EVLA Memo No. 15
Scientific Requirements for the EVLA Real-Time System

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10:53 September 26, 2000

Contents

1 Introduction

In this document we present the Scientific Requirements for the new VLA and EVLA real-time computing system. These requirements will be used by the real-time design team to construct the system requirements from which they will design the real-time system.

The scientific requirements have been prepared under the direction of the VLA Expansion On-Line Computing Oversight Committee, whose members are : F. Owen (chair), J. Benson, B. Clark, B. Glendenning, G. Hunt, M. Rupen, J. Wrobel. Members of the VLA and VLBA scientific staff have served as contact people for individual observing and calibration topics. Two public workshops were held during which the contact people presented their views for discussion. The contents of this document rely heavily on their efforts.

The contact people are :
T. Bastian - Solar Observing
B. Butler - Solar System Objects
C. Chandler - Water Vapor Radiometers
C. Carilli - Atmospheric Phase Interferometer
B. Clark - Auto-Phasing, Subarrays
M. Claussen - Spectral Line Observing, PT Link and the VLBA
D. Frail - Rapid Response to Sudden Bursters
T. Hankins - Pulsar Observing
R. Perley - RFI
M. Rupen - New Mexico Array (NMA), Total Power Measurements
D. Shepherd - Mosaicing
C. Walker - Antenna Pointing, Astrometry, Ionosphere
J. Wrobel - VLBI Requirements

The principle requirements that the new real-time system must meet are as follows :

- Replace the ModComp computers and control the current VLA hardware. Observers must be able to use the current OBSERVE/JOBSERVE control script files.
- Control the EVLA, the NMA, and fiber-linked VLBA antennas
- Control a hybrid VLA consisting of old and new hardware during the VLA to EVLA transition phase

This document contains two main sections. In Section 2 the scientific requirements collected by the contact people are presented. Section 3 is a distillation of the items in Sections 2 and from other sources, and provides a list of specific and largely quantitative specifications for the real-time design team. We have attempted to avoid designing the system ourselves and have strictly restricted the contents of this document to scientific requirements.

At this point we feel that it is useful to briefly describe the architecture of the proposed EVLA correlator, as embodied in the DRAO WIDAR correlator design. The scientific requirements in the following sections are to some degree based on the EVLA correlator capabilities and architecture, and certainly reflect the lexicon of the WIDAR design.

The WIDAR correlator is a hybrid XF correlator (cross-correlation followed by FFT's) with banks of digital filters on its front-end. The unique aspect of the WIDAR design is that the 2 GHz sampled baseband channels are digitally filtered into 16 subbands, each having a maximum bandwidth of 125 MHz. There is one bank of 16 subband filters for each of the eight 2z basebands. The individual subband filters within a bank may be set to bandwidths of 125 MHz / n, where n is a power of two. The minimum subband bandwidth is 8 MHz. The position of any subband within the 2 GHz channel is restricted to an integer number of subband bandwidths from the 0 Hz edge of the baseband channel. It will be possible for the correlator to support different subband bandwidths simultaneously within the same 2 GHz baseband channel. The subband filter outputs are decimated by a factor of 16 x n and fed into a conventional lagged correlator.

2 Scientific Goals for the EVLA Real-Time System

In this section we lay out the real-time scientific goals and requirements as specified by the contact scientists and other VLA users. Current capabilities are generally assumed to be common knowledge in the design group, and are not re-specified here. The following items are intended to be used as guidelines for the real-time system designers, supplementing the requirements in Section 3.0. The requirements in Section 3.0 include all items in Section 2.0. Purely technical and calibration goals are specified only in Section 3.0.

- continuum imaging
  - minimum correlator dump time : 100 millisec
- spectral line imaging
  - observers may specify different subband frequencies and bandwidths simultaneously within each 2 GHz baseband channel
  - observers specify spectral averaging and ranges of spectral channels to archive - different values allowed per subband within a subarray
  - maximum expected phase-center switching rate within the primary beam : 10 secs
  - observers may require different phase-centers for each of the eight 2 GHz baseband channels
  - within a receiver band maximum fast frequency switching rate : 1 sec
  - minimum correlator dump time : 100 millisecs (sustainable rate)
  - independent selectable tapers for cross correlation lags should be available for each subband
  - flexible interactive displays should be available to the VLA operator and observer : including auto and cross correlation spectra, spectral channels plotted versus time
- mosaicing
  - pointed and on-the-fly mosaicing should be supported and easily implemented by the observer
  - total power measurements are required

  - antennas must move in a controlled way while OTF scanning. Pointing errors < 10 arcsecs at K-band at the EVLA proposed scan rate < 2.5 degrees/min. Q-band OTFs may require slower scanning rates.
  - minimum correlator dump time : 100 millisecs (sustainable rate)
  - phase center model update rate : 100 millisecs (sustainable rate), must be synchronized with correlator dump times
  - the ability to apply WVR phase corrections is essential. This should be possible in real-time and during post-processing.
  - antenna encoder positions archived and available to observer in post-processing
  - most mosaicing observations will require a sustainable correlator output data rate of 25 Mbytes/sec, some may eventually need as much as 200 Mbytes/sec

- solar system objects
  - JPL Planetary Ephemeris on-line - user transparent
  - support observer supplied ephemerides
  - track fast moving objects (interferometer model, antennas) : 1 arcsec/second
  - near-field corrections in interferometer model
  - total power and mosaicing required
  - spectral resolution : 1 Hz
  - support observing low earth orbit satellites if it doesn't greatly increase the complexity of the real-time system

- solar observing
  - solar ephemeris - JPL Planetary Ephemeris on-line - user transparent
  - track position on solar disk, track solar rotation
  - rapid response to external notification of solar bursts
  - interactive displays and controls are important

- astrometry
  - high accuracy, high precision interferometer model
  - accurate Earth Orientation Parameters, antenna positions, etc.
  - rapid source switching (no less than) : 10 secs
  - fast band switching : 15 secs
  - exact interferometer model accountability in output data and archive
  - accurate u, v coordinates (0.1 millimeter)

- rapid response to sudden bursters
  - rapid response to external notification of sudden event
  - support pre-programmed observing mode
  - support (protected) Internet interactive control and data display

- VLBI and VLBA observing
    - geodetic accuracy for antenna positions
    - auto-phasing : phase all VLA baseband channels
    - sum-ports :sum all VLA baseband channels individually
    - sum-ports :sum up to 4 subarrays separately
    - requires S/X bands simultaneously if hardware is available
    - source switching : 10 secs
    - reference antenna pointing scan (interferometer mode): 1 minute
    - subarrays : up to 8 subarrays
    - single antenna observes simultaneously with phased subarrays
    - real-time WVR corrections may be necessary for phased-array operation at high frequencies
- pulsar observing
    - correlate multiple phase-centers within primary beam
    - support gating and binning on correlator
    - phased array analog sum for external pulsar machines
    - correlator output burst mode : 10 millisec
    - interactive displays and controls important
- total power measurements
    - solar system ephemeris on-line (planets, for flux calibration)
    - tipping scans
    - in-band frequency switching : < 1 sec
    - switch receiver bands : a few minutes
    - source position switching : 10 secs
    - on-the-fly mapping : a few seconds
    - up to one subarray per antenna
    - one subarray per observing band to monitor bright sources
    - minimum correlator dump time (auto-correlation spectra only) : 30 - 50 millisecs (sustainable rate)
    - total power sample rate : 30 - 50 millisecs
- NMA, PT Link, future real-time VLBA
    - VLA/NMA/VLBA scheduling and control must be tightly linked
    - support different simultaneous phase-centers for each baseband
    - phase-center switching within the primary beam : 5 secs
    - phase referencing : in-beam and out of beam calibrators

  - subarray switching : < 1 minute
  - source switching : 10 secs
  - NMA will often operate as a separate subarray
  - all NMA antennas may be used individually for VLBI
  - for NMA antennas used for VLBI, the real-time system will have to control the VLBA-type data recorders
  - astrometric observations will be common
  - minimum correlator dump time : 100 millisecs

- Desired but Unplanned EVLA Hardware
  - simultaneous dual-band feeds and receivers : S/X, C-band with K-band (and higher)
  - a few antennas specially equipped for accurate total power measurements : nutating subreflectors possibly on NMA antennas

3 Scientific Requirements

This section contains a complete set of scientfic requirements for the real-time computing system designers. The items in Section 2 and other requirements received from the contact people and the VLA staff are catagorized and described by computing subsystem.

3.1 Design Goals and Guidelines

The Design Goals and Guidelines subsection presents scientific requirements of a more general nature than in Section 3.2.

3.1.1 VLA - EVLA Hybrid Array

The real-time system must support simultaneous operation of the old VLA antenna systems and the upgraded VLA antenna systems during the transition phase. Array down time must be minimized as much as possible. The current VLA correlator will have to be supported until the new correlator is delivered and debugged, and operations using the old VLA must be possible using the current OBSERVE/JOBSERVE script files.

3.1.2 Flexibility

Although we all understand what *flexibility* means generally, it is difficult to exactly specify *flexibility* requirements for the real-time system. During the lifetime of the EVLA, we certainly expect unforeseen observing modes to emerge. The real-time designers should do their utmost to construct a system that will minimize software modifications needed to accommodate new observing requirements.

3.1.3 Support Interactive Observing

- provide required data and receive EVLA control parameters from the interactive control and data displays (through the Internet)
- provide required data and imaging control parameters to the on-line imaging pipeline

3.1.4 Correlator Output Data Rate

The current correlator design calls for 32,768 unpolarized spectral channels per baseline, and 666 baselines. At a maximum sustained dump rate of 100 milliseconds and two 4 byte words per visibility, the correlator will be capable of producing 436 Mbytes/sec. This is obviously beyond the capabilities of any currently affordable technology to write to an archive media. However there are sufficiently strong scientific reasons to attempt to archive data rates of 20 to 25 Mbtyes/sec. Even though this may prove to be technically difficult and expensive, we urge the real-time design team to make a strong effort to achieve archival data rates in the 20 to 25 Mbytes/sec range.

As the appropriate technology advances in the future and faster and cheaper media writers become available, the correlator-to-archive data rate can be increased. It is important that this part of the real-time system be designed with expandability in mind.

3.1.5 A Unified Data Archive

- archive essentially all data (scientific, engineering and operational)
- all archived data should be uniformly available, that is, accessing different kinds of archived data should be a relatively simple process. The details of where and how different types of data are archived should be invisible to the users.
- correlator output data should be archived in raw form
- complete interferometer model accountability is essential
- all observing related information, including OBSERVE script files and observing logs, should be archived

3.1.6 Distribution Data Format

- An upgraded version of the uv_FITS format is recommended
- Must accommodate the imaging pipeline requirements

3.2 Specific Requirements

3.2.1 Hardware Reconfiguration: How Often and How Fast

Reconfiguration Type	Rate	Speed	Limitation on Speed
OTF mosaic cell phase-center jump	100 millisec	100 microsecs	limited by phase rotator sychronization requirements
freq. swxing in rcvr band	1 second	100 microsecs	limited by LO settling time
phase-center swxing in primary beam	5 seconds	100 microsecs	limited by phase rotator sychronization
nodding source swxing	10 seconds	100 microsecs	limited by antenna servo settling time
redefine subarrays	few seconds	100 microsecs	limited by necessity of clearing out correlator buffers

3.2.2 Minimum Correlator Integration Times

- minimum correlator dump time (sustained) : 100 milliseconds
- minimum correlator dump time (burst mode) : 10 milliseconds

3.2.3 Time Frame

UTC and VLA LST should be used in all interfaces involving humans. Dynamic scheduling tools must use VLA LST, and the scan stop times in the observing control script files should be in VLA LST. UTC and VLA LST should both be available on the interactive control and display screens, while UTC only should be used as the time tags in the control scripts and archived data.

3.2.4 Integration Cycle Synchronization

The correlator integration cycles need to be synchronized in some manner to events in the observing schedule, and the calibration and correction data sampling. As well, a design goal should be to preserve the integrity of the first and last integration cycles in a scan. The EVLA will support various types of fast switching, and large numbers of spectral channels. Observers can be expected to schedule long integration intervals in order to reduce the correlator output data rate, while observing in short scans.

An observing scan should end precisely on an integration cycle boundary. The integration cycle boundaries must fall on times that are an even multiple of integration cycle times from a reference time. The reference time could be 0000 hrs UTC of the current day, or possibly a fixed date and time (e.g., 0000 hrs UTC 1 Jan 2000). The integration cycles will be in UTC seconds.

Since the observing control script files will contain only scan stop times and they will be in VLA LST, the real-time system must convert the scan stop times to the next integration cycle boundary. New scans will begin immediately following the end of the previous scan. No integration cycles will be missed during a scan change.

It is important, especially for OTF 100 millisec mosaicing, that the data in the first integration cycle of a new scan not be contaminated by the bad data that occurs during reconfiguration and model updates. As of this writing, it is not clear how to mask out the 100 microseconds or so of bad data. This will probably require special hardware and controllers in the correlator. The engineering details have yet to be worked out.

3.2.5 Special Requirements for Input Control Data

- source position precision : 10 microarcseconds
- antenna position, axis offsets : geodetic level of accuracy
- Earth Orientation Parameters : USNO Rapid Service (unless better comes along)
- JPL Planetary Ephemeris should be on-line and automatically available as needed
- JPL NAIF Spice Software should be available : the NAIF package reduces general JPL orbit files to state vectors
- pulsar phase ephemerides, gate boundaries and bin alignment will be provided by the observer and passed to the real-time system

3.2.6 Subarrays

A subarray is defined as a disjoint collection of antennas that operate independently of the other antennas in the VLA and NMA. The baselines between antennas in separate subarrays are discarded. The correlator configuration must be the same for all antennas within the same subarray.

Antennas within a subarray may have different observing frequencies as long as at least one baseband channel may be correlated. The real-time system will have to support the old and upgraded VLA antennas and electronics simultaneously during the VLA to EVLA transition phase

Two levels of subarraying are required. First, the VLA operations staff will assign antennas to specific observing programs. Second, the observing programs may freely schedule their antennas into subarrays.

3.2.7 Interferometer Model

A high accuracy interferometer model algorithm is desired. The GSFC CALC[1] program is used on the VLBA correlator and on other correlators world-wide. The CALC program provides a

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[1] CALC was developed by the Goddard Space Flight Center with assistance from other geodetic VLBI groups. It is maintained and distributed by Goddard as a service to the VLBI community.

geodetic level of accuracy and smoothness, and is generally a robust and dependable piece of software. CALC should be the default choice for the interferometer model algorithm.

Sidereal tracking and mosaicing observations require :

- lobe rotator phase and phase rate update interval : 50 milliseconds
- lobe rotator phase precision : 0.5 degrees of phase
- delay and delay rate update interval : 50 milliseconds
- delay model precision : 15.625 picoseconds

Fast moving objects within the solar system may require phase and delay polynomials having second or possibly third order terms.

The atmospheric model currently in CALC may prove to be insufficient for high frequency observing with the EVLA. We may have to employ a better model (if available), possibly using tipping scan data.

The CALC program also calculates local azimuth and elevation angles as part of its normal operation. The az/el's and their first derivatives are based on a geocentric vector pointing to each antenna. These geocentric baselines are in a terrestrial reference frame that has been rotated to the J2000 equinox by precession, nutation, diurnal spin, UT1 and polar motion rotation matrices. The antenna vectors are also corrected for solid earth tides, and annual and diurnal aberration. The azimuth and elevation angles are therefore suitably corrected. Updating the antenna pointing servos with new az/el's every 50 millisecs will keep the commanded az/el's to a sub-arcsecond level of accuracy.

3.2.8 Special Correlator Control Parameters

- spectral resolution - different values per subband
- observer specifies ranges of spectral channels to be written to the archive and interactive displays - different values per subband
- support different integration times per baseband channel in each subarray
- support different integration times for different antennas within a subarray - the observer should be able to specify longer integrations on the VLA internal baselines, and shorter integrations on baselines involving the NMA and VLBA antennas
- the observer should have the ability to separately specify pointing-centers and phase-centers
- burst mode : integration time and time interval between bursts, and UTC of first burst in an observing scan as the integration time
- selectable lag taper function
- option to archive correlator output in lags instead of spectral channels

3.2.9 Special Observing Modes

- auto-phasing
    - direct algorithm in the real-time system - the AIPS self-calibration algorithm could be used along with a list of important sources and models describing their structure
    - be able to mask out specified spectral line channels
    - sum correlator integrations for better solutions
    - phase different basebands (or subbands) to different positions
    - slave phasing of one baseband (or subband) to data from another
    - support interactive displays of phase solutions
    - archive phase solutions and a measure of phasing quality
- measure antenna pointing offsets
    - interferometer pointing mode (5-point) : as fast as the hardware allows
    - transfer pointing corrections for reference pointing
- measure antenna focus offsets
- tipping curve scans
    - allow the observer to customize the tipping scan parameters
    - elevation sweep - lower and upper angle limits
    - number of points to sample - evenly spaced in secant(z)
    - allow for antenna settling time
    - set sample integration time
    - may calculate opacity in real-time system, make opacities available to interactive display screens
    - single antenna subarrays for tipping scans
    - archive total power at sample positions and antenna pointing positions

3.2.10 Data and Measurements Collected in Real-Time

- correlator output data, real-time system design goal : 25 Mbytes/sec
- correlator validity line control
    - disable correlation during optical fiber propagation delay : lobe rotator model update is late and new source data is received late at the correlator.
    - others
- antenna pointing offsets (as described in 3.2.9)
- antenna pointing vectors

  - retrieve actual antenna pointing vector
  - calculate antenna pointing error (actual pointing - directed pointing)
  - outputs : pointing vector and pointing error must be available to the VLA operator's control screens and the observers interactive display
  - outputs : actual pointing vectors should be archived and distributed to the observers
  - outputs : archive pointing vectors at 100 millisecs intervals, the operator or observer should be able to switch this on or off

- antenna gain curves versus date/time and frequency are updated and maintained in the archive database

- Atmospheric Phase Interferometer
  - support interactive display that allows user input of parameters
  - support interactive display screens of API products and archival statistical data (diurnal, seasonal)
  - API outputs : amplitude and phase every 1 second
  - API outputs : RMS and monitor points every 1 minute
  - API outputs : structure function data products
  - API outputs : data products will be required by the dynamical scheduling algorithm and the VLA operators
  - API outputs : data rate 25 bytes/sec

- flagging data
  - support simple retrieval and display by EVLA operators and astronomers
  - will be constructed by real-time system, mainly from monitor data
  - flag when pointing errors exceed a specified threshold
  - flag when local oscillators are not locked
  - flag when shadowing occurs

- GPS data
  - the EVLA GPS system is unspecified at this time
  - interactive display of ionospheric data, real-time and archival
  - archive GPS output data, no real-time phase corrections are required
  - archive data on time scales of ionospheric variability, probably one or more minutes

- system temperature measurements
  - the real-time system will have to calculate system temperatures from cal on and cal off power levels, requires retrieving proper T_cal values
  - observer specifies the T_sys solution interval, the real-time system must be able to deliver T_sys measurements that are a multiple of both the T_sys switching cycle and the correlator integration time

  - T_sys's for each antenna and baseband channel must be available for real-time graphical display to VLA operators and interactive observers
- T_cal values versus date/time and frequency are updated and maintained in archive database
- tipping curve scans (described in section 3.2.9)
- total power measurements
  - support total power measurements while observing with the interferometer
  - support several specially equipped single antennas
  - solar system ephemeris on-line (planets, for flux calibration)
  - five-point observing mode
  - tipping scans
  - in-band frequency switching : < 1 sec
  - switch receiver bands : a few minutes
  - source position switching : 10 secs
  - standard mapping : a few seconds
  - one subarray per observing band to monitor bright sources
  - minimum correlator dump time : 100 millisecs (sustainable rate)
  - total power sample rate on specially equipped antennas : 30 - 50 millisecs
- visibility data weights, two kinds are required
  - weights whose values are proportional to the integration cycle completeness
  - weights whose values are proportional to the noise level in the data
- Water Vapor Radiometers
  - phase corrections may be calculated in real-time and applied to the interferometer phase model for high frequency observing, at 1 second intervals.
  - applying phase corrections in real-time should be an observer controllable option
  - WVR outputs : samples taken at closely spaced frequencies in 2 polarizations for noise cal on and off - there could be a fairly large number of WVR frequency channels
  - WVR outputs : samples at 1 second intervals
  - WVR outputs : data rate 80 bytes/sec per WVR receiver
  - WVR outputs : interactive display - real-time and archival
  - WVR outputs : all outputs must be archived

3.2.11 Corrections Applied in Real-Time

- Water Vapor Radiometer phase corrections must be applied to the interferometer phase model at 1 sec intervals for high frequency observations and high frequency auto-phasing
- antenna pointing and focus are corrected in real-time (of course)
- auto-phasing phase corrections are applied to the interferometer model in real-time (of course)
- RFI must be detected and excised in real-time

3.2.12 RFI Detection and Excision

The EVLA will certainly operate in an extremely hostile RFI environement. Radio interference is expected to be at least as high as 100,000 Jy over very narrow frequency ranges, < 3 kHz, and less powerful but scattered over 10's of MHz in the 2 GHz baseband channels. The scheme whereby RFI will be excised has not yet been developed. However at this point in time, regardless of how RFI will ultimately be removed, we can outline the requirements for an observer/operator RFI alert system. Such a system should include the following :

- warn the observer and operator of RFI in the observing bands based on an RFI catalog that has a history of RFI in time and frequency
- continuously monitor system temperatures or total power levels, and the amplitudes of each auto-correlation spectral channel
- control and receive (and display) data from a separate RFI monitoring radiometer, if such a system is built
- the RFI environment must be accessable to the observer, operator and scheduler through flexible display screens in real-time - they must be able to plot integrated total power spectra with zoom capabilies, and ranges of spectral channel amplitudes with time.
- the RFI history must be available to the dynamic scheduler
- support the ability to investigate and display the RFI environment generally through a variety of instruments and archival data
- an RFI description and the flagging that was applied must be archived

A Scientifically Relevant Data to be Archived

- Visibility Data
  - date and time of record
  - integration time
  - baseline_id
  - pointing center
  - phase-center
  - freq_id
  - subarray_id
  - channelization description
  - describe on-line calibration already applied
  - visibility data weights
  - u, v, w coordinates
  - raw correlator output visibilities
- Source Table
  - source type (star, planet, tipping, phase-center)
  - source IAU name
  - RA and DEC
  - RA and DEC first derivatives
  - coordinate reference frame
  - position and rate reference epoch
  - distance (parallax)
  - calibrator source type
  - label (text string from OBSERVE control script)
- Antenna Location Table
  - station name (VLBA_KP for VLBA, AW32 for VLA, NMA_BN for NMA)
  - antenna_id
  - pad number
  - x, y, z (geocentric position)
  - axis type
  - axis offset
- Antenna Table
  - antenna_id
  - start_time, stop_time

  - subarray_id
  - pointing offsets (both in ra/dec and az/el)
  - LO_offsets (one for each baseband)
  - LO_phase_offsets (one for each baseband - could support auto-phasing this way)
  - fast_integration_flag (different integration times per antenna)

- Subarray Table
  - subarray_id
  - observing project_id
  - correlation_configuration
  - LO_configuration
  - source_id (one for each baseband or model_id)

- Frequency Table
  - antenna_id
  - date and time of reconfiguration
  - sky frequency of 4 pairs of 2 GHz baseband channels
  - net sideband for each 2 GHz baseband channel
  - polarization for each 2 GHz baseband channel

- Local Oscillator Offset Table
  - antenna_id
  - date and time of reconfiguration
  - LO offset for each of 4 pairs of 2 GHz baseband channels

- Correlator Table
  - subarray_id
  - date and time of reconfiguration
  - for each of 16 subbands in each 2 GHz baseband channel :
    - subband lower edge frequency
    - subband bandwidth
    - net sideband
    - n_lags for subband correlator
    - long-term accumulator integration time
    - range(s) of spectral pixels written out
    - polarization mode : cross-hands on/off

- Auto-phasing Table
  - antenna_id
  - date and time of reconfiguration

  - phase correction applied to each 2 GHz baseband channel
  - quality measure of the auto-phasing

- Interferometer Model Accountability
  - date and time of model
  - time interval
  - antenna_id
  - source_id
  - total group delay, nth order polynomial (8 possible phase-centers)
  - total phase delay, nth order polynomial (8 possible phase-centers x 16 subbands)
- Flags Table
  - date and time range - flag condition active
  - antenna_id
  - baseband bad flag (8)
  - subband bad flag (8,16)
  - polarization bad flag (4)
  - RFI flagging description
  - reason for flag
- Antenna Pointing Corrections
  - antenna_id
  - date and time of measurement
  - pad number
  - pointing mode description
  - date and time of measurement
  - date and time of application
  - delta azimuth, delta elevation
- Antenna Polarization Corrections
  - antenna_id
  - date and time of measurement
  - frequency dependence
  - feed(s) position angles
  - polarization correction parameters
- Antenna Focus
  - antenna_id
  - date and time of measurement

  - receiver band - need more
  - subreflector position correction
  - subreflector angle correction
- Antenna Pointing Vectors
  - antenna_id
  - date and time of encoder readout
  - azimuth, elevation angles
- Pulsar Gate Weights
  - subarray_id
  - date and time of correlator integration interval
  - gate weights for each gate bin per subband
- System Temperatures
  - date and time of measurement
  - antenna_id
  - freq_id
  - baseband channel
  - system temperature
- Total Power Measurements
  - date and time of measurement
  - antenna_id
  - freq_id
  - baseband channel
  - system temperature (probably one for each subband)
- Atmospheric Phase Interferometer
  - date and time of measurement
  - amplitude and phase : 1 second intervals
  - RMS and monitor points : 1 minute intervals
- Surface Weather Measurements
  - date and time of measurement
  - weather station id
  - barometric pressure, temperature, dew point, wind speed and direction
  - precipitation measure
- WVR Data

  - date and time of measurement
  - antenna_id
  - WVR frequency bands
  - raw WVR output for each WVR frequency band
  - structure function fitting data products
  - phase correction (one for each subband)
- GPS Data - not yet specified
- RFI Data - not yet specified