The Long Wavelength Array 1+Pre-SRR Technical Meeting

September 21, 2007
8:30 a.m. – 2:30 p.m.
UNM's Science & Technology Park North
801 University Blvd. SE, Rotunda Room
Albuquerque, NM

Agenda

The purpose of this meeting is to discuss the LWA1+ subproject, which should produce at least one station in ~18 months, with the possible addition of two more (perhaps partially populated) stations. We will focus on the details of the requirements, the technical design, and the path by which we work toward the proverbial 'stake in the ground'. We encourage constructive discussion during the presentations. There will be a working lunch served during the Technical Work presentations.

0830 Scientific Requirements (Tracy Clarke, NRL/Interferometrics; Clint Janes, UNM)
It should be noted that the requirements for LWA1+ are not a simple subset of those for the LWA as a whole, because they give more emphasis to stand-alone station operation. We will discuss the status of the process to determine and document these requirements.

0930 System Architecture Review (Steve Ellingson, VT)
We will present the current status of the technical design for the station.

1000 System Engineering Processes (Janes)
We will discuss the procedures by which we will be executing the project.

1030 Status of UT-ARL Technical Work (David Munton, ARL)

1130 Working Lunch

1135 Status of NRL Technical Work (Paul Ray, NRL)

1230 Status of VT Technical Work (Ellingson)

It should be noted that, because the LWA Program funds only began flowing in the last few months, the work to be presented in these talks was largely done before that support was available.

1330 Path to SRR/PDR (Ellingson)
We will discuss the immediate milestones that we must reach, and the actions that need to take place to reach them.

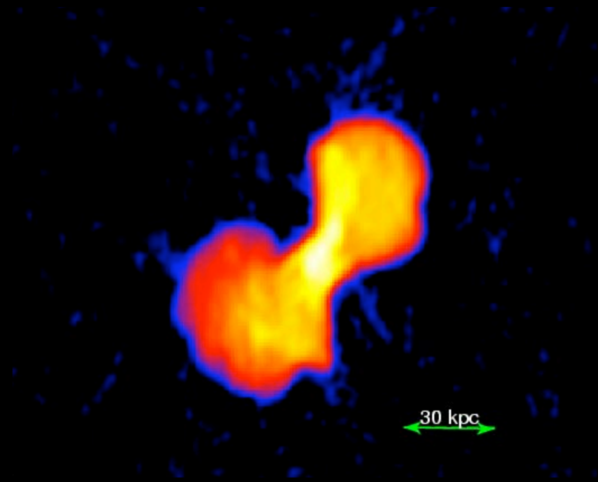
1400 From Stations to a System (Greg Taylor, UNM)
Although the focus of this meeting is the LWA1+ subproject, we will close the meeting with a discussion of how this work fits in to the larger context of the LWA Project.

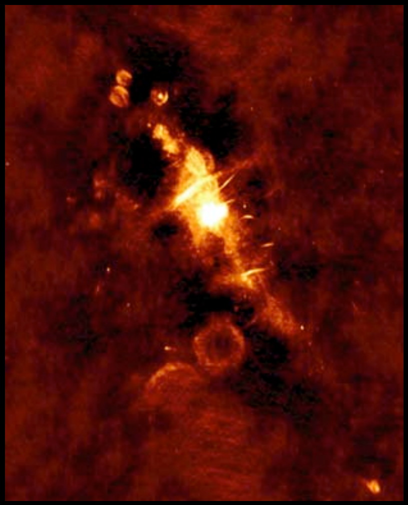
1430 Meeting Ends

LWA
Scientific Requirements

Tracy Clarke

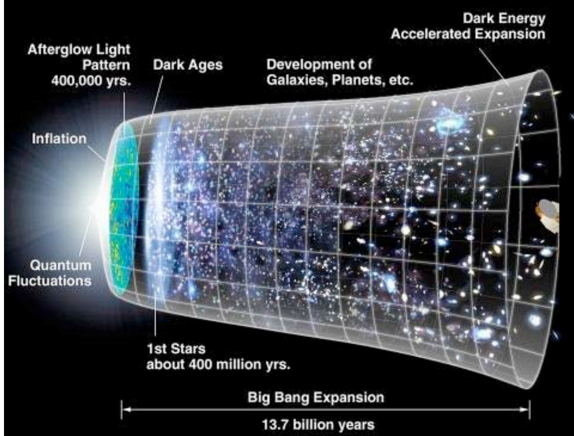
NRL/Interferometrics Inc.





Philosophy

- Step 1
  - Survey the Science:
    - » Start at the root with a list of LWA scientific goals
      - Astrophysics, Solar & Space-Science, & Ionospheric Physics
      - Emphasize a diversity of phenomena and capability for ***exploration science***
    - » Develop a list of instrumental requirements to reach each science goal
  - Outline the Specifications for the instrument:
    - » Derive requirements for LWA system based on requirements for scientific goals that stretch the capabilities to a maximum
- Step 2
  - Combine results with practical considerations (i.e. calibration, engineering, operations) to create a list of top-level technical specifications



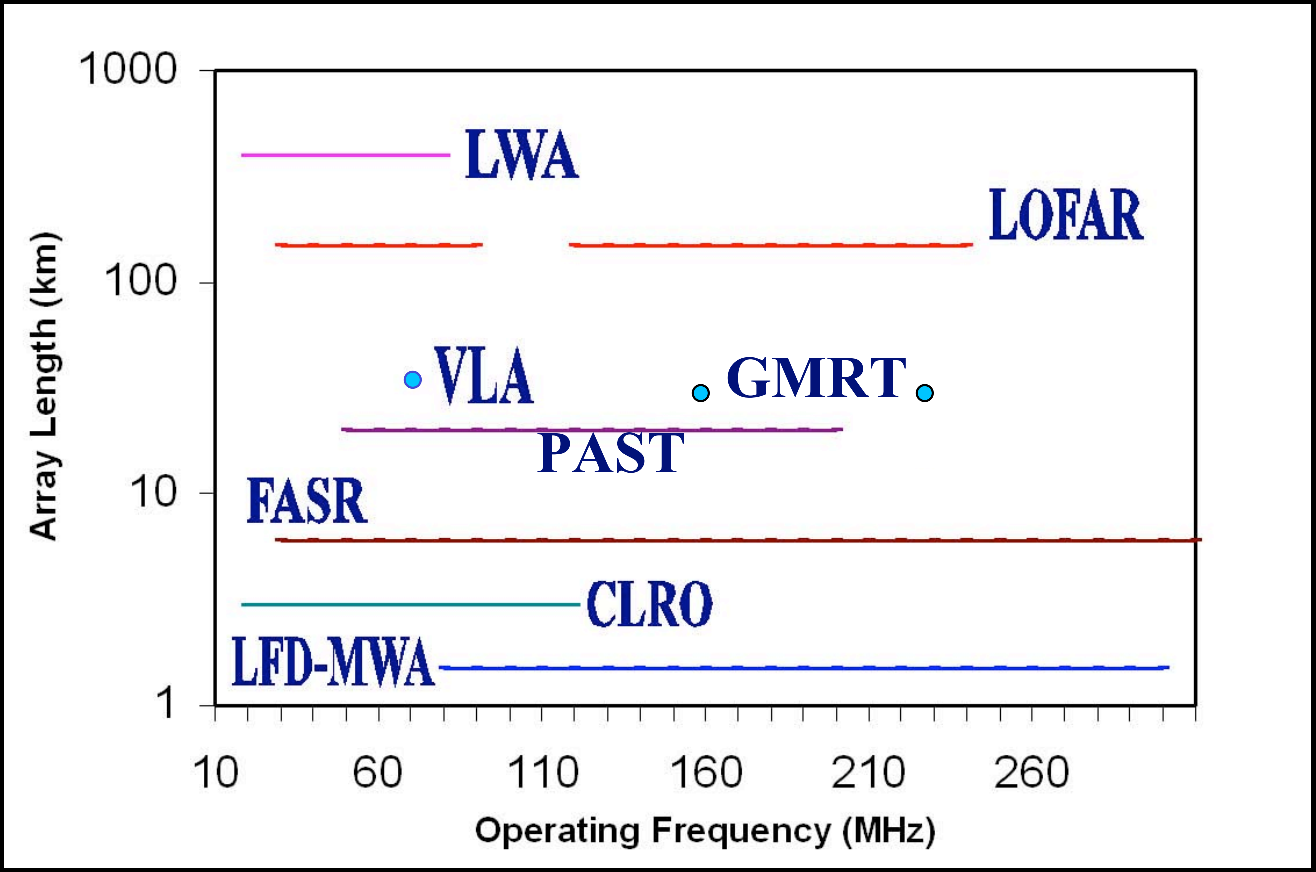
Key LWA Science Drivers

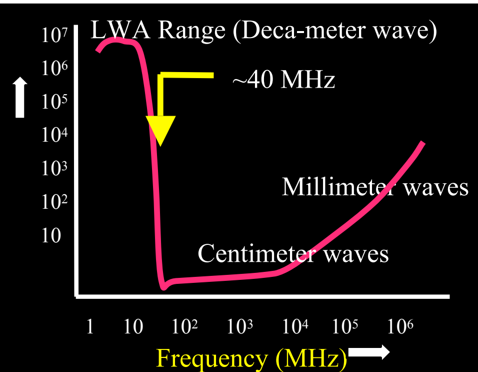
- Cosmic Evolution & The High Redshift Universe
  - Large Scale Structure - Dark Matter & Dark Energy
  - 1st super-massive black holes
  - pre-reionization – Dark Ages
- Acceleration of Relativistic Particles in:
  - SNRs in normal galaxies at energies up to 10^{15} ev
  - Radio galaxies & clusters at energies up to 10^{19} ev
  - Ultra high energy cosmic rays at energies up to 10^{21} ev and beyond
- Plasma Astrophysics & Space Science
  - Ionospheric waves & turbulence **(Watts Talk)**
  - Solar, Planetary, & Space Weather Science
  - Acceleration, Turbulence, & Propagation in the ISM of Milky Way & normal galaxies
- Exploration Science
  - Open the region < 100 MHz to exploration - in the footsteps of the VLA at cm λs
  - Emphasize pioneering capabilities for new frontiers – e.g. the Transient Universe
  - ***Maximizes the opportunity for Discovery Science through flexibility***

Phased Development Plan

Date	Phase	Milestone Description	Acronym
2007 Q4	Ia	System Requirements Review	SRR
2008 Q1	Ia	Preliminary Design Review for First LWA Station	LWA1+ PDR
2008 Q4	Ia	Critical Design Review for First LWA Station	LWA1+ CDR
2009	Ib	Long Wavelength Array Station #1 + Options	LWA1+
2009-2011	IIa	9 Station Long Wavelength Intermediate Array	LWIA-9
2011-2013	IIb	16 Station LWIA with Partial Core	LWIA-16
2013-2015	III	High Resolution LWA	LWA
2010-	IV	LW Operations and Science Center	LWOSC

LWA Discovery Space:
in frequency & baseline



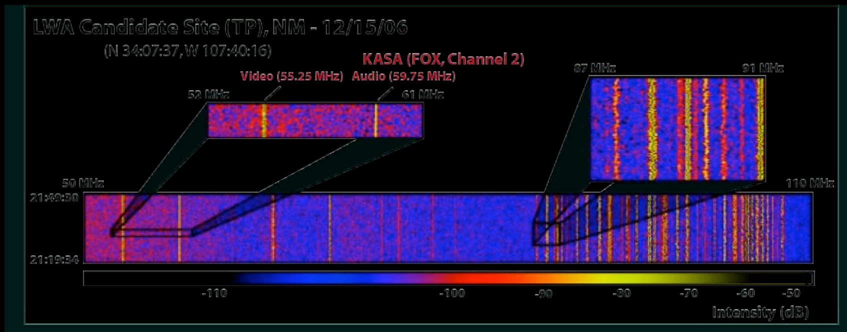


SR-1: Frequency Range

- <100 MHz the ionosphere has traditionally limited resolution & sensitivity
- Unique physical processes accessible only with low frequency data:
  - spectral turnovers, scattering, steep-spectrum emission , thermal absorption as a distance indicator, pre-reionization power spectrum
- Coherent processes (e.g. Jupiter "turn on" below 40 MHz)
- Ionosphere coordinated campaigns with HAARP - < 20 MHz
- HI studies of cosmic density fluctuations in the Dark Ages
  - $15 \leq z_{DA} \leq 200$ neutral gas decoupled from CMB ($88 \geq \nu \geq 7$ MHz)
- Cross-over science with 74 MHz VLA

Required: $20 \leq \nu \leq 80$ MHz (2 octaves)

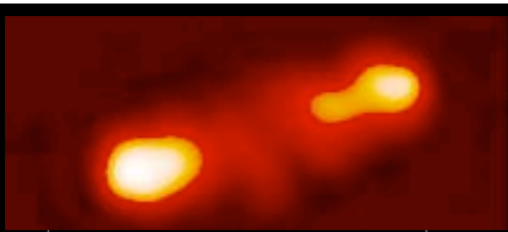
*Desirable: $2 \leq \nu \leq 111$ MHz (t_{FF}-80MHz = 2*t_{FF}-111MHz)*

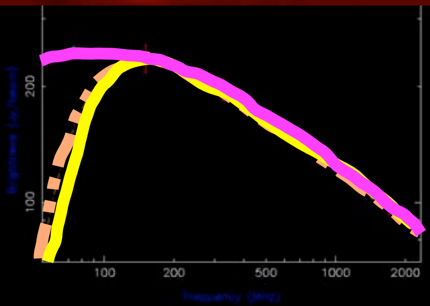


TS-1: Frequency Range

- Practical Considerations:
  - Economics: need to use a single dipole element
    - » $\Delta\nu_{max}$ ~ 3-4X for active antenna with 6 db sky-dominated T_{sys}
  - Due to the FM bands, a practical upper limit is 88 MHz: 4X gives 20-80 MHz
  - At higher frequencies where other instruments (eg. GMRT) are more sensitive
  - Practical lower limit tied to feasibility of ionospheric calibration & DR limits due to global RFI reflection
  - Ionosphere may permit measurements of bright sources to a few MHz, 9 MHz for bi-static radar, 10 MHz is optimistic lower bound for astrophysical calibration

Required: 20 MHz ≤ ν ≤ 80 MHz
Desirable: 9 MHz ≤ ν ≤ 88 MHz





SR-2A: Highest Angular Resolution

-
  - θ~10" to image 1' sources with ≥ 28 independent beams
  - High redshift radio galaxies ~ 5-10"
  - Jets: $\theta_{res} \leq$ 2" at 80 MHz to sample γ=50-200 e^- population responsible for IC X-ray emission at 0.2-8 keV
  - Knots: $\theta_{res} \leq$ 0.5" at 80 MHz

- Normal galaxies - $\theta_{res} \leq$ 2" at 80 MHz
- Scattering: - compete with cm VLBI for ISS (θ_{20cm}~5 mas): ≤ [25,1.5]" at [20,80] MHz

Exploration: ≥ 20 dB improvement over past low frequency arrays

Required: $\theta \leq$ [8,2]" at [20,80] MHz
Desirable: $\theta \leq$ [2,0.5]" at [20,80] MHz

TS-2A: Longest Baselines (B_{max})

- Science: ionospheric studies of wave propagation direction and dissipation

- Scattering limits on resolution in plane: [7,0.4]" at [20,80] MHz = [450,2000] km
- Practical upper limit: run out of calibrators of sufficient brightness
- Avoid classical confusion in short to moderate integrations

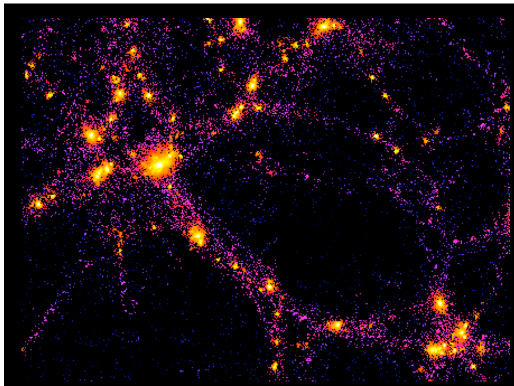
	20 MHz	*80 MHz*
100 km	***4.0 mJy, 0.18 h***	***0.2 mJy, 16 h***
400 km	***0.5 mJy, 11 h***	***0.025 mJy, 1040 h***
600 km	***0.3 mJy, 31 h***	***0.015 mJy, 2900h***

  – Sufficient resolution to mitigate strong source sidelobe confusion

Required: B_{max}≥ 400 km, or ≤[8,2]" at [20,80] MHz

Desirable: B_{max} ≥ 600 km, or ≤[5,1.4]" at [20,80] MHz

Ref: 400 km ~ [2.7E4,1.1E5]λ at [20,80] MHz; $B_{max-VLA}$~1.8E5 λ at 1400 MHz



SR-2B: Largest Angular Scale

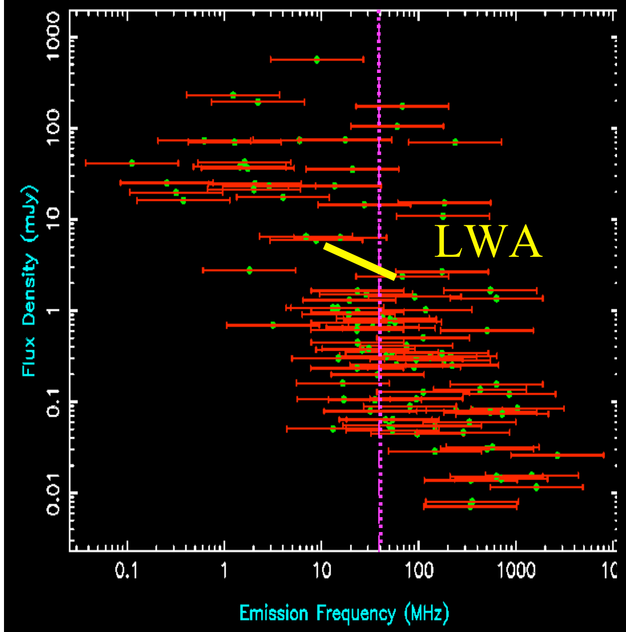
- Cosmic Ray Tomography (HII regions): $\theta_{LAS} \geq$ [40,10]' at [20,80] MHz
- Clusters and Large Scale Structure
  - Typical cluster ~ 2 Mpc = [2.5,0.3]º at z = [0.01,0.1]
  - Particle acceleration in supercluster filaments visible at redshifts comparable to the Coma Cluster (z~0.025) with sizes ~ 7° across
- Sun & Solar Wind (e.g. CMEs) : $\theta_{LAS} \geq$ [5,2]º at [20,80] MHz
- Cosmic density fluctuations in the Dark Ages on scales of ~1°

Requires: θ_{LAS} ***= [4,1]° at [20,80 MHz]***
Desirable: θ_{LAS} ***= [8,2]° at [20,80 MHz]***

TS-2B:
Shortest Baselines (B_{min})

- ***Science: constrains minimum ionospheric scale-size probe of structure***
  - need input from ionospheric community here

- ***Configuration studies required to quantify radial density profile of collecting area to realize naïve λ/D-based estimates <u>(Ray/Cohen Talk)</u>***
  - » ***Need simulations to demonstrate realistic capability of recovering extended structure in both snapshot & synthesis imaging***
  - » ***Need to determine radial density profile consistent with needs to avoid classical confusion in short to medium integrations***
- ***Can stations be closer than theoretical 100 m minimum (ie overlapping stations)?***
- **Required: B_{min}= 200 m {LAS=[4,1]° at [20,80] MHz}**
  Desirable: B_{min} =100 m {LAS=[8,2]° at [20,80] MHz}
  Ref: 200 m ~ [14,53]λ at [20,80] MHz; $B_{min\text{-}VLA}$~175 λ at 1400 MHz



SR-3: Thermal Noise Sensitivity

[sensitivities for $\Delta\nu$ = 8 MHz, Δt = 1 hr]

- Image weak & extended sources at mJy/bm sensitivity
  - Steep-spectrum sources - cluster relics and halos
  - Extra-solar planets
  - Cas A in M33 is a 40 mJy unresolved source
  - Deep searches for high redshift galaxies > 10X current
  - pre-reionization signals at 1-10 mK (τ~yr)
-
  - » eg. EVLA: σ_{20cm} = 6 μ Jy (stokes I, 1 hr)
  - » LWA competes for $\alpha \leq$ [-1.2,-1.5] at [20,80] MHz – much better for surveys because of large FoV
- Exploration: realize $\geq$ 20 db improvement over past imaging arrays

Required: σ = [0.7,0.4] mJy at [20, 80] MHz

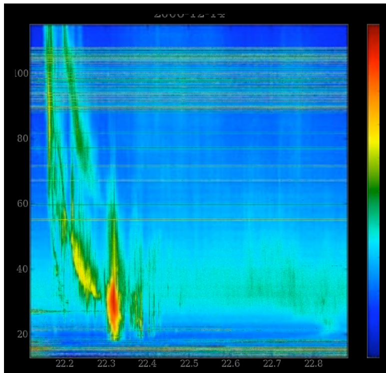
Desirable: $\sigma \leq$ [0.5*,0.1] mJy at [20,80] MHz

**Classical Confusion at 400 km*

TS-3A: Collecting Area

- A_e = 1E6 m^2 provides ≥ 20 dB sensitivity improvement over existing and past low frequency arrays
- # of Dipoles
  - Ω_{FWHP} ~ 3 steradians at [20,80] MHz
  - $A_{e\text{-dipole}} \sim \lambda^2/\Omega$ ~ [75,4.7] m^2 at [20,80] MHz (subtle function of ν)
  - A_e ~1 E6 m^2 at 20 MHz requires ~ 13,500 dipoles

Required: A_e= 1 E6 m^2 at 20 MHz
Desirable: A_e= 4 E6 m^2 at 20 MHz



SR-4: Instantaneous Bandwidth

- Continuum studies
  - Broader BW increases sensitivity but can introduce flux density errors
  - For SI work it is desired to have a few % flux accuracy or better
    - » $\Delta\nu/\nu$ = 10%: for α = [-0.7,-3], ΔS = [3,16]%
    - » errors may be mitigated in some cases by spectral modeling of data
- Broad-band phenomena (handle as special requirements, or address with multiple beams)
  - CR air-showers: $\Delta\nu > 32$ MHz at dipoles
  - Coherent emission from GRBs
  - Tracking drifts of solar bursts: $\Delta\nu \geq 32$ MHz
  - pre-reionization signal need $\Delta\nu$=50 MHz for sensitivity

Required: Tunable with $\Delta\nu_{max}$= 8 MHz: $\Delta\nu/\nu \leq$ [40,10]% at [20,80] MHz

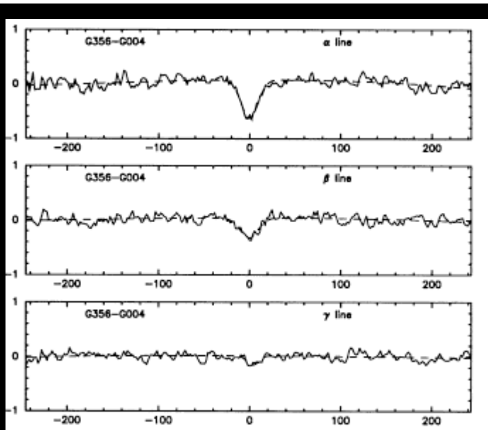
Desirable: Tunable with $\Delta\nu_{max}$= full RF

TS-4:
Instantaneous Bandwidth

- Imaging 'problems' associated with very wide BW can be solved in the software
- Full sensitivity imaging in face of changing primary beam
  - use constant primary beam to determine isoplanatic path corrections for data and apply to full sensitivity beam for final imaging (multiple copies of the full RF)
- Additional copies of data would require additional beamformers, link bandwidth, correlator capabilities etc...
  - need to weight trade-offs

Required: $\Delta\nu_{max}$= *8 MHz*

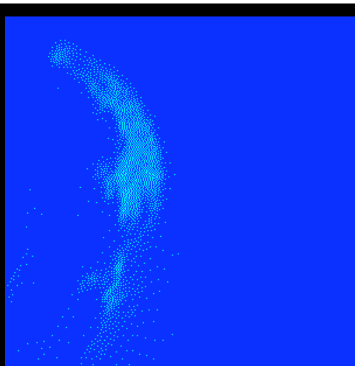
Desirable: $\Delta\nu_{max}$= *full RF recorded in 2 copies*



SR-5: Spectral Resolution

- *RRL from the cold ISM – e.g. 1.5 km/s at 20 MHz require $\Delta\nu_c \leq 100$ Hz*
- *HI absorption requirements: $\Delta\nu_c$ ~ few km/s, or $\Delta\nu_c \leq 1$ kHz at 100 MHz*
- *Radar: Solar: ≤ 100 Hz; Planetary: ≤ 10 Hz*
  - *Consider as special requirement?*

Required: $\Delta\nu_c \leq 100$ Hz
Desirable: $\Delta\nu_c \leq 10$ Hz



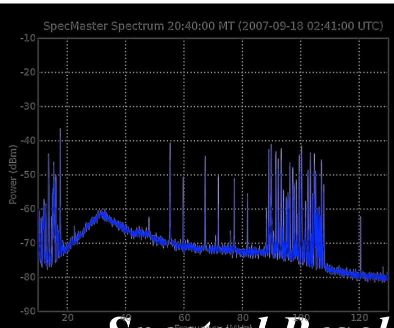
SR-6: Temporal Resolution

- Time variable phenomena such as:
  - Flare stars: **Δτ** ~ 50-100 msec
  - Solar & Space Weather , CMEs, Flares, IPS, IP Shock: **Δτ** ≤ 100 msec
  - Pulsars: **Δτ**~ 100 μs
- Cosmic-ray airshowers: **Δτ**~ 50 nsec at the dipoles – special application
- Ionospheric structure including TIDs: **Δτ**~ 10 msec? (need input here)

Requires: Δτ ≤ 100 msec

Desirable: Δτ ≤ 100 μsec

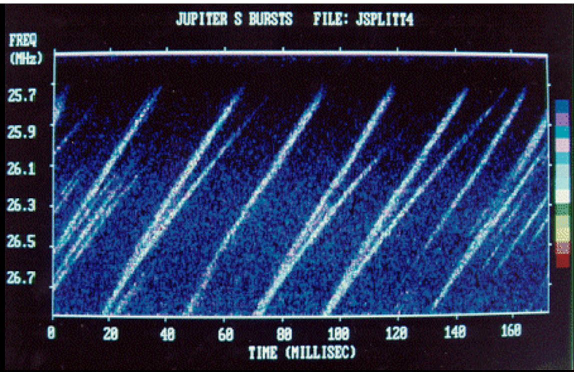
(need special provision for dipole based sampling at ***Δτ***≤ 50 nsec)



TS-5& 6: Spectral & Temporal Resolution

- ***Spectral Resolution***
  - ***RFI excision requires $\Delta\nu_c \leq 1$ kHz***
  - ***BW smearing: $\Delta\nu_c \leq 1.25$ kHz for 10% reduction in flux at first null on 400 km BL***
- ***Temporal Resolution***
  - ***Calibration – sample on timescales fast compared to ionospheric changes: ≤ 1 s***
  - ***Time-averaging smearing: $\Delta\tau \leq 0.9$ sec for 10% flux reduction at 20 MHz, primary beam first null and 400 km baseline***
- ***Correlator design is directly impacted: instrument bit-rate must support maximum desired timescales and spectral resolution requirements in combination with bandwidth, polarization, sampling rate, etc.***

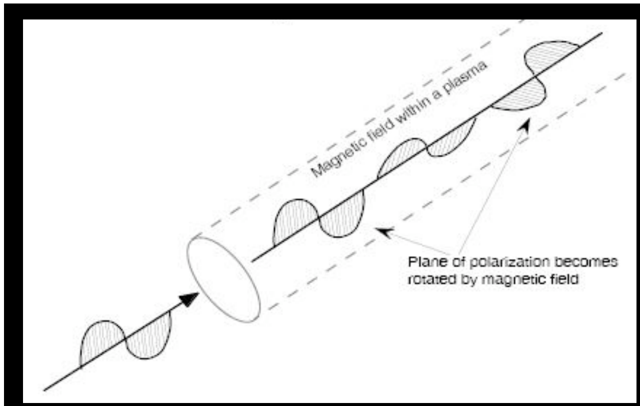
Required: $\Delta\nu_c \leq 100$ Hz, $\Delta\tau < 100$ msec
Desirable: $\Delta\nu_c \leq 10$ Hz, $\Delta\tau \leq 100$ μsec



SR-7: Polarization

- Jupiter's decametric bursts have preferred circular polarization
- Flare stars show circular polarization
- Polarization studies of pulsars, solar and interplanetary magnetic phenomena
- Second polarization provides increased sensitivity, confirm RRL detections
- 2 circular polarizations are required to mitigate against differential absorption of circularly polarized coherent sources

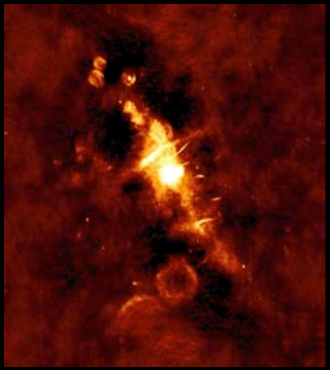
Required: dual circular polarization, isolation ≥ 10 dB
Desirable: dual circular polarization, isolation ≥ 20 dB



TS-7: Polarization

- Technical Requirement
  - Circular polarization must be presented to the correlator because of Faraday rotation in the ionosphere
- RFI excision using circular polarization as a discriminator
- Polarization purity – realizing ≥ 10 db over much of the sky will be challenging – hope to achieve ≥20 dB after calibration

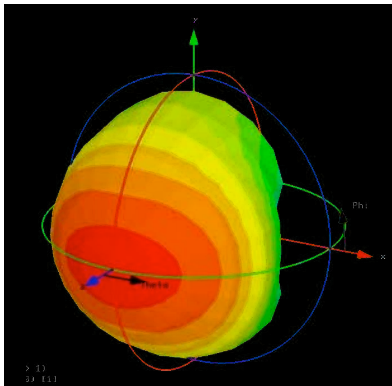
Required: dual circular polarization, isolation ≥ 10 dB
Desirable: dual circular polarization, isolation ≥ 20 dB



SR-8: Sky Coverage

- Declination coverage
  - Galactic center: good imaging to at least δ = -30° (Z=64°)
  - Solar and planetary: reach δ = -25°
  - maximize overlap with cm instruments like the VLA
  - Ideally would extend into the 4th quadrant, and include imaging of bright, isolated objects at low declinations
    - » Clark Lake imaging of eg. Fornax A, Puppis A
- Desire the widest possible sky coverage to maximize visible objects

Requires: Good imaging to $\delta \geq$ -30°, Z≤64°
Desirable: Bright objects to $\delta \geq$ -40°, Z≤74°



TS-8: Zenith Angle Coverage

- Zenith Angle Coverage
  - Ω_{HPBW} of our active antennas is ~ 100° (Z = 50° gives δ = -16°)
  - As demonstrated at Clark Lake and the 74 MHz VLA, observations to Z < 75° (δ > -40°) will be possible in good ionospheric weather and at reduced sensitivity
- Extend N-S array geometry to compensate for foreshortening at low zenith **(Ray Talk)**
  - elliptical array with circular beam at the celestial equator

Requires: Good dipole performance to Z = 50°

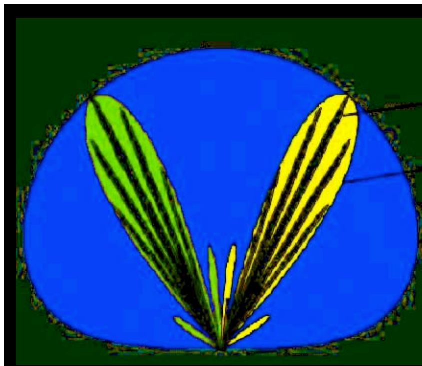
Desirable: Restricted dipole performance 50 < Z < 75°

SR-9 & TR-9: Primary Beam Width

- Science requirements:
  - Would like a FoV as least as large as the LAS we hope to image, to avoid mosaicking
  - Survey-speed will be maximized by larger FoV
  - Sky monitoring efficiency is also increased
  - A larger FoV improves the chances of finding rare and/or transient sources in each observation
- Technical Considerations
  - λ/D gives us $\theta_{FoV} \sim [8,2]°$ at [20,80] MHz for 100 m stations

Requires: FoV = [8,2]° at [20,80] MHz

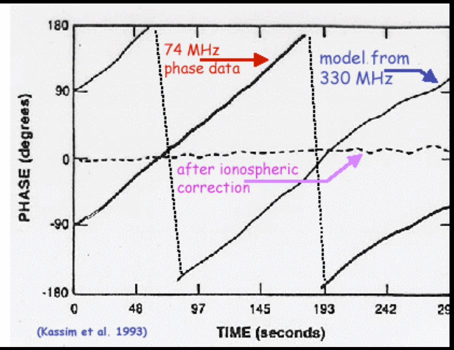
Desirable: FoV ≥ [8,2]° at [20,80] MHz



SR-10: Simultaneous Beams

- Useful to have at least 2 full sensitivity beams
  - "solar/dark ages dedicated beam", "student/outreach beam", "maintenance beam", "survey beam", "transient beam"
- Use of multiple beams enhances the survey speed of the instrument
- Many beams for 3D dynamic imaging of the ionosphere (community input)
- Multiple beams can be used to increase the instantaneous observed bandwidth for spectral studies

Requires: 2 fully independent dual pol. beams
Desirable: ≥ 2 fully independent dual pol. beams

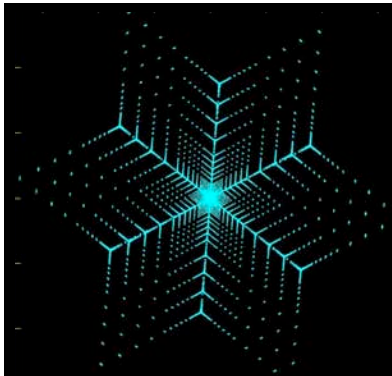


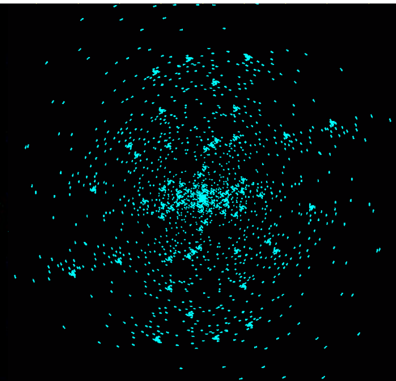
TS-10: Simultaneous Beams

- Can be used to increase instantaneous bandwidth with co-spatial pointings
- Phase Calibration
  - Option to bootstrap calibration from our highest frequencies where [phase distortions, sensitivity] are at a [minimum, maximum] to lower frequencies
  - More than 2 beams are required to allow removal of 2π phase ambiguities across frequency space
  - Multiple beams may be required to scan & self-calibrate 3C & 4C sources in sky on sufficiently short timescales

Required: > 2 full polarization beams

Desirable: ≥ 2 fully independent dual pol. beams





SR-11: Snapshot uv Coverage

- Flows from many scientific requirements
  - Need sufficient uv coverage to suppress main-beam and side-lobe confusion in order to obtain good dynamic range
  - Need to achieve good balance between angular resolution and demanding surface brightness sensitivity requirements
  - Snapshot capability requires good instantaneous uv coverage
  - Simulations required to derive the optimal array configuration **(Ray/Cohen Talk)**
    - » Ionospheric calibration may put priority on aperture plane coverage over uv coverage
    - » Need to sufficiently sample ionospheric pierce points required for Fourier (or other) characterization of ionospheric waves across FoV
  - Immovable stations is key challenge to achieving good uv coverage

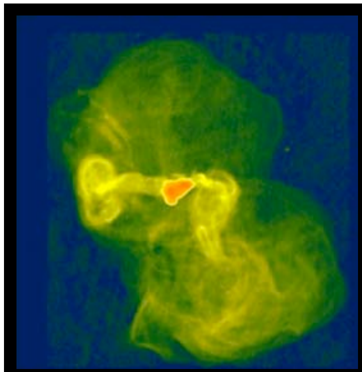
Required: Approach VLA multi-configuration uv coverage

Desirable: Exceed VLA multi-configuration uv coverage

SR-12: Ionospheric Zenith Angle Coverage

- Target two anomalies of interest to the ionospheric community:
  - the 'winter' anomaly in the northern hemisphere
  - the 'equatorial' anomaly within 20 degrees of the magnetic equator
- NM is close to the ionospheric equator yet still provides access to the northern regions

Required: Access to ionospheric equator and northern regions – satisfied by NM



SR-13: Dynamic Range

- Scientifically flows from many requirements, most notably sensitivity to faint emission in presence of bright sources in the field
- Thermal noise limited imaging beyond short integrations and ideally to CC limits
- Thermal noise is not the main limitation
  - » Sidelobe & main beam confusion, RFI
  - » Calibration errors (e.g. poor phase calibration related to ionosphere)
- Simulations needed to verify calibration & imaging performance
- DR to accommodate powerful solar bursts – requires special consideration

Required: DR ≥ [1 x10^3,2x10^3] at [20,80] MHz

1 hr thermal noise in presence of 1 Jy source

Desirable: DR ≥ [2x10^3,8x10^3] at [20,80] MHz

20 MHz limit assumes 400 km classical confusion limit in presence of 1 Jy source.

Array Layout
Guidance for Number & Size of Stations

- Station Diameter (D_S)
  - VLA : D_S = 25 m too small at 74 MHz (6.2 λ), OK at 300 MHz (27 λ)
  - The equivalent at 80 MHz is D_S = 100m or 4X smaller FoV (16X in area)
- # of Dipoles per station (N_{DS})
  - Minimize station sidelobes, & preserve collecting area across 20-80 MHz
    - » N_{DS} = 250-350 allows a natural taper to minimize primary beam sidelobes
  - Estimate needed for calibration: $N_{DS} \geq 234\ (\lambda_m/4)^{0.1}$
    - » Based on VLA experience (self-cal and VLSS) – LWA memo #52
- ***For N_{DS} = 256 dipoles, and [0.7,0.4] mJy at [20,80] MHz: # of stations N_s = 53***
- ***uv coverage: N_S= 53 matches multi-configuration VLA: $4N_{VLA}^2 \sim N_{LWA}^2$!!***

Required: D_S= 100m, N_{DS}= 256, N_S = 53

Desirable: D_S > 100m, N_{DS}> 256, N_S > 53

Simulations needed to verify calibration & imaging performance

Technical Specifications: Summary

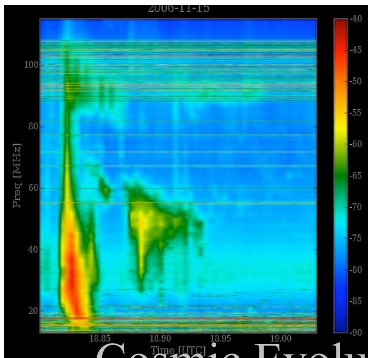
	Required	**Desirable**
Frequency Range:	20 MHz to 80 MHz	9 MHz to 88 MHz
Angular resolution:	$\theta \leq [8,2]''$	$\theta \leq [5,1.4]''$
LAS at [20,80] MHz:	= [4,1]°	= [8,2]°
Baseline range:	200 m to 400 km	100 m to 600 km
Sensitivity [20,80 MHz]:	$\sigma \leq [0.7,0.4]$	$\sigma \leq [0.5,0.1]$
Dynamic range:	$DR \geq [1x10^3,2x10^3]$	$DR \geq [2x10^3, 8x10^3]$
$\Delta\nu_{max}$ (per beam):	$\Delta\nu \geq 8$ MHz	$\Delta\nu$ = full RF
$\Delta\nu_{min}$:	$\Delta\nu \leq 100$ Hz	$\Delta\nu \leq 10$ Hz
Temporal Res:	$\Delta\tau = 100$ msec	$\Delta\tau \leq 0.1$ msec
Polarization:	dual circular > 10 dB	dual circular > 20 dB
Sky Coverage:	$Z \leq 64°$	$Z \leq 74°$
Primary Beam [20,80] MHz:	= [8,2]°	≥ [8,2]°
# of beams:	2 fully independent	≥ 2 fully independent
Configuration:	2D array, N = 53 stations	2D array, N≥53
Philosophy:	User-oriented, open facility; proposals solicited from entire community	
Mechanical lifetime:	≥15 years for potentially long lifetime	

Phased Development Plan

Date	Phase	Milestone Description	Acronym
[illegible]	[illegible]	[illegible]	[illegible]
2007 Q4	Ia	System Requirements Review	SRR
2008 Q1	Ia	Preliminary Design Review for First LWA Station	LWA1+ PDR
2008 Q4	Ia	Critical Design Review for First LWA Station	LWA1+ CDR
2009	Ib	Long Wavelength Array Station #1 + Options	LWA1+
2009-2011	IIa	9 Station Long Wavelength Intermediate Array	LWIA-9
2011-2013	IIb	16 Station LWIA with Partial Core	LWIA-16
2013-2015	III	High Resolution LWA	LWA
2010-	IV	LW Operations and Science Center	LWOSC

Technical Specifications: Individual Phases

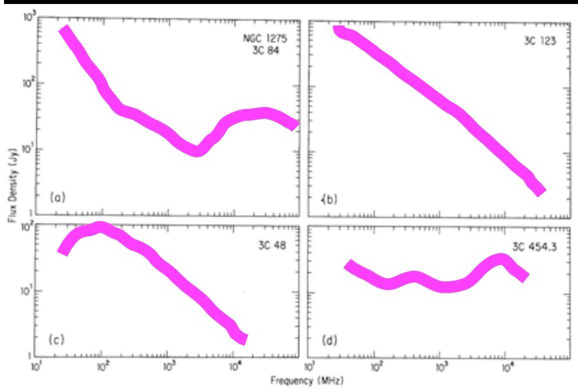
	LWA-1(+)	LWIA	LWA	Remarks
Freq Range	[10,88] MHz	→	→	
No. of Stations	1 (+2 small)	16		
Max Baseline	a few km	200 km	400 km	min: 100 m (core)
Resolution	(TBD)	[16,4]"	[8,2]"	
T_{sys}	G.N.D.*	→	→	9000 K @ 38 MHz
Sensitivity/bm	[40, 25] mJy	[3, 2] mJy	[0.7, 0.4] mJy	2 pol, 1 h, 8 MHz
sky coverage	$Z < 74^{o}$	→	→	includes GC
Primary Beam	$[8,2]^{o}$	→	→	zenith pointing
Simult. beams	3	→	→	ortho. circ. pols.
Time resolution	10 ms (10 ns)	→	→	(raw sample mode)
Freq resolution	100 Hz	→	→	



On the Path to the LWA: LWA-1+

- Cosmic Evolution & The High Redshift Universe
- Acceleration of Relativistic Particles in:
  - UHECR
- **Plasma Astrophysics & Space Science**
  - RRL – e.g. detect in ~ [5,25] hrs @ [≤40,74] MHz, Δν=0.1 kHz (1-2 km/s @25 MHz)
  - Solar bursts – e.g. study fast (50 ms) narrow-band (<10 kHz) structures
  - Jupiter decametric bursts – e.g. fine temporal and spectral structure seen by Voyager
  - ISM tomography – e.g. single pulse studies
- **Exploration Science**
  - ***bright transients – e.g. GCRT J1745-3009: ≥ 5σ detection if α ≤ -1***
  - ***nearby pulsar spectra – e.g. detect 68 bright, low DM pulsars***

- ***Significant engineering and commissioning experience***
- ***Insight into limitations for deep integrations***
- ***Combination with 74 MHz VLA expands science of both instruments***

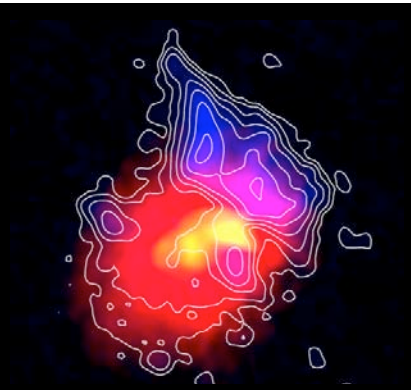


On the Path to the LWA: LWIA (9 stations)

Opens ability to self-calibrate and image bright sources (Cohen, Clarke, & Lazio 2007)

- *74 MHz VLSS gives 362 LWIA targets – e.g. 5 SNR, 5 halos/relics, 8 cooling core, 100's of extragalactic radio sources*
- *more than 4800 targets possible using BW smearing techniques*
- *science limited mainly to compact emission regions.*

- *Cosmic Evolution & The High Redshift Universe*
  - *HzRG – e.g. compact steep-spectrum sources with no optical counterparts*
- *Acceleration of Relativistic Particles in:*
  - *Radio Galaxies – e.g. low frequency spectra*
- *Plasma Astrophysics & Space Science*
  - *Ionospheric Turbulence – e.g. hundreds to thousands of ionospheric pierce points*
- *Exploration Science*
  - *"Deep Spot" Surveys – e.g. deep fields around bright sources*
  - *Fainter Transients & Pulsars – e.g. follow-up spectra*



On the Path to the LWA: LWIA + core (16 stations)

Addition of 6 core stations widens science to mapping of diffuse emission in LWIA target lists. Expands science potential of LWIA list but does not reach wide-field imaging.

- Cosmic Evolution & The High Redshift Universe
  - LSS – e.g. explore DM & begin to place constraints on DE with available clusters
- **Acceleration of Relativistic Particles in:**
  - galaxy clusters – e.g. mapping diffuse radio halo/relic emission + spectral studies
  - SNR – e.g. mapping extended and filamentary structure + spectral studies
- **Plasma Astrophysics & Space Science**
  - Solar – e.g. begin to study CME's ?
- Exploration Science

Backup Slides

Technical Specifications: Summary

	Required	**Desirable**
Frequency Range:	20 MHz to 80 MHz	9 MHz to 88 MHz
Angular resolution:	$\theta \leq [8,2]$"	$\theta \leq [5,1.4]$"
LAS at [20,80] MHz	$\geq [8,2]°$	$\geq [16,4]°$
Baseline range:	100 m to 400 km	50 m to 600 km
Sensitivity [20,80 MHz]:	$\sigma \leq [0.7,0.4]$	$\sigma \leq [0.5,0.1]$
Collecting Area (m^2)	$A_e = 1 \times 10^6$	$A_e = 4 \times 10^6$
Dynamic range:	$DR \geq [1\times10^3, 2\times10^3]$	$DR \geq [2\times10^3, 8\times10^3]$
$\Delta\nu_{max}$ (per beam)	$\Delta\nu \geq 8$ MHz	$\Delta\nu$ = full RF
$\Delta\nu_{min}$	$\Delta\nu \leq 100$ Hz	$\Delta\nu \leq 10$ Hz
Temporal Res	$\Delta\tau = 100$ msec	$\Delta\tau \leq 0.1$ msec
Polarization:	dual circular > 10 dB	dual circular > 20 dB
Sky Coverage:	$Z \geq 64°$	$Z \geq 74°$
FoV [20,80] MHz	[8,2]°	$\geq [8,2]°$
# of beams:	2 fully independent	$\geq$ 2 fully independent
Configuration:	2D array, N = 53 stations	2D array, $N \geq 53$
Philosophy:	User-oriented, open facility; proposals solicited from entire community	
Mechanical lifetime	$\geq$15 years for potentially long lifetime	

Discovery Space – what is left?

√ ■ New wavelengths - just about finished

- *The region below 100 MHz is the last poorly explored one*

√ ■ Angular resolution & sensitivity

- *The LWA will increase both the angular resolution and sensitivity by more than two orders of magnitude compared to Clark Lake*
  - » *Like going from Einstein to Chandra (while skipping ROSAT & ASCA)*

√ ■ Volume of space sampled

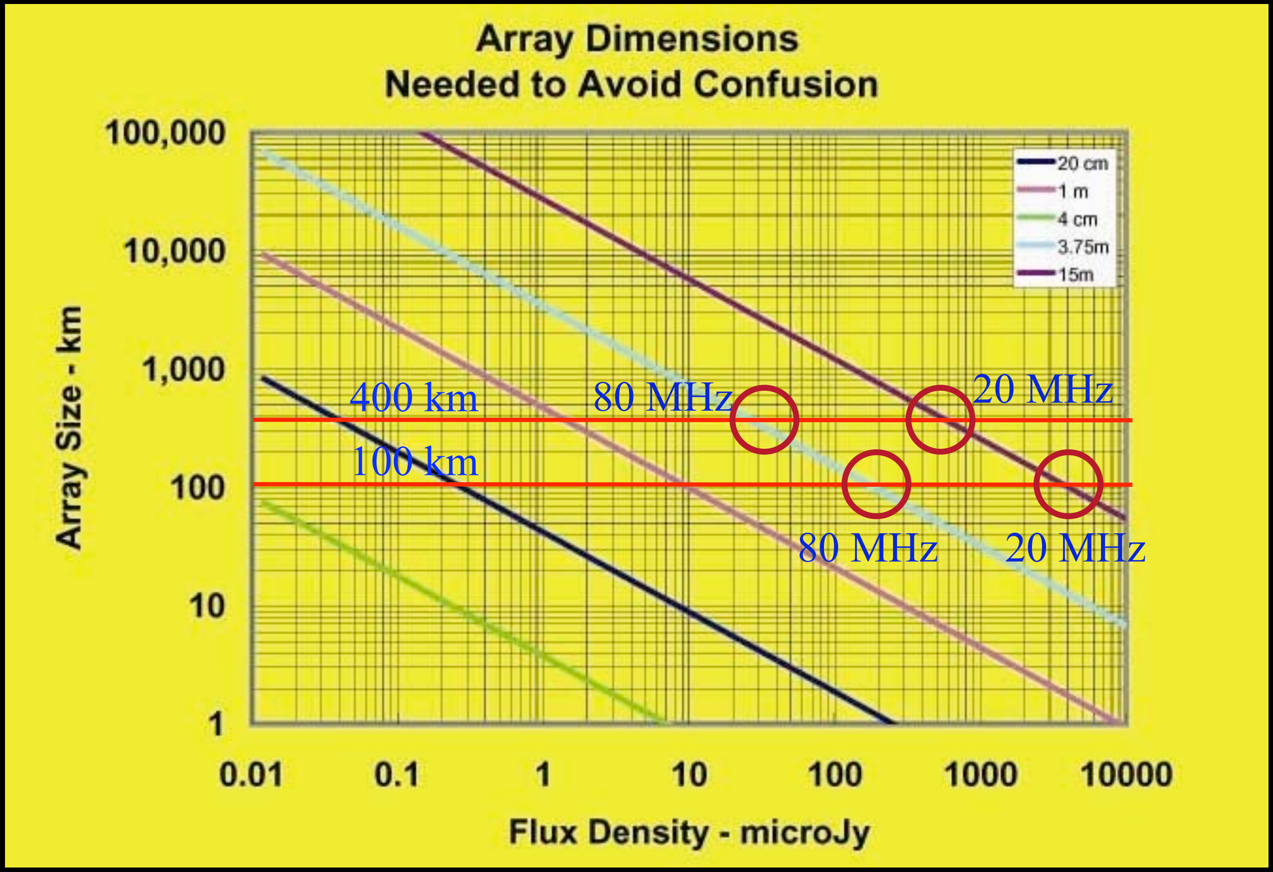
- *An area where low frequency instruments, with their intrinsically large fields of view, will naturally thrive*

√ ■ New observing paradigms: multi-beaming

- *Another natural capability of an electronic low frequency array*

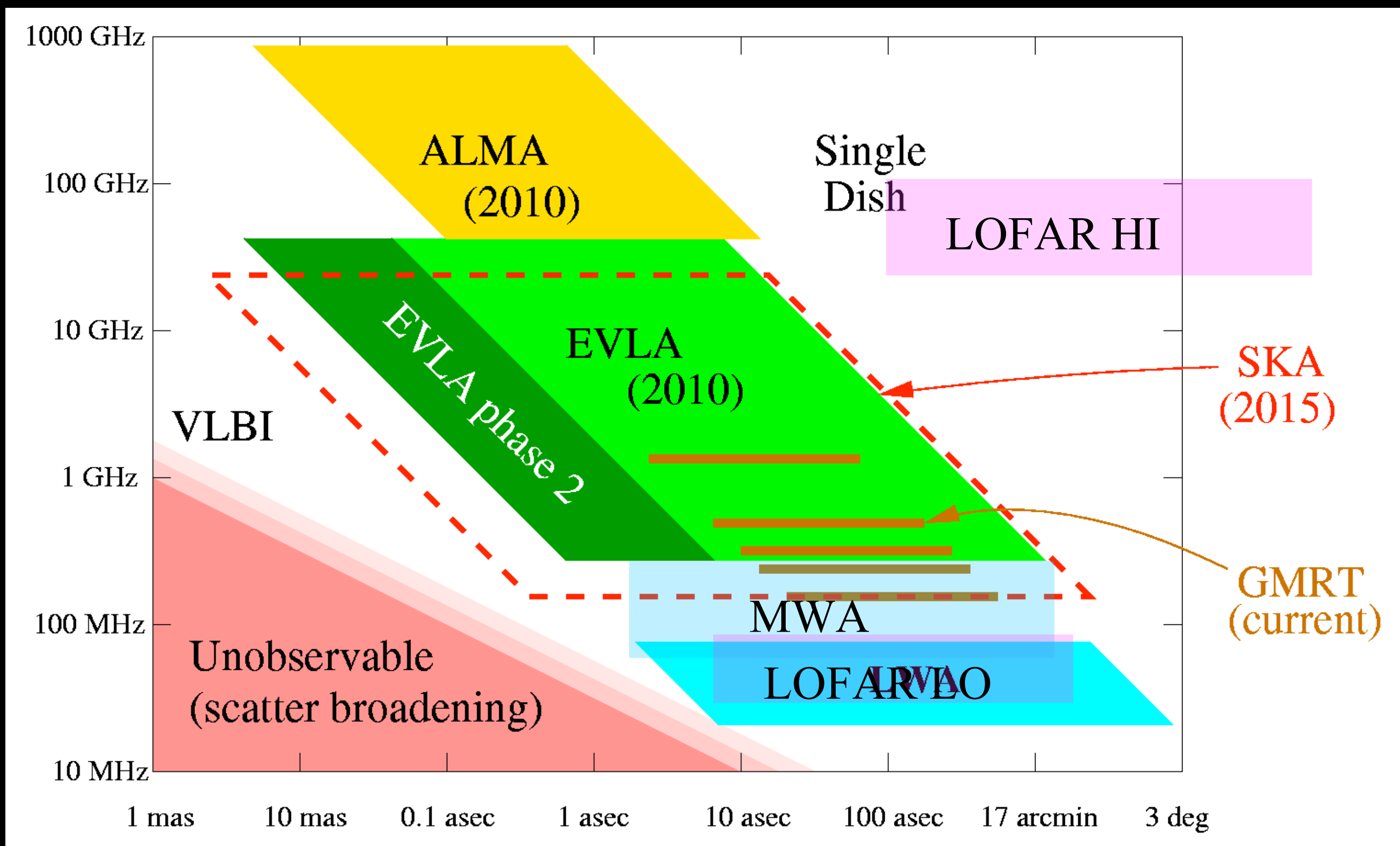
The LWA efficiently exploits the last remaining areas of astrophysical discovery space

LWA Classical Confusion Space

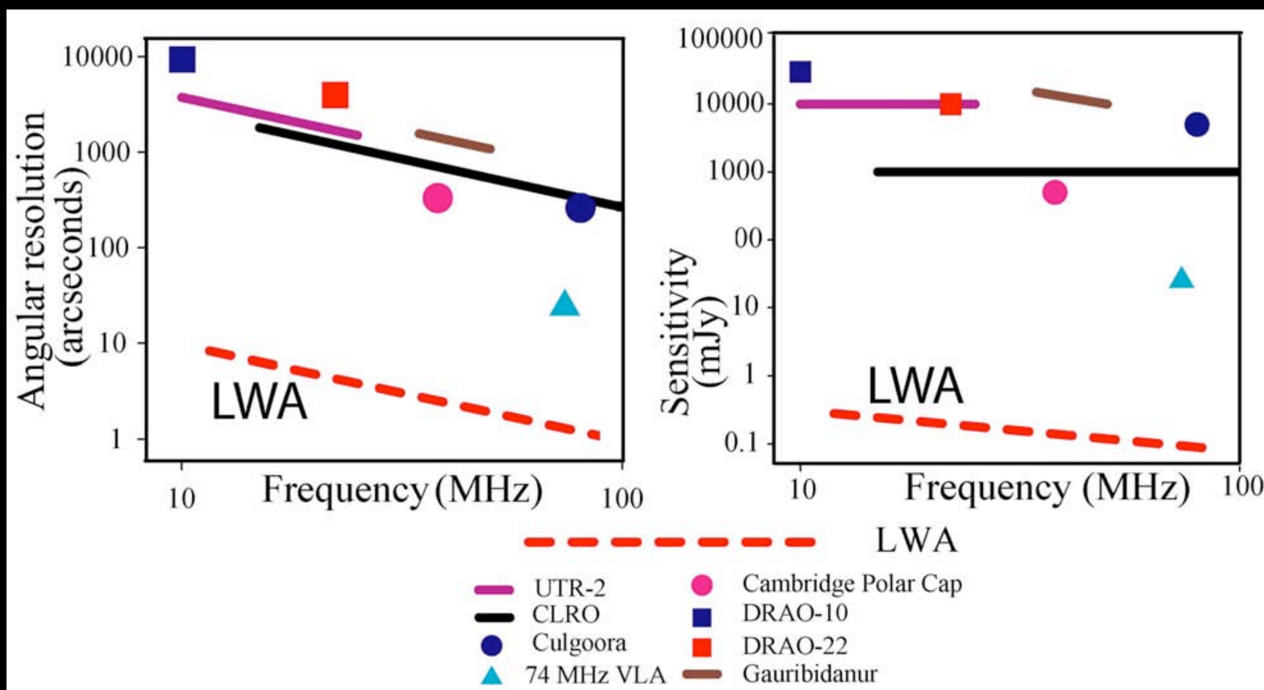


(slide courtesy KIK – consistent with Cohen LWA specific confusion calculations)

LWA Discovery Space
in frequency, resolution, & surface brightness



LWA Discovery Space:
in resolution & sensitivity



ν

Phased Development:

Time	Phase	Description	Acronym
2004	0	Existing 74 MHz VLA	VLA74
2006-2008	I Funded!	Long Wavelength Development Array +Long Wavelength Array Station #1	LWDA LWA-1
2007-2008	**Ib**	**LWA Station #1 (LWA-1) + LWA Outlier Stations (LWA-2 & 3)**	
2008-2010	II	9 station Long Wavelength Intermediate Array	LWIA
2010-2012	III	16 station LWIA + Core	LWIA+C
2012-2014	IV	High Resolution LWA	LWA
2009-	V	LW Operations and Science Center	LWOSC

System Architecture Review

Kickoff Meeting, Albuquerque, NM
September 21, 2007

Steve Ellingson
LWA Interim Systems Engineer
Virginia Polytechnic Inst. & State University
ellingson@vt.edu

System Architecture

- At the moment, focus is on station architecture.

- Purpose of an architecture (document):
  - Define subsystems, interfaces, and concise identifying nomenclature; WBS development
  - Framework for developing subsystem and interface specifications
  - Also in our case serves as the engineer's "What is LWA?" answer

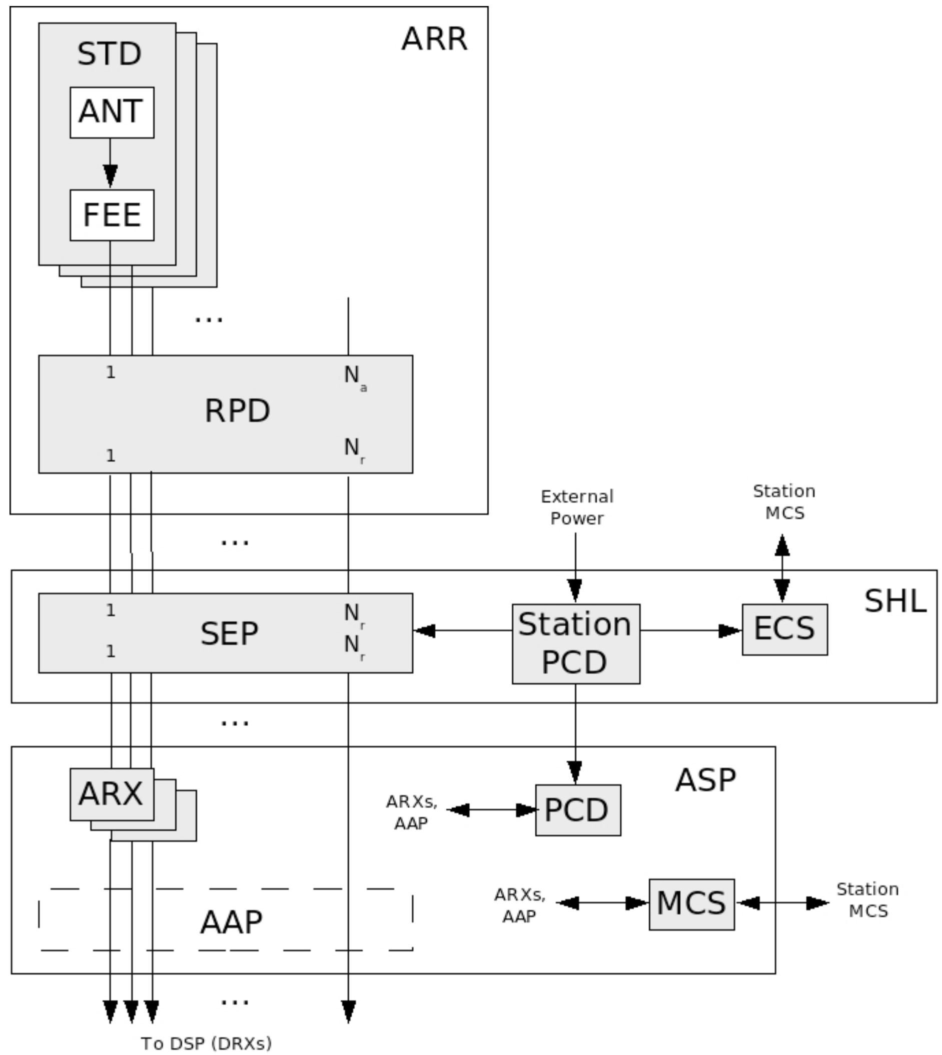
- Current manifestation:
  - Station Architecture Document ver. 0.5 (Aug 28, 2007)
  - Past work: Memo 35 (Apr 2006) – still useful.

Subsystem Definitions

ARR = Array
- **STD = Stand**
  - **ANT = Antenna**
  - **FEE = Front End Electronics**
- **RPD = RF and Power Distribution**

SHL = Shelter
- **SEP = Shelter Entry Panel**
- **PCD = Station Power Conditioning & Distribution**
- **ECS = Environmental Control System**

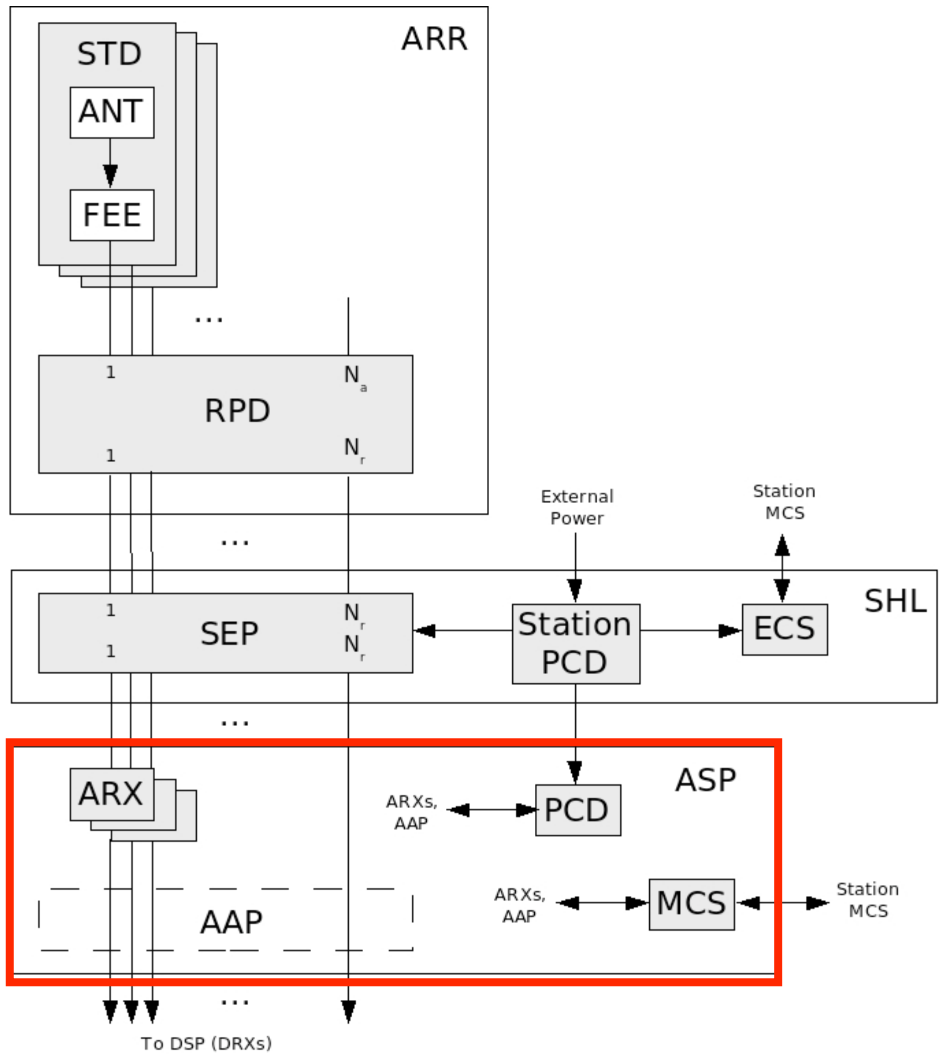
ASP = Analog Signal Processing
- **ARX = Analog Receiver**
- **MCS = Monitoring & Control System**
- **AAP = Analog Array Processing (Hopefully not needed!)**



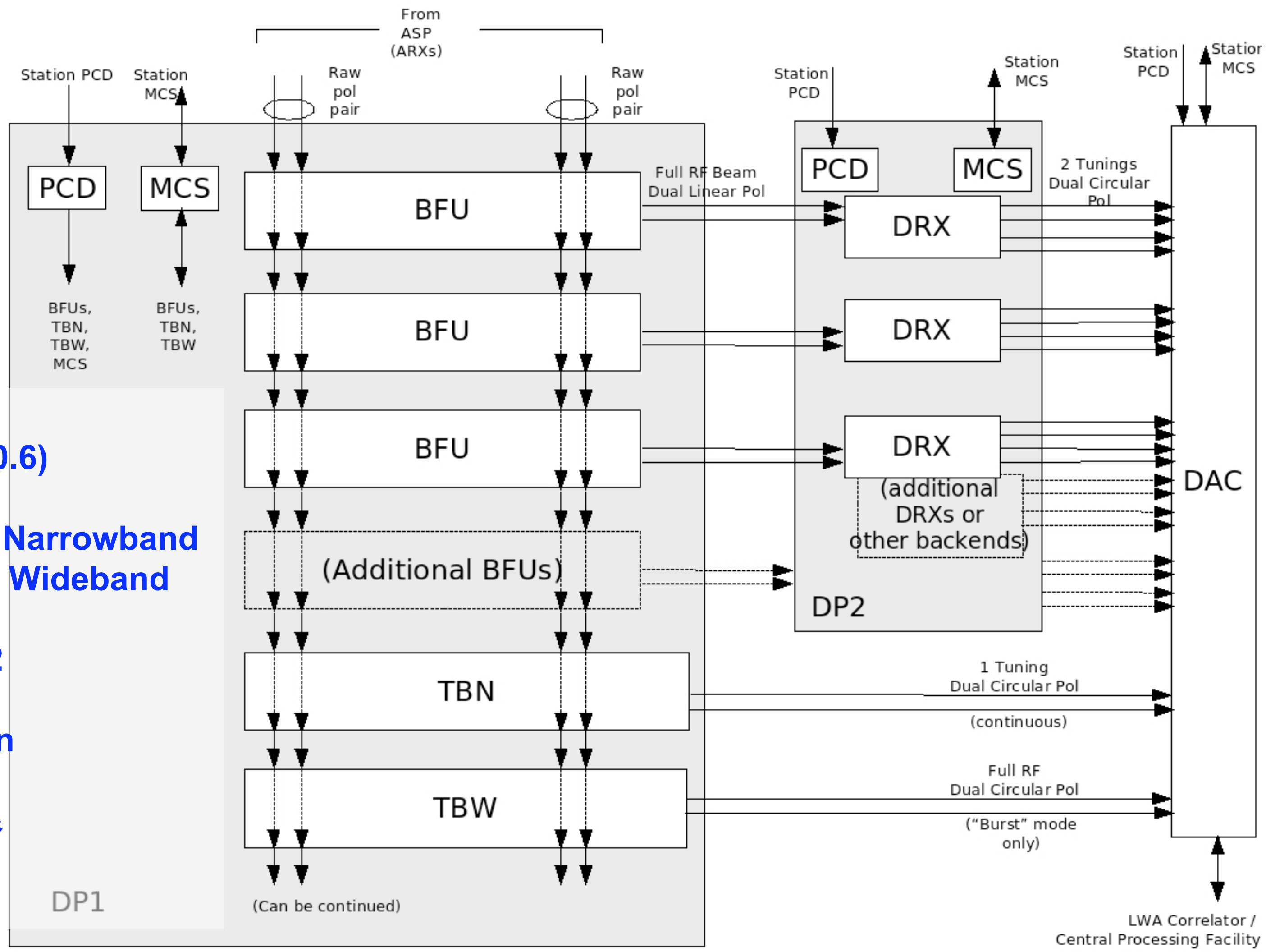
Subsystem Definitions

Most Level-1 subsystems (e.g. ASP) will be large chassis or racks of some sort, with local PCD and MCS subsystems, e.g.:
- **ASP-PCD**
- **ASP-MCS**

Level-1 subsystems may also have attributes independent of their constituent Level-2 subsystems: e.g.:
- **ASP-EMD (Electromechanical Design)**



Subsystem Definitions

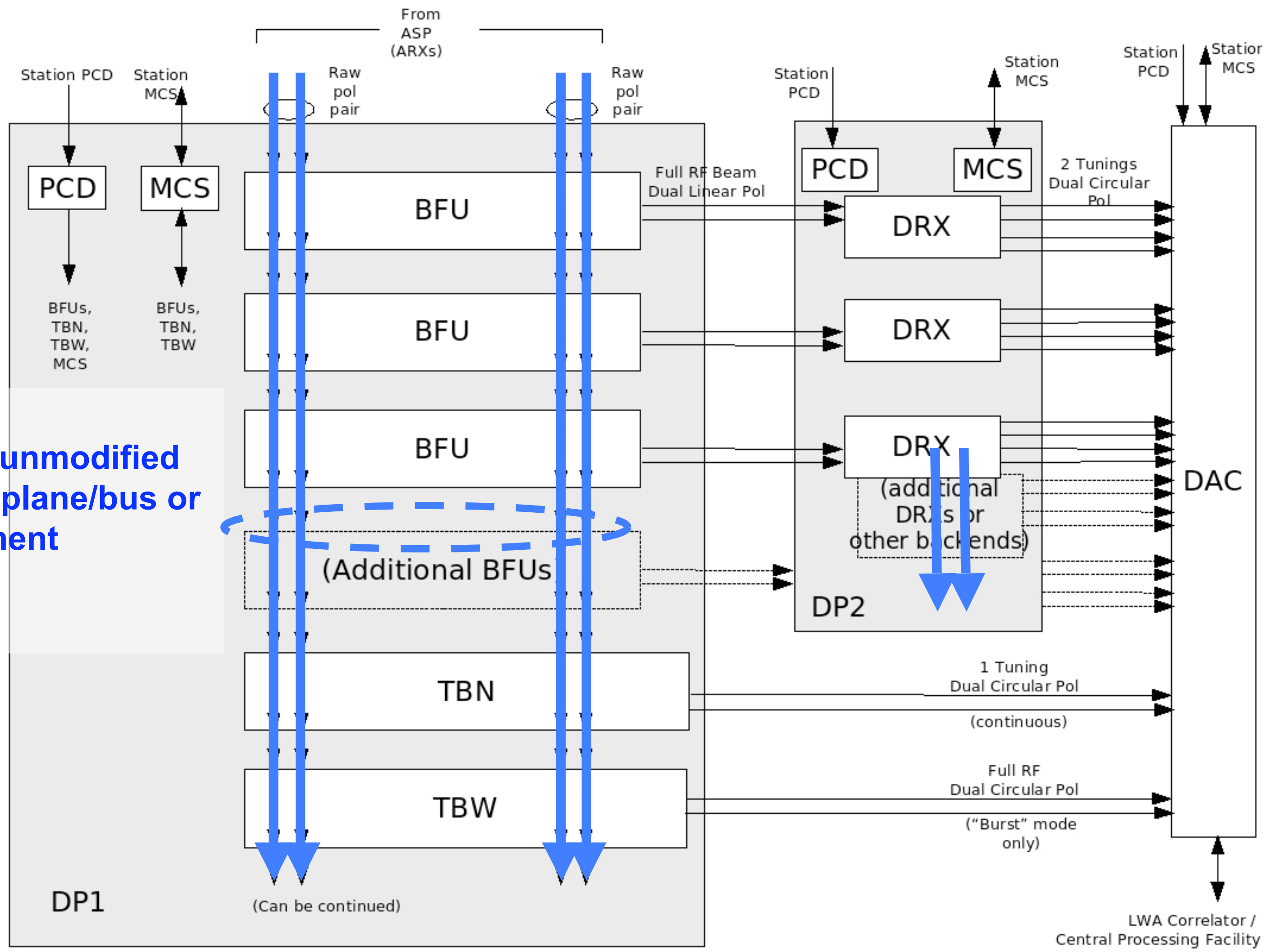


DP1 = Digital Processing 1
- **DIG = Digitizer (new in v.0.6)**
- **BFU = Beamforming Unit**
- **TBN = Transient Buffer – Narrowband**
- **TBW = Transient Buffer – Wideband**

DP2 = Digital Processing 2
- **DRX = Digital Receiver**
- **Backends, via daisy chain**

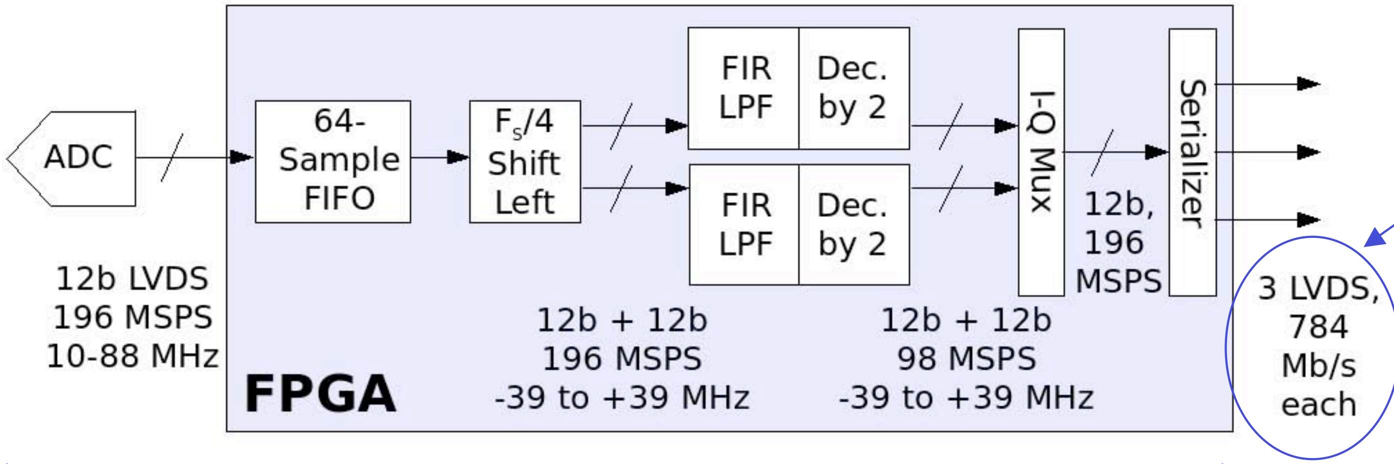
DAC = Data Aggregation & Communications
(Interface to the world)

DP1 & DP2 Daisy Chains



DP1 & DP2 Daisy Chains:
- **Primarily for distributing unmodified input data without a backplane/bus or complex fanout arrangement**

New Since ver. 0.5



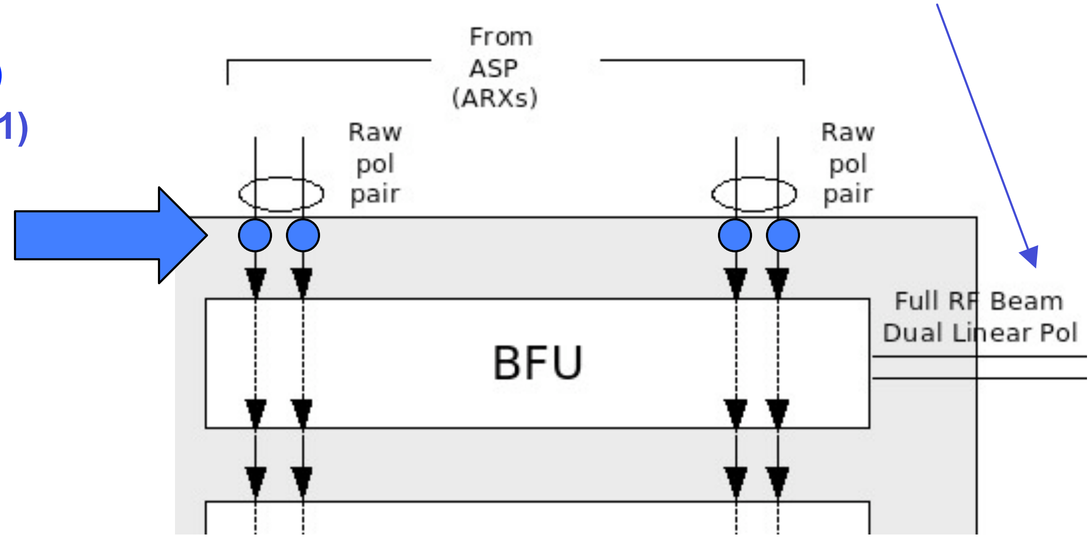
Changed:
Now 4 lanes @ 686 Mb/s each

Same format as DIG output

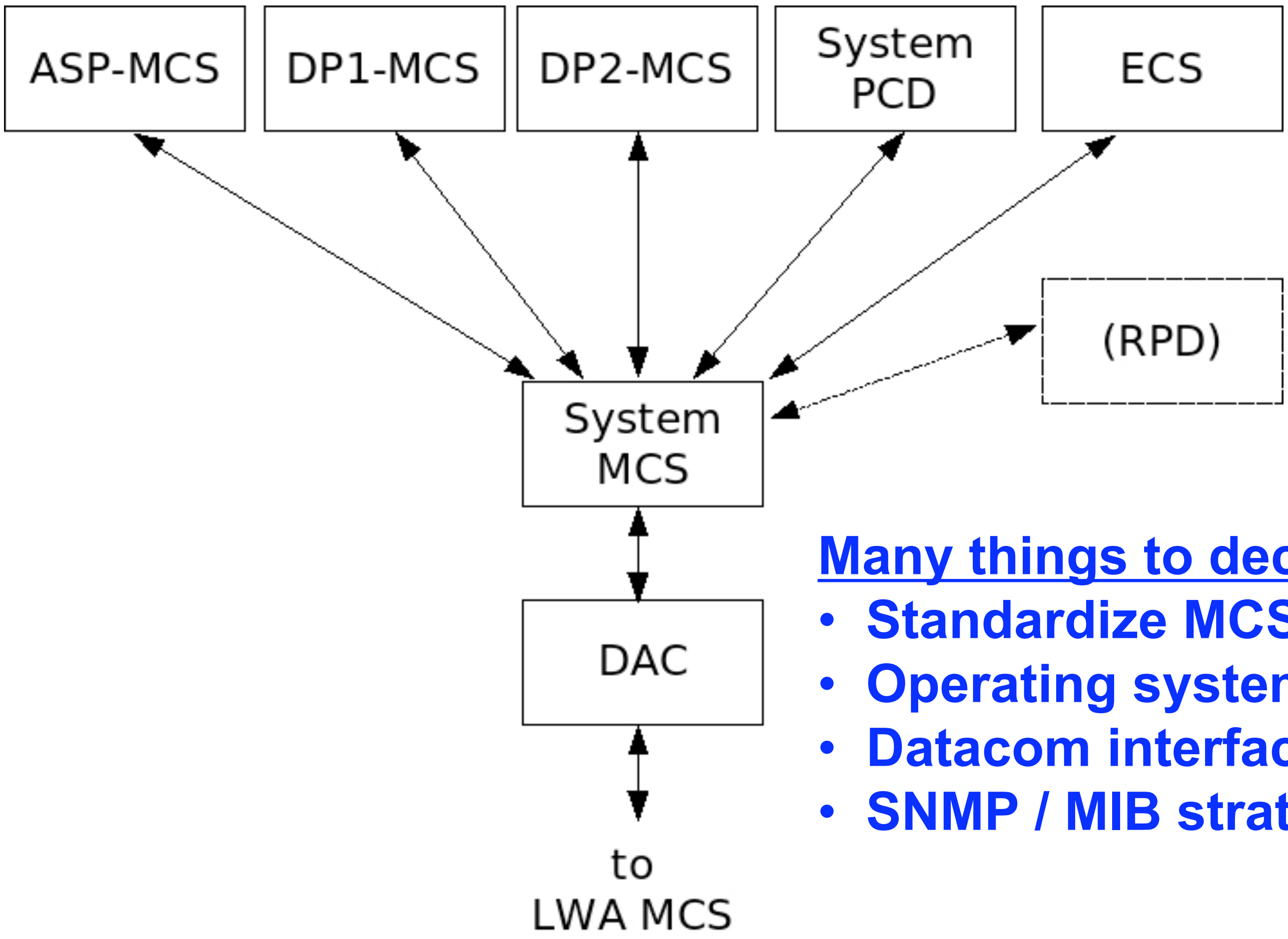
Digitizer (DIG)
(LWA Memo 101)

DIG becomes the source of the DP1 daisy chain

10-88 MHz RF BW
98 MSPS / antenna
~ 3 Gb/s / ANT



Monitoring & Control Arch.



<u>Many things to decide & specify here</u>

- **Standardize MCS hardware?**
- **Operating system(s)?**
- **Datacom interfaces/standard(s)?**
- **SNMP / MIB strategy?**

ICDs

- ICD = Interface Control Document
- Specifies an interface between (sub)systems
  - Electromechanical, Data, Monitoring & Control, Power
- Nominally completely worked out by PDR, becomes unattached annex to Architecture document.
- Doing ICDs well allows:
  - Firewalling of effort between institutions
  - Enabling of modular upgrade(s) post-IOC
  - Ability to accept or oursource alternative backends

ICDs (who might do 'em)

- STD-RPD (NRL/UNM)
- RPD-SEP (NRL/UNM/ARL)
- SEP-ASP (ARL)
- ASP-DP1 (ARX-DIG) (VT)
- DP1 Daisy Chain (VT)
- DP1-DP2 (BFU-DRX) (VT/ARL)
- DP2 Daisy Chain (ARL)
- DAC Sky-Side (ARL/???)
- DAC Ground-Side (ARL/???)
- Inter-MCS (???)
- Station PCD Sky-Side (ARL)
- Station PCD Ground-Side (ARL)

DP1/DP2 Backends

- Potential outsourced / alternative backends for DP1:
  - All-Sky Monitor
  - Custom transient detection/capture (e.g., for UHECRs)
  - Perhaps BFU, TBW, and/or TBN

- Potential outsources / alternative backends for DP2:
  - Pulsar machine(s)
  - Custom spectrometers; e.g., with enhanced RFI mitigation or ultra-fine spectral resolution (e.g., for RRLs)
  - Direct-to-disk recorders

- DP2 backends could be either pre- or post-DRX; i.e., full-RF beam or reduced BW &/or channelized beam

Timebase & Clocks

- Timebase – not yet in Architecture document
  - No special requirements for LWA1.
  - LWA1+ needs three with sufficient accuracy to do interferometry over kilometer-scale baselines.
  - No point in specifying LWA-grade timebase(s) for LWA1+, but should be thinking about requirements.
- Clock distribution – not yet in Architecture document
  - Synthesize 196 MHz sample clock (easy)
  - Coherently synthesize & distribute 512 copies (potentially difficult)
- Time stamping/embedding protocol for downstream processing
- Expect this to become a Level-1 subsystem in a future version of the Station Architecture document.

Station Calibration

- Problem of determining the *array manifold*; i.e., the set of delays+phases associated with each possible plane wave over the locus of possible directions of incidence.
- Cannot be assumed that this can be determined solely from geometry, due to our awkward mutual coupling situation. Also, can't rely on a few bright sources (underdetermined problem)
- Probably OK to assume that this stationary (approximately constant) over hours or maybe even days
- Methods:
  - TBW visibilities + sky model (Solve inverse problem)
  - Beacons (may be useful esp. as sanity check & diagnostic)
  - Signal injection (512 directional couplers? Yuk!)

Real-Time RFI Mitigation

- High dynamic range front end, receiver & ADC
- ARX: Reconfigurable bandpass and gain control
- DIG: Asynchronous pulse blanking (APB), bad data flagging
- BFUs capable of space-time nulling, static or adaptive.
  - ATA has pioneered this… our situation is actually quite similar
  - Might be effective against ATSC
- DRXs: Time-frequency blanking, static or adaptive
- Custom canceling devices (another ATSC countermeasure)

Concluding Remarks

- Parts of the effort leading up to SRR are moving fast; keep an eye out for new memos and versions of system documents.

Long Wavelength Array

System Engineering

Clint Janes, “Kick-Off” Review, 2007-Sep-21

“WBS” Requirements

- System Technical Requirements
- System Requirements Review (Nov. 9)
- Project Book
- Management of Interface Control, MCS, Data Communication
- PA procedures (Configuration Management, Quality Assurance, Safety, Environmental Plans incl RFI and EMC)
- Conduct of PDR, CDR
- Integration procedures, Acceptance & Verification

Process

- SRR
- ICDs
- PDR
- Prototype and qualification
- CDR
- Production and verification
- Acceptance and integration
- Science validation
- Commissioning

System Requirements Review

Plan is for internal reviewers to make comments by November 9, then pass documents to TAC:

- Science Requirements
- System Architecture
- System Technical Requirements
- WBS (task descriptions, cost models)
- Product Assurance Procedures
- Project Book

Product Assurance

- Documentation Management
  - Currently BaseCamp and LWA memo series
  - Need archive under revision control for production
- Configuration Management
  - Need numbering system related to WBS for production documents and parts
  - Will keep track of parts for 13,300 antenna stands
- Reliability
  - Lots of parts, locations. Need to minimize downtime for observing and for maintenance cost. (quality parts, QA program, ESD plan, design standards)
- Verification and acceptance procedures; integration tests.
  - Matrix showing how all project requirements will be met (A, I, & T)
- EMC Plan, environmental requirements
  - Detrimental PFD low; electronic noise must be kept out of antenna sidelobes.

Project Book Example

- **The Sloan Digital Sky Survey Project Book**
- **Index**

-

Project Book Outline

- **Project**

  Overview [Memo 56], Science Requirements [Memo xx], Technical Requirements, WBS, Evaluation & Commissioning, Operations

- **Station**

  Architecture [Memo xy], Antenna/Stand [Memo 50], Electronics, Timebase and Distribution, Array & Calibration [Memo 21], Infrastructure [Memo 48], Software

- **Interferometer**

  Interferometer Array [Memo 55], Data Communications [Memo 57], CorrelatorInterferometer Software, Ionospheric Modeling & Calibration [Memo 52], Data Archive

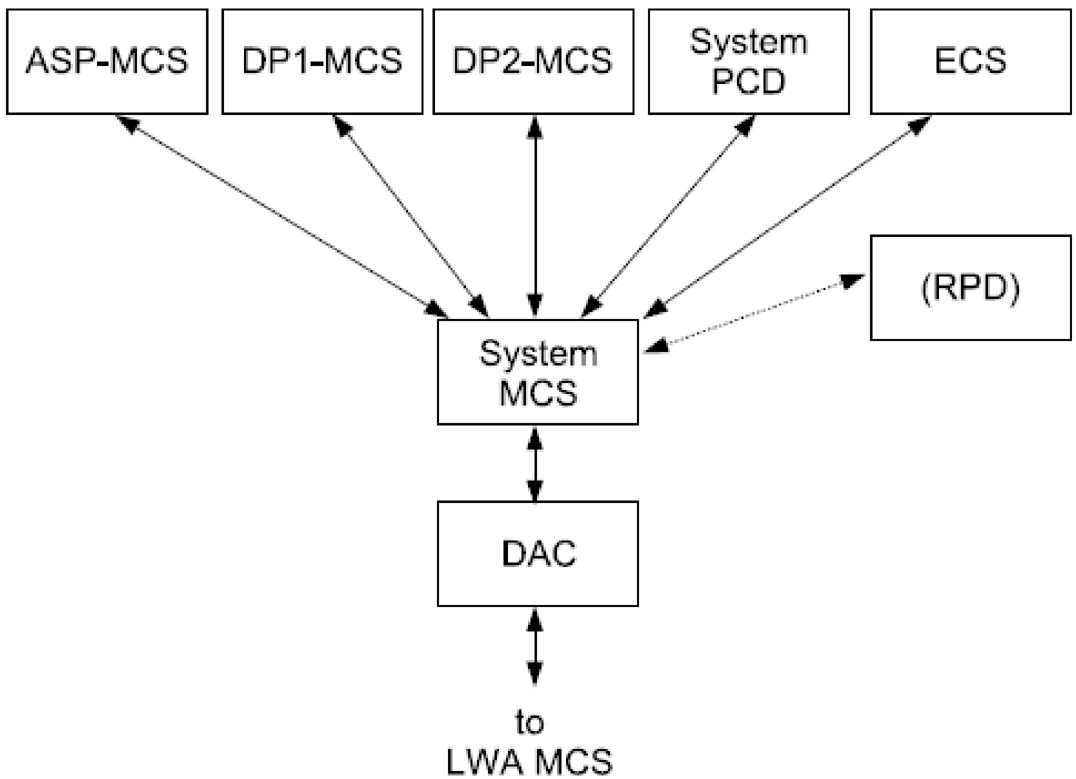
Monitor and Control System

Requirements: Need for monitor and control, estimate on BW required, RFI concerns, timing issues

Survey of technology available (Ethernet interfaces; eg, Rabbit3000, EVLA MIB; ALMA CAN; ATNF PCI)

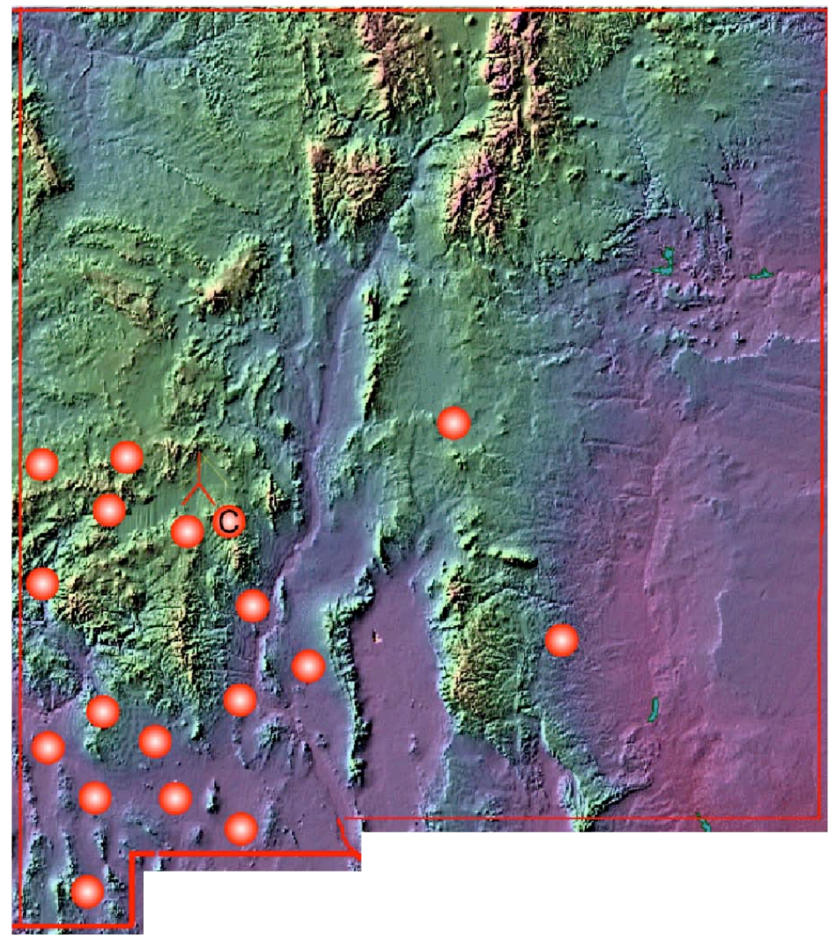
Assignment to System Engineering to come up with full plan, perhaps with student help

MCS Block Diagram

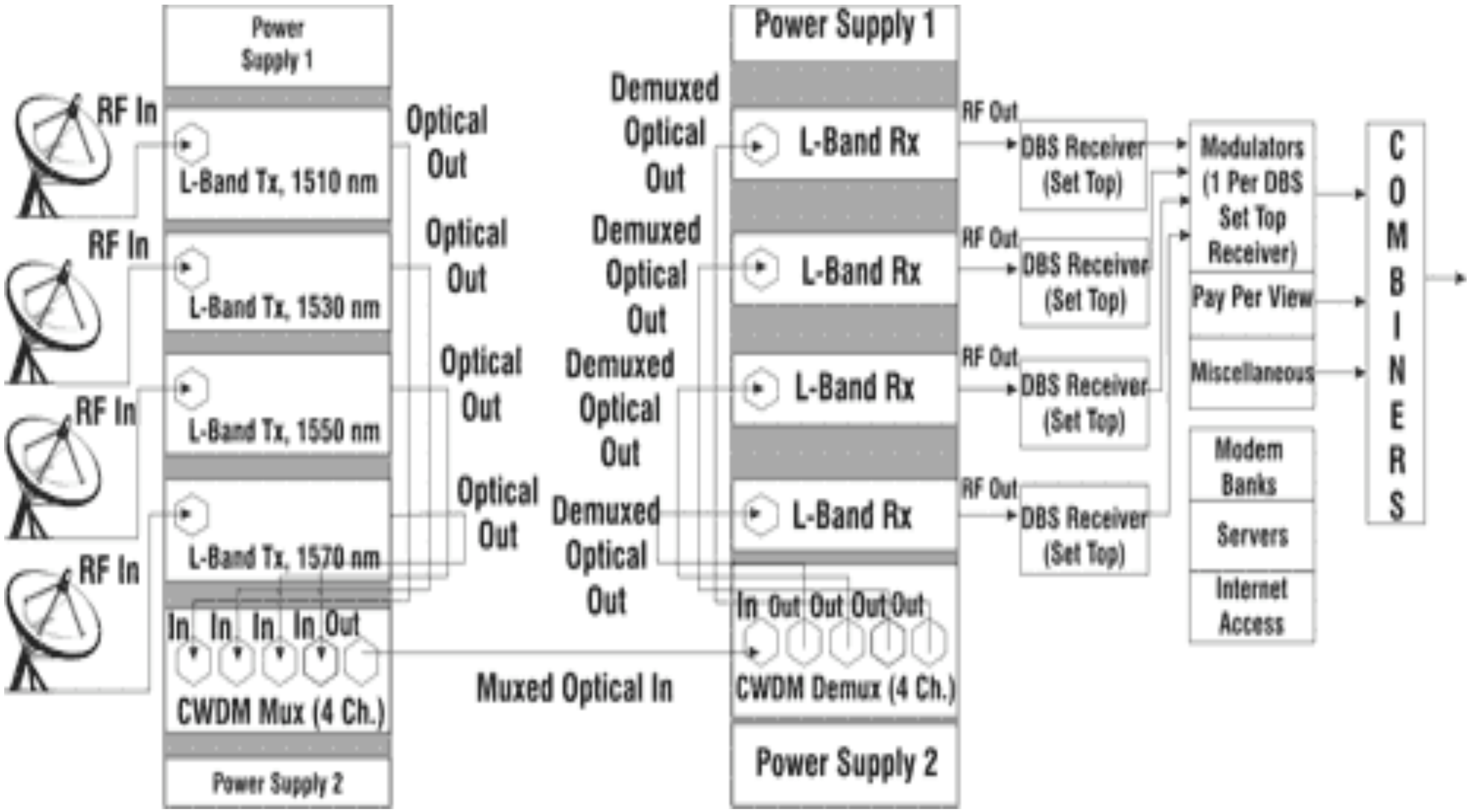


Data Communication

- Requirements: Uni-directional, 500+ Mbps BW req’d, formatting (time stamp, etc)
- Technology (eg, Ethernet, WDM, CWDM, DWDM, Mark V, RAID)
- Assignment to System Engineering to come up with full plan, perhaps with student help



Unidirectional CWDM (Coarse Wavelength-division Multiplexing)




PREPARE FOR GLORY!
Long Wavelength Array

Applied Research Laboratories

The University of Texas at Austin

Current LWA Efforts

David Munton, Aaron Kerkhoff, Johnathan York,

Tom Gaussiran

21 Sept 2007

muntond@arlut.utexas.edu

512-835-3831

Topics to Address

- Antenna Simulation Work & Mutual Coupling– A. Kerkhoff
- ADC Survey – J. York
- Shelter Design & GPS Receivers – D. Munton
- Determining Ionospheric Corrections – T. Gaussiran

Applied Research Laboratories

The University of Texas at Austin

Comparison of Dipole Antenna Designs for LWA

Aaron Kerkhoff
21 September 2007
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512-835-3173

Introduction

ARL
The University of Texas at Austin

- Motivation: How do antenna designs being considered for the LWA compare with those from other low frequency radio telescope projects? Can anything be learned from these designs?
- Compare performance of leading candidate antenna designs for LWA with those used in other systems
  - Blade dipole (LWA)
  - Fork dipole (LWA)
  - Wire inverted-V dipole (LOFAR low-band: 30-80 MHz)
  - Vertical bow-tie dipole (MWA LFD: 80 to 300 MHz)
- Performance metrics considered
  - Sky noise frequency response
  - Radiation pattern quality, beamwidth, axial ratio at different frequencies
  - Effective collecting area at the zenith
  - Sensitivity to vertically polarized signals incident from the horizon

Dipole Antenna Designs Considered

ARL
The University of Texas at Austin

LOFAR low-band wire inverted-V

MWA LFD vertical bow-tie

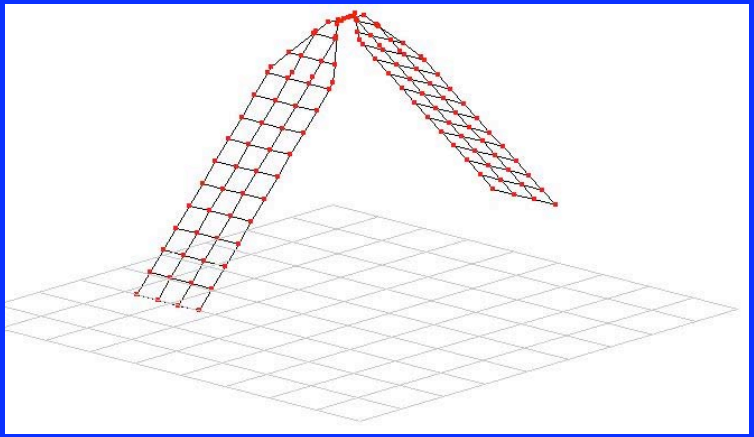
LWA blade

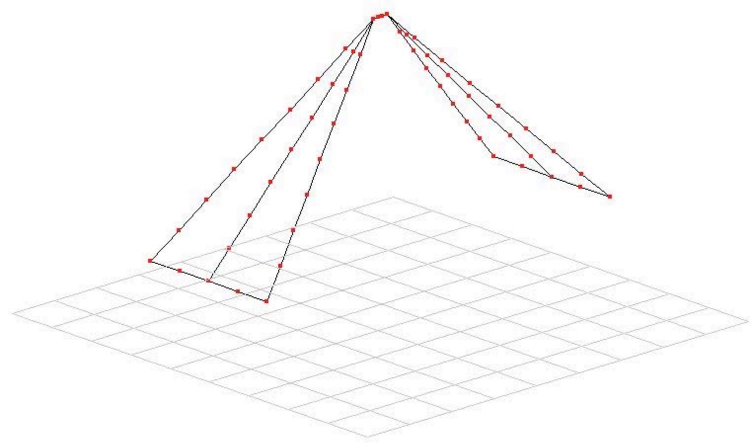
LWA fork

Analysis Approach / Assumptions

ARL
The University of Texas at Austin

- Use NEC2 code to simulate response of each antenna design
- Analyze each antenna design as is – i.e. no further optimization performed
  - Design information for LOFAR antenna not available – pick dipole length = electrical length of blade; try both thin (radius = 1.5 mm) and thick (10 mm) wires
  - Scale all MWA antenna dimensions up by factor of 3.6 to fit to LWA band
- Other assumptions
  - Assume baseline LWA active balun design concept: low input impedance (nominally 100 Ω) and noise temperature between 120 to 250 K
  - Assume infinite PEC ground - approximates effects of ground screen, but greatly reduces computational complexity
  - Only single dipole considered – no mutual coupling effects included



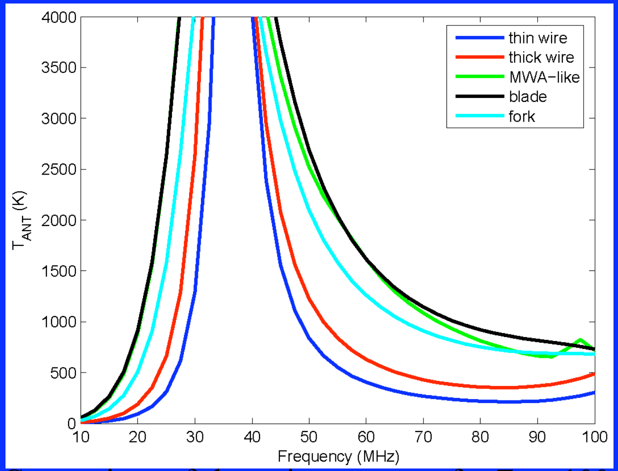


NEC models for blade and fork antennas

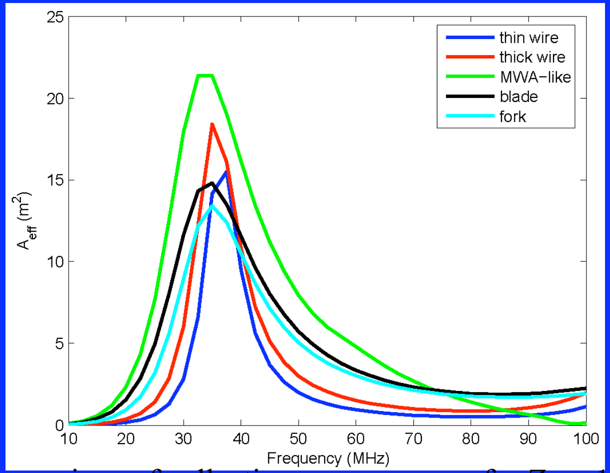
Sky Noise Response and Collecting Area Comparison

ARL
The University of Texas at Austin

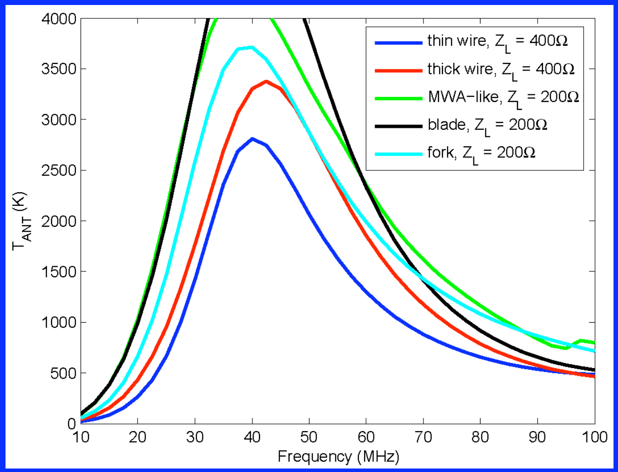
- Broadband dipoles (blade, fork, and MWA) provide high values of T_{ANT} and A_e over entire LWA band with low Z_L. Wire dipoles do not.
- Bandwidth of wire dipoles increased substantially with higher values of Z_L



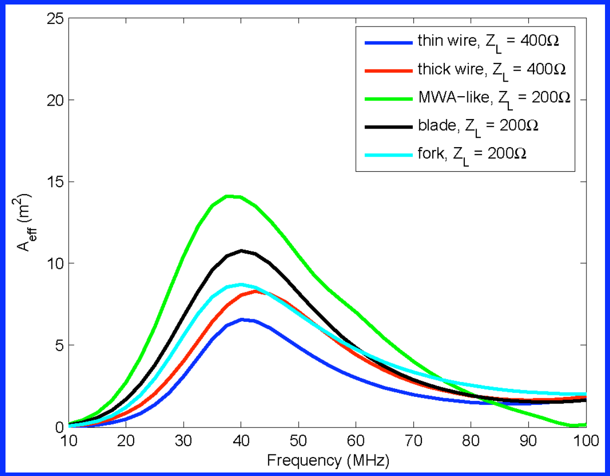
Comparison of sky noise response for Z_L = 100 Ω



Comparison of collecting area response for Z_L = 100 Ω



Comparison of sky noise response for higher values of Z_L

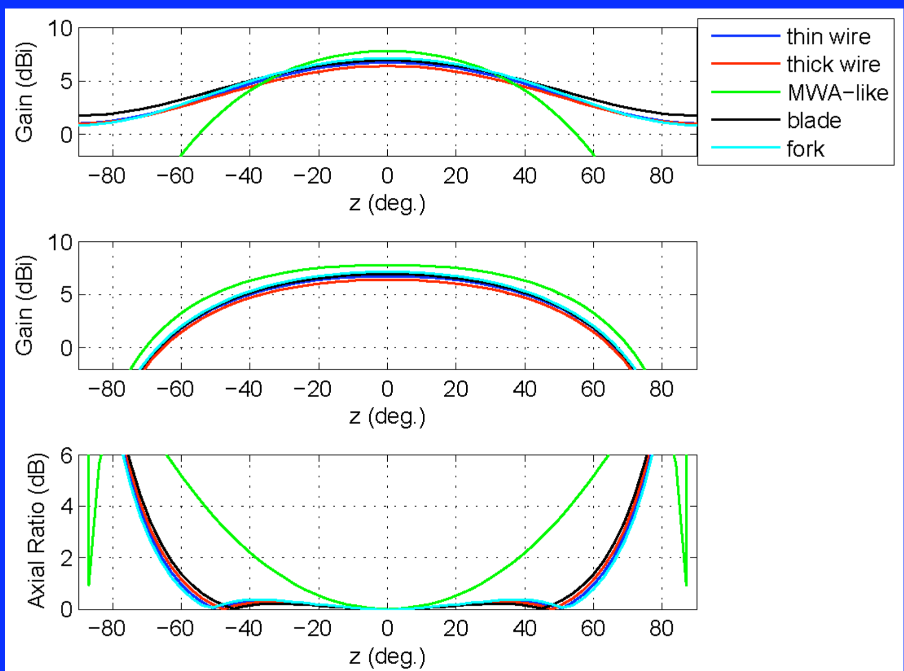


Comparison of collecting area response for higher values of Z_L

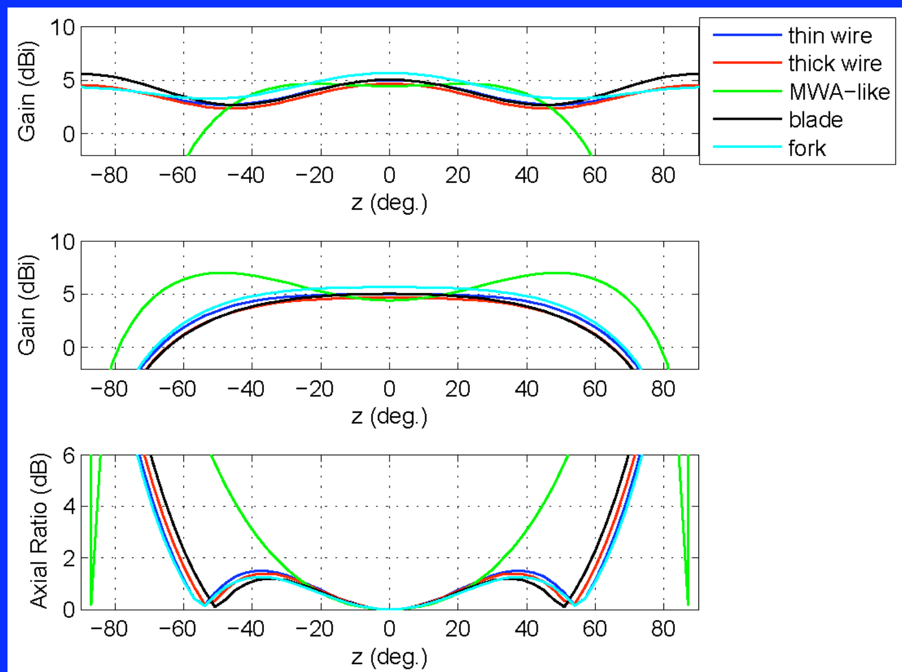
Radiation Patterns Comparison

ARL
The University of Texas at Austin

- All antennas exhibit reasonable E- and H-plane beamwidths and axial ratio values over all or most LWA band except MWA dipole
  - MWA dipole has narrow E-plane beamwidth, null in H-plane at zenith at higher frequencies and high axial ratio values at all frequencies
- All antennas (except MWA dipole) exhibit E-plane sidelobes at higher frequencies
  - Blade sidelobes are highest, fork sidelobes are lowest



E-plane (top), H-plane (middle), axial ratio (bottom) at 38 MHz



E-plane (top), H-plane (middle), axial ratio (bottom) at 74 MHz

Comparison of Sensitivity to Signals Incident at the Horizon

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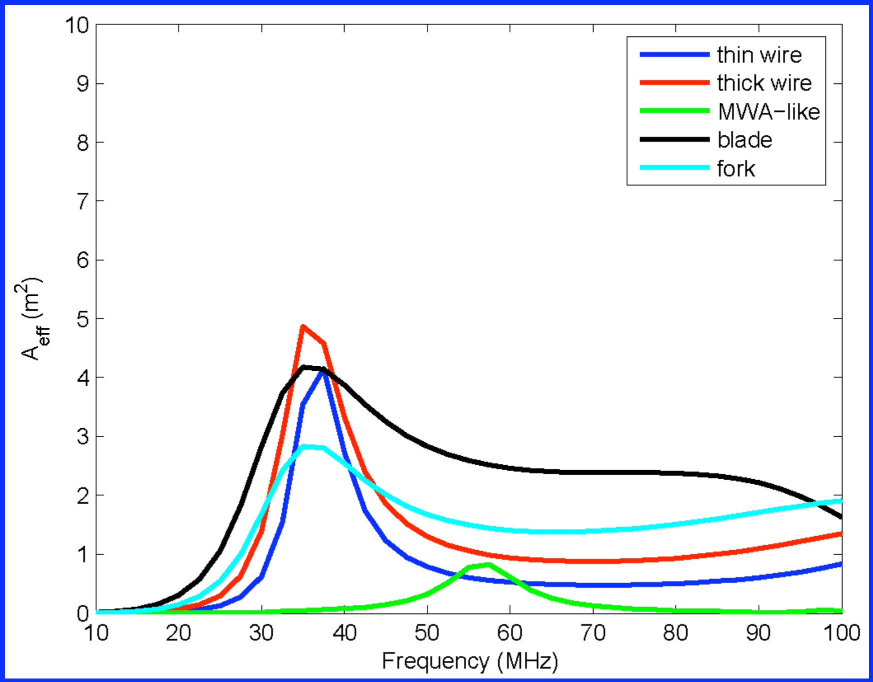
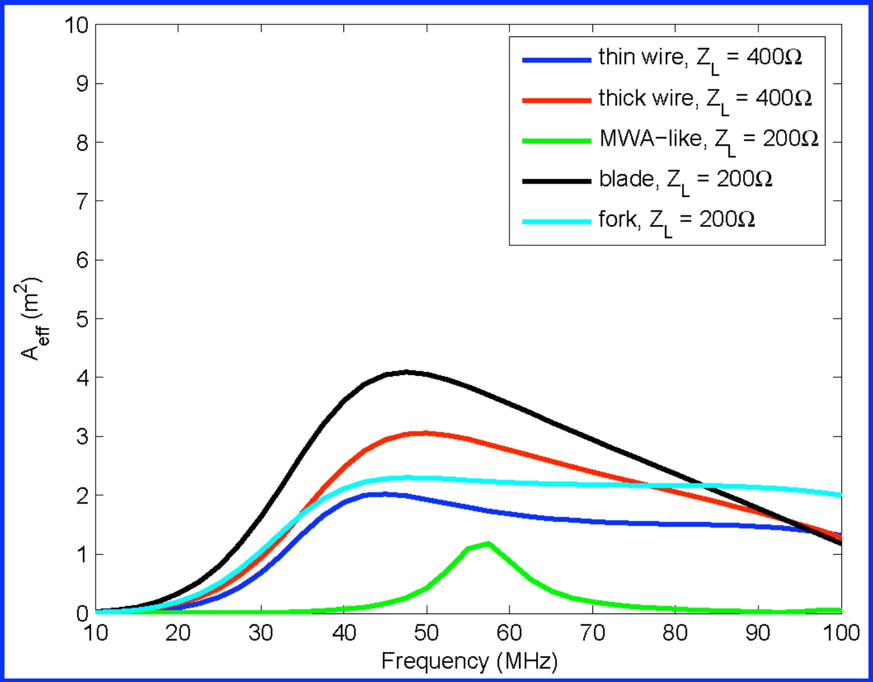
- Blade dipole has highest sensitivity to vertically polarized signals incident at the horizon over LWA band due to high pattern sidelobes in E-plane
- MWA dipole has lowest sensitivity due to pattern nulls in both principal planes
- Relative sensitivity of other antennas depends on the balun input impedance



Sensitivity to signals at horizon for Z_L = 100 Ω



Sensitivity to signals at horizon for higher values of ZL

Conclusions

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- Blade and fork dipoles are the most promising designs given current estimates of active balun input impedance (100 Ω to 150 Ω) and noise temperature (120 K to 250 K)
  - High sky noise and collecting area over LWA band
  - Reasonable radiation patterns over LWA band
- The thick wire inverted-V dipole may be a possibility **if** good balun performance (noise temperature and gain) can be maintained with higher values of input impedance (i.e. 400 Ω or more)
  - Low frequency performance may still be an issue
- The MWA dipole, as is, does not appear to be suitable for LWA
  - Problems with radiation patterns
- Future antenna comparisons should include effects of finite-sized ground screens and mutual coupling between antennas
- **Further optimization of any of the antenna designs is possible subject to the final system requirements and characteristics of other system components**

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Reduction of Mutual Coupling Effects in Pseudo-Random Phased Arrays

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21 September 2007
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Introduction

- Relatively sparse pseudo-random (PR) array layout with 256 antenna elements is currently planned for LWA
  - Has the advantage that a large aperture can be formed with relatively few antenna elements and without grating lobes
- Sparse PR arrays can suffer from significant variation in terminal currents over different array elements and beam pointing directions [1]
  - Significantly increases complexity of calibration (antenna and direction dependent)
- A uniform array layout mitigates this problem
  - A much higher density of antennas are required to prevent grating lobes at higher frequencies
  - For a fixed station size, this requires many more antennas (possibly a factor > 2), which would increase station cost significantly
- Therefore, it is desired to reduce mutual coupling effects in the PR array
  - Approach considered here: design array layout neglecting antenna effects; then design antenna element for low mutual coupling

[1] S. Ellingson, *LWA memo #75*

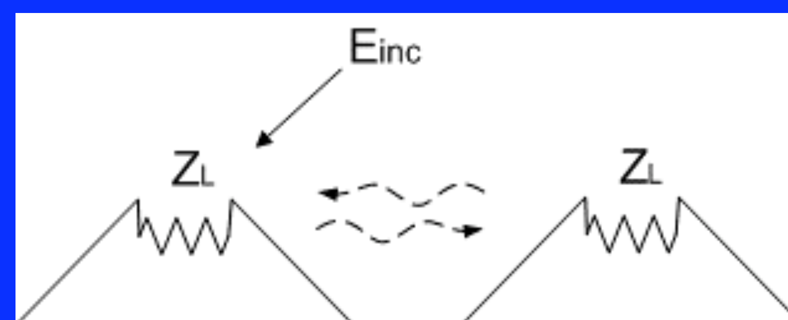
Calculation of Mutual Coupling Between Two Antennas

- Two definitions of mutual coupling between two antennas are provided in [2]
- "Transmit mode" coupling: $C_{tr} = \dfrac{P_L}{P_D}$

  P_D = power radiated by transmitting antenna when excited at feed
  P_L = power delivered to load of receiving antenna
  - Related to S-parameter measurement between two antennas: $|S_{21}|^2 = (1-|S_{11}|^2)C_{tr}$
  - Involves both transmitting and receiving elements – not consistent with concept of receive array
- "Receive mode" coupling: $C_{rec} = \dfrac{P_{L,un-ex}}{P_{L,ex}}$

  $P_{L,ex}$ = power delivered to load of antenna excited by plane wave
  $P_{L,un-ex}$ = power delivered to load of the un-excited antenna
  - More consistent with concept of a receive array
  - Can evaluate coupling response for a wide range of plane wave incidence angles

Transmit case



Receive case

—— Direct / radiated
- - - - Scattered

[2] Daniel, *IEEE TAP*, 1974

Mutual Coupling Properties of Wire Inverted-V Dipoles

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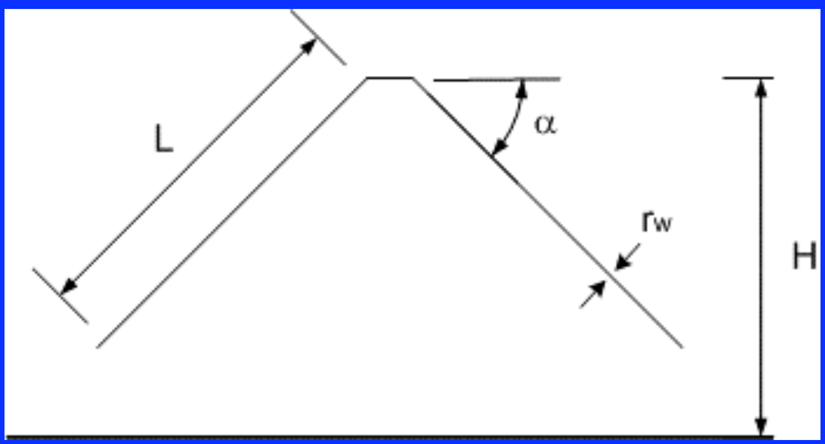
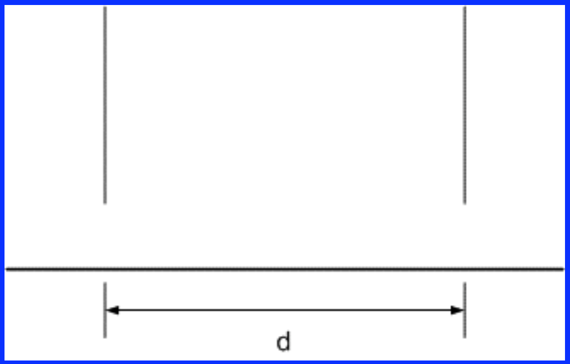
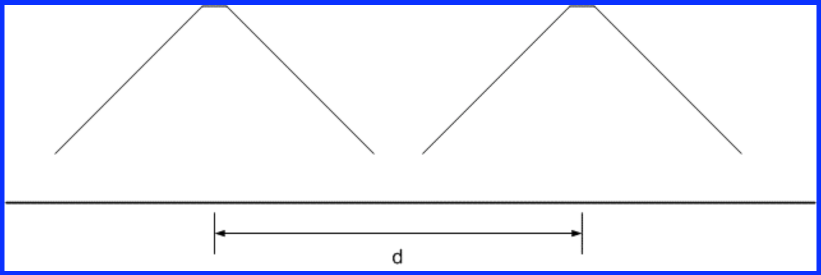
- Consider wire dipoles operating over PEC ground
- NEC2 used to calculate transmit and receive mode coupling
  - Parallel and colinear orientations of dipoles
  - Calculate receive coupling at various plane wave incidence angles



Geometry of wire inverted-V dipole antenna



Parallel dipole orientation



Colinear dipole orientation

Mutual Coupling Properties of Wire Inverted-V Dipoles, cont'd

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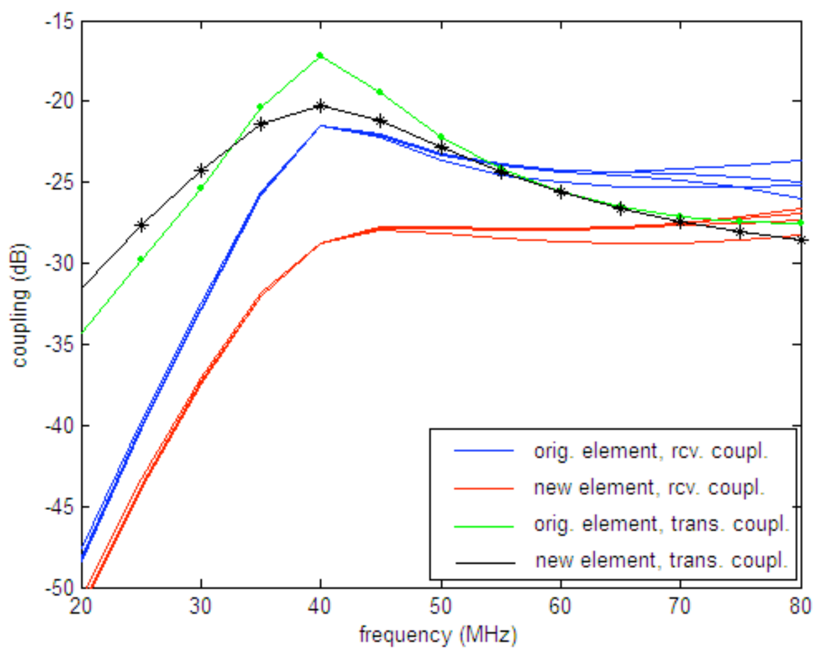
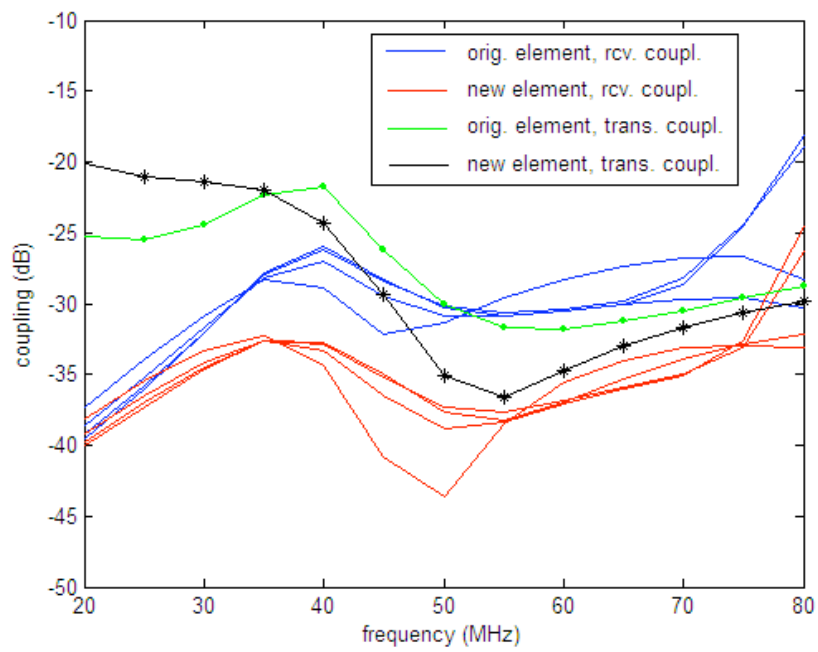
- Start with "compact" dipole design from [1]: L=1.77m, H=1.77m, α=45º, r_w=9.5mm, and assume Z_L = 100 Ω and dipole separation d = 4 m ("orig." design below)
  - Coupling varies significantly with frequency, antenna orientation, and incidence angle
  - Transmit and receive don't always exhibit same trends with frequency
- Antenna dimensions and Z_L were modified to reduce coupling ("new" design below)
  - Changing H to 1.2 m, α to 30º, and Z_L to 200 Ω (all other design parameters the same) reduced coupling over all frequencies, orientations, and incidence angles (up to 8 dB improvement)



Parallel dipole orientation



Colinear dipole orientation

Mutual Coupling Effects in Large Phased Arrays of Wire Inverted-V Dipoles

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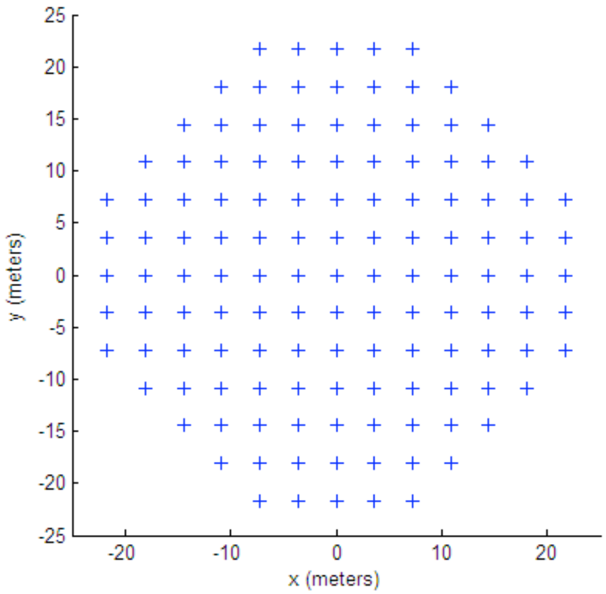
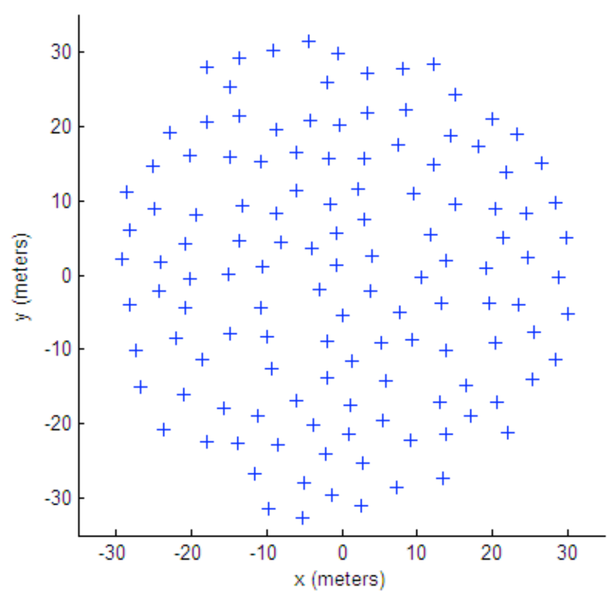
- Used procedure described in [1] to evaluate different array designs using NEC
  - Generate multiple instances of antenna model and place according to array layout
  - Place load impedance at terminals of each antenna to simulate balun / pre-amp
  - Excite array by plane wave
- Array layouts considered:
  - Uniform array from [1] with antenna spacing = 3.61 m
  - LWA baseline PR layout with minimum antenna spacing = 4 m
  - Reduced number of antennas to ~ 128 to reduce simulation run time



129 element uniform array



128 element PR array

Mutual Coupling Effects in Large Phased Arrays of Wire Inverted-V Dipoles, cont'd

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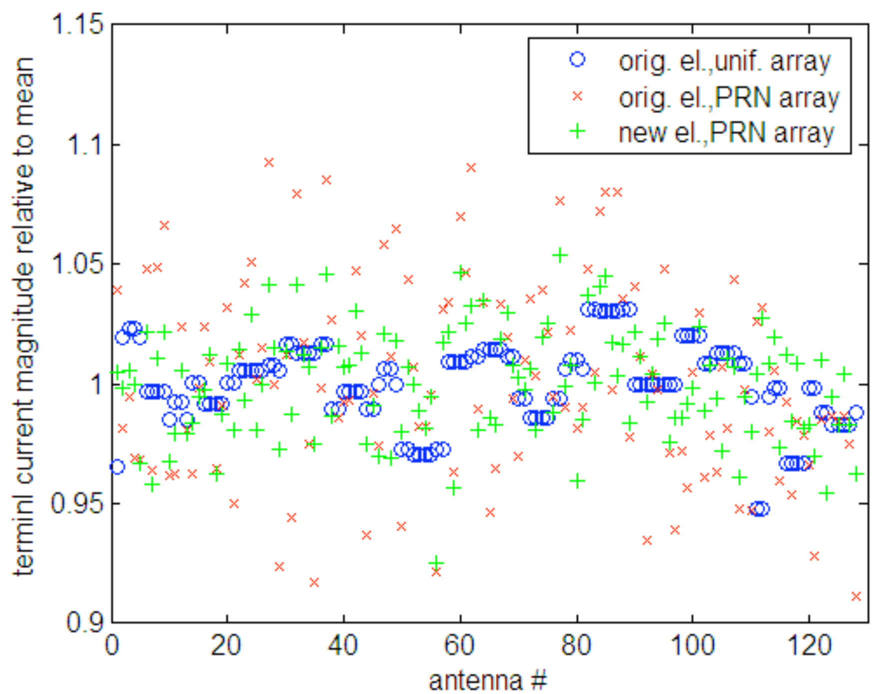
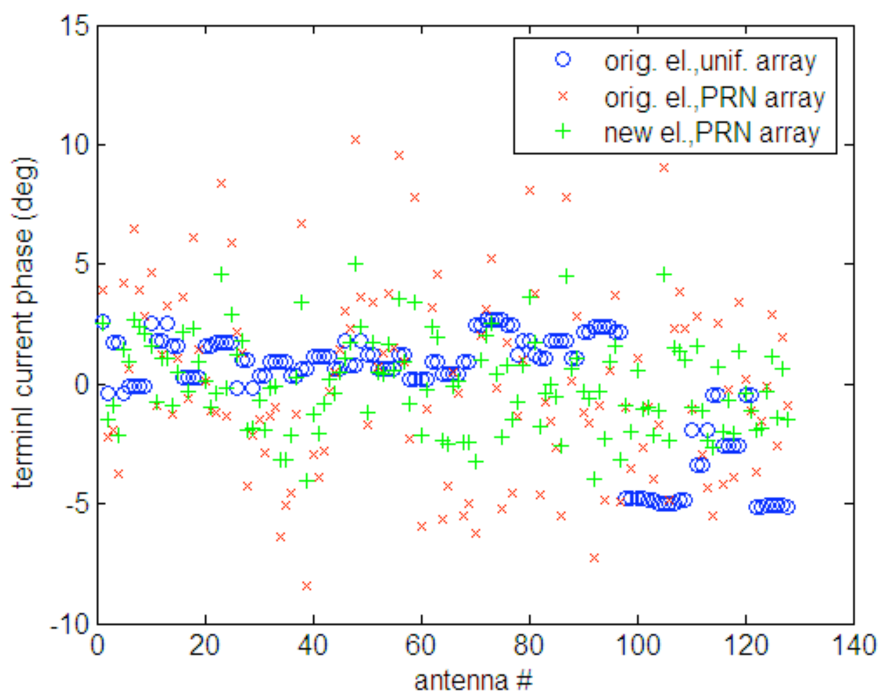
- Comparison between different element design / array layout combinations of terminal currents at all antennas for f = 40 MHz, z = 0º
  - Current uniformity much better in uniform array than in PR array when original antenna element used
  - Current uniformity in PR array much improved when new antenna element used



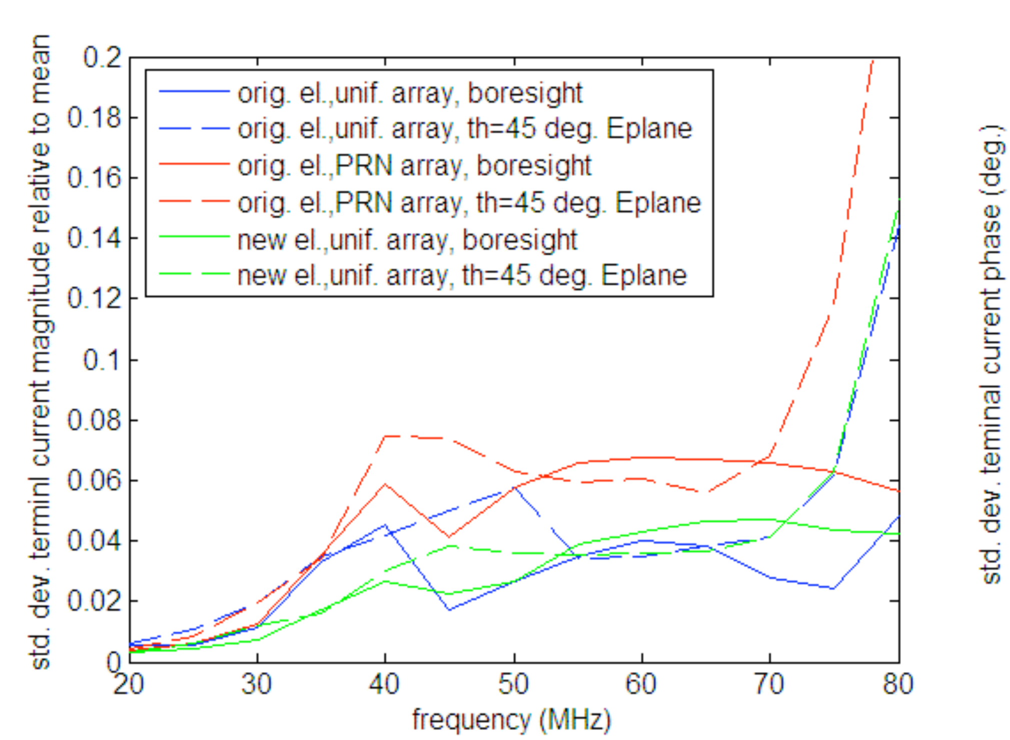
Current magnitude at each antenna



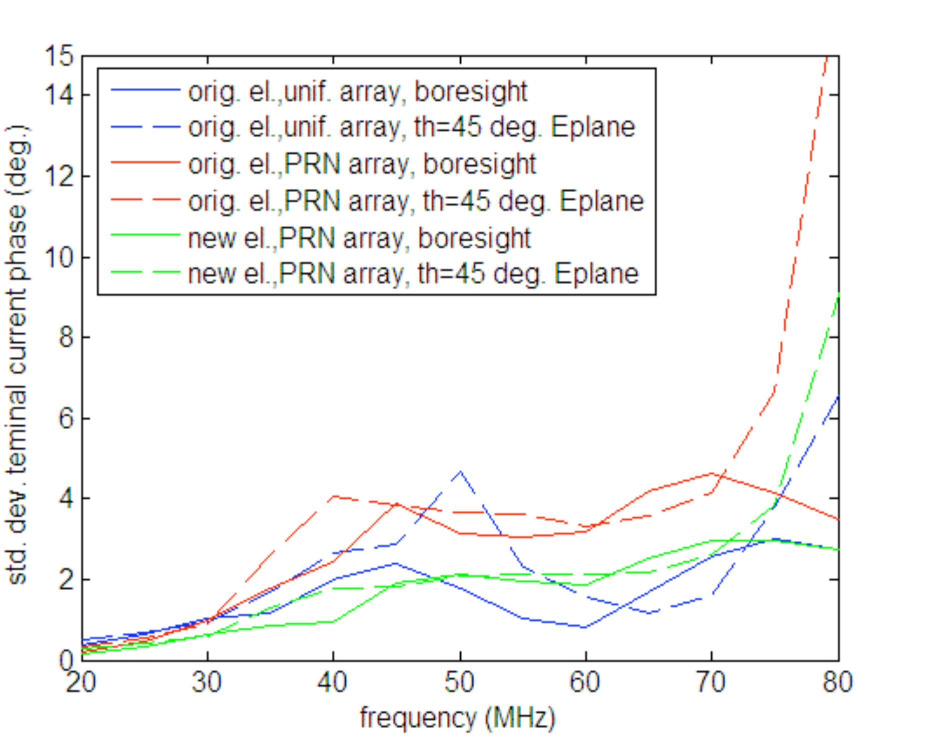
Current phase at each antenna

Mutual Coupling Effects in Large Phased Arrays of Wire Inverted-V Dipoles, cont'd

- Calculate standard deviation over all antennas of current magnitude and phase for multiple frequencies and incidence angles
  - With original dipole design, the uniform array exhibits much better terminal current uniformity (by a factor of up to 2) than the PR array over most frequencies and pointing directions
  - The performance of the same PR array is greatly improved (by a factor of over 2 in some cases) over all frequencies and pointing directions with the new, reduced coupling dipole design



Standard deviation of terminal current magnitudes



Standard deviation of terminal current phases

Initial Result for Blade Dipole

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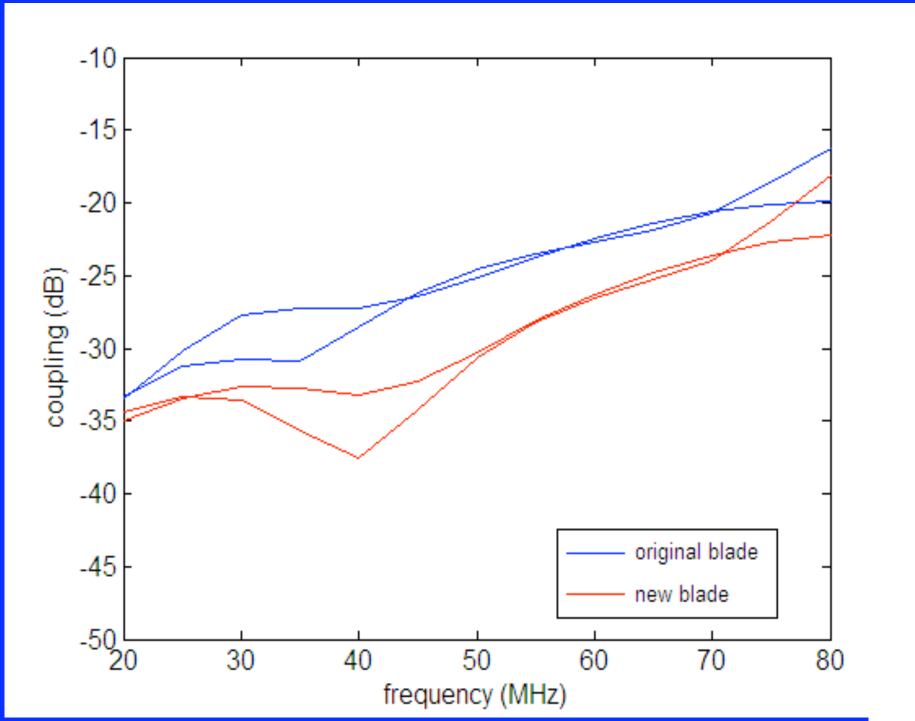
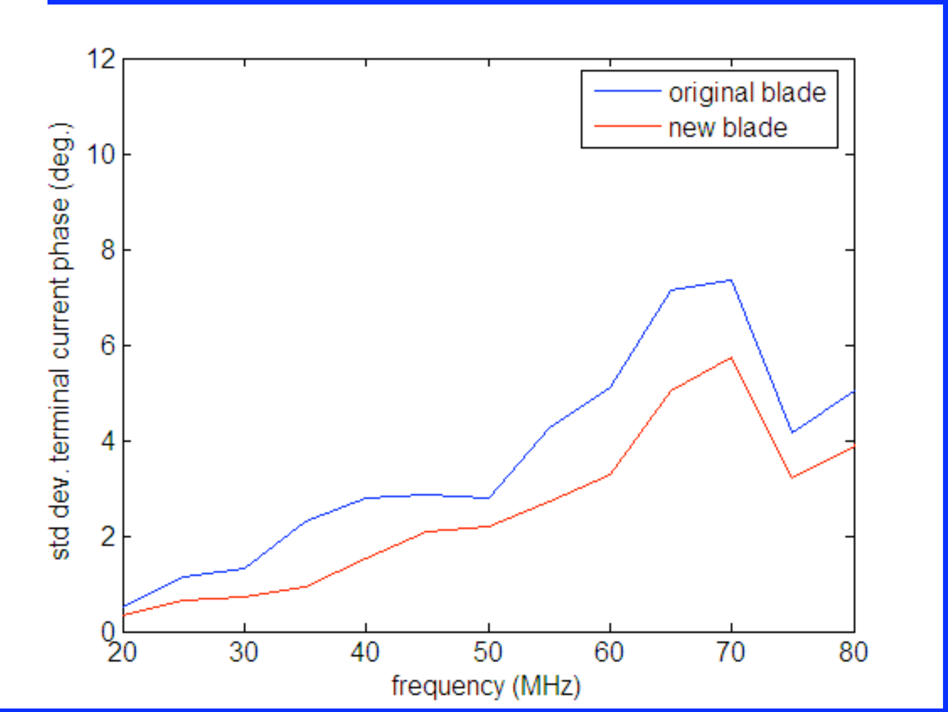
- Start with baseline blade dipole design for LWA (aka "big blade")
- Modify dimensions to reduce mutual coupling between antennas
- Simulate both designs in a 16 element PR array
  - Necessary due to high number of unknowns in antenna model
- Coupling between two antennas is reduced and current uniformity in array is improved over all frequencies, antenna orientations, and incidence angles with the new blade design



Receive coupling for colinear orientation



Standard deviation of terminal current phase over all antennas

Inclusion of Mutual Coupling Effects in Optimization of LWA Antennas

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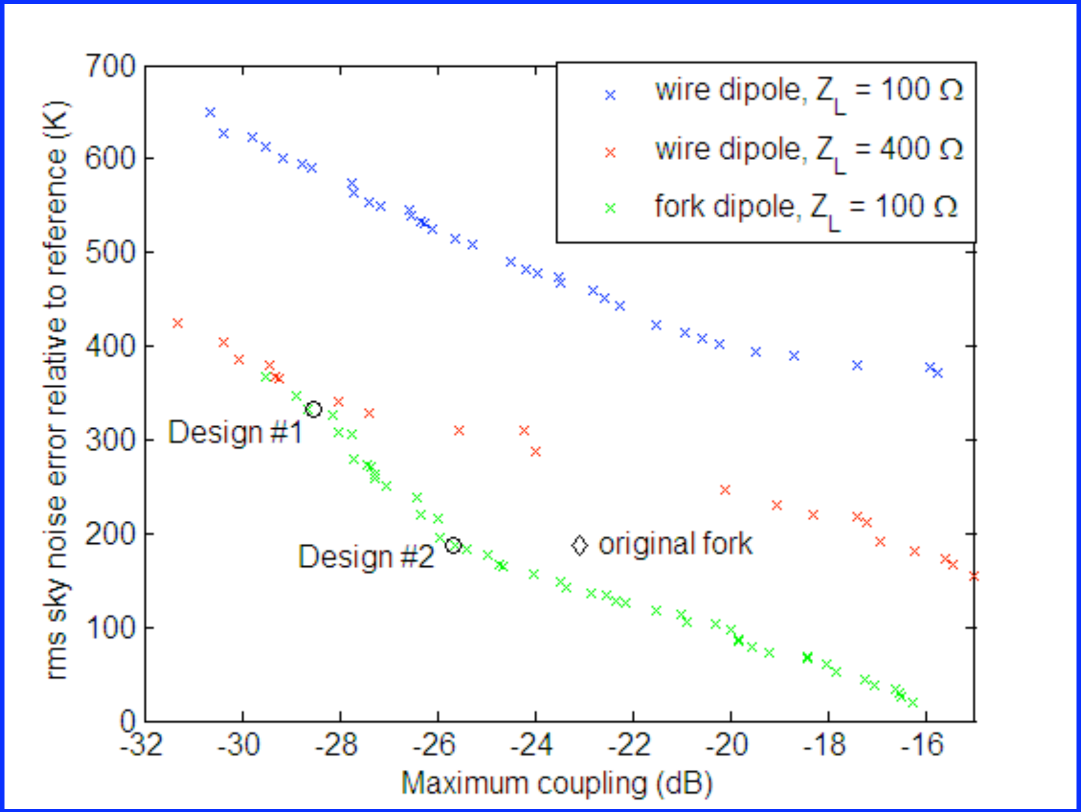
- Apply Pareto Genetic Algorithm (GA) multi-objective optimization to the design of LWA antennas including mutual coupling effects
  - Previously optimized blade dipoles in terms sky noise frequency response and radiation pattern quality [3]
- Initial Pareto GA results
  - Optimize sky noise response and mutual coupling
  - Consider wire inverted-V dipoles and fork dipoles over PEC ground



[3] A. Kerkhoff, H. Ling, *2007 IEEE AP-S Symp.*

Inclusion of Mutual Coupling Effects in Optimization of LWA Antennas, cont'd

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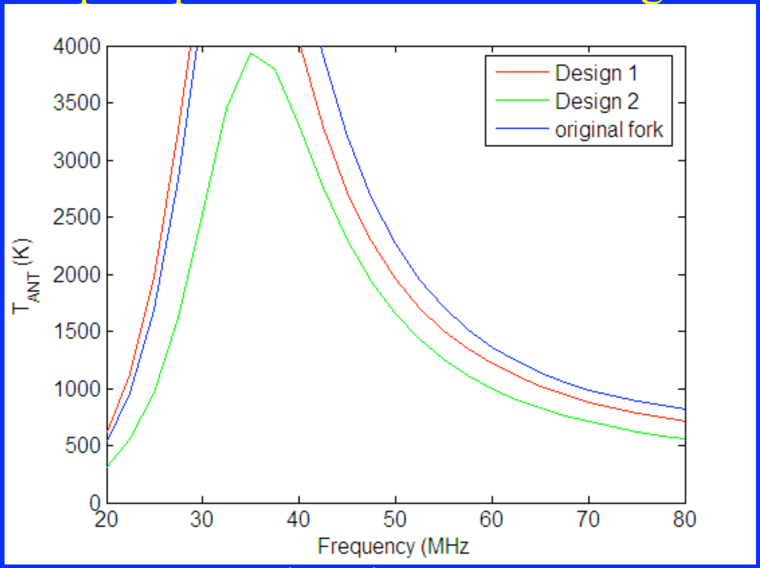
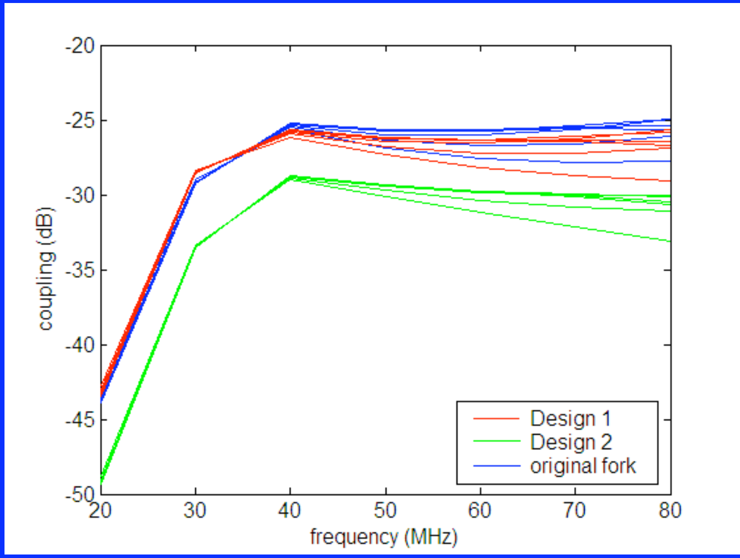
- Compare performance of two designs from final fork dipole Pareto front for d_{ANT} = 4 m

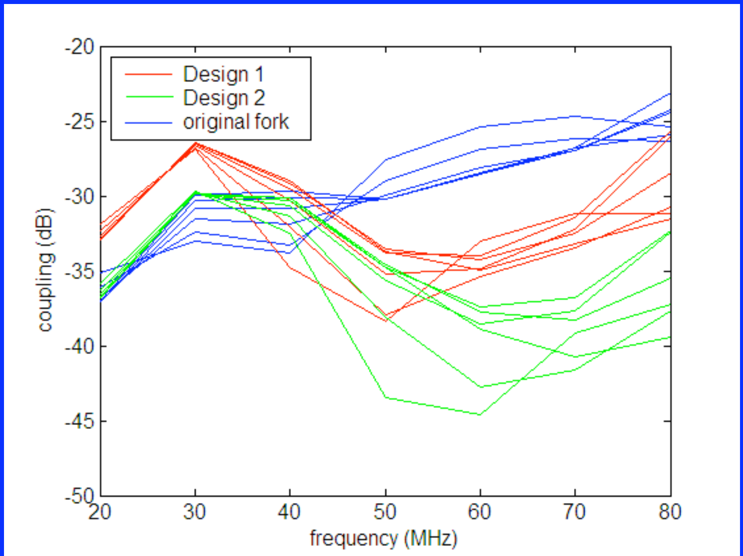


Sky noise response

	Design 1	Design 2	Original
L (m)	1.335	1.138	1.500
β (º)	29.5	38.9	15.0
w_f (m)	0.100	0.10	0.090
α (º)	32.4	24.0	15.0
H_{ANT} (m)	1.250	0.967	1.500
r_{wire} (m)	0.0096	0.0070	0.0095



Receive coupling for parallel orientation



Receive coupling for colinear orientation

Conclusions

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- Demonstrated a relationship between the receive coupling performance of an antenna element and its performance in a phased array
  - This provides an computationally efficient approach to improving the current uniformity of elements in a PR phased array: reduces complexity of array calibration
- Will continue to use Pareto GA to study performance trade-offs for different LWA antenna candidates
  - Wire, fork, and blade-like dipoles
  - Study effects of element separation distance on performance trade-offs; could lead to improved guidelines for station layout design
  - Include radiation pattern quality as third objective
- Important to perform measurements to validate simulation results
  - Ideally want to measure terminal currents in large array (100's of elements) with a few different element designs to verify mutual coupling trends shown here
  - Measurements with a much smaller array (16 to 32 elements) may be sufficient to verify accuracy of simulation
  - Use some combination of LWDA / RTA for this purpose?
  - Use a size-scaled (down) version of the array to simplify measurements?

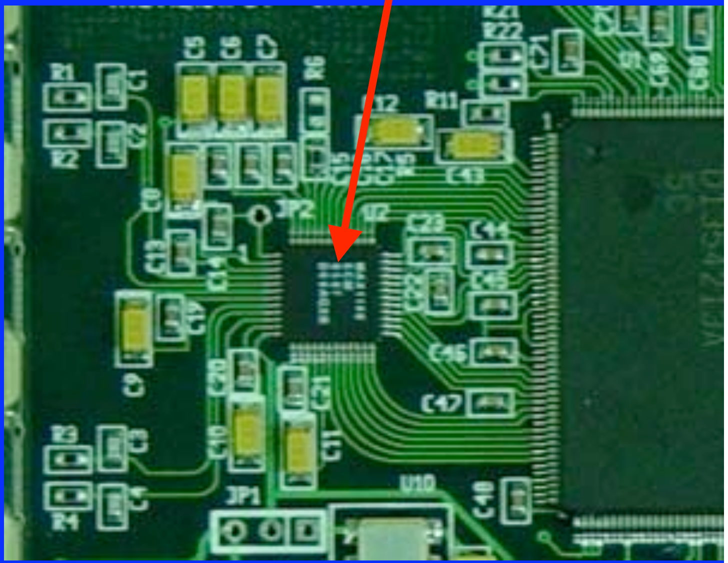
ADC Survey

Outline

- Analog-to-Digital Converter Introduction
- Market Survey Results
- Pareto Analysis
- Candidate Downselection

Analog-to-Digital Converter Introduction

- What is it?
  - COTS integrated circuit about 1cm square
  - Available from several vendors
- What does it do?
  - Converts the analog signal from the antenna into a digital stream of bits suitable for processing by readily available digital electronics
- Why is it important to LWA?
  - Forms a critical link in the receive chain electronics
  - Bounds key LWA performance metrics:
    - Frequency Coverage
    - RFI tolerance

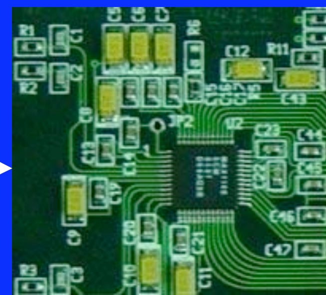


LWDA Receiver

ADC Introduction

Analog Voltage
from Antenna

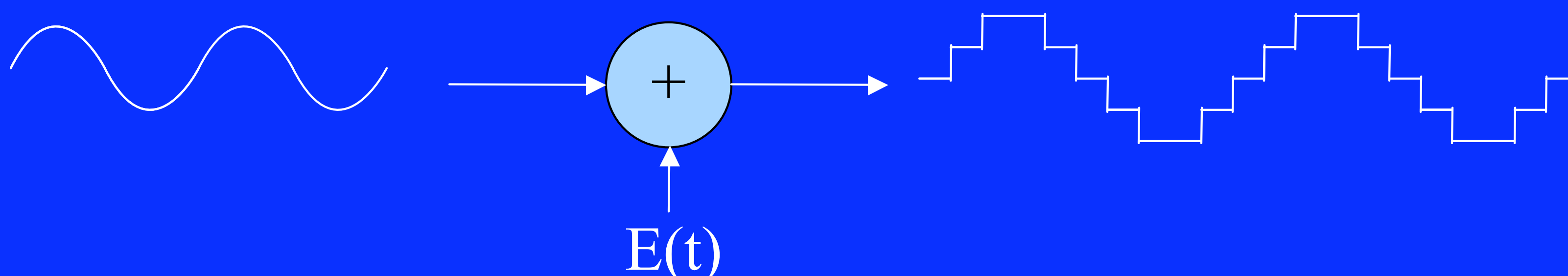
(e.g. 53.215mV)

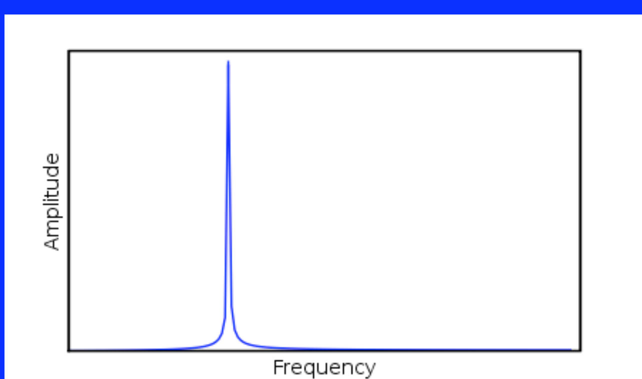


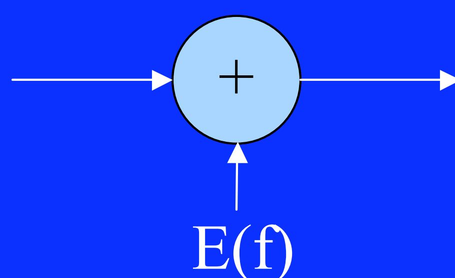
Error Term
(e.g. -0.215mV)

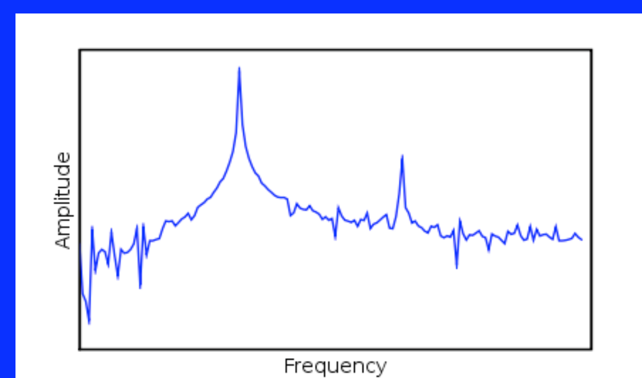
Digital Value
Output

(e.g. 53)









ADC Evaluation Metrics for LWA

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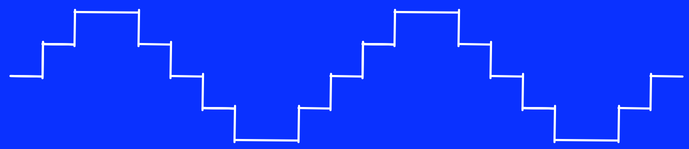
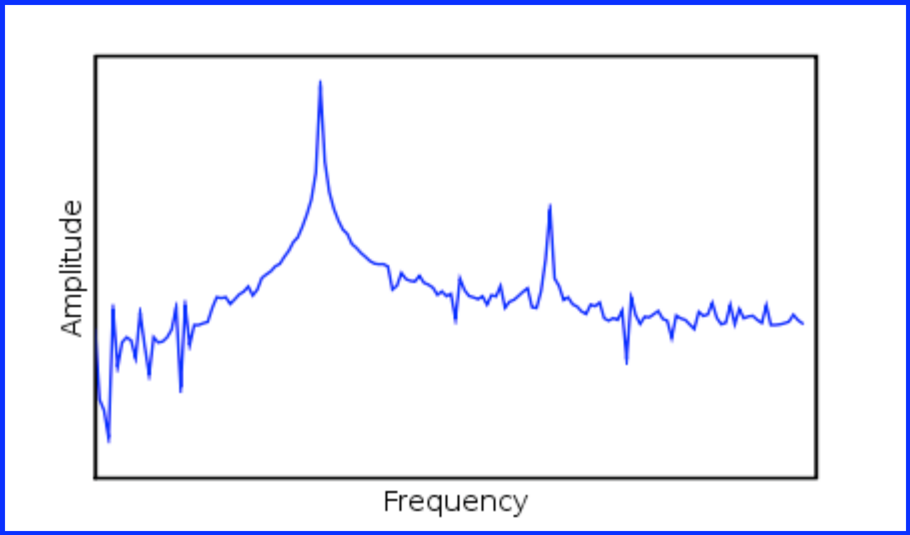
- Cost (per channel)
- Power consumption
- Long-term availability
- Sample Rate
- Number of quantization levels
- Dynamic Performance
  - Signal to Noise Ratio
  - Spurious Free Dynamic Noise





Market Survey

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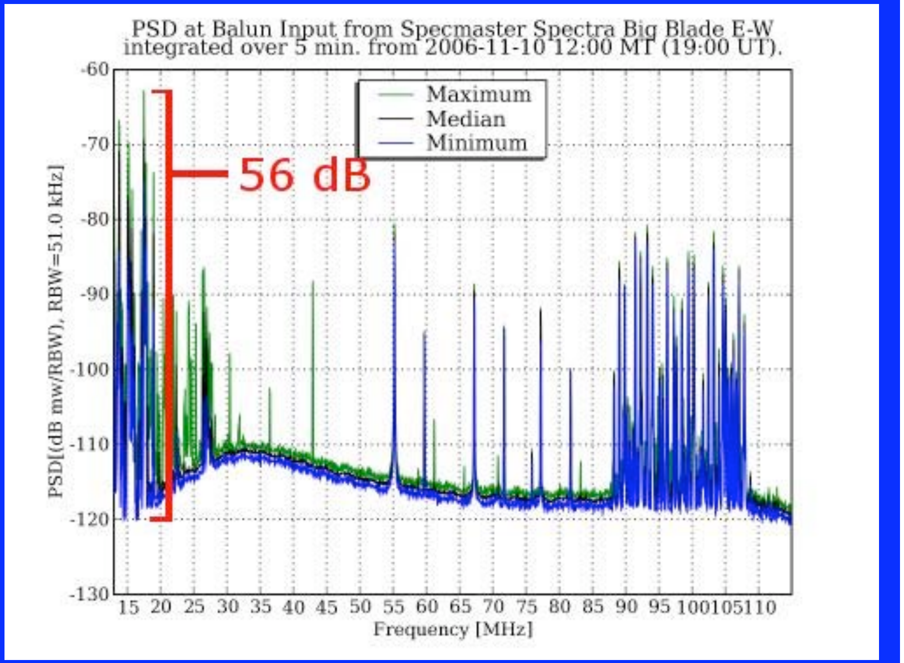
- Goal: Develop a list of suitable ADCs
- Requirements Flowdown
  - LWA will operate over 20-80 Mhz => Sample rate 200 MSPS or greater
  - LWA must operate at the VLA site => Signal to noise ratio 47 dB or greater (thank you to the SpecMaster folks!)
- Gather metrics for each candidate
  - Power, cost, performance, etc
  - ~25 metrics gathered for each ADC



Initial Candidate Summary

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- Vendors with ADCs meeting requirements
  - Analog Devices,
  - e2v,
  - Maxim IC,
  - Linear Technologies,
  - Texas Instruments,
  - National Semiconductor
- 45 devices were examined
  - Sample rate >= 200 MSPS,
  - SNR >= 45 dB,
  - SFDR >= 60dB.

MSPS	8-Bit	10-Bit	12-Bit
200	45	32	20
210	41	31	20
250	28	18	10
300	16	9	4

Vendor	Number
Analog Devices	11
e2v	9
Maxim IC	4
Linear Technologies	11
Texas Instruments	2
National Semiconductor	8

Pareto Domination Analysis

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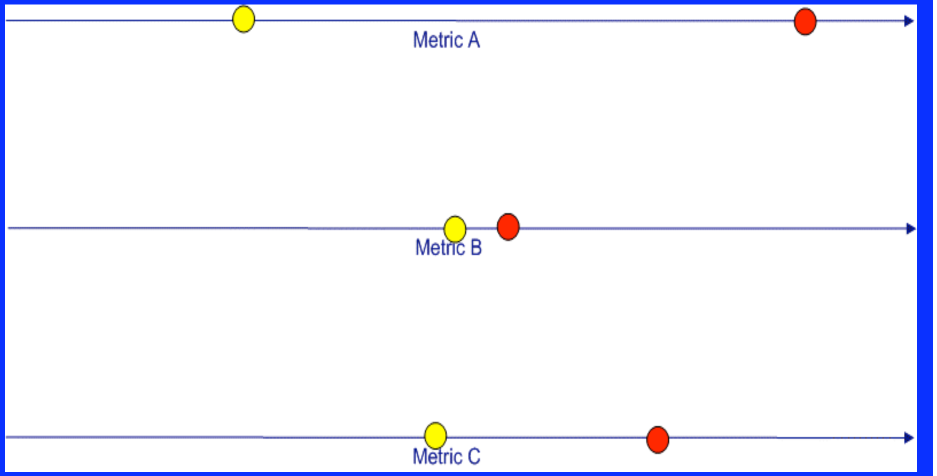
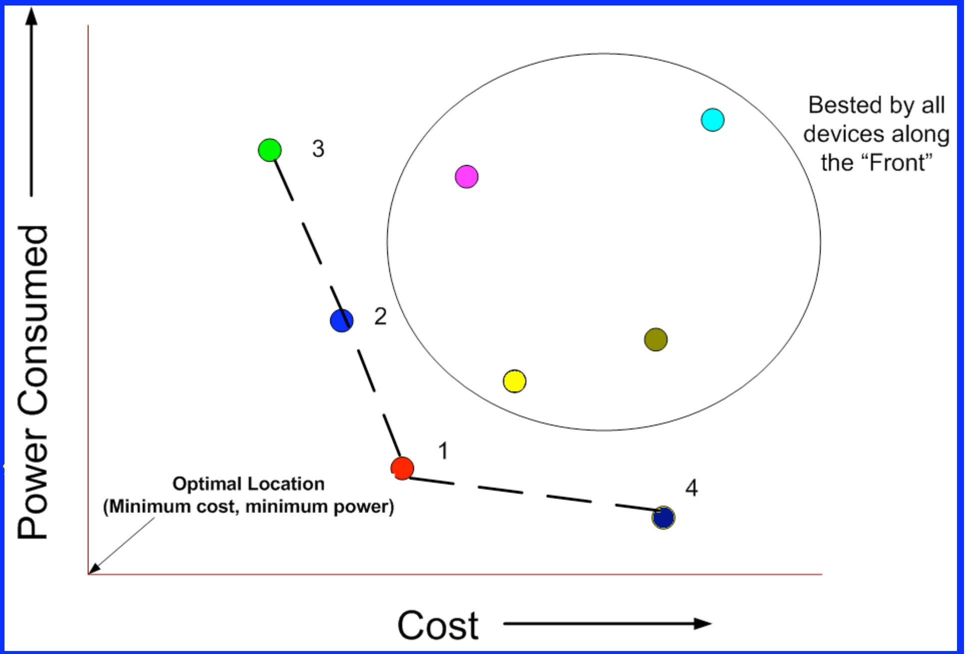
- Purpose
  - Expose tradeoffs using the candidates' performance across many metrics
- Method
  - One dimensional ranking for all devices on each metric
  - Look at 2-D "scatterplot" orthogonal projections of the n-dimensional metric space
    - Expose dependent-relationships
    - Expose trade-offs
  - Pareto Domination analysis:
    - Eliminate any device A which is outscored by device B across all metrics
  - Select candidates along the Pareto "frontier"





SNR vs Price per Channel

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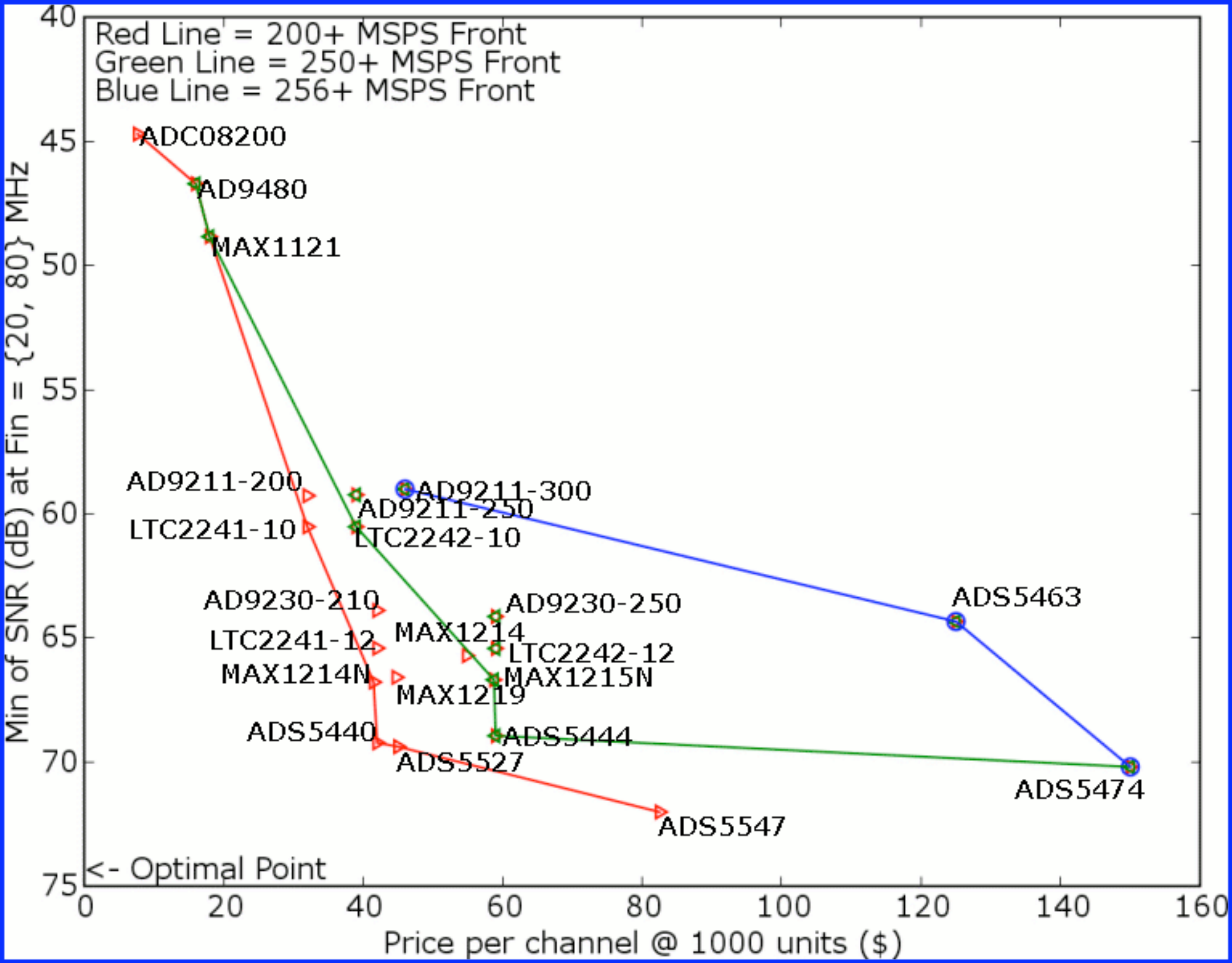

Selection Strategies

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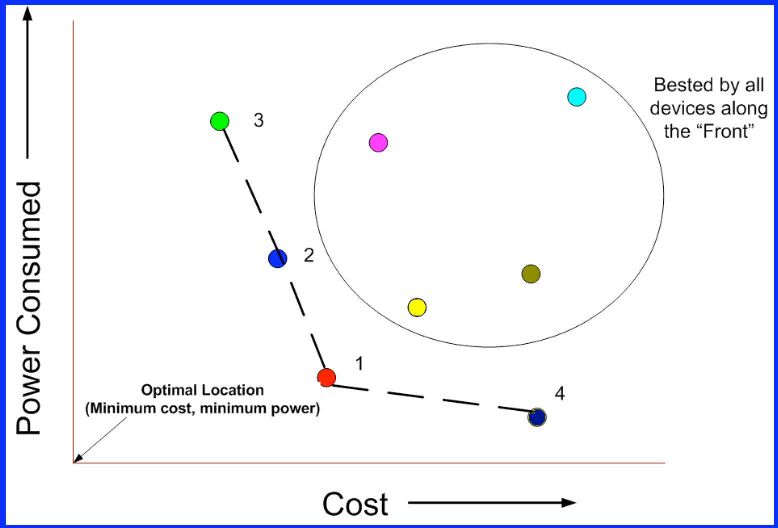
- Pick at the extreme of the Patero frontier
  - Yields the best candidates for the selected metric
  - Suitable if one metric is known to be much more important than another
- Pick near the "knee" of the Pareto frontier
  - Yields candidates that are individually "well-rounded"
  - Suitable if relative importance of metrics are unknown, and little additional knowledge is expected
- Pick candidates spread across the Pareto frontier
  - Yields a diverse field of candidates that as a group are "well-rounded"
  - Suitable if relative importance of metrics are unknown, and more knowledge is potentially expected
  - Powerful risk-mitigation technique



Final Results of Pareto Analysis

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- Five ADCs stood out as being on the Pareto frontier on four important 2-D projections for their sample rate
  - AD9211-300
  - MAX1215N
  - ADC08200
  - ADS5463
  - ADS5474
- These five ADCs have been recommended for further evaluation
- May need to be revisited as requirements are better defined

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The LWA Shelter

Why work on this now?

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- LWDA Lesson
  - Early location of infrastructure and shelter will stimulate work at the site!
- Resolve Time and Money Questions
  - Production Lead times
    - 4 months?
    - Vendor bid process lead time, 4 weeks?
    - Unknown times need to be pinned down.
  - Unknown costs
    - Cost target $35-50K (LWA pile of parts memo)
    - What will this buy us vs. what we need?
    - Need to get realistic cost estimates to allow us to make informed tradeoffs.
  - Vendors
    - Who are the vendors we want to bid on this?

Modified Shipping Container Option

- ISO standard containers
  - *ISO 668-1995 Series 1 freight containers -- Classification, dimensions and ratings*
  - *ISO 1161-1984 Series1 freight containers -- Corners fittings, specifications*
- Vendors exist who modify to customer spec.
  - Standard options
- Initial goal
  - Get the vendors to talk to us

20 ft by 8t Shelter

Basics

- Must provide
  - Weatherproofing
  - Power Distribution
  - Air Conditioning
  - RF Shielding
  - Easy access to rack, electronics and cabling
  - Work Area
  - Other
    - Safety Hardware
    - Access
    - Foundations & Mounting
    - Signal Entry Panel

- Initial Questions
  - How big?
  - How much power?
  - How much AC?
  - How much shielding?
  - Layout?

Shelter Size Estimate

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- Think in terms of rack space required
  - Number of racks ARx (512) - 2 - 3
  - Number of racks power supplies – 1
  - Number of racks beamformer, DRx, Data Capture – 1 per set, say 3 total
  - Computers, UPS, GPS, networking – 1
  - Total ~ 8 racks
- Total linear dimension ~ 20 ft
  - 24” wide rack
  - 2ft each end work space
- Total width: rack + clearance ~ 8 ft
- Tight fit in a 20ft shelter
  - What about work space?
  - Air flow for AC

LWA 1+ (Crude) Power & AC Estimates

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- Scale up LWDA power requirements (memo # 69)
  - Total power of about 13kW independent of AC
  - Total power of about 16.5kW with AC
  - Need to establish a final value before procurement of shelter
  - A 120 V/200A service looks sufficient
- AC must remove heat from electronics
  - Must remove about 13kW
  - One ton AC removes about 3.5kW (at a 13 SEER efficiency)
  - AC needs ~ 13/3.5 ~ 4 tons
  - Open question
    - Do we need a plenum to route AC to electronics

Where are we now?

- Developed
  - Estimates on shelter requirements
  - Initial vendor list for modified containers
  - Initial specification for review
  - Continue to update these
- Initial WBS prepared
  - Production time is a significant unknown
  - Does not include electronics/rack integration
- Initial drawings in preparation
  - Provided to vendor with specification
    - Layout
    - Power distribution
    - Patch panels
    - Lighting

Plans & Issues

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Plans

- Gather more information from vendors
  - Get cost estimates from specification
  - Determine cost drivers from estimates
  - Determine current lead times
- Refine specification as design progresses

Issues

- Is 20' big enough?
- RF shielding requirements?
  - What steps should be take for shielding?
- Arrangement of SEPs?
  - More than one panel likely
- Site Installation
  - These are heavy
  - Crane/forklift required?
  - Foundations

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GPS Receivers

Application of GPS In LWA1+?

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- What do we need GPS for?
  - Precise timing (single station)
  - Coincident TEC measurements
- Requirements for a GPS Receiver?
  - If we want TEC => must be dual frequency receiver with access to raw data.
  - Provide single station precise timing
    - 1 pulse per second.
    - At least one 10 MHz sine wave.
    - Ability synch computers to GPS time
      - NMEA
      - NTP
  - 12 channels.
  - Single station timing requirements
    - Stability ~ $3 * 10^{-9}$ over eight hours
  - Networked device.

Some Products Available

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- Dual frequencies is the most difficult condition to meet
  - Septentrio
    - PolaRxTR which is a dual frequency (codeless) timing receiver
      - Accepts an external 10MHz, no oscillator options
  - Symmetricom, Spectracom
    - Dual frequency, but only SAASM based devices
- Single Frequency (L1 C/A) timing receivers are easier
  - Symmetricom
    - XLi model - single 1 pps, IRIG B, 10MHz add-on, NTP, upgradeable
    - 4411A – four 1 pps, four 10 MHz, IRIG B
  - Spectracom
    - Model 9383 – single 1 pps, single 10 Mhz, NTP, upgradeable
  - CNS Systems (aimed at VLBI market)
    - CNS Clock II – single 1 pps, single 10 MHz, IRIG B (option), NTP (option)
    - Windows software

Product Comparison & Pricing

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- Rough costs including
  - Base unit
  - OCXO upgrade
  - Antenna & cable

Manufacturer	**Model**	**~Cost ($)**
Symmetricom		
	Xli	4875
	4411A	4400
Spectracom		
	9383	5190
CNS		
	Clock II	2395

Applied Research Laboratories
The University of Texas at Austin

Ionospheric Measurements from Low Frequency Radio Telescopes

Thomas L. Gaussiran II, David C. Munton, Michael H. Montgomery, Roy S. Calfas
The Applied Research Laboratories,
The University of Texas at Austin
Aaron Cohen
Naval Research Laboratory

Motivation

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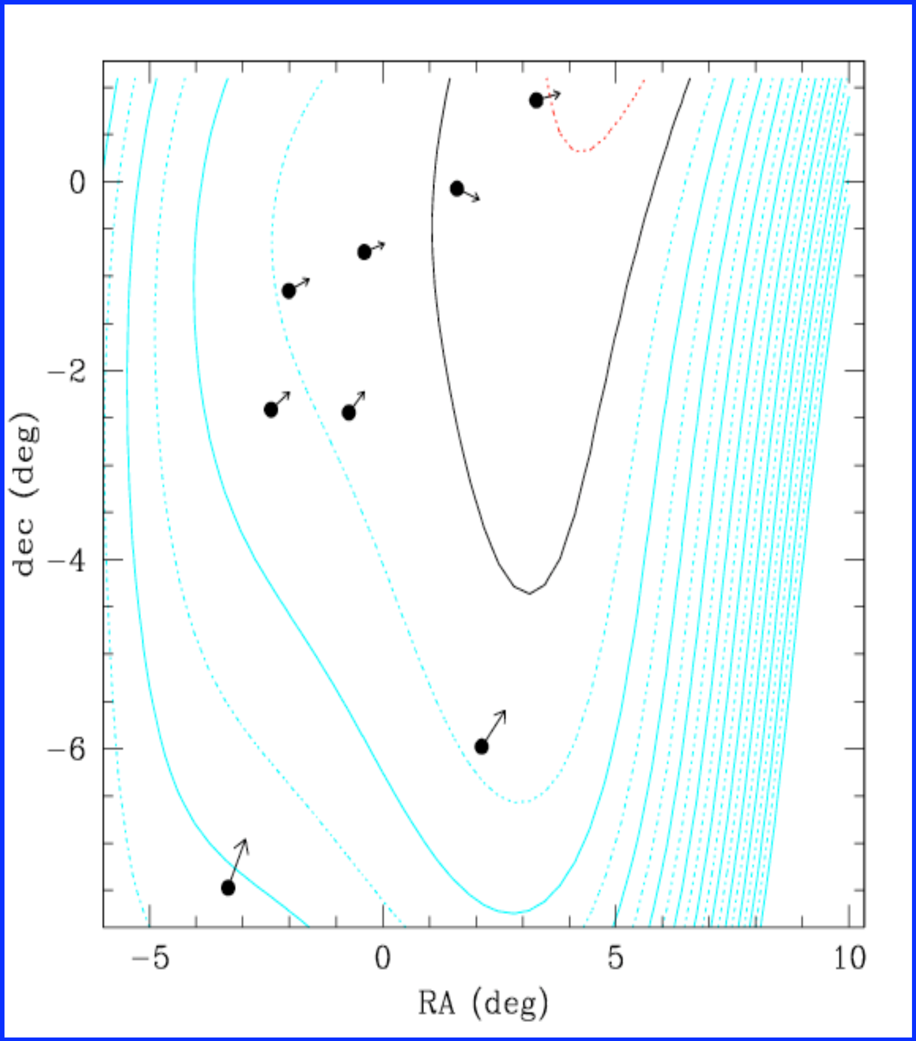
- Understand the interplay between
  - Ionosphere
  - Low frequency radio telescope observations
- Ionosphere causes apparent motion of sources in the sky
  - Similar to optical twinkle
  - At best, this blurs the image
  - At worst, calibration is impossible



Questions to be investigated

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Usefulness of radio telescopes to ionospheric science

- How well do ionospheric reconstructions made using traditional sensors (e.g. GPS) compare with measurements made with a low frequency radio telescope (spec. VLSS)?
- Using two different types of measurements can we show that a model of the ionosphere matches all of the measurements?

Usefulness of ionospheric science to radio telescopes

- Could ionospheric measurements with 'traditional' sensors be utilized to help to calibrate a low frequency radio telescope to allow for a boot-strap method?

Very Large Sky Survey (VLSS)

- Conducted by the NRL using the 74 MHz system at the VLA
  - Data was collected for ~ 3 months in 2003, primarily at night (but not all)
  - As part of the calibration process, each observed source was matched with a 'true' position as determined from a high frequency sky survey
  - Additional instrument calibration provided by focusing on Cygnus A for each observation period
- Each source at each integration period yielded a corrected position available as either a ΔRA/ΔDec or ΔEl/ΔAz
- In October 2003 there were ~ 20K such sources

Approach to Simulation

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- Collect traditional measurements
  - GPS TEC
  - GPS Occultation
  - OSEC
- Reconstruct an ionosphere via IDA3D utilizing measurements
- Ray trace through reconstructed ionosphere to a series of true positions of many targets
  - Launch rays at 2 GHz and 74 MHz
    - 2 GHz assumed "undeviated" path
  - Extract Δelev and Δaz

Ionospheric Data Assimilation in 3D (IDA3D)

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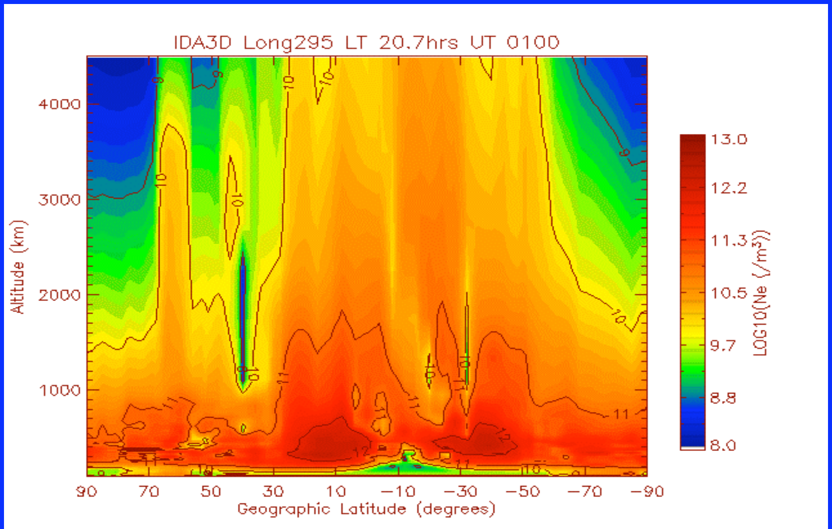
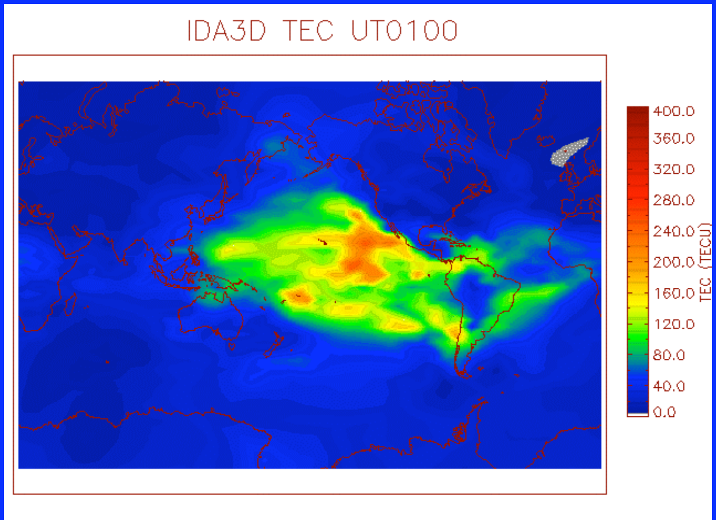
- Data assimilative model developed at ARL:UT
- Objectives
  - Prior based on realistic physics
  - True 3D geometry
  - Formal estimates of accuracy of solution
  - Use previous time history of solutions in prior
- Solution: Kalman filter, statistical minimization
  - Based on 3DVAR method from atmospheric data assimilation (Daley,1991,2000), or discrete inverse theory (Menke,1989)
  - Covariances either derived or estimated from measurements
  - Optimal solution if covariances are exact
- Data Types
  - GPS - Ground, Occultation, OSEC
  - CIT
  - *In-situ*
  - Ionosonde





Movement of Objects

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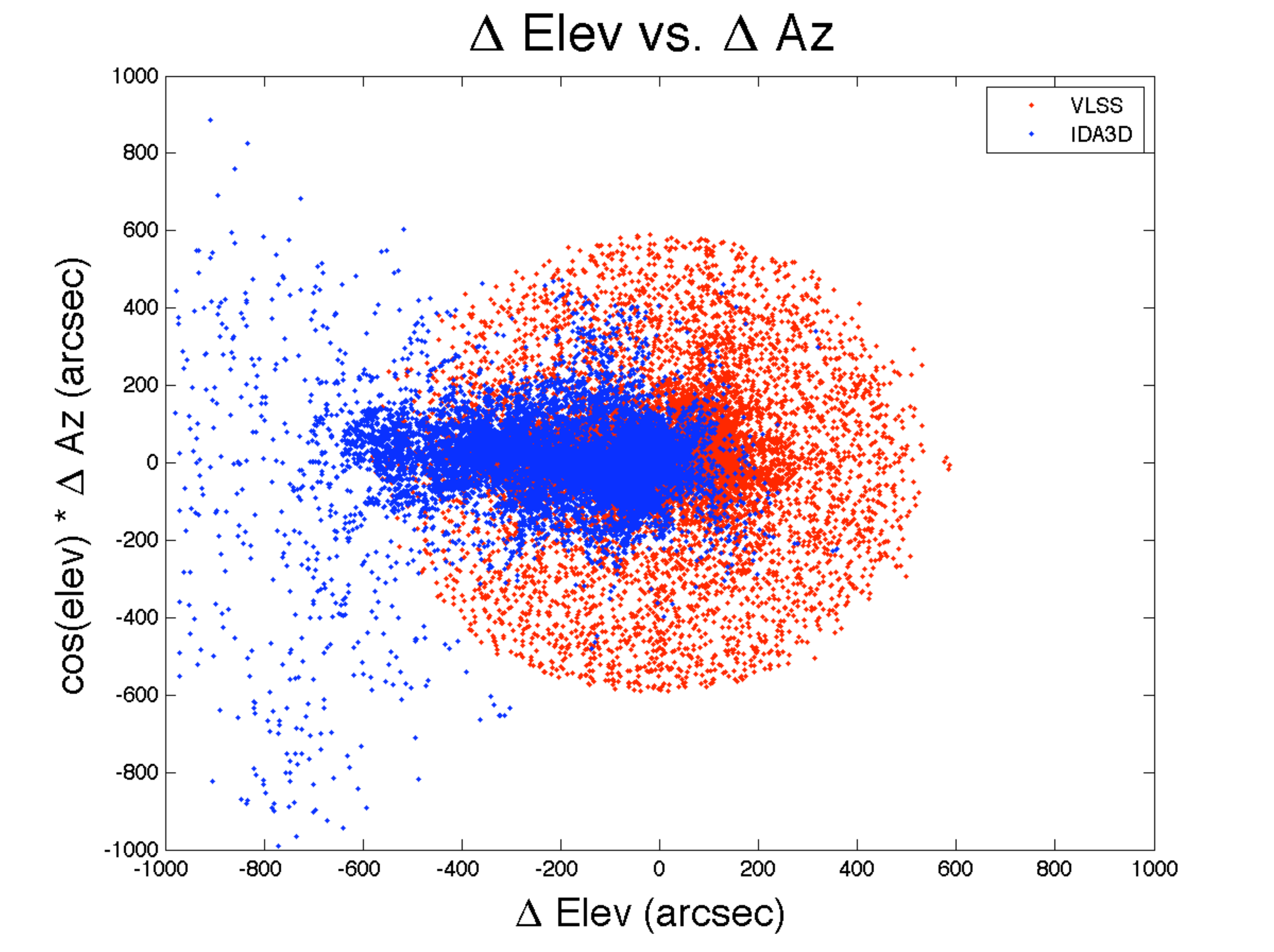

Elevation Dependence

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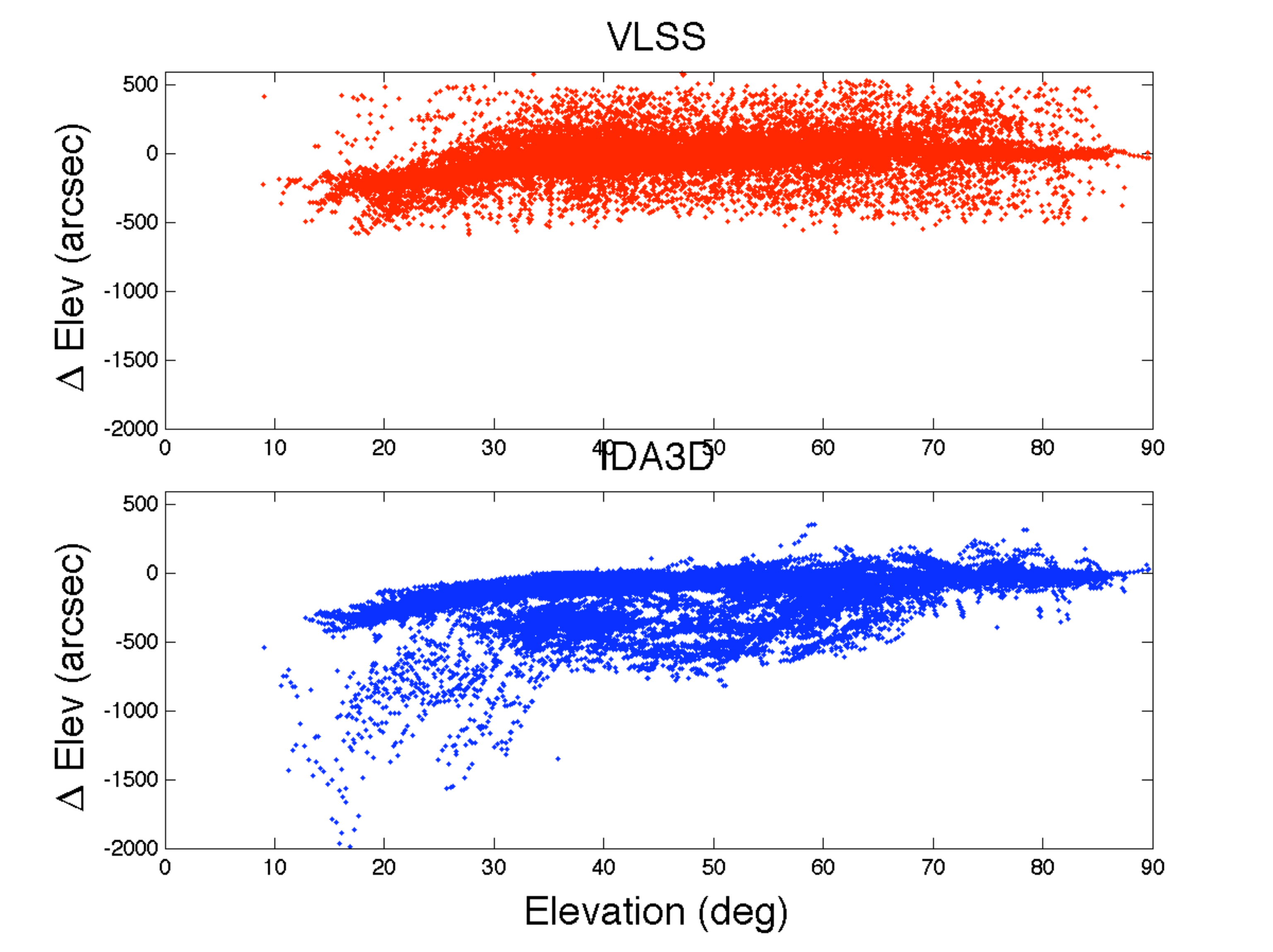
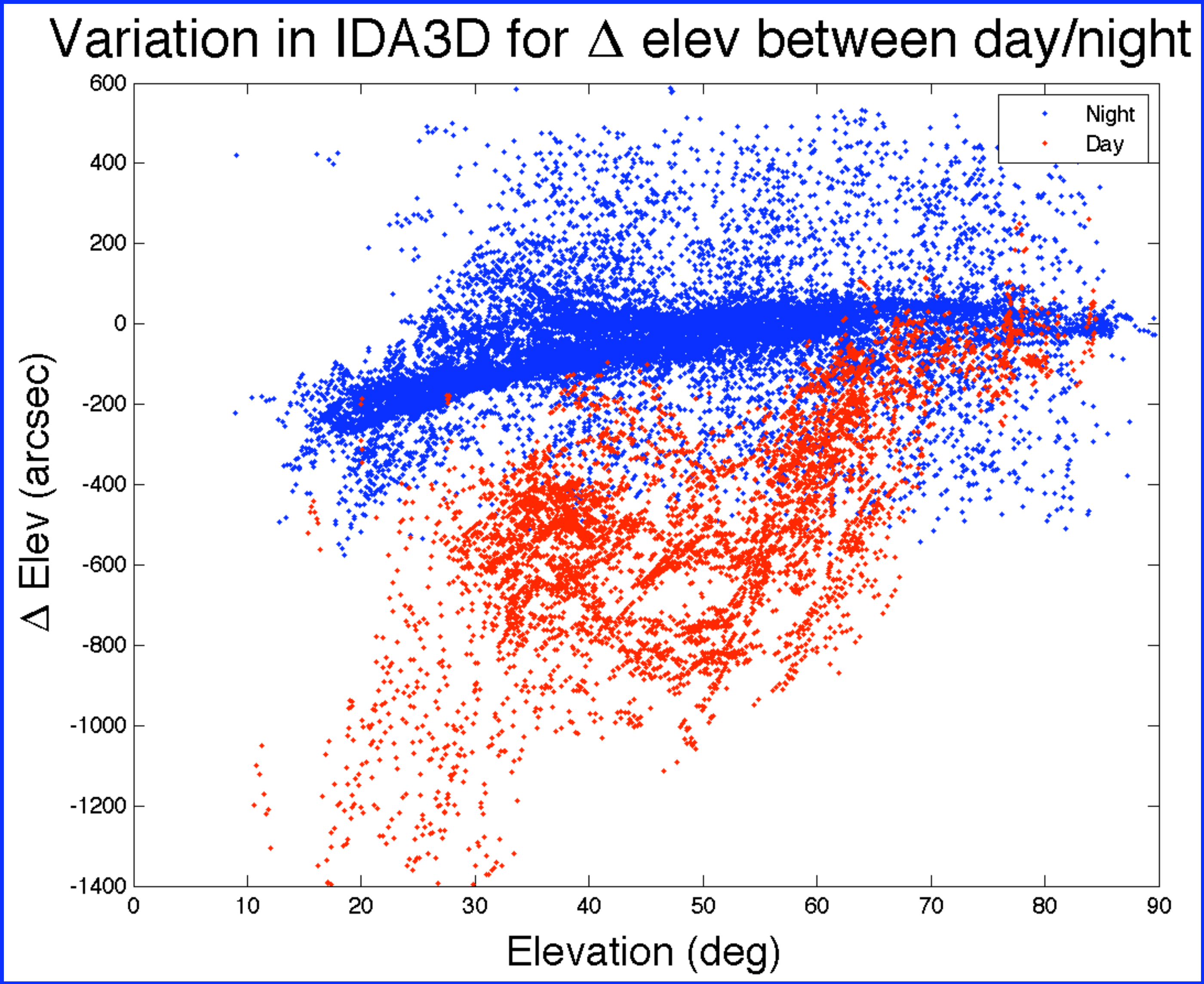


IDA3D Day/Night Dependence



Compare data

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Given these data sets we can calculate the angular distance of each source from its true position:

$$\Delta\alpha^2 = \Delta el^2 + (\cos(el) \cdot \Delta az)^2$$

Where for the raytraced data this means:

$$\Delta el = el_{2000} - el_{74}$$

$$\Delta az = az_{2000} - az_{74}$$

Angular Distance Day/Night

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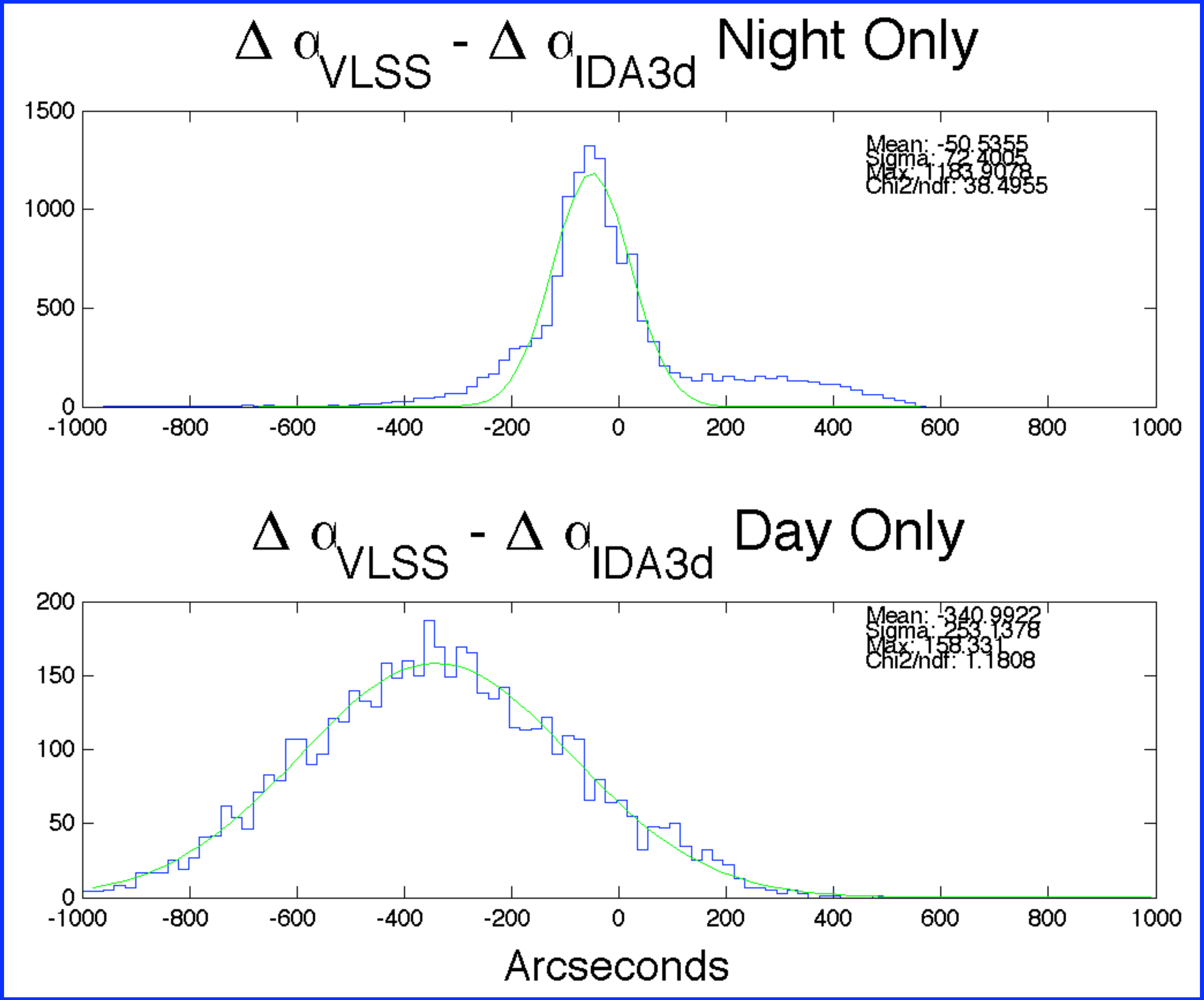

Answers to questions

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- VLSS implies that IDA3D may be slightly overestimating electron density, possibly by having correlation lengths which are too long
- Agreement between IDA3D and VLSS measurements
  - IDA3D analyses provide agreement with VLSS data to within a σ of 70”
  - Implies that LWA and other low frequency telescopes could be used as a new ionospheric probe. Especially useful for small scale investigations.
  - Good agreement between two very different methods of sensing the ionosphere
- Also indicates that if we need ionosphere to allow for boot-strap calibration of telescope it might be possible
  - Improves miss from 100’s arcsec (even more if we consider Cygnus A calibration) to 70 arcsec
  - Includes overall bias which is not handled via traditional calibration techniques
  - IDA3D results show promise in providing “bulk level” calibration

Further Analysis

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- Need to remove overall bias introduced by VLSS reference to Cygnus A
- Need to complete other months of data (5x more data to analyze)
- Look at sensitivity of IDA3D results based on correlation lengths
- Investigate possibility of extraction of small scale structure information from VLSS data

Status of NRL Technical Work

Paul S. Ray & Aaron Cohen (presenting)

Naval Research Laboratory

NRL Contributors

- Paul Ray
  - NRL System Engineer; Science
- Dan Wood (Praxis)
  - Software engineering
- Kurt Weiler
  - Project Management
- Ken Stewart
  - HAARP experiments; Antennas
- Henrique Schmitt (Interferometrics)
  - LWDA analysis; Science
- Emil Polisensky
  - UMD Grad Student; Configuration studies; LWA sky model
- Wendy Peters
  - LWDA analysis; RFI excision; VLSS; Science
- Nagini Paravastu (ASEE)
  - Electrical engineering; Antennas; EM simulations; Testing
- Joseph Lazio
  - Transient searches; RFI excision; LWDA analysis; Science
- Namir Kassim
  - Project Scientist
- Brian Hicks
  - Electrical engineering; FEE designs; Prototyping; Antennas; Software
- Ken Dymond
  - Ionospheric research
- Robert Duffin (GMU)
  - GMU Grad Student; Solar monitoring; RFI studies
- Pat Crane
  - LWDA site manager, site selection
- Clayton Coker
  - Ionospheric research
- Aaron Cohen
  - Configuration studies; VLSS; Ionospheric Calibration; Science
- Tracy Clarke (Interferometrics)
  - LWDA analysis; Science requirements; Transient pipeline; Science
- Richard Bevilacqua
  - Executive Committee

NRL Technical Efforts

- NRL has a long-running technical effort that includes LOFAR prototyping efforts (such as the NLTA) and the LWDA
- Recently, work has become more focused on the specific needs of the LWA
- The aspects that will be described here are:
  - Antenna designs
  - Front-end electronics
  - Field testing
  - Software for observing control
  - Sky model
  - Rapid Test Array
  - HAARP experiment
  - Array & station configuration studies
- *Much* is being skipped, including LWDA science exploitation, the NVSS, ionospheric calibration, science analysis, RFI excision, ...

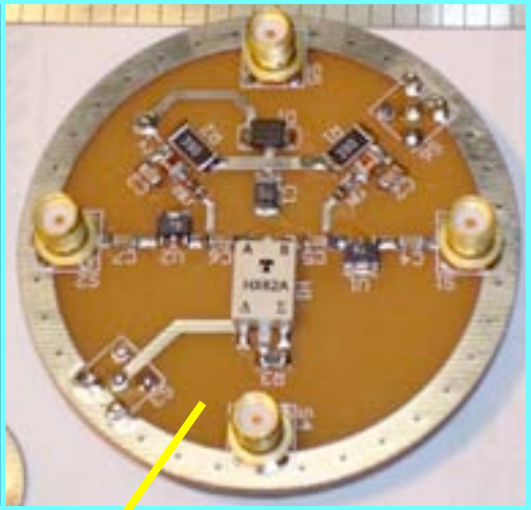
LWA Antenna Requirements

- Broad band to cover 20–80 MHz
- “Drooped” elements for better E-/H- plane beam pattern symmetry
- Cross polarized to form circular polarizations
- Low-noise preamp at feed point designed for sky noise dominated operation
- Survivability in New Mexico desert
- Large quantity at low cost

Baseline Antenna + FEE

LWA Memo #35

- Big Blade antenna design is a scaled-up version of the LWDA antenna
- LWDA balun uses Gali-74 front end amplifiers and Tele-Tech hybrid as a balun
- Performance is quite good, but many engineering issues remained, so we sought to answer them:
  - Mechanical design
  - Cost
  - Lower-noise front end
  - Power supply options
  - Ground screen

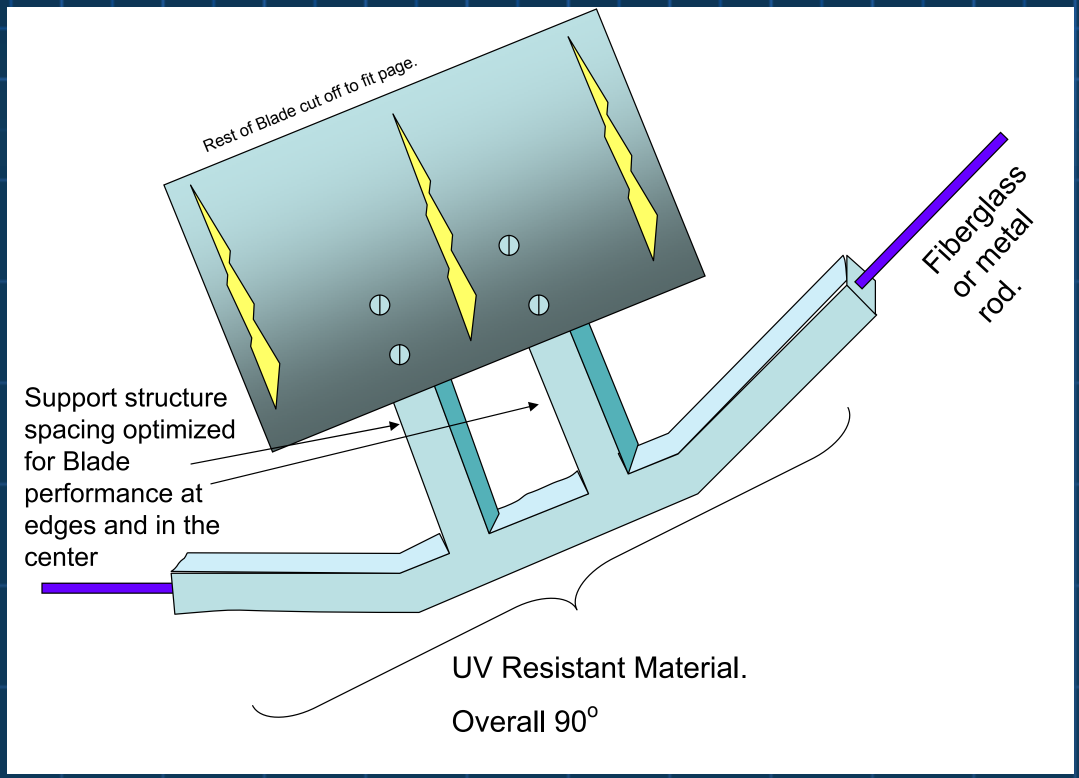


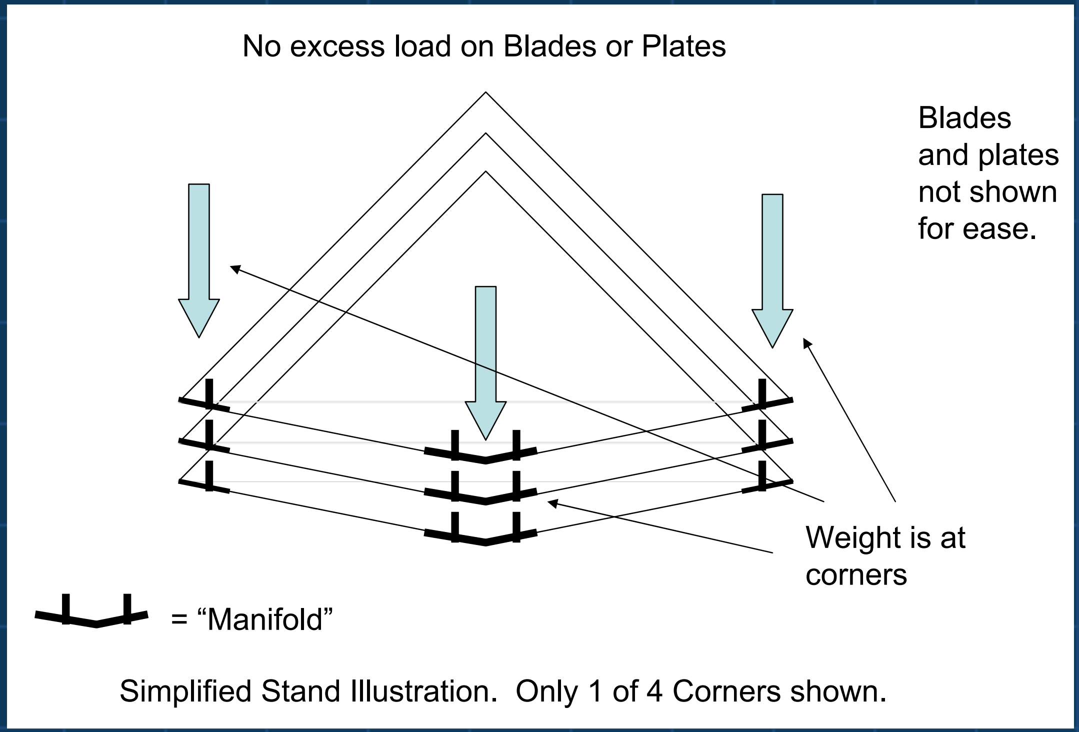
Baseline LWDA Active Balun (Hicks/Tele-Tech)

Baseline Big Blade antenna

Blonder Tongue Design & Quote

- Visited and worked with Blonder Tongue Laboratories in New Jersey to obtain manufacturing quote for baseline Big Blade design
- Their design used 0.125" Al blades with UV-resistent molded UHMW polyethylene to form the pyramidal supports
  - Specific design details are proprietary and were not disclosed
- Price for fully assembled stands was $595/unit and would be shipped on flatbed truck from NJ to NM





Alternate Antenna Designs

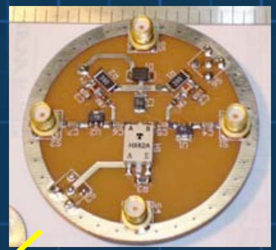
- Wire dipole (LOFAR)
- Blade outline designs (NLTA & Burns)
- MWA bowties
- Fork & Tied Fork

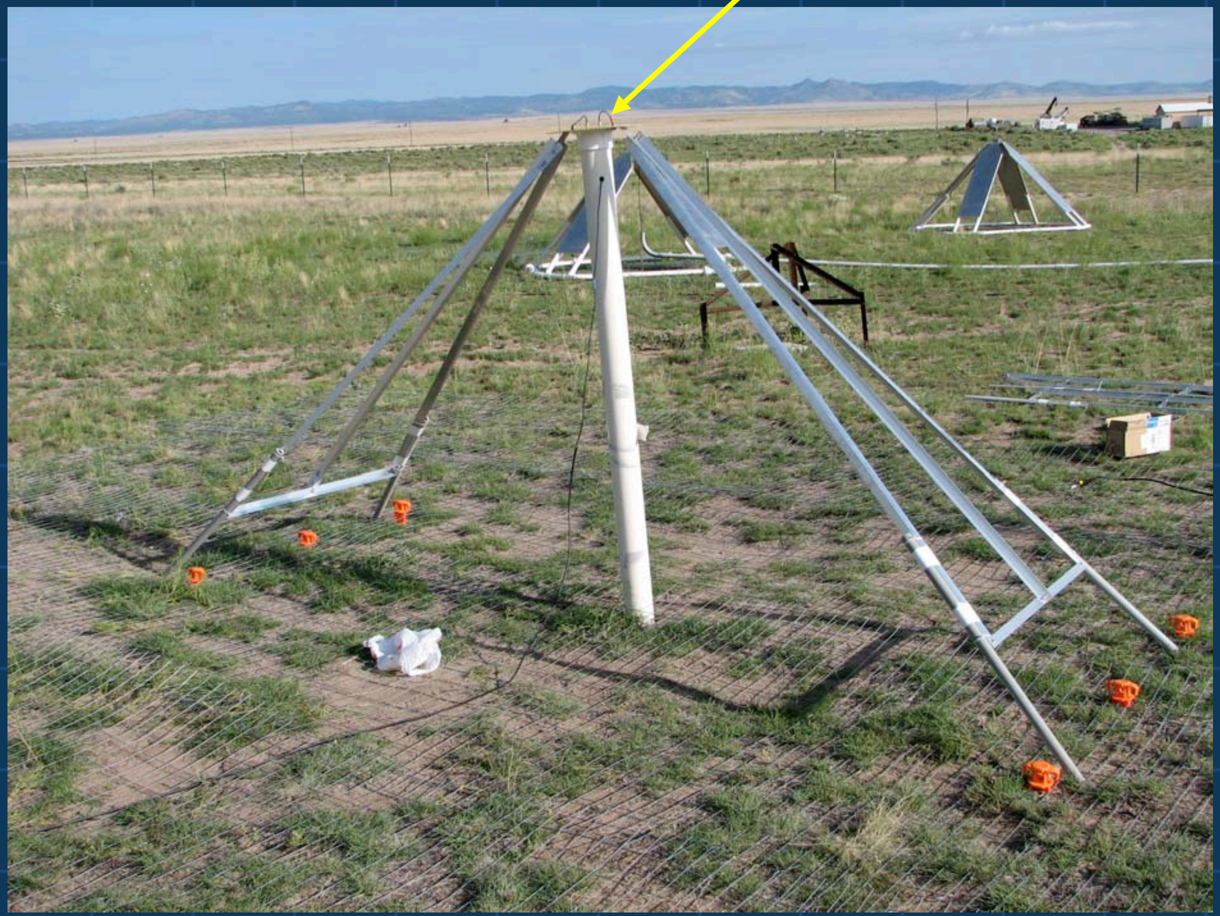
Simulations and field measurements favor Tied Fork as prime alternate to Big Blade, though Big Blade remains “gold standard”

The Tied Fork Antenna

- Sheet aluminum replaced by strips of angled aluminum
- Same low noise preamp
- Less wind loading
- Lower materials cost
- Less intricate support structure
- Lower total cost per antenna

Low noise preamp

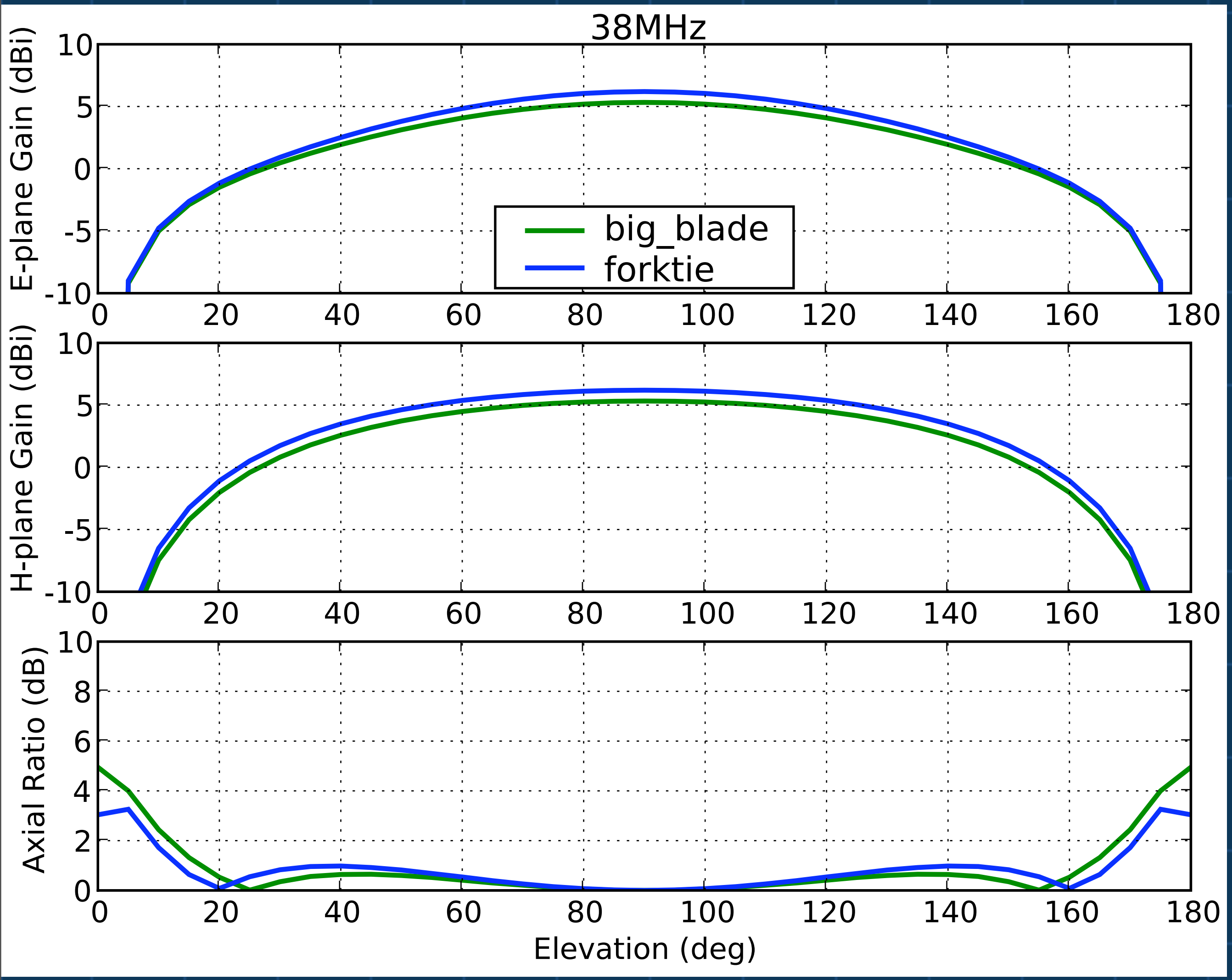


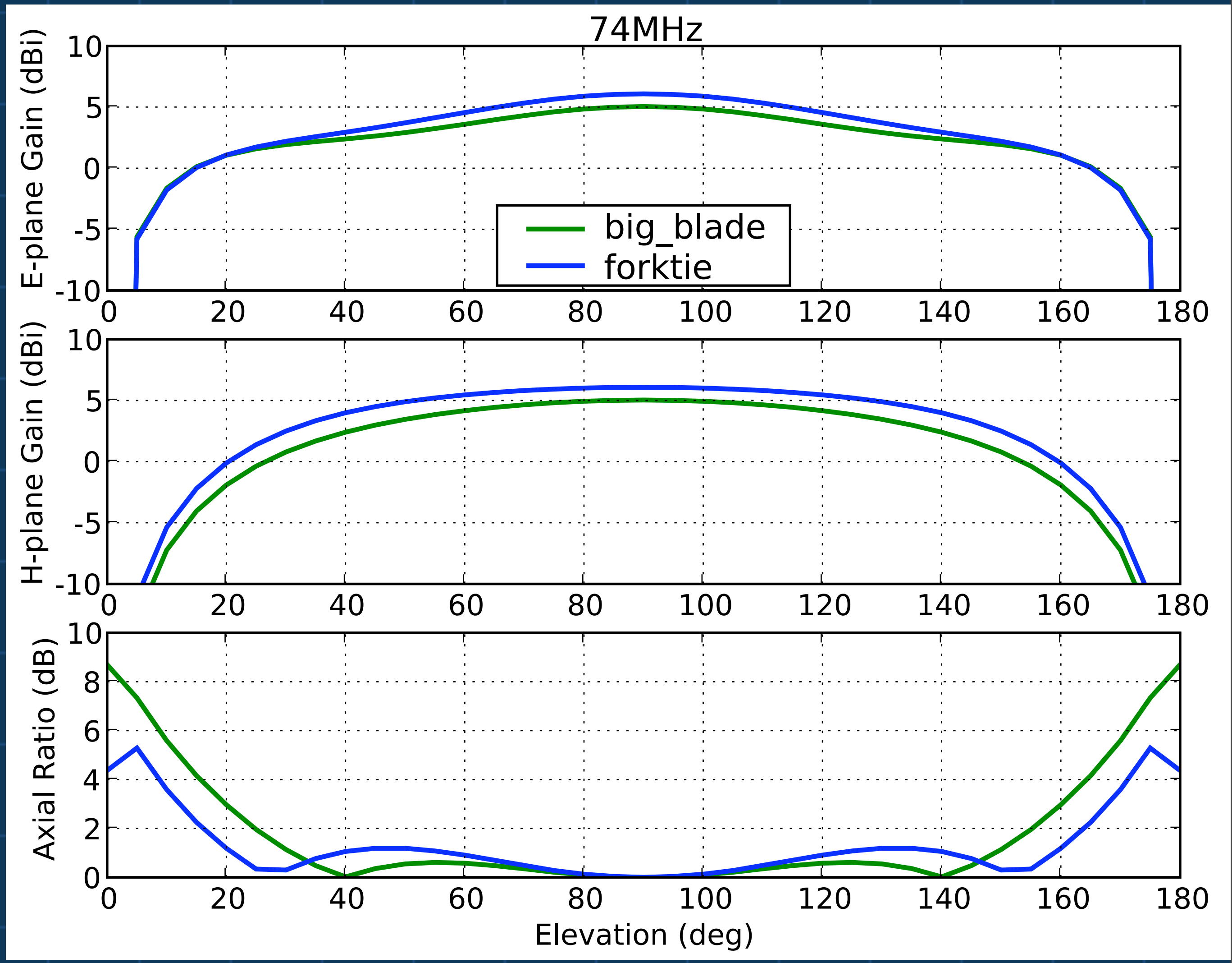


Tied Fork antenna prototype

LWA Memo #88

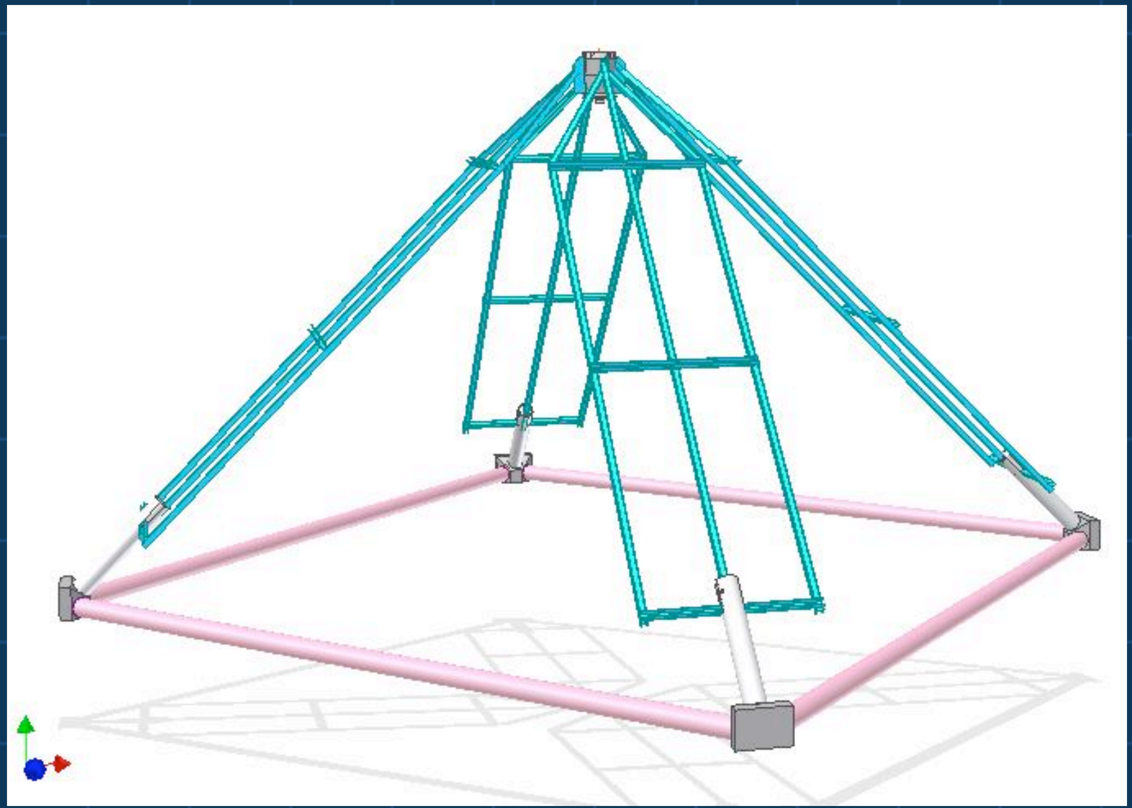
Beam Patterns



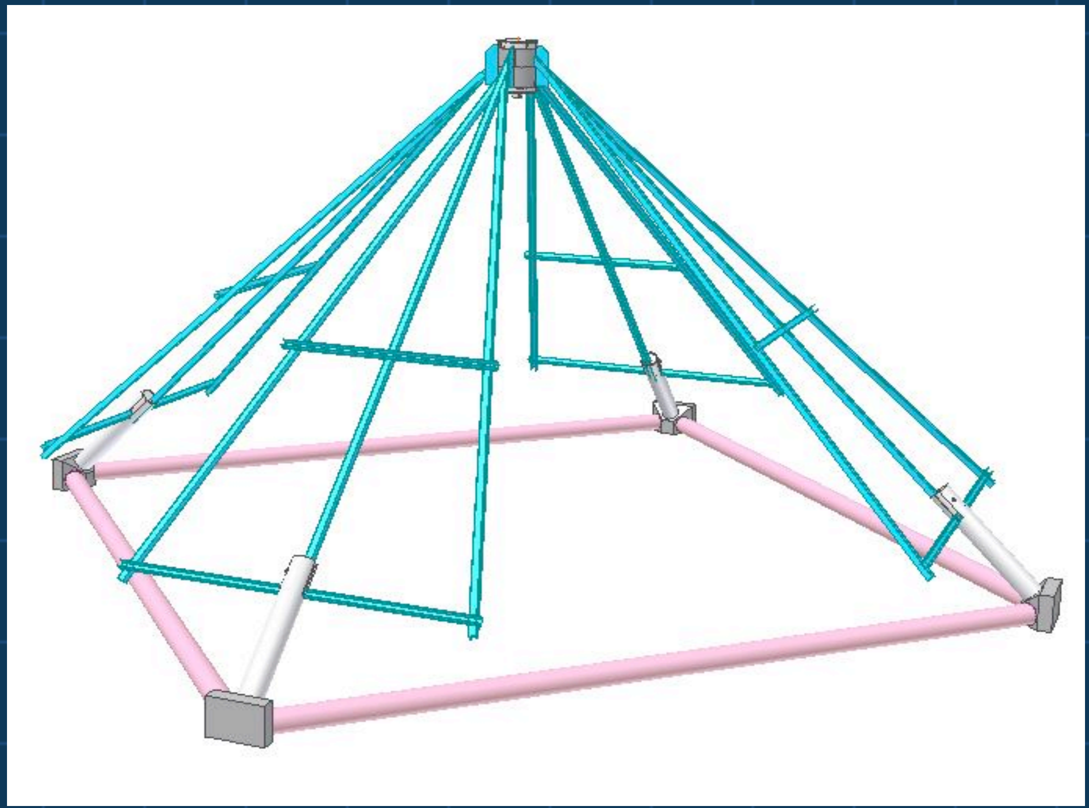


Burns Industries Antenna Concepts

- Small company from NH with manufacturing plants in China
- Designed and manufactured antennas for MWA project
- Worked through several mechanical designs for us
- Nearly ready to produce prototypes



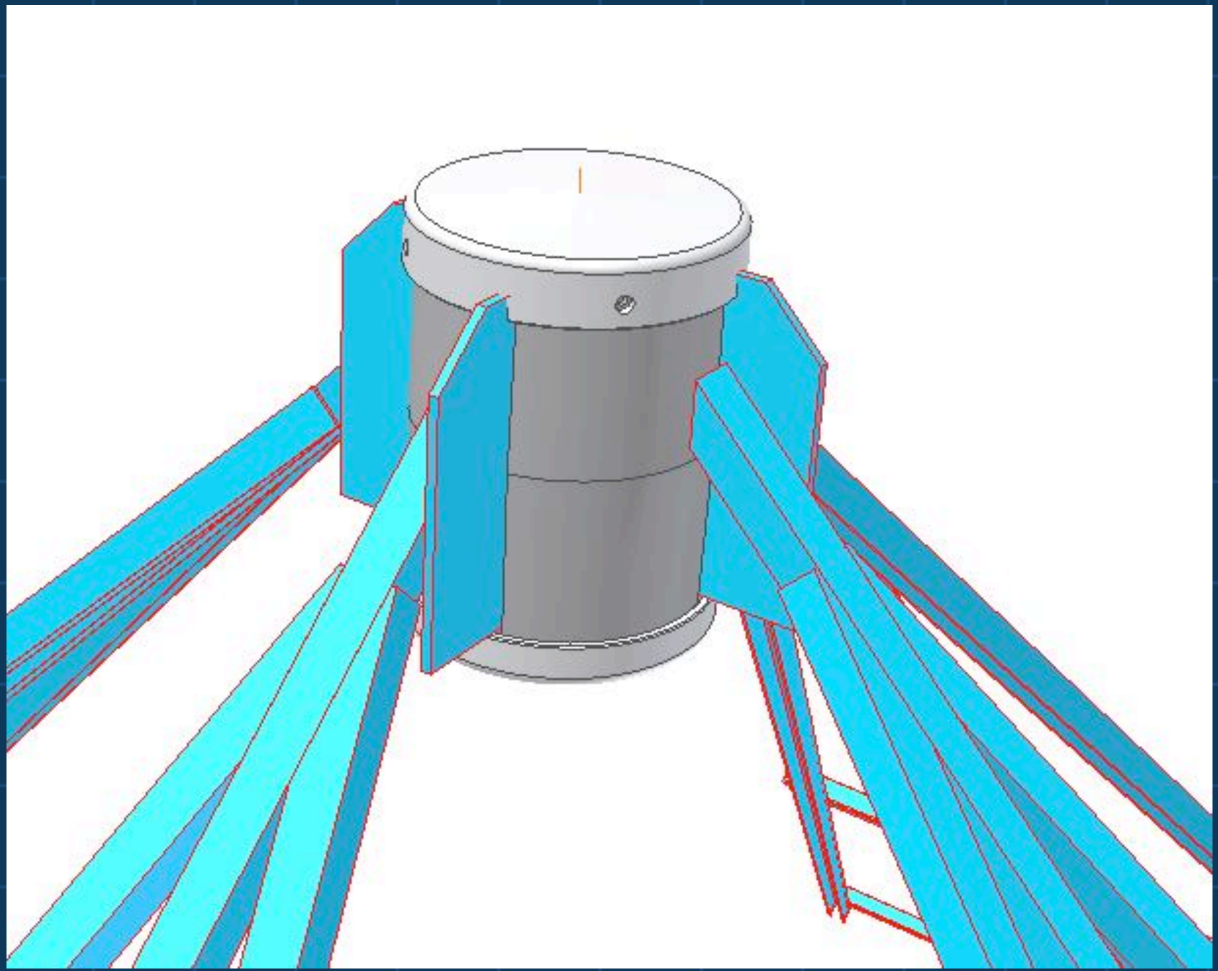
"Burns Dipole"



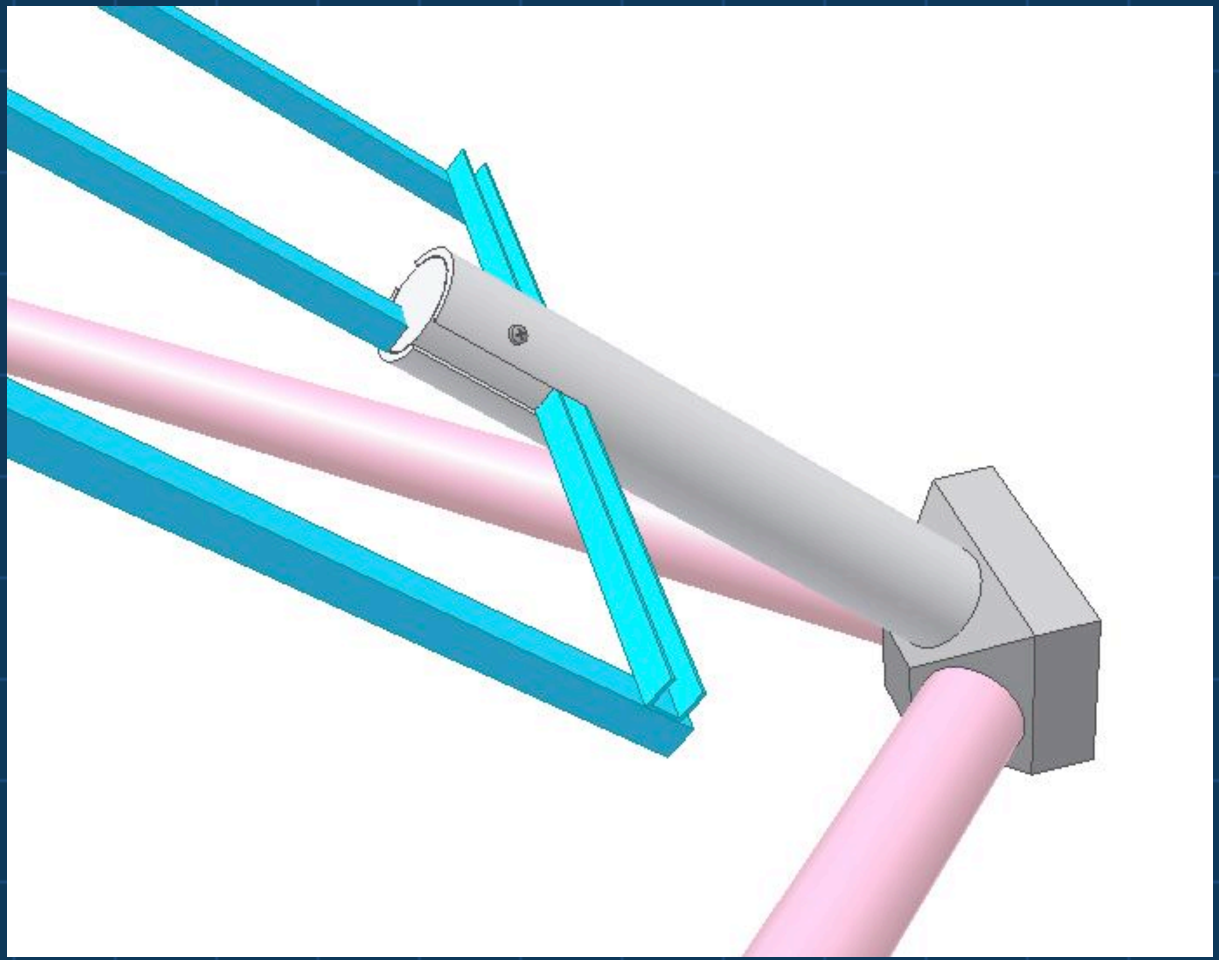
"Tied Fork"

Closeups

Hub

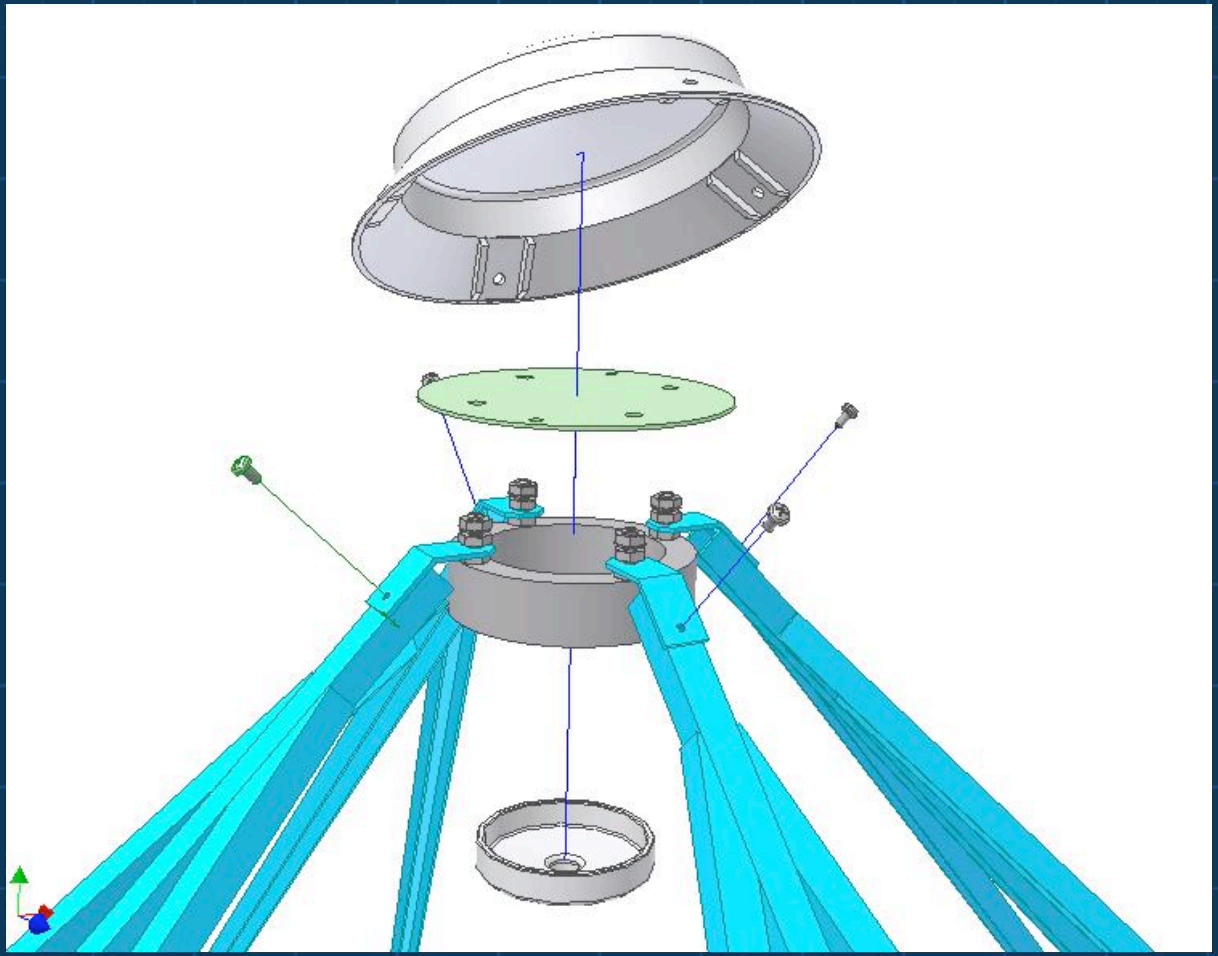


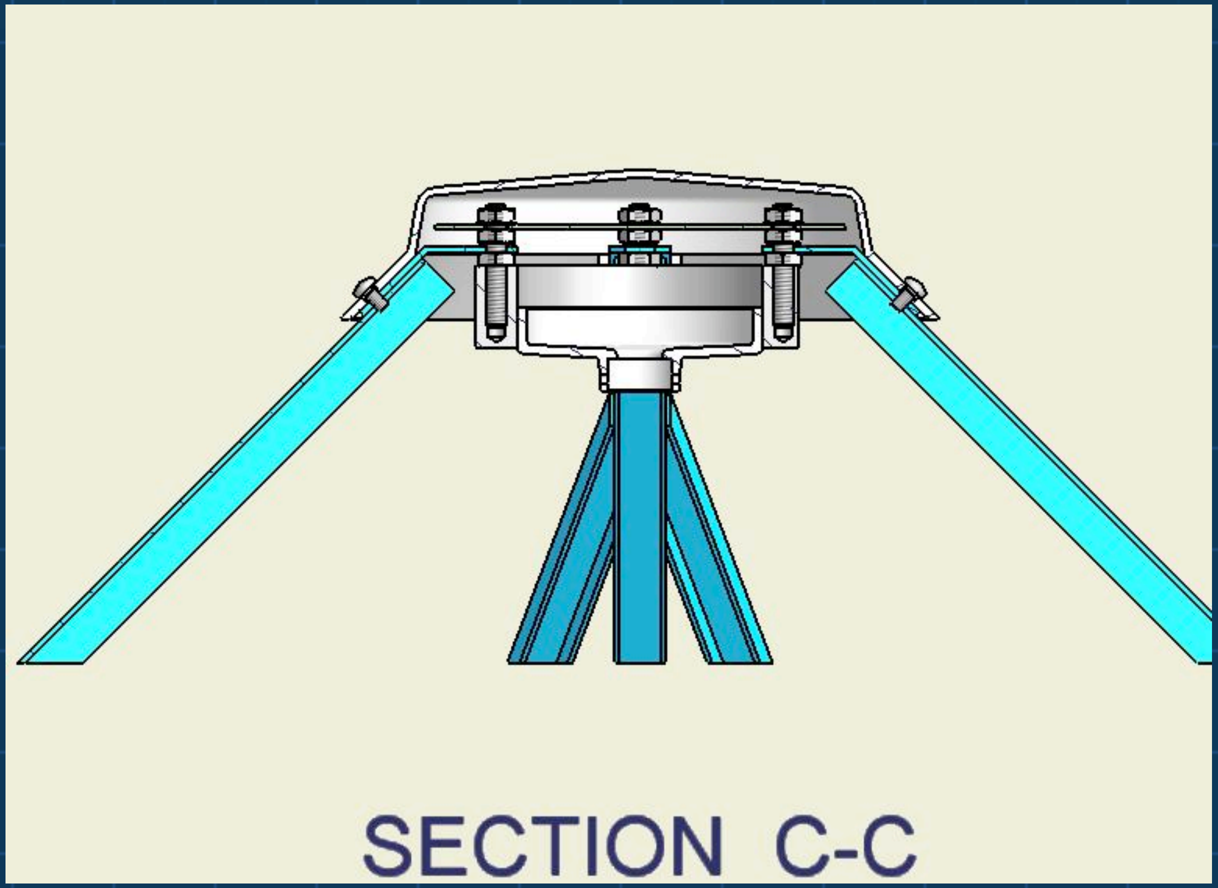
Foot mount



- Hub borrowed from MWA design and houses active balun.
- Hub design addresses moisture and ventilation issues to protect balun electronics.

Redesigned Hub





- Hub redesigned by Burns to accommodate Brian Hicks' "back-to-back" circuit board layout of balun.

Cost Estimate (for “Burns Dipole”)

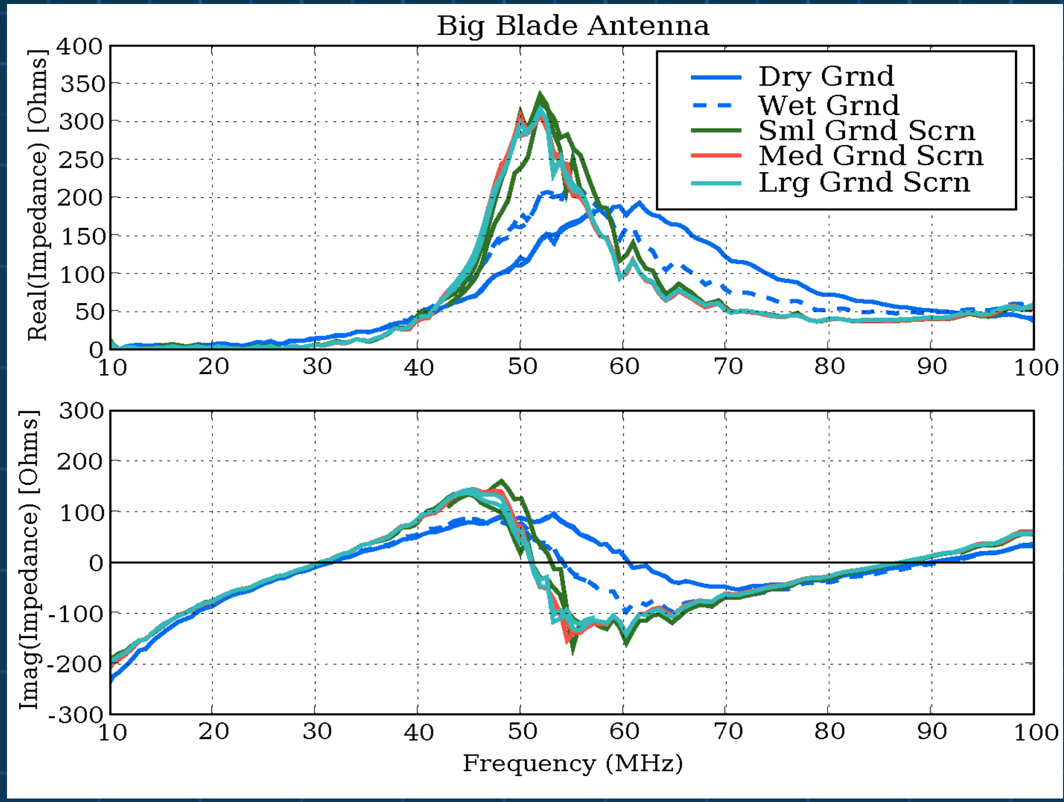
- **Total package: $80K (~ $312/unit)**
  - Package includes antenna design development, prototypes, tooling, and 256 LWA-1 antennas
- **Cost per antenna is anticipated to be <$100 in quantities of 5K to 15K**
- **Not included in package so far:**
  - Active balun
  - Ground screen material
  - Redesigned hub
  - Any changes to elements from “Burns Dipole design” (e.g. – mesh material needed to approximate Big Blade, change in element shape)

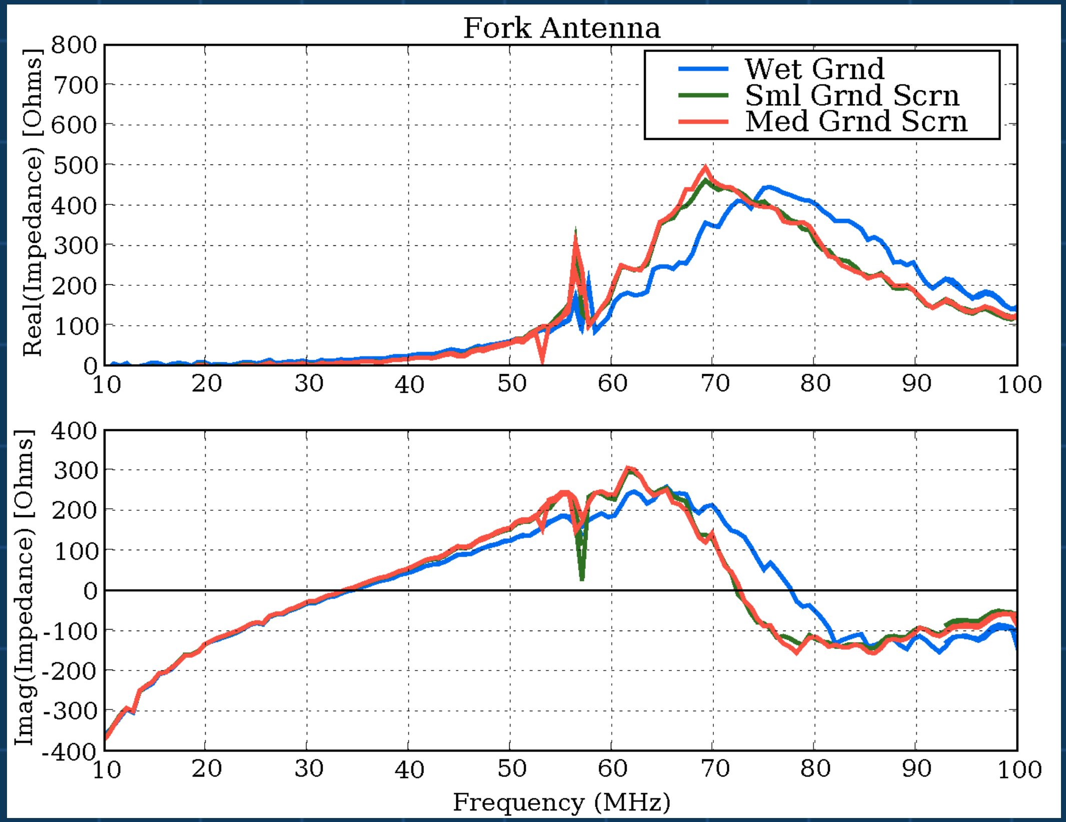
Development Program Details

- Burns will explore the issues and costs associated with welding a mesh material to the antenna elements to more closely approximate the performance of a Big Blade antenna.
- Burns intends to provide us with prototypes of the top 2 or 3 LWA antenna candidates to field test before settling on a final design to be produced in quantities of 256 for LWA-1.
  - All design work so far has been for free, but we’ll need to pay for prototypes
- Burns Industries also sells coaxial cable, and can also manufacture the balun if NRL provides the layout.
- Anticipated (rough) timeline: prototypes in 2007, 256 antennas in 2008, mass production in 2009.

Ground Screen Effects

- **Field measurements made of impedance over dry/wet ground and different size ground screens**
- **Results**
  - Ground screens appear to be required to stabilize performance as conditions change
  - A small (3m x 3m) ground screen is sufficient





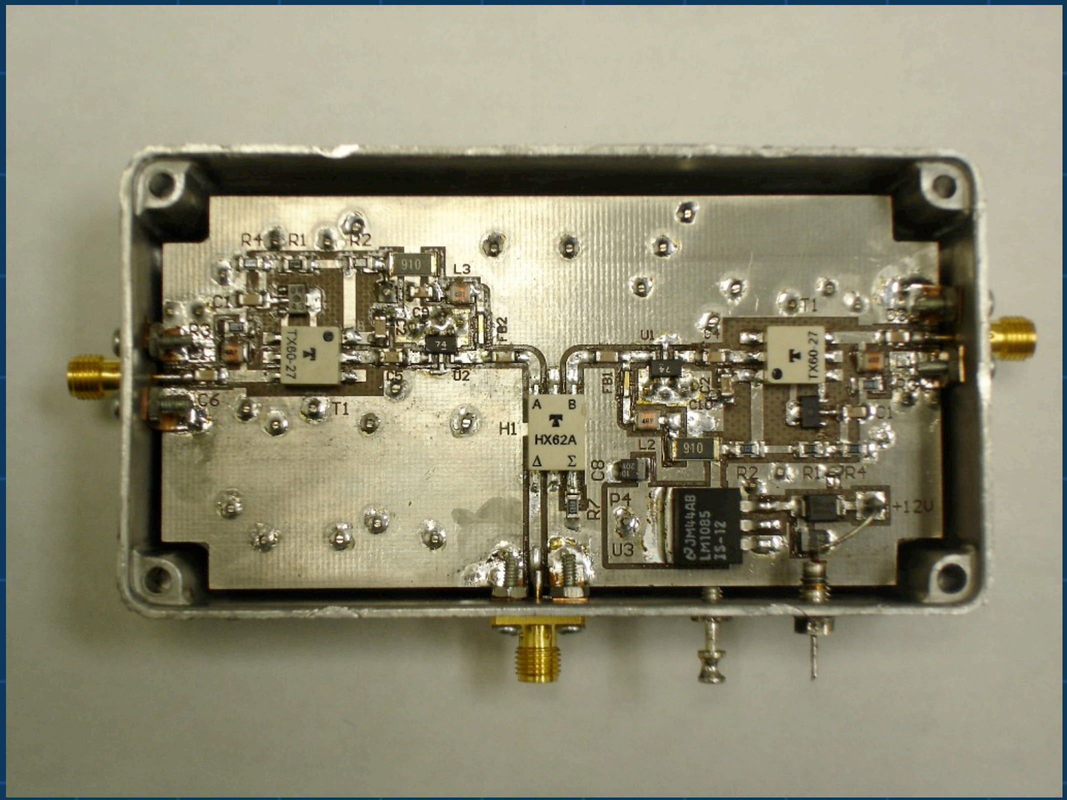
LWA Memo #90

FEE Development

- Close relationship with Tele-Tech Inc who makes specialized hybrids and impedance transformation parts
  - Manufacturing partner on LWDA balun
  - New parts and cost reductions motivated by our project
- Designed, built and tested discrete gain stage
- Investigated power supply options
- Addressed several issues in new FEE revision built for Rapid Test Array

Discrete Gain Stage

- +8 dB gain stage developed with 120 K noise temperature in collaboration with NRAO
- Significant performance improvement, but increased cost (~$40/ FEE)

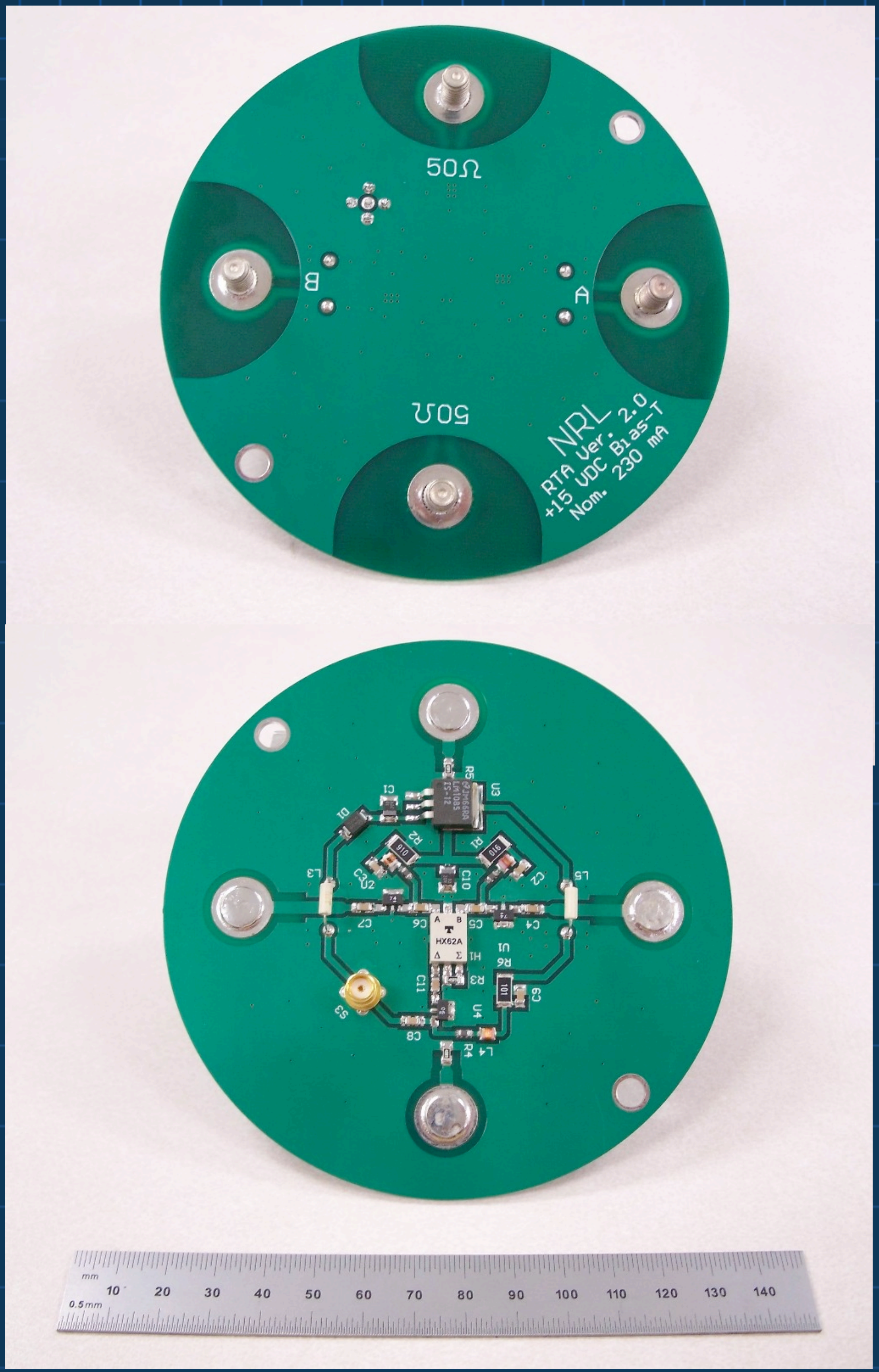


Prototype D120P balun incorporating discrete gain stage

LWA Memos #71, #81

G250R Balun

- **New FEE unit designed for RTA**
- **Several improvements**
  - **Additional Gali-6s gain stage to overcome cable losses**
  - **Voltage regulator on bias-Tee**
  - **Less expensive connectors to antenna**
  - **New form factor to fit on top of mast**

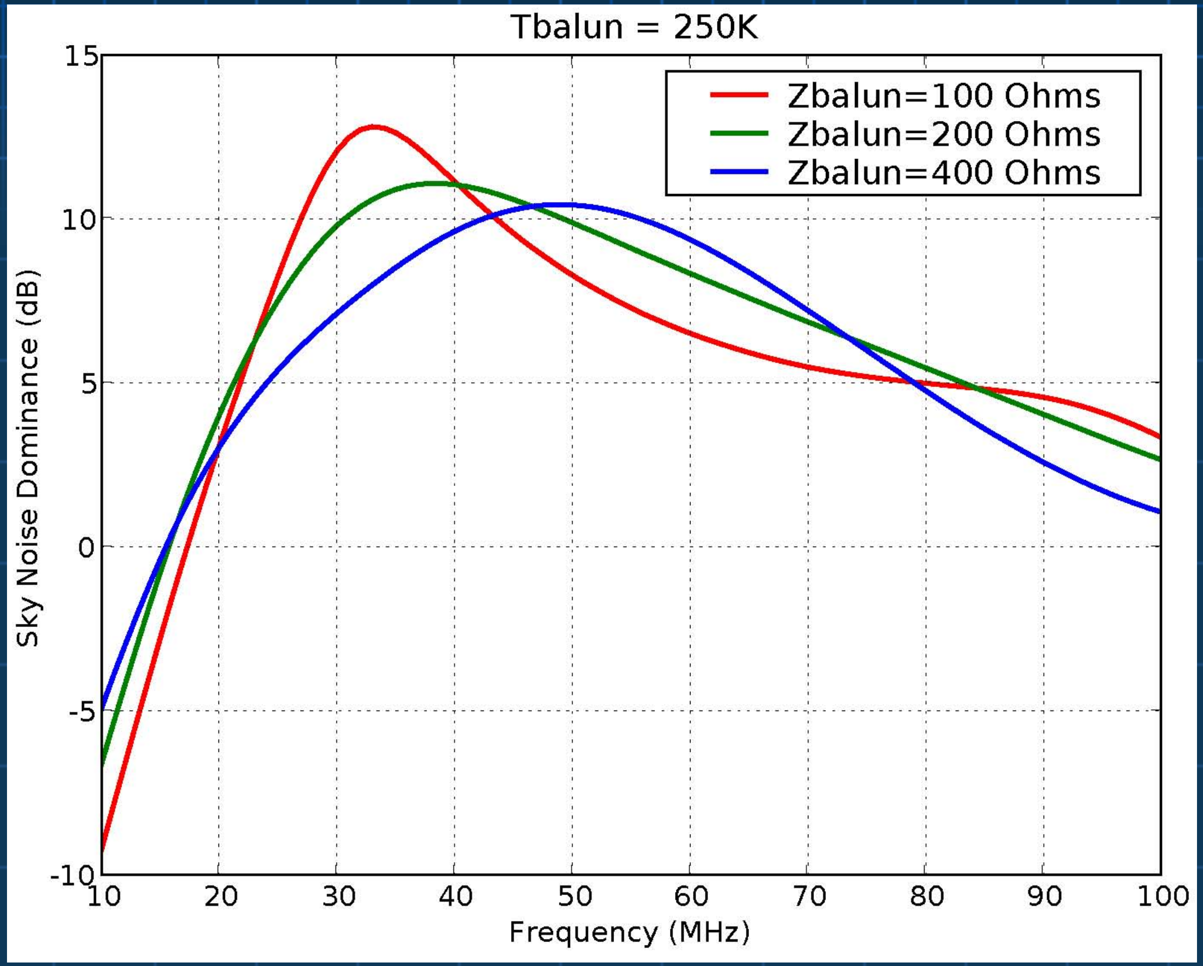


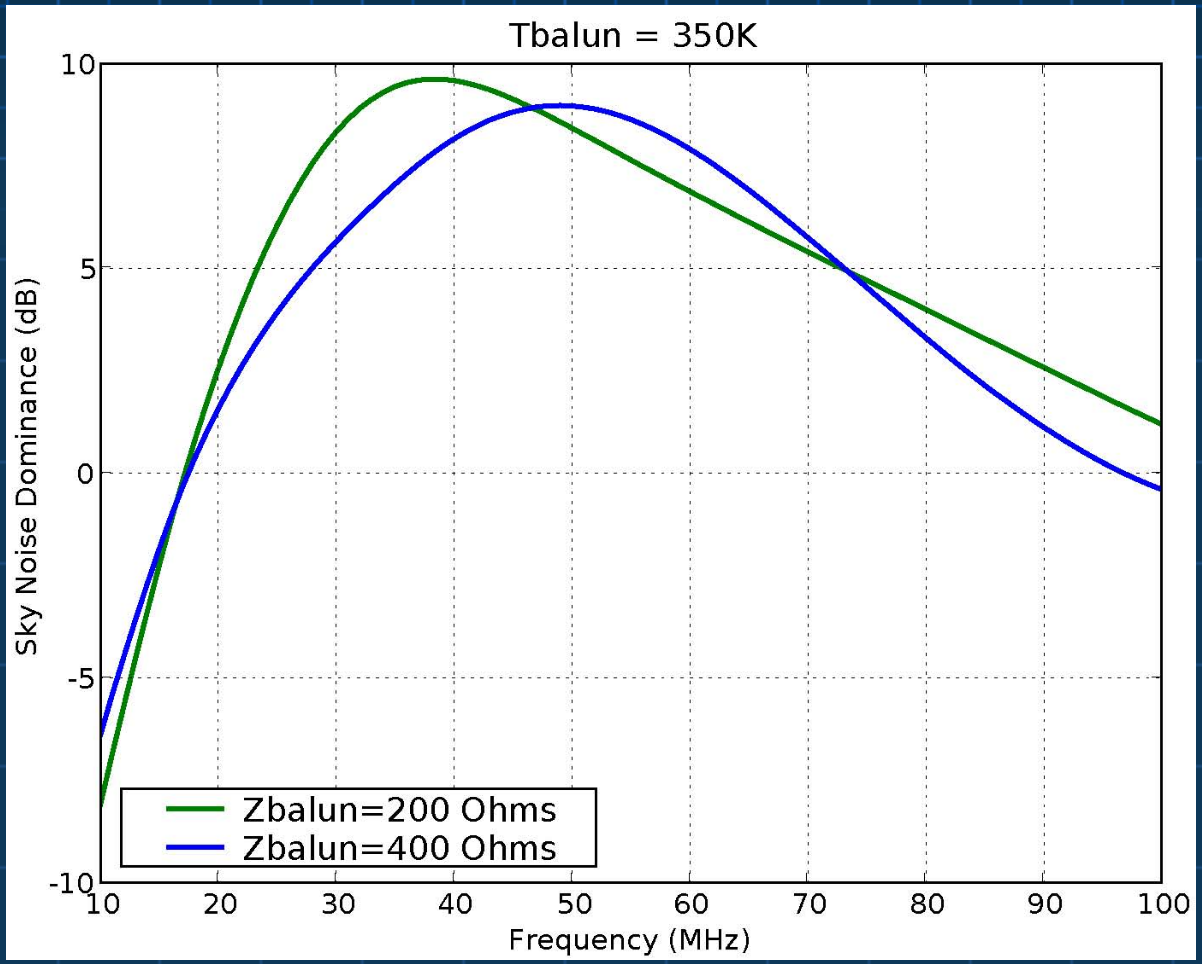
FEE Input Impedance and Noise Temperature

- Several antenna designs show improved performance with higher input impedances
- But, native impedance of both Gali-74 and NRL-NRAO discrete gain stage are 50 Ω (100 Ω balanced)
- Does the efficiency improvement outweigh the insertion loss of an impedance transformation stage?

Memo in progress...

Sky Noise Dominance – Big Blade

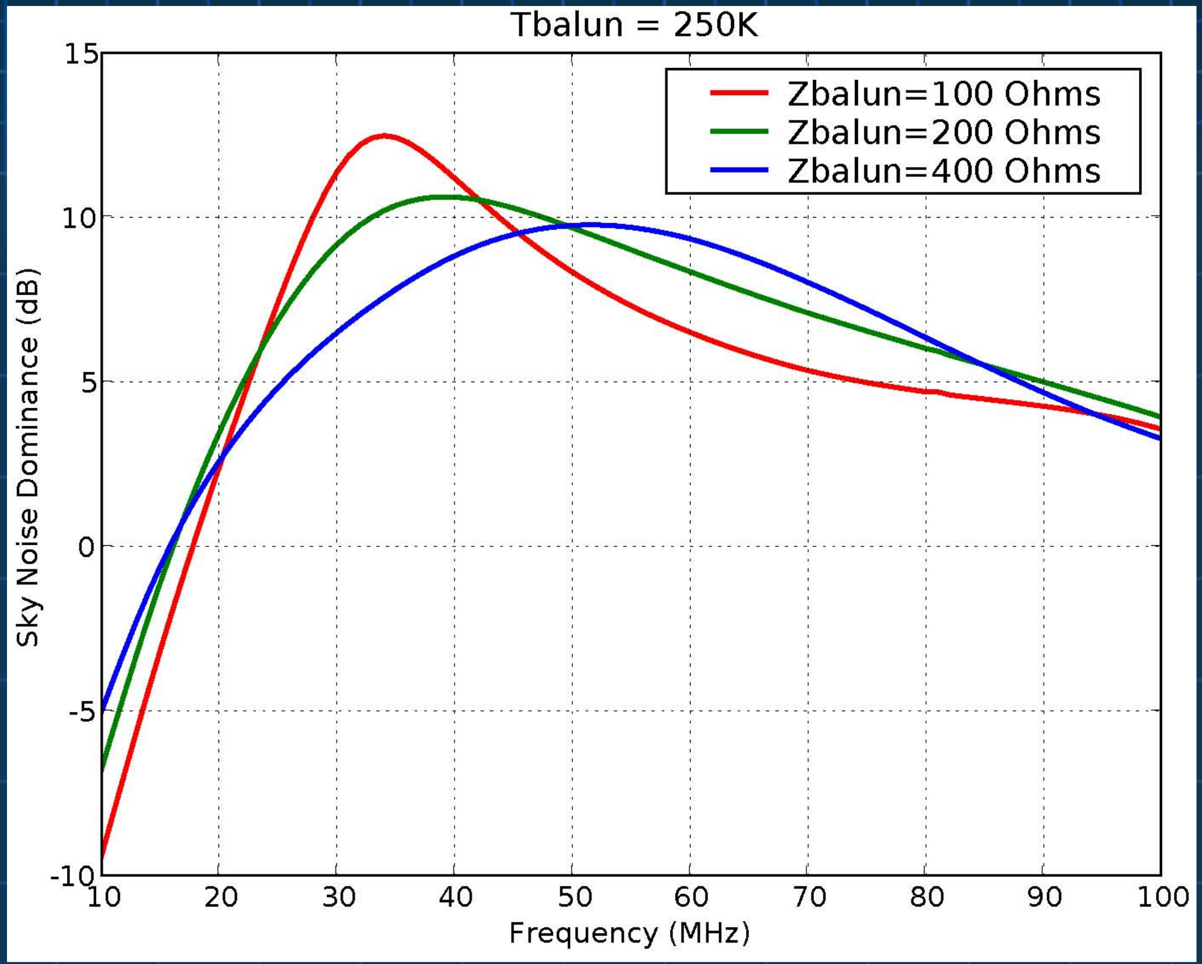


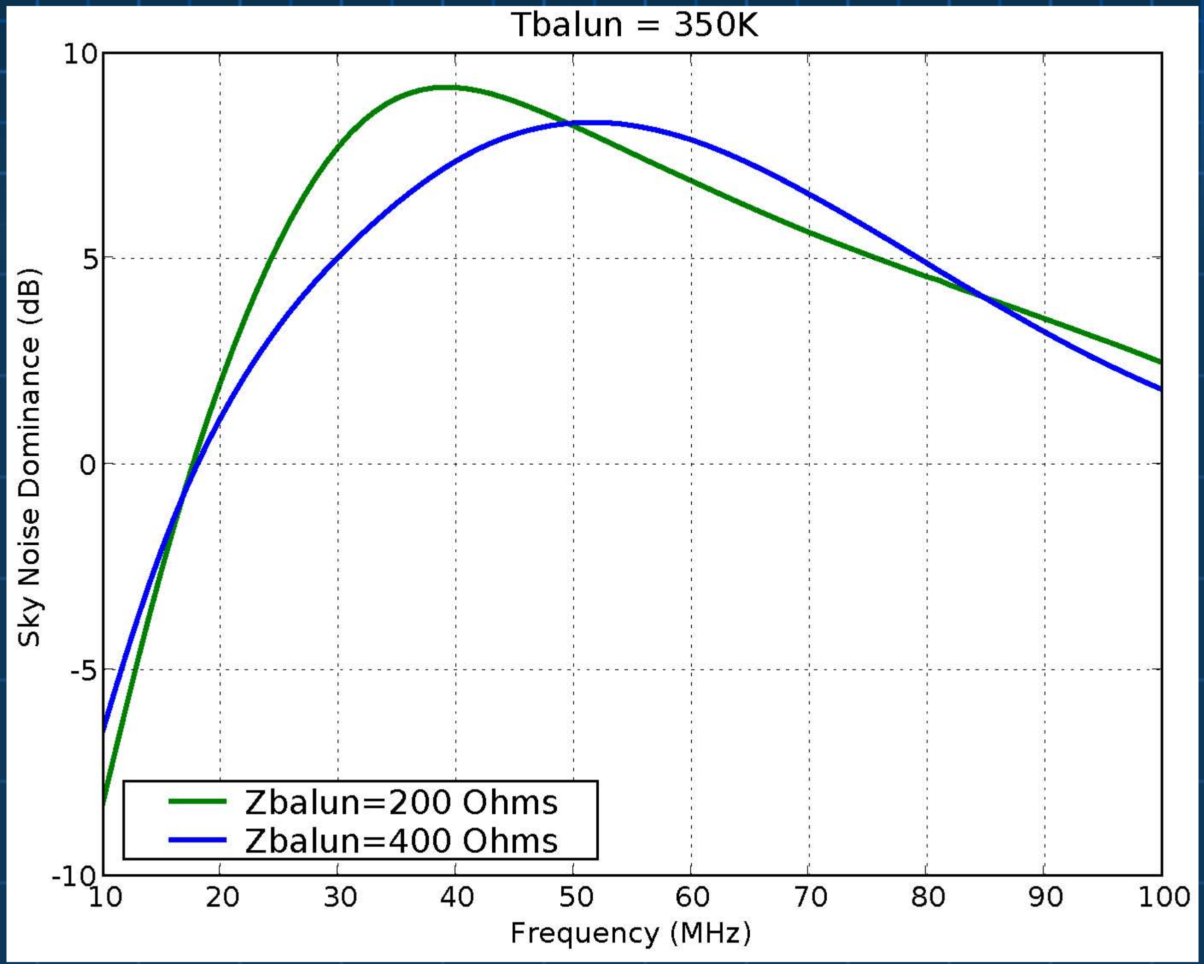


	Tbalun = 250 K			Tbalun = 350 K		
	D > 0dB	D > 3dB	D > 6dB	D > 0dB	D > 3dB	D > 6dB
Zbalun = 100 Ω	18-100	20-100	23-64			
Zbalun = 200 Ω	16-100	19-97	23-76	18-100	21-87	25-65
Zbalun = 400 Ω	16-100	20-87	27-74	18-96	23-81	32-68

(Frequency ranges in MHz)

Sky Noise Dominance – Tied Fork

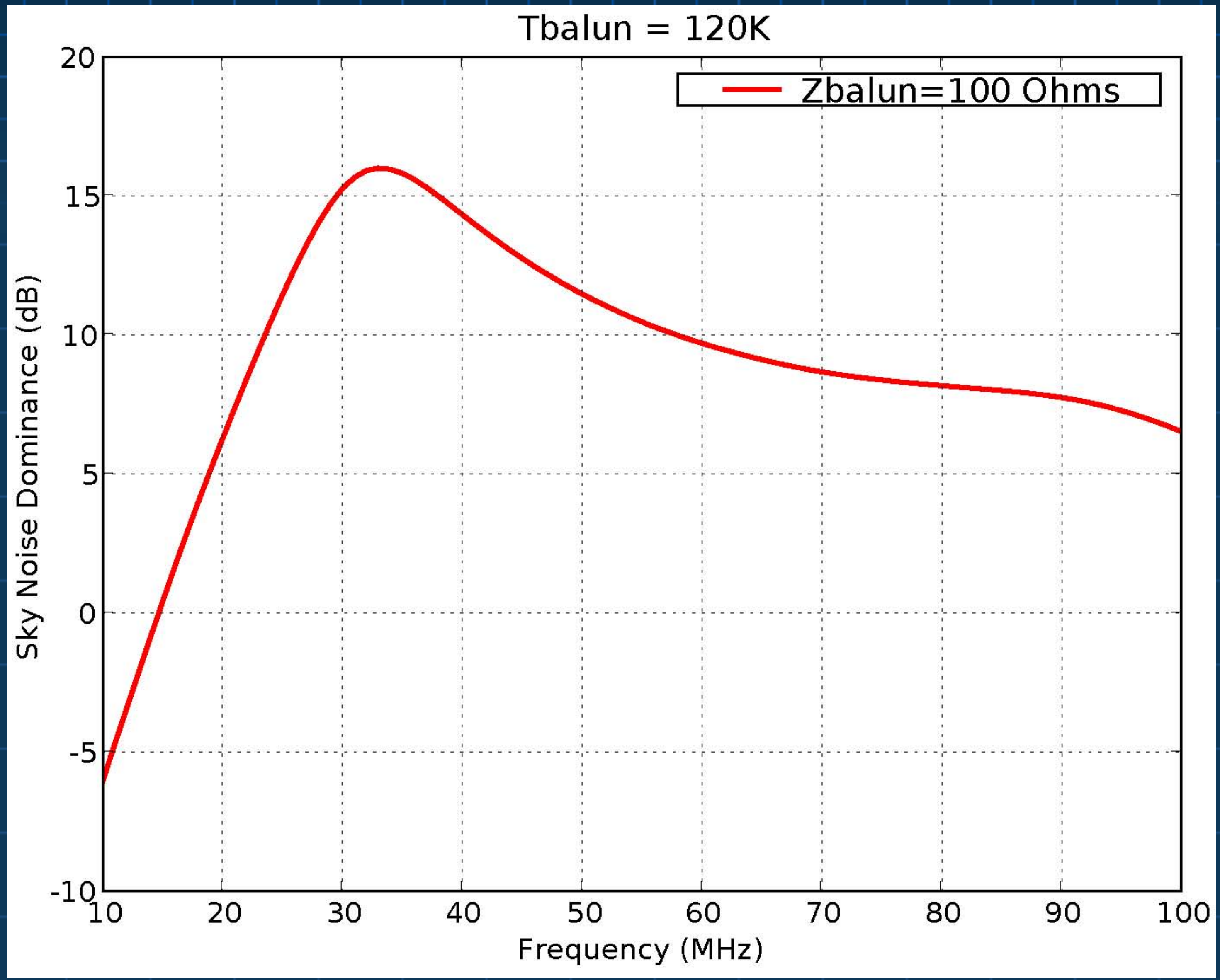




	Tbalun = 250 K			Tbalun = 350 K		
	D > 0dB	D > 3dB	D > 6dB	D > 0dB	D > 3dB	D > 6dB
Zbalun = 100 Ω	18-100	21-100	24-63			
Zbalun = 200 Ω	17-100	20-100	24-80	18-100	22-95	27-66
Zbalun = 400 Ω	16-100	21-100	29-81	19-100	25-91	34-73

(Frequency ranges in MHz)

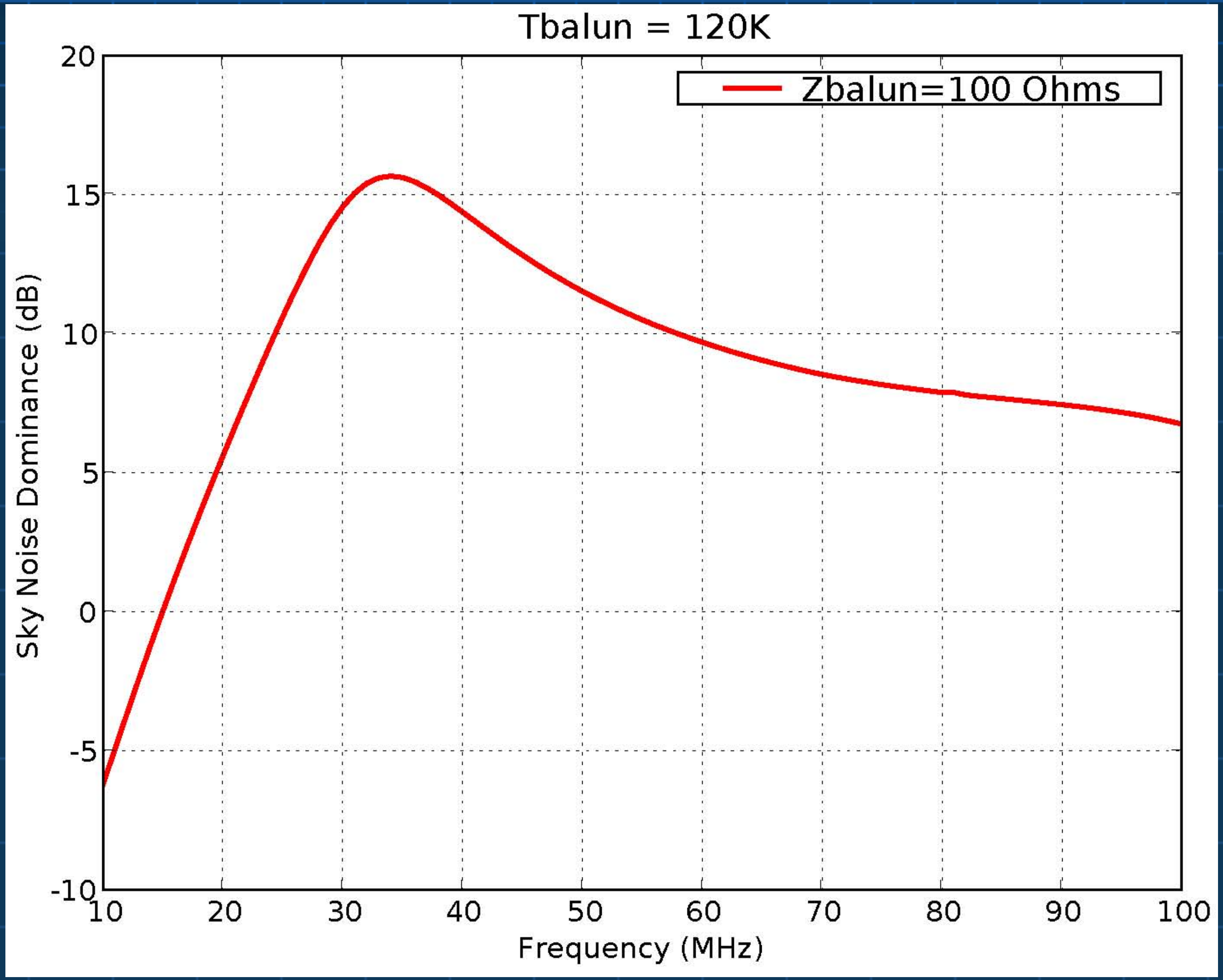
Sky Noise Dominance – Big Blade/Discrete Balun



	Tbalun = 120 K		
	D > 0dB	D > 3dB	D > 6dB
Zbalun = 100 Ω	15-100	18-100	20-100

(Frequency ranges in MHz)

Sky Noise Dominance – Tied Fork/Discrete Balun



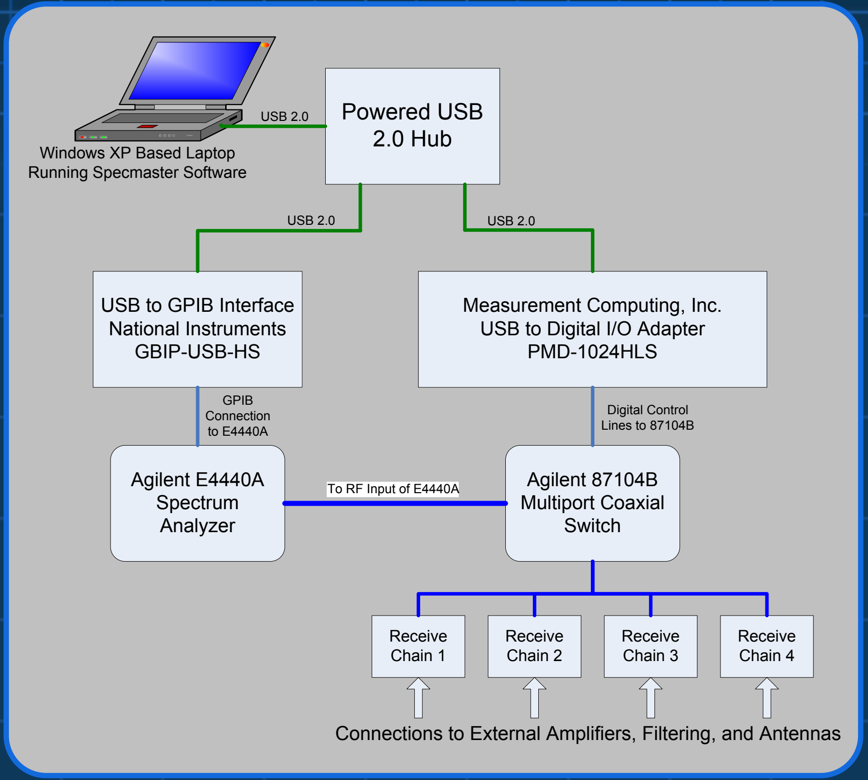
	Tbalun = 120 K		
	D > 0dB	D > 3dB	D > 6dB
Zbalun = 100 Ω	15-100	18-100	21-100

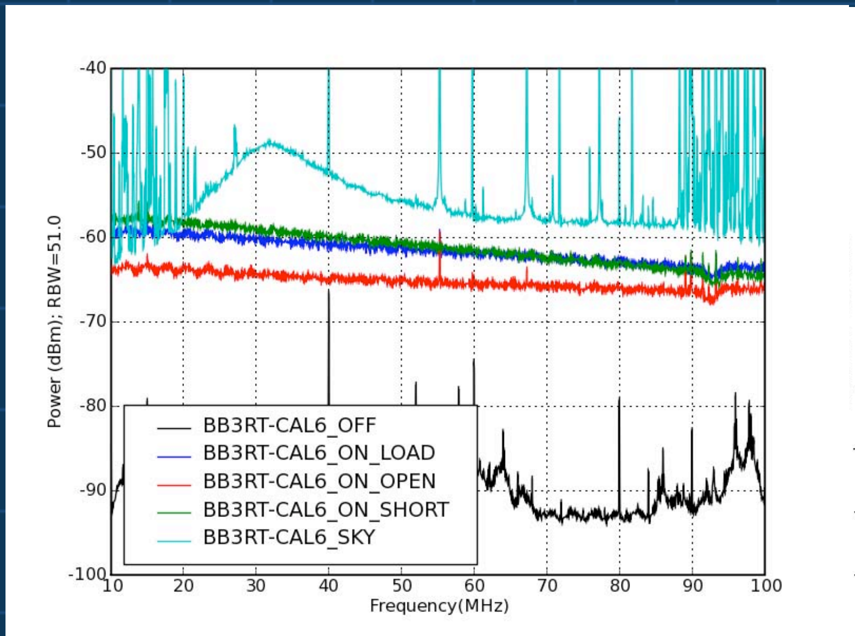
(Frequency ranges in MHz)

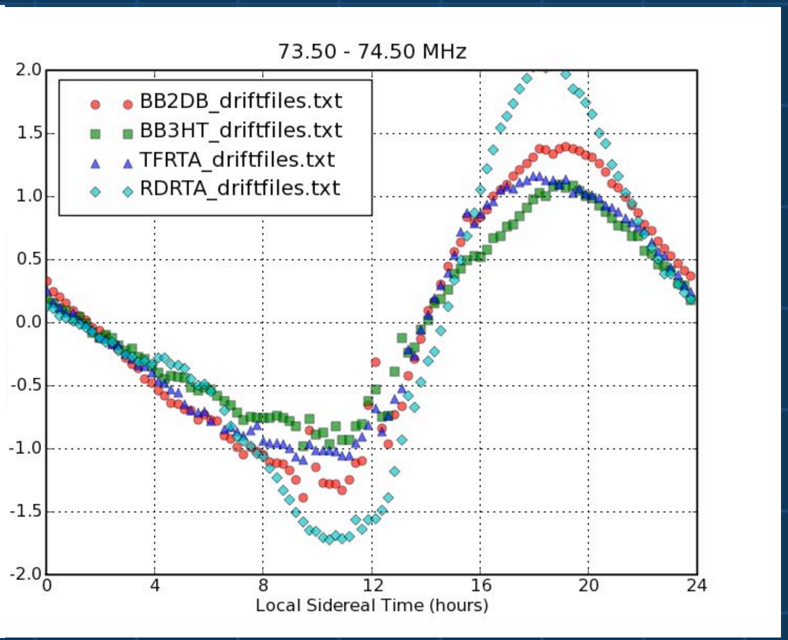
Field Testing

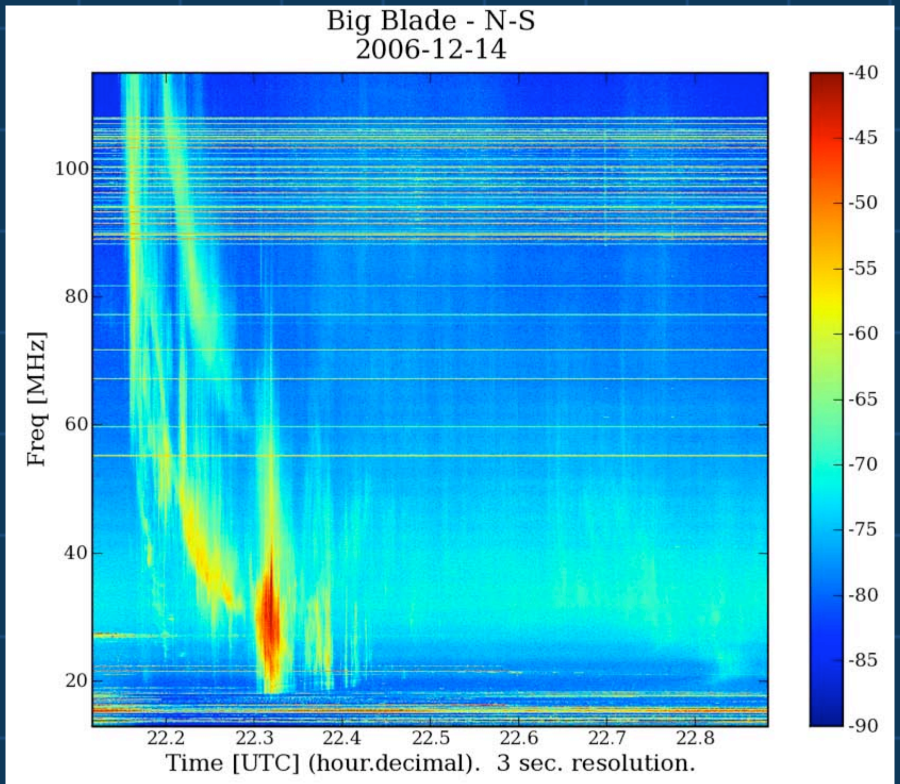
LWA Memo #74

- **Specmaster System**
  - 4-input spectrum analyzer with custom control software on laptop
  - Makes routine spectral measurements for solar bursts and RFI monitoring









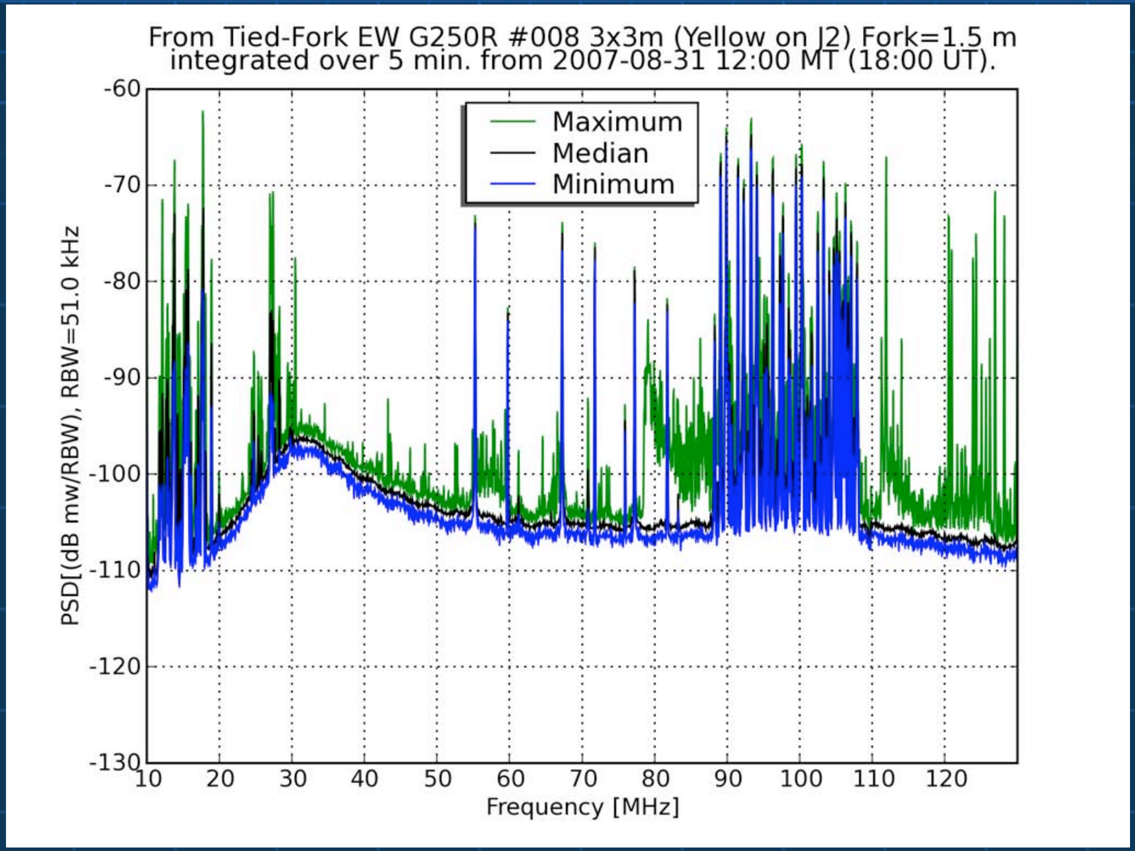
Spectra and drift curves

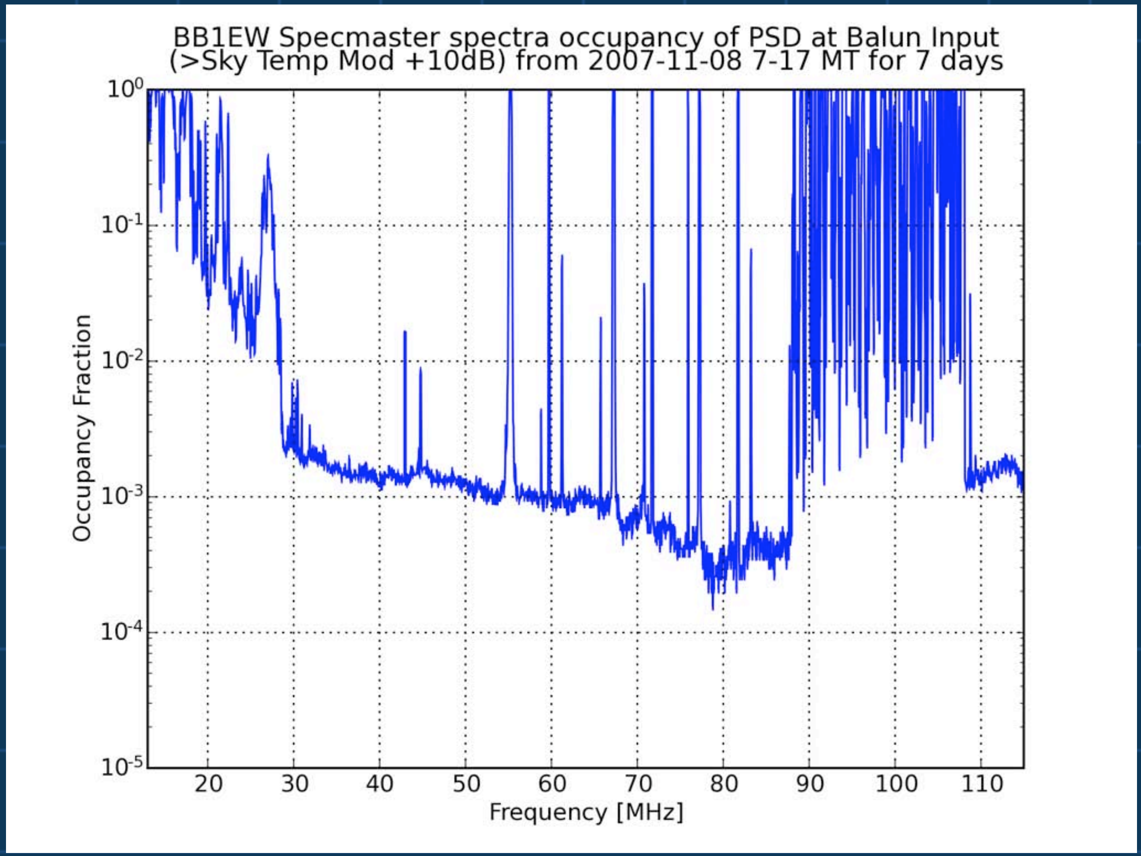
Solar burst dynamic spectra

Live and historical data at http://lwa.nrl.navy.mil/rduffin/

RFI Studies

- Used Specmaster for RFI survey of LWDA site to provide input for LWA receiver design (linearity and dynamic range requirements)
- Results:
  - Spectral plots
  - Occupancy plots
  - Tabulated strong RFI signals for receiver simulation inputs





LWA Memo #84

RTA Development

- Developed concept for Rapid Test Array with several goals:
  - Passive impedance and mutual coupling measurements
  - Ionospheric monitoring
  - Interferometric measurements of dipole response
- Hardware developed
  - Fork antennas (built by UNM)
  - New active balun (G250R)
  - 8-port bias-Tee and combiner
  - Testing ComBlock DAQ

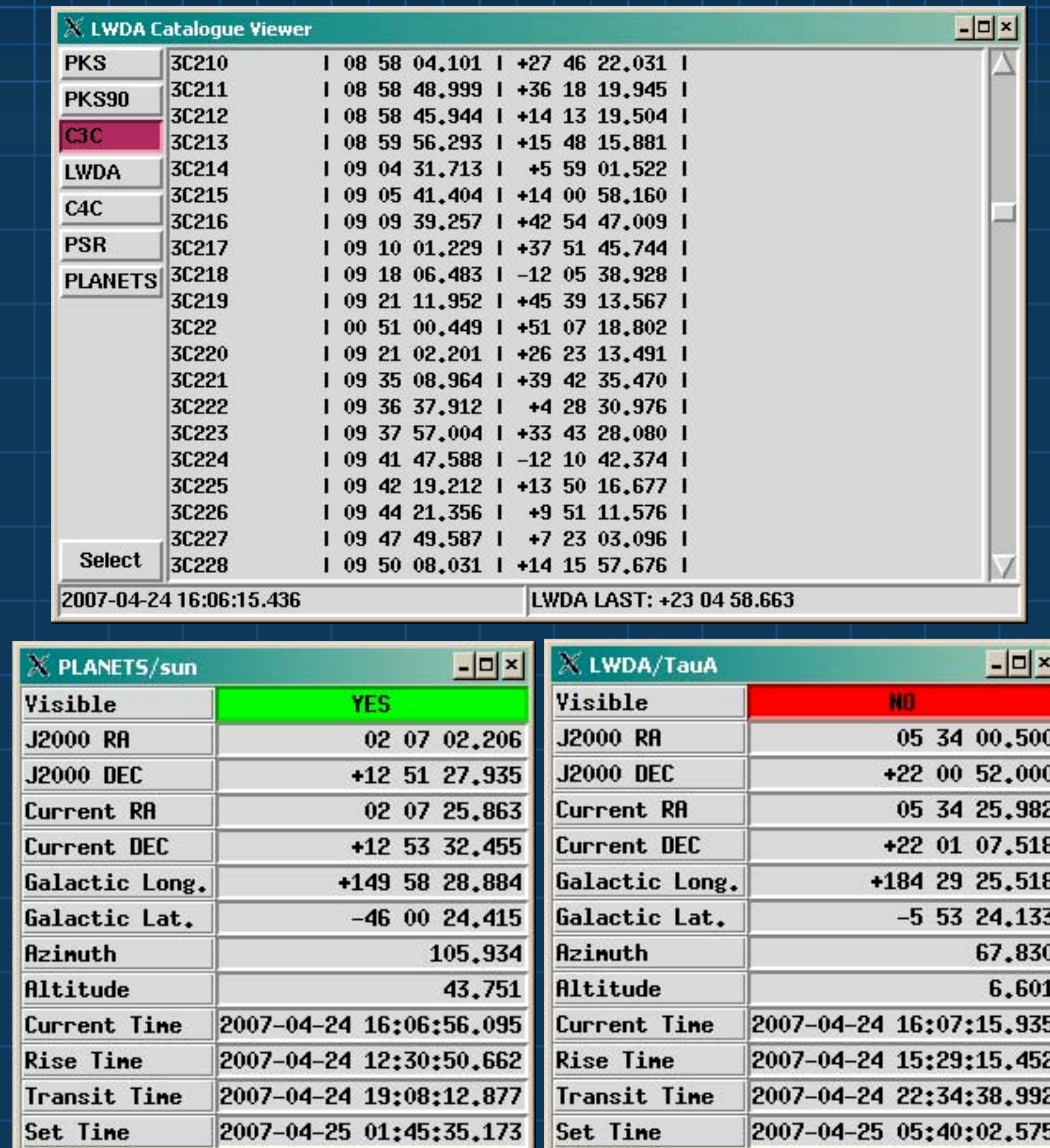
LWA Memo #91

LWDA/LWA Software

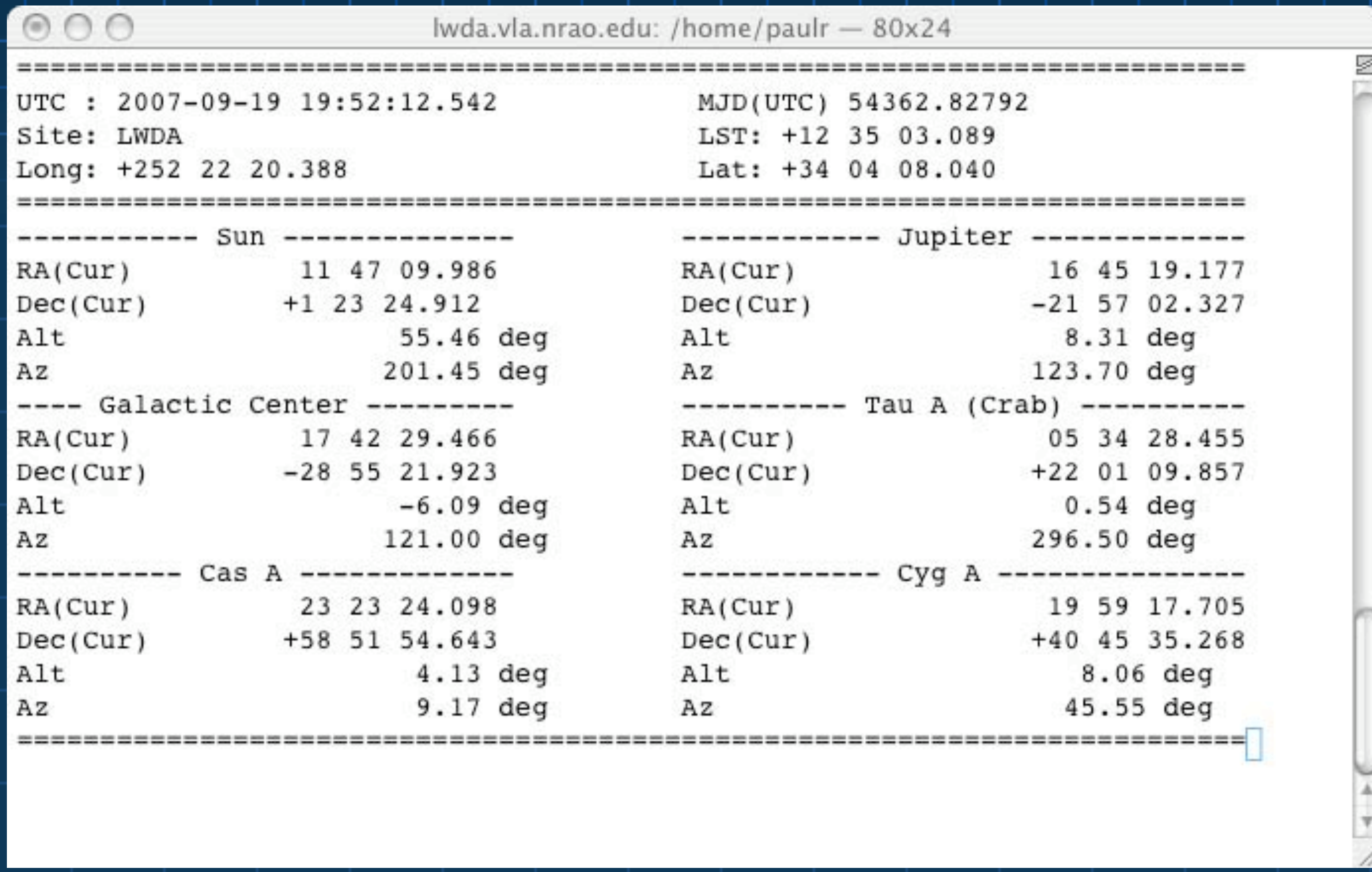
- Organized as a small set of Python packages
  - Most code written in Python
  - Some hardware interface code written in C
- Heavy use of available third-party Python and C packages:
  - Numpy
  - Matplotlib
  - Pyfits
  - FFTW
  - Libnova
- Use of third-party data analysis packages
  - AIPS
  - Sigproc
  - Presto
- All code kept in SVN repository

Observation Catalogs

- Can be accessed by any application
- Contain source name, aliases, and J2000 equatorial position
- Catalogs can be added easily if a computer readable text version of the catalog is available
- Current catalogs:
  - LWDA (Custom catalog for keeping our own short list of sources)
  - PSR
  - 3C
  - 4C
  - PKS
  - PKS90
  - Planetary model VSOP87 from libnova for sun, moon, jupiter locations



Astronomy Library

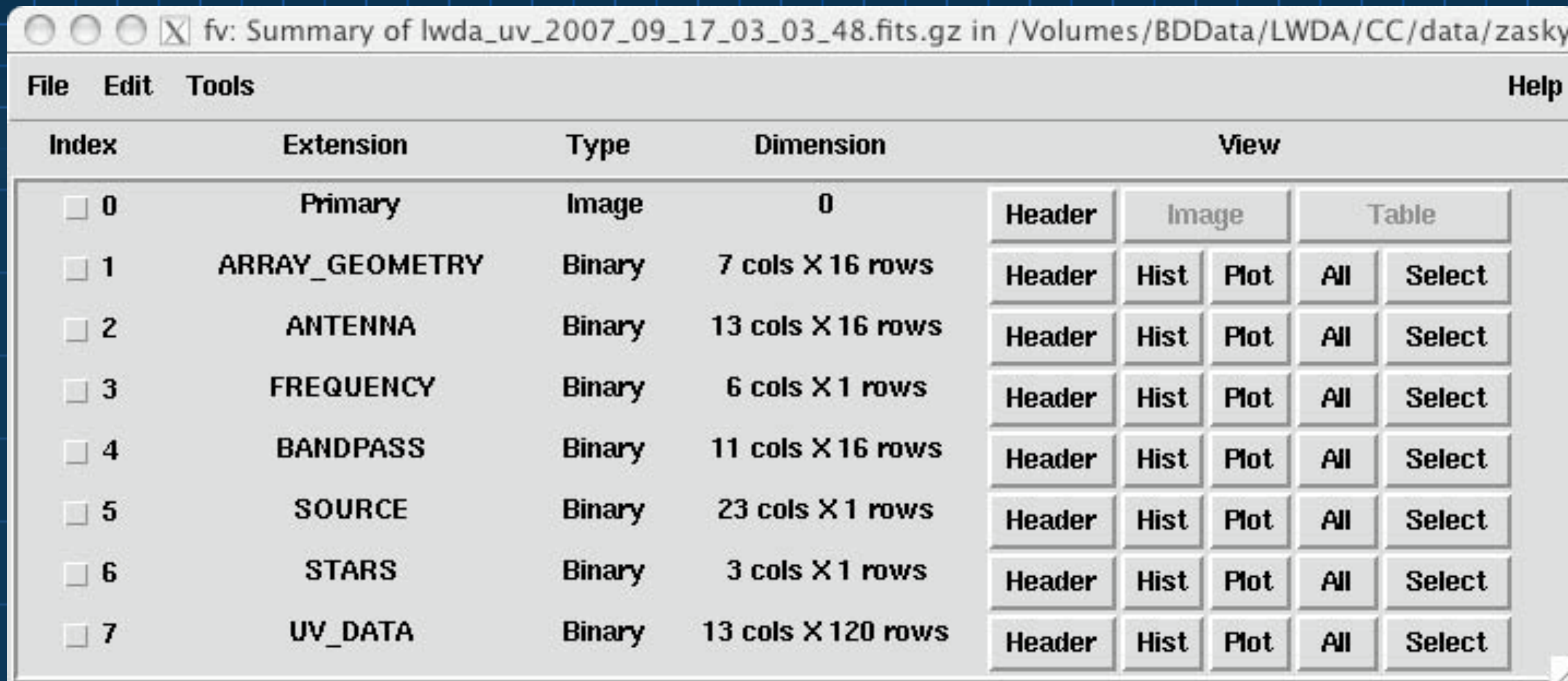


```
lwda.vla.nrao.edu: /home/paulr — 80x24
================================================================================
UTC : 2007-09-19 19:52:12.542           MJD(UTC) 54362.82792
Site: LWDA                              LST: +12 35 03.089
Long: +252 22 20.388                    Lat: +34 04 08.040
================================================================================
----------- Sun --------------          ------------ Jupiter -------------
RA(Cur)            11 47 09.986         RA(Cur)                 16 45 19.177
Dec(Cur)          +1 23 24.912          Dec(Cur)                -21 57 02.327
Alt                     55.46 deg       Alt                          8.31 deg
Az                     201.45 deg       Az                         123.70 deg
---- Galactic Center ---------          ---------- Tau A (Crab) ----------
RA(Cur)            17 42 29.466         RA(Cur)                 05 34 28.455
Dec(Cur)          -28 55 21.923         Dec(Cur)                +22 01 09.857
Alt                     -6.09 deg       Alt                          0.54 deg
Az                     121.00 deg       Az                         296.50 deg
---------- Cas A -------------          ------------ Cyg A ---------------
RA(Cur)            23 23 24.098         RA(Cur)                 19 59 17.705
Dec(Cur)          +58 51 54.643         Dec(Cur)                +40 45 35.268
Alt                      4.13 deg       Alt                          8.06 deg
Az                       9.17 deg       Az                          45.55 deg
================================================================================
```

Example of live status monitor

- Python wrapper around libnova C library
- Date and time conversions
- Coordinate system conversions
- Sidereal time
- Precession, nutation, aberration
- Planetary positions
- Will investigate SLALIB as replacement for libnova

FITS-IDI File Format

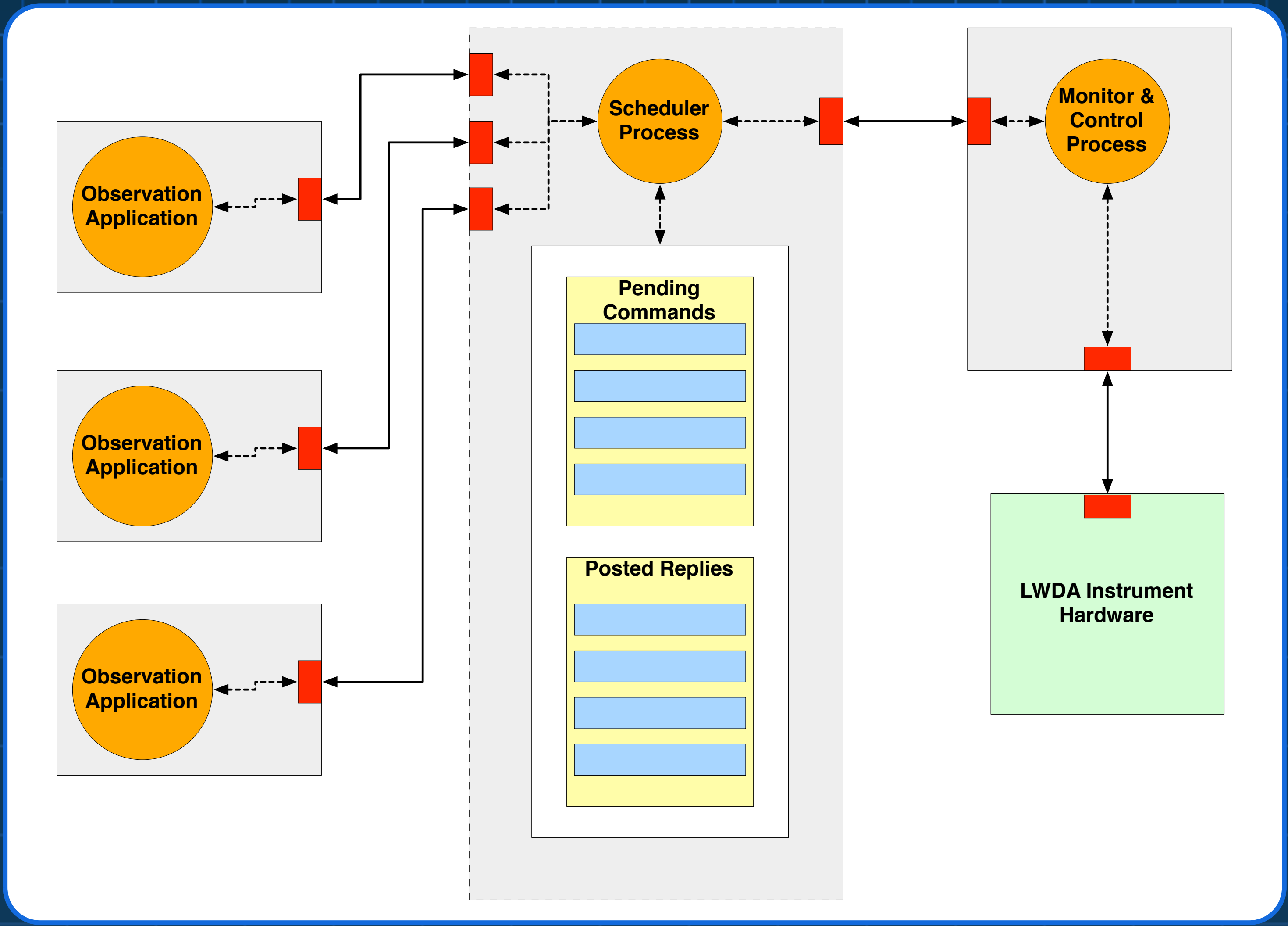


- Chosen as data format for LWDA all-sky UV image observations
- Format defined and documented by NRAO
- Can be used as input for AIPS
- Contains:
  - UV baseline correlator data
  - Array geometry and position
  - Time in UTC and local sidereal
  - Current and J2000 equatorial position of zenith
  - Current bandpass calibration data
  - Receiver frequency configuration

LWDA Networking

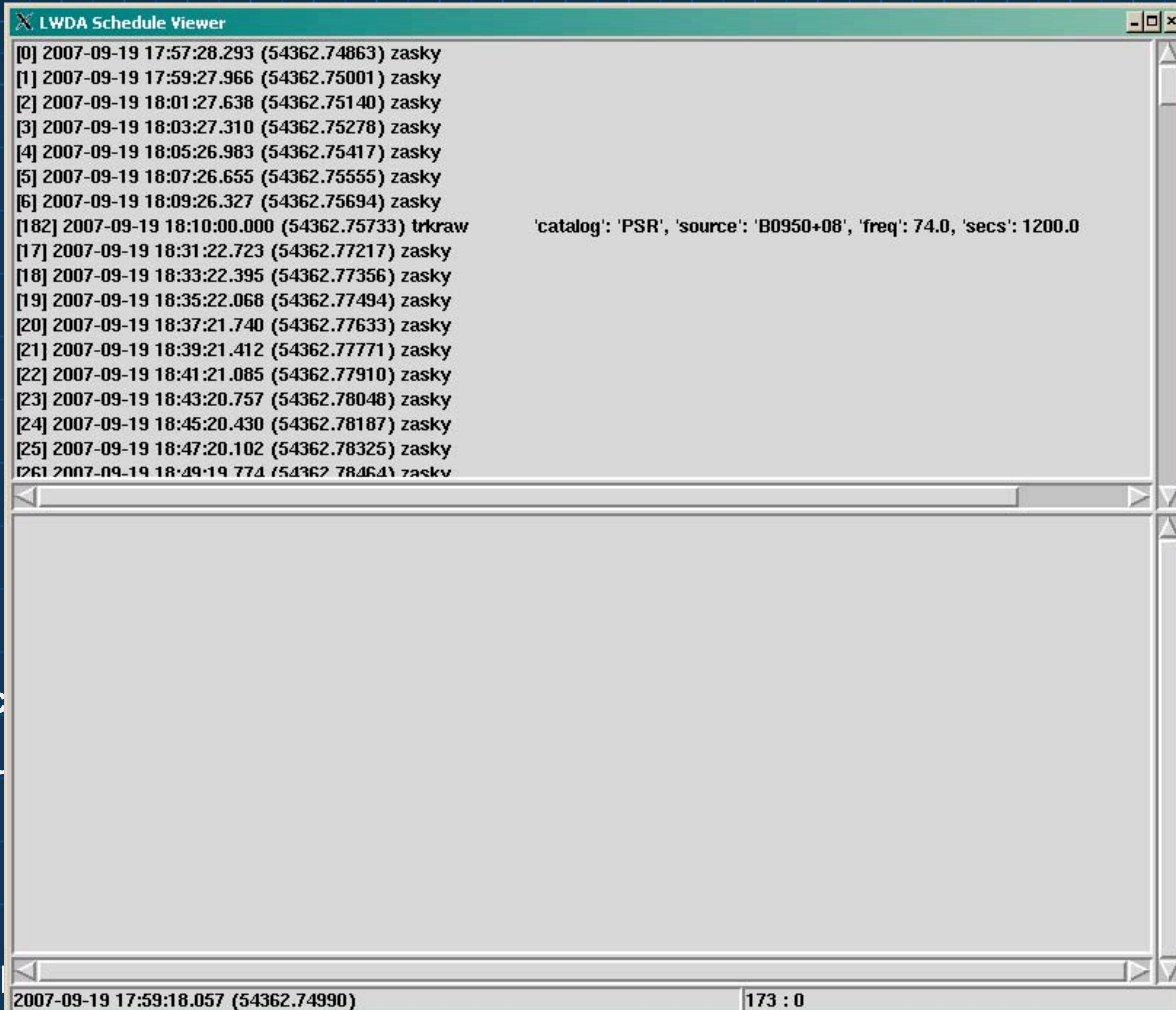
- Remote instrument site makes network issues prevalent for software
- Developed generalized Python RPC framework
  - Standard RPC command and reply
  - Removes most network issues from application development
  - Uses python pickle module to allow Python objects to be sent as command arguments and received as replies
- RPC used for LWDA scheduler

Scheduling an Observation



- Scheduler runs as master process on LWDA site computer
- Queues for commands and replies
  - Commands may be time tagged or immediate
  - Applications may schedule commands days in advance
  - Replies posted to scheduler for up to one hour
- All activity logged to file
- Tools for creating, viewing, and managing a simple observation schedule

Scheduling an Observation



- Sc
- Qu
- Al
- Tools for creating, viewing, and managing a simple observation schedule

Status

- Recently transitioned from initial engineering interface to our scheduler system
- Pointed observations at three predicted best pulsars for LWDA observation
  - B0950+08
  - B2016+28
  - B0823+26
- Continuous sky imaging when array not being used for other purposes
  - All-sky survey for transients with 2 (sidereal) minute sampling
  - 29558 images collected earlier this year with old software
  - 4260 images collected with new software since we restarted observations last week

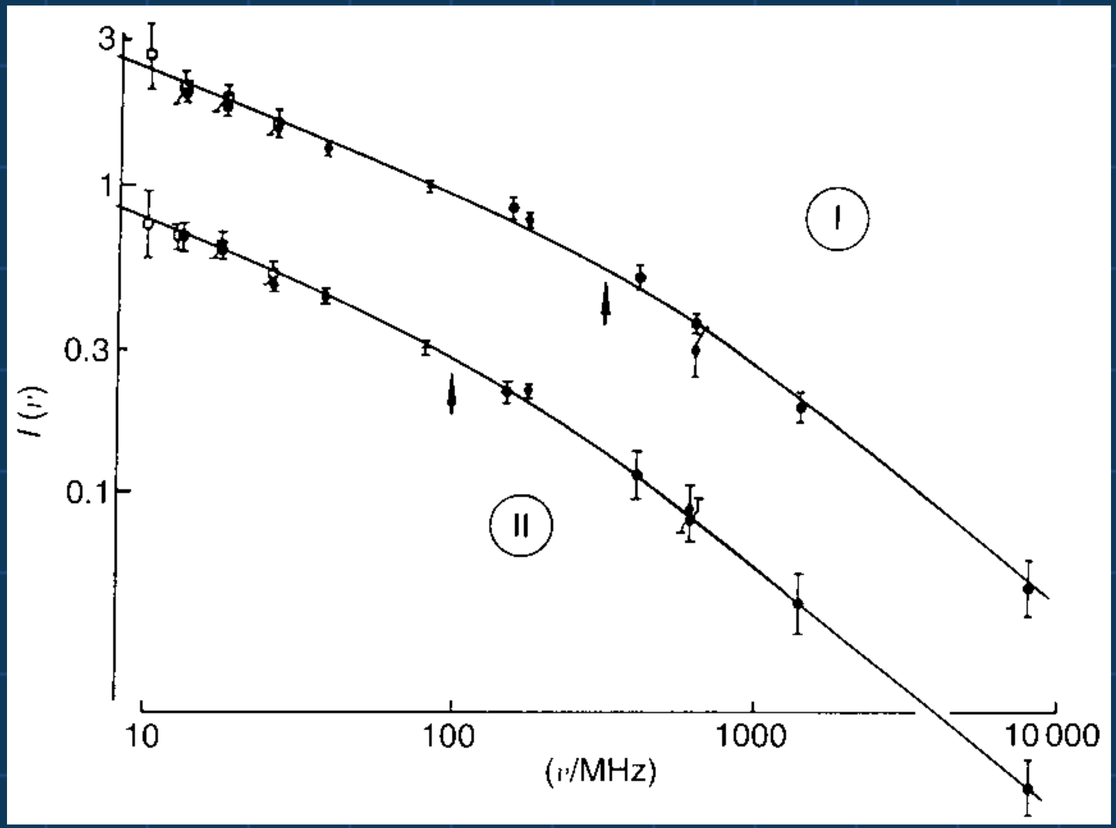
LF Sky Model

- Desire sky model to allow accurate characterization of performance using drift curve data
- Must incorporate data from all sky maps and frequency dependence

LFmap – C program to generate sky maps

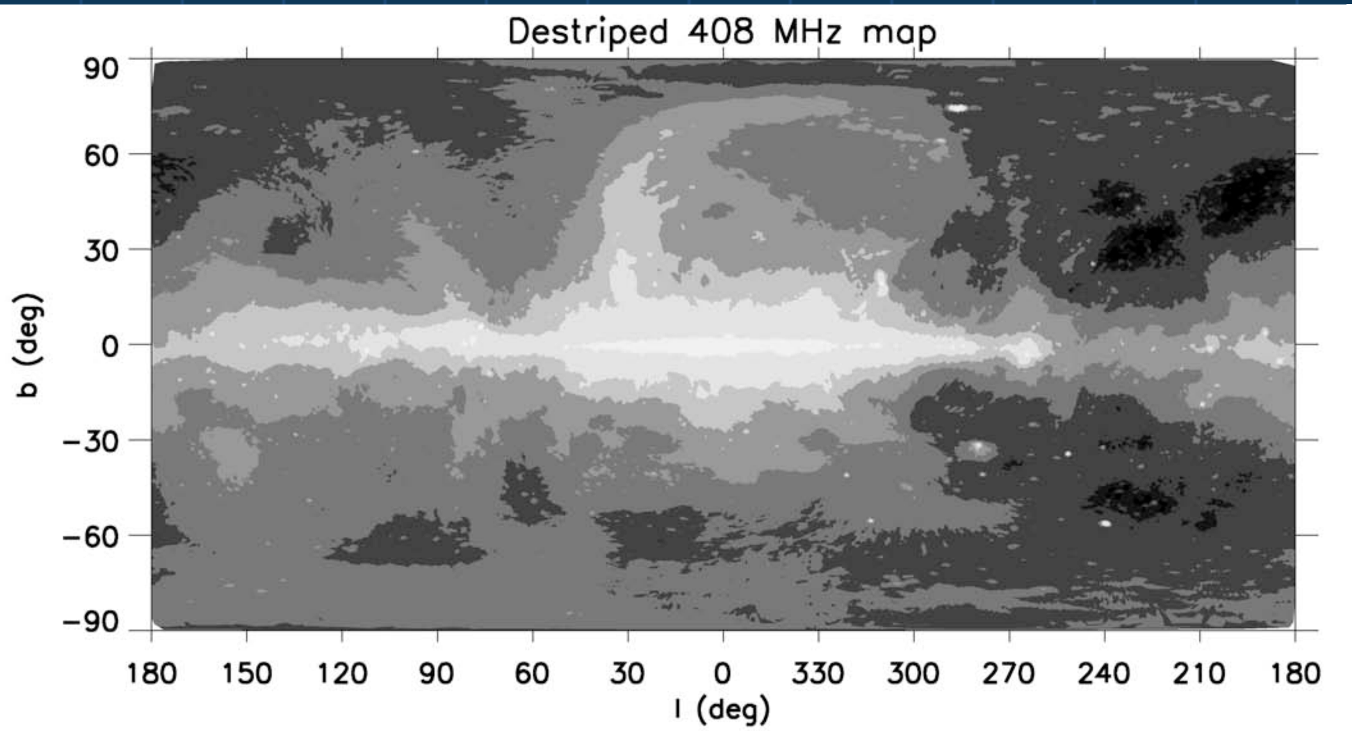
- Decomposes sky into CMB, extragalactic, and Galactic emissions
- TEG calculated following Lawson et al. (1987)
- TGAL calculated with destriped 408 MHz map and spectral index map of Platania et al. (2003)
- Spectra of TGAL bends below ~200MHz, map is scaled to this frequency then new indices calculated with 22 MHz map of Roger et al. (1999)
- 22 MHz map also used to account for HII absorption regions near GC below ~45 MHz.

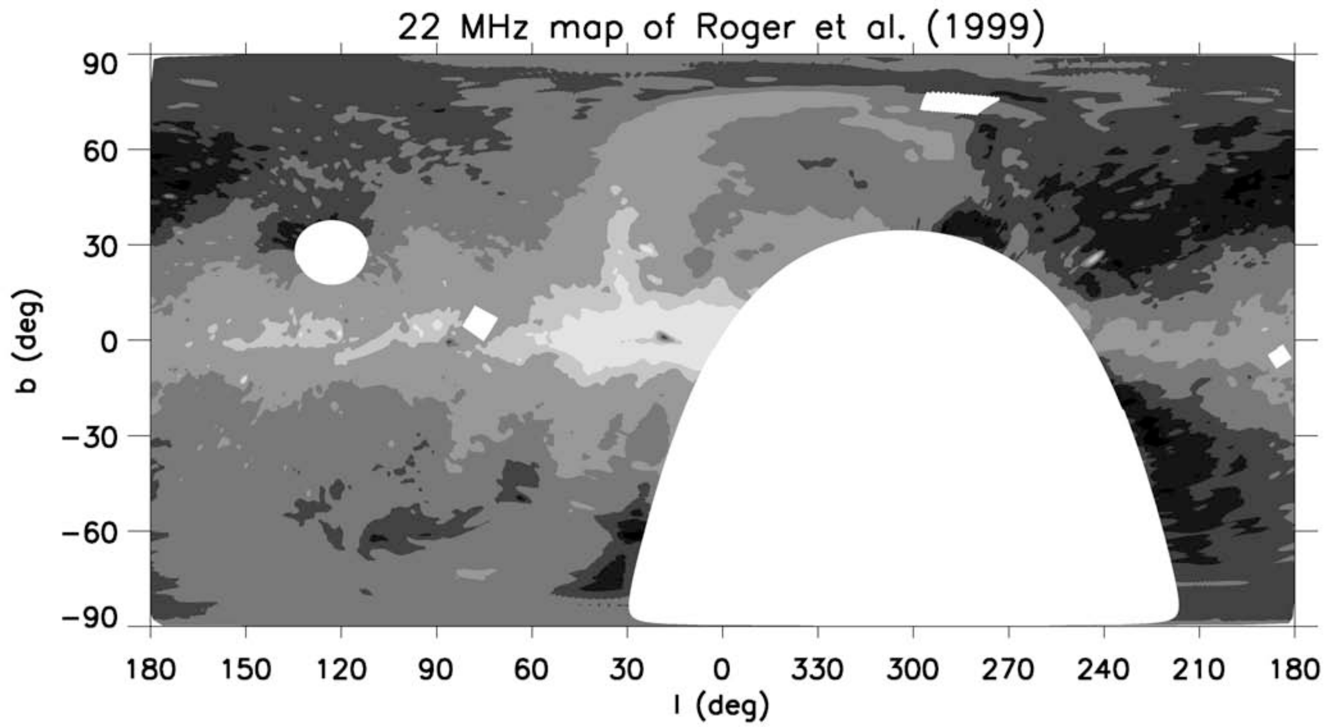
Right: Spectral bending of Galactic emission for 2 regions on the sky.



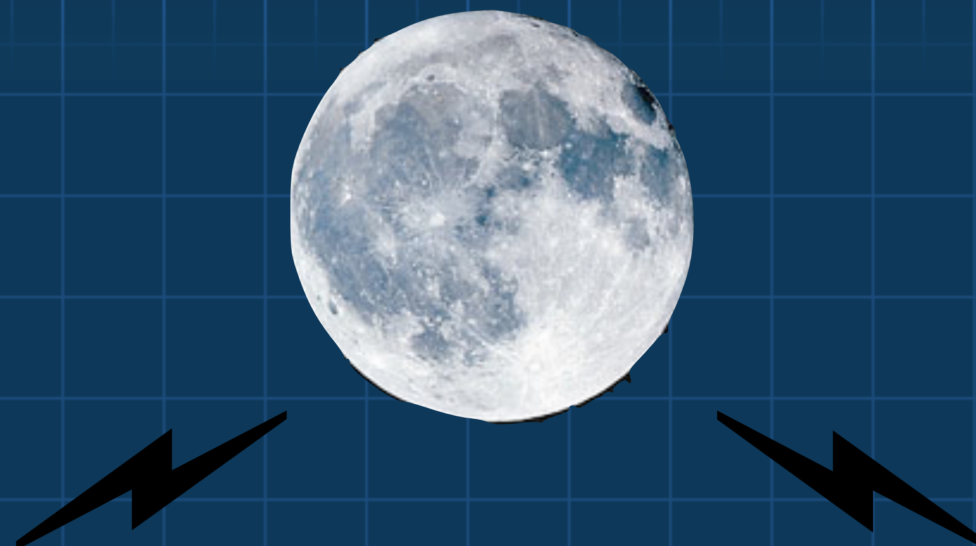
Deficiencies of LFmap

- 22 MHz map not an all-sky map. Incomplete for dec > 75° and < -27° and around strong sources. Indices for incomplete regions crudely set to average index of corresponding regions of complete map.
- 22 MHz map doesn't sample all HII regions near GC. Makes calculated brightness temperatures too high. Affects lowest frequency maps the most.
- Discrete sources have unique spectral indices. Only indices for Cas A and Cyg A are set separately (from Whitfield 1957).
- Discrete sources have low frequency cut-offs due to absorption (< ~30 MHz for Cas and Cyg). LFmap does not correct any discrete sources for absorption.





HAARP/LWA Moon Bounce Experiment



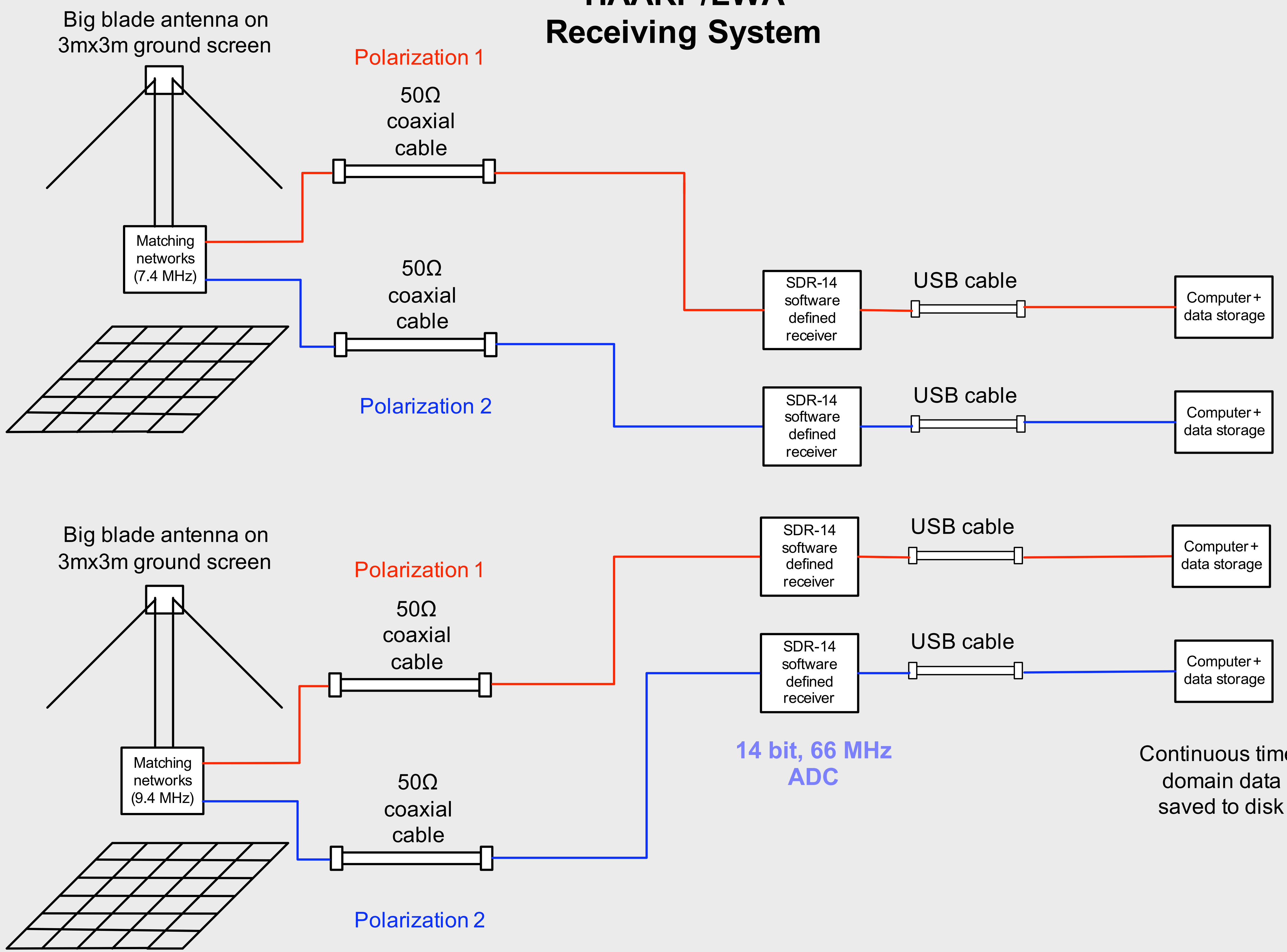
High Frequency Active Auroral Research Program (HAARP) Gakona, Alaska

LWA Big Blade Antenna New Mexico

Overview

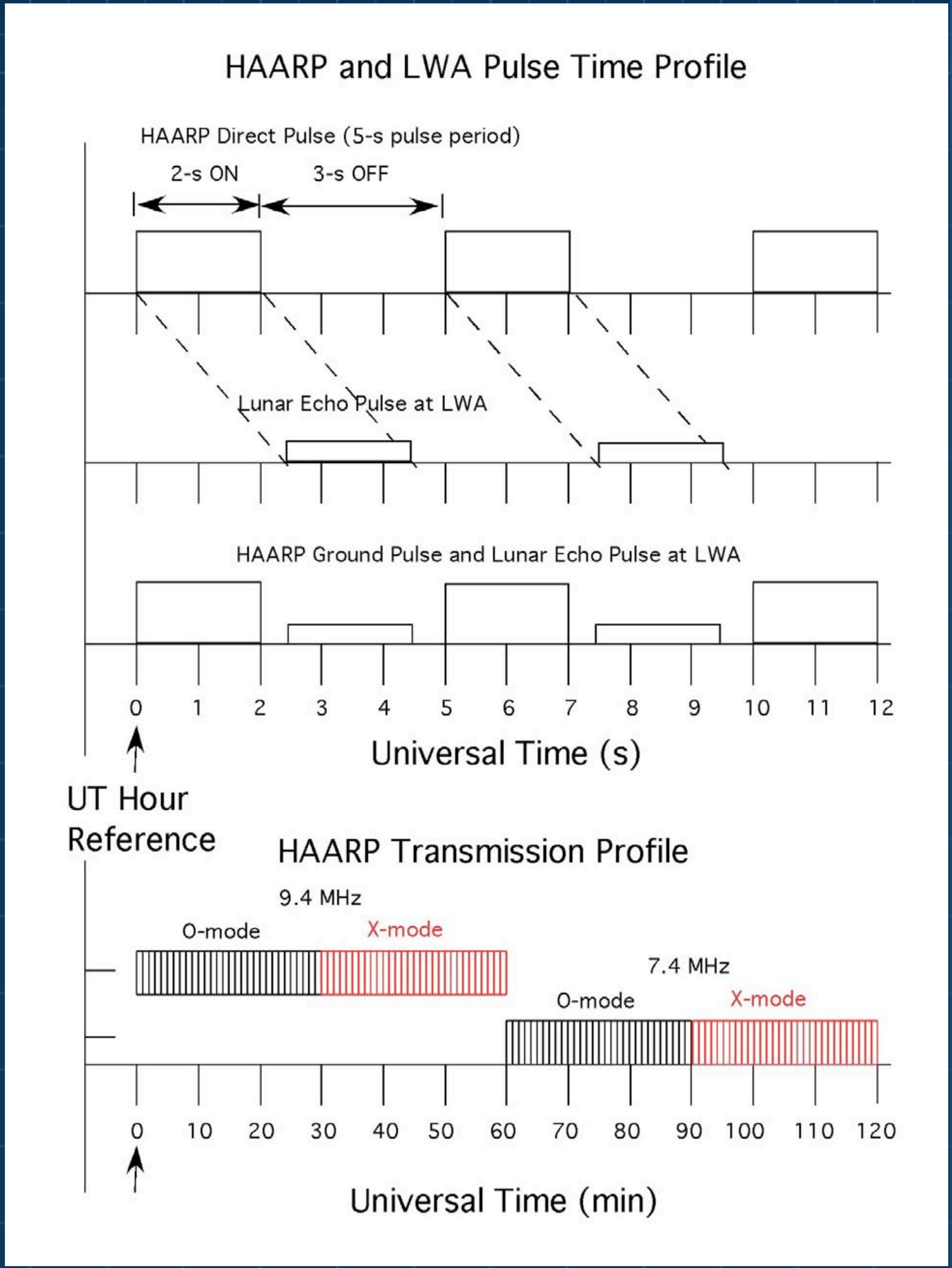
- Goals
  - To conduct bistatic lunar radar echo experiments and measure the lunar radar cross section at a low frequency (7.4 and 9.4 MHz)
  - To measure the performance of LWA antennas below their design range with possible applications to ionospheric research
- Development
  - Experiment architecture
  - Matching networks
  - Control and analysis software
- Execution
  - Planned for October/November

HAARP/LWA Receiving System



HAARP Characteristics

- HAARP will transmit a 2-s pulse every 5 s for 1 hr at each of two frequencies: 7.4MHz and 9.4MHz
- Transmitter power: 3.6 MW
- Number of antennas: 180
- Array area: 22.6 acres
- Array gain: 31 dB
- Half-power beam width:
  - 6º N-S plane
  - 4.7º E-W plane
- Effective radiated power: 96 dBW
- Circular polarization
- Estimated SNR at LWA receiver: 25 dB in 1 Hz bandwidth



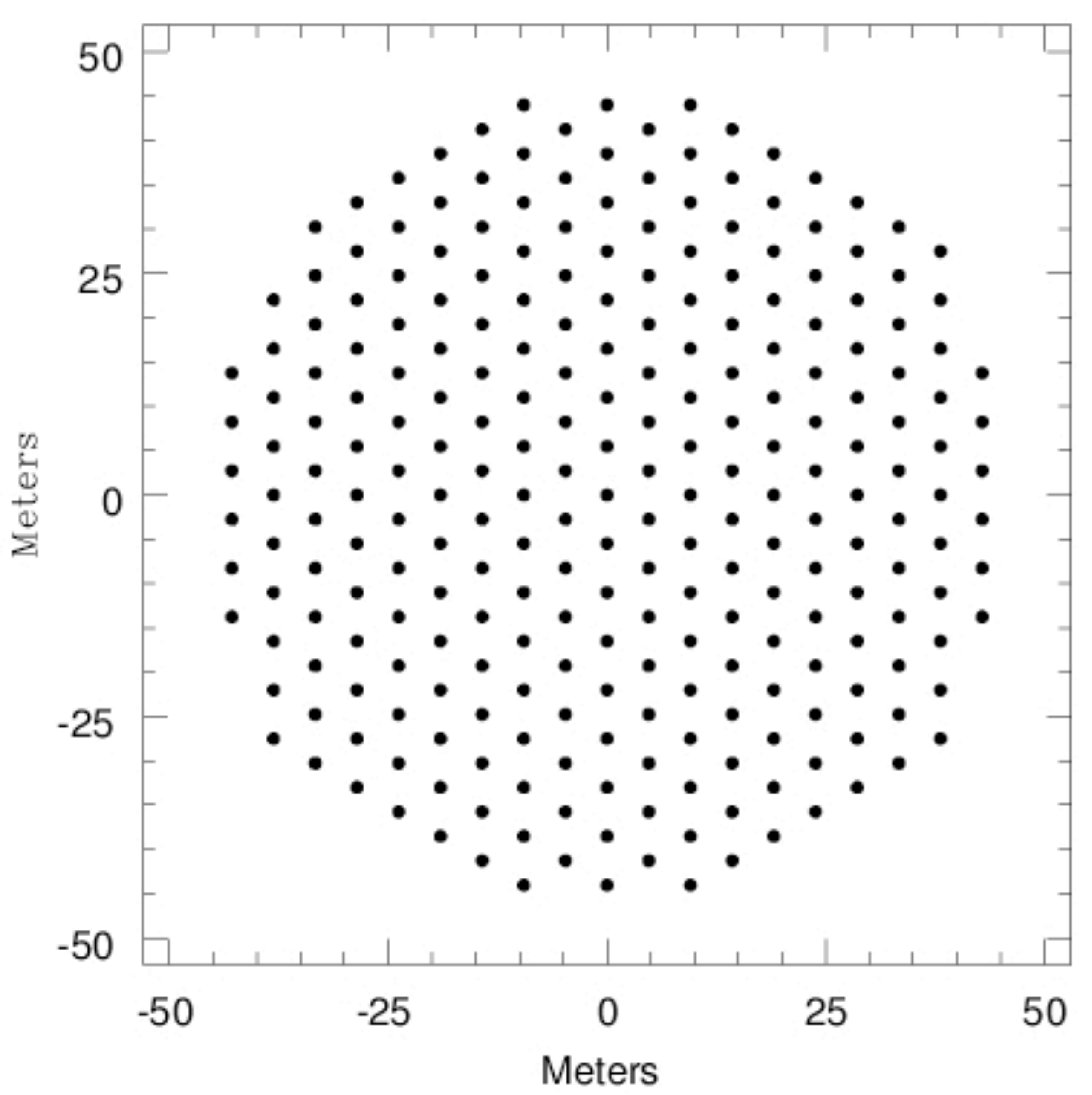
Station Configuration: Issues to Consider

- Beam shape and size
- Sidelobe levels
- Element spacing
- Mutual coupling effects
- Ellipticity?

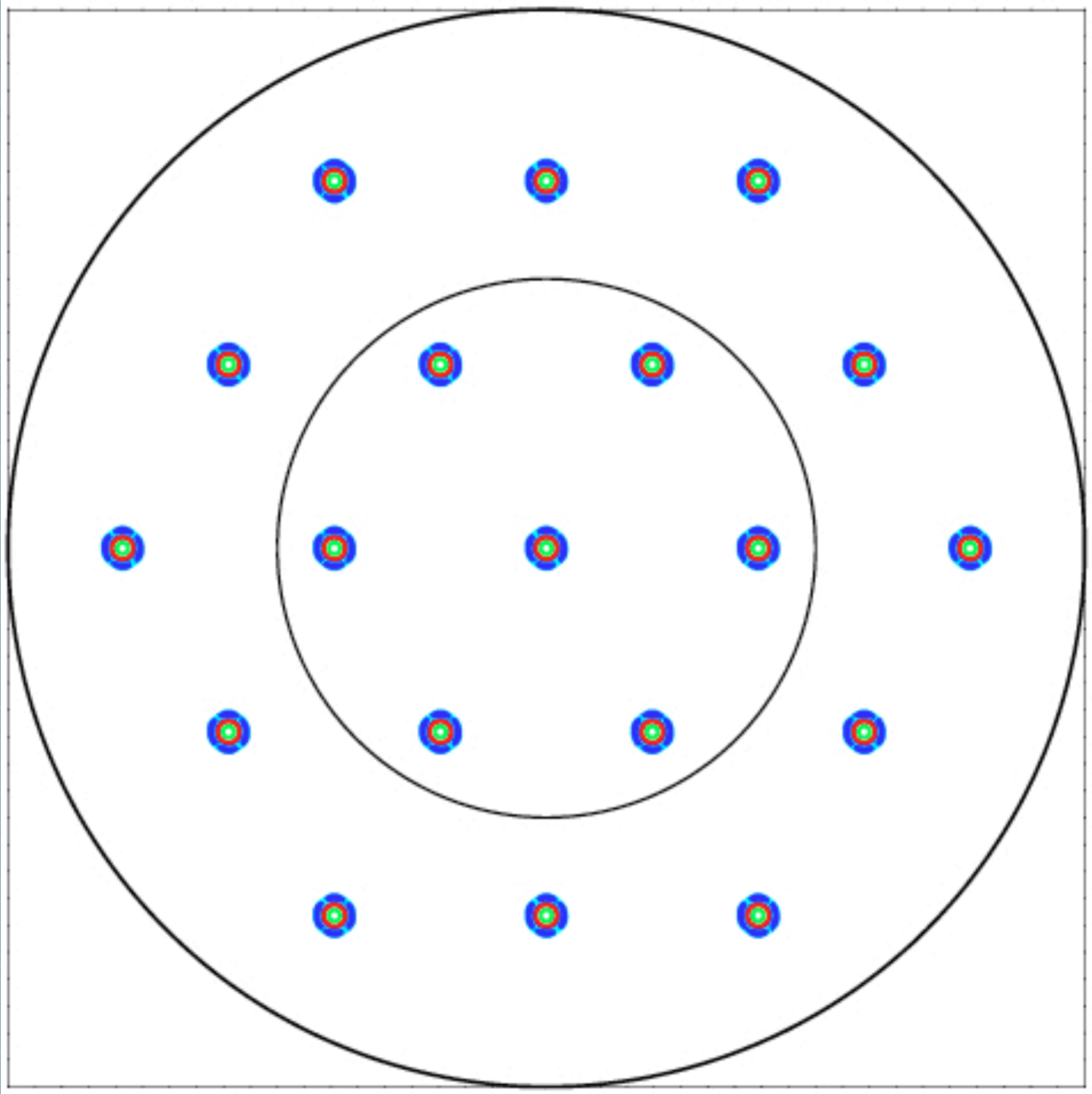
LWA Memos #14, #21

Station Configuration: Regular Pattern

Station Map



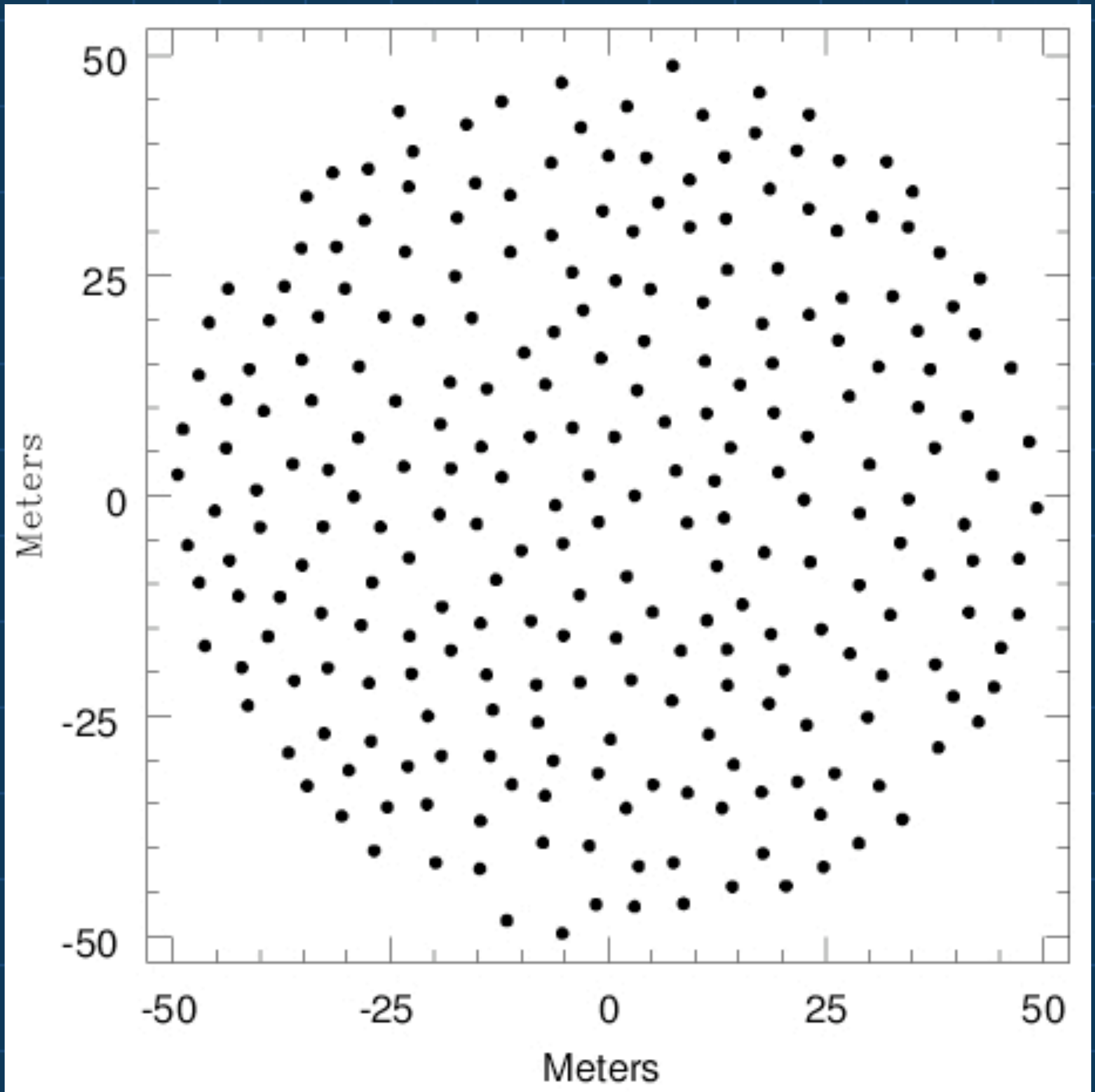
Beam Pattern (80 MHz)



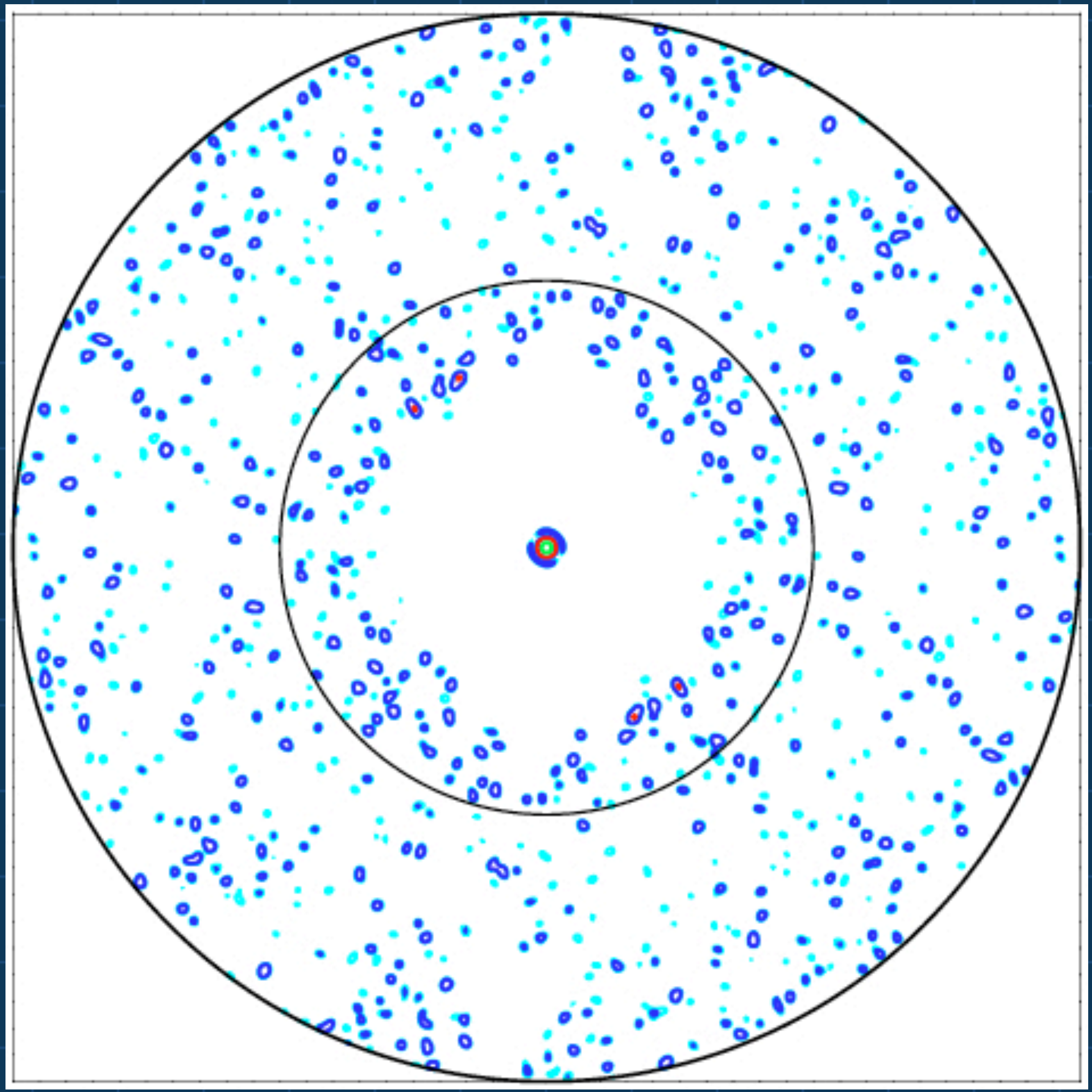
Maximum Sidelobe = 0 dB!!!

Station Configuration: Random Pattern

Station Map



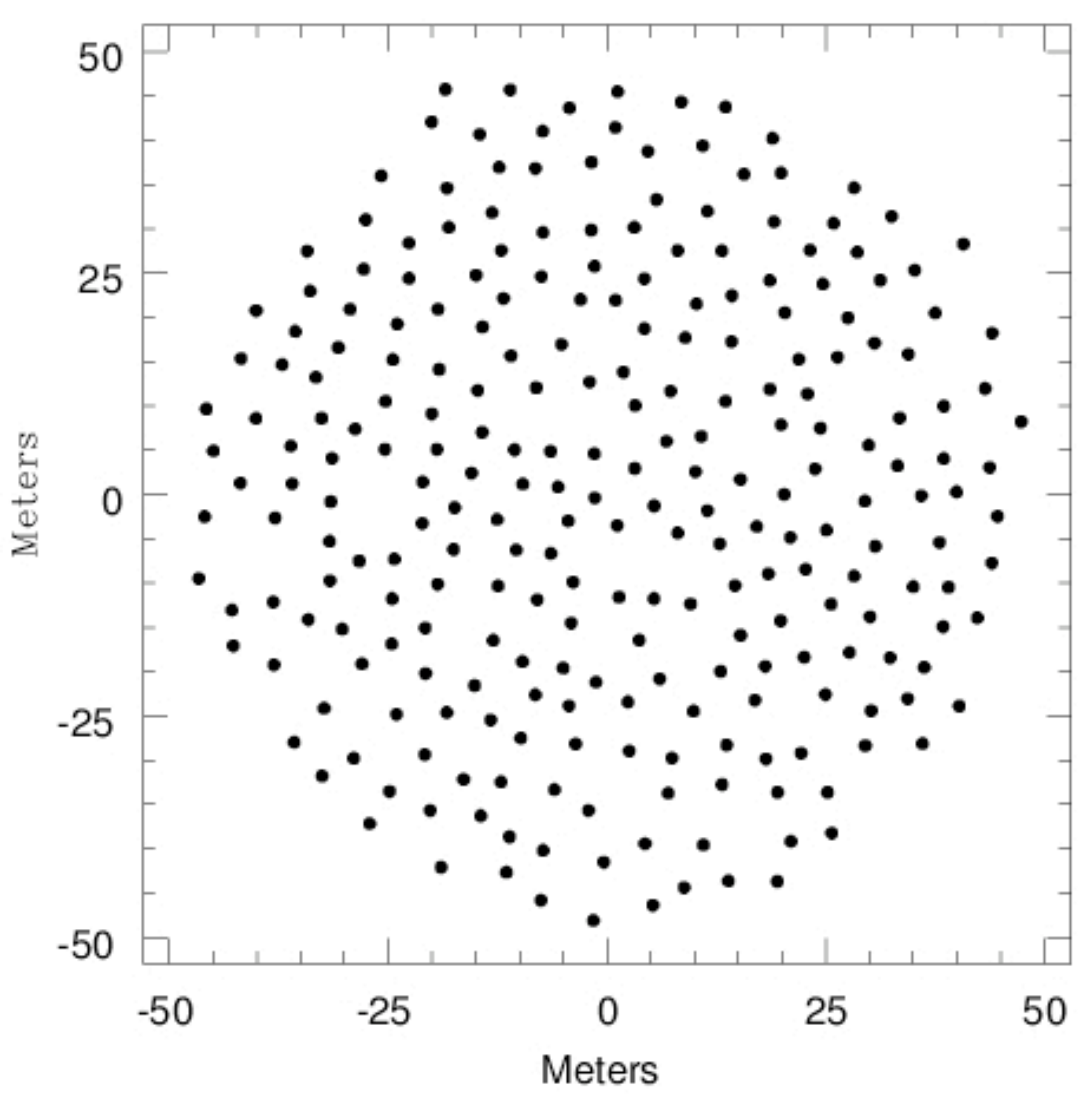
Beam Pattern (80 MHz)



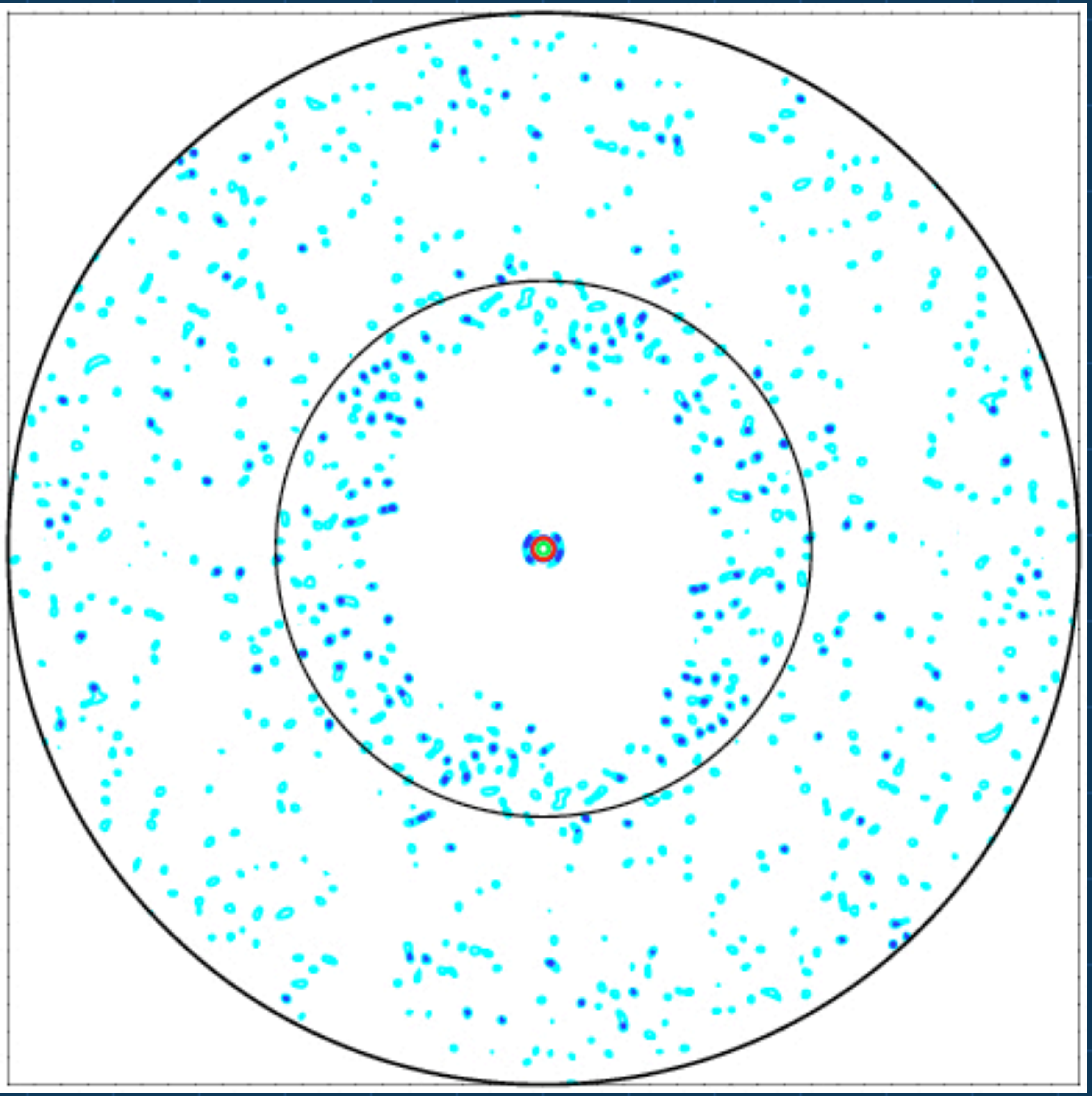
Maximum Sidelobe = -13.7 dB

Station Configuration: Optimized

Station Map



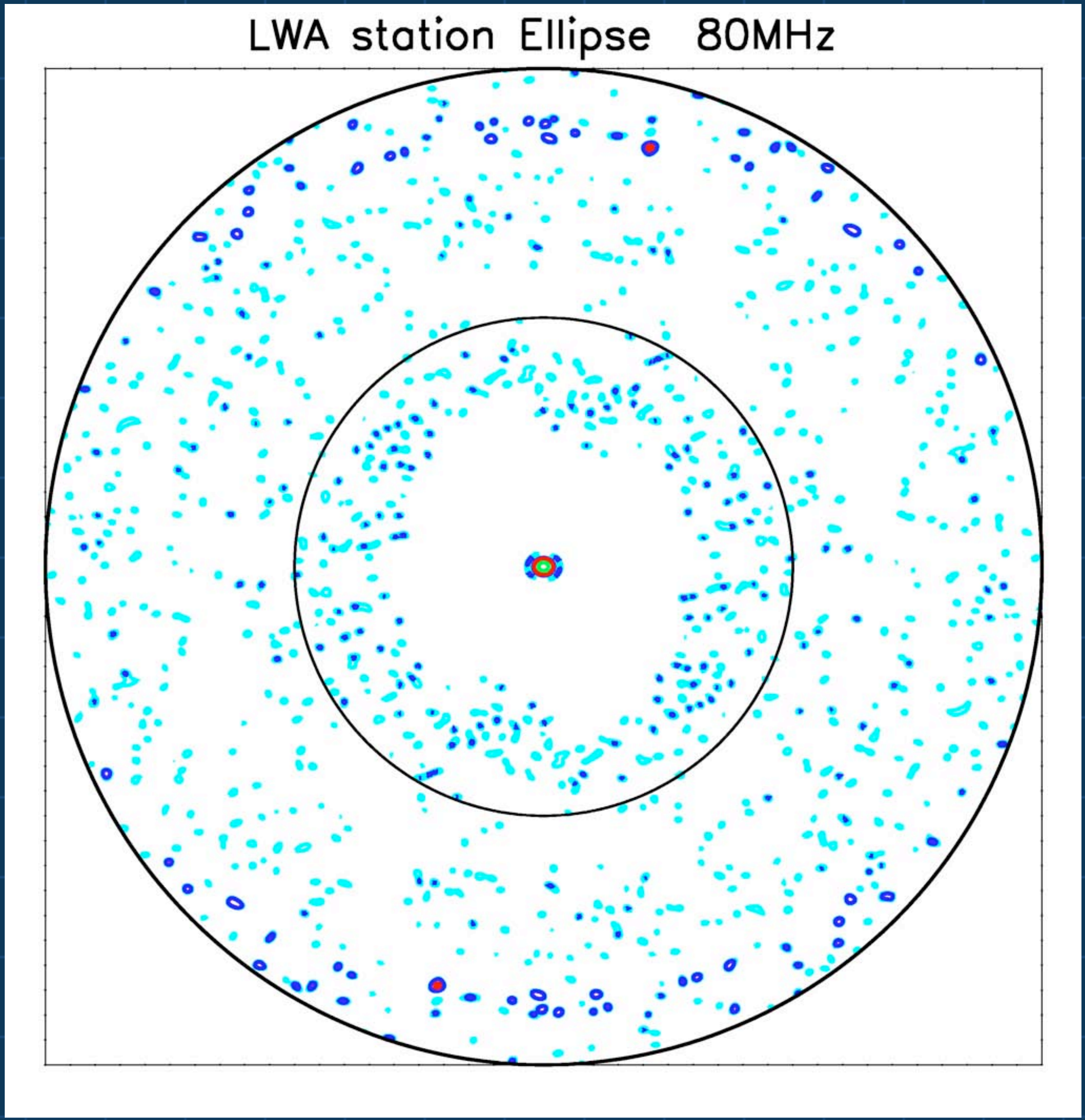
Beam Pattern (80 MHz)



Maximum Sidelobe = -17.7 dB

Station Configuration: Future Work

1. **Incorporate any results from mutual coupling analysis**
   - EM simulations and RTA measurements planned
2. **Consider elliptical stations to produce circular beam at the celestial equator**
   - In progress...

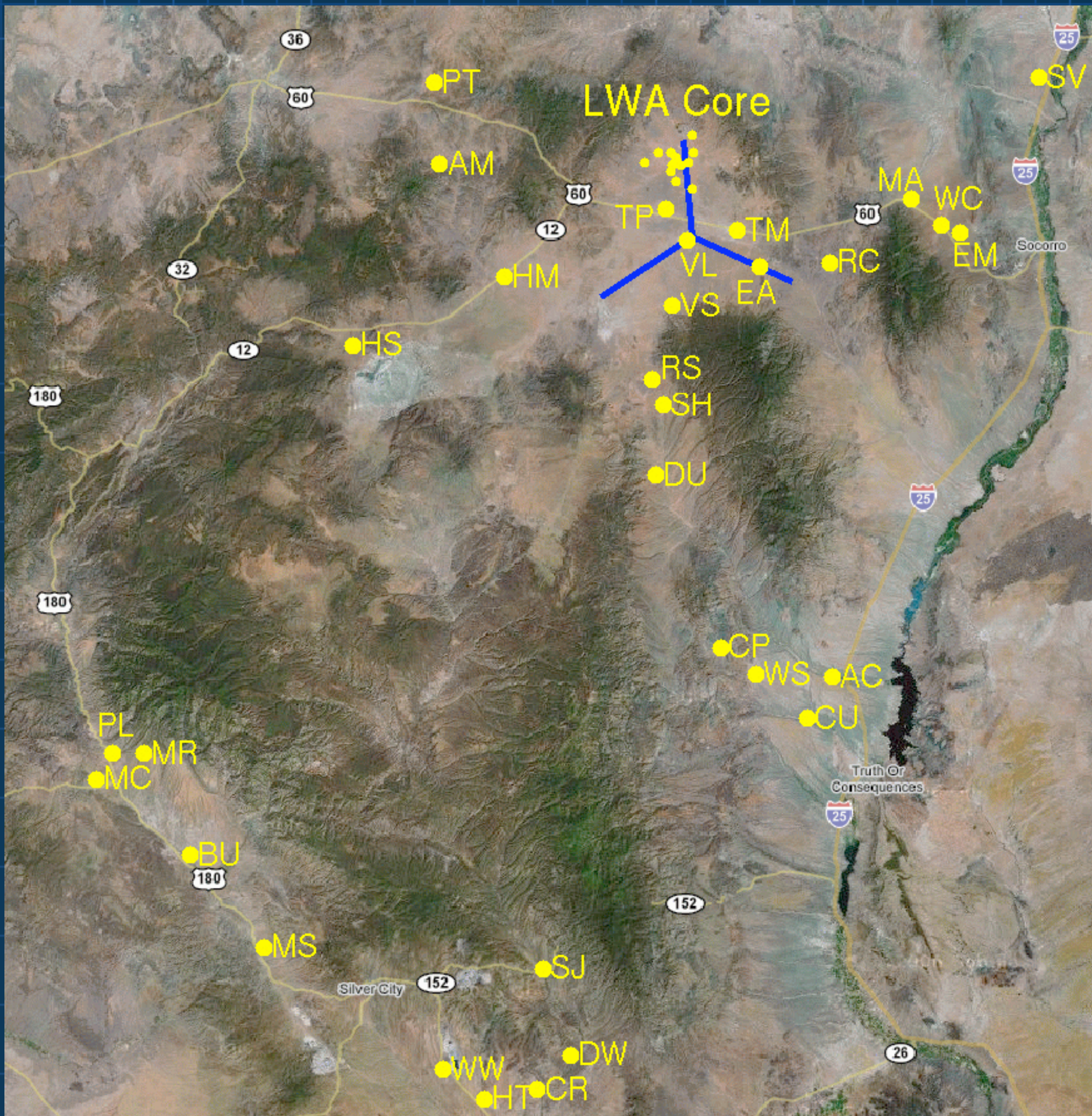


Array Configuration: Issues to Consider

Rating an LWA station site	Rating an array configuration
Terrain Access to Roads, Power, Fiber Land Ownership Fiber Access RFI Environment	UV-coverage Resolution Sensitivity to large scales Synthesized beam shape and size Image Fidelity

LWA Site Studies

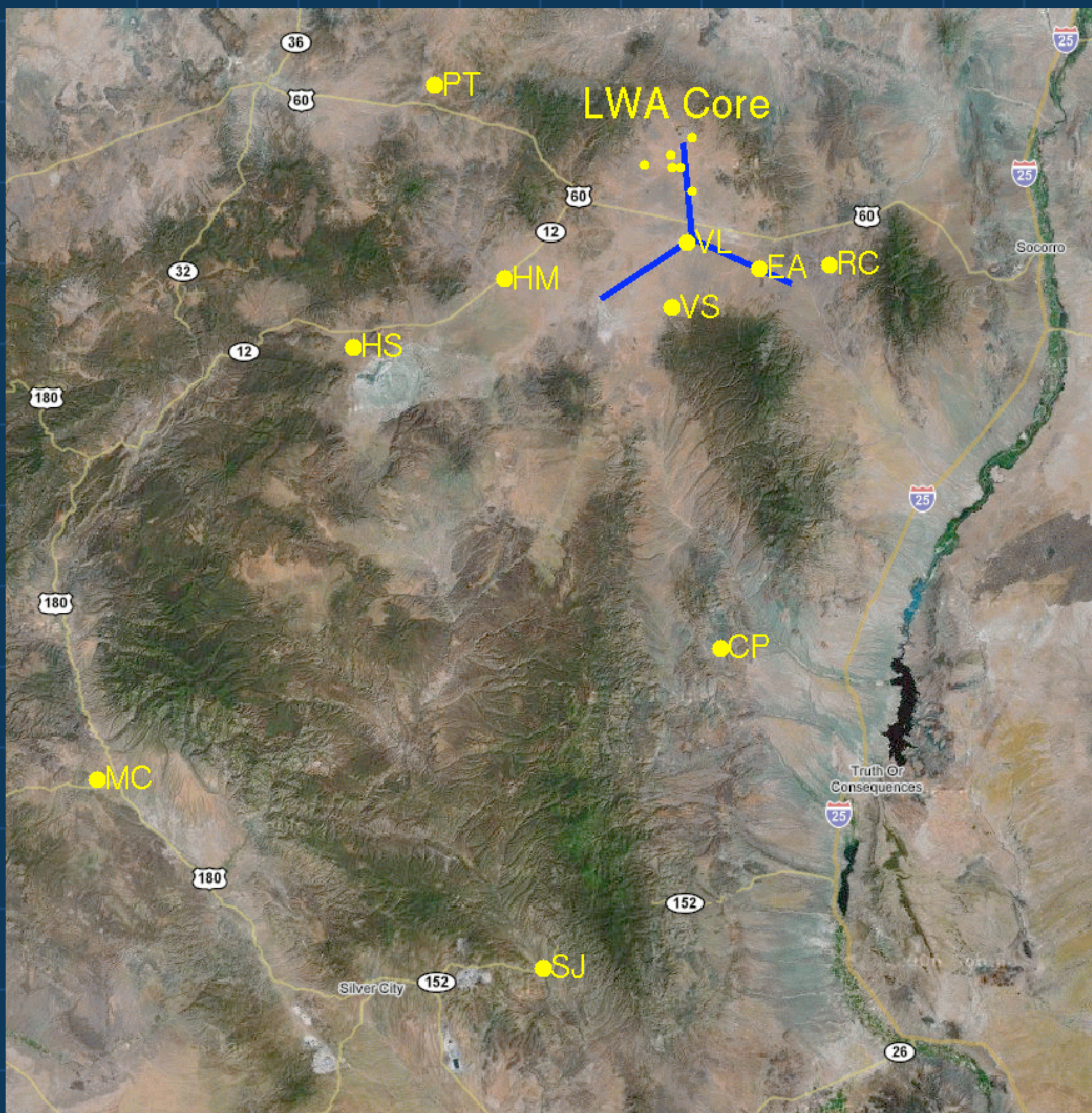
Map of potential LWA sites visited so far



- 32 potential sites visited (mostly by P. Crane and J. Dickel)
- The LWA core will most likely be located near the VLA north arm
- The LWIA will comprise about 6 station in the core and 10 outlier stations.
- Work is ongoing to learn about fiber access, RFI, etc.

LWIA: The Long Wavelength Intermediate Array

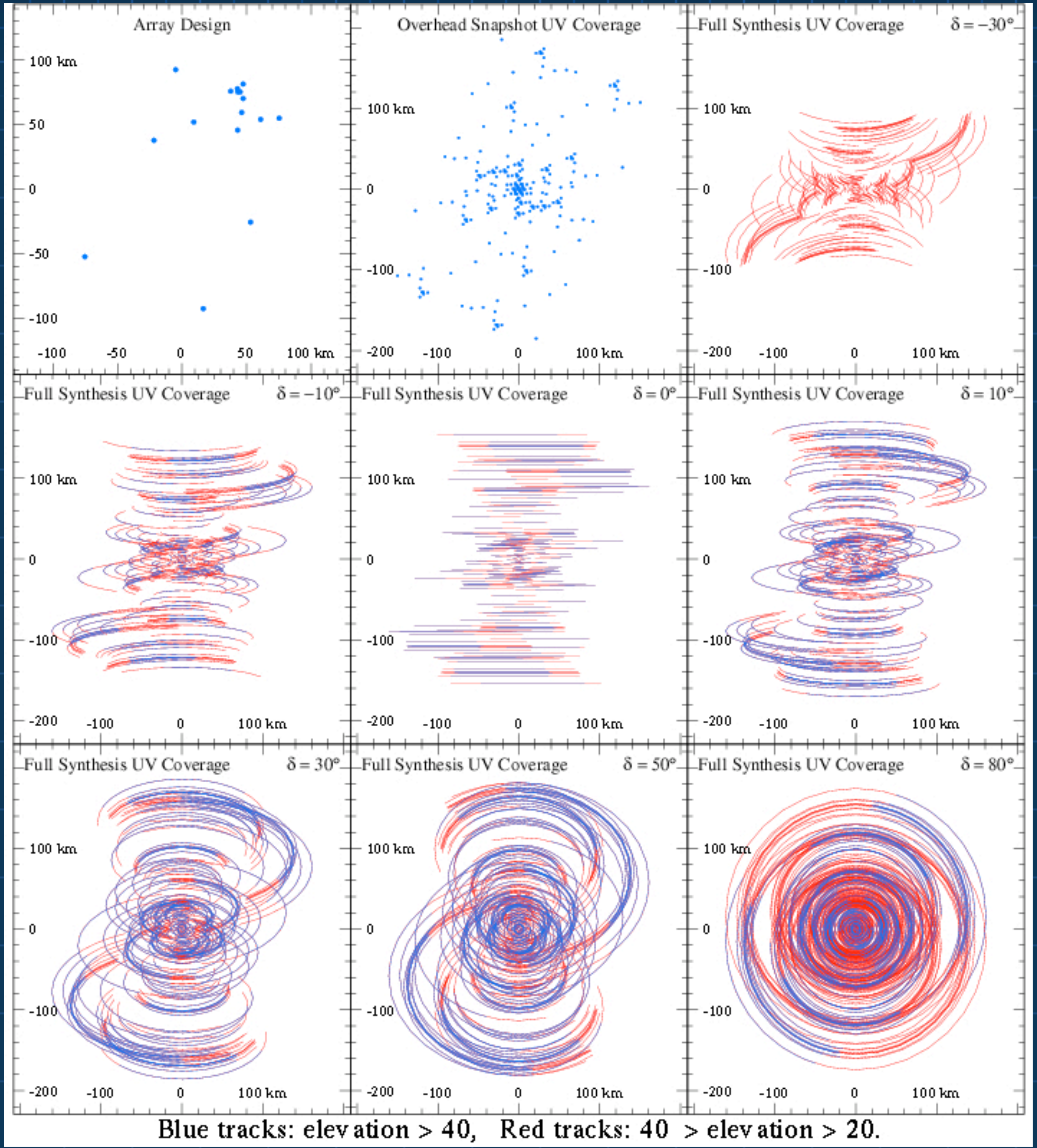
Potential LWIA Configuration



- 16-stations in "intermediate" array
- 6 in core
- 10 outlier sites
- 150-200 km maximum baselines
- Able to self-calibrate and image bright, isolated sources

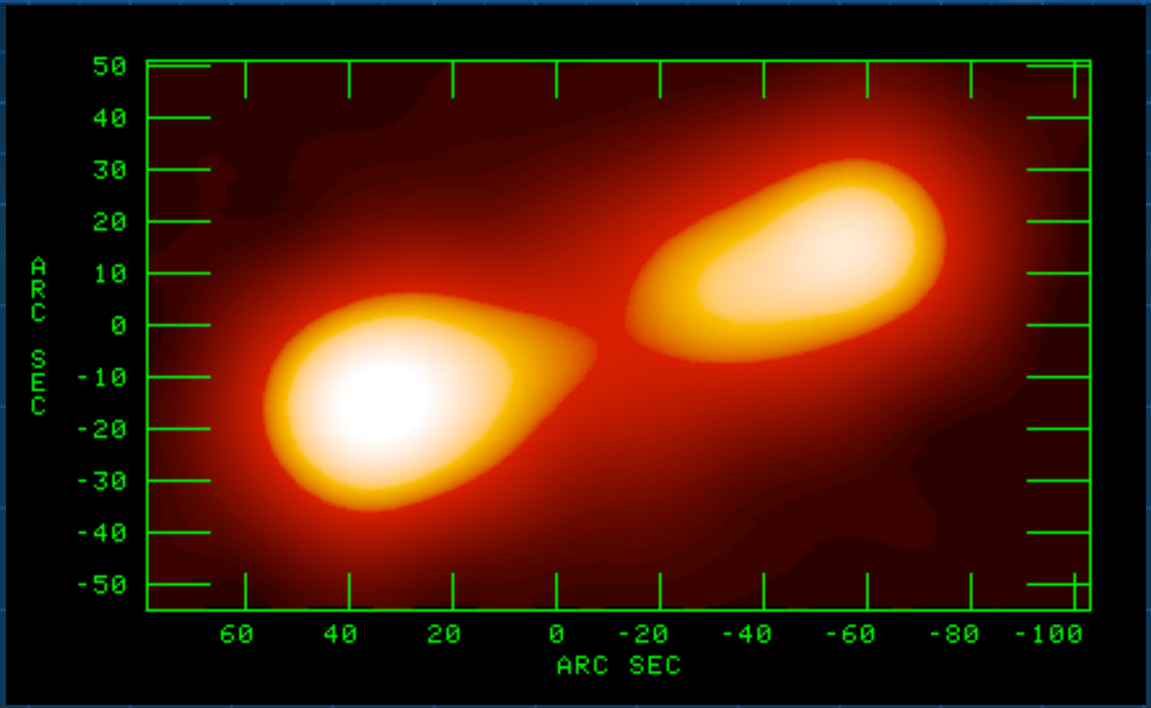
Array Configuration: UV-coverage

UV-coverage for potential LWIA configuration

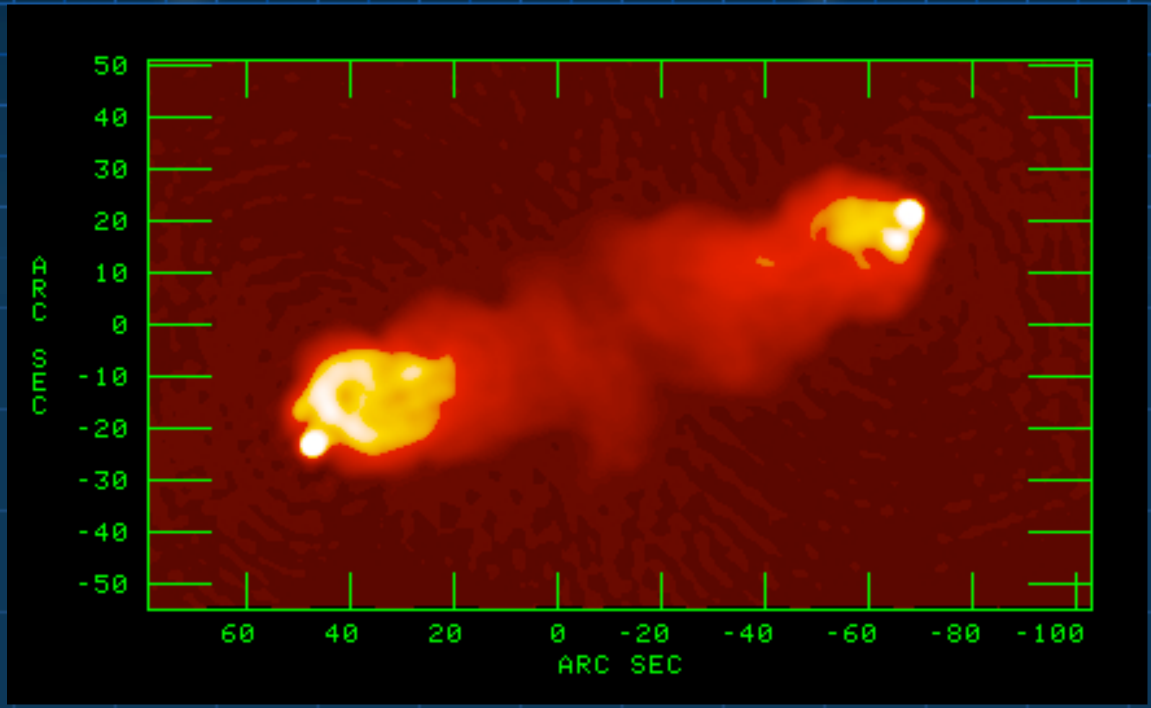


- **Earth-rotation synthesis greatly enhances UV-coverage**
- **UV-coverage varies with source declination**
- **UV-coverage plots can reveal "gaps" to be filled.**

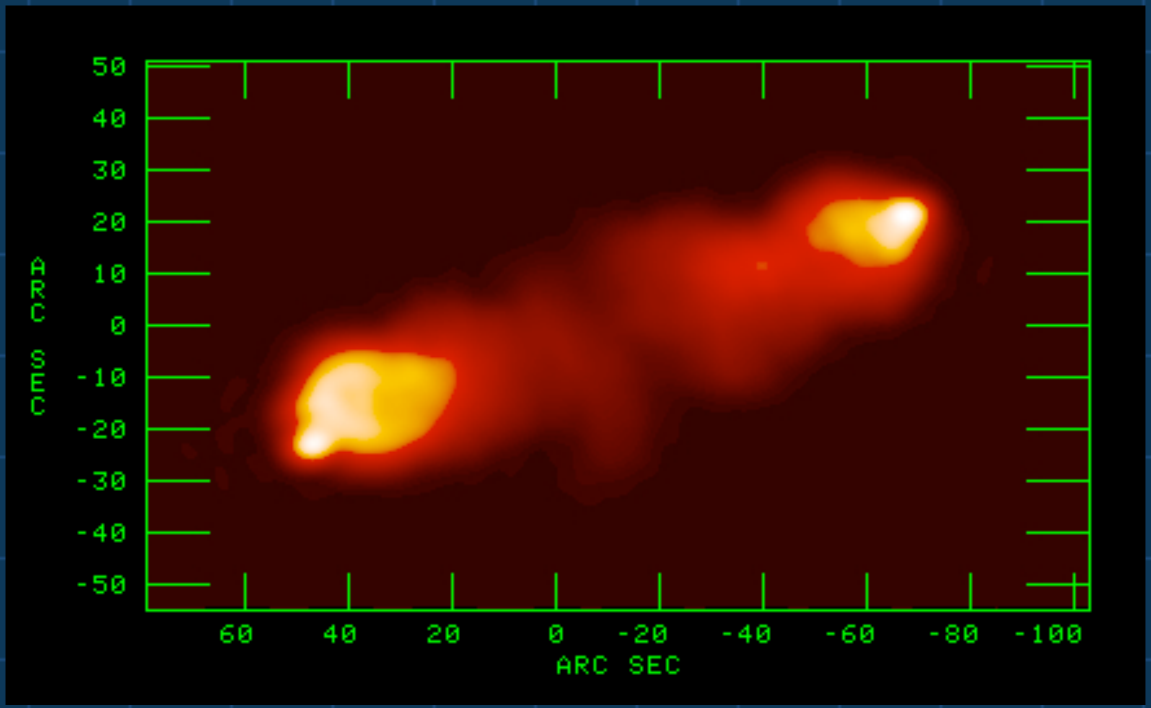
Simulating Image Fidelity



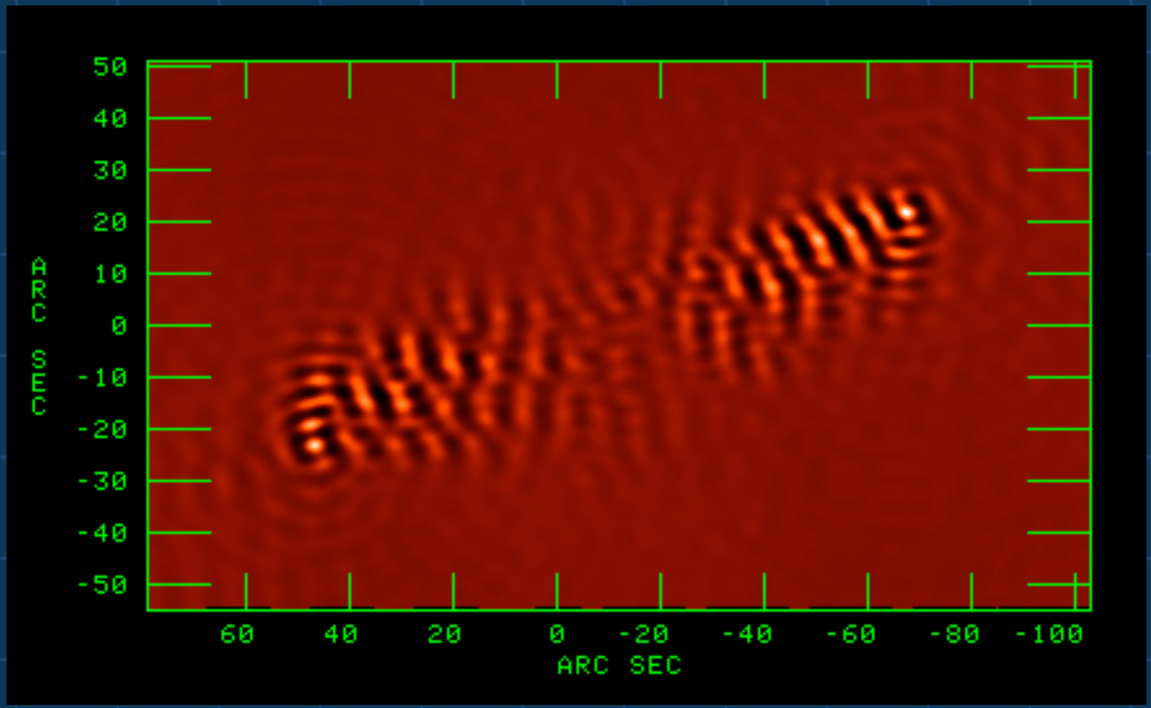
74 MHz VLA A-configuration Image



High-frequency image used as model



Simulated LWIA image at 74 MHz

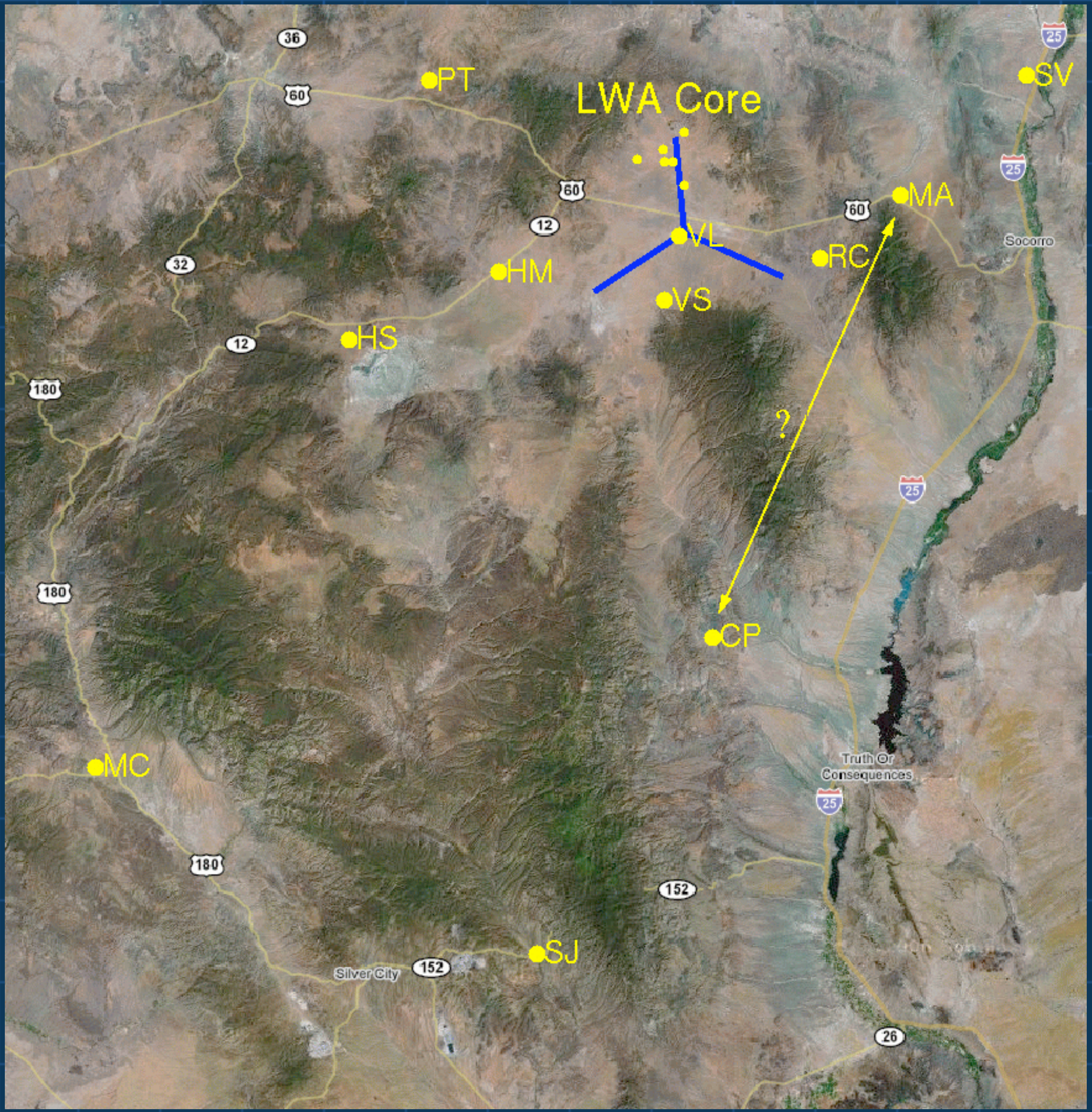


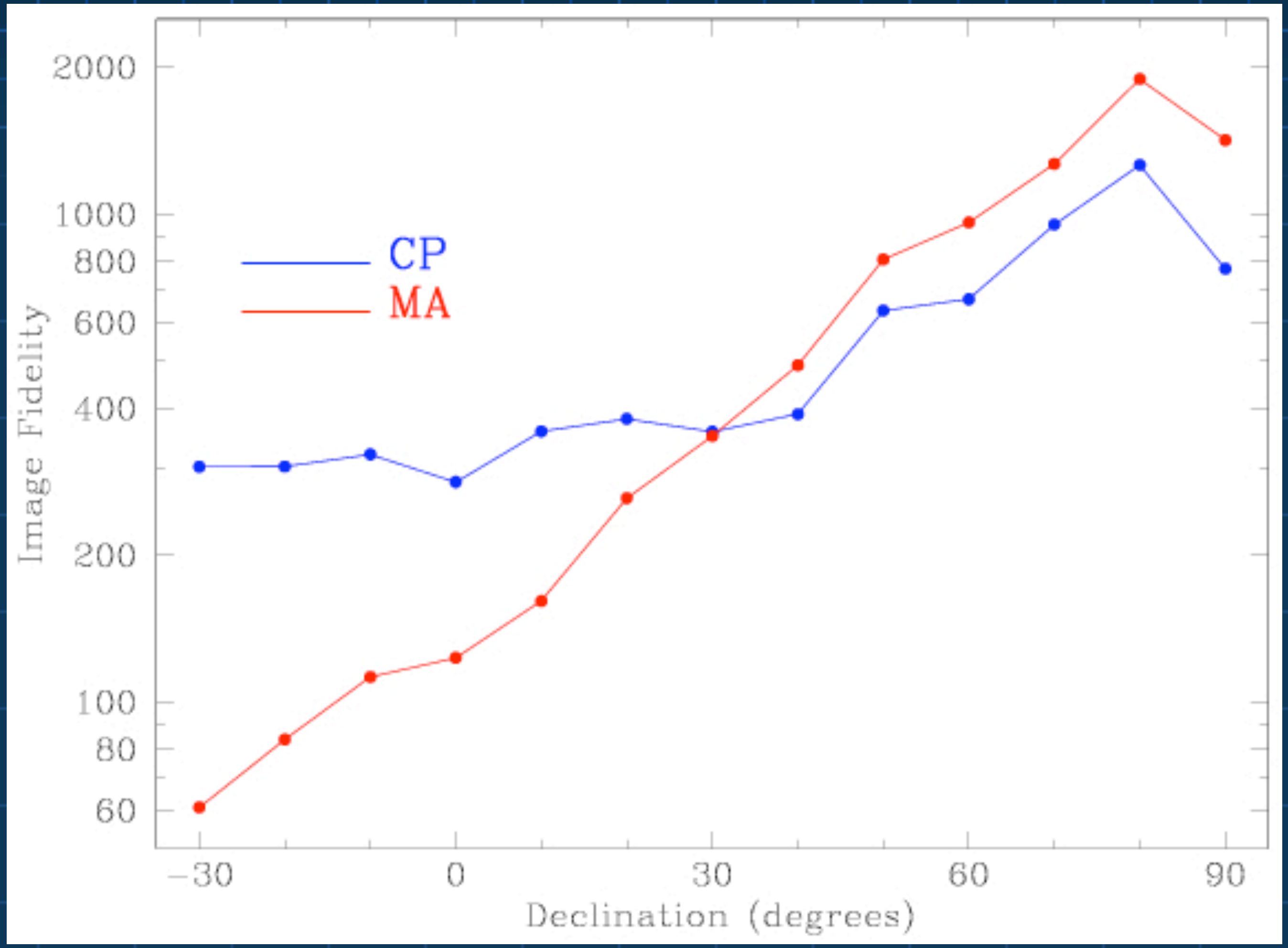
Residual image

Image Fidelity = (Peak flux density)/(RMS of residual image)

Array Comparisons

Potential LWIA Configuration





- **Image fidelity is a function of source declination.**
- **The above plot shows the difference in image fidelity from adding either CP or MA sites to a given array configuration.**

Array Configuration Summary

- Site studies are ongoing
- Many promising sites have been identified, and we continue to gather information on these.
- We have developed quantitative methods for rating the merit of any given array configuration.

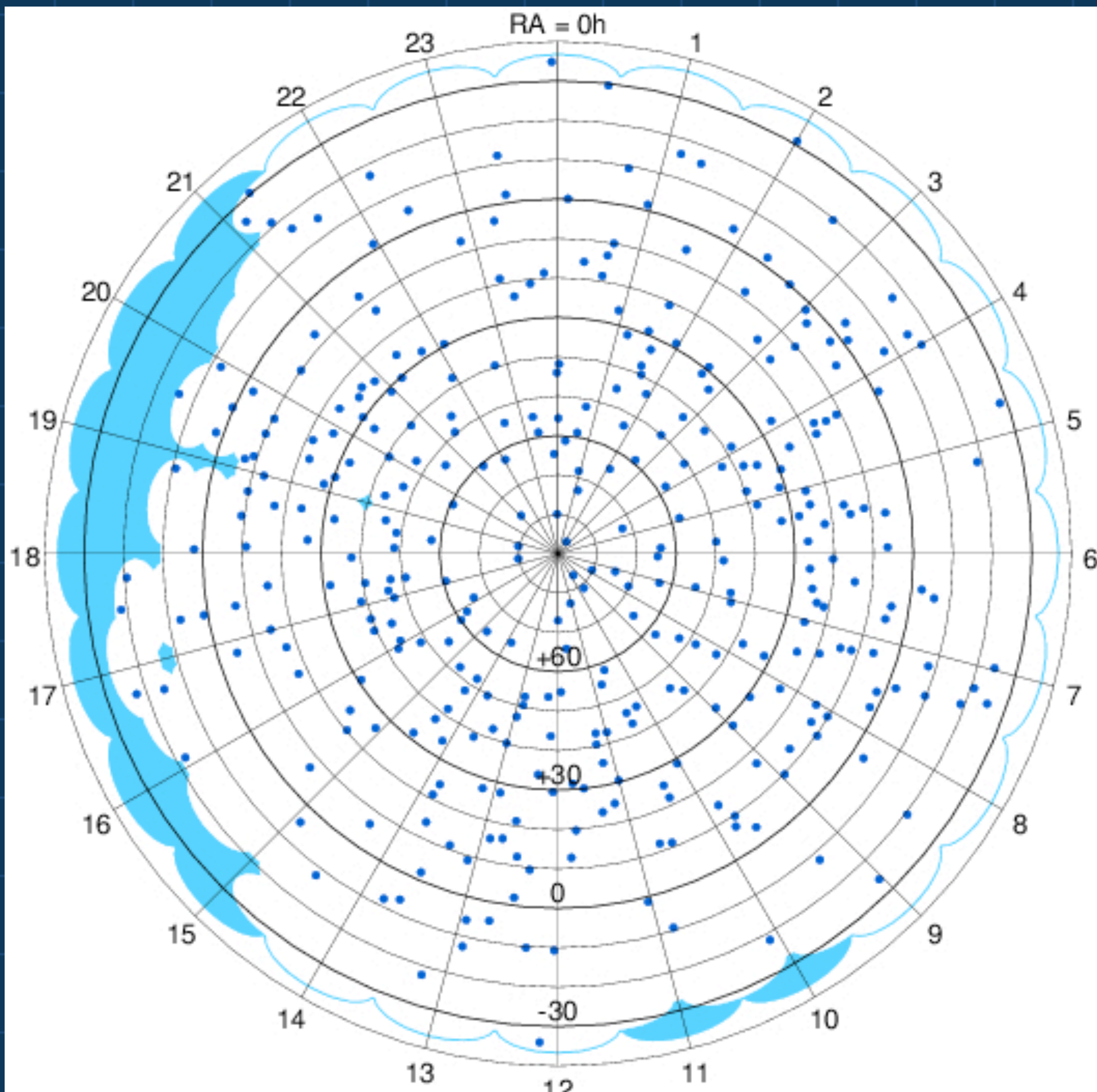
LWA Memo #55

Capabilities of the 16-Station LWIA

- The effective collecting area and resolution will both be more than 5 times that of the VLA at 74MHz, allowing for unprecedented views of astronomical sources.
- With only 16 stations, it is unlikely that we will be capable of full-field ionospheric calibration
- Self-calibration on bright, isolated sources will be the main mode of operation, but we can explore other methods.

LWIA: Astronomy and Ionospheric Studies

Calibrator Sources Identified Using VLSS

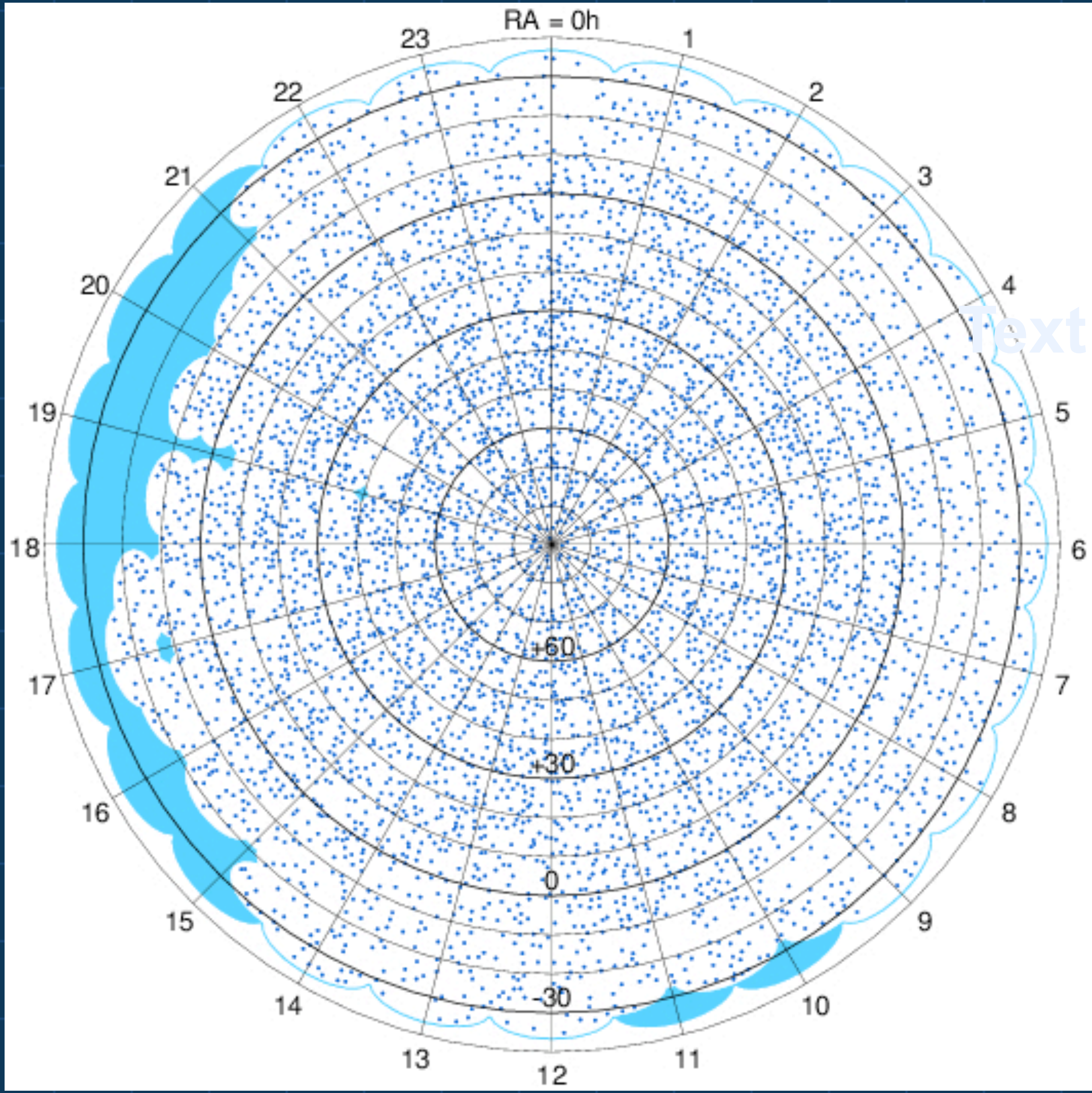


- **VLSS identified 362 sources for self-cal with the LWIA.**
- **Astronomy: 5 SNRs, 5 halo/ relic systems, 8 cooling-core clusters, 100s of radio galaxies...**
- **Ionosphere: At least 100 sources available for ionospheric probes at all times (versus only a few GPS satellites).**

LWA Memo #80

LWIA: Astronomy and Ionospheric Studies

Sources possibly visible with BW-smearing



- With bandwidth smearing on baselines up to 150km it may be possible to self-calibrate over 4,000 sources
- We can test more sophisticated ionospheric calibration methods to learn more about our needs for the full LWA

LWA Memo #80

Summary and Plans

- Significant progress has been made on a wide variety of technical fronts
  - Simulations, prototyping, and field measurements have provided data to support system design decisions
  - Antenna and FEE heading towards PDR readiness
  - Demonstration experiments have provided (and will provide) valuable experience and proof-of-concept data
- Now working to conform to project plan being developed as we head towards SRR and PDR
- Organizing efforts under new WBS and coordinating with System Engineer and Project Manager via weekly TWG telecons

Subsys	WBS	Lead	Status	Tasks
STD	1.3			• Stand Design/Dev/Fab/Document/Install/Test/Operations training
ANT	1.3.1			• Antenna
				• Simulation Activities
		Paravastu	Starting Soon	• Detailed comparison of the sky noise dominance of the Fork or inverted-V compared to the big blade. For the fork/V we will include the increased noise temperature of the balun that results from using an autotransformer to get the higher impedance, and the tradeoffs to get higher impedances will be evaluated.
		Paravastu		• Will work with Steve Ellingson on array optimizations incorporating mutual coupling, performing simulations, analysis, and measurements as required.
				• Prototyping Activities
		Ray	In Progress	• Write up Antenna/Balun Test Procedure including impedance measurements, spectral, and diurnal variation measurements. Perhaps Y-factor measurements?
		Ray	In Progress	• Will do a performance analysis of existing big blade from existing Specmaster data, similar to LWA Memo #60.
		Polisensky	In Progress	• Complete development of sky temperature model with effects of absorption.
				• Analysis of Specmaster drift scan data from recent antenna measurements, including comparison with predictions.
				• Analysis of spectral data from recent antenna measurements (on, off, load, short, etc...). Includes calibrated noise source (Y-factor) measurements.
				• Build prototype of PDR STD design and test in the field
				• Present candidate antenna designs at PDR
EMD	1.3.2			• Electromechanical Design
				• Burns Industries Design Work
		Paravastu et al.	Done	• Get preliminary quotes for manufacture of 256 LWA antennas
		Paravastu/ Hicks		• Look at hub design issues such as size, FEE board sizes, connections to antenna, etc...
		Paravastu		• Explore cost-performance tradeoffs among element shapes: Tied Fork, Blade outline, or Big Blade
				• Develop PDR-ready design for STD
GND	1.3.3			• Ground Screen
		Paravastu	Starting Soon	• Comparison of field impedance measurements for Big Blade, Tied Fork, and Burns Dipole over ground screens with CST and NEC4 simulations.
		Paravastu		• Analysis of optimal size of ground screen. Sims might include zenith gain, collecting area, and beam profile as a function of ground screen size.
				• Define how a ground screen might be implemented in an LWA station (i.e. building coaster sized screens into antenna frame, needing wires to be continuous in both E- and H-plane directions, etc.) Working with Steve Burns and Eduardo on this.
FEE	1.3.4			• Front End Electronics
				• Documentation
		Hicks	Starting Soon	• Write memo documenting the production version of the TeleTech balun, as used in the LWDA, including features, costs, parts lists, and photos.
		Hicks	Starting Soon	• Write initial memo documenting new G250R balun design, layout, and costs, S-parameters, 1 dB compression. (IP2/IP3 and Noise Figure will be done in a later memo when we figure out what equipment we can use)
				• Design Studies
				• Prototype Construction
		Hicks	Done	• Develop new balun revision with voltage regulator and additional gain stage
		Hicks		• Develop a PDR-ready balun prototype for LWA-1 incorporating lessons from current spate of memos
				• Prototype Field Testing
		Hicks		• Document field performance of new G250R balun and understand source of improvements over LWDA balun
RFD	1.3.5			• RF and Power Distribution
		Hicks	Starting Soon	• Draft a memo on the pros and cons of using 75 ohm cable considering various options and accounting for performance, cost, and availability
RTA				• Rapid Test Array
				• Hardware Construction
		Hicks	Starting Soon	• Build new run of RTA baluns with minor revisions
		Hicks	In Progress	• Construct 8-port bias-T to enable upgrade to 8-element RTA-2
		UNM		• Complete construction of 8 more RTA antennas to bring total to 12 (8 in RTA-2 and 4 for RTA-1)
		UNM		• Build fence to protect RTA-2
				• Testing
		Schmitt	In Progress	• Analysis of visibility data from RTA-2 + LWDA

Subsys	WBS	Lead	Status	Tasks
HAARP				• Experiments with HAARP
				• Management
		Stewart	In Progress	• Develop work plan and budget for HAARP moon bounce experiments
				• Hardware Construction
		Stewart	Done	• Design matching network and balun to allow operation at low frequency
		Hicks	In Progress	• Build PC boards with network and balun
				• Experiments
		Stewart	In Progress	• Design Test Plan for HAARP Moon bounce experiments
				• Execute HAARP Moon bounce experiments
LWDA				• Long Wavelength Development Array
				• Engineering
				• Time domain RFI survey
				• Array calibration with astronomical sources
				• Software
		Wood	In Progress	• Work with J. York to debug LWDA low level control software
				• Science
				• Detect pulsar with the LWDA
				• Perform all-sky transient survey
				• Study giant pulses
				• Study solar bursts at high time resolution
	1.10			• Data Processing S/W Design/Dev
	1.10.?			• Data Format
		Wood	Done	• Develop and document FITS-IDI format for LWDA/LWA single station all-sky visibility data
	1.11			• Data Post-Processing and Analysis S/W
	1.11.1			• Post-Processing Tools
		Clarke		• Develop AIPS pipeline to process all-sky transient survey
ASP	1.5			• Analog Signal Path Design
	1.5.1			• Analog Receiver
		Duffin	Done	• Do RFI survey to serve as input for receiver design specifications

NRL Contributors

- Paul Ray
  - NRL System Engineer; Science
- Dan Wood (Praxis)
  - Software engineering
- Kurt Weiler
  - Project Management
- Ken Stewart
  - HAARP experiments; Antennas
- Henrique Schmitt (Interferometrics)
  - LWDA analysis; Science
- Emil Polisensky
  - UMD Grad Student; Configuration studies; LWA sky model
- Wendy Peters
  - LWDA analysis; RFI excision; VLSS; Science
- Nagini Paravastu (ASEE)
  - Electrical engineering; Antennas; EM simulations; Testing
- Joseph Lazio
  - Transient searches; RFI excision; LWDA analysis; Science
- Namir Kassim
  - Project Scientist
- Brian Hicks
  - Electrical engineering; FEE designs; Prototyping; Antennas; Software
- Ken Dymond
  - Ionospheric research
- Robert Duffin (GMU)
  - GMU Grad Student; Solar monitoring; RFI studies
- Clayton Coker
  - Ionospheric research
- Aaron Cohen
  - Configuration studies; VLSS; Ionospheric Calibration; Science
- Tracy Clarke (Interferometrics)
  - LWDA analysis; Science requirements; Transient pipeline; Science
- Richard Bevilacqua
  - Executive Committee

Status of VT
Technical Work

LWA Pre-SRR Kickoff Meeting – Albuquerque, NM
September 21, 2007

Steve Ellingson
ellingson@vt.edu

Bradley Dept. of Electrical and Computer Engineering
Virginia Polytechnic Institute & State University

Virginia Tech 1872

LWA

Eight meter wavelength Transient Array (ETA)

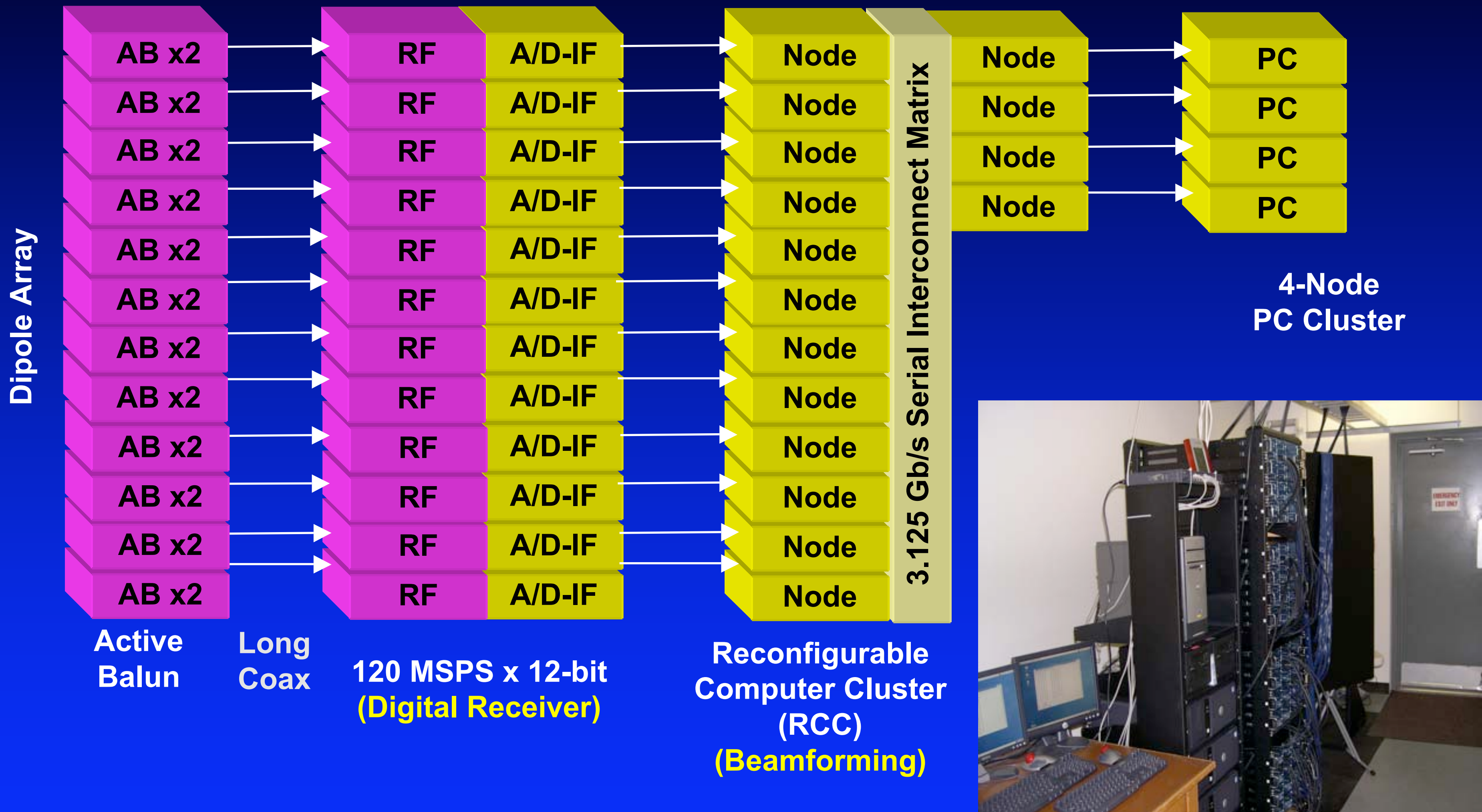
- **Operational continuous, all-sky, low-frequency, "source agnostic" search for single dispersed pulses with 10 < DM < 1000 pc cm^{-3} using an array of 12 dual-polarized dipoles, Galactic noise-limited in 29-47 MHz. Also underway:**

- **Evaporating primordial BH pulse search**
  - **~1 hour/night, same sidereal time each night**
  - **Timed so that B0950+08 is high in sky (~4 sigma in 1 hr - our sanity check)**
  - **25.5 h collected, 3 h fully processed, no detections > 5σ for 10 < DM < 100**
  - **When existing data is processed, will have improved density limit by OMs**

- **GCN-triggered GRB prompt emission search**
  - **5 "very good" triggers so far**
  - **1 trigger fully analyzed, No detections > 5σ for 10 < DM < 100**

Virginia Tech

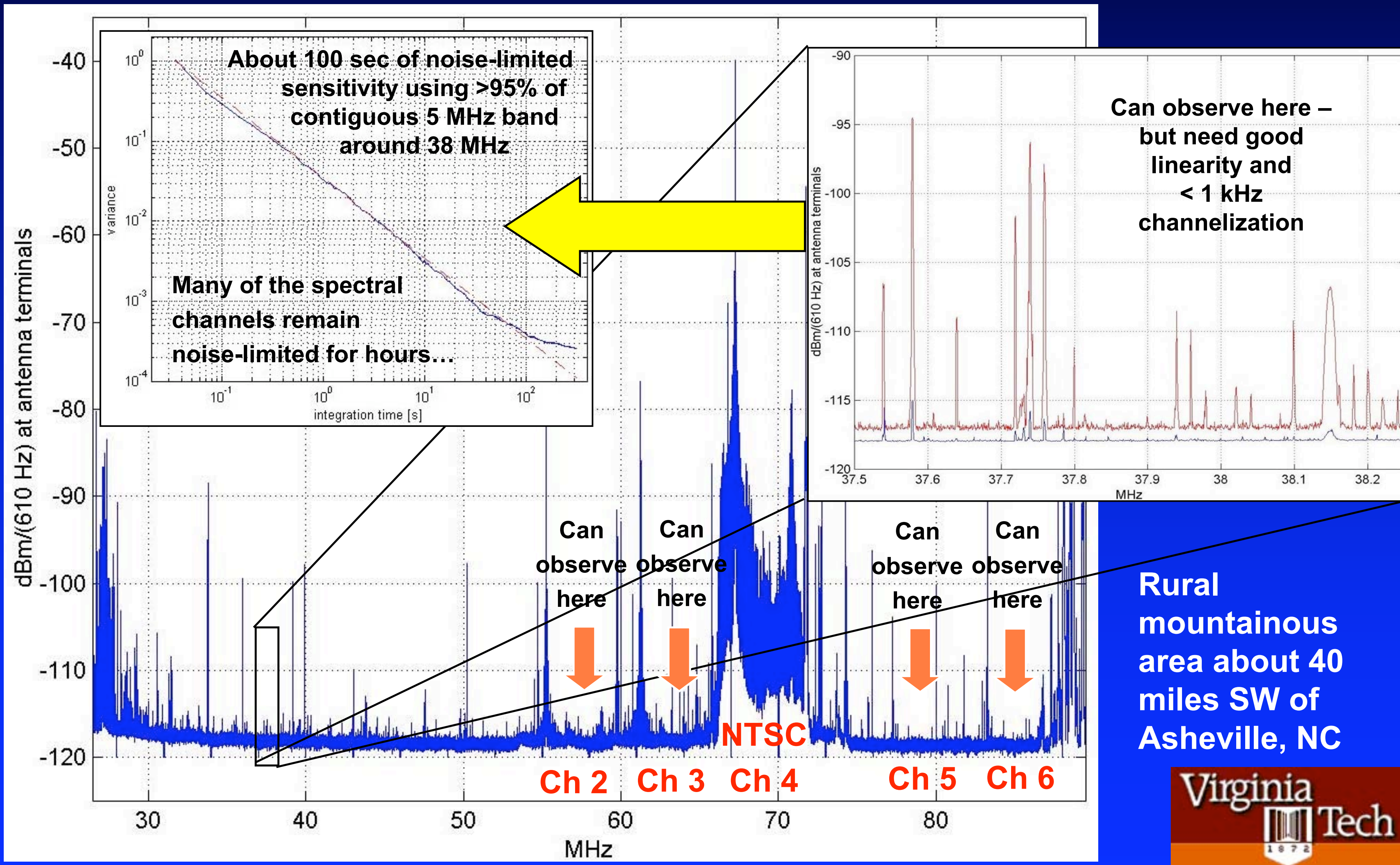
ETA System Design



29-47 MHz (120 MSPS 12b direct sampling)
5 MHz processed bandwidth (7.5 MSPS 7b+7b)
8 fixed "patrol beams"

Virginia Tech

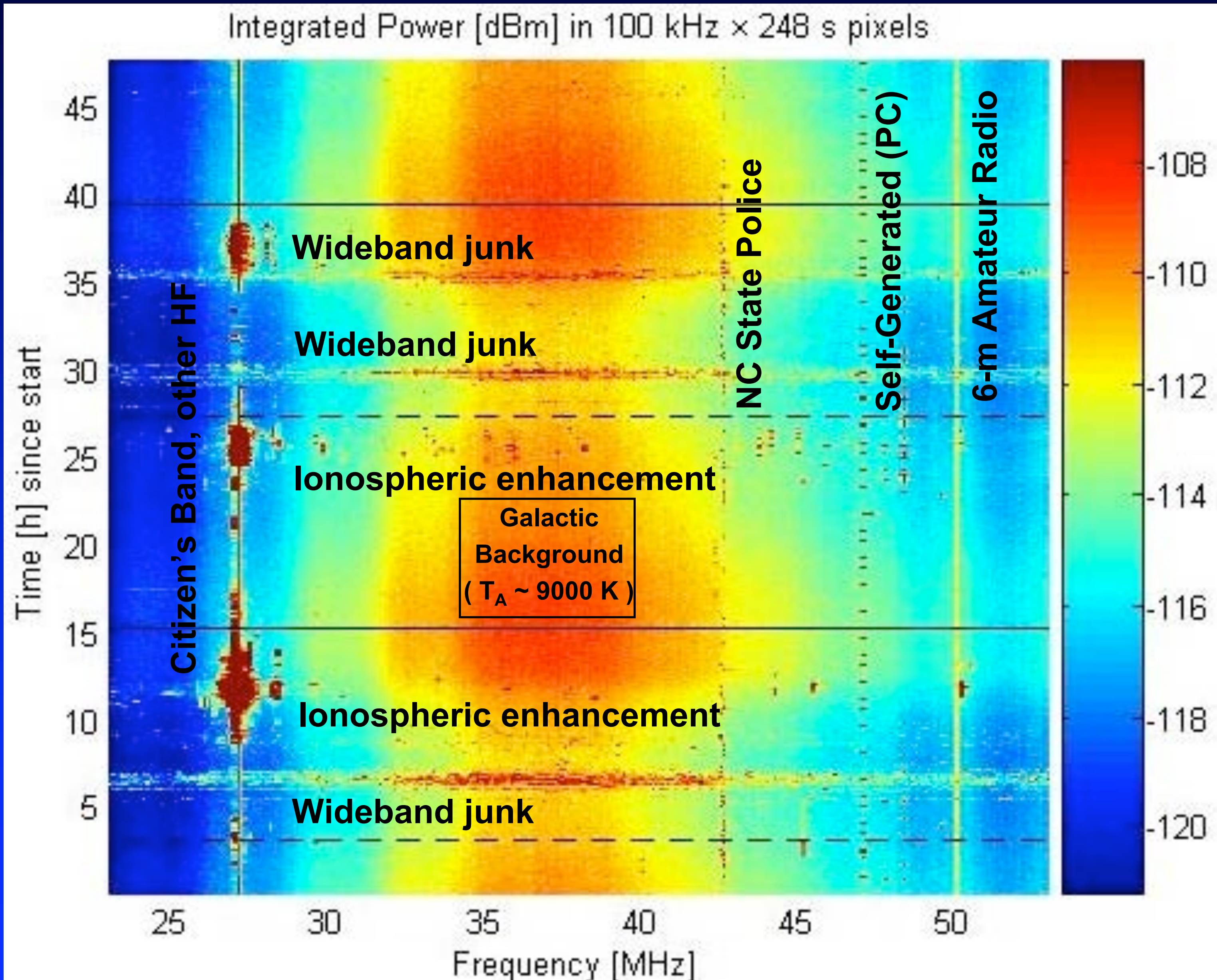
ETA RFI: Bad News / Good News



Rural mountainous area about 40 miles SW of Asheville, NC

Virginia Tech 1872

ETA RFI: Time-Domain Perspective



Not visible: Impulsive (~125 kHz) RFI

Almost all of this stuff can be either <u>avoided</u> or <u>edited</u> out.

The real problems are the associated problems of <u>time</u> (=money) and <u>labor</u>, respectively!

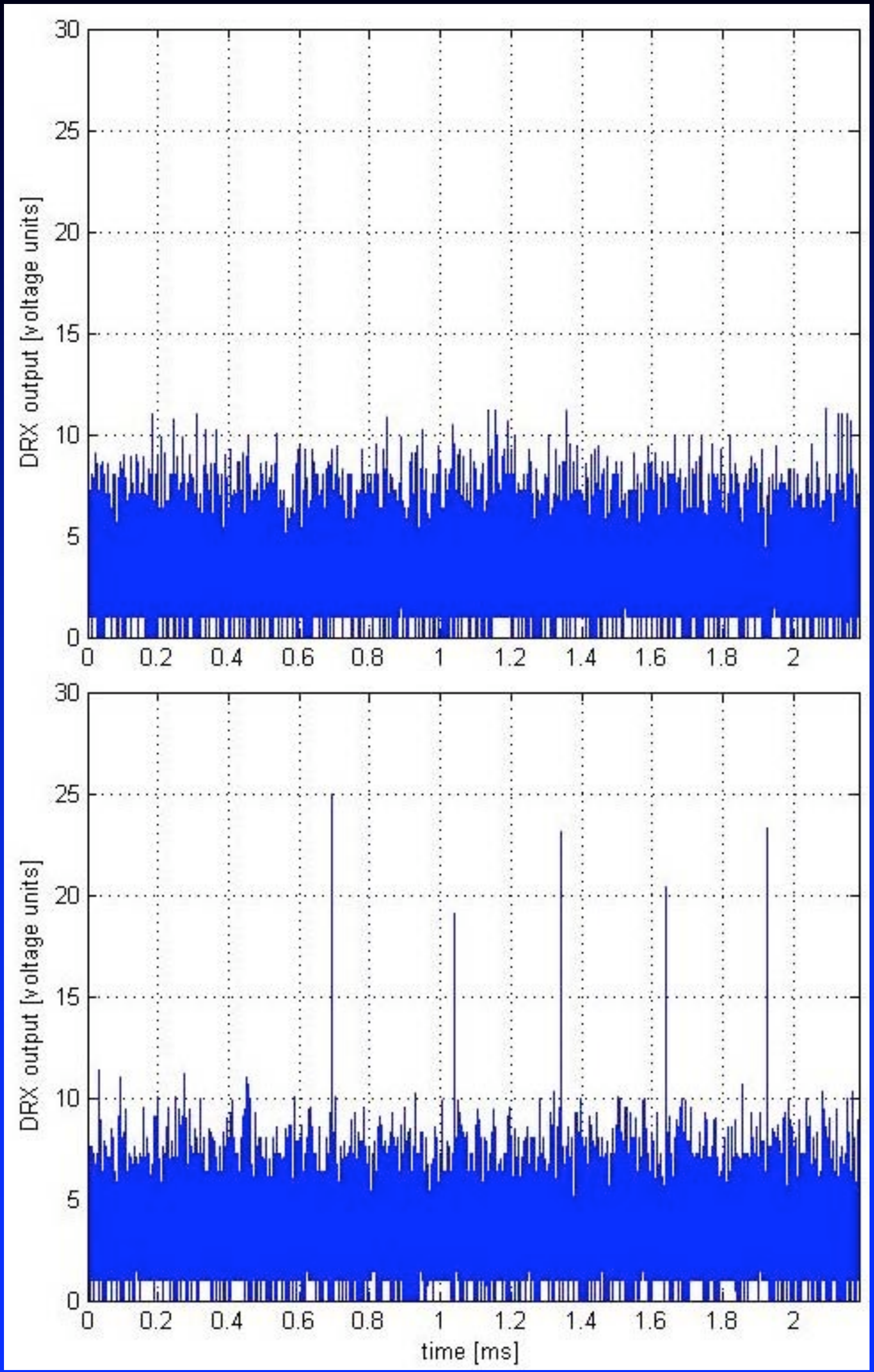
T_R ~ 300 K (i.e., sky-noise dominated)

Virginia Tech 1872

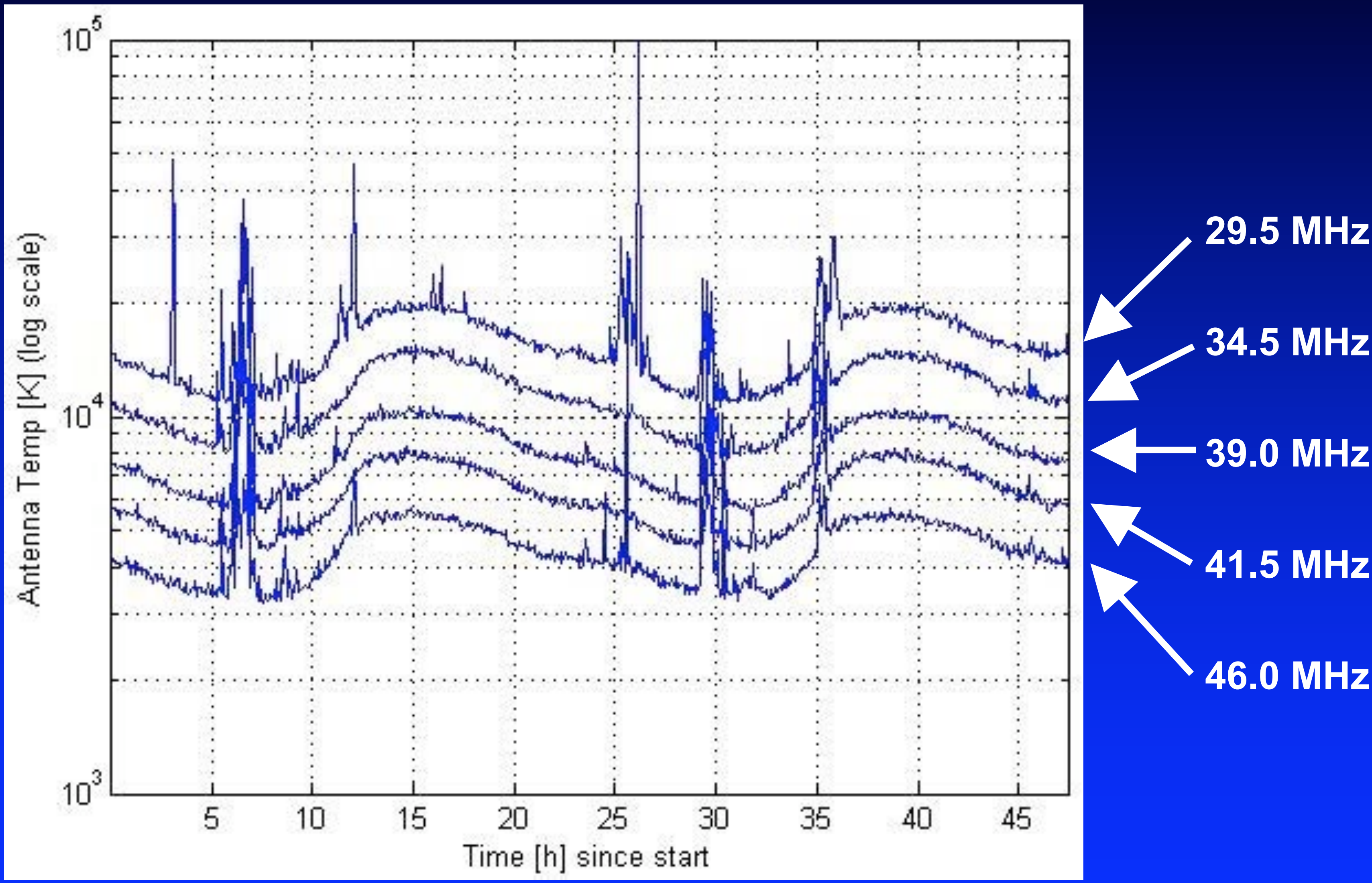
Impulsive RFI

Quiet Period

Noisy Period
(Not really a problem unless time resolution of search approaches ~100 μs)



Galactic Background Diurnal Variation

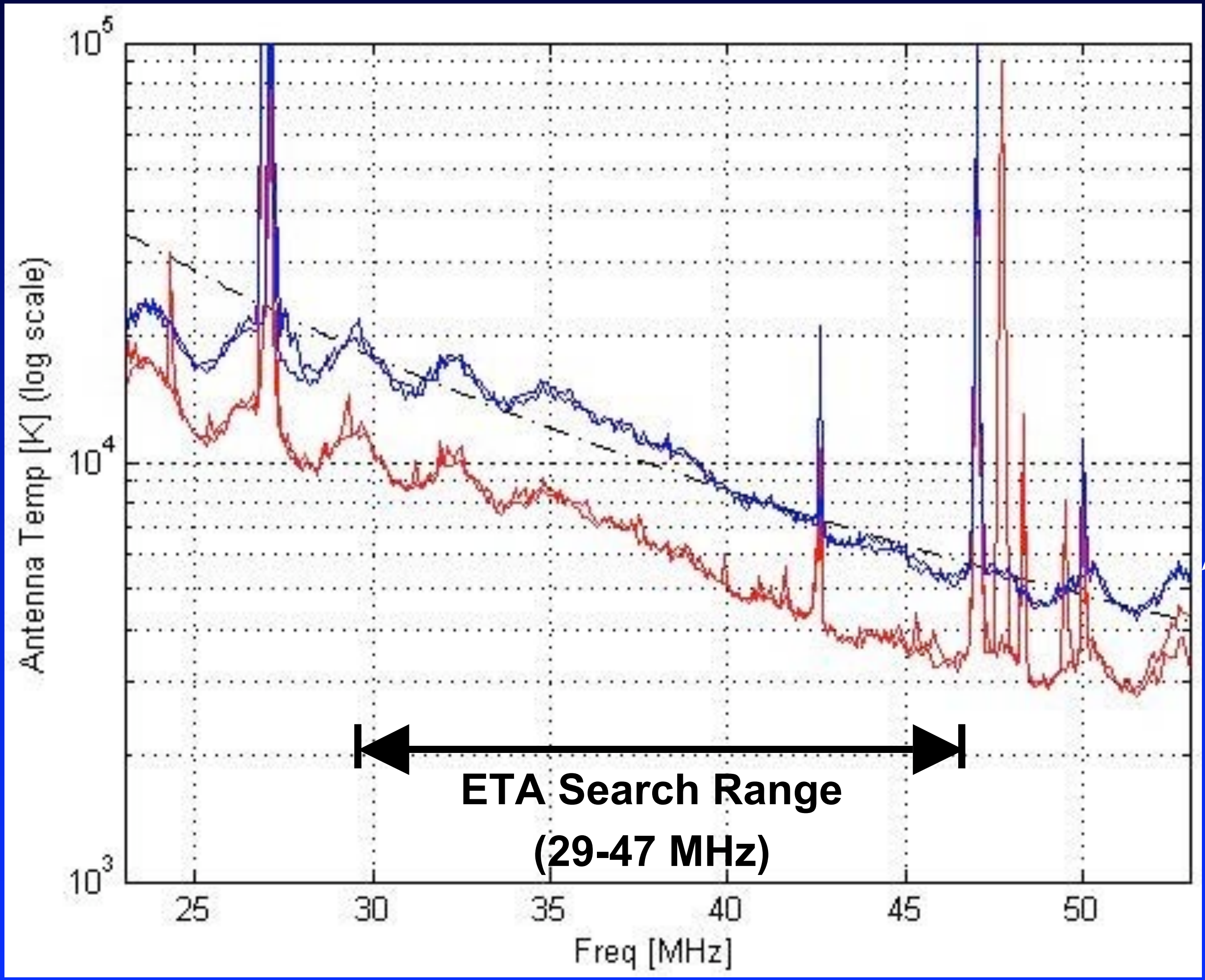


Ellingson, Simonetti & Patterson (2007), *IEEE Trans. Ant. & Prop.*, 55, 826.

Total power in 1 MHz bandwidth
No RFI Mitigation applied !

Virginia Tech

Confirmation of Galactic Noise-Limited Sensitivity



2 observations 24 h apart @ Galactic max

Static sky model

2 observations 24 h apart @ Galactic min

Ellingson, Simonetti & Patterson (2007),
IEEE Trans. Ant. & Prop., 55, 826.

ETA2 !

- Anticoincidence improves sensitivity far more effectively than increasing collecting area
- 2nd copy at distant site would be extremely useful > ETA2
- Funding
  - Underrun in NSF project budget > 1-year NCE
  - $60K equipment allocation from VT Dept. of Physics
- ETA2 will be essentially a mobile, prototype LWA1+ outrigger station
  - Built into trailer
  - Antenna stands completely portable
  - Battery powered (hopefully)

Activities Since Sys Eng Appt. (5/06-6/07)

- Self-funded during this period

- Memo 45 (Cost Model) 8/11/06
- Memo 72 (Program Charter, w/Rickard) 12/27/06

- Memo 65 (Collecting Area) 12/27/06
- Memo 67 (Collecting Area) 12/31/06
- Memo 73 (Collecting Area) 1/13/07
- Memo 75 (Array Design) 1/28/07

- Memo 63 (ARX, w/Harun) 11/14/06
- Memo 82 (ARX, w/Harun) 3/28/07
- Memo 89 (ARX, w/Harun) 5/30/07

- Memo 61 (DDCs, w/Anderson) 11/9/06

- Memo 85 (Canceling of NB RFI, w/Lee) 5/4/07

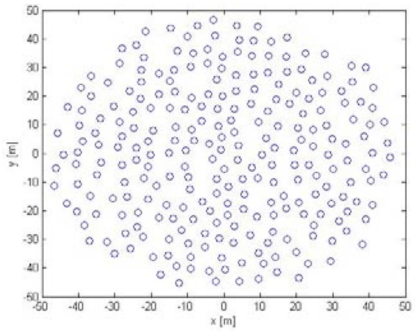
Mutual Coupling Effects

Ground	Load	θ	Single Stand A_e^e	A_e^d	A_e^i	[m²] Array $A_e^d/256$	$\Delta\%$	e_{ap}
PEC	$(Z_A^{p1})^*$	0°	27.55	29.52	27.76	25.22	−15%	0.82
		45°E	9.74	9.28	8.72	12.66	+36%	0.58
		45°H	23.16	22.31	23.73	16.07	−28%	0.74
PEC	100Ω	0°	23.78	25.49	23.97	25.96	+2%	0.84
		45°E	8.41	8.01	7.53	10.16	+27%	0.47
		45°H	20.00	19.26	20.49	14.25	−26%	0.66
Realistic	$(Z_A^{r1})^*$	0°	18.08	19.50	18.22	22.08	+13%	0.72
		45°E	6.39	5.55	5.21	7.47	+35%	0.34
		45°H	15.20	17.04	18.12	12.18	−28%	0.56
Realistic	100Ω	0°	16.24	17.41	15.73	19.08	+10%	0.62
		45°E	5.74	4.98	4.49	6.40	+28%	0.29
		45°H	13.66	14.71	15.65	11.56	−21%	0.53

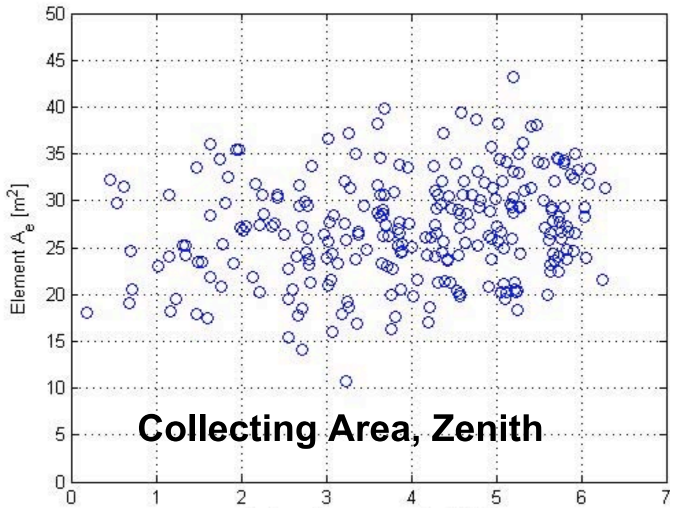
PR Layout, Simple dipoles, 38 MHz
Memo 73

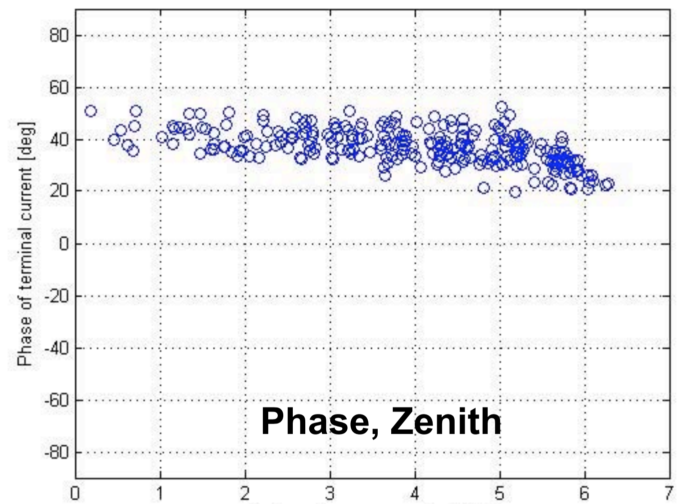
	Single Dipole, ROT	**Single Dipole, Rx-mode**	**Single Dipole, Tx-mode**	**Array, Rx-mode**	**Aperture Efficiency**

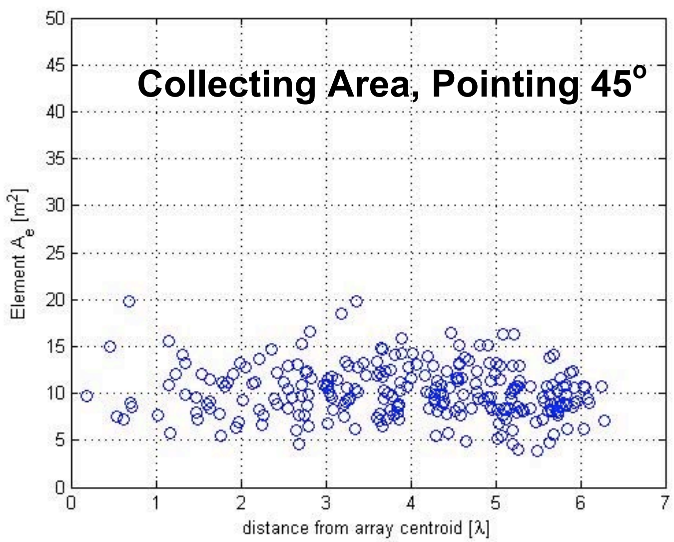
Pointing-Dependent Mutual Coupling Effects (1/2)

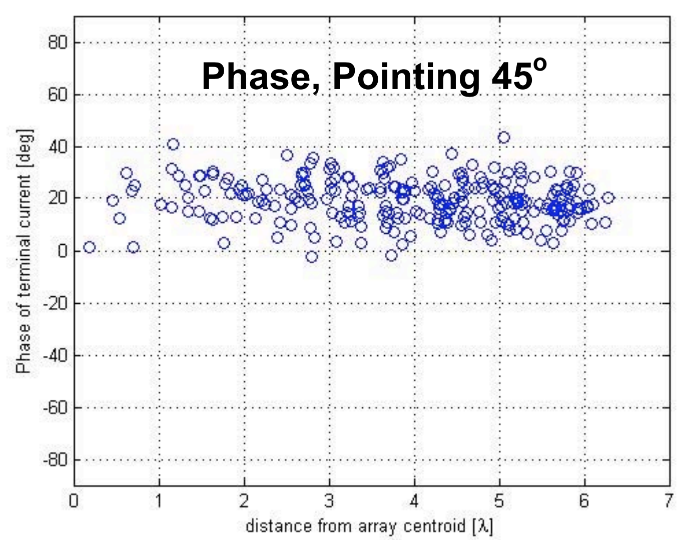


NRL PR 4m mean



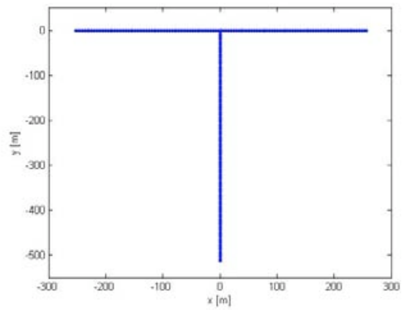




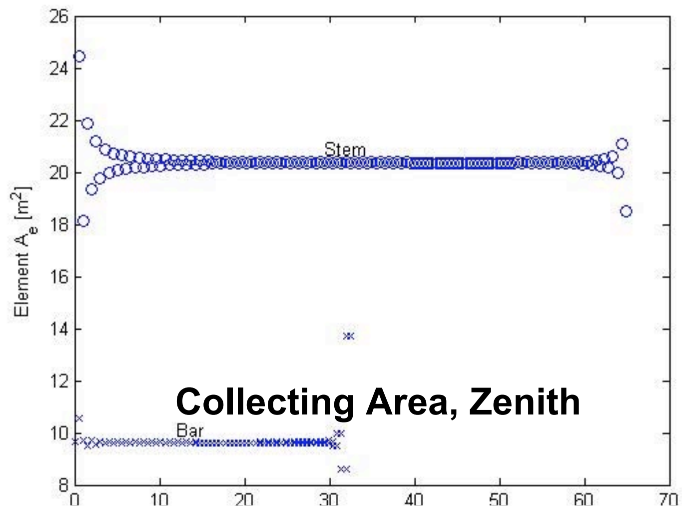


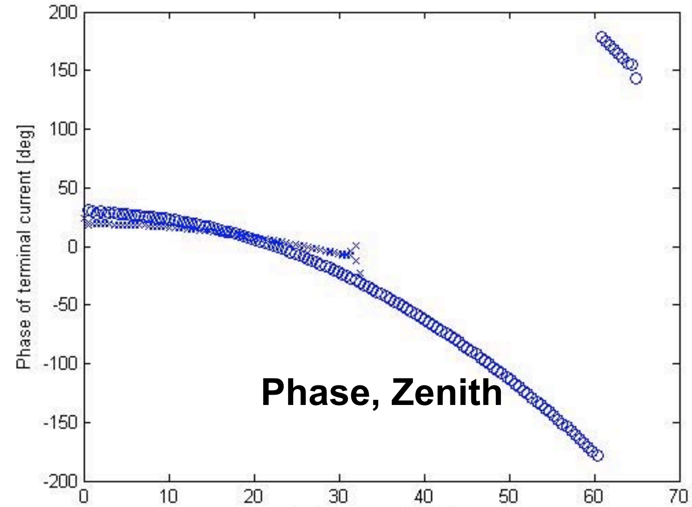
Memo 67

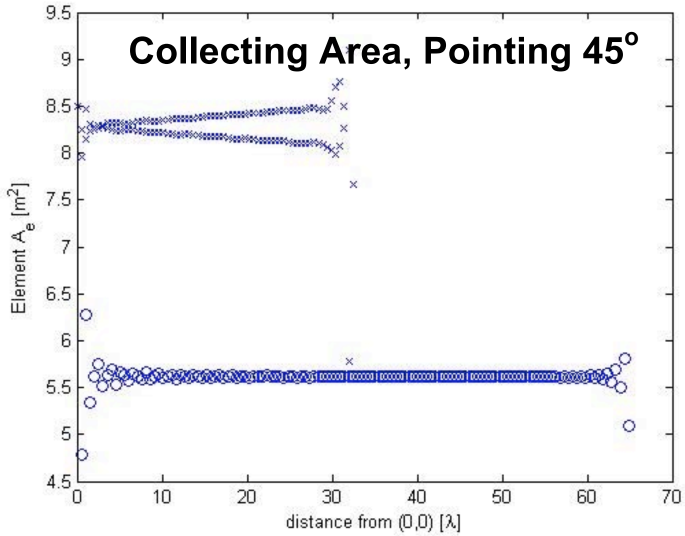
Pointing-Dependent Mutual Coupling Effects (2/2)

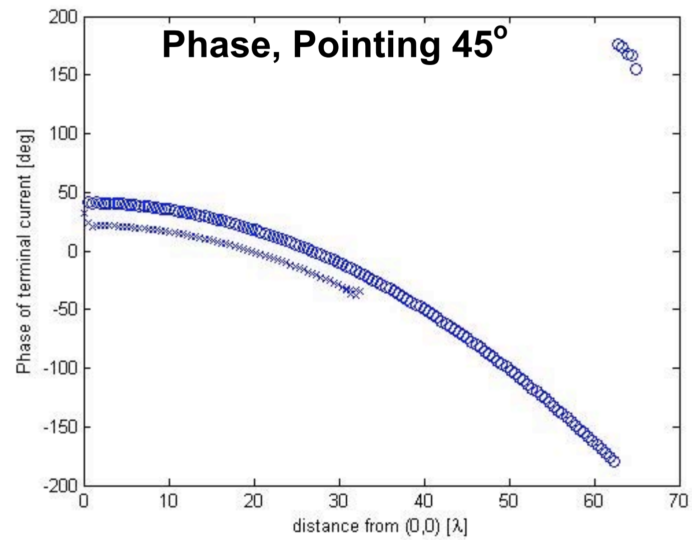


Clark Lake TPT









Memo 67

Activities Since ONR Project Start (6/07-Now)

- $118K, 11 months (6/07-4/08), supporting 1 Ph.D. student
- $30K (extension), 5 months (4/08-9/08) *pending*

- Memo 94 (Number Stands/Station) 7/20/07
- System Architecture Document (Currently v. 0.5)

- Transitioning main effort
  - Sys Eng appointment ends with SRR approval
  - Determined in Aug 07 that certain critical path subsystems were very high risk with respect to desired PDR timeframe
  - Transitioning to primarily design role on these subsystems
  - Array design

- Memo 98 (ADC Selection) 8/31/07
- Memo 101 (Digitizer & Freq Plan) 9/11/07
- Prelim. DP1 Daisy Chain & DP1-DP2 ICD (Currently v. 0.1)

ADC Candidates

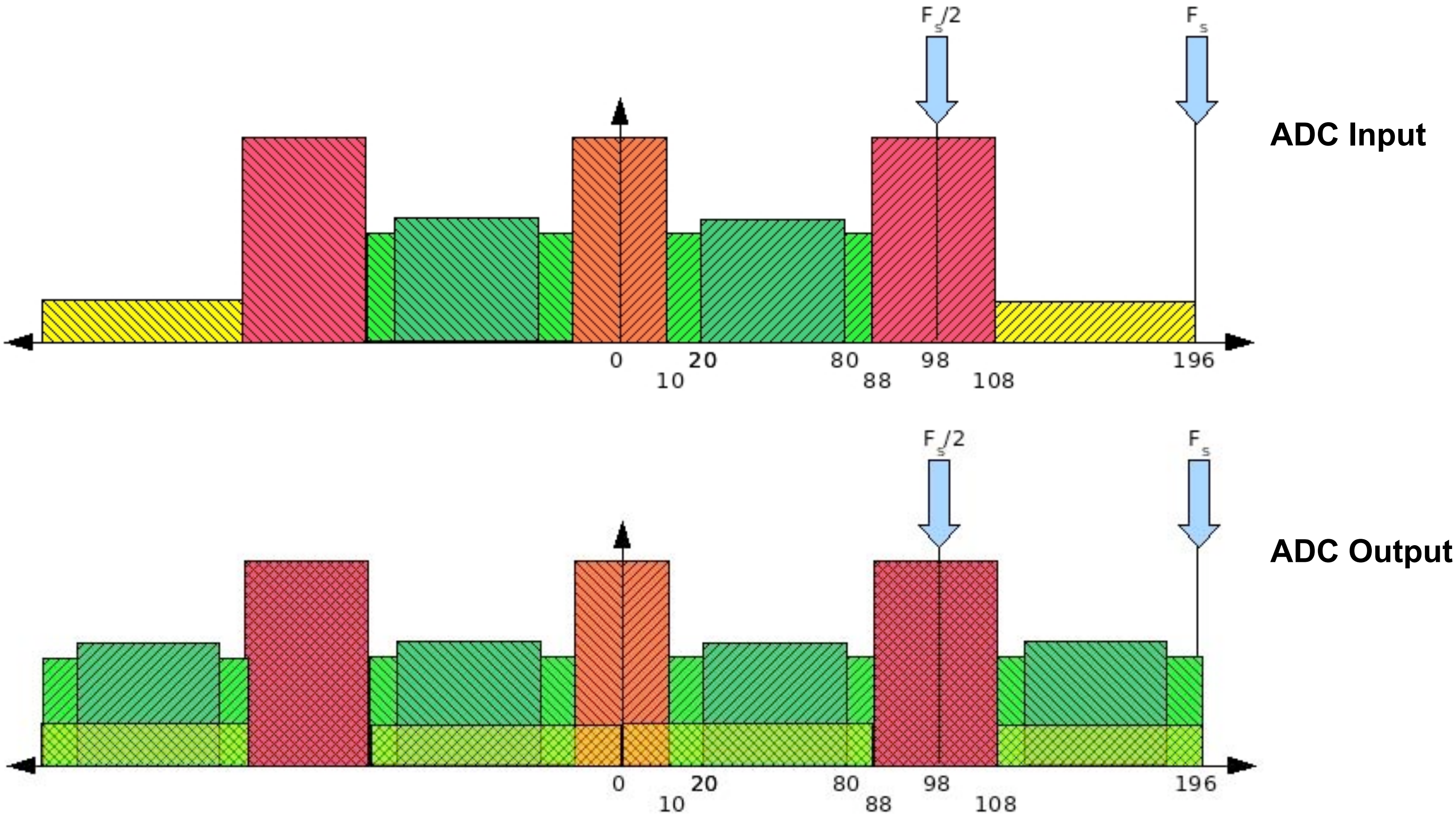
SORT PRIORITY ==>									1	2		
Mfr	Part No	Selected in ARL Study?(1)	# input chan	MSPS	bits	$ (1K)	Output Format	Typ Pwr [mW]	SNR 80 MHz [dB]	SFDR 80 MHz [dB]	Eval. Priority	comments
TI	ADS5474	YES	1	400	14	$150.00	LVDS	2500	69	85		Exclude -- can do nearly as well with MAX12
Maxim	**MAX1215N**	**YES**	**1**	**250**	**12**	**$89.50**	**LVDS**	**886**	**67**	**85**	**1**	**SELECT: This looks really good.**
TI	ADS5463	YES	1	500	12	$125.00	LVDS	2250	64	83		Exclude -- can do nearly as well with AD923(
ADI	AD9430-210	no	1	210	12	$55.00	LVDS	1500	64	82		Exclude -- can do nearly as well with AD923(
ADI	**AD9230-250**	**no**	**1**	**250**	**12**	**$59.00**	**LVDS**	**434**	**64**	**78**	**3**	**SELECT: Almost as good as MAX1215N a**
ADI	AD9230-210	no	1	210	12	$42.00	LVDS	383	64	78	4	[SELECT as alternate to -250 version if samp
ADI	**AD9211-300**	**YES**	**1**	**300**	**10**	**$46.00**	**LVDS**	**437**	**59**	**80**	**2**	**SELECT: Competitive with AD9230, allow**
ADI	AD9480	no	1	250	8	$16.00	LVDS	439	47	68	5	Exclude(2) -- Not compete in terms of SNR
National S	ADC08200	YES	1	200	8	$7.67	CMOS	210	45	56		Unacceptable -- SNR too low, SFDR very po

Notes

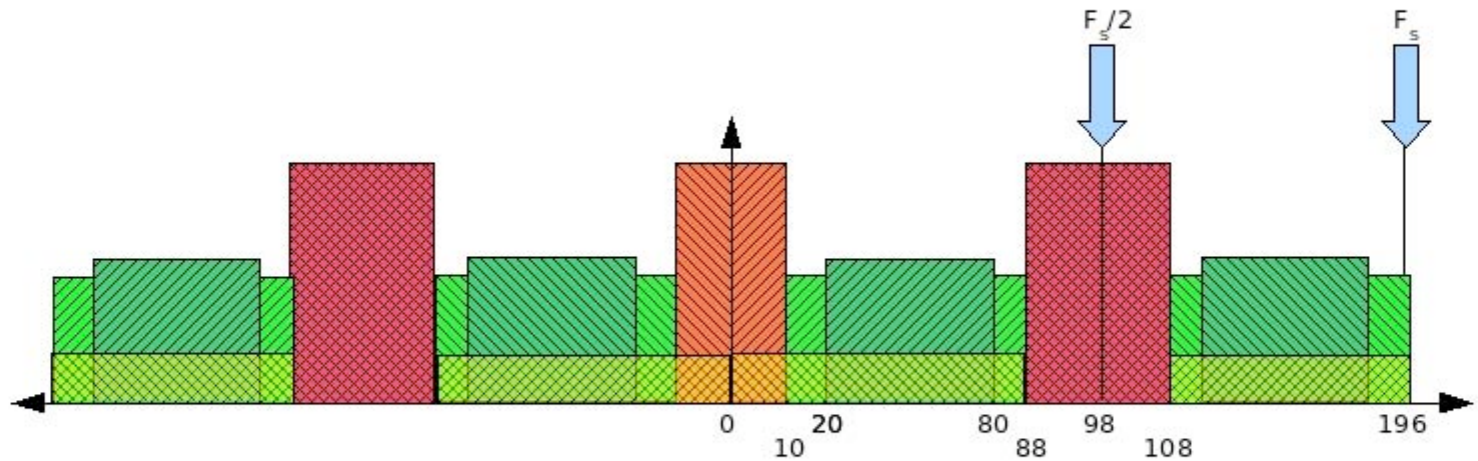
(1) York, Sitaram, and Shuhatovich, "LWA ADC Candidate Selection DRAFT v0.2", 8/23/07
(2) Revisit this choices if ADC cost appears to become a constraint, as cost is dramatically less
(3) Typ pwr, SNR, and SFDR specs taken from ARL study (see (1))

- Memo 98
  - Maxim MAX1215N (12b, 250 MSPS, $90)
  - Analog Devices AD9211 (10b, 300 MSPS, $46)
  - Analog Devices AD9230 (12b, 250 MSPS, $59)
- Evaluation underway

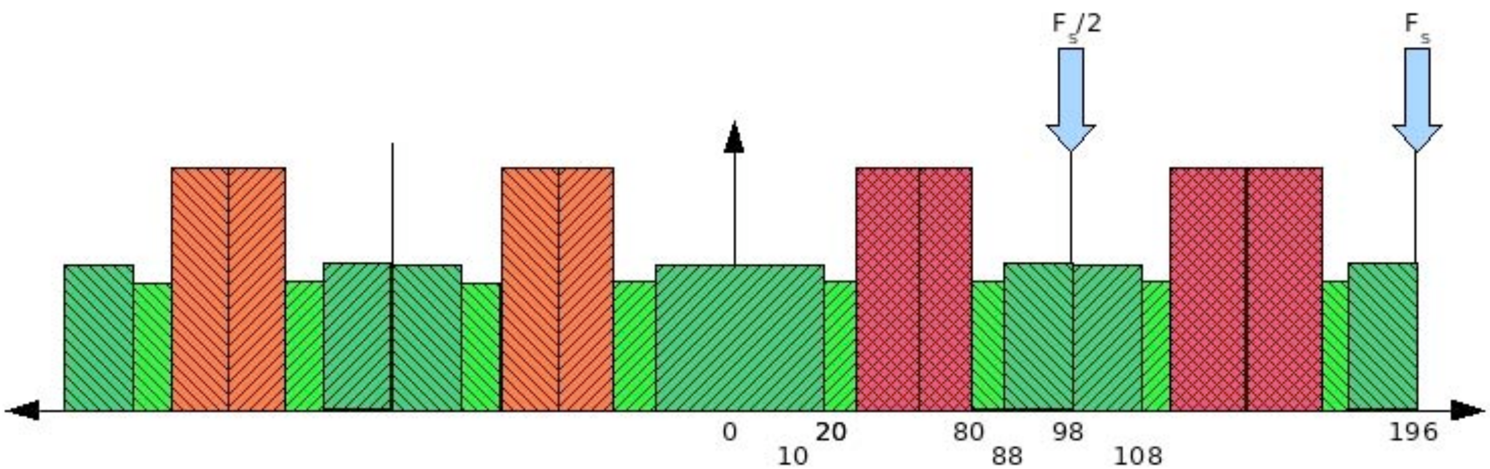
Digitizer / Frequency Plan



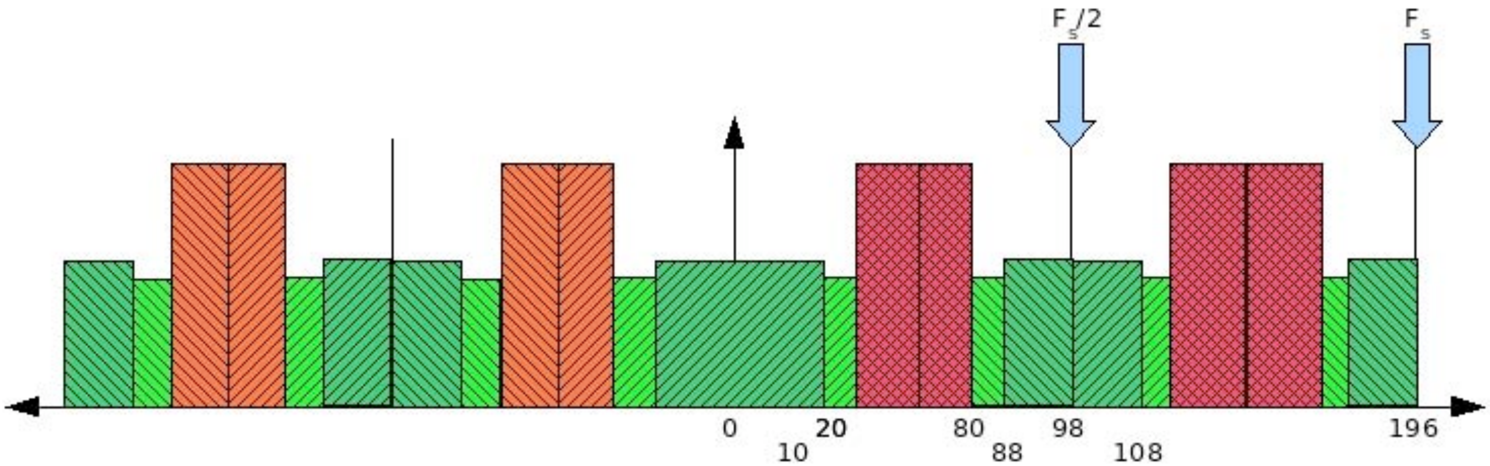
Digitizer / Frequency Plan

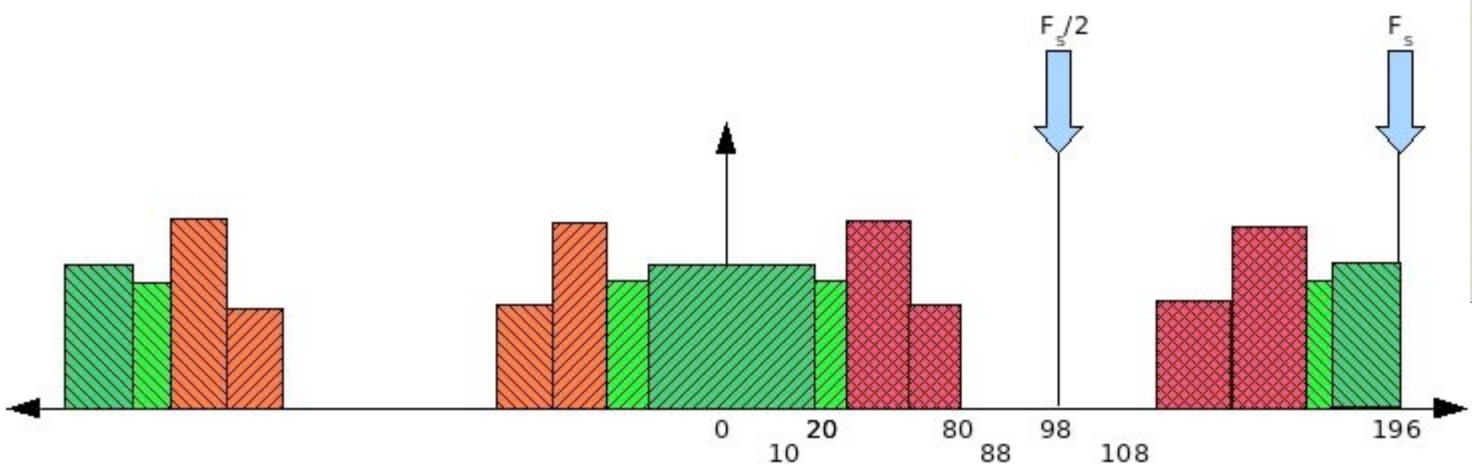


Fs/4 Shift Left

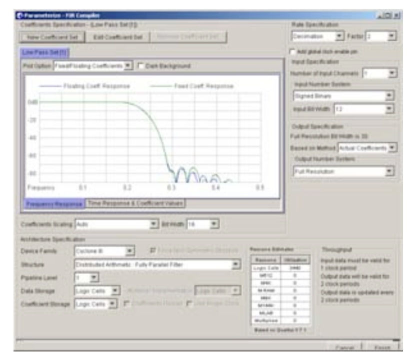


Digitizer / Frequency Plan

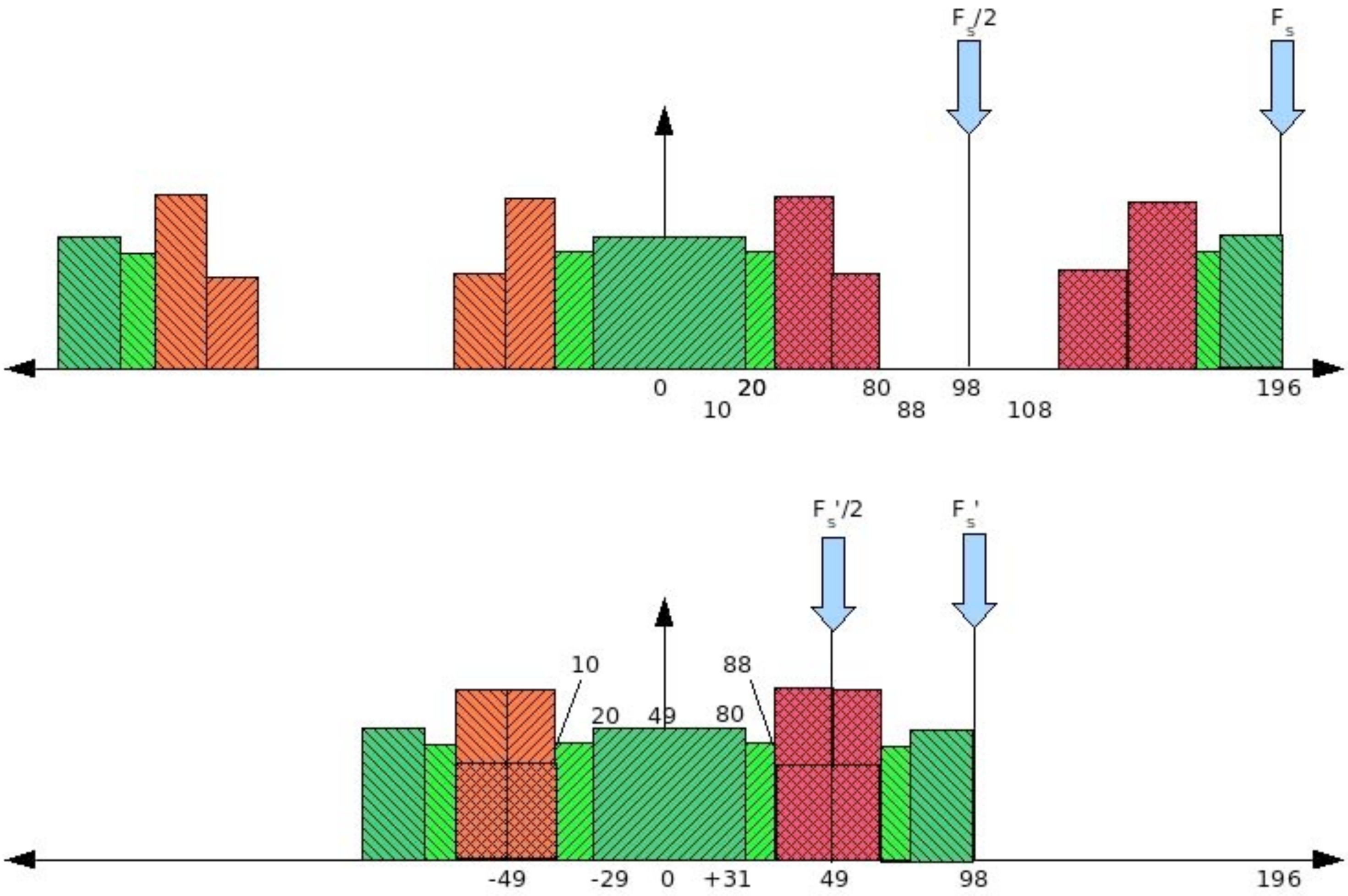




Pre-Decimation Filter

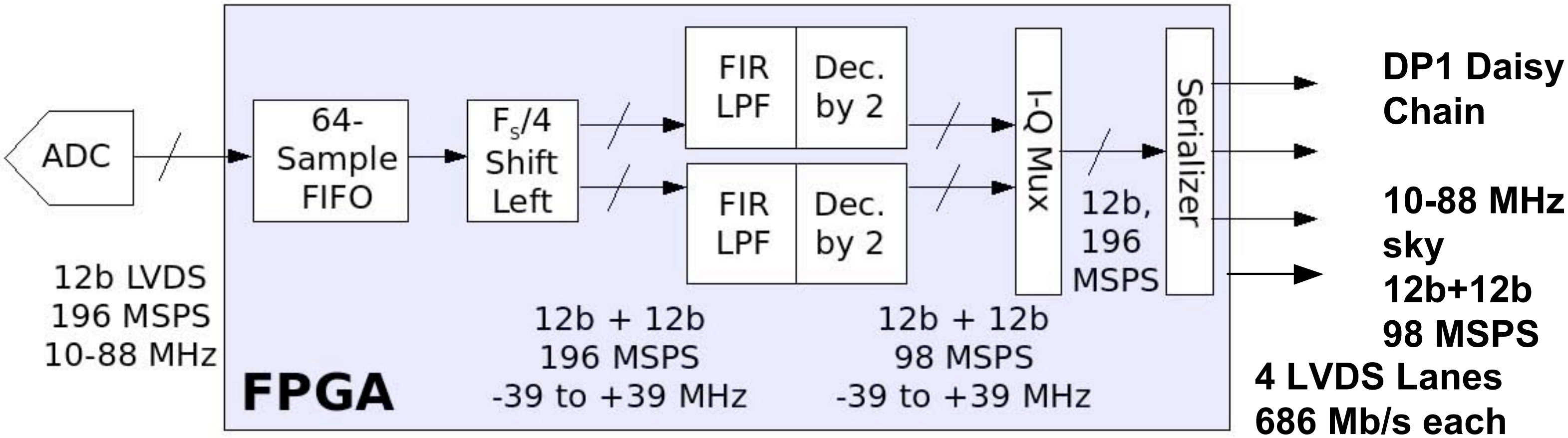


Digitizer / Frequency Plan



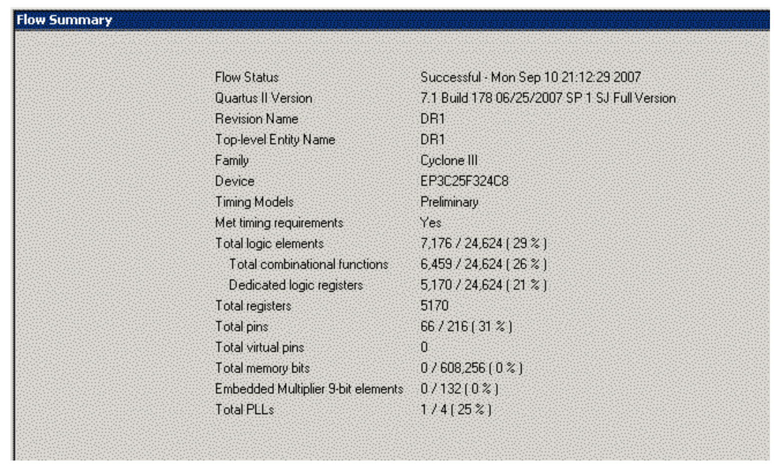
Decimate by 2

DIG (ADC + Postprocessor) Summary



- Not optimum! (Simply an "existance proof") Can certainly be made more efficient

- As shown, realizable in one Altera Cyclone III FPGA ($50, qty 1), including I/O

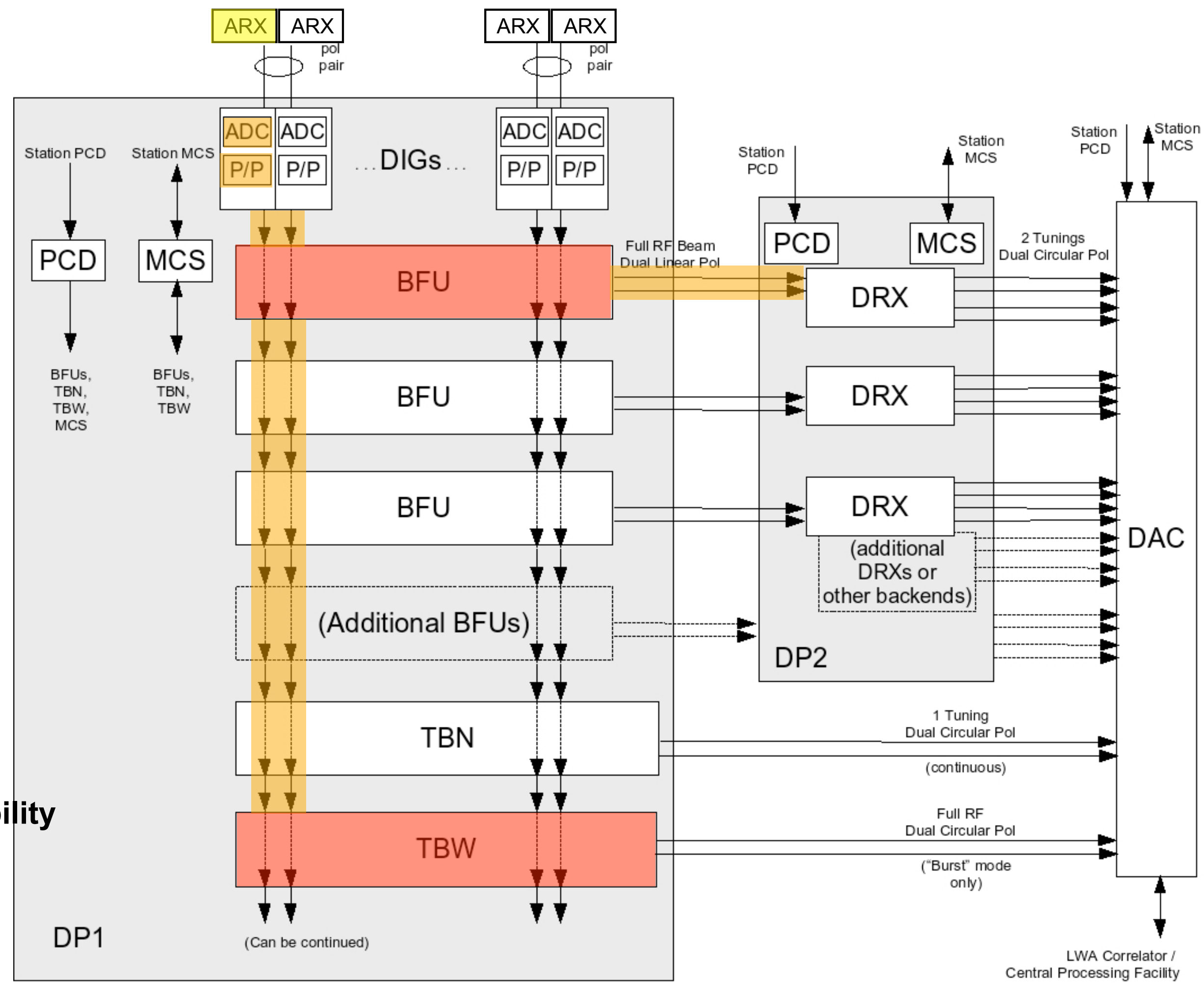


Flow Summary

Flow Status	Successful - Mon Sep 10 21:12:29 2007
Quartus II Version	7.1 Build 178 06/25/2007 SP 1 SJ Full Version
Revision Name	DR1
Top-level Entity Name	DR1
Family	Cyclone III
Device	EP3C25F324C8
Timing Models	Preliminary
Met timing requirements	Yes
Total logic elements	7,176 / 24,624 (29 %)
Total combinational functions	6,459 / 24,624 (26 %)
Dedicated logic registers	5,170 / 24,624 (21 %)
Total registers	5170
Total pins	66 / 216 (31 %)
Total virtual pins	0
Total memory bits	0 / 608,256 (0 %)
Embedded Multiplier 9-bit elements	0 / 132 (0 %)
Total PLLs	1 / 4 (25 %)

Memo 101

VT DP1 Design Effort Status (Now)



PDR* ready

Hardware Eval/ Field Test

Documented Progress - Feasibility

No documented progress

Other Activites

- ETA2 Synergy
  - Platform for field evaluation of PDR-state LWA subsystems
  - Potential outrigger for LWA1
  - 3 way (ETA+LWA1+ETA2) anticoincidence

- Memo series maintainer
  (http://www.phys.unm.edu/~lwa/memos)
- Short course – active antennas
- Short course – FPGA-based signal processing

- Large pool of scientific/technical experts and excellent, motivated, multidisciplinary students. Could do more given more $$$!

Thanks!

Acknowledgements:

Cameron Patterson	Faculty, ECE CCL
John Simonetti	Faculty, Physics
Kyehun Lee	Ph.D. Student (SE)
Mahmud Harun	Ph.D. Student (SE)
Kshitija Deshpande	Ph.D. Student (SE)
Wyatt Taylor (graduated)	M.S. Student (SE)
Sean Cutchins	Ph.D. Student (JS)
Mike Kavic	Ph.D. Student (GM)
Brian Martin	M.S. Student (CP)
Vivek Venugopal	M.S. Student (CP)

Path to SRR/PDR

Kickoff Meeting, Albuquerque, NM
July 21, 2007

Steve Ellingson
LWA Interim Systems Engineer
Virginia Polytechnic Inst. & State University
ellingson@vt.edu

SRR/PDR Process

- Overall management plan described in Program Charter, LWA Memo 72 (Dec 27, 2006)
- Steps:
  - SRR = System Requirements Review
  - PDR = Preliminary Design Review
  - CDR = Critical Design Review
  - IOC = Initial Operational Capability: LWA1, LWA1+, …
- Note we are proceeding at several levels simultaneously:
  - LWIA and LWA (the 9-/16- and 52-station interferometers)
    - Necessary to consider these for station design context & long-lead issues
  - LWA1+ (Station #1 + 2 smaller outriggers)
    - Main effort for next 18 months at least
    - LWA1 IOC is the "keyhole" through which we must pass

LWA1+ vs. LWA

- The science requirements document will address LWA1+, LWIA, and LWA simultaneously from earliest versions
- Technical requirements document
  - Focus at SRR on station (LWA1) requirements
  - Incorporate outrigger (LWA1+) requirements at PDR
  - Incorporate LWIA/LWA requirements after LWA1+ IOC
    - delay because we want to account for lessons learned
- Certain LWIA/LWA-specific technical issues are long lead / high risk items and will be managed separately from the LWA1+ effort during this period
  - Data communications
  - Correlator
  - Full-field calibration

SRR

- SRR = System Requirements Review
- Review/approval of
  - Science Requirements (Kassim)
  - Technical Requirements & Product Assurance Plan (Janes)
  - Station Architecture (Ellingson)
  - WBS, Budget, & Task definitions (i.e., who's doing what) through CDR (Rickard)
  - Maybe other stuff
- External Process (note: no SRR face-to-face meeting!)
  - Distribute review items to TAC members NLT ______
  - TAC members individually respond NLT _____
  - EC reviews TAC response, responds NLT ______
  - EC approval constitutes formal acceptance of items reviewed

SRR – Internal Process

- Step 1: Get necessary documents in distributable draft form (_____)
  - Preparation of science requirements document (Kassim)
  - Technical Requirements & PA documents (Janes)
  - Station Architecture (Ellingson)
  - WBS, Budget, Task definitions through CDR (Rickard)
  - Cost models [Janes (station) > Taylor (site/ops) > Rickard]

- Step 2: Period for mutual/open review and comment (_____)
- Step 3: Authors finalize documents (_____)
- Step 4: Final review by project management (_____)
- Step 5: Packages shipped to TAC (_____)
- Step 6: Rickard receives TAC responses, distributes to EC as they arrive

Subsystem/ICD Assignments

• ARR-STD	NRL
• ARR-RPD	? (presumably some combination of NRL & UNM)
• ASP	*not assigned*
– ARX	VT (through PDR, then ?)
• DP1	*not assigned*
– BFU	VT (through PDR, then ?)
– TBW	VT (through PDR, then ?)
– TBN	*not assigned*
• DP2	*not assigned*
– DRX	ARL
• DAC	*not assigned*
• MCS	*not assigned*
• SHL	ARL
• Clock/Distr.	*not assigned*

- ICD Assignments
  (see Sys Arch Review talk
  for list of ICDs)

PDR

- PDR = Preliminary Design Review
- Review/approval of
  - **Preliminary design and associated cost data** (SysEng)
  - Revisions to science requirements (ProjSci)
  - Revisions to tech reqs, PA plan, and system architecture (SysEng)
  - Revisions to cost models and spending profile (ExecPD)
- External Process (No PDR meeting currently planned)
  - Distribute review items to TAC members NLT _______
  - TAC members individually respond NLT ______
  - EC reviews TAC response, responds NLT _______
  - EC approval constitutes formal acceptance of above items

Issues

- Need to get commitments on subsystem assignments
  - and workplans that support PDR/CDR/IOC goals
- Use RTA to resolve mutual coupling questions by PDR
  - Means answers well in advance of PDR
  - Experiment plan
- RFI management plans
  - Internal (self-RFI, EMI shielding) plan (Perhaps in PA plan, but elaboration will probably be required) (Who?)
  - External mitigation plan (Ellingson; see beginnings of this discussed in other presentations)
- Systems engineer changing after SRR
- Engineer shortage -- BIG problem

From Stations to Systems

Greg Taylor (UNM)

September 21, 2007

(LWA: http://lwa.unm.edu)

Systems Tasks

- Site Acquisition and outfitting
- Data Communications
- Monitor/Control and Timing
- Correlator
- Central infrastructure
- Archives
- Post-Processing Software
- User Support
- Operations Plan

Data Communications

- Monitor and Control of Stations
- Need to transmit station beams to correlator
  - 5.6 Gbps for full RF, 576 Mbps for 8 MHz
- NRAO designed Fiber communications board by Steve Durand
  - Build prototype for LWA1

LWIA Site selection - Sites Visited to date + Fiber

Correlator

- Hardware Correlator
  - iBOB/BEE2 by Dan Wertheimer (UCB/SETI)
- Software Correlator (DiFX by Deller)
  - Development ongoing at NRAO/Swinburn
  - USNO/NRL/NRAO Meeting planned Sept. 25 in DC
  - NRAO/UNM Meeting planned Sept 28 in Socorro

Archives

- Host Archive at UNM HPC to allow re-processing, take advantage of high storage capacity, bandwidth
- LWIA requirements
  - Assuming 1 kHz resolution, 16 stations, 120 baselines
  - 1.5 MB/integration/baseline/beam per 8 MHz
  - 1.4 Gbps correlator data rate (EVLA early limit is 0.2 Gbps)
  - Automatic RFI excision, average to 10 kHz (narrow fields)

  Still requires archiving 0.14 Gbps = 1.5 Tb/day/beam

  ~5 TB/day if we operate 3 beams, 50 TB/day if we are imaging wide fields

  We will probably have to throttle data rate at the outset

Post-Processing Software

- Synergy with other instruments
- Masaya Kuniyoshi (UNM) working with Sanjay Bhatnagar and Kumar Golap (NRAO) on Simulating the LWA data (including primary beam effects)
- Gianfranco Gentile (UNM) working with Kumar Golap on wide field imaging
- NRL efforts with Bill Cotton

Central Infrastructure

- Need to house/support the correlator
- Centrally located maintenance facility
- Lodging

User Support

- Open skies observing policy
- Some dedicated programs (ionospheric monitoring, space weather, transient surveys, dark energy, etc.)
- Minimum 3 staff scientists
- Broadband connection to the archive
- Suite of LWA calibration tools

Operations Plan

- Retain operational capability at all times (LWA Memo 56)
- Once LWA1 is operational, issue first call for proposals
- Regular proposal calls, externally refereed and then reviewed by the LWA Selection Committee

Operations Costs

- Power costs for LWIA
  - 30 kW/station, 10 cents/kW-hr + correlator (50 kW)
  - $460 k/year to keep the lights on
- Communications costs (WAG)
  - $10 k/station (wildly optimistic) + archive (16k/yr)
  - $176 k/year for communications
- Maintenance
  - $5k/station for 1% failure rate = $80 k/station
- Land Costs
  - $16 k/year for all leases
- Project office staff 10 FTE = $1200 k/yr
- Total = $1.9 M/year for LWIA, with overhead $2.9 M/year

SUMMARY

- Other parts of the LWA System need to be developed in parallel with building the station
- We will need a minimum of $3 M/year to operate the LWIA
- We cannot afford to create our own post-processing software from scratch
- We need to simulate realistic LWA data so we are better prepared to deal with the real thing