

LWA Strawman Design

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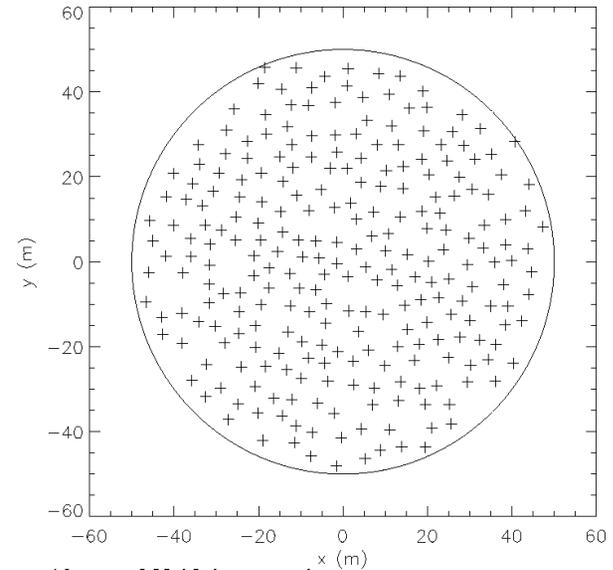
This document is the result of a “brainstorming” session at VA Tech on March 23-24, 2006. The goal was to produce a “strawman” design for the LWA that would help with the project planning, and provide a common reference design that would allow scientists and engineers working on various aspects of the LWA development to have a short, clear picture of the full instrument design. Note that this is a *strawman* design, **not** a final, fleshed out design. It exists to provide a baseline with which to compare design alternatives and to suggest aspects of the design where work is needed and can be most beneficial for the project. Further, we considered what subset of the strawman design might be incorporated into LWA-1, the first full station to be developed.

So far, this reflects only the technical opinions of the authors and has not been officially adopted by the project. Comments and suggestions are encouraged.

Aspects Not Yet Included

- Array configuration
 - We assume ~52 stations of 256 dipoles each. However, a plan for the final array configuration as well as the order of station construction is clearly critical, and competing factors must be included in the analysis including: spatial sampling of ionosphere, u-v coverage, fiber access, scientific usefulness if funding ends before all stations are completed, enabling early tests of calibration on long baselines, etc...
- Ionospheric calibration
- Wide field imaging performance
- Post correlation processing and data storage
- Mechanical designs (lifetime, manufacturability)

Antenna & Station

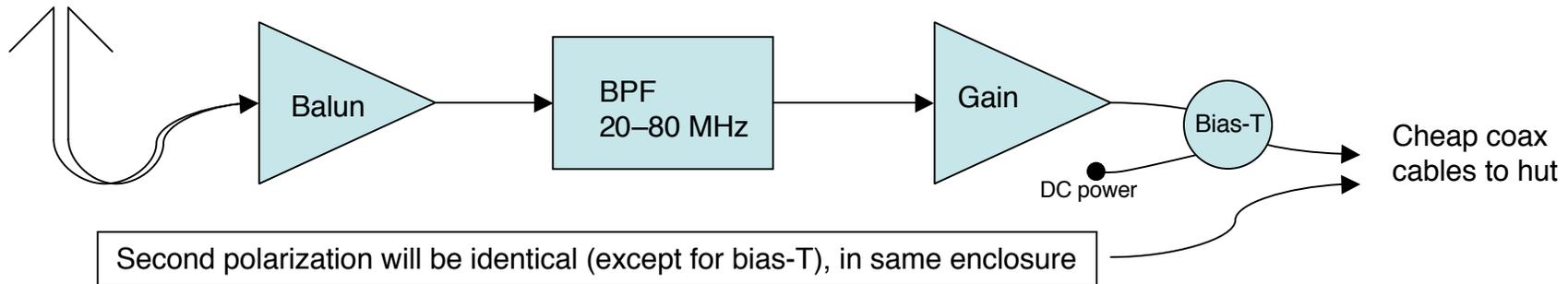


- Baseline “big blade” antenna on pyramidal mount (mastless PVC pipe)
 - Usable, but small improvements could yield big benefits
 - Question: How will it be secured to the ground?
 - Key issue is **manufacturability**
 - Build one here, and start durability tests NOW!
- Assume 256 “stands” in Emil’s optimal station config
 - *Nomenclature*: Each “stand” supports two “dipoles”
- Improvements to consider
 - Ground screen
 - Impedance match improvements
 - Survivability

Critical Antenna Issues

- Mutual coupling
 - Start simulations
 - Tests needed soon with small numbers of antennas (1, 2, 9, ...)
 - Measure S-parameters as antennas are added
 - Use as feedback to simulation
- **COST & MANUFACTURABILITY!**
- **ACCURATE** antenna pattern measurement (~5%)
- Accurate sky noise measurements
 - Move beyond 1 dB measurements (requires digital receiver and serious data analysis)

Front End Electronics (at antenna)

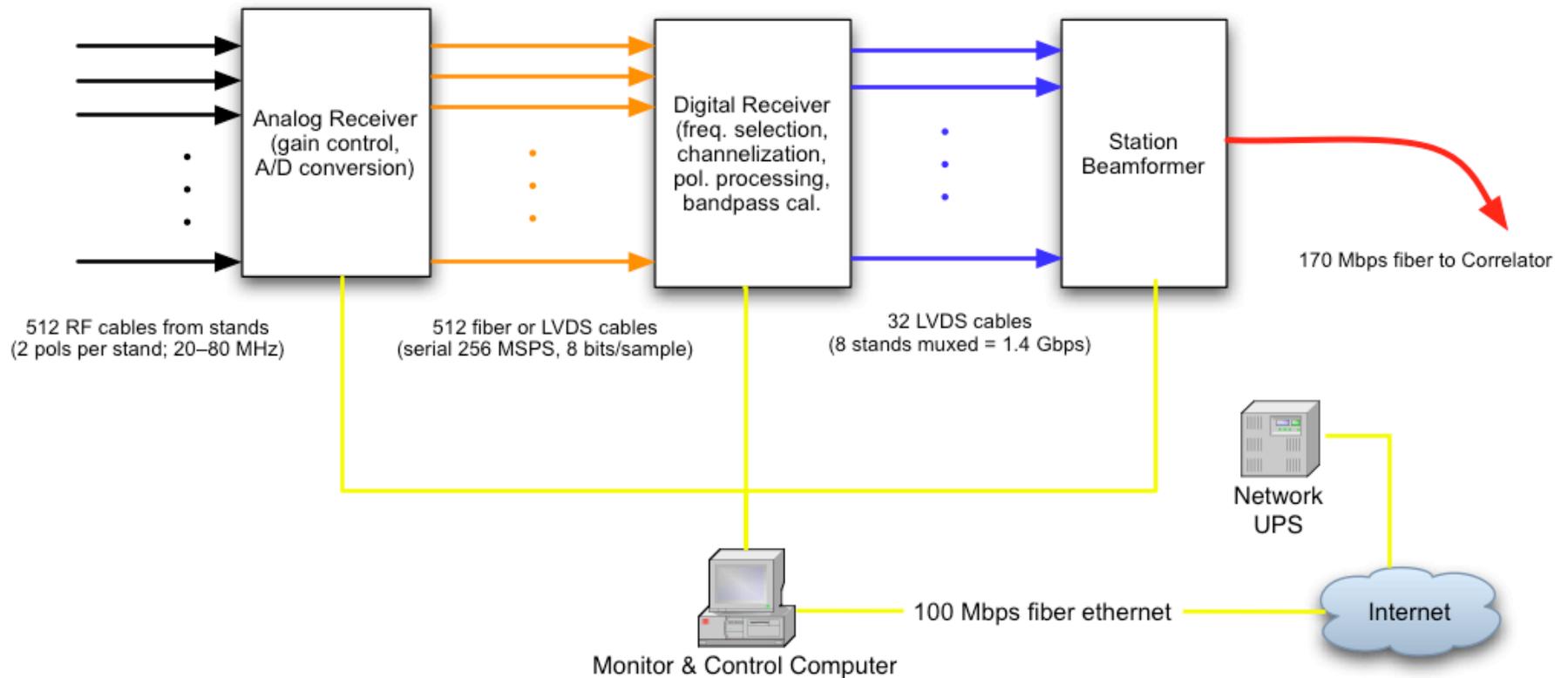


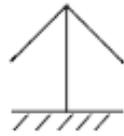
- Should be on single board in enclosure
- Bandpass Filter (BPF) should be cheap discrete components
- Baseline balun is Hicks' design based on GALI-74
- Powered by bias-T (unless this admits RFI)
 - Test RFI from bias-T on LWDA, consider bias-T improvements or separate power
- Improvements to work on:
 - Lower balun T_{eff} to a goal of 170K
 - Lower cost of design (cheaper transformer, etc.)
 - Revisit input impedance for mutual coupling mitigation and better match to antenna
 - Output impedance match to cable
 - Packaging

RFI Issues to Consider

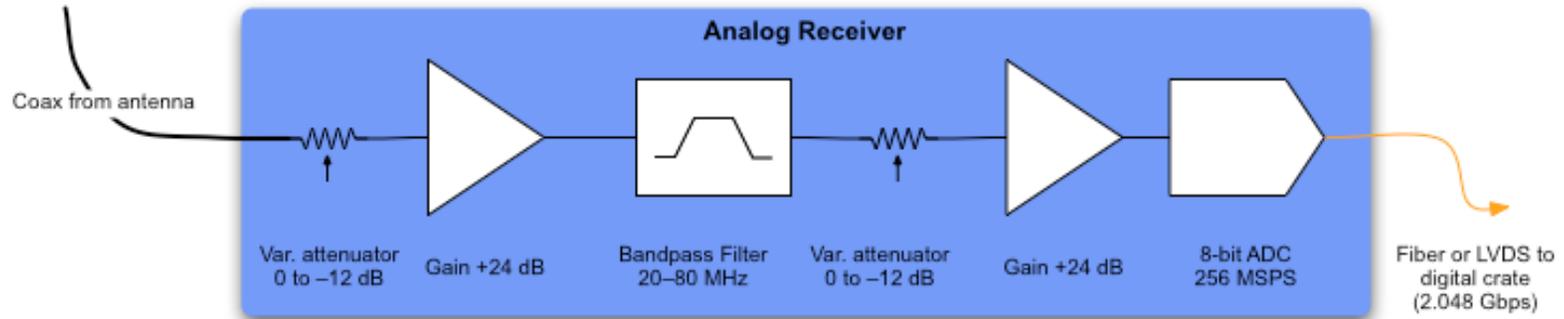
- RFI understanding is critical to receiver design (linearity and ADC dynamic range)
- Watch out for digital TV and BBPL
 - Need monitoring of current levels at range of candidate sites around NM
 - Want to know SOON when stations go digital
 - FCC Database: <http://www.fcc.gov/fcc-bin/audio/tvq.html>
- Time-domain Monte Carlo simulation of intermod products in the receiver based on real measured levels will be important for receiver design

Physical Overview of Station Electronics





Analog Receiver Chain



- Single good enclosure with compartments for several (8?) receivers
 - Separates analog receiver from digital electronics
 - Fiber connection would be preferable for RFI reasons, but may be too expensive (needs study)
- Strawman ADC is 8-bit flash at 256 MSPS
 - Flash architecture is safest for quantizing noise in low-order bits
 - 8 bits should be sufficient given VLA site RFI levels, but more would be safer
- Issues to explore
 - Can we get more ADC bits without introducing worse SFDR performance?
 - Test candidate ADCs with real input, before choosing a part to use
 - Data sheet SFDR doesn't reflect our needs accurately
 - Should make “gold standard” analog chain (\$\$\$) for use in testing

Strawman GNI Analysis

Analysis done with *cascade*, available at
<http://rfcascade.sourceforge.net/>

```
defaults rin=50 rout=50
#
# Hicks' balun + BPF + gain at antenna
balun g=24 iip3=7.5 nf=2.7
bpf1 g=-1.0 nf=1.0
gain2 g=24.0 iip3=6.0 nf=5.0

# Cable (cheapo RG-59, 500 ft at 80 MHz)
cable g=-13.0 nf=13.0

# Receiver in hut
# Variable attenuator g=0 to g=-12
# NB: att. noise figure = -gain!
att1 g=-12.0 nf=12.0
gain3 g=24.0 iip3=6.0 nf=5.0
# Antialiasing filter
bpf2 g=-1.0 nf=1.0
# Variable attenuator g=0 to g=-12
att2 g=-12.0 nf=12.0
gain4 g=20.0 iip3=20.0 nf=15.0
```

RESULTS:

With ATT1=0 & ATT2 = 0 (max gain):
G=77.0 dB, IIP3=-37 dBm, $T_{\text{eff}} = 254\text{K}$

With ATT1=-12 & ATT2 = -12 (min gain):
G=53.0 dB, IIP3=-18.3 dBm, $T_{\text{eff}} = 264\text{K}$

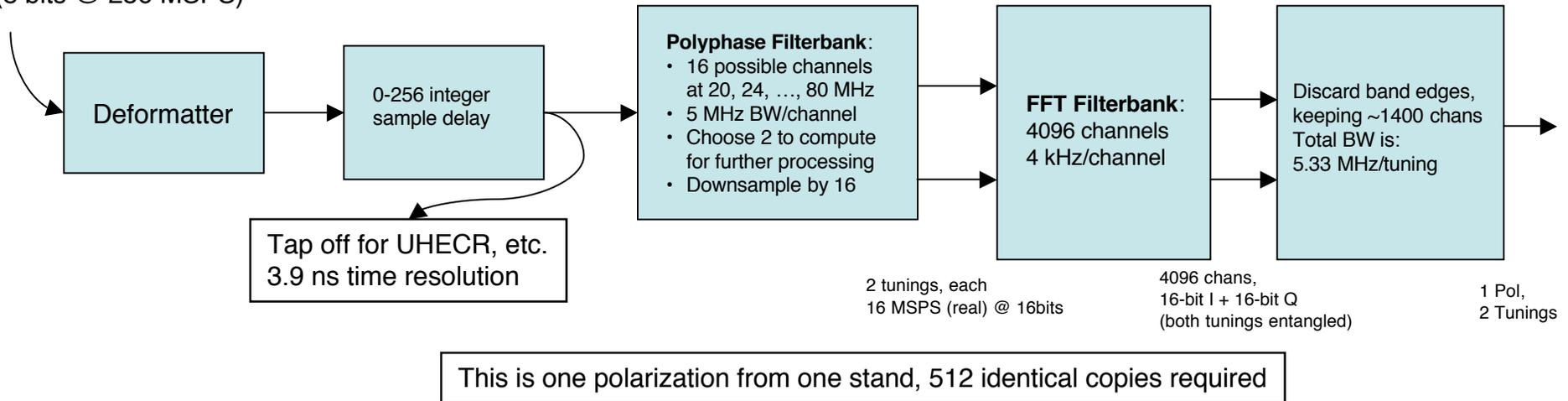
If balun can be improved to nf=2.0 (170 K)
then range becomes:

G=77.0 dB, IIP3=-37 dBm, $T_{\text{eff}} = 173\text{K}$

G=53.0 dB, IIP3=-18.3 dBm, $T_{\text{eff}} = 183\text{K}$

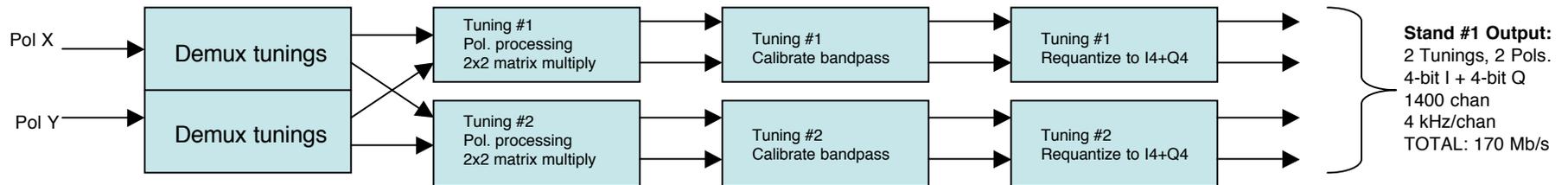
Digital Receiver (1)

Fiber link from Analog RX
(8 bits @ 256 MSPS)

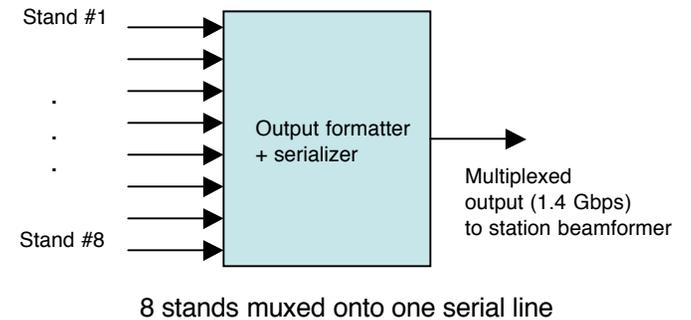


- Integer sample delay not needed for beamforming (phase beamforming is sufficient), but easy to implement
- Produces 2 tunings, ~5 MHz wide, optionally overlapped
- Channelized in this stage to ~4 kHz resolution in two stages
 - This accomplishes the “F” of the FX correlator
- Note, no NCO or CORDIC tuner (to save FPGA resources)
 - Fixed center frequencies on a 4 MHz grid
- Can get finer spectral channels, by reducing total bandwidth (not dynamically) to stay within available FPGA resources

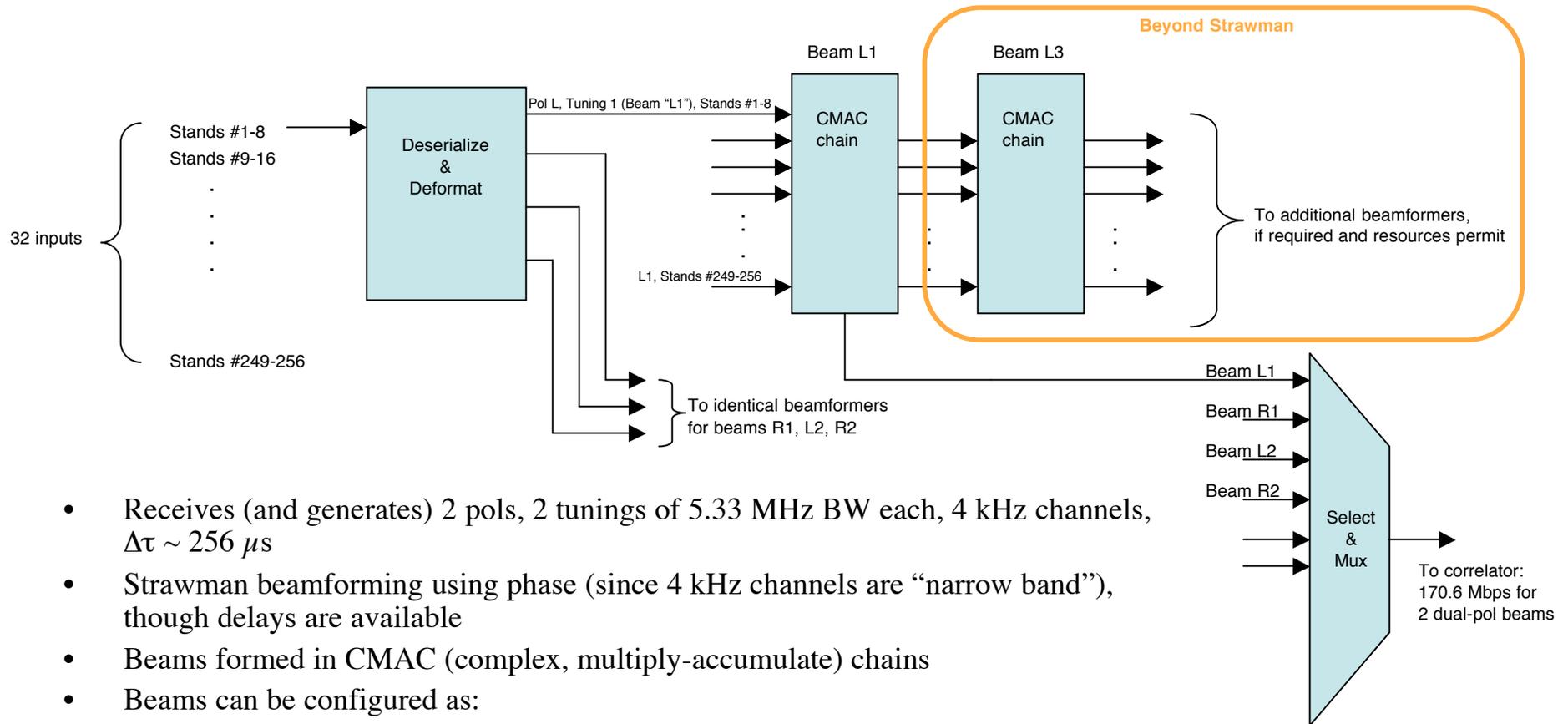
Digital Receiver (2)



- Combines polarizations with general 2x2 matrix multiply
 - Can convert X, Y to L, R and apply more general calibration, if needed
- Bandpass calibration (general complex factor per channel)
 - Could blank bad RFI channels at this step to reduce required dynamic range
 - Scale amplitudes to be optimal for 4-bit quant.
- Requantize to 4 bits I + 4 bits Q
 - Issue: Is it OK to requantize before beamforming?
- Need to think about bookkeeping issues (blanked channels, applied gains, etc.)
- Output formatter multiplexes 8 “stands” together for transport to station beamformer
 - $8 \times 170 \text{ Mb/s} = 1.4 \text{ Gbps}$



Station Beamformer



- Receives (and generates) 2 pols, 2 tunings of 5.33 MHz BW each, 4 kHz channels, $\Delta\tau \sim 256 \mu\text{s}$
- Strawman beamforming using phase (since 4 kHz channels are “narrow band”), though delays are available
- Beams formed in CMAC (complex, multiply-accumulate) chains
- Beams can be configured as:
 - 2 dual pol beams pointed in same direction at different freqs
 - 2 dual pol beams pointed in different direction (same or diff. freqs)
 - 4 single pol beams pointed in any direction (at 1 or 2 diff. freqs, NOT 4)
- Output to correlator is 42.6 Mbps per single pol beam
 - 2 tunings, 2 pols = 170.6 Mbps to the correlator
- Issues:
 - How many beams can be formed in available FPGA resources?

Long Distance Datacom

- EVLA 10 Gbps capability is overkill and too costly
- Need to investigate options soon! Long lead times!
- Must have plan for delay calibration for remote stations
- Investigate Fibre Channel solutions being explored at GB for GBT
- Recorded data (VLBI mode) might be useful in stages where realtime fiber connections aren't available
 - Modest speed IP connection could be used for M&C and some data transfer

Correlator

- Evolving capabilities required
- Baseline BEE2-based correlators (PAPER, etc.)
 - Question: Is this easily adaptable for our needs?
- Time/frequency standard will be GPS-disciplined Rubidium standards (e.g. Timing Solutions TSC 4410A; cost ~\$7k/station)
- Issues to investigate
 - How to digitize VLA dish data stream?
 - Data recorders for non-realtime analysis with software correlator
 - How hard would it be to write our own software FX correlator?

Comparison with LWA Requirements

| Parameter | LWA Spec | Strawman |
|---------------------|-------------------------------------|--|
| Freq range | 20-80 MHz | 20-80 MHz |
| Station sensitivity | Gal. Noise Dom., 256 dipoles | Yes, at least +6 dB |
| BW per beam | 4 MHz | ~5 MHz |
| Channel BW | 100 Hz | ~4 kHz |
| Time resolution | 10 ms | TBD mod 256 μ s (in correlator) |
| Polarization | 1 circular | Two orthogonal (full can be done in correlator) |
| Sky coverage | $z > 40^\circ$ (3 dB) | $z > 47^\circ$ (3 dB @ 40 MHz) $z > 61^\circ$ (3 dB @ 60 MHz) |
| FOV | $[8^\circ, 2^\circ]$ @ [20, 40] MHz | ✓ |
| # Beams | 4 single pol | 2 full pol. |

LWA-1 Strawman Design

- Assumptions:
 - Want to design first station that gets us as close as possible to the final design, but is likely achievable on the assumed schedule.
 - PDR Nov 2006, CDR June 2007
- Use LWA Strawman design for:
 - Antenna, Station configuration
 - Front end electronics
 - Analog receiver
 - Digital receiver stage (1) & (2)
- Will correlate with single outlier dipole of known pattern (e.g. COTS EMI measurement dipole over ground screen)

Beamformer

- In lieu of beamformer:
 - Record only 156 kHz total bandwidth (of 5 MHz total BW per beam) to get data rate down
 - Both beams and polarizations preserved
 - Build data aggregation board to combine 32 inputs of 8 stands each into 5 streams of ~50 MB/s, which can be PC recorded
- Why 156 kHz?
 - Most that can be practically recorded from all antennas in station (keeping 2 beams + 2 pols)
- Using recorded data we can:
 - Implement beamformer in software
 - Test beamforming algorithms
 - Do full sky imaging/transient searches
 - Capability not available in LWA
 - Investigate mutual coupling effects

LWA-1 Utility

- Demonstrates most functions needed for LWA
- Enables key measurements
 - Accurate antenna pattern measurement
 - Accurate station beam characterization
- Develops test equipment for future work
- Will expose unexpected problems:
 - RFI characteristics
 - Polarization/mutual coupling
 - ...

Comparison of LWA-1 with LWA Requirements

| Parameter | LWA Spec | LWA-1 Strawman |
|---------------------|-------------------------------------|---|
| Freq range | 20-80 MHz | 20-80 MHz |
| Station sensitivity | Gal. Noise Dom., 256 dipoles | Yes, at least +6 dB |
| BW per beam | 4 MHz | ~156 kHz |
| Channel BW | 100 Hz | ~4 kHz |
| Time resolution | 10 ms | TBD mod 256 μ s (in correlator) |
| Polarization | 1 circular | Two orthogonal (full can be done in correlator) |
| Sky coverage | $z > 40^\circ$ (3 dB) | <Nagini> |
| FOV | $[8^\circ, 2^\circ]$ @ [20, 40] MHz | ✓ |
| # Beams | 4 single pol | 2 full pol. |

LWA-2

- Like LWA-1 but with full beamformer added
- Incorporate incremental improvements in other subsystems and “lessons learned”