A/D bits Real in, 16 or 32 bits I/Q out
 - Increases sampled dynamic range by ratio of SR/DDC-BW
- **FIFO memory 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 Time for Temp-Corrected Oscillator 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 2-4+ sites has its own Universal Time transmit time slot-Master receives all



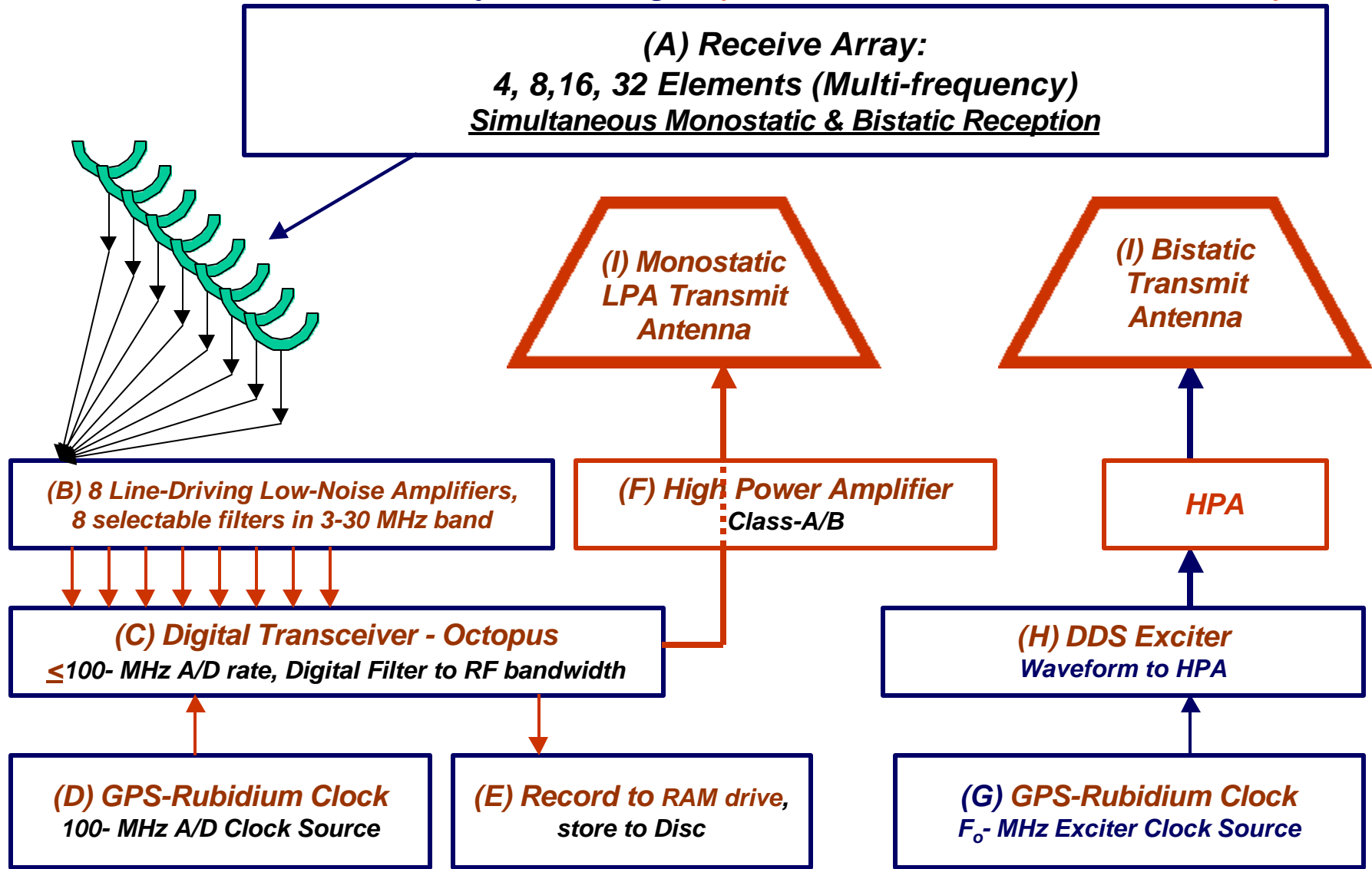


Low Cost, 8-channel Octopus Digital Radar Transceiver

- **Variety of output signal available from Top Auxiliary SMA/Bracket**
 - Pulse Envelope, DSS output direct & mixed, receiver blanking pulse, trigger, GPS 1-PPS
- **8 antenna inputs to 8 100-MHz A/D converters**
- **SMA connector pair for clock & trigger input/output**
- **Four 2-chan A/Ds, two 4-chan Digital Down Converters for RF filtering**



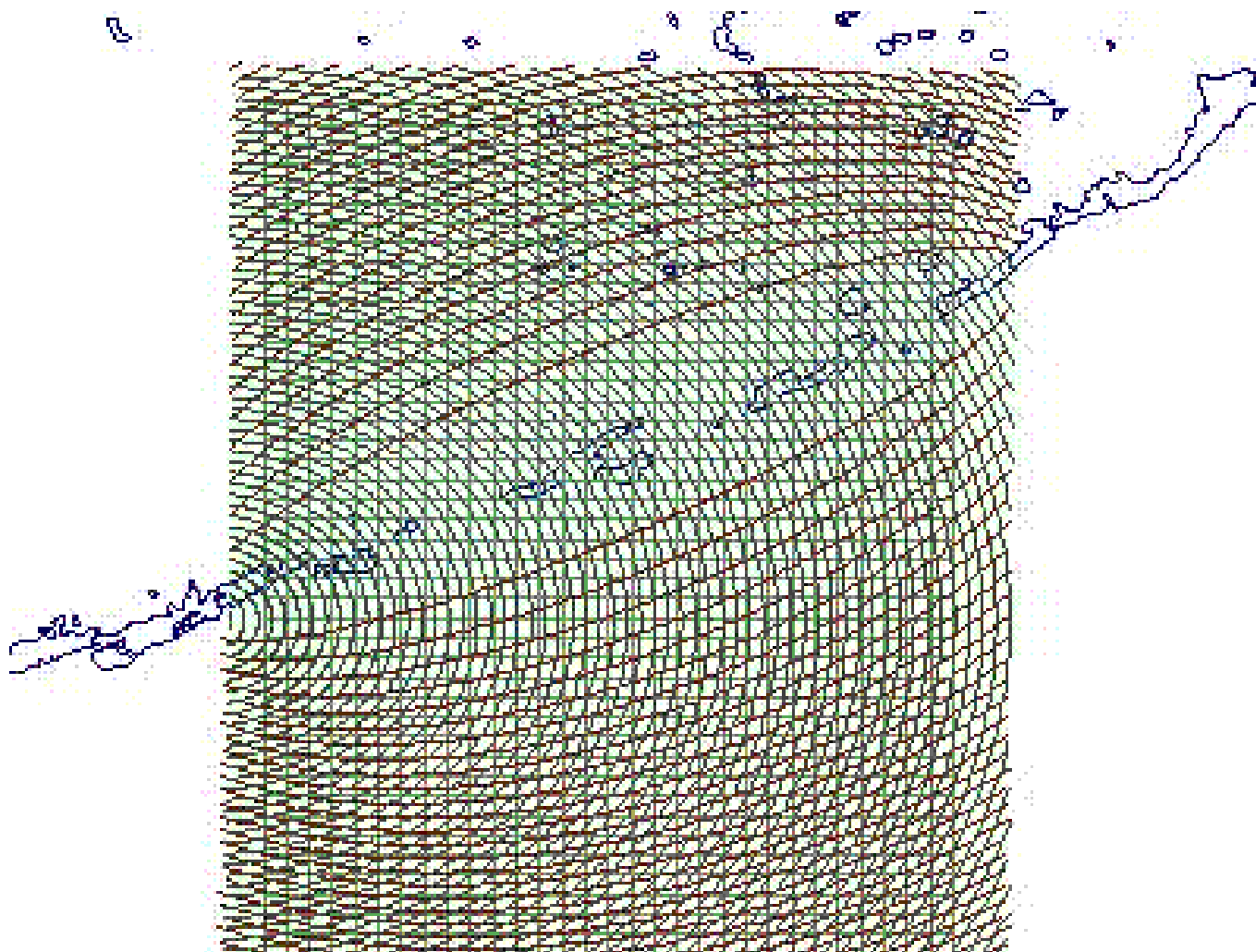
HF Radar System Design - (SBIR hardware issues in red boxes)



2-Site Bistatic Coverage Example:

Florida Keys, 1-km Pulse, variable bistatic spatial resolution

Map currents at each 0.1-deg lat/lon, interpolated from range-azimuth data



Radar Issues addressed using Phase-1 SBIR funds:

- **A. Multi-frequency Transmit Antenna developed (3-60 MHz)**
 - Log Periodic Monopole Array built
 - Unique element design to achieve very low frequencies with short elements
- **B. Tunable High Power Amplifier (HPA) prototype built**
 - EB104 ISR design, controllable with Octopus transceiver
 - Commercial HPA's have different external control methods-define in house
- **C. Current measurement using a Small 4-Element Receive Array**
 - Direction-of-Arrival (DOA) processing using 4 Elements & Root-MUSIC
 - ISR Hire, recent GMU Ph.D. grad under Prof. Harry Van Trees

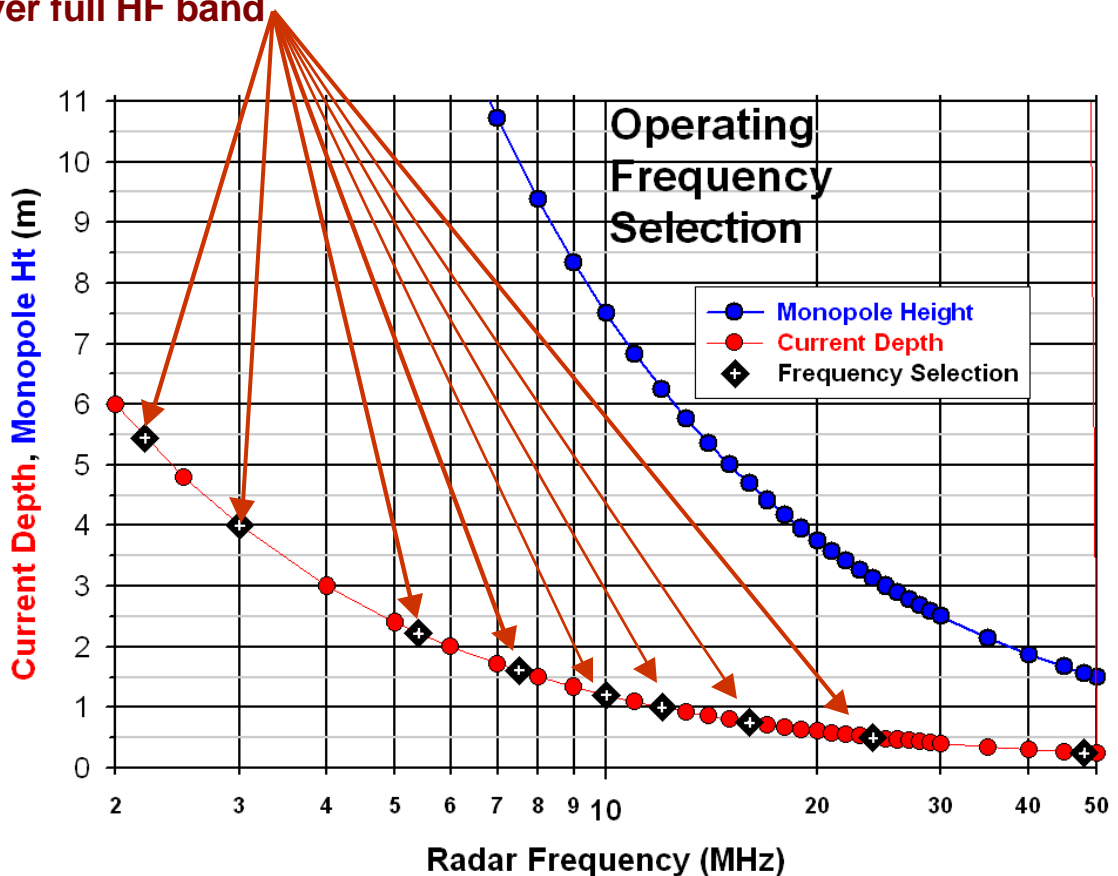


Broadband Transmit Antenna requirement using a single HPA driven by Vertical Current Shear Measurement:

Desired depth defines transmit antenna size - unrealistic at 3 MHz

- Currents measured represent average over ~4% of Radar wavelength
- Multiple frequencies probe deeper, providing depth dependence, shear
- 5-10 frequencies desirable over full HF band

Extreme height of $\lambda/4$ monopole at desired low frequencies creates problems of deployment, maintenance, as well as environmental impact



Solution: Log Periodic Array for continuous frequency coverage over 3-30 MHz

- **LPA Features:**
 - Monopole elements at high frequencies, but height increases with longer wavelengths
 - Switch to Proprietary design element for <15.4 MHz, 3-m fixed height
 - Single feed line connecting all elements, RF balun for impedance matching
- **Allows for single HPA, no need for switching between frequencies**
 - Space - limited cases could use 4-frequency, 4-monopole antenna, 4 HPA's & low power switching
- **Has been built, tested (<2.5 SWR over 3-50 MHz band) under SBIR funding**



High Power Amplifier solution - develop our own unit:

- **Maintain full control of integration with Octopus external control bus signals**
 - Control signals vary between manufacturers, allows us to set standard spec relative to Octopus
- **Multiple units triggered on alternating pulses, switching done at low level**
 - Single unit sufficient for LPA antenna, continuous frequency capability 3-50 MHz
- **EB104 prototype developed using COTS HF components**
 - 600 kWatt CW output possible
 - can be Frequency Modulated for pulse compression (as WERA FM-CW or CODAR FM-Chirp)
- **Rack-mount Prototype below**
 - has temporary temperature and current sensors for monitoring
 - will be integrated into final system, digitally monitored by transceiver



Small Receive Array for Current Mapping - DOA processing for 4 elements

- **Market demands minimal-area system**
 - Coastal space at a premium
- **Short arrays of few elements are required**
 - Beam forming approach thus are not feasible
- **DOA algorithms necessary to derive radial currents**
 - Allows 3-6 element solution



Multi-frequency Doppler Spectra from Point Loma August '03 Experiment
 (Radar Frequency (MHz), expected Bragg line shift (Hz) indicated for each plot)

Radar Setup:

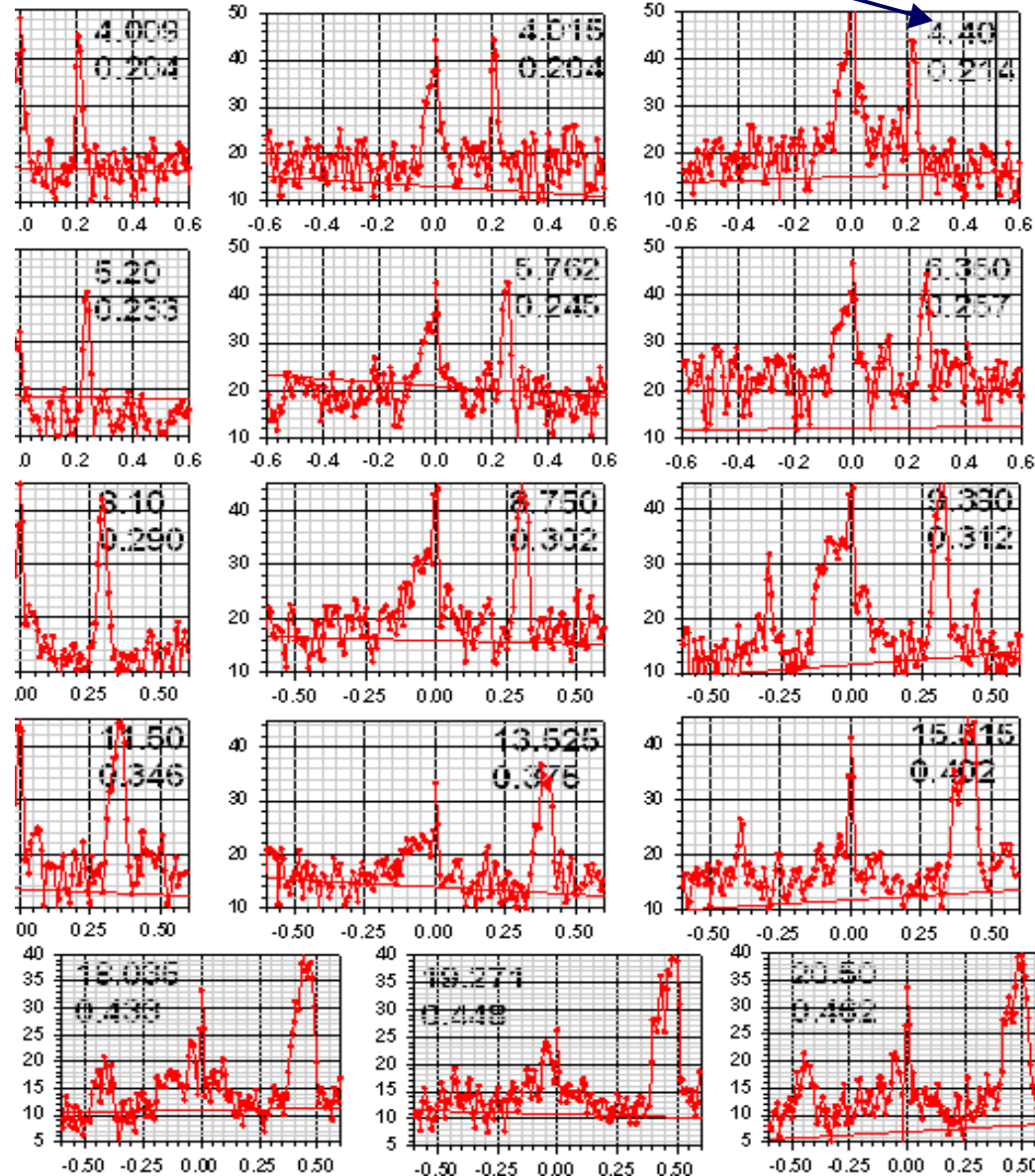
- 32 Frequencies using ISR digital receiver
- 4 kW SPAWAR HPA, ISR Exciter
- Monocone 3-30 MHz Transmit antenna
- 4-element receive loop array

15 of 32 spectra shown

- Broadened, but minimally shifted spectra indicate along-shore cross current
- Change with radar frequency indicates current varies with depth - shear present.

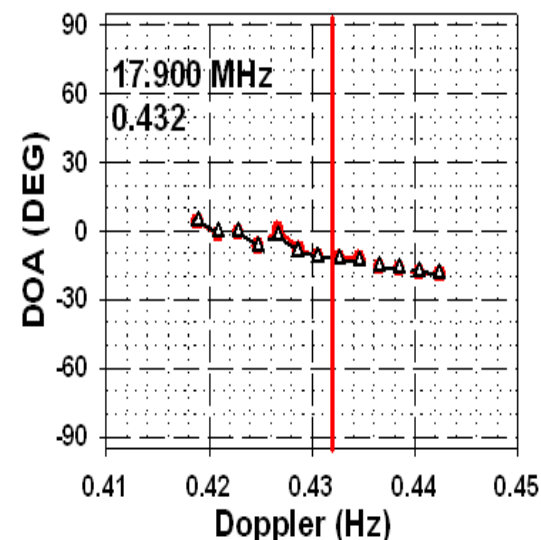
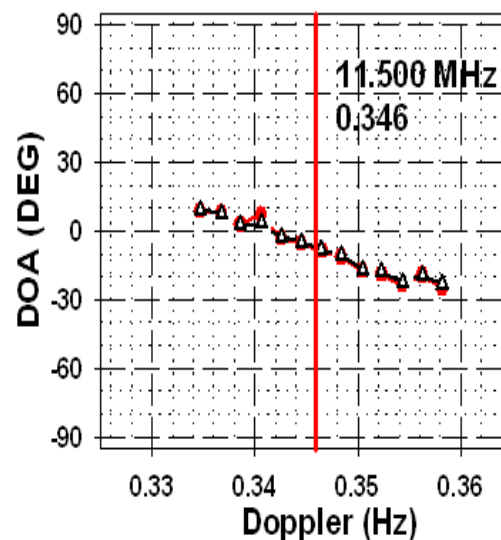
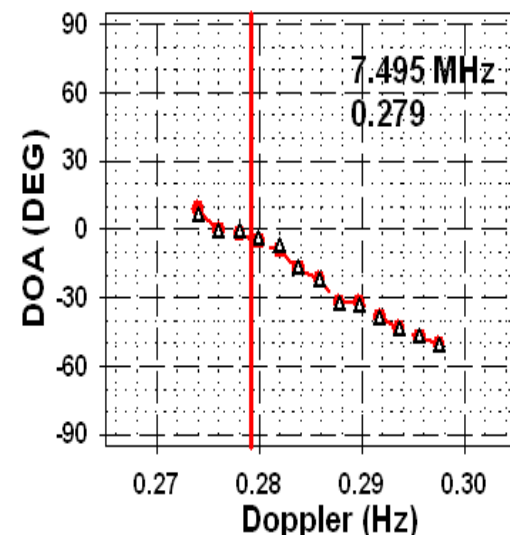
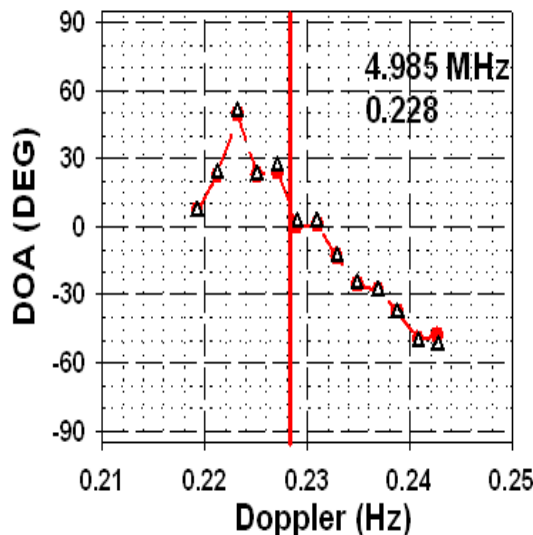
Can we derive radial currents from such 4-antenna data using DOA Methods?

- Compare phase difference between 4 antenna elements for each Doppler spectral filter encompassing the broad Bragg line
- The frequency spacing from the predicted filter is a measure of radial velocity for the direction determined from phase comparisons



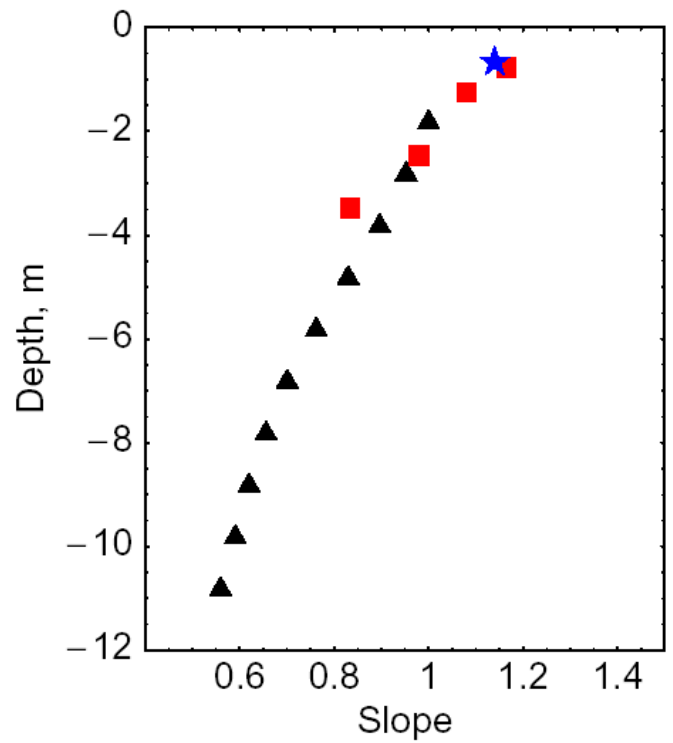
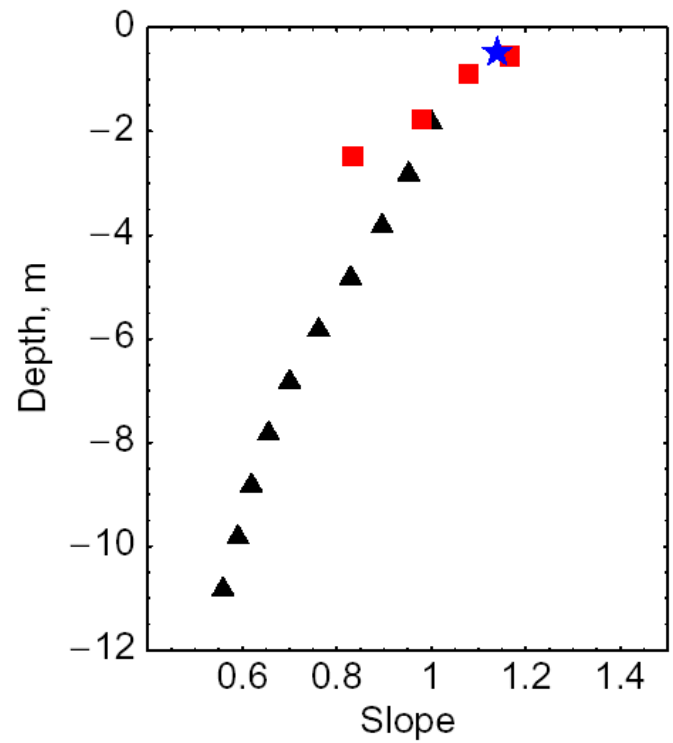
Root MUSIC Algorithm used to derive currents from I/Q samples @ each Doppler filter

- Developed by ISR, Dr. Lillian Xu
- Tested first on dedicated target data, boat outbound along bore-site
- Root-MUSIC chosen for use
 - Teague (IGARSS 2002) concluded better than MUSIC algorithm
- Trend of results in agreement with expected behavior due to crossing current along coast
- Red line indicates expected Bragg shift in Hz, spread about it indicates radial component of an along-shore current
- **RESULT: Radial current vs azimuth**



Vesecky, et al, HF current shear vs. ADCP (IGARSS 2001)

- **Currents measured at 4 radar frequencies (Red Squares)**
 - Red squares represent radar measurement 1-km spatial average
- **Acoustic Doppler Profiler (Black Diamonds)**
 - point measure of current shear compares well with 1-km spatial radar average



Wind Speed maps from Current Shear measurement maps

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, $u_a(z)$ current velocity in water, $u_w(d)$
- 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: $u_a(0)r_a = u_w(0) r_w$
- Wind speed can thus be estimated by inversion of stress continuity equation, referenced to standard 10-m height.

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

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

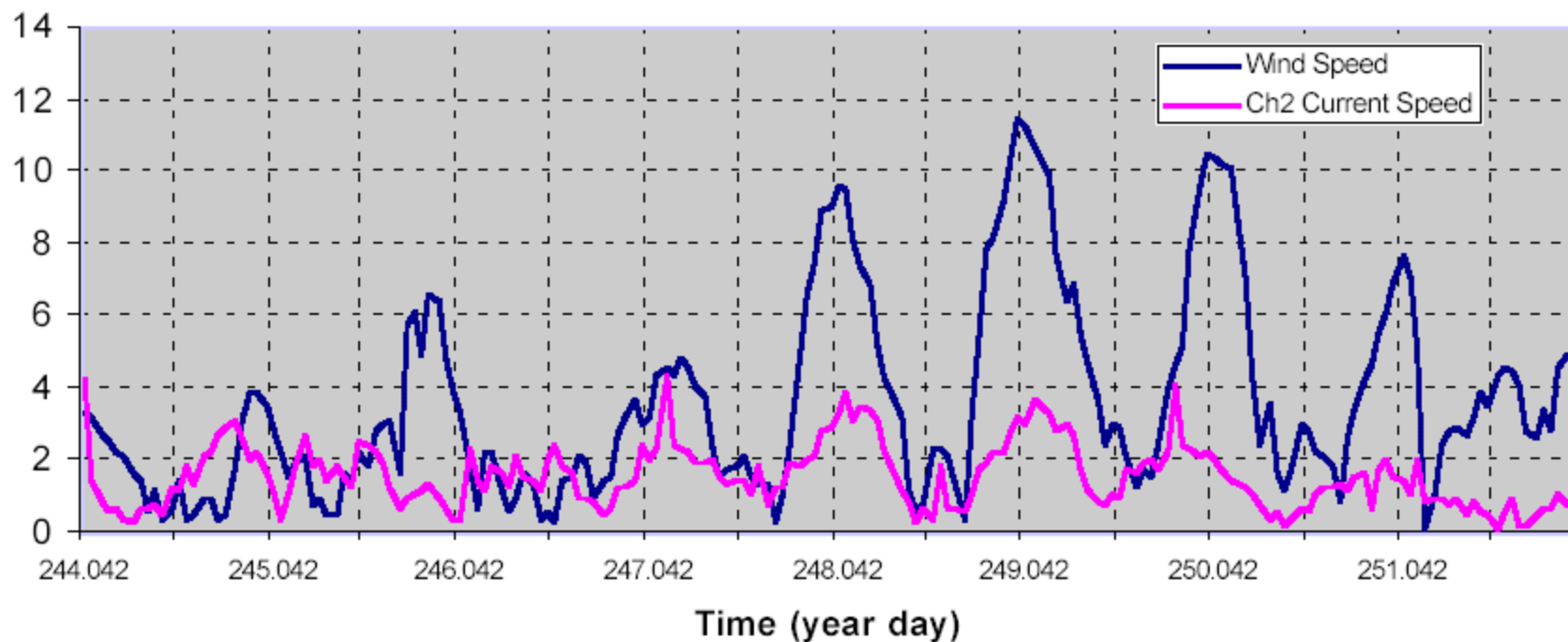
k is the von Karman constant 0.4

g is the acceleration due to gravity



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



Summary

Phase-1 SBIR identified, built and tested critical hardware and processing components to allow future demonstration of current shear measurement capability

- **Technology for multi-frequency current shear measure outlined, designed, built**
 - **Log-periodic monopole transmit array (LPMA) for testing, ship classification potential**
 - Allows any frequency choice in 3-50 MHz band
 - ~ 60 ft long, may not satisfy some users' spatial constraints
 - Multiple resonant monopole choice an option for 4-5 frequency operation for commercial systems
 - **Class A/B High Power Amplifier designed, prototype built and being used**
 - Pair may be required to cover 3.5-30 MHz in tow steps due to 2nd harmonic nature of Class A/B
 - **DOA algorithms developed, tested on West Coast data using identical receive array**
 - Root MUSIC algorithm chosen for simplicity and speed of calculation
 - **Deployed full HF radar at FRF, tested LPMA, HPA, exciter card**
 - Fully transportable radar van, Chesapeake Bay mouth tests Spring '04 for ONR31
- **Current shear measurements to begin October 03**
 - **Transceiver software due to be completed**

