Software Radar Data Architectures for Optimal Science Yields

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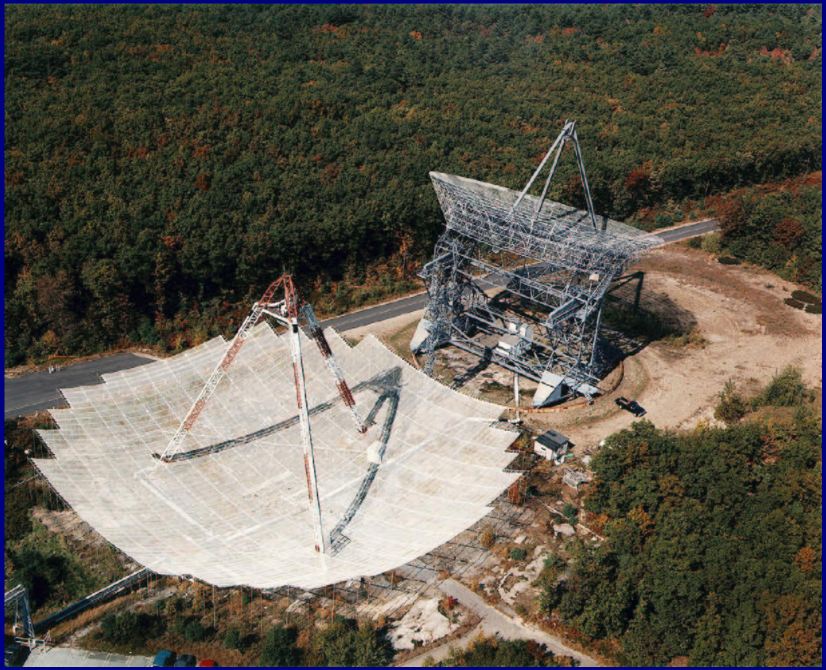

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Software Patterns for Software Radar

Channel	Multicast pathway for data, command objects
Signal Chain	Data flow from creation to final consumption

Distributor	Gathers data, formats, places on network in channel
Listener	Reports activity on selected channel(s)
Recorder	Records activity on selected channel(s)
Replayer	Rebroadcasts previously recorded channel(s) from archive

Filterer :

- Numerical mixer
- Digital filtering
- Rate conversion
- Autocorrelation
- Cross-correlation
- Digital beamforming
- Waveform identification

Enables practical signal chains

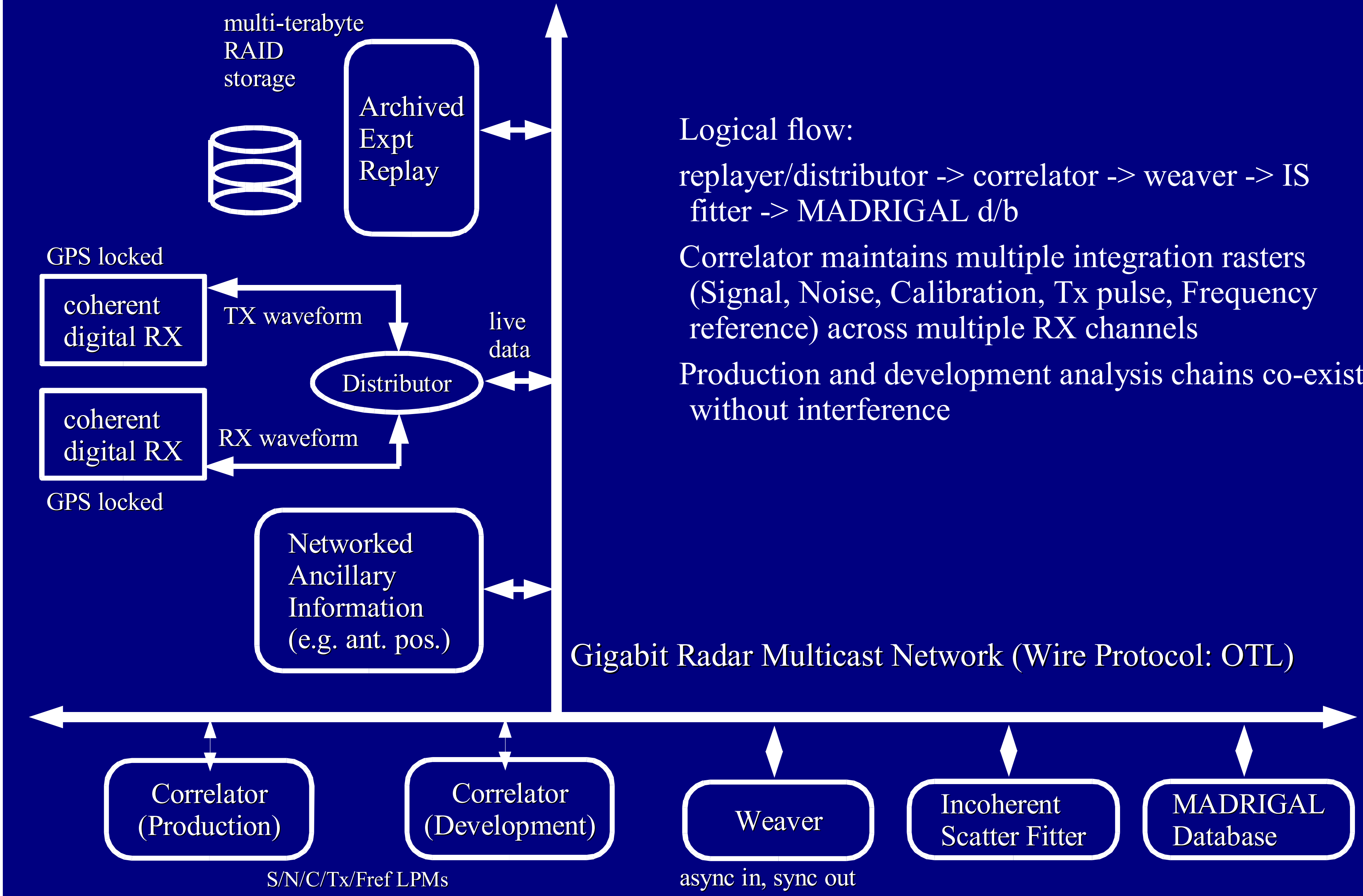
Each component performs a limited prescribed system operation and has a *well-defined interface*

Software Patterns for Software Radar

Trigger	Issues data or command object in response to external stimuli
Bridge	Connects objects across disparate networks
Proxy	Provides simulated or derived service on selected channel(s)
Scheduler	Maintains synchronous schedule of event launching
Weaver	Gathers asynchronous information into a synchronous packet for post-processing (e.g. integrated spectra)

Each component performs a limited prescribed system operation and has a *well-defined interface*. The network architecture helps enforce this modularity.

Typical Signal Chain for Incoherent Scatter Processing



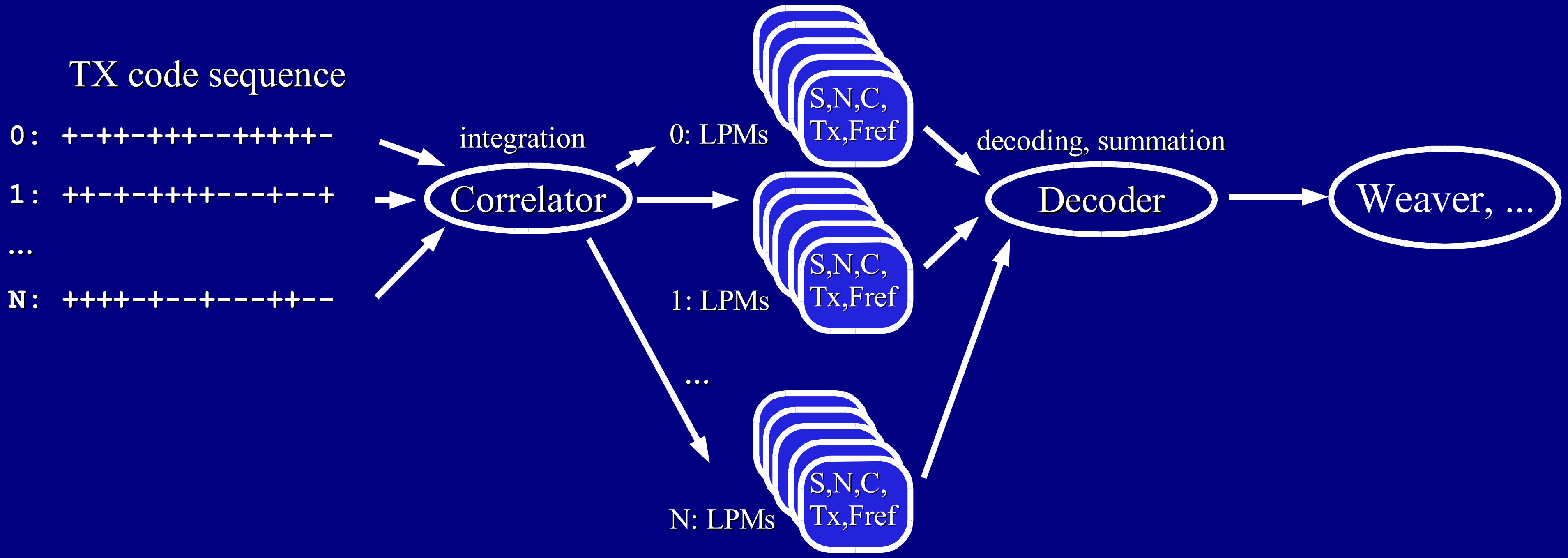
Logical flow:

replayer/distributor -> correlator -> weaver -> IS fitter -> MADRIGAL d/b

Correlator maintains multiple integration rasters (Signal, Noise, Calibration, Tx pulse, Frequency reference) across multiple RX channels

Production and development analysis chains co-exist without interference

Coded Pulse Correlation Estimation: Decoding Algorithm



TX code sequence

0: +-++-+++--+++++-

1: ++-+-++++---+--+

...

N: ++++-+--+---++--

integration

Correlator

0: LPMs

1: LPMs

...

N: LPMs

S,N,C,
Tx,Fref

S,N,C,
Tx,Fref

S,N,C,
Tx,Fref

decoding, summation

Decoder

Weaver, ...

- Correlator summation is done code by code (Lehtinen, 1986)
- Decoder uses FIR filter decoding with known transmitted sequence
- LPMs for individual codes transmitted over the wire for other clients (e.g. performance monitors, TX pulse shape evaluations)
- Decoding step can use actual sampled TX phase from TX channel for improved decoding

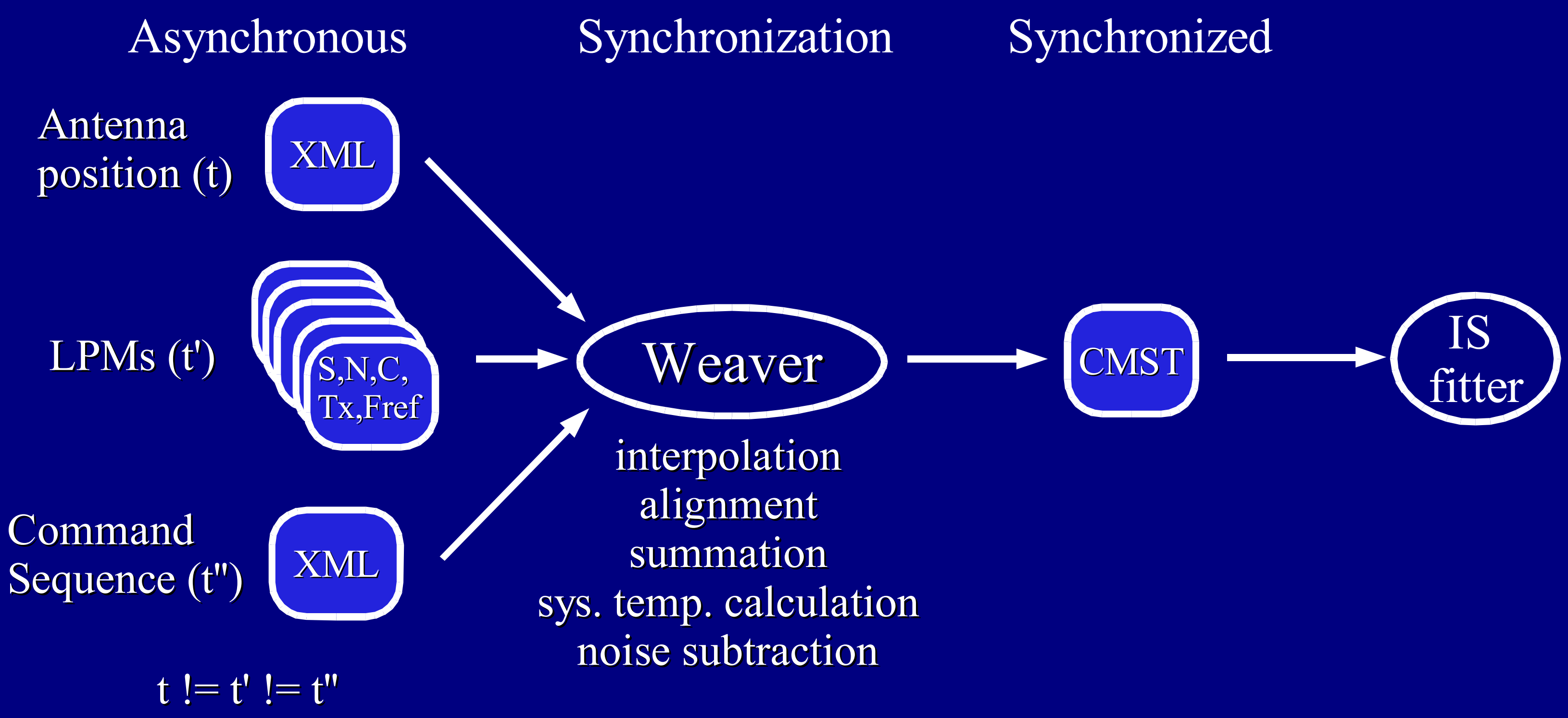
Transmitted Pulse Sequence Identification

TX Pulse envelope → Edge detection → Baud determination → Phase identification → Code space search

- Process through phase identification is order N operation (i.e. linear)
- Code space search is <= order M (M = number of codes) for deterministic sequences, such as alternating codes
- For true random sequences:
  - Cross-correlation of TX sampled signal with RX signal is better approach
  - Identify code quality through examination of TX signal self-ambiguity
  - Processing becomes exactly the same as for passive radar
    - (TX sampled signal = reference waveform)

Transmitted pulse identification allows complete decoupling of transmitter from receiver systems:
a fundamental enabler for multistatic geometries / distributed systems
(analogous to multicast data architecture benefits)

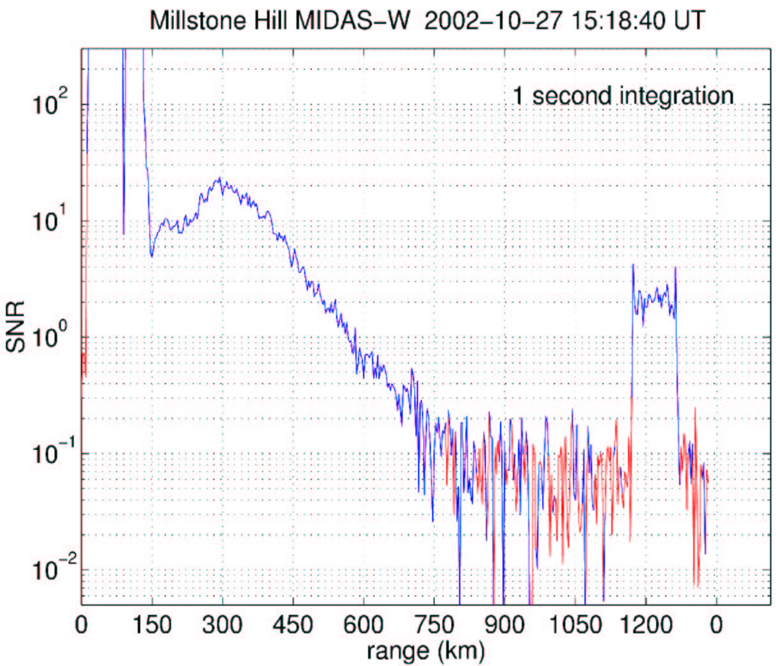
The Weaver Pattern:
Asynchronous -> Synchronous Information

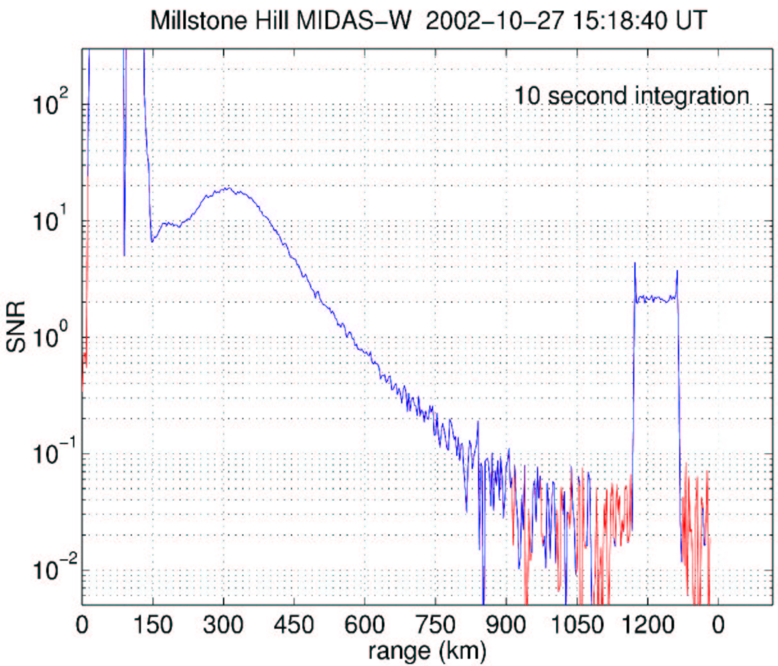


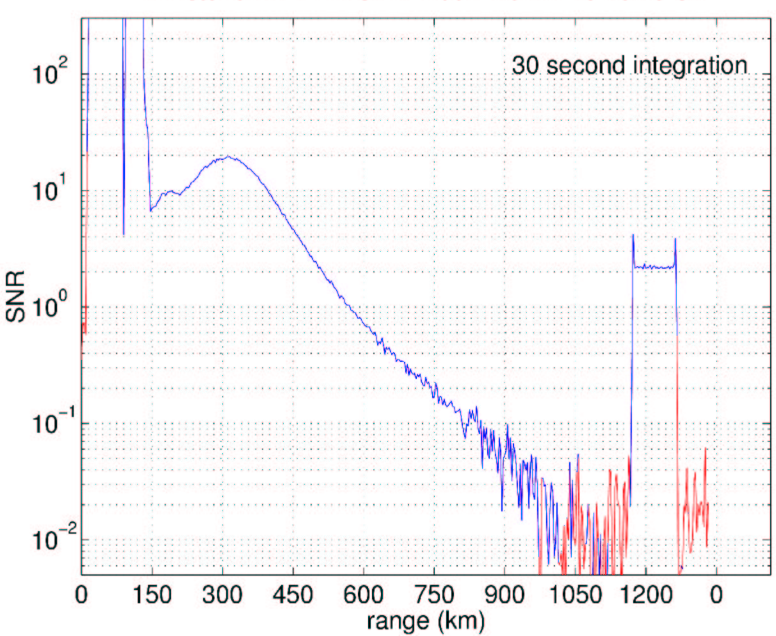
Allows radar subsystems to maintain independent information flows

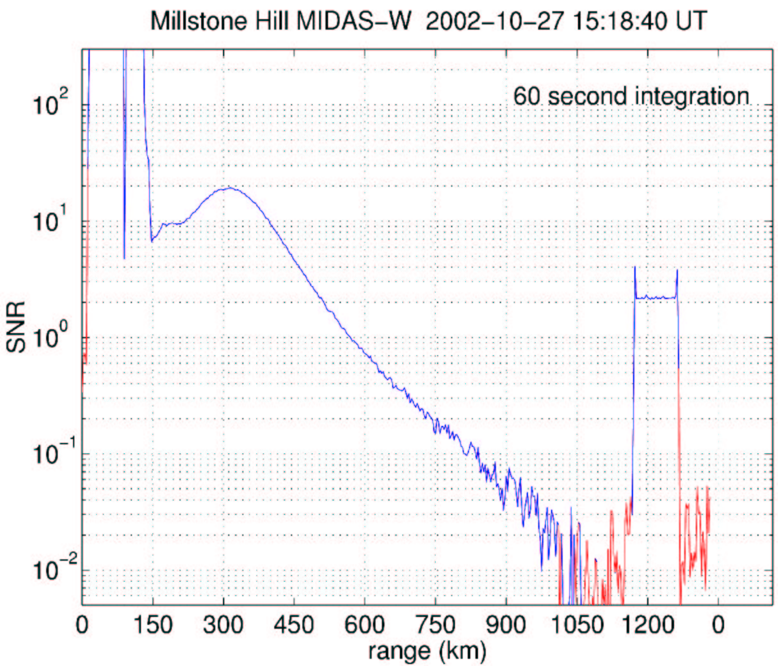
Enables traditional record-based IS analysis in parallel with other system agents which examine only subsystem data

Example : Simultaneous Parallel Analysis



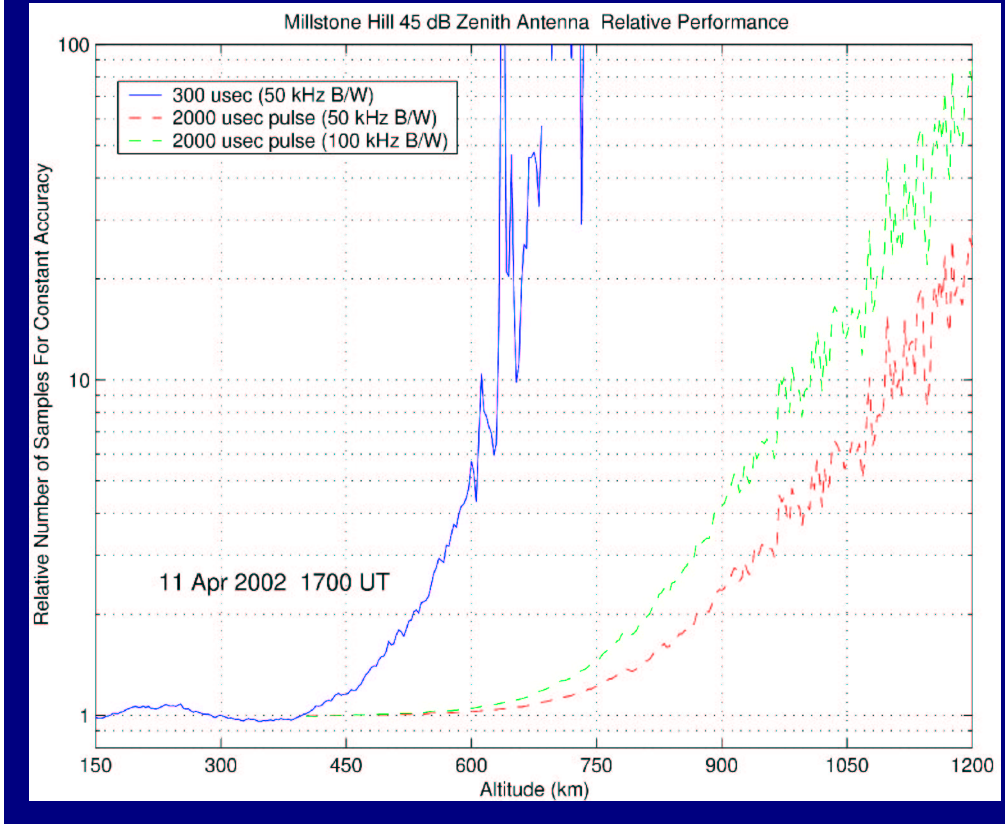


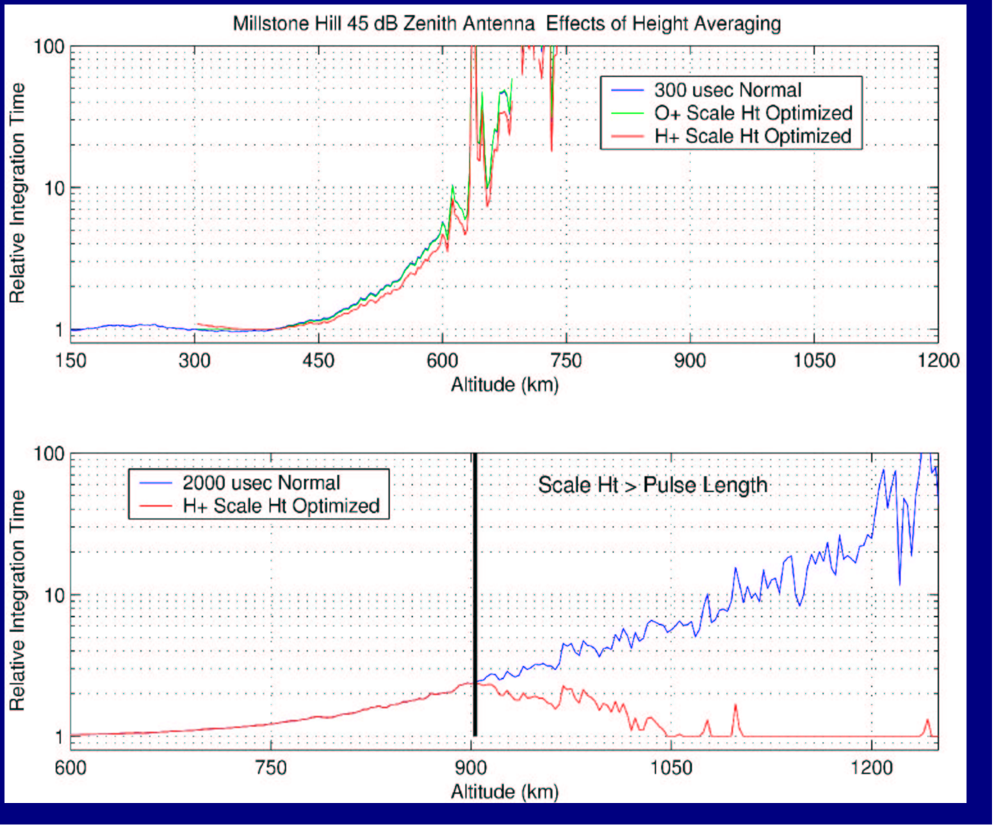




Example : Science-Targeted Multi-Resolution Processing

- Reanalysis of topside light ion data allows optimal bandwidth selection as a function of altitude, maximizing SNR for given radar power-aperture product
- Applying physical knowledge of ionosphere/exosphere variations in vicinity of O+/H+ transition height allows selection of optimal altitude averaging to minimize measurement variance
- Temporal averaging adjustments maximize time resolution for given accuracy





Example : Symbiotic Analysis - Meteor Head Echoes

TX sequence: E/F region observations (alternating code)

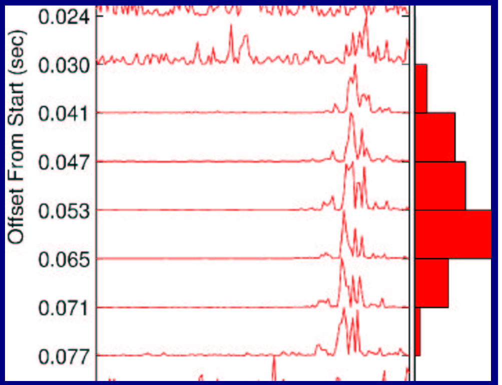
Multicast backbone

Production
IS analysis
chain

IS parameters (range, time)
to MADRIGAL d/b

Meteor processing:

- Transient identification
- Decoding
- Meteor sequence assembly
- Parameter analysis:
  - head echo cross section
  - velocity
  - deceleration
  - polarization ratio
- Parameter storage to MADRIGAL d/b
- Snapshot buffer capture saved on RAID terastore



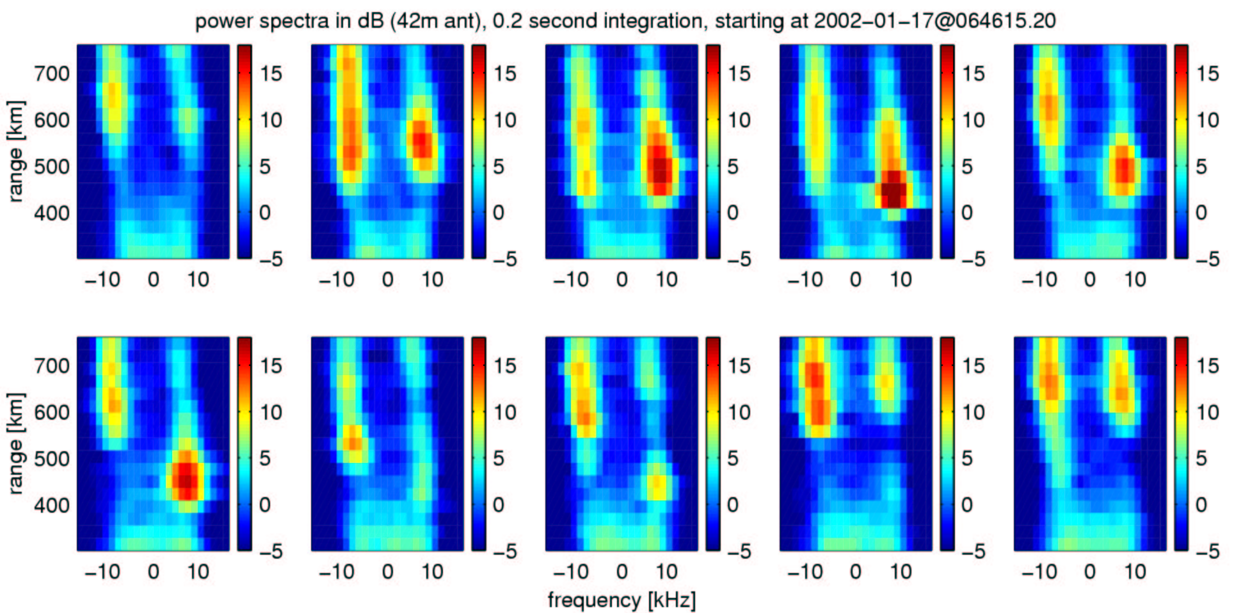
Meteor module can collect statistics opportunistically whenever transmitter is operating (not just for special meteor experiments)

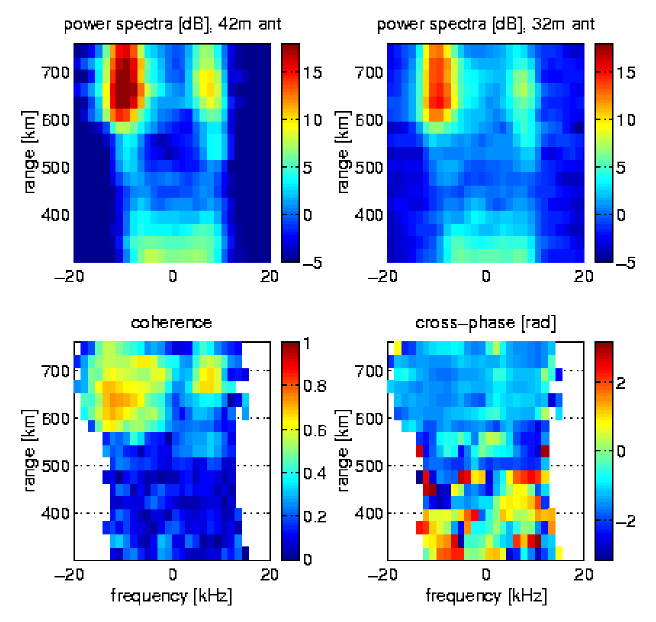
Multicast architecture leaves production IS parameter derivation undisturbed

Under development in summer 2003

Example : New Science By Sampling Existing Radar Systems at IF Taps

- Software radar implementation in portable system used to obtain sub-second resolution power spectra and interferometry of auroral plasma instabilities
- EISCAT Svalbard radar data obtained by subsampling existing receiver IF frequency without disturbing production radar processing stack
- Results show that simultaneous up/down shifted ion-acoustic peaks are real, and not due to temporal/ spatial resolution induced ambiguity (as previously thought)
- Interferometry localizes structures to < 300 m wide (comparable to optical aurora)





Grydeland et al,
Interferometric observations of filamentary structures associated with plasma instability in the auroral ionosphere,
GRL (submitted), 2002.

Summary

- Software Radar enables multi-client distributed data architectures
- Production and experimental systems can coexist
- Intermediate analysis products available for system reliability monitoring
- Costly transmitter time serves parallel science objectives
- Transmitter and receiver separation enables multistatic geometries naturally
- Software patterns for implementing experimental instrumentation and data analysis
- Patterns are applicable beyond ionospheric radar
- Network-centric instrumentation enables meta-instruments

Technology operational at Millstone Hill ISR since November 2001
Community development coordinated using the open source model
through the Open Radar Initiative

The Open Radar Initiative
Reliable Technology for Radio Science

http://www.openradar.org

http://www.haystack.mit.edu/midas_w