The Generic High Frequency Doppler Radar: progress report and recent developments

The *radlab* group:

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Antony Kirincich, Ian Fernandez (Woods Hole Oceanographic Institution)

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Louis Marié (IFREMER)

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Peter Milne, John McLean (D-Tacq Solutions Ltd.)

Classification of HF radars

- most present oceanographic HFDR are homodyne frequency-modulated linear chirp continuous wave radars (FMCW)

- differ only in the details of signal handling and digital processing

- pulsed radars no longer used

- pseudo-random phase coding not widely used (easily implemented with modern digital syntheziers)

	signal	RX antennas	phased arrays	TX rejection	algor.	digitization, anti-aliasing	I/Q cos/sin
CODAR	FMiCW	ferrite+active monopole	compact cross-loops +monopole	Interrupted/ gated TX	DF	?	?
WERA	FMCW	passive monopole or active loop	linear, square, curved	beamforming TX arrays or bistatic	BF or DF	digitization 6 kHz, active analog LPFs	analog
Generic HFDR	FMCW	passive or active monopole, or active loop	linear, square, grid	beamforming TX arrays or bistatic	BF or DF	digitization 6 MHz, ΔΣ oversampling + FIR decimation, final 750 Hz	digital

Frequency-modulated homodyne radar

- Δt is travel time to & return from range
- Δf is frequency in FFT that gives range
- Shorter times and lower frequencies are closer ranges
- Maximum range indicates a maximum time and maximum frequency
- 150 km R, 100 kHz B, 1/3 s Tchirp:
  - Δt = 2R / c = 1 ms
  - Chirp rate = B / Tchirp = 300 kHz/s
  - Δf = Dt * Rchirp ~ 300 Hz
  - Minimum Fs for Nyquist = 600 Hz

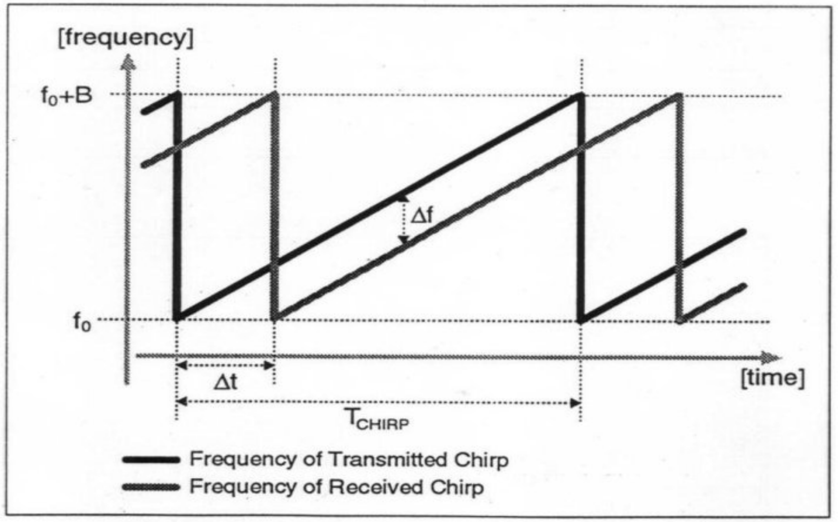
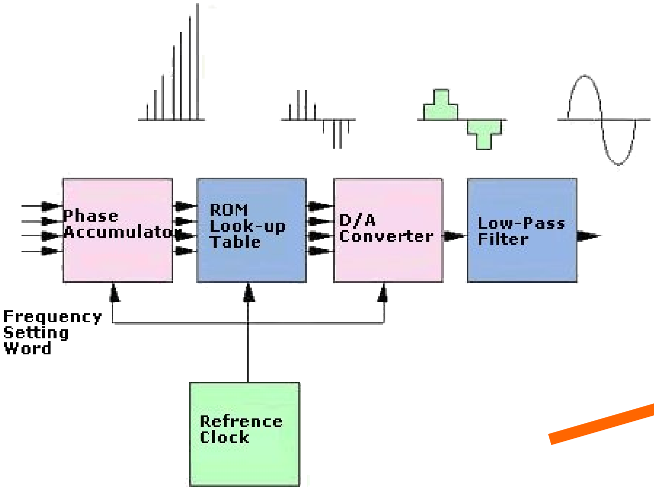
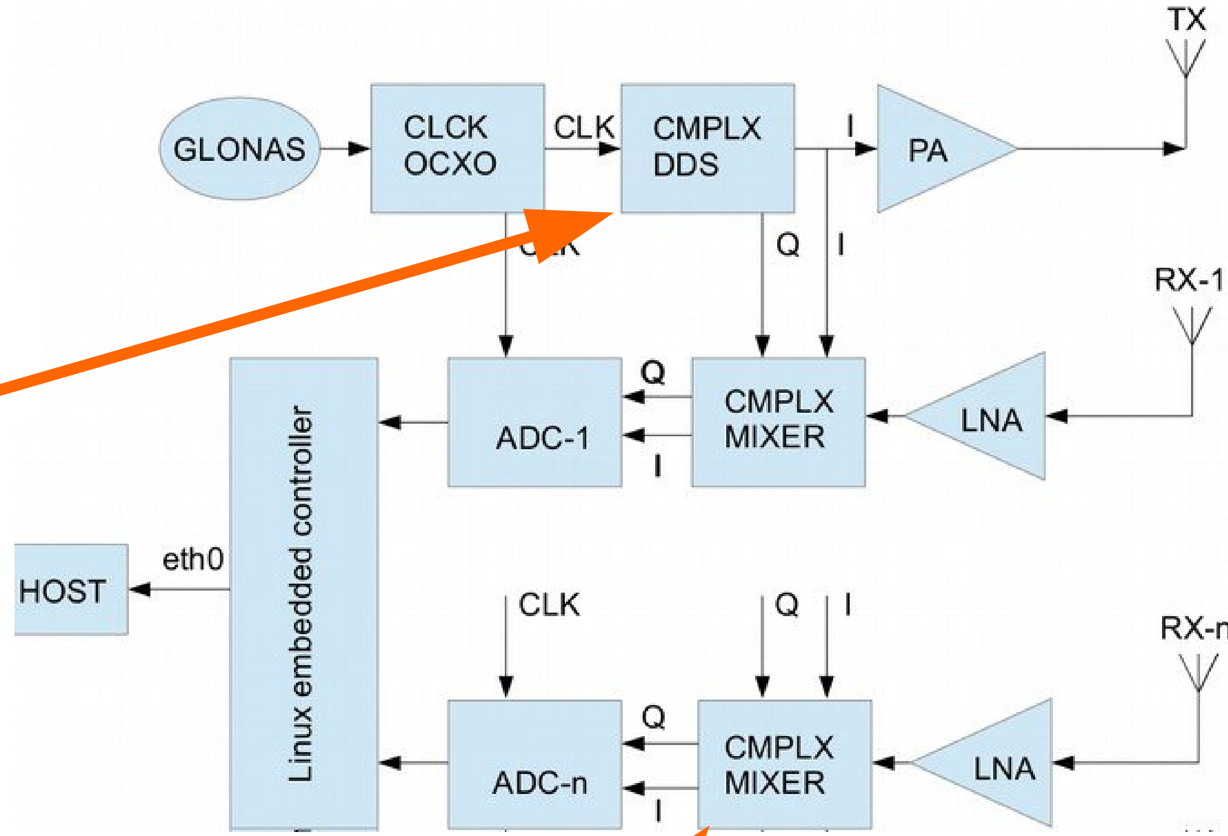


Figure 2: Range resolution using a frequency chirp.



Direct Digital Synthesizer

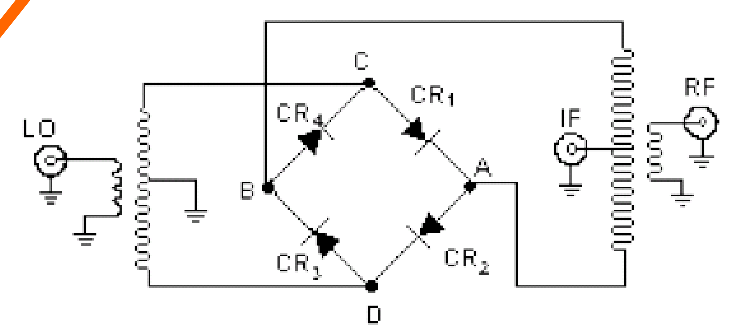


Double-Balanced Mixer/quadrature detector:

I: $2 \sin x \sin y = \cos(x-y) - \cos(x+y)$

Q: $2 \sin x \cos y = \sin(x-y) + \sin(x+y)$

if $x = (\omega + \Delta\omega)\, t$ **and** $y = \omega\, t$ **then** $x - y = \Delta\omega\, t$



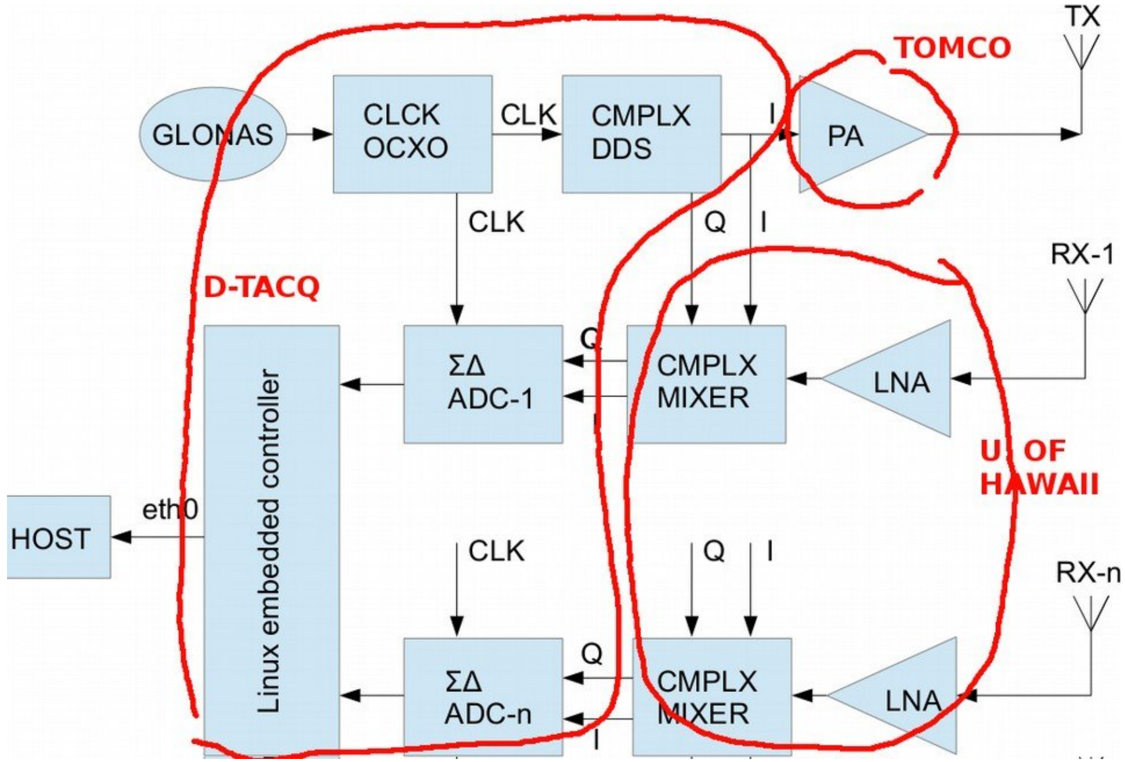
Objectives/achievements:

- open-source open-design freely available
- out-sourced production (batch of 40 produced in < 6 months)
- minimize cost (non-profit ~60% hardware & ~40% overhead + support)
- scale to arbitrary number of channels (∞!)
- minimize power consumption

    300 W DC for 8-channel 50 W RF ~ 9 solar panels
    100 W DC for 4-channel 10 W RF ~ 3 solar panels

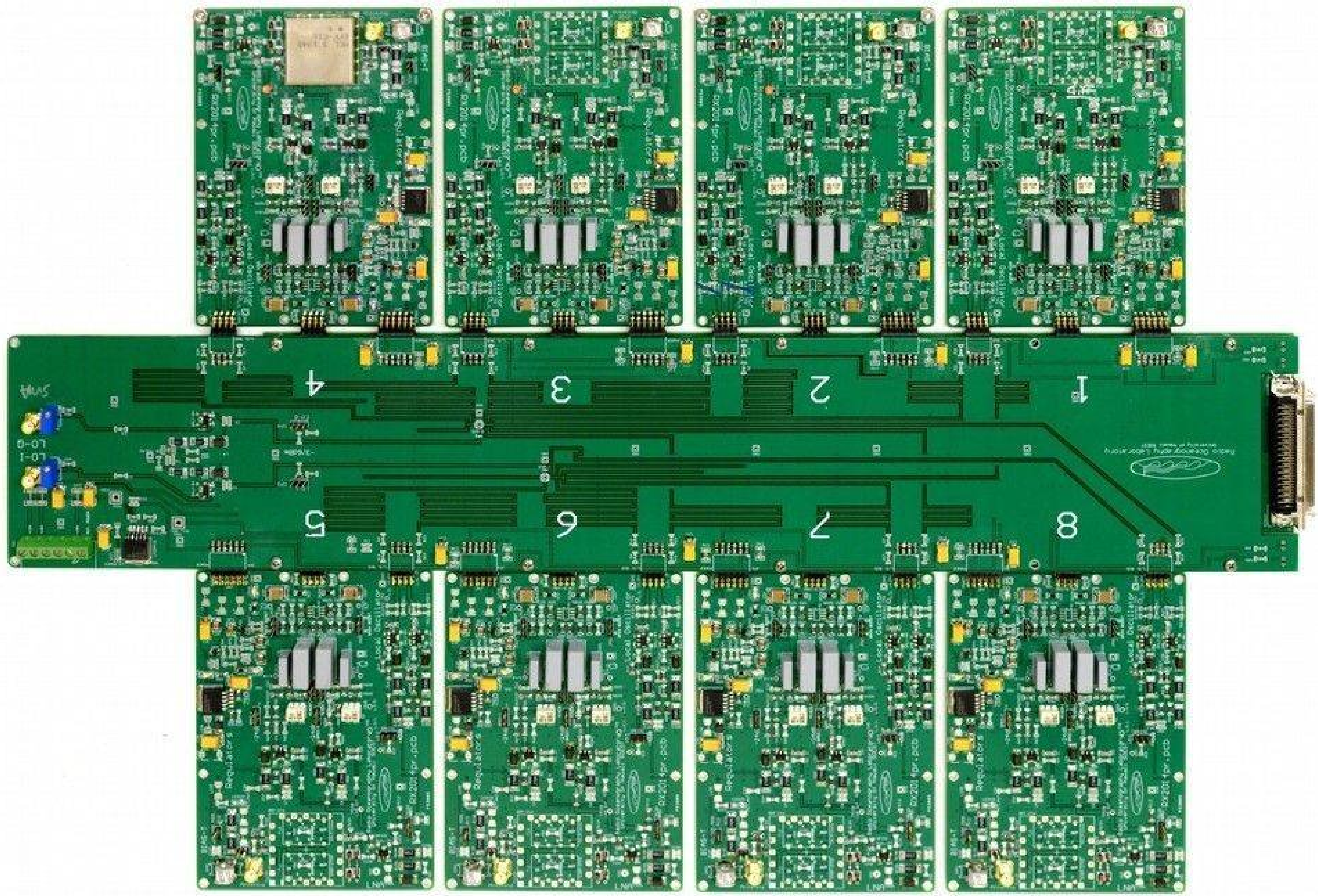
- solar/wind/fuel cell operation by default (24 DC supply thorough, no AC inverter)
- distribution through partnerships with research institutes (share of intellectual products)
- final assembly by end users, enabling seamless local maintenance/repairs
- multiple community-based and commercial post-processing software solutions

Architecture

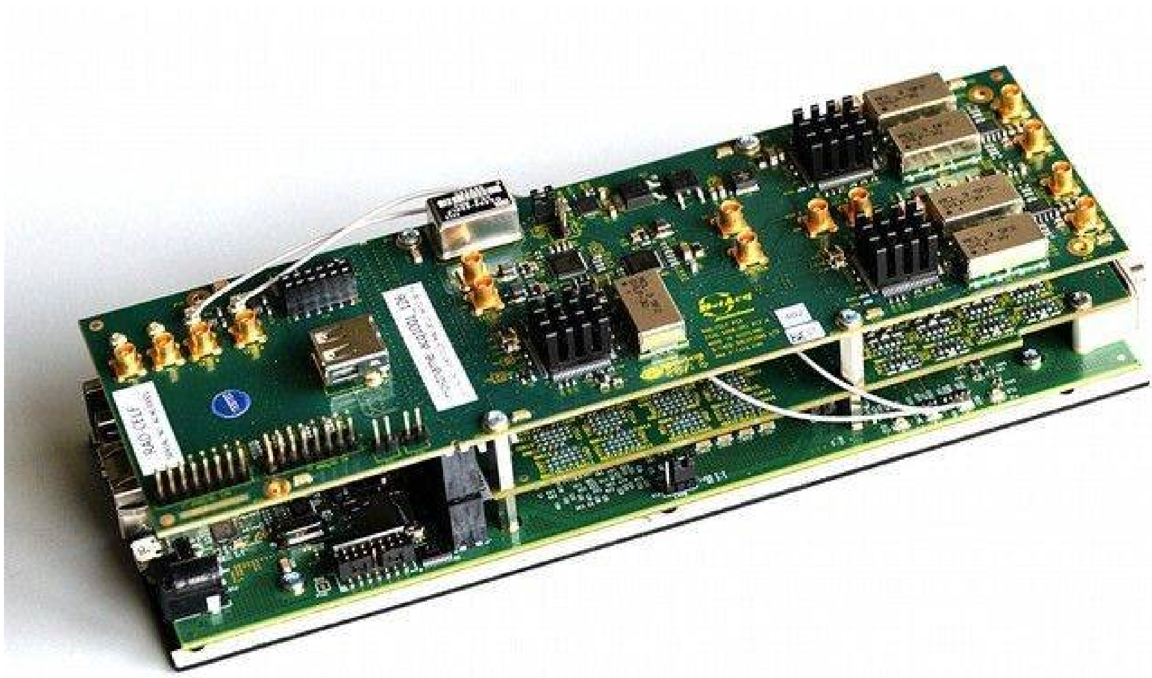


- oven-controlled crystal oscillator with thermal mass (OCXO, Taitien, TW)
- GNSS slaving through digital clock remapping (U-Blox, CH)
- direct digital synthesis (DDS) of transmit and orthogonal local oscillator signals (D-Tacq)
- choice of 50 W class AB (TOMCO-RF) or 10 W class E power amplifiers (U. Hawaii)
- λ/8 passive TX&RX monopoles, optional λ/16 active RX monopoles (U. Hawaii)
- complex demodulation by homodyne translation of HF to audio band (U. Hawaii)
- ΔΣ ADC 24-bit with 2^13 oversampling+decimation, audio frequency 750 Hz (D-Tacq)
- sub-assemblies controlled by Linux embedded computer (D-Tacq)

University of Hawaii 8-antenna complex homodyne receiver

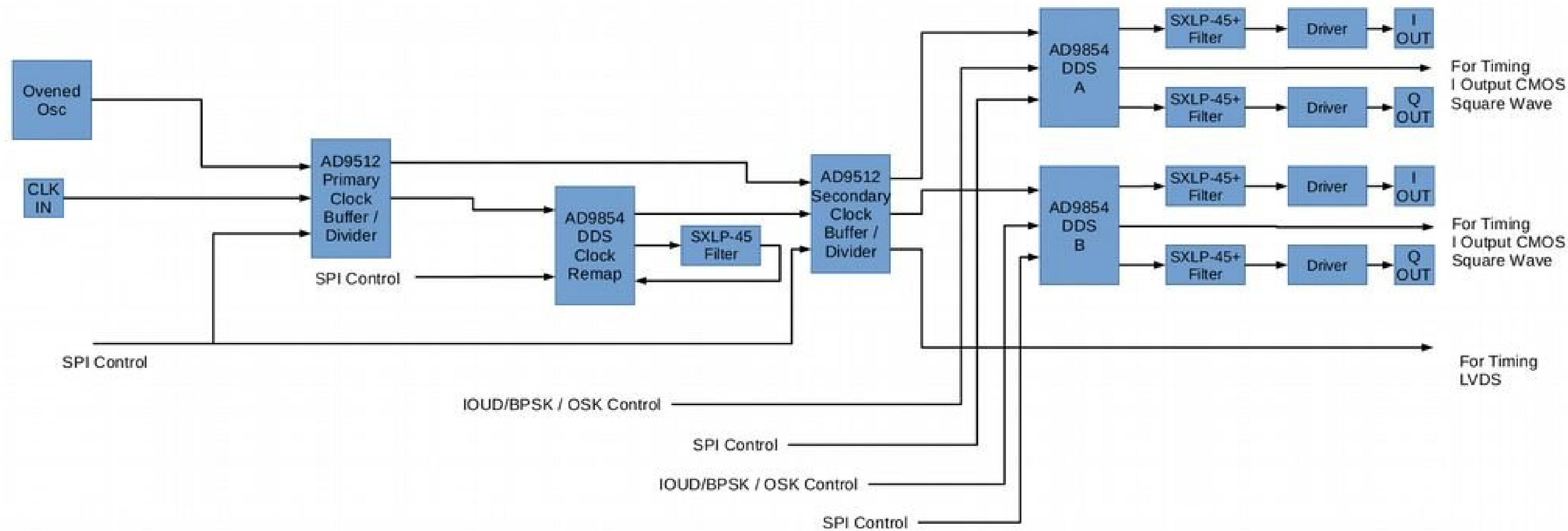


D-Tacq Solutions integrated digital HF radar/sonar controller



- Xilinx Zynq embedded processor
- FPGA, DSP cores, Cortex ARM on one chip
- 100 MHz crystal oscillator at ITAR phase noise limit
- 8, 16 or 32-channel 24-bit delta-sigma ADC board
- up to 24 MHz sampling
- 512*32 FIR decimation to 750 Hz final sampling
- raw time series 24 kbyte/s for 8 antennas (<4-G speed)
- archive on USB drive (5 years on 4 Tbyte drive)
- OEM cost $8,000

D-Tacq Solutions radar/sonar signal generator (UH concept)



MK-II: 20 built (2012)

MK-III: 40 built (2017), 60 built (2021)

2022:

FCC Part 90

Certification approval by UL

Thanks for the coaching, Chad!

TCB

GRANT OF EQUIPMENT AUTHORIZATION

TCB

Certification
Issued Under the Authority of the
Federal Communications Commission
By:

UL Verification Services Inc. (formerly UL CCS)
47173 Benicia Street
Fremont, CA 94538

Date of Grant: 04/19/2022

Application Dated: 04/19/2022

University of Hawaii
1000 POPE RD
MARINE SCIENCE BLDG 402
HONOLULU, HI 968222336

Attention: Pierre Flament , Researcher

NOT TRANSFERABLE

EQUIPMENT AUTHORIZATION is hereby issued to the named GRANTEE, and is VALID ONLY for the equipment identified hereon for use under the Commission's Rules and Regulations listed below.

FCC IDENTIFIER: 2A562-MK3-PW-PA-TX
Name of Grantee: University of Hawaii
Equipment Class: **Licensed Non-Broadcast Station Transmitter**
Notes: **Oceanographic High Frequency Doppler Radar**

Grant Notes	FCC Rule Parts	Frequency Range (MHZ)	Output Watts	Frequency Tolerance	Emission Designator
	90	4.438 - 4.488	23.66	100.0 PM	48K4F1N
	90	5.25 - 5.275	25.23	100.0 PM	23K1F1N
	90	13.45 - 13.55	15.17	100.0 PM	98K6F1N
	90	16.1 - 16.2	15.0	100.0 PM	98K7F1N
	90	24.45 - 24.65	16.14	100.0 PM	192KF1N
	90	26.2 - 26.42	15.6	20.0 PM	211KF1N

Output power listed is EIRP. This device must be installed to provide a separation distance of at least 10.66m, 3.55m and 2.3m for device operating below 10MHz, between 10-20MHz and above 20MHz from all persons, respectively. It must not be collocated or operating in conjunction with any other antenna or transmitter except in accordance with FCC multi-transmitter product procedures. End-Users must be provided with transmitter operation conditions for satisfying RF exposure compliance.

Post-processing tools developed by the community of users:

- BF and variants (UH, NCU, IFREMER)
- phase-based MUSIC DF for antenna clusters (WHOI)
- minimum-phase-error DF for 4-antenna arrays (UABC)

Compatible commercial processing tools available:

- BF for currents, wind and waves by SeaView Sensing Ltd.
- MUSIC DF for arbitrary arrays by MIO/Université de Toulon
- BF for currents, wind and waves by University of Hamburg/Gurgel

The Helical Antenna*

JOHN D. KRAUS†, SENIOR MEMBER, IRE

Summary—The helix is a fundamental form of antenna of which loops and straight wires are limiting cases. When the helix is small compared to the wavelength, radiation is maximum normal to the helix axis. Depending on the helix geometry, the radiation may, in theory, be elliptically, plane, or circularly polarized.

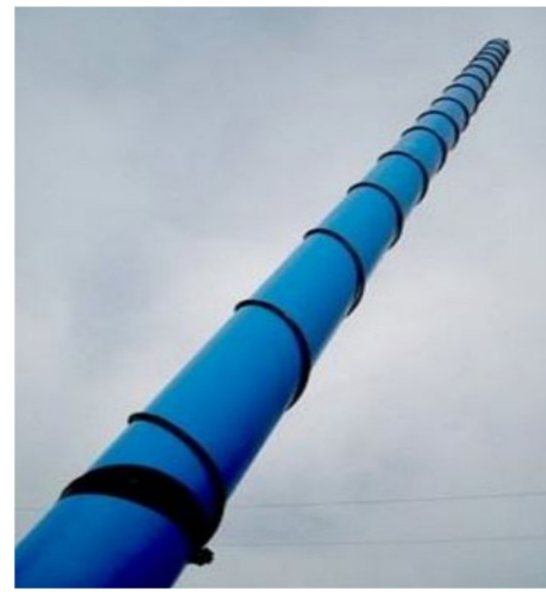
When the helix circumference is about 1 wavelength, radiation may be maximum in the direction of the helix axis and circularly polarized or nearly so. This mode of radiation, called the axial or beam mode, is generated in practice with great ease, and may be dominant over a wide frequency range with desirable pattern, impedance, and polarization characteristics. The radiation pattern is maintained in the axial mode over wide frequency ranges because of a natural adjustment of the phase velocity of wave propagation on the helix. The terminal impedance is relatively constant over the same frequency range because of the large initial attenuation of waves on the helix. The conditions for circular polarization are analyzed, and the importance of the array factor in determining the radiation pattern of a long helix is discussed.

* Decimal classification: R125.1×R326.61. Original manuscript received by the Institute, June 7, 1948. Presented in part, 1948 IRE National Convention, New York, N. Y., March 23, 1948.

† Department of Electrical Engineering, Ohio State University, Columbus, Ohio.

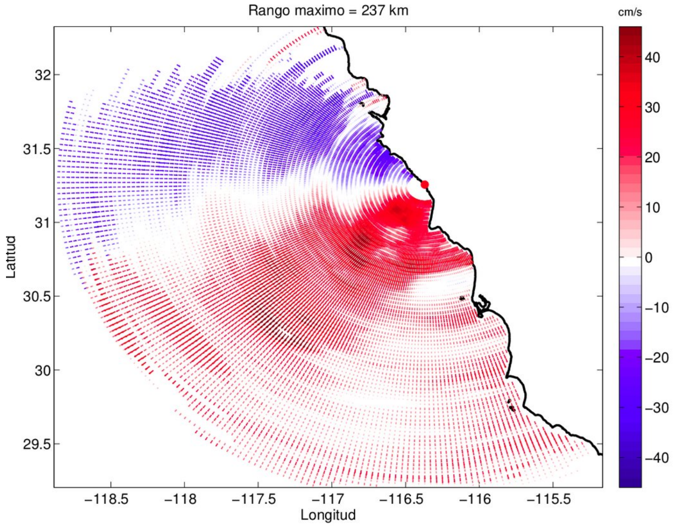
Introduction

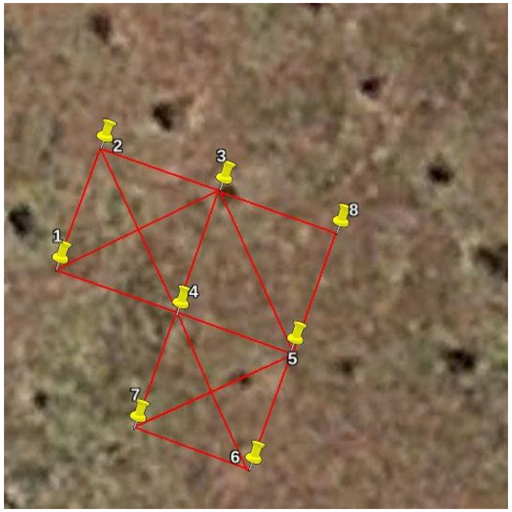
A HELIX is a fundamental geometric form. It has applications in many branches of physics and engineering. For example, in mechanical systems the helix or coil spring is a familiar structure; in electrical systems, a helical conductor or inductor is a common type of circuit element; and in many dynamic phenom-



The transmit antennas are normal-mode helical monopoles (Kraus, J.D., "The Helical Antenna", *Proc. I.R.E.* 1949 pp. 263-272). They consist of an AWG-16 vertical wire of length λ/4 wound over a mast of height λ/8 and diameter λ/300, a 3-loop tuning air-coil, and a network of 4 underground radials of length λ/4 (λ is the electromagnetic wavelength). The air-coil diameter is adjusted to achieve resonance using a standard commercial VSWR meter.

Helical monopole: 8 MHz (creosote timber)





(3^2-1)
direction-finding cluster

- **λ/4 wire coiled on λ/8 treated wood**
- **geometric scaling defines frequency**
- **base coil-loading for tuning**
- **fully waterproof, potted junctions, RG213 pig-tail**
- **4 buried λ/4 wire radials, approximate impedance 50Ω VSWR 1.1-1.2**
- **wide band f/30**

Active antenna array:
13.5 MHz range 130 km
(Chevron Kapolei)

Ultra-compact
phase-stable radial-less
antenna, λ/16 mast

Current deployments of UH Generic HF radars:

- *Hawai'i, the Pacific Island Observing System (feeding into HFRnet):*

- 5 radars at 13.5, 16 and 26.5 MHz operating on Oahu, since 2009
- 2 radars at 16 and 24.5 MHz operating on Hawai'i, since 2012
- 2 radars at 13.5 MHz in Guam and Rota, starting 2025

- *Mexico (X. Flores, UABC):*

- 3 radars at 24.5-26.5 MHz, covering Bahia de Todos Santos (Ensenada), installed 2015
- 2 long-range radars at 8 MHz range up to 250 km offshore Baja California, installed 2016
- 15 long-range radars at 7-8 MHz, covering the Gulf of Mexico, installed 2018

- *New England (A. Kirincich, Ian Fernandez, WHOI):*

- 6 radars at 16 MHz mapping the New England shelf, starting 2018

- *Luzon strait (Charina Repollo, UPD-MSI, with TORI):*

- 3 long-range radars at 8 MHz, collaboration Philippines/Taiwan/Hawaii, 2019-2023

- *Quebec (C. Chavanne, ISMER):*

- 2 mobile solar-powered radars at 16 MHz deployed in the St Lawrence estuary, since 2018

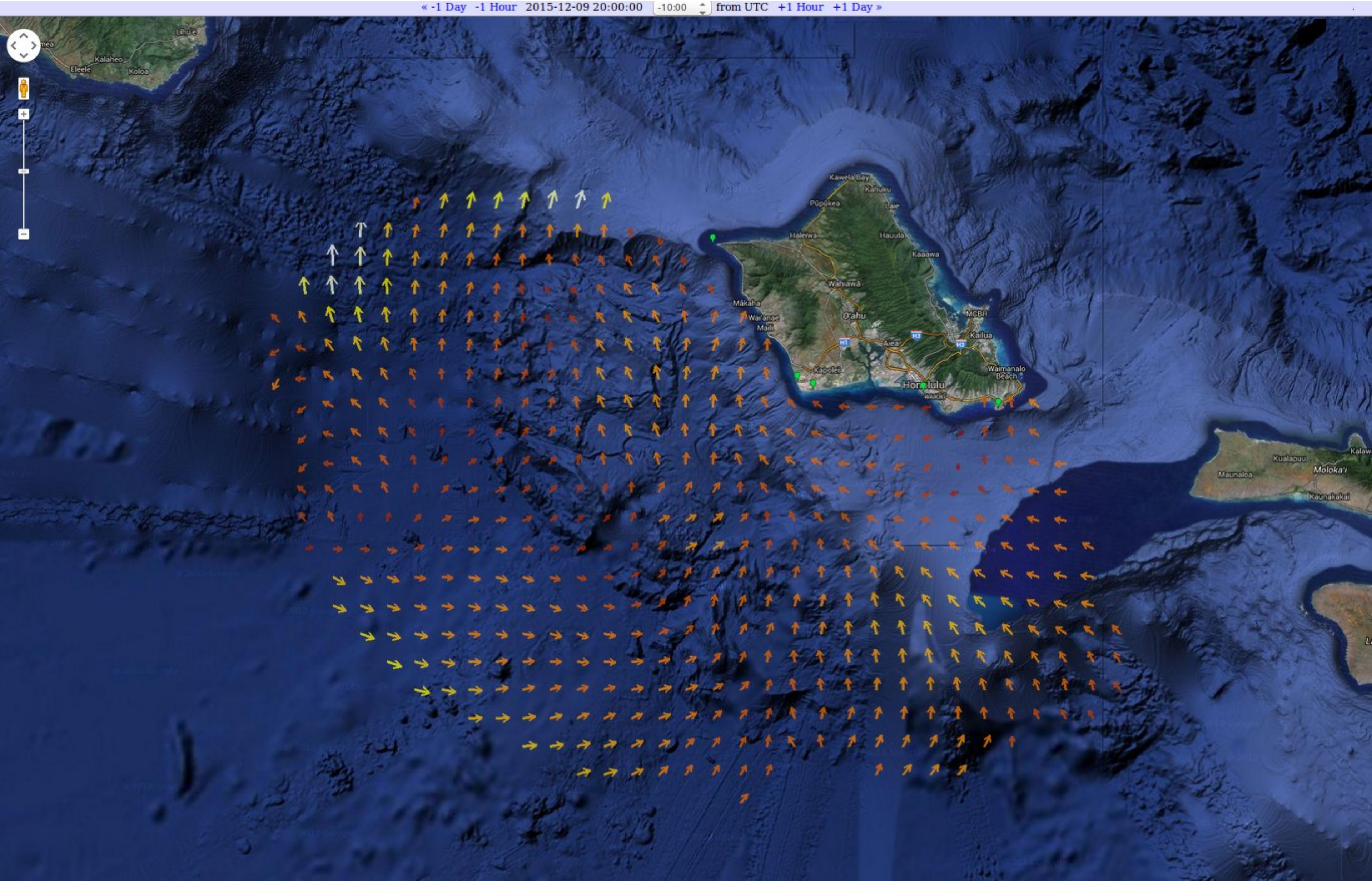
- *France (L. Marie, IFREMER):*

- 1 long-range radar at 4.5 MHz over the southern Bay of Biscay, since 2021

- *Taiwan (Chien Hwa, NCU; Jin-Wu Lai, NAMR; Cheng Da Li, IHMT)*

- 21 radars at 25-30 MHz covering harbors around TW, since 2018

NOAA Integrated Ocean Observing System: hourly current maps

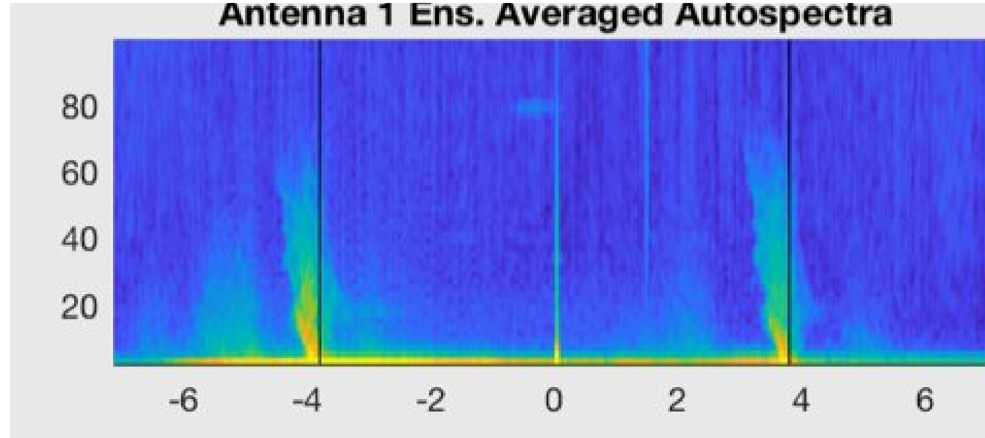


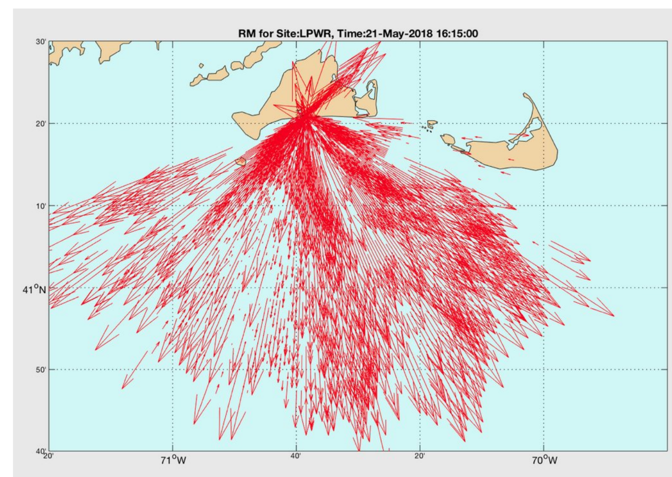
Woods Hole Oceanographic Institution:

6 radars @ 16.15 MHz, 15 W,
100 kHz BW, 80 km range

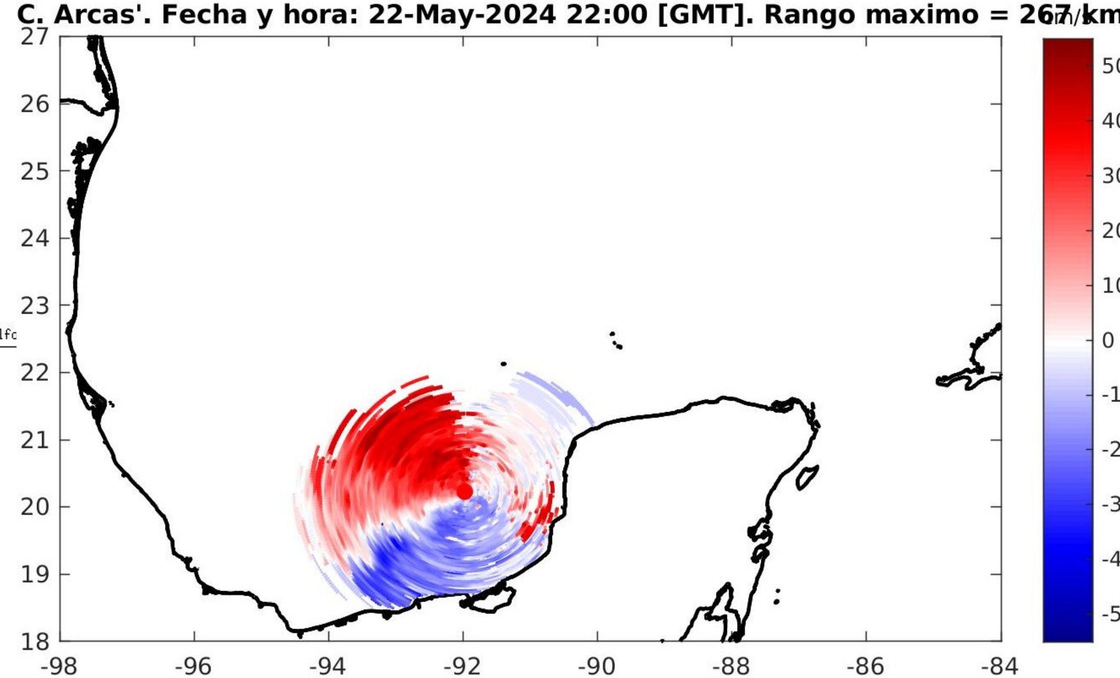
- Martha's Vineyard
- Nantucket
- Westport MA
- Maine, Rhodes Island

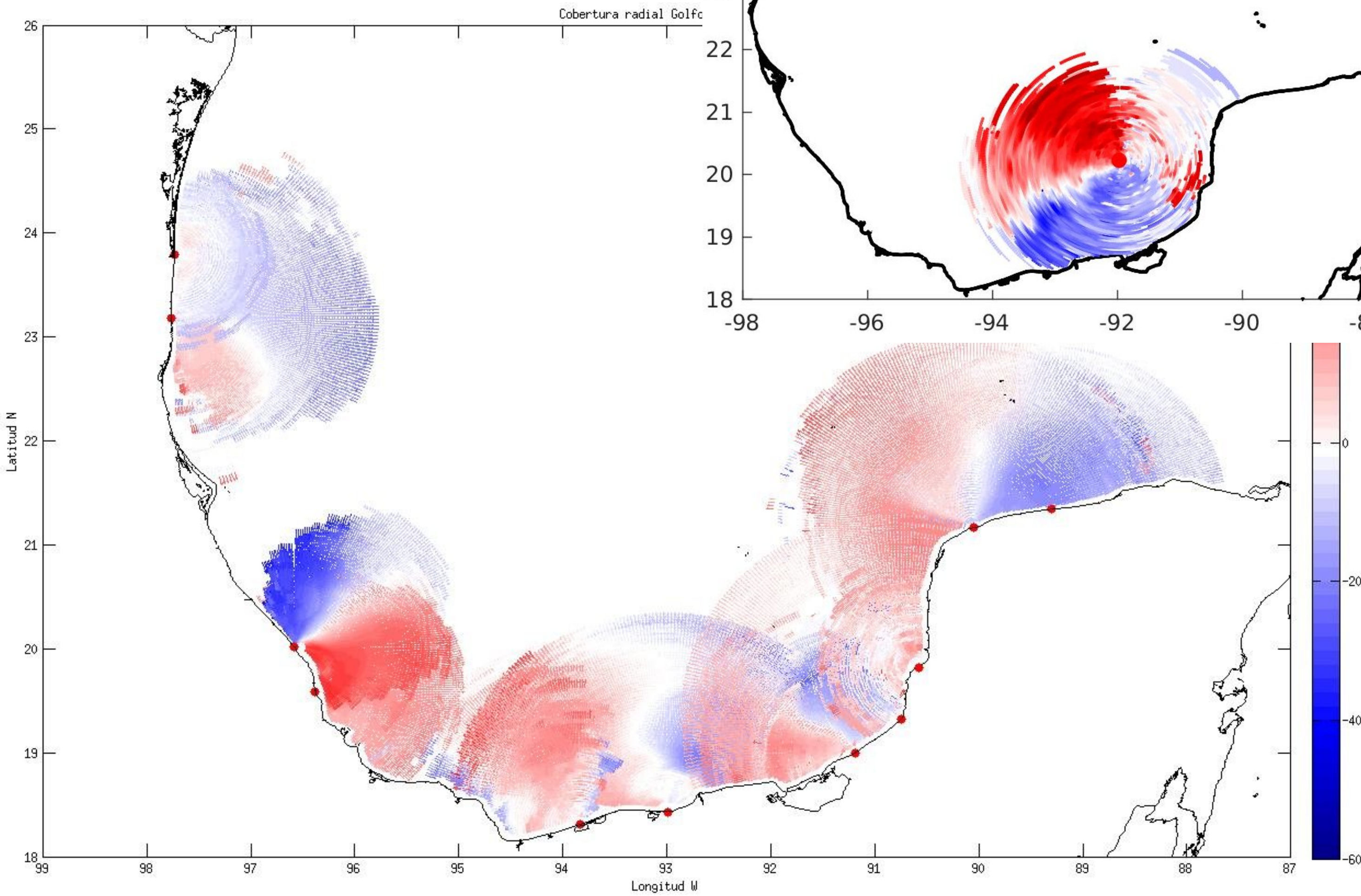
All (3^2-1) direction-finding RX clusters
(algorithms Anthony Kirincich, Brian Emery)

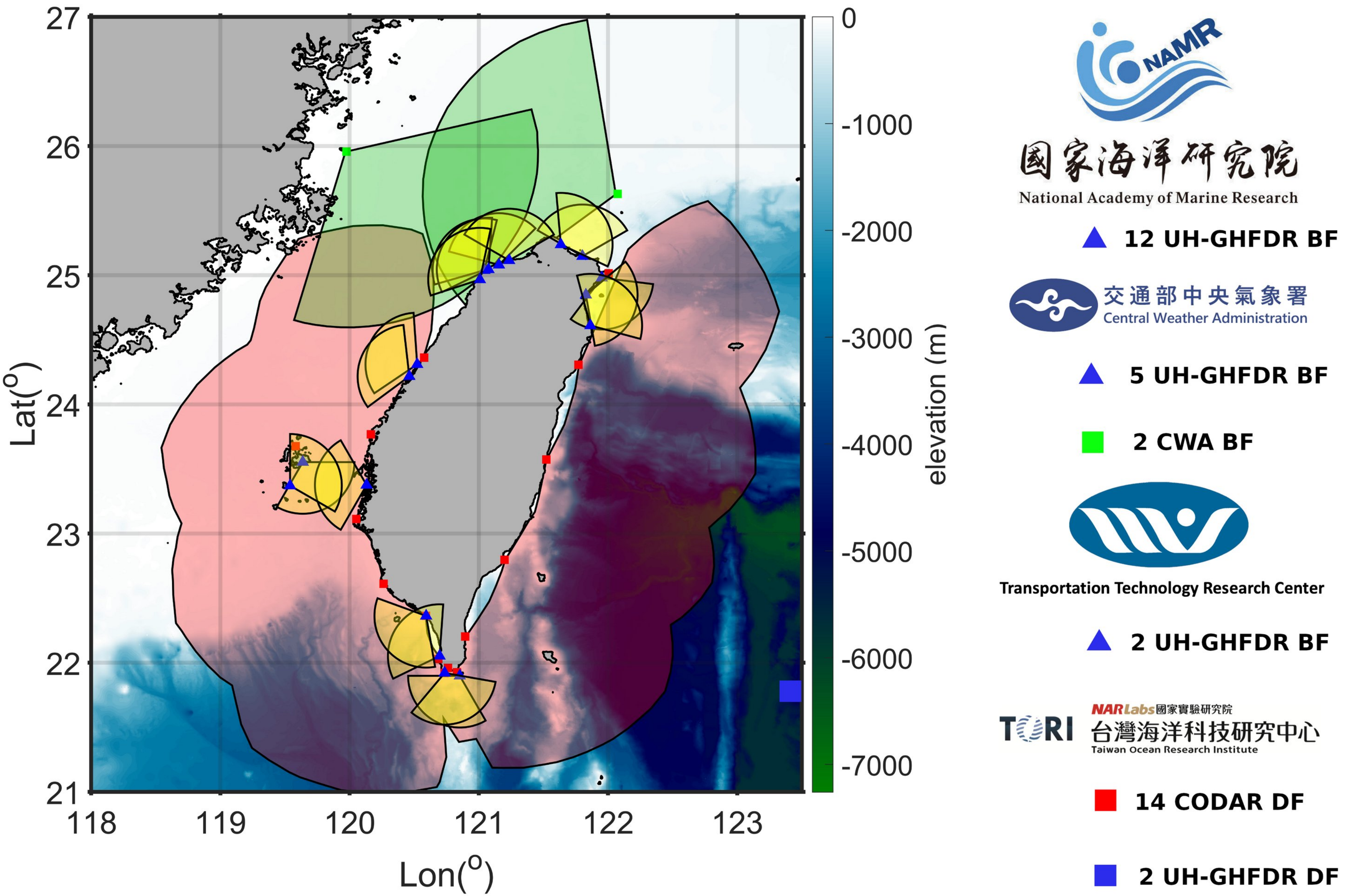




Universidad de Baja California: GoM 15 UH-HFDR, 7-8 MHz



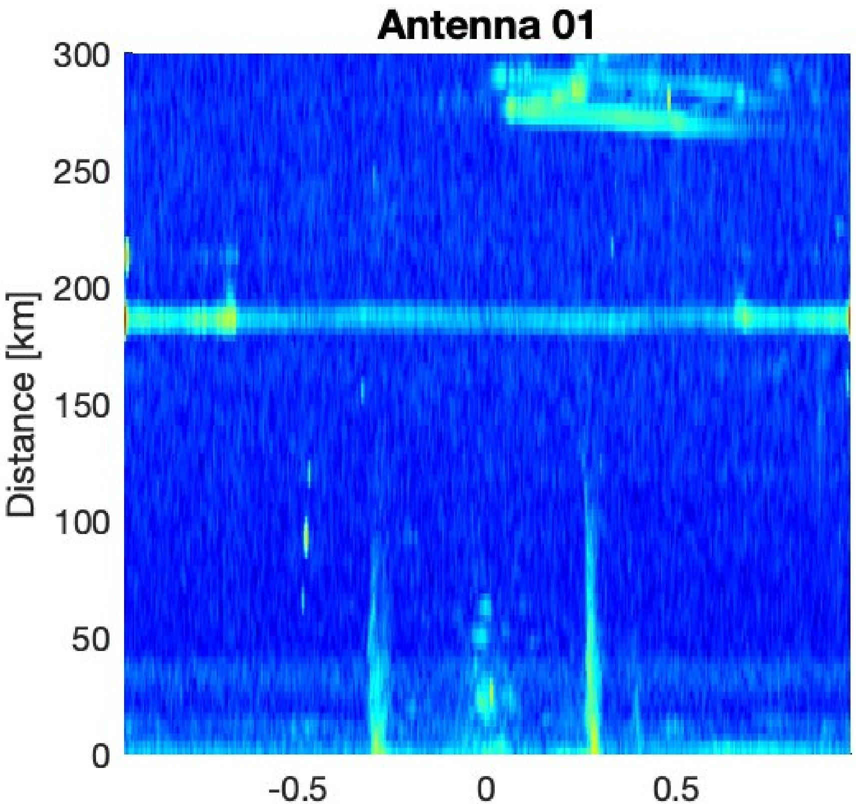


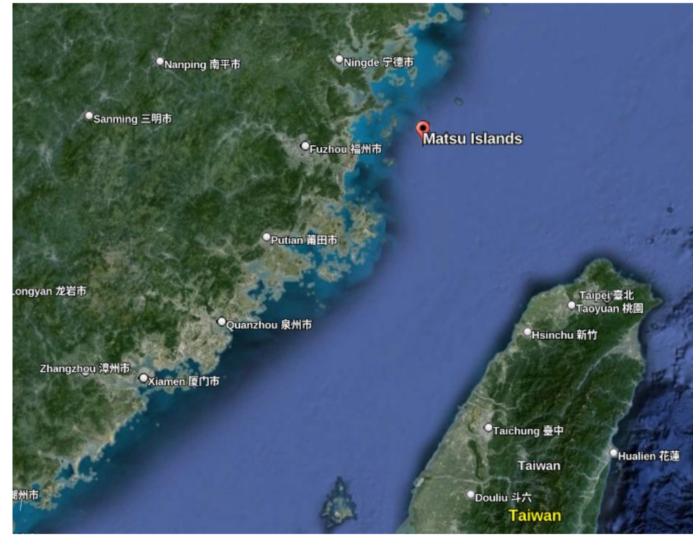


Taiwan HF Radar Coverage and Bathymetry Map.

Penghu island TW 32 antennas range 40 km @ 26.5 MHz

UH electronics at 8 MHz interfaced to TW-CWA radar in Dongju/Lienchiang (Matsu Island): sweep 0.52s, bandwidth 50kHz, audio sampling 12kHz, decimation to 375 Hz, averaging 30 min.



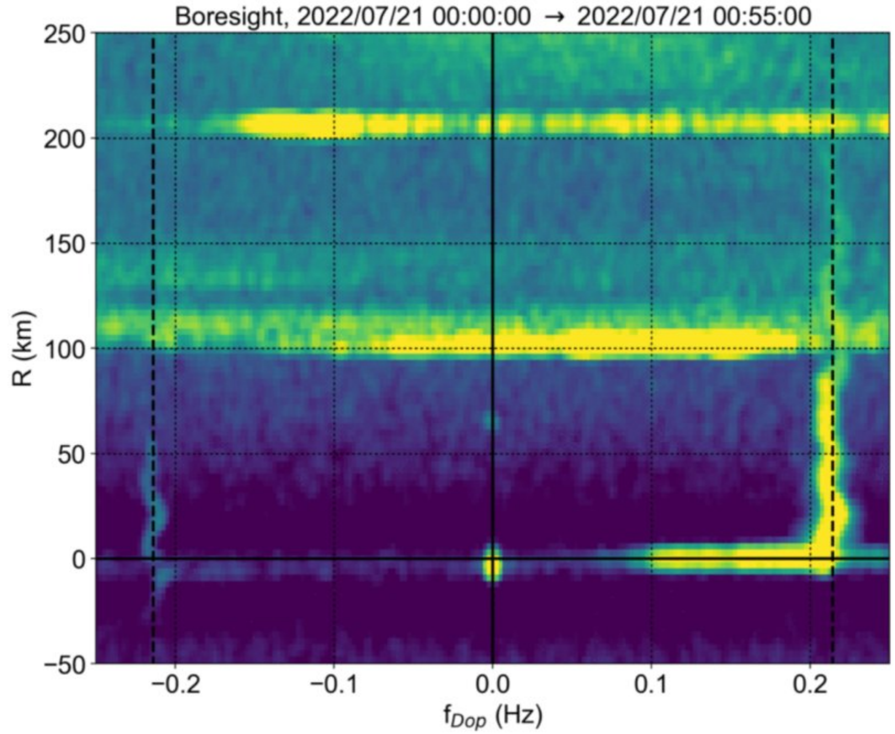


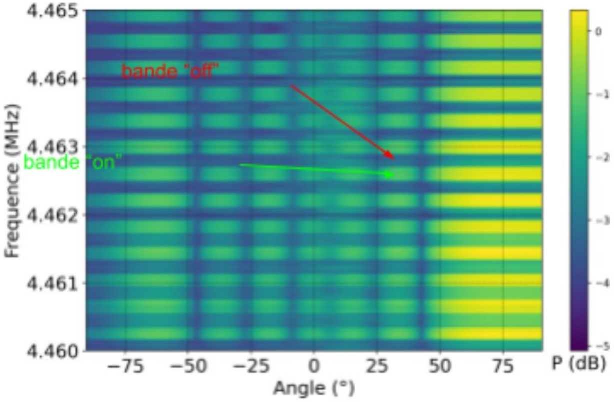
World first:
analog fiber-optic connection to remote TX

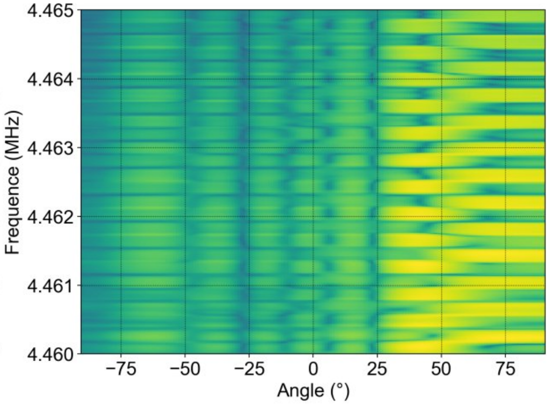
https://rfoptic.com/

UH electronics at 4.5 MHz installed by IFREMER in Mimizan (SW France): sweep 1s, bandwidth 50kHz, audio sampling 12kHz, decimation to 375 Hz, averaging 30 min.

World first: standard aluminum street lighting poles on concrete foundation installed by commercial contractor



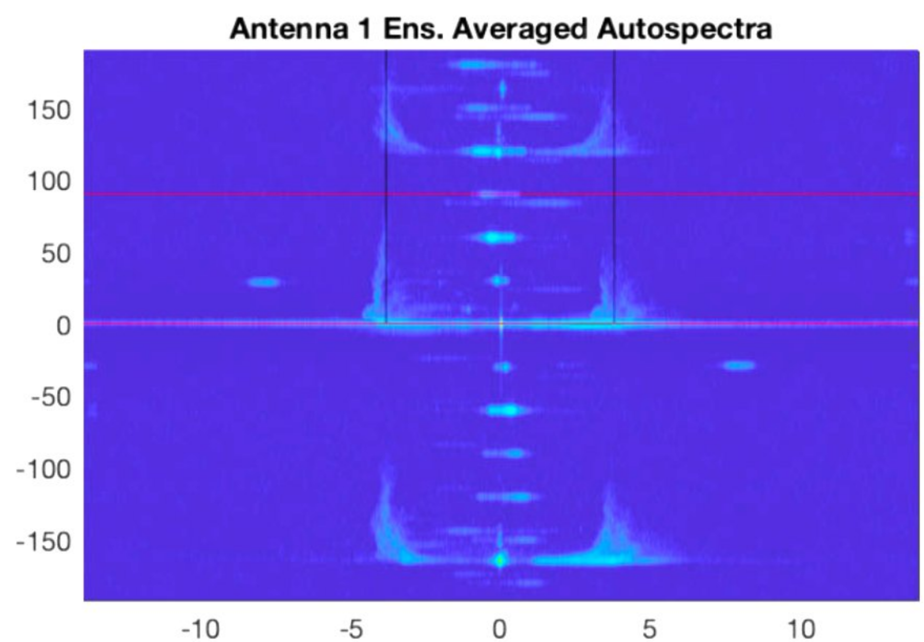




Recent development:
all-constellations GNSS synchronization:

- use best PPS timing board on the market: U-Blox F9T
- tested ±7 ns PPS jitter on fixed position
- firmware modules implemented in FPGA controller
  - ntp server on local network good to 1 ms
  - iterative remapping of OCXO to 1 mHz using dedicated DDS by counting clock cycles between PPS
  - code to start chirp and ADC on exact PPS

- clock stability to 0.01 mHz maintained by chip-scale Rb clock



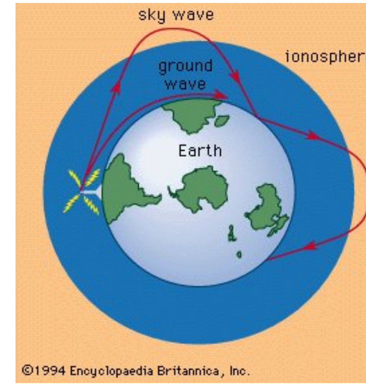
- *Applications:*
- 1: distant TX and RX without cable connection

  (allowing single-antenna TX)
- 2: multi-static operation for both

  elliptical and circular solutions

Space weather applications (ONR)

- use opportunistic of HFDR signal for ionospheric studies
- passive high-bandwidth receivers installed Palau, Taiwan, Philippines
- detect many chirping transmitters, few identified
- trend-setting paper by Scripps' group



Observations of Ionospheric Clutter at Near Equatorial High Frequency Radar Stations

by Thomas M. Cook *,†, Eric J. Terrill, Carlos Garcia-Moreno and Sophia T. Merrifield

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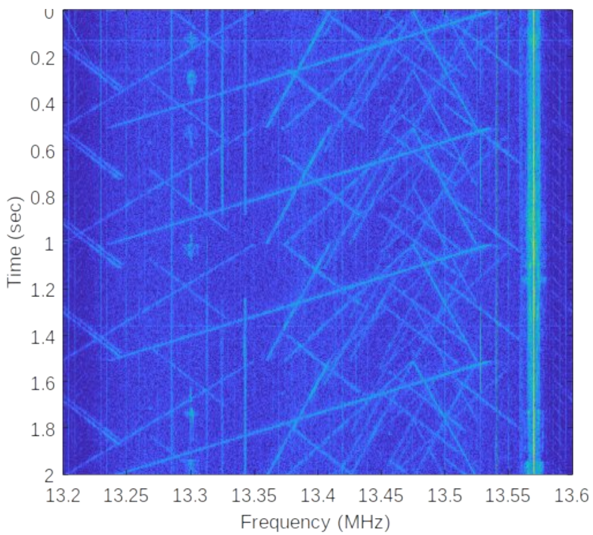

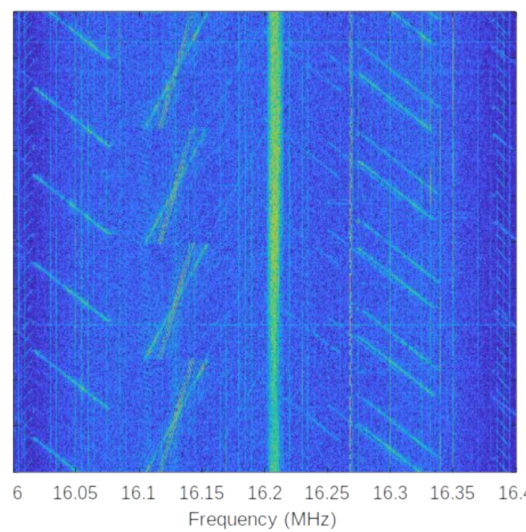

Are we seeing the end of homodyne HFDR?
Are software-defined HFDR next?

Radiowave Oceanography W ×

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