NRAO ALMA Correlator Upgrade Proposal

Rich Lacasse and many collaborators
(presenter: Rodrigo Amestica)

Atacama Large Millimeter/submillimeter Array
Karl G. Jansky Very Large Array
Robert C. Byrd Green Bank Telescope
Very Long Baseline Array

Collaborators

- Ray Escoffier NRAO (retired)
- Joe Greenberg NRAO
- Bob Treacy NRAO
- Rodrigo Amestica NRAO
- Alejandro Saez JAO/NRAO
- John Webber NRAO (retired)
- Alain Baudry Université de Bordeaux
- Mircea Stan UVA
- Al Wootten NRAO

Outline

- Scientific Motivation
  - Observing Efficiency
  - Higher time resolution
- Technical Approach
  - Upgrade as opposed to replace
  - Good "bang for the buck"
- How the upgrade affects some other systems in ALMA
- Status

Proposal in a Nutshell

- Double the current bandwidth, providing instantaneous coverage of the entire IF band (4-12 GHZ, USB and LSB, 2 polarizations).
- Increase the number of spectral channels by a factor of 8 (down to 1.9 KHz in dual pol)
- Increase the time resolution, at least in hardware, by a factor of 16, down to 1 msec, with TBD ability to output results. Spigot port provided.

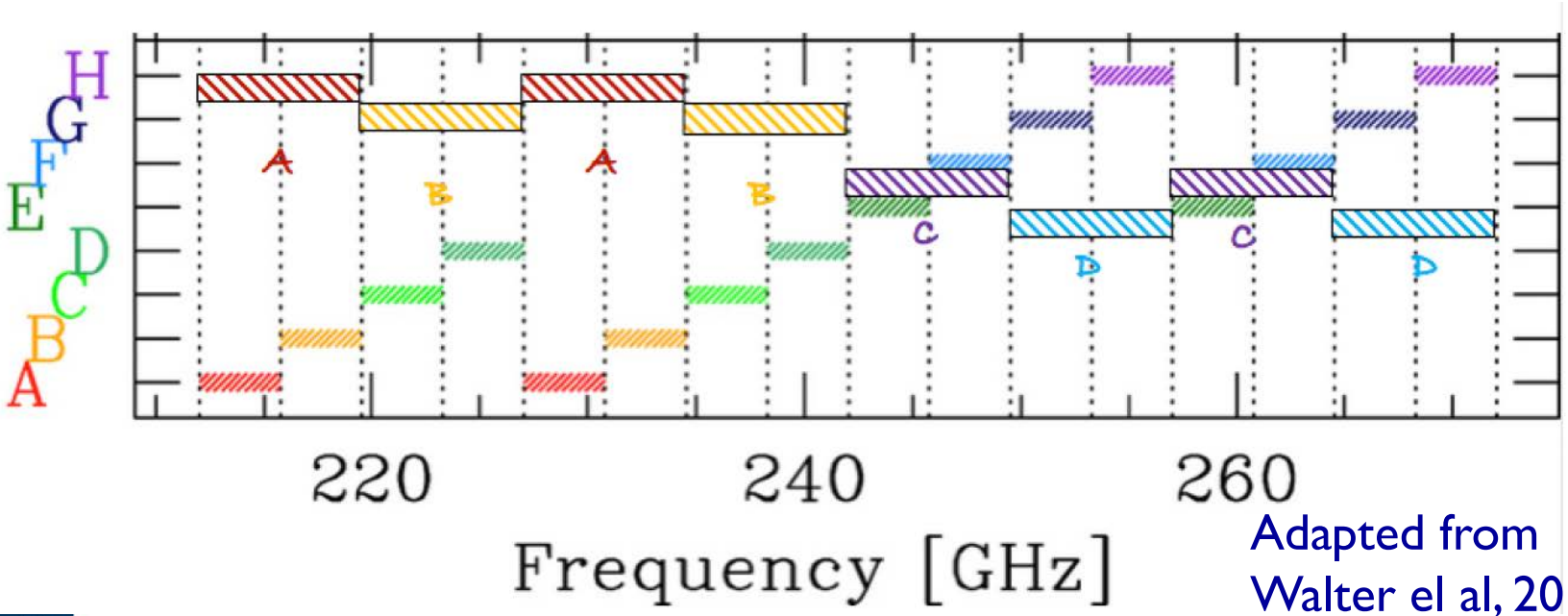
Scientific Motivation

- A ROAD MAP FOR DEVELOPING ALMA, ASAC Recommendations for ALMA 2030, Bolatto et. al. states:

  *"The ability to provide and process **wider instantaneous bandwidths**, together with continuous improvements in receiver sensitivity, can bring **scientifically significant increases in observation speed**. The ultimate goal is to **correlate an entire receiver band in one go**, with no loss of sensitivity. This requires improvements not just to the receivers themselves, but also to the digitizers, the IF transport, **the correlator**, and the archive."*
  *…**Doubling the bandwidths of the** digitizers, fiber-optics transmission, **correlator**, and archive seem, likewise, eminently possible with current technology.*
- Efficiency improvement gained by 4-bit correlation
- There is some interest in higher time resolution (FRBs, pulsars, solar)

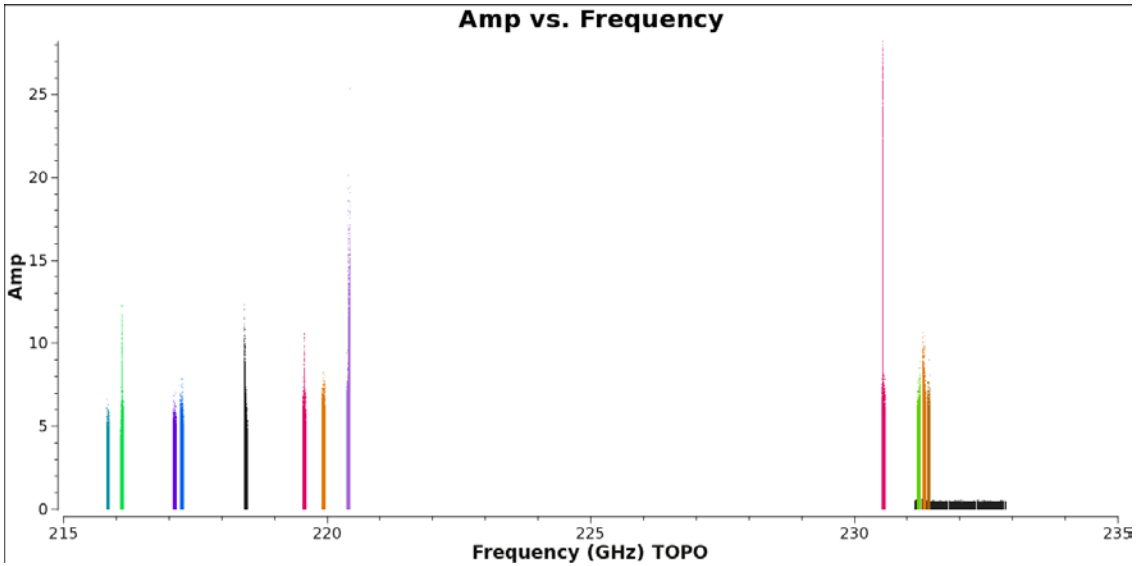
Obvious Advantages

- **Root-2 increase in continuum sensitivity**
- **Factor of 2 increase in spectral survey speed (e.g., Band 6 below)**



Adapted from Walter el al, 2016 and Wootten, 2017

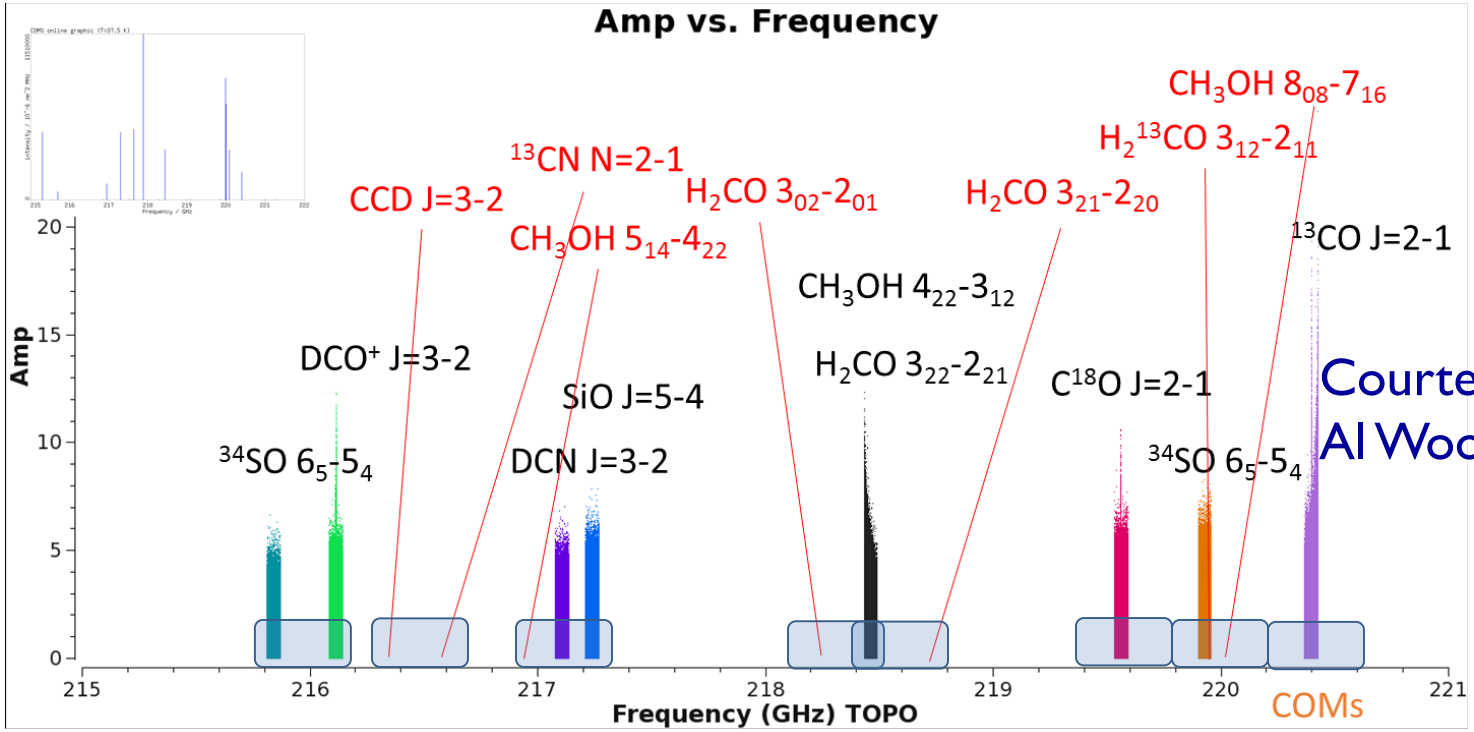
Scientific Motivation – multi-line obs.



Courtesy of Al Wootten

- Typical Correlator Setup, Starved for BW at high resolution
- 12 high resolution 62.5 MHz windows available (need one low res window for continuum)
- Many ***lines cannot be covered*** *(all available windows are in use!)*
- Upgraded correlator provides broader windows at higher resolution

Scientific Motivation – multi-line obs. 2



Courtesy of Al Wootten

- In Red are important lines that are missed with current correlator
- Upgraded correlator accesses all the missed lines at the current resolution, using wider filters, shown in blue.

Scientific Motivation – efficiency trades

Dual polarization, 2 GHz modes

Total Bandwidth	Number of Spectral Points	Spectral Resolution	Correlation	Sample Factor	Minimum dump time[1]	Sensitivity[2]
2 GHz	32768	61 kHz	2-bit x 2-bit	Nyquist	512 msec	0.88
2 GHz	16384	122 kHz	2-bit x 2-bit	Twice Nyquist	256 msec	0.94
2 GHz	8192	244 kHz	4-bit x 4-bit	Nyquist	128 msec	0.99

- At narrower bandwidths, trade-offs to improve sensitivity are possible
- Software for twice-nyquist and 4x4-bit correlation is currently unavailable, but will be developed in parallel with the upgrade.

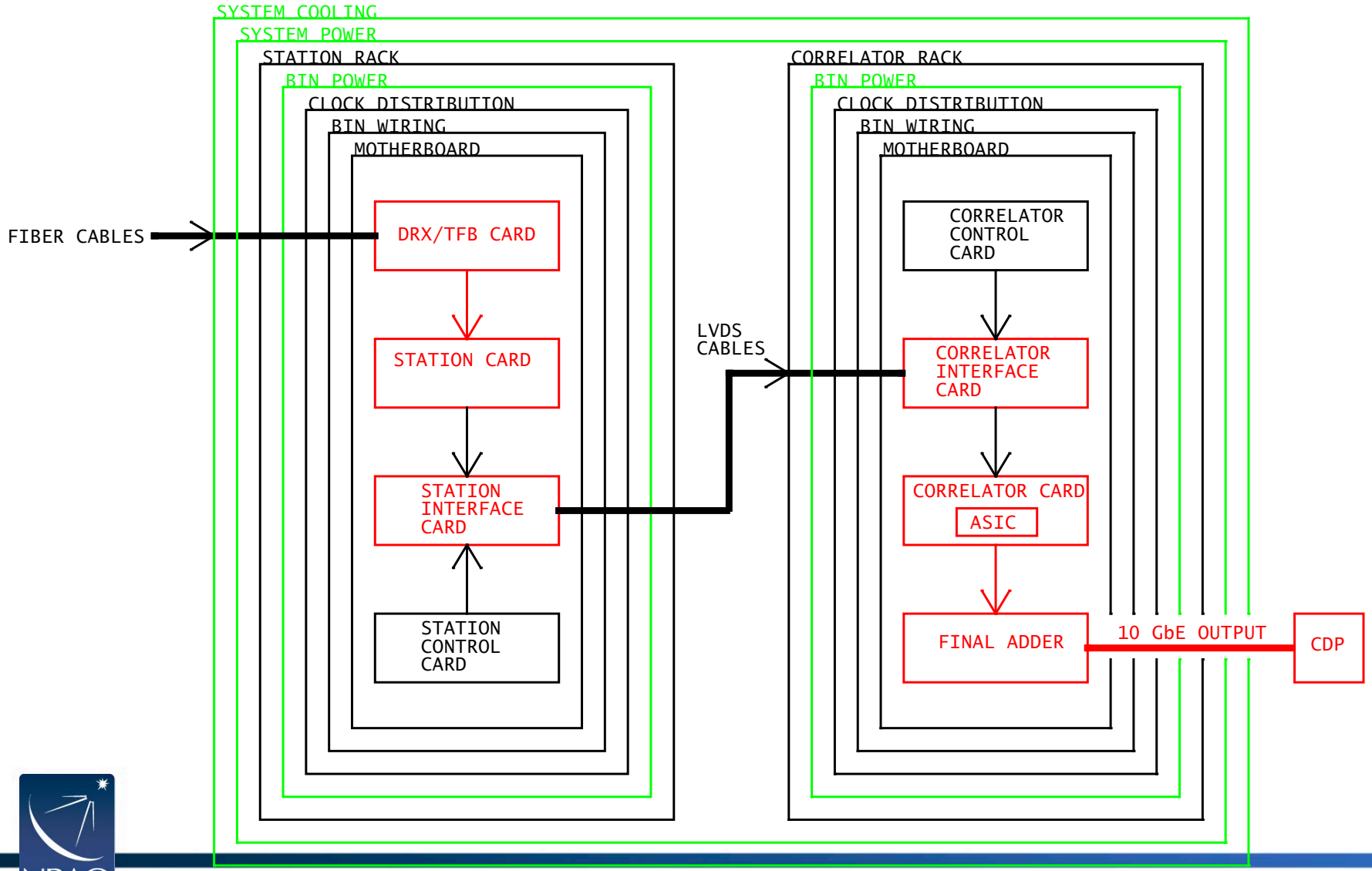
Note 2: Correlator sensitivity only; multiply by sampler sensitivity to get overall sensitivity.

Technical Approach

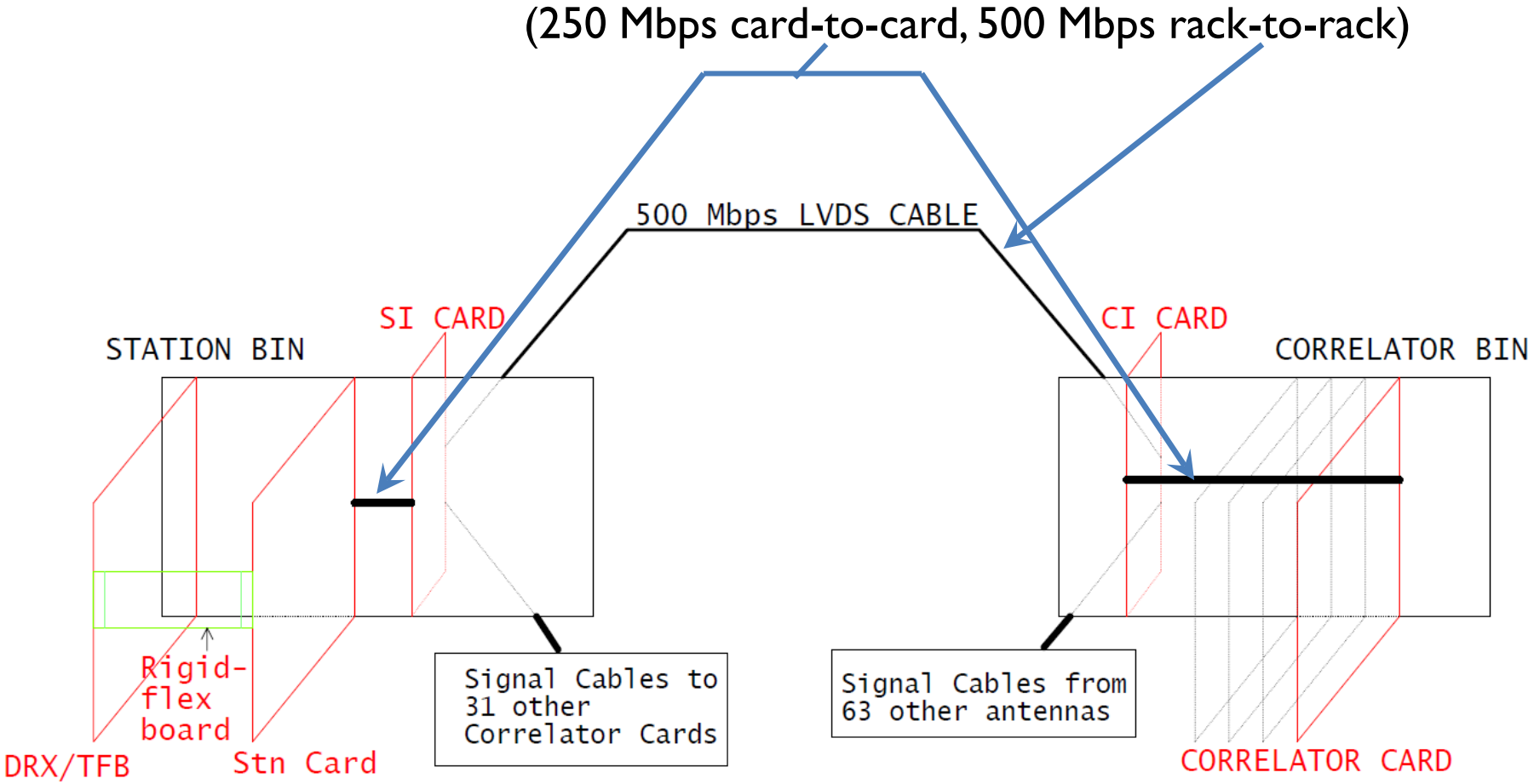
- The ALMA Correlator design was begun around the year 2000.
- In the intervening years, technology has progressed significantly (surprise!)
- A group in North America and Europe recently completed a study project focused on upgrading the correlator
  - Approach: upgrade the ***existing*** infrastructure
  - Saves time, money and a lot of software
- The study project has led to an ALMA development proposal
  - Still being evaluated
  - Will concentrate on the technical approach and interfaces, which is what is of interest here

Correlator Configuration:
Station Bins, Correlator Bins, Computers

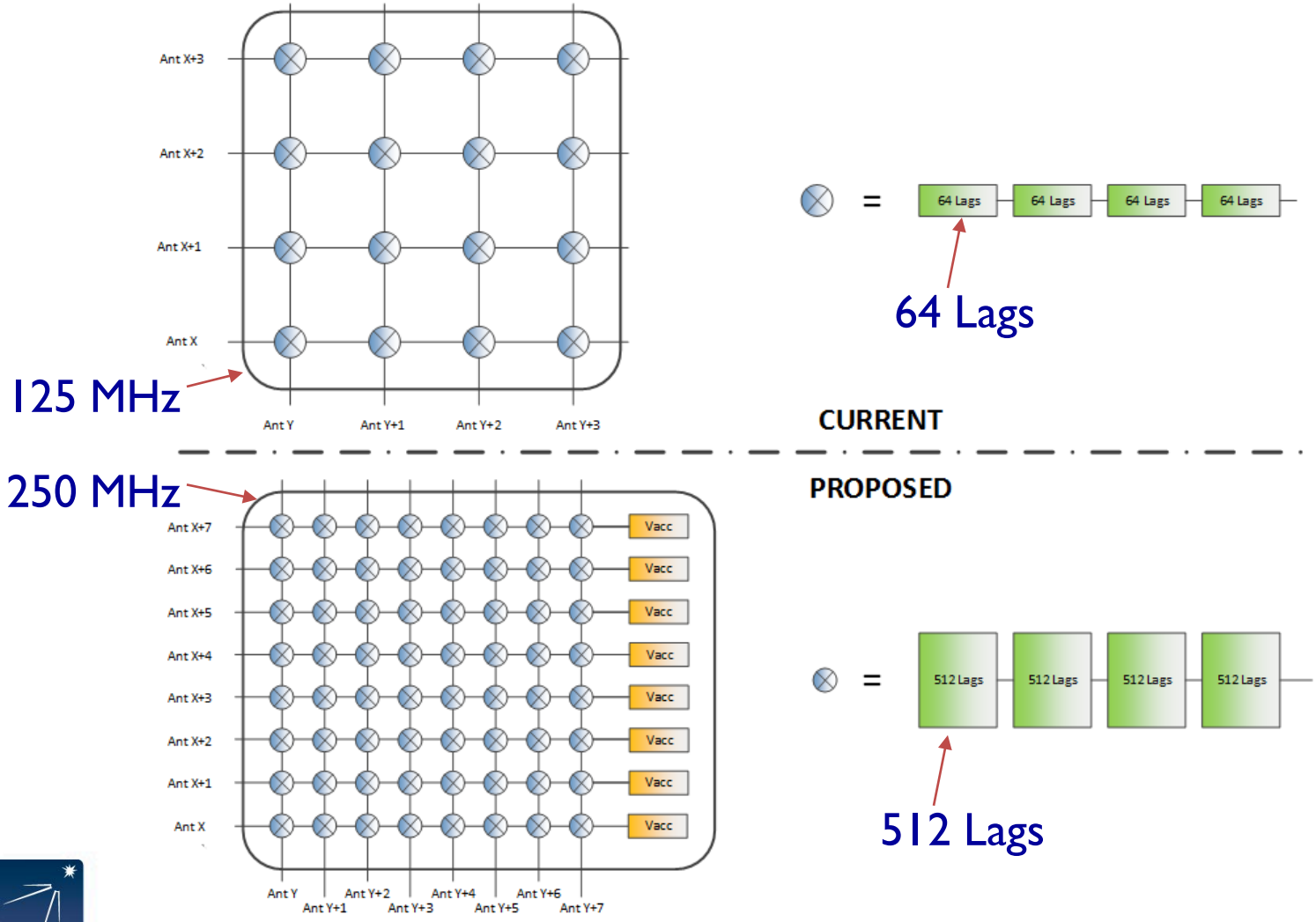
Block Diagram (black existing, red new, green reduction)



Signal Interface



Implementation Details: ASIC



Key External Interface Requirements

Sample Rate

- Currently 4 Gs/s, 3-bit
- **Improve to 8 Gs/s, 3 or 4-bit**
  - Note that correlator design has 2, 3 and 4 bit modes
  - The new 4-bit modes will have better spectral resolution than the current 2-bit modes (not available for all bandwidths)

Output Data Rate

- Flexible: data can be time or spectral averaged to accommodate required data rates.
- Currently <= 60 MB/s peak, 6 MB/s average
- **500 MB/s average or more is possible.**

System Test Approach

- Goal is to minimize disruption to a very busy observatory
- System Test in Charlottesville using
  - "5th Quadrant"
  - Sophisticated pseudo-random data sources (allow testing sensitivity, spectral resolution, etc.)
  - Production software with very few modifications
- System Test at the OSF
  - "5th Quadrant
  - Real-world signal chain
  - Production software

Upgrade Effects on ALMA System

Anti-Aliasing Filter

- Filter in front of the sampler and associated electronics

Samplers and Data Transmission

- Discussed later in this session!

Software in other systems:

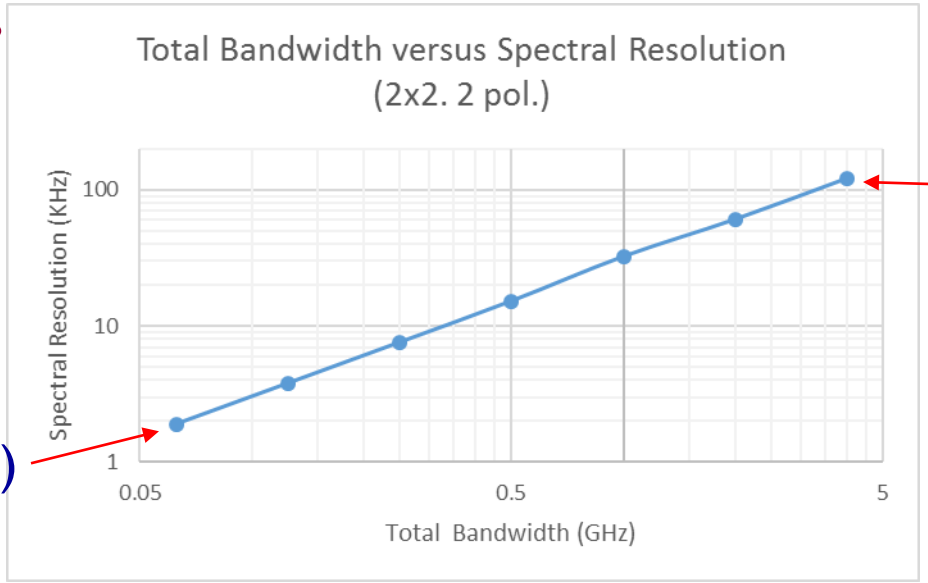
- M&C for Front End and Back End (bandwidth)
- Telescope Calibration (TELCAL, 8X # points)
- Observing Tool (all new capabilities)
- Data transmission between systems (hardware and software)
- Data analysis (CASA, calibration, 8X # points, BW)

What It Does Not Do

Correlation Resolution Limitations

- Widest bandwidths are still 2-bit x 2-bit resolution
- 4x4-bit correlation is possible only at narrower bandwidths
- Does not quite get to 1 KHz resolution in dual-pol modes

Correlator still trades spectral resolution for bandwidth.



(122 KHz, 4 GHz)

(1.9 KHz,62.5 MHz)

Summary

- ALMA2030 vision calls for doubling the bandwidth
- Our proposed design does this and improves spectral and time resolution as well
- We feel that our design accomplishes that with
  - Minimum cost
  - Minimum disruption
  - Minimum effort
  - Minimum risk
  - Fast time to operation
- Awaiting approval…

Thanks… and Questions?

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