EVLA Real-Time Science Software Requirements

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Change Record

Revision	Date	Author	Section/ Page affected	Remarks
1.0	2004-Oct-20	B. Butler	All	First Real Version
1.1	2004-Nov-15	B. Butler	All	Incorporating Ken & Barry comments
1.2	2004-Nov-22	B. Butler	All	Incorporating further comments

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Contents

Introduction

This document is one in a series of documents attempting to set down in detail the requirements on all of the different software associated with the EVLA. The other documents are: *EVLA e2e Science Software Requirements* (hereafter referred to as the *e2edoc*) *; EVLA Offline Data Processing Requirements, EVLA Operations Software Requirements*, and *EVLA Engineering Software Requirements*. This document draws heavily from EVLA Memo 15: Scientific Requirements for the EVLA Real-Time System, by Frazer Owen and John Benson. Information from the NRAO common software models (Observing, Project, and Archive) is also used herein. For instance, the placement of observing quantities into the various necessary databases is described in the Archive model. These documents may be found in the CommonNRAOModels area of the NRAO wiki. Finally, the document describing the overall design of the EVLA software (EVLA Computing Memo 33) contains the current high level software design, and a particularly useful section defining terms (section 11).

This is a living document and subject to revision at any time by the authors. The intent is to write down the requirements as completely as possible at a given time, but we must retain the ability to remedy oversights, reflect changes in philosophy with respect to the software, and react to the realities of schedule and budget (via feedback from the external community, NRAO scientific staff, EVLA Computing Division and EVLA project in general).

The prioritizing scheme is described below. Where possible we have made the requirements quantitative, and clearly defined the meaning of qualifiers and adjectives. However, there may be instances where the substance of particular requirements is necessarily subjective (e.g., "ease of use" and "robustness" type requirements). Rather than spelling these out in detail, we have have left these "squishy" requirements as-is, and will rely upon the authors and those charged with evaluating and accepting the software to take these properly into account. There are also a number of places, such as the headers to sections, where we discuss the philosophy behind our choice of requirements. In those cases, the discussions are given as *italicized* text and are not meant as requirements in and of themselves.

General description

The overall design of the EVLA software (see EVLA Computing Memo 33) splits the software into three general areas:

1. Offline subsystems: proposal, observation preparation, archive, and data reduction;

2. Online subsystems: scheduler, data capture and format (DCAF), and the quick-look pipeline;

3. Real-time subsystems: executor, M&C (including both antenna and correlator M&C) and several independent modules such as CALC and telescope calibration (TelCal).

Most of the requirements for the software in the offline and online areas are included in the *e2edoc*. In addition, requirements for much of TelCal are included therein. We do not concern ourselves here with the requirements already covered in that document, but rather the rest of the real-time subsystems: executor, M&C, CALC, and those parts of DCAF and TelCal that were not covered in the previous documents.

The Monitor and Control (M&C) system of the EVLA is a complex interconnection of many devices, both low-level and high-level, along with the software that drives them. This system is responsible for turning abstract observational concepts (that can be quantified, notably into observing scripts) into concrete commands to operate the telescope in the proper and desired fashion. Of course, the software is a critical part of the system, and we must be sure that it supports the hardware of the system and satisfies the higher level scientific requirements related to it.

Whatever software is delivered in the end, it should be straightforward to modify that software, changing or adding functionality. It should be possible to hire a programmer from outside the project (who has not

been intimately involved with the history of the software development) to do this in a timely fashion (not taking years for that programmer to learn the "system").

Priorities

We have adopted a priority scheme similar to that in the *e2edoc* document, which is a 2 dimensional scheme encompassing both the importance and the timescale for a particular requirement.

The importance can have the following values:

1 = essential
2 = important
3 = desirable, but not critical

It is intended that Priority 1 items must be present and work with high efficiency. Priority 2 items should be present, though there may have to be sacrifices in performance or availability may be delayed. We expect that the software will fulfill all Priority 1 and 90% or more of Priority 2 requirements. Priority 3 items should be considered for upgrades or development.

The timeframe of deployment is matched to the EVLA Phase I Project schedule (see the *EVLA Project Book*). The timescale phases are:

A = transition phase (2004 Q4)
B = prototype correlator (2006 Q1)
C = interim correlator (2007 Q2)
D = shared-risk science operations (2008 Q2)
E = full science operations (2009 Q2)
F = EVLA Phase II (unknown)
G = "eventually" sometime after completion (ongoing)

Note that these are slightly different than those used in the other requirements documents, as the dates have changed slightly in the past 12-18 months.

1 Executor

The EVLA will be controlled by commands, which are bundled together into scripts. During normal observing, these scripts will be embedded in Scheduling Blocks, which are created by the Observation Preparation Tool. The SBs are fed to the Executor by the Scheduler, which determines what is to be observed next. In interactive mode, SBs are fed directly to the Executor (it is a matter of semantics whether it is considered that they still are fed to the Scheduler, but given infinite priority so that they are always executed immediately) by an operator, astronomer, or engineer. In manual mode, commands are typed directly into the Executor. In any of these modes, the Executor then interprets the script (or command), gathers necessary system parameters and information, and passes along commands to the M&C systems.

1-R1 The Executor shall handle the observing for the EVLA in the main modes:

    1-R1.1 Manual mode: a facility shall be provided for direct submission of commands and scripts to the Executor, either from a file, or directly from keyboard input.
    Priority: 1 Timescale: A

    1-R1.2 Normal mode: normal EVLA observing shall be dynamically scheduled in quasi-real time based upon the queue of SBs - in this case the Executor is fed SBs by the Scheduler.
    Priority: 1 Timescale: E

    1-R1.3 Interactive mode: a facility shall be provided for the normal dynamic queue to be suspended, and control passed over to an observer (e.g., overriding priorities in the main queue, or through use of an auxiliary queue) so that the observer can submit a PB or SBs for immediate observing.
    Priority: 1 Timescale: E

1-R2 The Executor must control the passing of antennas into and out of "astronomical" subarrays, given such information within the SB.

    Priority: 1 Timescale: E

1.1 Required System Parameters

The Executor will need to get parameters from the telescope configuration, site properties, and monitor databases, and in some cases directly from TelCal in order to function properly. We outline the required parameters here.

1.1-R1 The following quantities from TelCal are needed when appropriate (for more information on each of these items, e.g., types of patterns that should be supported, etc..., see the RTCAT section of the *e2edoc*):

    1.1-R1.1 Autophasing information for each antenna, IF, and subband.
    Priority: 1 Timescale: D

    1.1-R1.2 Reference pointing offsets, for each antenna, for the appropriate band.
    Priority: 1 Timescale: D

    1.1-R1.3 Reference focus offsets, for each antenna, for the appropriate band.
    Priority: 2 Timescale: E

    1.1-R1.4 WVR derived delay offsets, for each antenna - provided at 1 second intervals.
    Priority: 2 Timescale: E

1.1-R2 The following quantities are needed from the various other databases or directly from the M&C subsystems:

    1.1-R2.1 Quantities for the entire array:
        1.1-R2.1.1 Earth Orientation Parameters (EOP);
        Priority: 1 Timescale: A

1.1-R2.1.2 Central weather station meteorological quantities (ambient temperature, dew point temperature, wind speed, wind direction, ambient pressure). The ambient and dew point temperatures are used to calculate the refractive pointing adjustment in the case that they are not available from each antenna.
Priority: 1 Timescale: A

1.1-R2.2 Quantities for each antenna pad:

1.1-R2.2.1 Pad position (X, Y, Z, relative to geocenter);
Priority: 1 Timescale: A

1.1-R2.2.2 Pad azimuth and tilt offsets;
Priority: 1 Timescale: A

1.1-R2.2.3 Pad delay;
Priority: 1 Timescale: A

1.1-R2.2.4 Pad connection type (VLA, VLBA, NMA).
Priority: 1 Timescale: F

1.1-R2.3 Quantities for each antenna:

1.1-R2.3.1 Pad number;
Priority: 1 Timescale: A

1.1-R2.3.2 Global pointing model (12 terms);
Priority: 1 Timescale: A

1.1-R2.3.3 K-term;
Priority: 1 Timescale: A

1.1-R2.3.4 Delay offset from pad location;
Priority: 1 Timescale: A

1.1-R2.3.5 wind speed and direction from the two anemometers;
Priority: 1 Timescale: A

1.1-R2.3.6 temperature and humidity from each antenna if available (to calculate refractive pointing adjustment).
Priority: 1 Timescale: F

1.1-R2.4 Quantities for each band/receiver on each antenna:

1.1-R2.4.1 Pointing collimation offsets;
Priority: 1 Timescale: A

1.1-R2.4.2 Reference pointing offsets (as derived from TelCal);
Priority: 1 Timescale: D

1.1-R2.4.3 Subreflector rotation setting, as a function of elevation (the elevation coefficients will probably be 0 for all bands except K-, Ka-, and Q-, but for generality they should be included);
Priority: 1 Timescale: A

1.1-R2.4.4 Default focus for each band, as a function of frequency within the band, temperature and elevation (the temperature and elevation coefficients may be 0 for C-, L-, P-, and 4-bands, but for generality they should be included);
Priority: 1 Timescale: A

1.1-R2.4.5 Focus offset (as derived from TelCal);
Priority: 2 Timescale: E

1.1-R2.5 Quantities for each baseband:

1.1-R2.5.1 Delay offset from pad + antenna, one each for parallel and cross-hands;
Priority: 1 Timescale: A

1.1-R2.6 Quantities for each subband:

1.1-R2.6.1 peculiar gain and delay;
Priority: 1 Timescale: A

1.2   Control Script Language

The Control Script Language (CSL) is the language of the script interpreter for the Executor. It defines the commands available for setting up the instrument, and for executing simple and complicated observations. It also allows for flow control, conditional execution, etc...

1.2-R1 The expert user/developer shall be able to send direct orders to the hardware and to basic quasi real-time software through simple scripts in a Control Script Language. These scripts, once fully developed and tested, will evolve into standard observing modes.

  Priority: 1 Timescale: A

1.2-R2 The minimum amount of observing activity that can be obtained by issuing a single observing command (subscan) is described by a subscan descriptor (see appendix). These parameters fully describe the data taking activity during that subscan, including telescope motion and switching schemes.

  Priority: 1 Timescale: A

1.2-R3 The CSL shall include commands to actually control the hardware (antennas, LOs, correlators) for data taking, according to the subscan descriptor.

  Priority: 1 Timescale: A

1.2-R4 All times used in the CSL should be in IAT.

  Priority: 1 Timescale: A

1.2-R5 Source positions used in the CSL should have a level of precision of 10 μasec.

  Priority: 1 Timescale: A

1.2-R6 It shall be possible to split the antennas into subarrays within the CSL. There should be a facility to remove and add antennas to subarrays, as a function of time.

  Priority: 1 Timescale: E

1.2-R7 It shall be possible to command antenna pointing independent of phase center pointing.

  Priority: 1 Timescale: C

1.2-R8 The CSL shall include commands to convert more generic input observing parameters into subscan descriptor parameters when this can only be done at the time of the observation. This includes:

  1.2-R8.1 coordinate conversion to the antenna system;
    Priority: 1 Timescale: A
  1.2-R8.2 LO and IF filter setting according to frequency and doppler tracking parameters;
    Priority: 1 Timescale: A
  1.2-R8.3 ephemeris calculations for moving bodies (where either the calculated accuracy must be at least 1 milliarcsec, or there must be enough precision allowed for in input ephemerides to obtain that accuracy):
    1.2-R8.3.1 using an input ephemeris table as a function of tabulated time;
      Priority: 1 Timescale: D
    1.2-R8.3.2 using standard internally calculated ephemerides for the major bodies in the solar system;
      Priority: 1 Timescale: D
    1.2-R8.3.3 using input orbital elements.
      Priority: 3 Timescale: G
  1.2-R8.4 calibrator selection. These should be determined once at the beginning of the relevant SB. The heuristics for determining these calibrators are to be provided by the scientific staff. The types of calibrations to be supported in this way are: time variable complex gain (CG); bandpass (BP); flux density scale (FD); and polarization (P). It should be possible to:

1.2-R8.4.1 take a calibrator from a supplied list, given a date range of applicability (for CG, BP, FD, and P);
Priority: 1 Timescale: D

1.2-R8.4.2 take a calibrator from a supplied list, given an LST range of applicability (for CG, BP, FD, and P);
Priority: 1 Timescale: D

1.2-R8.4.3 take a calibrator from a supplied list, given a quick observation of each at the beginning of the SB, and heuristics based on flux density and distance to the calibrator (for CG);
Priority: 2 Timescale: E

1.2-R8.4.4 choose a calibrator by making a mosaic of the region surrounding the target location (of specified size), and choosing the "best" calibrator found (based on heuristics to be supplied by the scientific staff).
Priority: 3 Timescale: G

1.2-R8.5 calibration cycle time, for time variable complex gain calibration. This should either be determined once at the beginning of the SB, or throughout based on TelCal results. The heuristics for determining these cycle times given current conditions or TelCal results are to be provided by the scientific staff.
Priority: 3 Timescale: G

1.2-R8.6 subscan integration times.
Priority: 3 Timescale: G

1.2-R9 The CSL shall provide facilities to transmit information to the quicklook pipeline and to TelCal.

Priority: 2 Timescale: D

1.2-R10 Features in the language built-in functionalities should include:

1.2-R10.1 macros for abbreviation of frequently typed sequences;

1.2-R10.2 procedures to which parameters may be passed;

1.2-R10.3 definition of variables and arrays, with numeric or character count;

1.2-R10.4 evaluation of expressions, including built-in functions;

1.2-R10.5 conditional execution facilities;

1.2-R10.6 loops;

1.2-R10.7 error recovery facilities including a time out;

1.2-R10.8 interrupt facility in procedure execution.

Priority: 1 Timescale: A

1.2.1   Documentation and Help

Since staff (and other expert) astronomers will need to access the CSL, there should be sufficient documentation and help facilities so that somebody not familiar with the CSL can use only those facilities to become proficient at running it. Such documentation and help should be easily accessible.

1.2.1-R1 There shall be a variety of help and documentation facilities available for the CSL. These shall include:

1.2.1-R1.1 An introductory "cookbook," including examples, designed to let a new user who is familiar with the EVLA and interferometry in general know how to operate the EVLA via the CSL.
Priority: 1 Timescale: C

1.2.1-R1.2 A more detailed User's Manual.
Priority: 1 Timescale: D

1.2.1-R1.3 A complete Reference Manual for the CSL.
Priority: 1 Timescale: E

1.3 CALC

The EVLA software must have a mechanism to calculate (and deliver to the antennas) delays to each antenna, given the geometry of the array and sources as a function of time. It would be possible to more generically specify the requirements here, but the decision to use the CALC[1] package to do this calculation has already been made, so we find no compelling reason to ignore that fact. CALC will be called by the Executor when needed to calculate the delays to the antennas.

1.3-R1 The lobe rotator phase polynomial should have a precision of 1 ps, and should be updated often enough and have enough terms to represent the lobe rotator phase to 1 ps accuracy at all times.

   Priority: 1 Timescale: A

1.3-R2 The delay model should have a precision of 15.625 ps, and should be updated often enough and have enough terms to represent the delay model to 15.625 ps accuracy at all times.

   Priority: 1 Timescale: A

1.3-R3 The atmospheric model portion of CALC may need to be supplanted by a more accurate model (see the *e2edoc* for details on such a model).

   Priority: 2 Timescale: E

2 Monitor and Control

The Executor sends individual commands to the EVLA hardware in order to set up the instrument properly for observing. The hardware (the hardware portion of the M&C system) is divided into two major subsystems - the antenna and the correlator. Each is commanded separately.

2-R1 Required hardware configuration rates are given here. Each is specified as a *rate*, which is how frequently such a reconfiguration must be able to be made, and a *speed*, which is how long it takes to complete such a reconfiguration.

   2-R1.1 OTF mosaic cell phase-center saltation: rate=100 msec; speed=100 μsec (limiting factor is phase rotator synchronization).
   Priority: 2 Timescale: E

   2-R1.2 frequency switching within a band: rate=1 sec; speed=100 μsec (limiting factor is LO settling time).
   Priority: 1 Timescale: D

   2-R1.3 frequency switching between bands: rate=10 sec; speed=3 sec (limiting factor is subreflector motion).
   Priority: 1 Timescale: D

   2-R1.4 phase center switching in the primary beam: rate=5 sec; speed=100 μsec (limiting factor is phase rotator synchronization).
   Priority: 2 Timescale: E

   2-R1.5 nodding source switching: rate=10 sec; speed=5 sec (limiting factor is antenna settling).
   Priority: 1 Timescale: D

   2-R1.6 subarray redefinition: rate=3 sec; speed=100 μsec (limiting factor is clearing out the correlator buffers).
   Priority: 1 Timescale: E

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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.

2.1   Antenna

As a general rule, the antenna M&C software must support all of the devices within an antenna - being able to both monitor and control them to their full capabilities. In other words, it should be possible to do everything that an engineer directly controlling a module can do via the antenna M&C software. Of course this also means that it must support all of the commands sent by the Executor, and at a higher level, all of the things that the astronomer wants to do (and embodies either in a standard observing script or a modified one). This means, of course, that all of the non-correlator instrumental setup items listed in the Observation Preparation section of the e2edoc must be supported (see the Hardware component, in requirement 2.1-R9). Items in the Archive section of that document should also be supported (what quantities get archived, etc...). Requirements from the EVLA Engineering Software Requirements document should also be honored.

2.1-R1 It should be possible to track sources with the antenna which move at non-sidereal rates, up to 10 times sidereal. The commanded pointing at the antenna should remain accurate to the specified path on the sky to $1/60^{\text{th}}$ of a primary beam FWHM at all times.

Priority: 1 Timescale: A

2.1-R2 The commanded pointing positions should be archived, at whatever rate they are sent to the antennas.

Priority: 1 Timescale: C

2.1-R3 If measurements of the actual pointing vectors of the antennas are available, they should be archived at 100 msec intervals.

Priority: 1 Timescale: C

2.2   Correlator

As a general rule, the correlator M&C software must fully support all of the capabilities of the WIDAR correlator. In other words, it should be possible to do everything that an engineer directly controlling WIDAR can do via the correlator M&C software. Of course this also means that it must support all of the commands sent by the Executor, and at a higher level, all of the things that the astronomer wants to do (and embodies either in a standard observing script or a modified one). This means, of course, that all of the correlator setup items listed in the Observation Preparation section of the e2edoc must be supported (see the Correlator setup subcomponent, in requirement 2.1-R9.10). Items in the Archive section of that document should also be supported (what quantities get archived, etc...).

2.2-R1 The data rates shown in Table 1 should be supported (the system should be able to support the maximum data rate continually during a given configuration).

Priority: 1 Timescale: E

2.2-R2 The minimum sustained correlator integration time should be 100 msec (but note that the total data output cannot violate the total data output rates listed in the above requirement).

Priority: 1 Timescale: E

2.2-R3 The minimum burst correlator integration time should be 10 msec (but note that the total data output cannot violate the total data output rates listed in the above requirement).

Priority: 1 Timescale: E

2.2-R4 It should be possible to specify that lags or spectra are archived.

Priority: 1 Timescale: E

Table 1: EVLA Data Rates

Timescale	Configuration	Maximum Data Rate (MB/s)
B	any	0.1
C	B,C,D	0.4
C	A	4.0
D	B,C,D	0.7
D	A	8.0
E	B,C,D	2.2
E	A	25
2012	B,C,D	5.0
2012	A	75
F	B,C,D	20
F	A	250
G (2017)	B,C,D	140
G (2017)	A	1600

2.2-R5 It should be possible to specify whether the Van Vleck correction is done in the CBE (Correlator BackEnd) or not.

Priority: 1 Timescale: D

2.2-R6 It should be possible to specify whether the conversion to estimated flux densities is done in the CBE (Correlator BackEnd) or not. In order to do this conversion, the following quantities must be known to the CBE (or archived, in the case that the conversion is not done in the CBE):

   2.2-R6.1 Gain, $G_{i,\nu}$ per antenna i and frequency ν. This can be approximated by: $G = f/(p\,\eta_a\,\eta_i)$, for decorrelation factor f, pointing and focus error factor p, aperture efficiency η_a, and interferometer efficiency η_i (accounts for electronic gain, e.g., LO coherence losses). Note that aperture efficiency vs elevation [the "gain curve"] should be stored in the appropriate database;

   2.2-R6.2 System temperature, T_{sys} at the time. This is obtained by measuring the difference in the power with the cal on and off, and knowing the cal temperature (T_{cal}). This means that T_{cal} as a function of frequency (not just band) must be stored in the appropriate database. Note that T_{sys} should be referenced to outside the atmosphere, so the opacity τ is also needed (estimated or measured).

Note that the conversion from true correlation coefficient between antennas i and j, ρ_{ij}, to flux density in Jy for the EVLA is:

$$V_{ij} = 5.625\,\rho_{ij}\,\sqrt{T_{sys_i}\,T_{sys_j}\,G_i\,G_j}\quad. \tag{1}$$

Priority: 1 Timescale: D

2.2-R7 The data written into the science data archive should conform to the NRAO Science Data Model. This is TBD at this date, but will likely be very similar to the ALMA Science Data Model.

Priority: 1 Timescale: C

3   Blanking and Flagging

Data that comes out of the correlator must be blanked (individual correlator dumps within a correlation

integration are noted as bad and not included in the sum), and flagged (an indication that entire integrations may potentially be bad).

3.1   Blanking

3.1-R1 For OTF mosaicing, the data in the first integration of a new subscan can be contaminated by bad data that occurs during hardware reconfiguration and model updates. Any such bad data should be blanked in the correlator.

Priority: 2 Timescale: E

3.1-R2 The minimum amount of blanked data shall be an integer multiple of $10\mu s$.

Priority: 2 Timescale: E

3.1-R3 Weights generated for the correlated data should reflect the amount of data blanked.

Priority: 2 Timescale: E

3.2   Flagging

3.2-R1 Flags that flag an antenna (and all of its cross-correlations, of course) as bad:

3.2-R1.1 Antenna not at commanded position flag. This can come directly from the ACU MIB, unless the MIB is not responding. It should be possible to override the default limits for this, which should not be a function of observing frequency (simply a fraction of FWHM of primary beam).
3.2-R1.2 Subreflector out of position. Similar to above.
3.2-R1.3 Focus out of position. Similar to above.
3.2-R1.4 LO (specifically, the L305 module) oscillator out of lock. Here, if the MIB is not responsive, a flag should not necessarily be generated, since the MIB is not critical to correct operation.
3.2-R1.5 Antenna is shadowed.
3.2-R1.6 RFI is detected - either by the correlator itself, or by some external measurement system.

Priority: 1 Timescale: C

3.2-R2 Flags that flag one or more basebands on an antenna as bad:

3.2-R2.1 L301-1 or L301-2 out of lock.
3.2-R2.2 L302-n out of lock.
3.2-R2.3 No IF power.
3.2-R2.4 Deformatter out of lock.

Priority: 1 Timescale: C

4   Time

4-R1 The fundamental time frame of the EVLA real-time system should be IAT. For display purposes, LST and local civil time should also be available. All data should be labelled/time-tagged with IAT time.

Priority: 1 Timescale: A

4-R2 Subscans should be specified by including either IAT start times or durations in the CSL.

Priority: 1 Timescale: A

4-R2.1 For higher level functions (reference pointing, delays, focus, TIPs), it should be possible to specify that the real-time system use whatever time is necessary.
Priority: 1 Timescale: A

4-R3 Correlator integration dump times should be specified in durations in IAT seconds (with fractions supporting down to 1 msec).

Priority: 1 Timescale: A

4-R4 A subscan should be an integral number of dump times in duration, and should stop on an even multiple of the dump time from a reference time of 0000 hours IAT in the current IAT day.

Priority: 1 Timescale: A

Appendix: Subscan Descriptor

The following quantities are used to describe a single subscan's worth of observing:

- Project ID

- Subarray ID

- Scheduling Block ID

- Source information:
  - Source ID
  - Catalog (YES, NO)
  - Catalog name
  - Solar system object (YES, NO)
  - Solar system name or filename of input ephemeris table
  - Coordinate system (EQ, GA, HO)
  - Epoch
  - Lambda at Epoch
  - Beta at Epoch
  - Lambda motion at Epoch
  - Beta motion at Epoch
  - Velocity
  - Velocity frame (TOPO, GEO, HEL, LSR)
  - Doppler track (CONT, ONCE, NONE)
  - Source type (PHASECAL,FLUXDENCAL,BANDPASSCAL,TESTTARGET,SCIENCETARGET)
  - Filename of input FITS cube describing source
  - Number of source components = NC
  - for each source component:
    - Type (POINT, GAUSS, DISK)
    - Flux density
    - Spectral index
    - Offset from phase pointing center
    - Major axis
    - Minor axis
    - PA
    - limb-darkening (for DISK only)
    - other parm 1
    - other parm 2

- Phase center information:
  - System (Hor, Eq)
  - Pattern mode (NONE, CIRCLE, POINTS)
  - Start coordinate
  - End coordinate
  - Angular velocity
  - Number of points
  - List of coordinates and times (for POINTS)

- Number of antennas = NA

- for each antenna:
  - Antenna ID
  - Position of antenna (X,Y,Z)
  - Antenna pad ID

- · Pointing model:
  - ○ 12 terms, plus refractive offset
  - ○ Pointing offset (Az, El)
- · Focus model:
  - ○ Default focus
  - ○ Focus offset
- · Delay model:
  - ○ Default delay
  - ○ Delay offset
- · Pointing pattern:
  - ○ System (Hor, Eq)
  - ○ Pattern mode (NONE, CIRCLE, POINTS)
  - ○ Start coordinate
  - ○ End coordinate
  - ○ Angular velocity
  - ○ Number of points
  - ○ List of coordinates and times (for POINTS)

- − FE information:
  - · Frequency band ID
  - · L3O1 Frequencies (X 2)
  - · Number of basebands = NBB
  - · per baseband:
    - ○ Polarization products
    - ○ IF Frequency
    - ○ IF Frequency Bandwidth
    - ○ L3O2 Frequencies (X 4)

- − Correlator information:
  - · Integration time
  - · Polarization products
  - · Number of basebands = NBB
  - · per baseband:
    - ○ Number of subbands = NSB
    - ○ per subband:
      - · Center frequency
      - · Total bandwidth
      - · Frequency Resolution

- − Water Vapour Radiometer:
  - · Use YES NO

- − Data processing script