Software Radar and the Framer Pattern: Applying Context to Continuously Recorded RF Data

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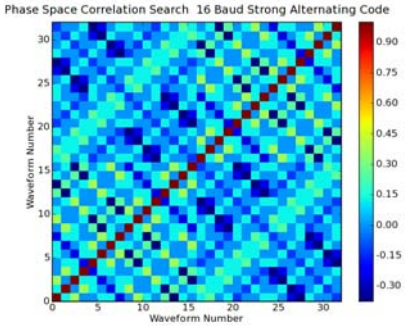
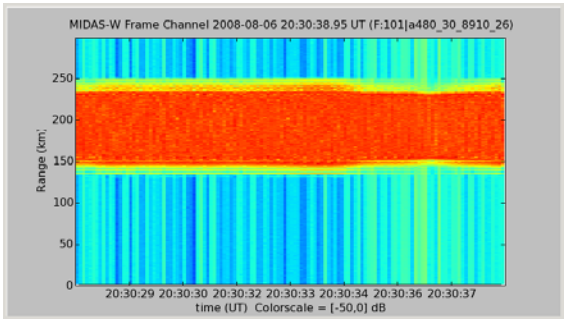
Special thanks to Tom Grydeland

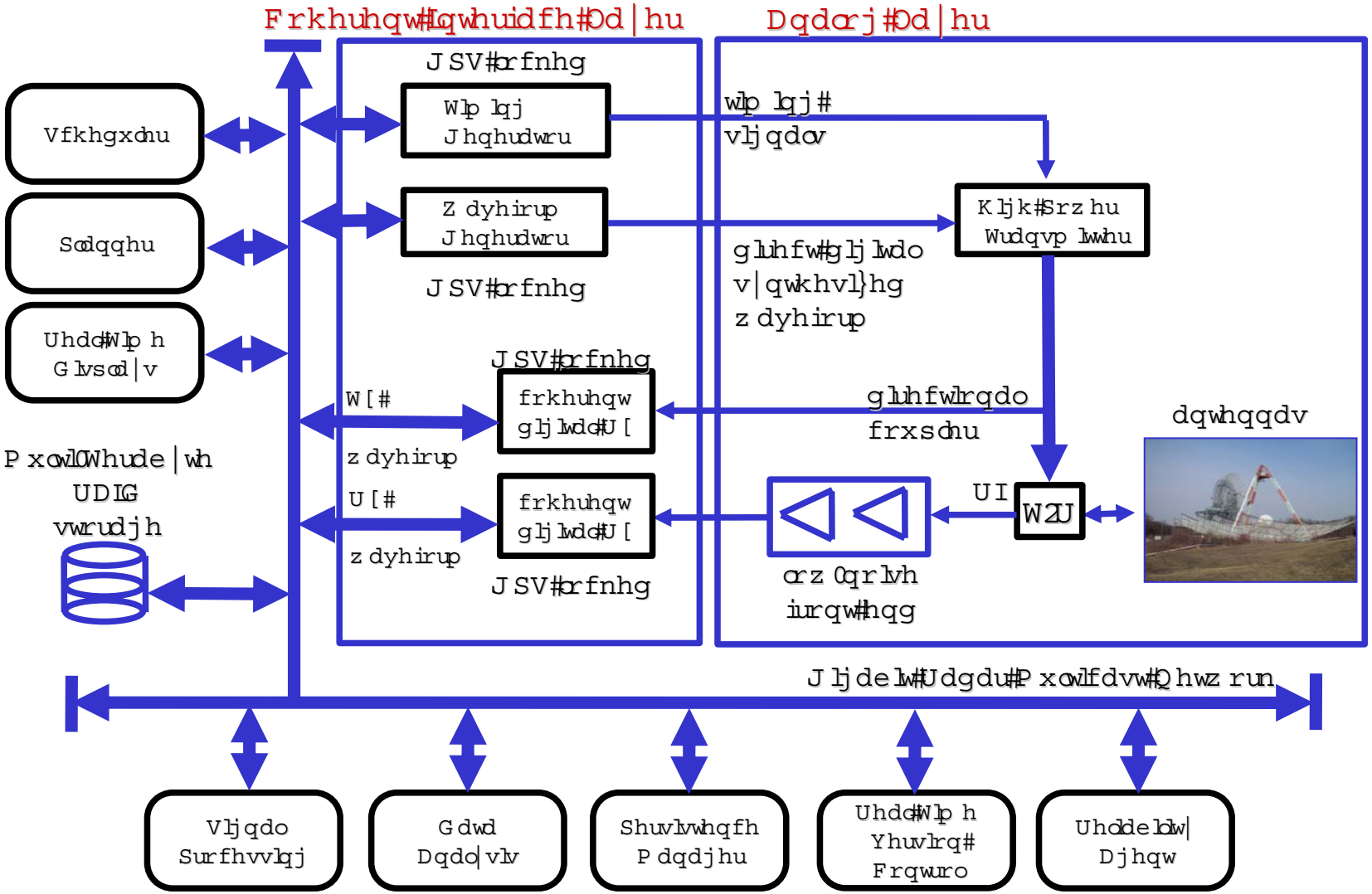




Outline

- Software Radar Concepts
- Synchronization: The Framer Pattern
- Examples at UHF
- Signal Classification Literature: Clues for Waveform Identification?

Software Radar Architecture



Networked Coherent Software Radio

Udglr#U[2W[#p sdnp hqwhg#Sulp dulo#q#Vriwz duh

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JSV#Drfnhg#Rvflodwruv#dqg#Ddjqp hqw#4#sduw#q#4H44;

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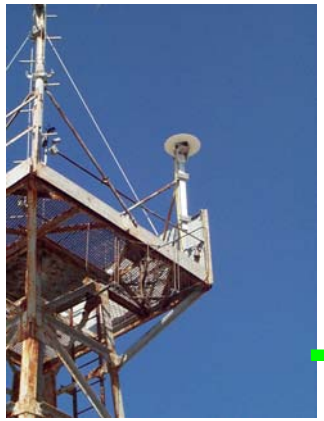
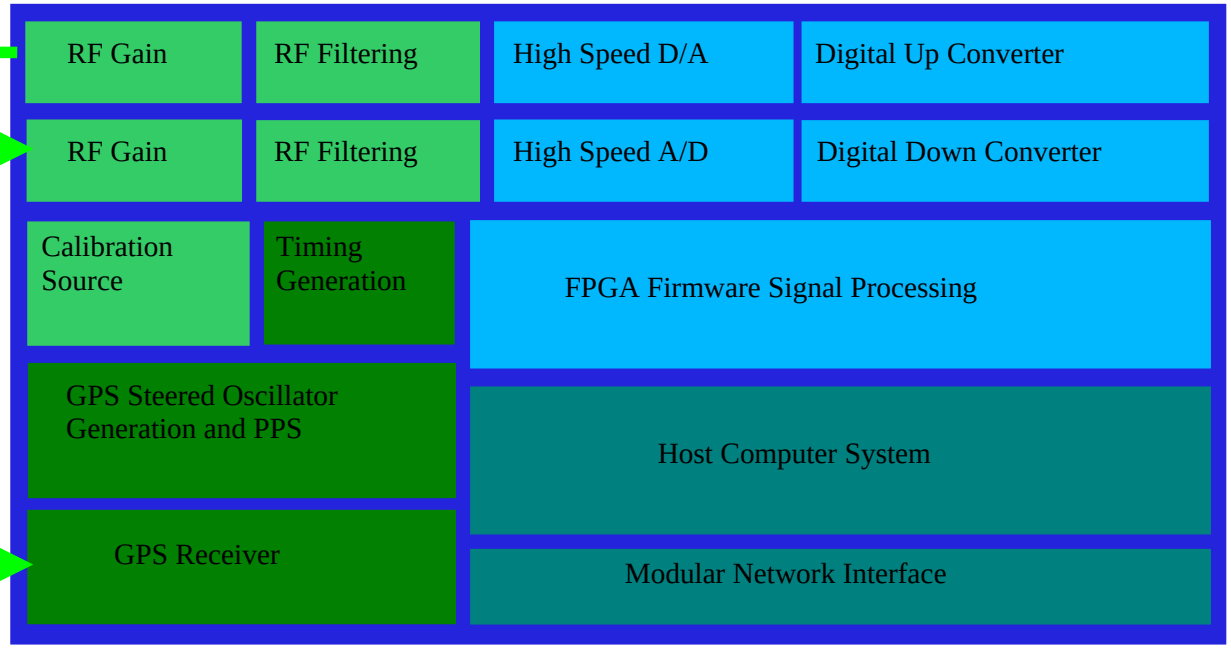




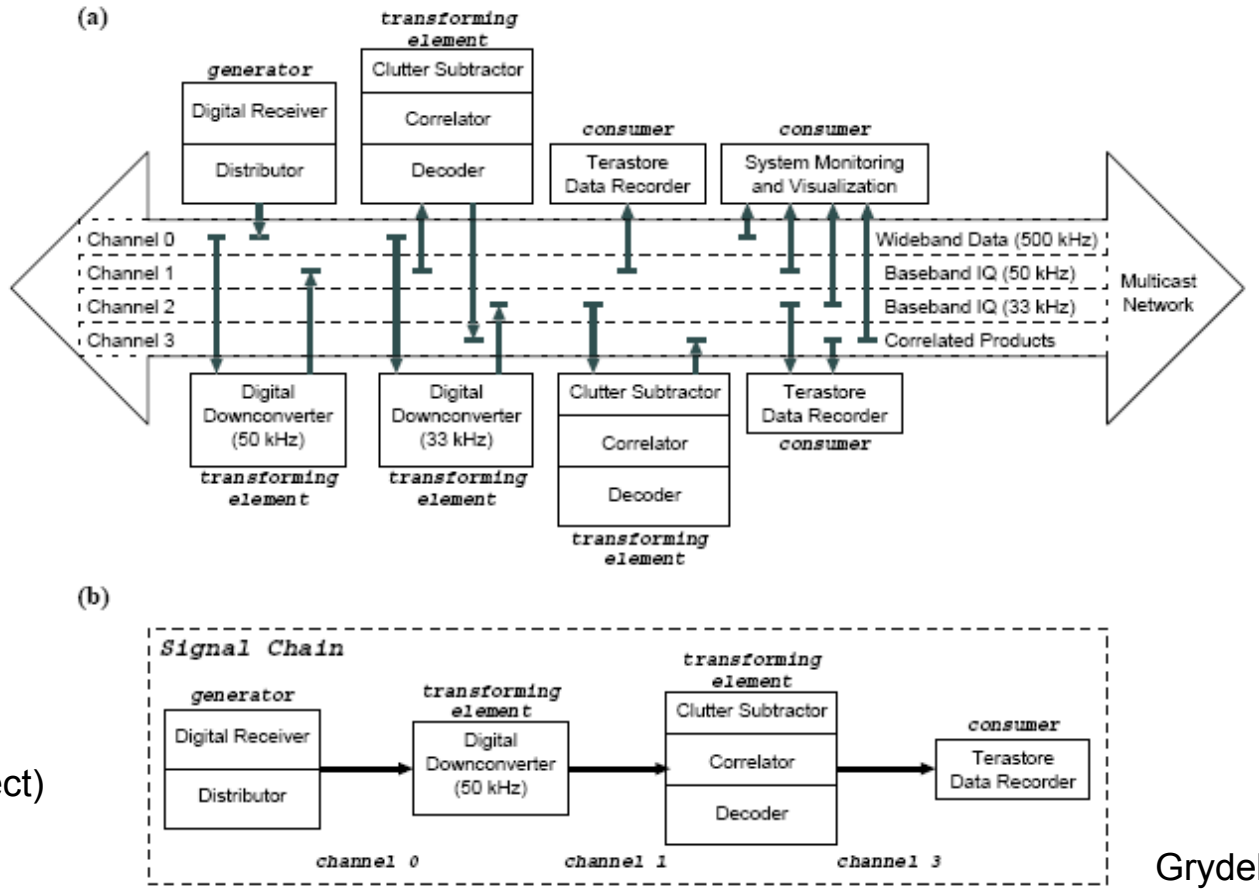
Implementing Software Radar: MIDAS-M

Globally coherent

16U SKB Shockrack Enclosure
Zyfer L1 GPS Frequency Reference : NTP, PPS, Modular and Expandable
GPS steered oscillators 10 MHz, 72 MHz, 105 MHz, (10 sec Allan Variance < 1E-11)
2 Echotek Digital Receiver cards (3 analog channels each, 14 bit ADC, digital down converters)
4 Dual CPU computers per node (2 RX hosts, 2 processing), 500 GB per computer (2 TB total)
Gigabit Network Switch for data interconnect, uplink, and expansion
1500W UPS system, N-connector Cables, linear power supply
All elements monitored and controlled via Ethernet

Software Radar Requires Software Patterns

In software engineering, a design pattern is a general, reusable solution to a commonly occurring task or problem (e.g. Gamma et al, 1994).



Not shown:
Selector
(e.g. RFI reject)

Grydeland et al, 2005

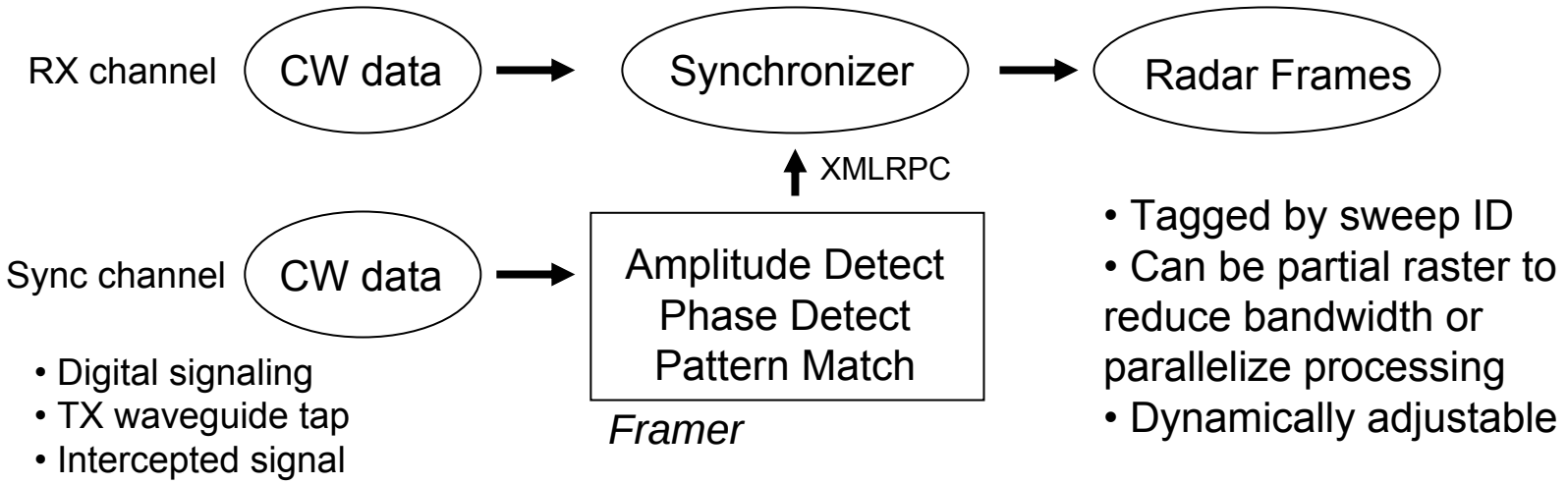
The Framer Pattern: Radar Synchronization

Software radars feature digital receivers run in either:

- Triggered mode
- CW mode (general RF capture) – allows multiple use scenarios

producing Level-0 data as I/Q or IF received voltages – all possible information retained.

For CW inputs, signal chains need a method to apply radar context:



Framer Processing

Amplitude detection:

- Remove median
- Form abs(power)
- Threshold detect above data variance

Phase detection:

- $\tan^{-1}\frac{Q}{I} = \phi_k$
- Unwrap phase
- Look for large jumps in

$$\Delta\phi = \phi_k - \phi_{k-1}$$

consistent with binary (e.g.) phase flips

Pattern matching:

Maximize correlation with known phase patterns

Or.. Construct phase patterns from sampled phase (analogies to passive radar processing)

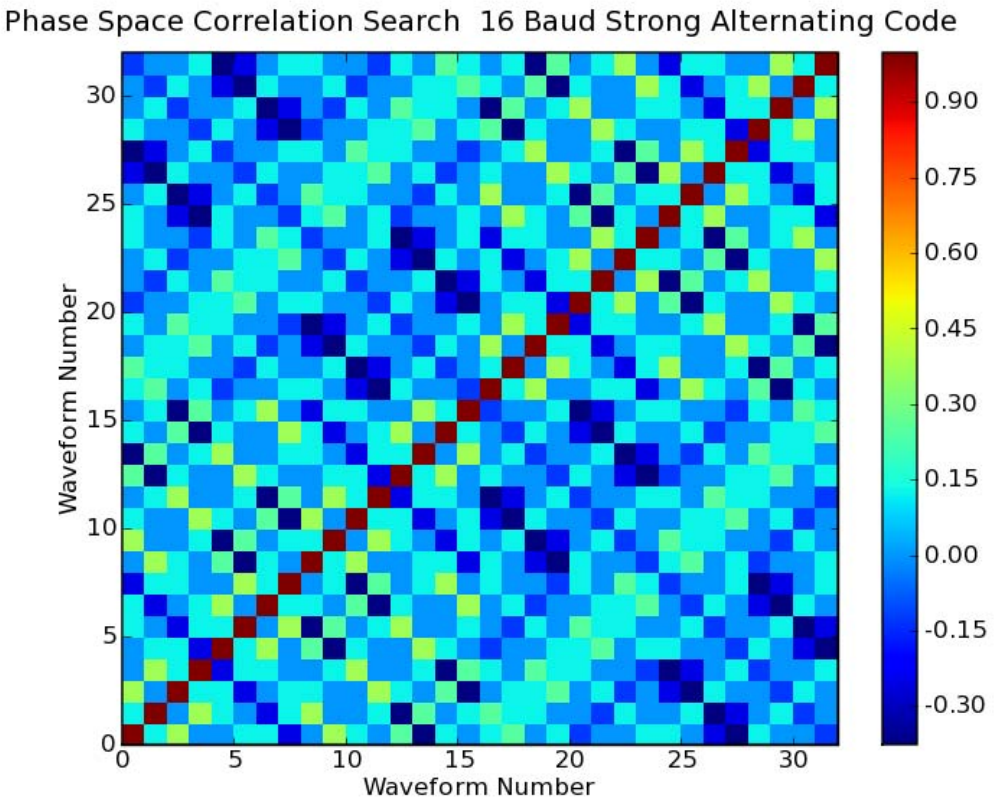
Framer Processing: Phase Pattern Match

For this code set, straightforward correlation match to each waveform

Match to entire code sequence (not just one waveform) for greater noise immunity

Not all sequences are unique: code #1 of unrandomized alternating code = uncoded pulse! Longer pattern matches provide ambiguity resolution

Run-length encode detected sequences to speed detection



Intercept Framing: Comparison to Passive Radar

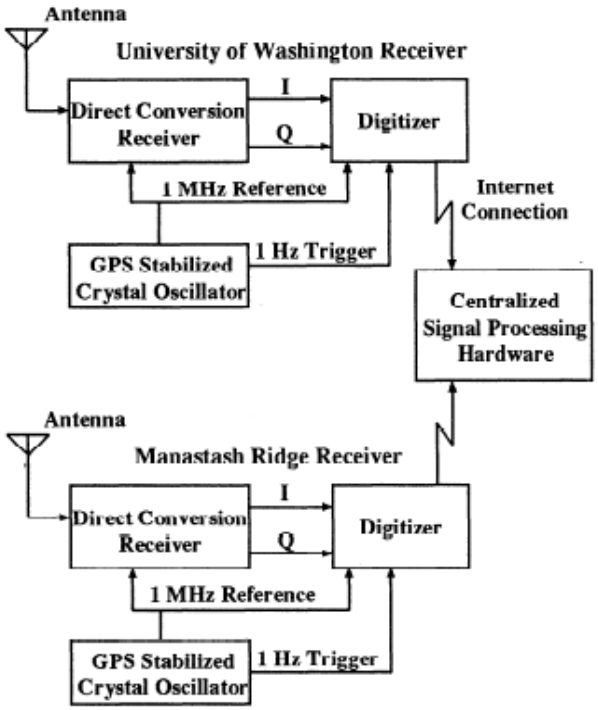
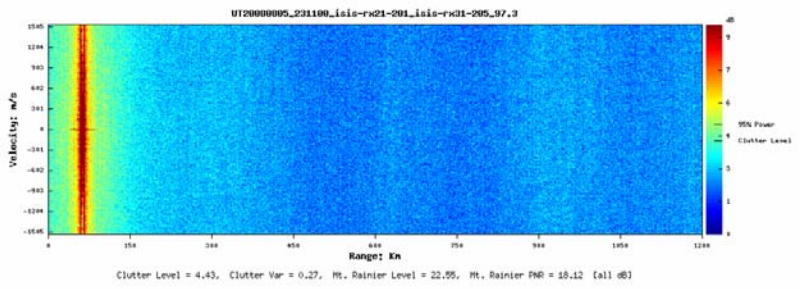
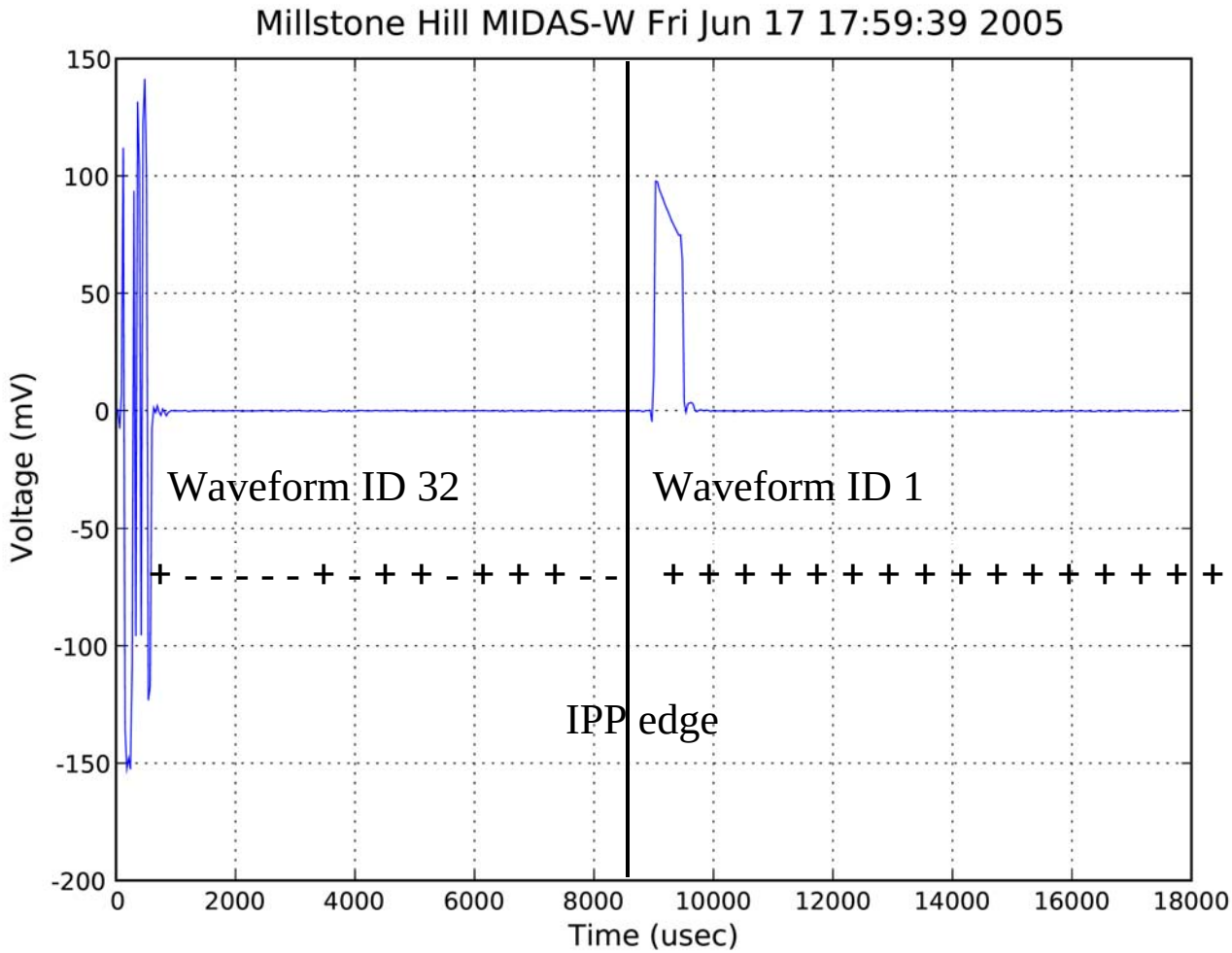


Figure 5. A block diagram of the system. The two receivers exchange data via a true, fast internet connection. The sampling and mixing synchronization is provided by Global Positioning System receivers.

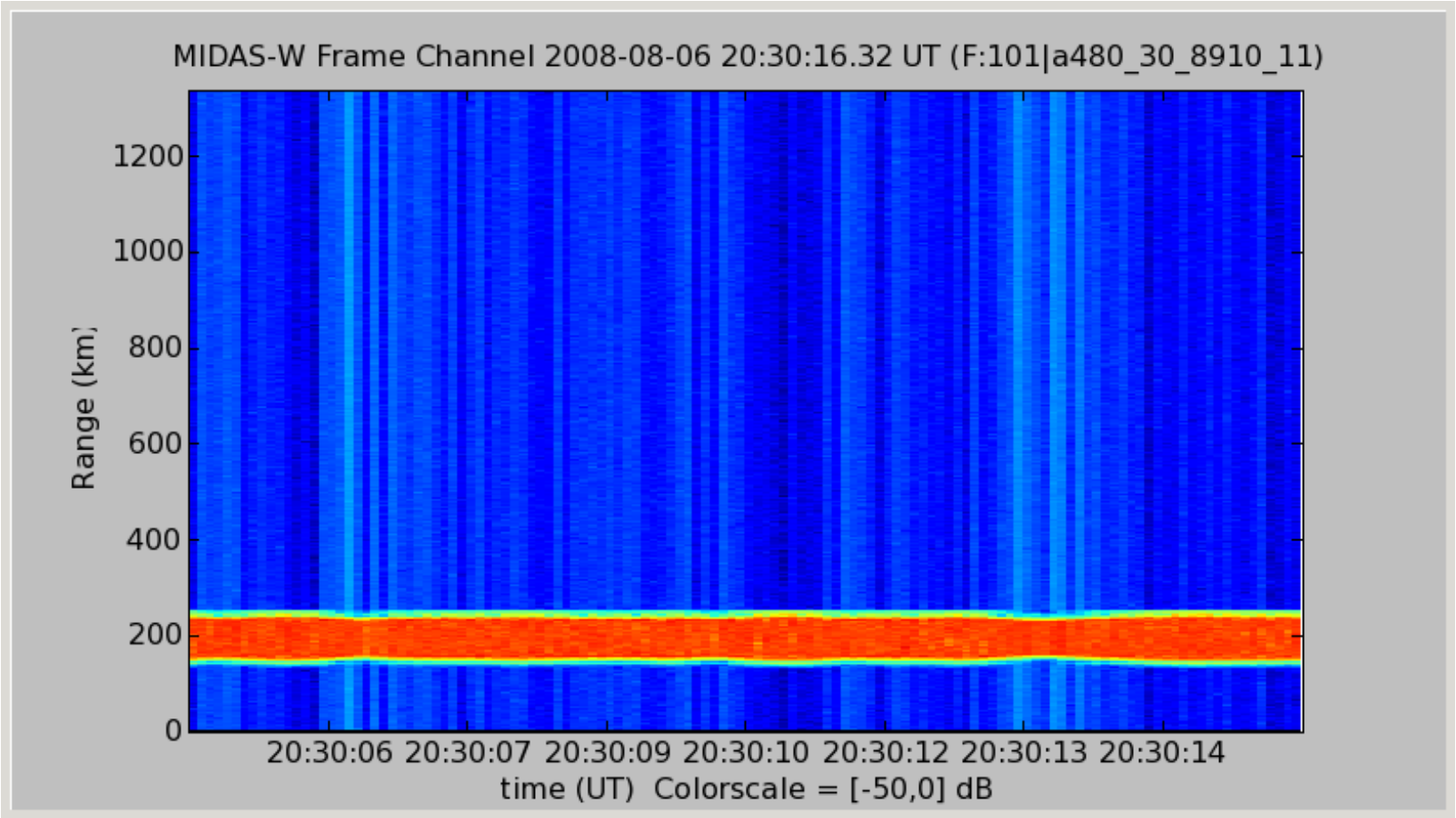


Passive radar performs full 4-correlation (assumes little).
We instead try to use apriori knowledge to avoid some of this work, and in the process "trust" the exciter/driver/transmitter…

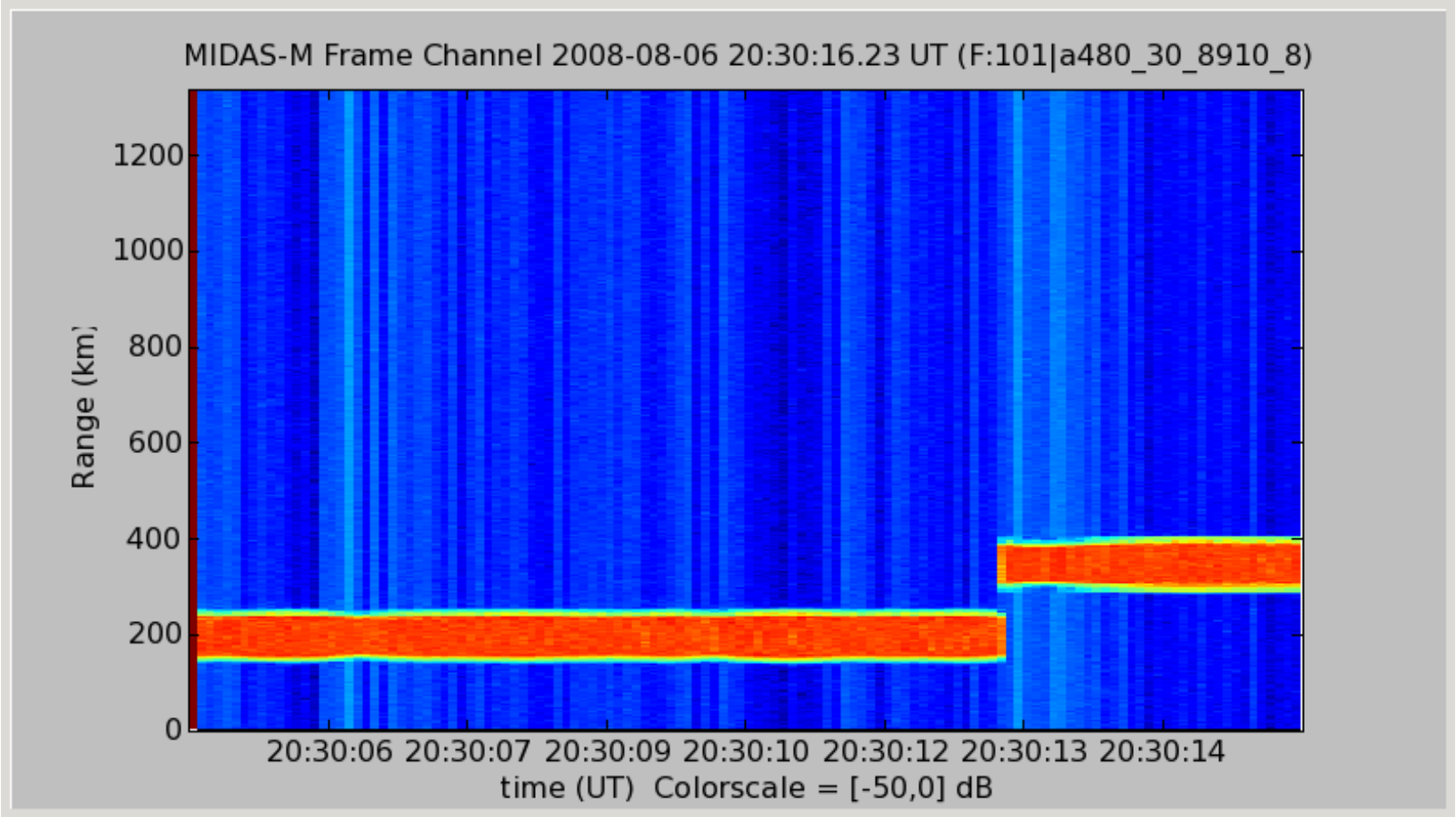
Framing From Millstone Hill Waveguide Tap



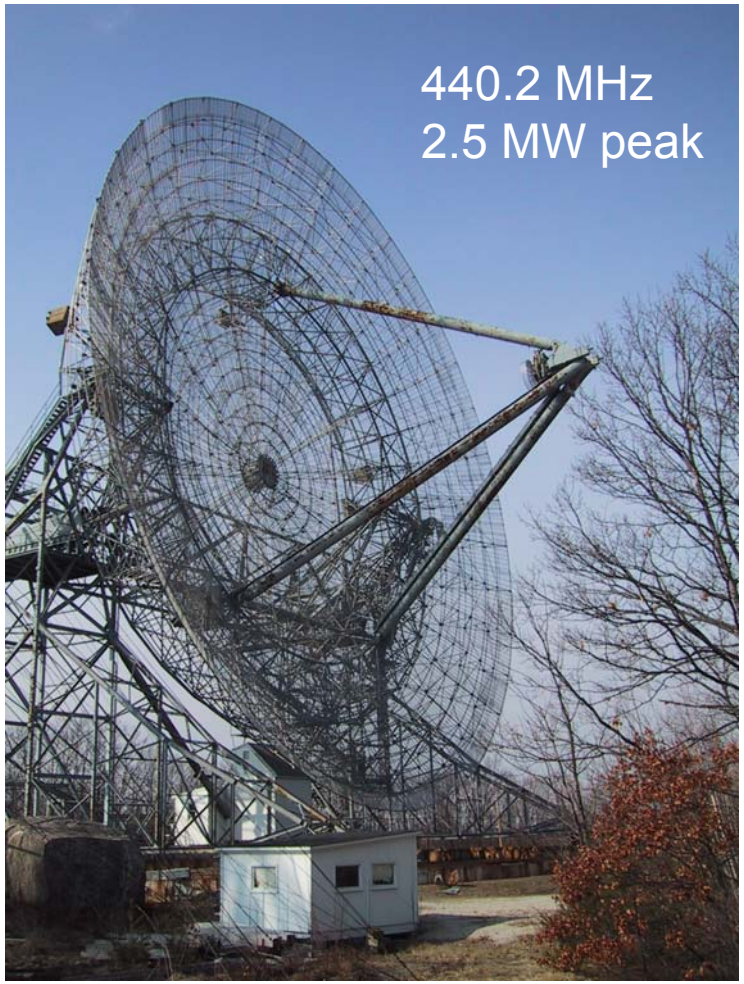
Framing Stability



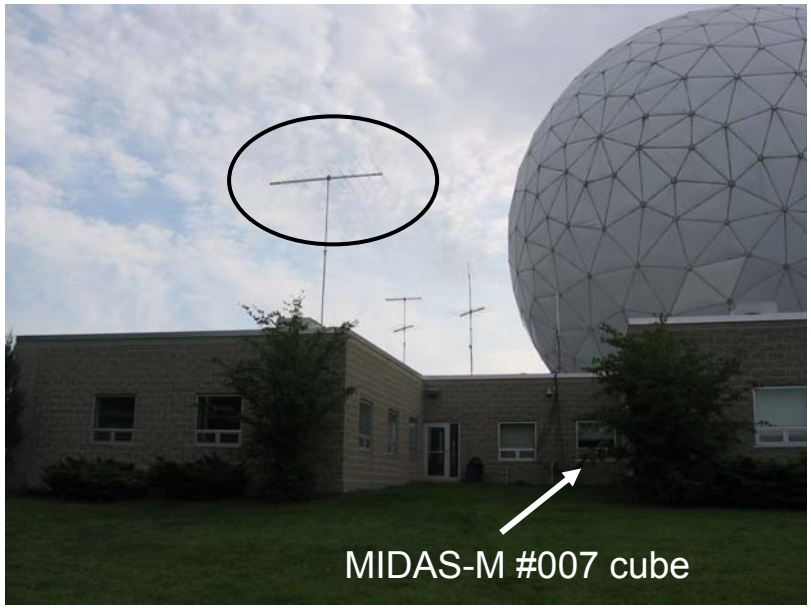
Dynamic Framing Adjustment



Framing With Locally Intercepted TX Signal



TX: Millstone Hill MISA antenna
46 meter diameter: 42 dB gain

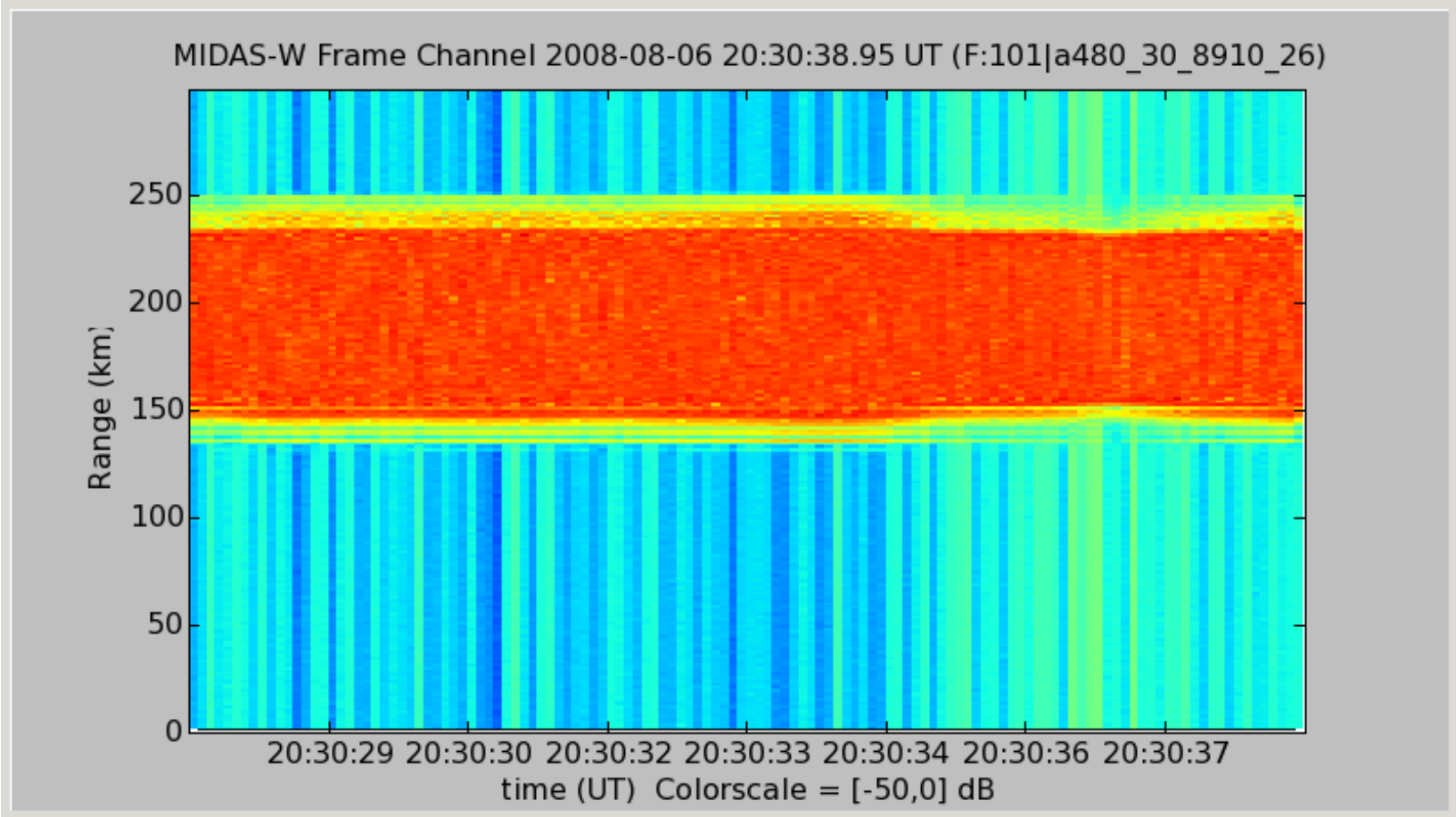


MIT Haystack Atmospheric Sciences Wing
RX: Log periodic intercept antenna
In MISA near field
No attempt to point main lobe at MISA

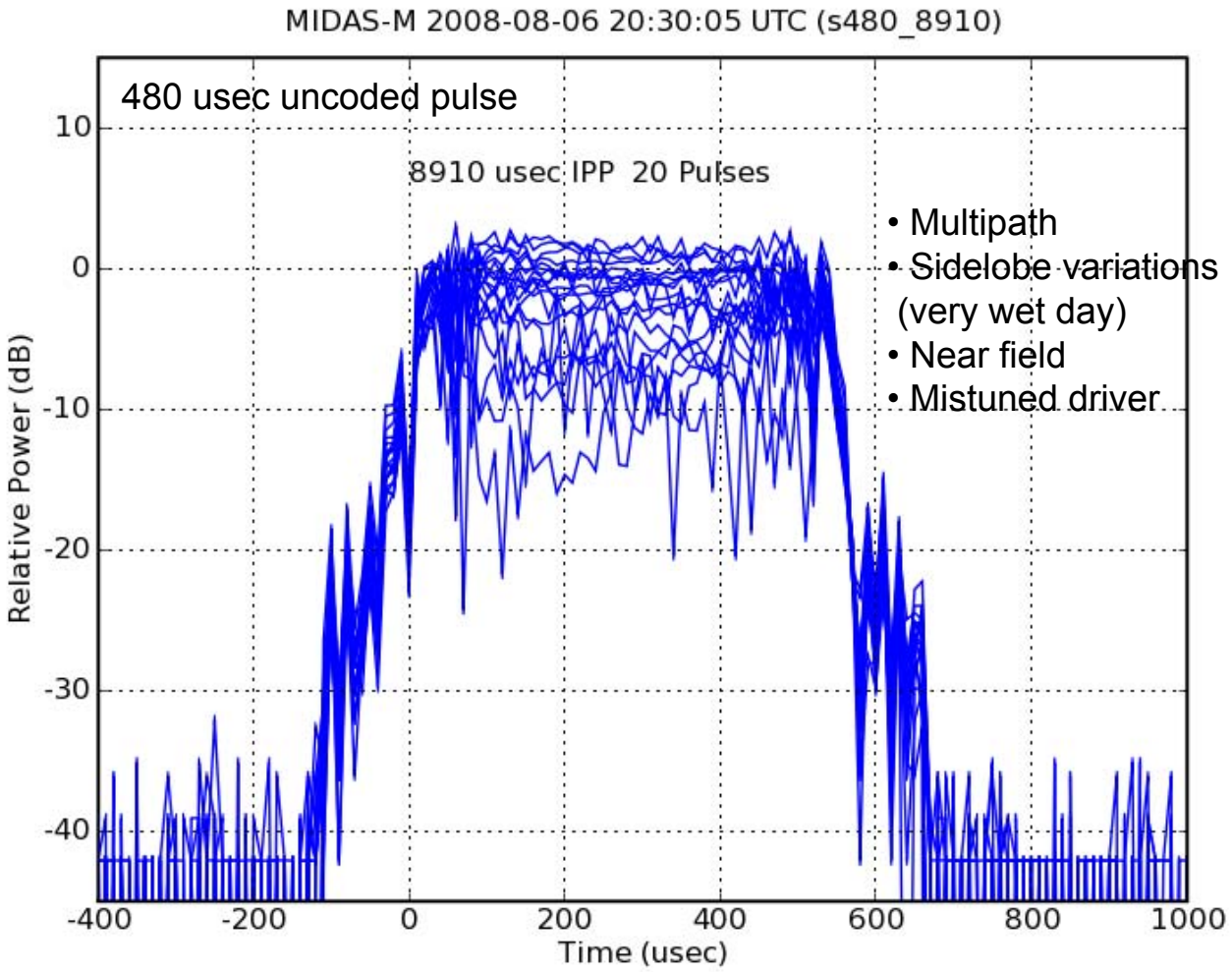
Interleaved 480 usec single pulse
and 16 baud strong alternating code

Framing With Locally Intercepted TX Signal

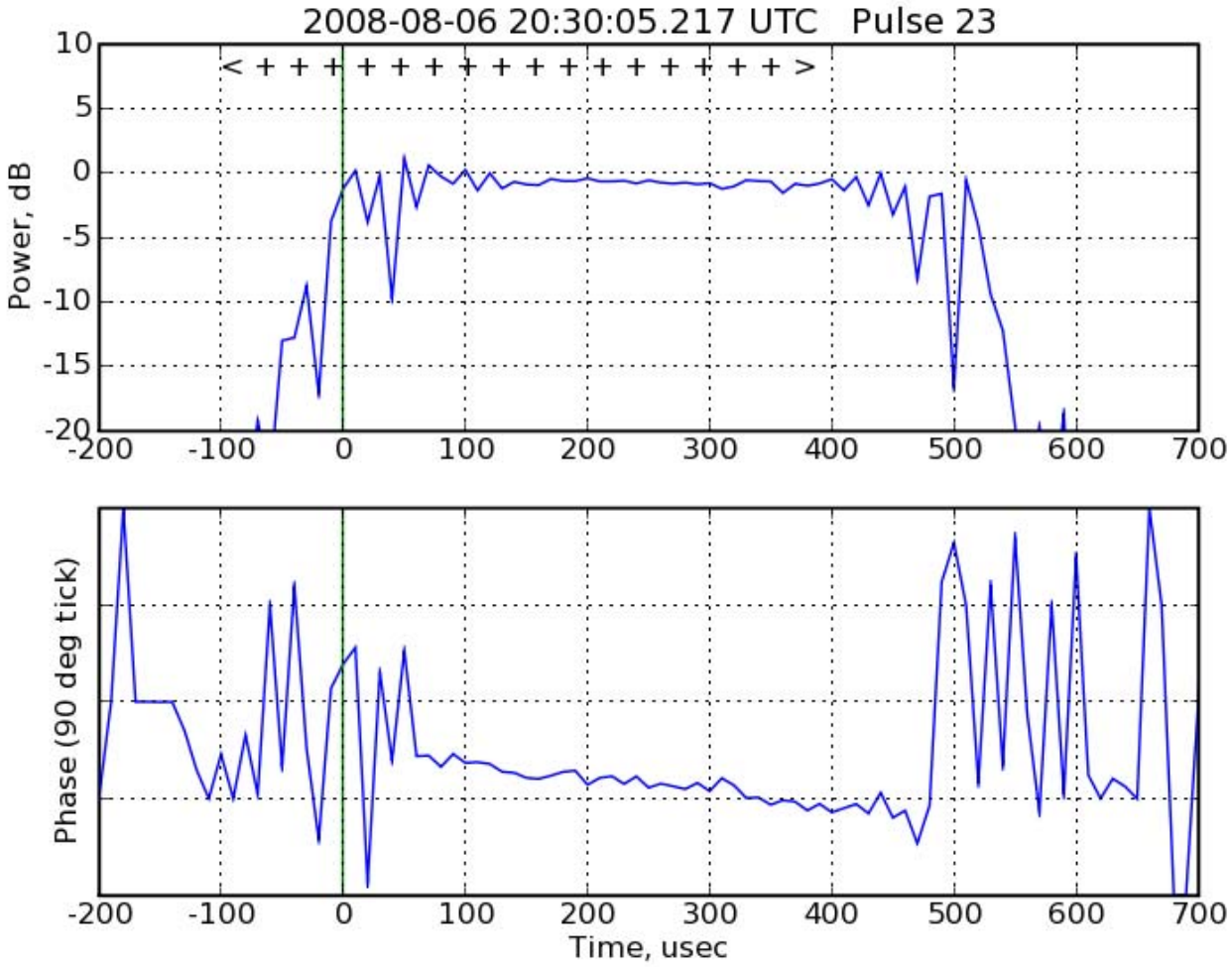
Intercepted Signal Amplitude Detection



Intercepted Signal Amplitude Detection



Intercepted Signal Phase Detection



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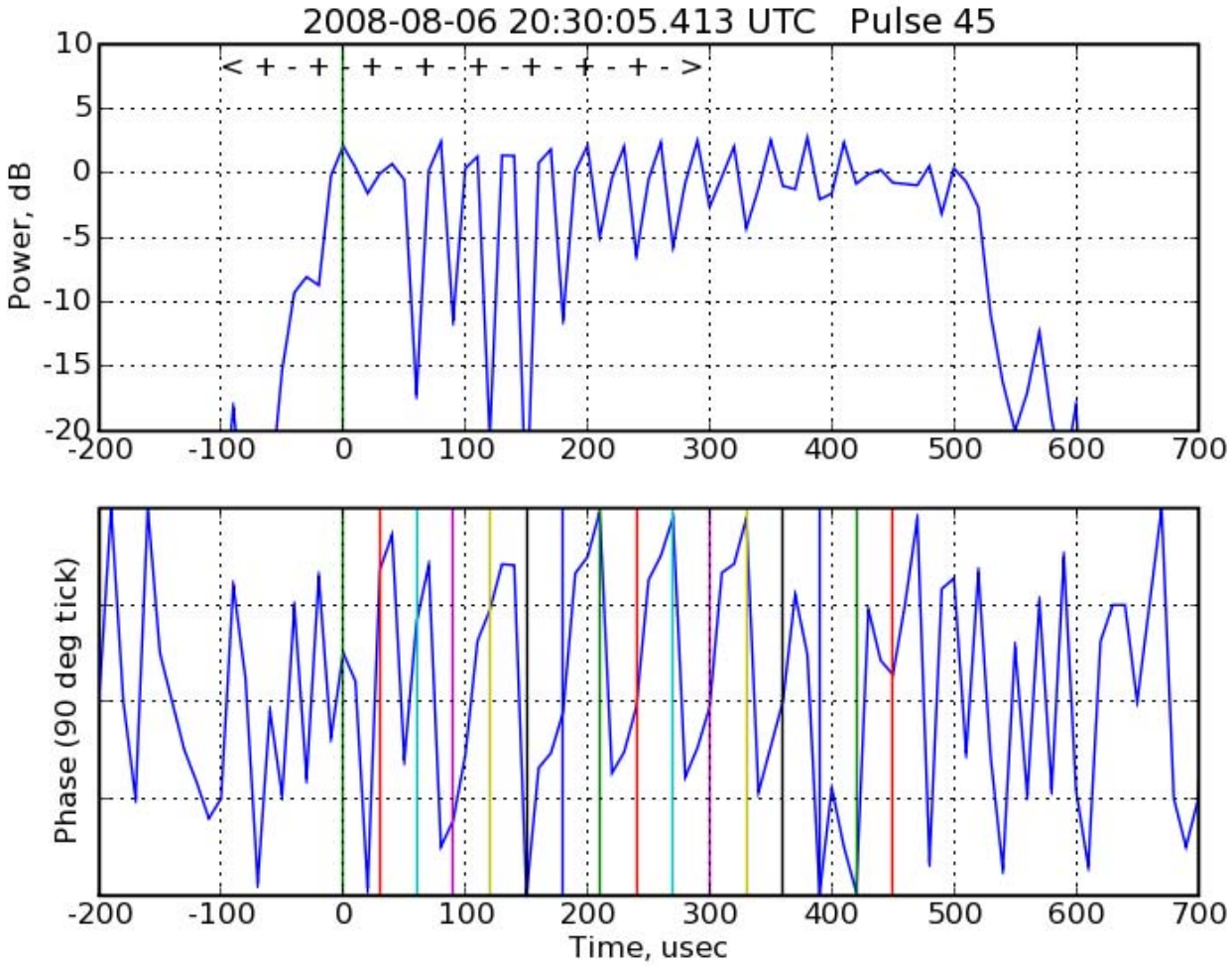
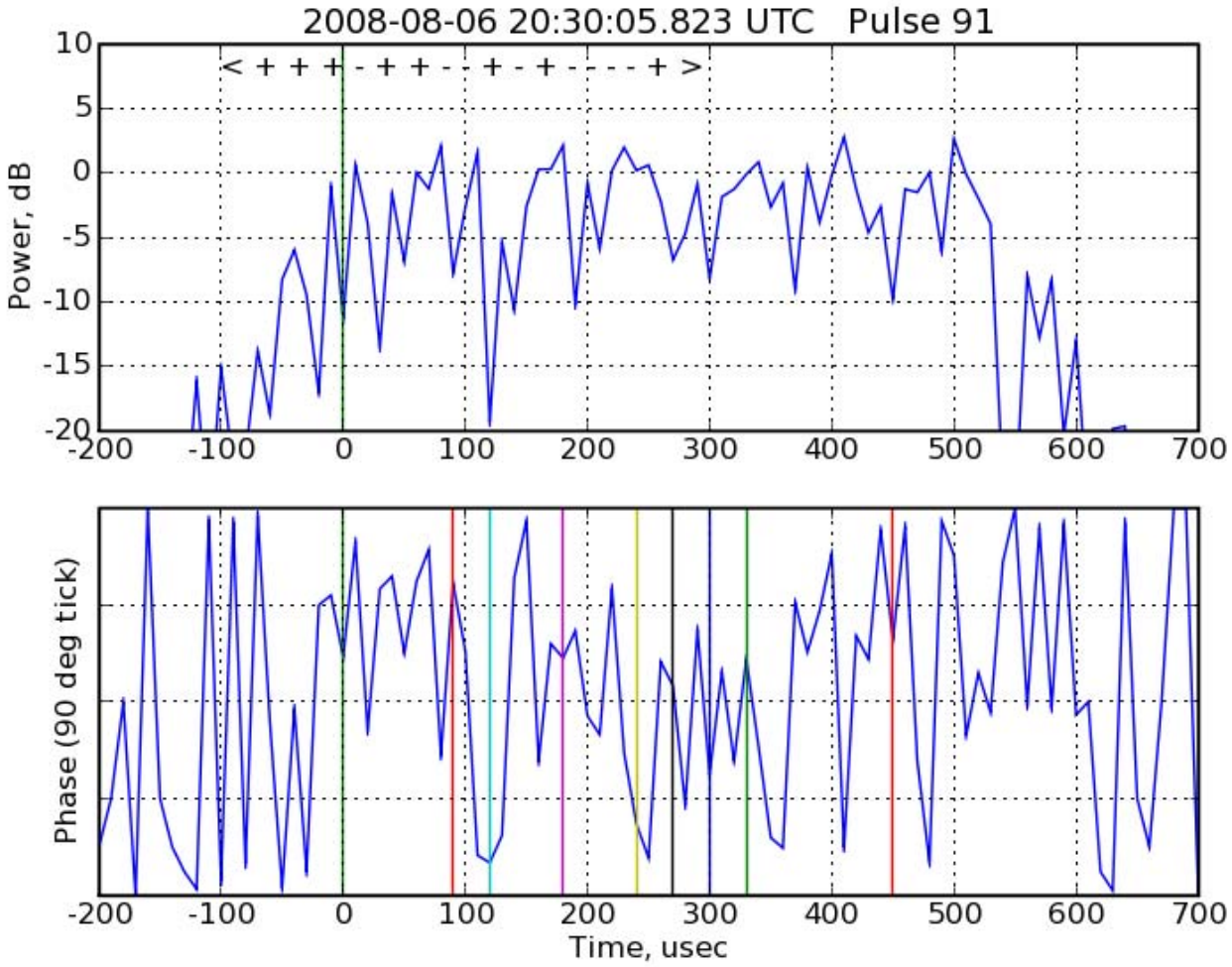


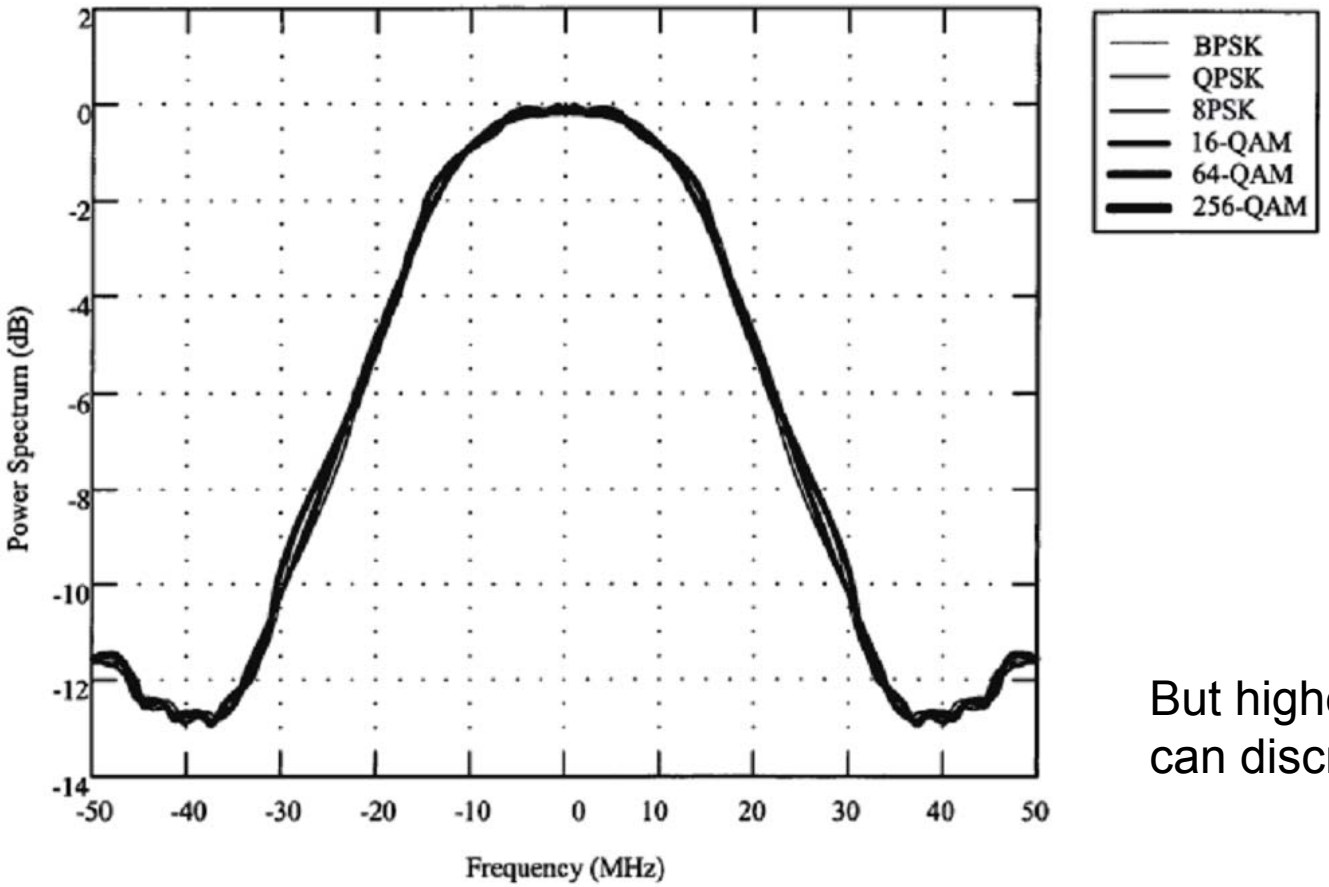
Intercepted Signal Phase Detection



Signal Identification: Power Spectrum Not Enough

U.S. Patent Jan. 31, 2006 Sheet 1 of 13 US 6,993,440 B2

Anderson et al, 2006



But higher order moments can discriminate..

Signal Identification Using Higher Order Moments

Cumulants of 3rd order and larger have useful properties:

- For Gaussian random process, == 0 by definition
- Deterministic sets have much less degenerate spaces unlike 2nd order stats

Any real-world deviation from nominal waveform implementation causes 4th order cumulants to diverge in a distinguishable manner independent of signal power – can identify

- Frequency change (chirp)
- Phase noise
- TX timing, phase jitter
- Pulse amplitude change

$$cum[rr^*_{\tau_1} r_{\tau_2} r^*_{\tau_3}] = E[rr^*_{\tau_1} r_{\tau_2} r^*_{\tau_3}] - E[rr^*_{\tau_1}]E[r_{\tau_2} r^*_{\tau_3}] - E[rr_{\tau_2}]E[r_{\tau_1} r^*_{\tau_3}] - E[rr^*_{\tau_3}]E[r^*_{\tau_1} r_{\tau_2}]$$

(4th order auto-cumulant as a function of three lags)

Signal Identification: Waveform Classification

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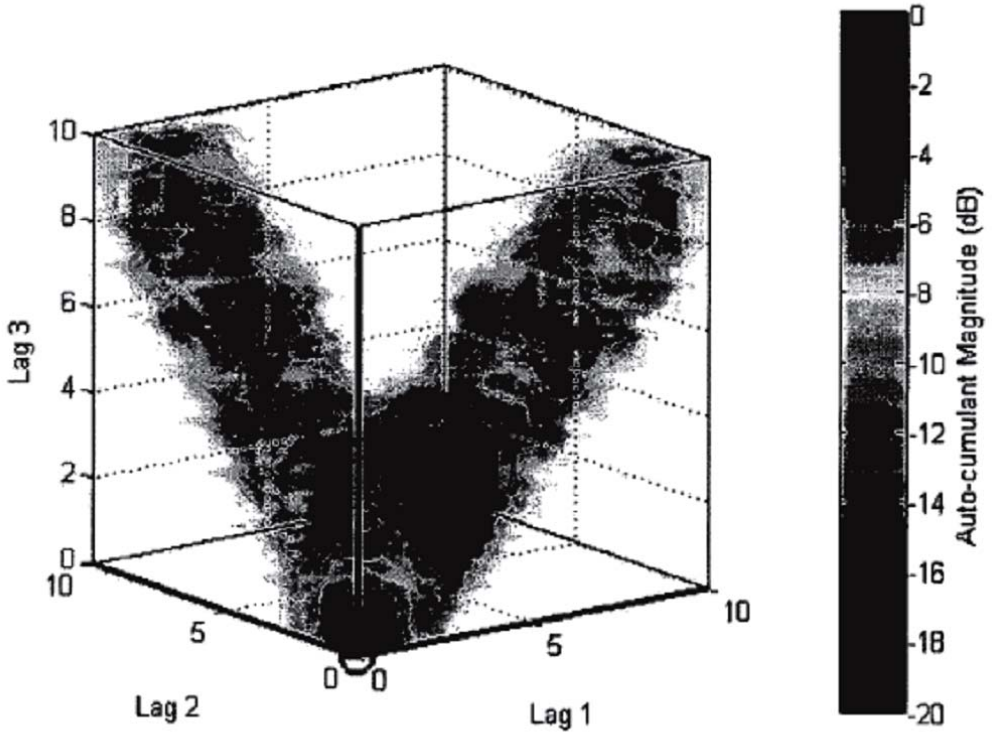
Anderson et al, 2006



PSK Modulation
4th Order Auto-Cumulant

Signal Identification: Waveform Classification

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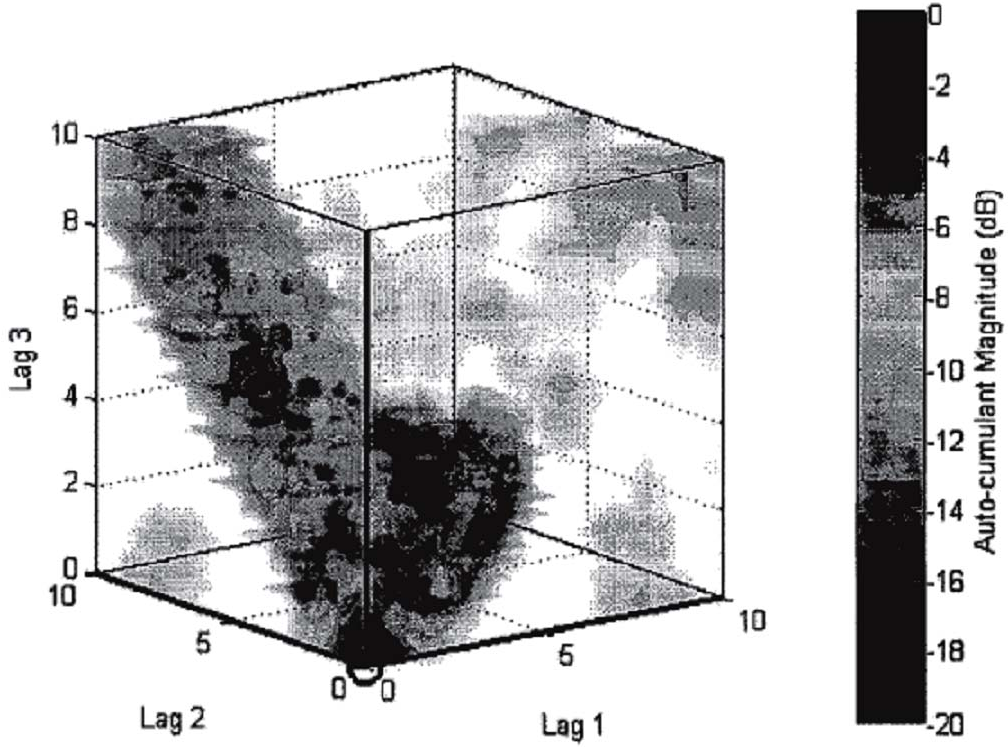

16 QAM Modulation
4th Order Auto-Cumulant

Summary

- Framing pattern applies radar context to generalized RF capture data from software radar platforms
- Full synchronization, waveform pattern identification possible with sufficient quality sync signals
- Care must be exercised when using intercept signals
- Apriori waveform set restriction helps considerably
- Signal identification literature has ideas for more robust waveform ID and stable sync
- Side benefit is continual monitoring of TX health / stability
- Framing will be in production use at Millstone Hill soon