EVLA Memo #129

TEST AND VERIFICATION PLAN

Critical On-the-Sky Tests Using the WIDAR Prototype Correlator

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ABSTRACT

This document describes the critical on-the-sky tests which are required before placing the final hardware procurement orders for the WIDAR correlator. These tests form the most crucial subset of those discussed in Carlson (2006), which lays out a more complete plan for bringing up both the hardware and the software associated with the WIDAR Prototype Correlator.

Contents

1. Introduction

The Wideband Interferometric Digital Architecture (WIDAR) correlator is fundamental to the operation of the Expanded Very Large Array (EVLA), processing the multi-gigahertz bandwidths provided by the new front ends and digital transmission system, and allowing the flexible spectral tuning and channelization required to make effective scientific use of these bandwidths. Given such a central role, there is a fundamental responsibility to check that this most important part of the EVLA actually works, so far as we can reasonably tell, before proceeding with the final hardware procurement orders. A great many functional tests have been and will be carried out off-line, using computer-generated test vectors and the like; but there is still some small chance that on-the-sky testing will reveal some hidden, low-level systematic effect that could be devastating, were it to find its way into the final system. Accordingly, NRAO and DRAO have mandated a series of critical on-the-sky tests which must be completed satisfactorily before the final hardware procurement. This document defines these critical tests and lays out the criteria for "satisfactory completion" of each test.

- These critical tests are intended to reveal possible *hardware* problems, which can only be fixed by modifying the fundamental design of the boards, chips, etc. Errors in FPGA programming, software issues, and the like are obviously important, but can be fixed after the fact, and thus do not lie on the critical *hardware* path for the correlator.
- Many intermediate developments and tests are implicit in the critical tests defined here – for instance, establishing real-time delay tracking. The intent here is not to lay out a complete plan for bringing up the prototype correlator, but to direct attention to the absolutely essential tasks of that correlator. A first draft of the complete plan is given in Carlson (2006).
- The on-the-sky tests described here and in Carlson (2006) are in addition to the many basic functional tests done at DRAO, described for example in Fort (2006), Fort (2007) (Station Board), Carlson (2006b), and Carlson (2006c) (Correlator Chip).
- The highest priority of the prototype correlator is to complete the critical tests defined here. Anything not essential for these tests – e.g., more advanced software integration, or trying out possible long-term observing modes – is a distraction, and should wait until these critical tests are done, or for the arrival of the 10-station correlator.

Carlson (2006) laid out the (now somewhat out of date) wiring and capabilities of the prototype correlator, and gave a basic chronology for testing that system. The current document specifies which tests are considered critical for *hardware* testing. All of the tests given in Carlson (2006) are useful and important, but the subset given here must be completed before ordering the bulk of the hardware for the final system, and hence lies upon the critical path for that final system. For this reason the tests listed here must be given higher priority than others which would primarily reveal software or FPGA programming bugs, which could be fixed at a later date.

1.1. The Prototype Correlator

The critical tests defined here are intended to be carried out using the first correlator hardware installed at the VLA site. This prototype correlator (PTC) will initially consist of two Station Boards (StB) and one Baseline Board (BlB). This will allow correlation of ~ 1 GHz per polarization for each of two EVLA antennas using 4-bit re-quantization; note that this gives 16 sub-band pairs.

Two additional StB will be shipped out a few weeks later, providing half the bandwidth (~ 0.5 GHz in each polarization, or ~ 1 GHz for one polarization) for each of 4 EVLA antennas.

There are several known problems with the boards which will be used for the PTC. In particular, the first BlB has one column which is not working, and one correlator chip has one bad accumulator in one correlator chip cell (CCC). The current plan is to work around these problems through careful tuning of the board setups used for the tests.

We may add the second prototype BlB to the PTC if that seems useful, but this must be traded off against the benefits of leaving this board in Penticton for DRAO to work with.

The relevant (rough!) hardware schedule as of 5 June 2008 is as follows:

- 28 May 2008: PTC test rack leaves DRAO
- 4 June 2008: PTC test rack installed at VLA
- mid-/late June 2008: Test vector fringe test (pre-requisite for shipment of PTC correlator boards)
- 9-20 June 2008: Brent Carlson and Dale Basnett at VLA site, connecting high-speed cables in PTC rack (as well as first 8 racks of final correlator)
- Late June 2008: PTC correlator boards (two StB, one BlB) shipped
- 1 July 2008: PTC correlator boards arrive at VLA
- Early July 2008: PTC "sanity checks" (does the PTC work at the VLA as it did at DRAO?) and software integration; begin on-the-sky testing
- July 7-18: Carlson and Fort in Socorro to train NRAO staff in the use of the PTC
- Mid-July 2008: Additional two StB arrive at VLA site
- 23 September 2008: Conclusion of critical on-the-sky testing (i.e., the subject of this document)
- October 2008: 10-StB, 3-BlB correlator arrives at VLA site
  - This assumes we cannibalize the StB from the PTC – that is, four of the 10 StB in the 10-StB correlator are taken from the PTC.

  - The BlBs by contrast represent the revised boards based on problems found during the first round of testing at DRAO; we will *not* re-use the BlB(s) from the PTC.
  - This is the first time e-MERLIN gets any BlBs.

- 21-22 October 2008: WIDAR Correlator Critical Design Review

The wiring of the PTC is significantly different from that of the final correlator. In particular, the PTC's BlB will be set up to correlate all 16 sub-band (SB) pairs for one BaseBand (BB) pair for 2-4 antennas; this is very different from the final correlator, where each BlB *pair* will correlate a *single* SB pair for up to 32 antennas. Specifically, for the two StB system all 16 sub-bands from one StB go into the upper RXP chip on the BlB, and all sub-bands from the other StB go into the lower RXP chip. This initial 2-StB system will allow correlation of 1 GHz per polarization.[1] The PTC will then be re-wired (a fairly easy operation) when the additional two StB arrive; at that stage one can correlate half the bandwidth (or a single polarization product) for all four antennas.[2]

The intent is that all PTC tests can be carried out over the internet, mostly from the AOC and DRAO. The PTC can for instance be power-cycled remotely. The PTC will be located in the old correlator room.

1.2. Interfacing with the Antennas

The data from the antennas must be fed into the PTC, but we do not wish to lose those antennas from normal operations (using the old VLA correlator) when the PTC is not observing. This requires splitters to copy the antenna data to both the PTC and the old correlator, which in turn means that we must choose the antennas to use with the PTC in advance. Those antennas are as follows:

- 25 (N2 in D & DnC)
- 18 (N3 in D, N12 in DnC)
- 23 (E9 in D & DnC)
- 19 (W4 in D & DnC)
- 26 (N6 in D & DnC)

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[1] Note however that only the 8-bit samplers will be available, limiting the inputs to the Station Boards to 1 GHz in a single polarization.

[2] Since only the 8-bit samplers will be available, we will be limited to 1 GHz going into each Station Board, allowing 1 GHz in a single polarization from each of 4 antennas, or 1 GHz in each polarization from each of 2 antennas.

- 4 (W9 in D & DnC)

The last two antennas (26 and 4) are intended as backup in case something happens to one of the first four. Switching inputs amongst these antennas requires physically changing the cables, as does switching between single and full polarization. Such re-cabling should be done as seldom as possible.

Currently we envision observing with one correlator or the other at a given time: that is, one cannot observe with the old correlator while using the PTC. This means that ~ 23 antennas will be sitting idle while we observe with the PTC. This is not thought to be a major problem, as the fraction of time spent in actual observing will be much less than that spent trying to understand the results. While simultaneous observing with both correlators is possible in principle, it would require a substantial software effort, involving key EVLA personnel.

One final restriction is that multiple 3-bit samplers will not be available until after the conclusion of the OTS tests. Hence all such tests will be done using the 8-bit samplers, producing 1 GHz of bandwidth, and requiring two Station Board inputs per sampler (i.e., two StB inputs [one entire StB] per antenna, per polarization).

1.3. Running the Tests

The software and control environment of the PTC is described in some detail in Sahr (2008); here I give a very high-level overview. In brief, a script identical to those used currently at the VLA will be executed using the current VLA Executor, which will control the antennas and the front-ends. An independent set of correlator configuration files, developed by the WIDAR Test Builder, will be executed in parallel using the WIDAR Test Executor, which will control the PTC. The only direct inputs to the PTC from the "standard" VLA will be (1) the data from the antennas; (2) the timecode; (3) the 128 MHz clock; and (4) the delay models. The correlator output will include (1) the StB and BlB auxiliary products (state counts, power measurements, wideband autocorrelations, and the like); (2) correlator lag frames and lag sets; and (3) the actual binary data (visibilities), in version 1.0 of the Binary Data Format. The first and second of these may be examined using the Real-Time Data Display (RTDD) and compared with "golden" files using Intelligent Diff. The visibility data, together with a minimal Science Data Model (SDM) containing information such as the transformation between channel number and frequency, may be examined directly using ALMA's SDM and BDF browsers. More typically they will be filled into a CASA Measurement Set (MS) using the ALMA 5.1 SDM2ms filler, and the resulting MS will be written out by CASA (in UVFITS format) and read into AIPS (FITLD) for detailed examination and analysis.

1.4. Reaching a Decision

In the best of all possible worlds, the tests described here would be carried out easily and with obvious success, with no ambiguity and no delay in the subsequent hardware procurement orders. In practice this is highly unlikely, and some judgement will be required in declaring an end to the critical tests, and deciding on an appropriate response. The WIDAR schedule is a major risk for the project as a whole. However, bringing the PTC to the VLA site will require a fair amount of software integration, and potentially lead to substantial delays which cannot be predicted or easily mitigated. How can we put these tests on the critical path, if there is no firm prediction as to how long they might take?

Currently the project plans to address this problem in four ways.

1. Make these tests the highest priority for the PTC, and for associated software, hardware, and scientific personnel, as soon as the PTC arrives.
2. Assign a single scientist (Rupen) primary responsibility for ensuring that the critical tests are in fact carried out. Additional personnel include:
   - the existing correlator team: primarily Carlson, Fort, and Vrcic of DRAO; and Ben Frej, Butler, Clark, Ferraro, Moeser, Pokorny, Revnell, Robnett, Rowen, Ryan, Shores, and Sowinski of NRAO
   - scientific support: primarily R. Perley and Momjian of NRAO, with others (e.g., Dhawan) on call
   - post-processing support: Greisen for AIPS; Moellenbrock for CASA
3. Hold frequent regular meetings with project management (nominally weekly) after the PTC arrives, to discuss progress on the critical tests.
4. Specify a hard date for a formal review of the outcome of the critical tests. This formal review will lead to one of three possible outcomes:
   - **Go**: The test results thus far are deemed sufficient to place the final large-scale hardware procurement orders.
   - **No-go**: The tests have revealed hardware problems that must be fixed before large-scale procurement.
   - **More testing needed**: The tests done thus far are inconclusive – more must be done to verify the hardware before proceeding to large-scale procurement.

The project currently (June 2008) carries a date of 21-22 October 2008 for the go/no-go review, which will be part of the WIDAR Correlator Critical Design Review. The tests themselves are scheduled to be completed a month before this date, on 23 September 2008.

2. The Critical On-the-Sky Tests

Here I summarize the *complete* set of critical on-the-sky (OTS) tests which the WIDAR Prototype Correlator must pass before we place the final procurement orders. These are intended to ensure that there are no fundamental hardware problems with the production system. Again I emphasize that these are *not* the full set of PTC tests; rather, these are the tests which lie on the critical hardware path.

The critical OTS tests with the PTC are as follows:

1. First fringe check, with delay tracking
2. Phase continuity checks
3. Closure check
4. Deep "continuum" integration
5. Spectral line consistency check
6. Sub-band aliasing test
7. Recirculation check
8. Deep spectral line integration

These individual tests are defined in detail in the subsequent subsections.

Several tests are missing from this list which were originally considered critical. The rationale for these deletions is as follows:

- Synchronous detection of switched noise source: upon reflection this seemed more likely to reveal software than hardware errors, and is in any case subsumed into the subsequent critical tests.
- First fringe check, no delay tracking: this adds nothing not covered by the first fringe check *with* delay tracking, and may be skipped altogether if the latter works.
- Deep integration using 3-bit initial quantization: the 3-bit samplers will not be available until after the scheduled end of the critical OTS tests.
- Sub-band stitching: while this is fundamental to the operation of the correlator, it seems impossible to distinguish algorithmic and/or software difficulties from hardware errors, on the timescale of these tests.

2.1. First fringe check, with delay tracking

Brent's test 13.

2.1.1. Requirements

- Antenna/baseline: single short baseline with well-known LO fiber delay.
- Observing frequency: low frequency (for slow fringing and stable atmosphere) without radio frequency interference (RFI) and without strong lines ⇒ probably L band
  Offset antennas by 10 kHz.
- Source: strong, unresolved continuum source (for strong, stable fringes, preferably in single 1 MHz channels)
  At L band the expected thermal (rms) noise level for a 1 MHz channel is $\sim$ 350 mJy in 1 second for a single baseline (single polarization).
- Time required: very short (minutes).
- Correlator input
  - Delay tracking ON
  - Single polarization
  - 8-bit initial quantization
  - Digital comb generator
- Correlator setup
  - 4-bit re-quantization
  - One sub-band near the center of the baseband, maximum bandwidth (128 MHz)
  - No recirculation
  - Integration time: $\sim$ 1 second.
  - CBE: Fourier transform
- Correlator data products
  - Wideband and sub-band data quality indicators (state counts, power measurements, etc.)
  - Sub-band auto- and cross-correlation
- Post-processing
  - RTDD: display amplitude and phase vs. frequency.

- Comparison (old correlator) data
  - None required

2.1.2. Definition of success

1. Tone generator amplitude and phase vs. time should be stable (with delay tracking active).
2. State counts, auto-correlation spectra, power measurements should be within normal regions.
3. Cross-correlation fringes should be detected with the RTDD.
4. Phase behavior vs. time should be as expected from the atmospheric conditions. In particular, drifts, jumps, and glitches must be absent or the source understood.
5. Cross-correlation amplitude and phase vs. frequency should be as expected based on old correlator (signal-to-noise ratio, phase slope, any additional bandpass features).

2.2. Phase continuity checks

New test, aimed at showing that the correlator resets to the previous state with no amplitude or phase discontinuities in various circumstances.

2.2.1. Requirements

- Antenna/baseline: single short baseline with well-known LO fiber delay.
- Observing frequency: low frequency (for slow fringing and stable atmosphere) without radio frequency interference (RFI) and without strong lines ⇒ probably L, C, X bands
  Offset antennas by 10 kHz.
- Source: strong, unresolved continuum source (for strong, stable fringes, preferably in single 1 MHz channels)
  At L band the expected thermal (rms) noise level for a 1 MHz channel is $\sim$ 350 mJy in 1 second for a single baseline (single polarization).
- Time required: very short (minutes).
- Correlator input
  - Delay tracking ON
  - Single polarization
  - 8-bit initial quantization
- Correlator setup
  - 4-bit re-quantization
  - One sub-band near the center of the baseband, maximum bandwidth (128 MHz)
  - No recirculation
  - Integration time: $\sim$ 1 second.
  - CBE: Fourier transform
- Correlator data products
  - Wideband and sub-band data quality indicators (state counts, power measurements, etc.)
  - Sub-band auto- and cross-correlation
- Post-processing
  - RTDD: display amplitude and phase vs. frequency.

- Comparison (old correlator) data
  - None required

2.2.2. Definition of success

1. Phase, amplitude, and delay should return to previous values when the array is driven to a second source and back again.
2. Phase, amplitude, and delay should return to previous values when the array is driven to another frequency within the same band and back again. Delays should be the same with both frequency tunings.
3. Phase, amplitude, and delay should return to previous values when the array is driven to a second frequency band and back again. Delay changes with band should be consonant with the known line length differences for the various receivers.

2.3. Closure check

New test.

2.3.1. Requirements

- Antenna/baseline: four antennas for closure. Slight preference for longer baselines and an unresolved source, to allow 4-antenna mapping, and to check the point spread function.
- Observing frequency: prefer low frequency to avoid pointing questions; prefer high frequency to avoid complex fields
  ⇒ X band (also offers simplest LO setup)
  Offset antennas by 10 kHz each.
- Source: simple source which is strong enough to allow direct display of closure quantities vs. time with minimal averaging (seconds). Should be placed *away from* the phase center.
  Rms noise for one baseline, 1 MHz, in 1 second, at X-band, is 280 mJy.
- Time required: hours – sufficient to achieve dynamic range of $> 10^4 : 1$, if limited by thermal noise (4 hours at X-band with 64 MHz gives 0.12 mJy/beam) – 3C 84?
- Correlator input
  - Delay tracking ON
  - Single polarization
  - 8-bit initial quantization
- Correlator setup
  - 7-bit re-quantization, to minimize quantization corrections
  - One sub-band, 64 MHz bandwidth
  - No recirculation
  - Integration time: ~ 1 second.
  - CBE: Fourier transform
- Correlator data products
  - Wideband and sub-band data quality indicators (state counts, power measurements, etc.)
  - Sub-band auto- and cross-correlation
- Post-processing

- CASA/AIPS to display closure quantities, calibrate, and image.

- Comparison (old correlator) data
  - Desirable to compare directly with old correlator data at 1 MHz spectral resolution, to show the effects of uv-coverage.

2.3.2. Definition of success

1. Closures (amplitude and phase) vs. time for individual channels should be stable, on timescales from seconds to hours.
2. Closures (amplitude and phase) vs. time for the sub-band as a whole should be stable, on timescales from seconds to hours.
3. Noise in closures should integrate down over time as expected.
4. Noise in closures should integrate down with frequency averaging as expected.
5. Closures (amplitude and phase) should be consistent with expectations from old correlator, in terms of (i) closure values and (ii) closure noise levels.
6. Self-calibrated data should yield an image consistent with expectations in terms of (i) off-source noise level, (ii) off-source noise characteristics, (iii) source structure, (iv) source flux densities, (v) lack of obvious artifacts. Dynamic range should not be limited by closure errors (i.e., should achieve thermal noise level both near and far from the source); note that this requires choosing a source sufficiently simple that the sparse (4 station) uv-coverage does not limit the image. Source should be chosen to give an expected dynamic range $> 10^4 : 1$.

2.4. Deep "continuum" integration

Part of Brent's test 20.

2.4.1. Requirements

- Antenna/baseline: four antennas for closure. Slight preference for longer baselines and an unresolved source, to allow 4-antenna mapping, and to check the point spread function.
- Observing frequency: prefer low frequency to avoid atmospheric and pointing questions; prefer high frequency to avoid large bandwidth ratio (and corresponding complexities of primary beam, changes in source flux and structure, etc.) and to avoid very complex fields
  $\Rightarrow$ X band (also offers simplest LO setup)
  1 GHz bandwidth at 8 GHz gives a bandwidth ratio of $BWR \sim 1.14$.
  Offset antennas by 10 kHz each.
- Source: mostly but not entirely empty field.
  A 0.5 Jy source would allow tracking the phase without saturation.
  One hour at X-band with 4 antennas, 1 GHz, single pol'n should give rms noise in the image of $\sim$ 0.07 mJy/beam. This suggests a somewhat fainter source, since it's unlikely we will achieve very high dynamic range images with only four antennas.
  A single 128 MHz sub-band would give an rms noise in an hour of $\sim$ 0.2 mJy/beam with 4 antennas at X-band; the corresponding rms noise for a 1 MHz channel should be $\sim$ 2.2 mJy/beam.
- Time required: full track (6-8 hours on-source).
- Correlator input
  - Delay tracking ON
  - Single polarization (or dual if we trust that)
  - 8-bit initial quantization
- Correlator setup
  - 4-bit re-quantization
  - Widest possible bandwidth (nominally 1 GHz)
  - No recirculation
  - Integration time: $\sim$ 1 second.
  - CBE: Fourier transform
- Correlator data products

  - Wideband and sub-band data quality indicators (state counts, power measurements, etc.)
  - Sub-band auto- and cross-correlation
- Post-processing
  - CASA/AIPS to calibrate and image.
- Comparison (old correlator) data
  - Likely none needed. If desired, to simulate this fairly directly with the same 4 antennas in continuum mode would take a factor $1024/200 \sim 5$ more time. Better bet: image with 27 antennas in continuum for about the same amount of time, and simulate a 4-antenna observation to be sure that will work.

2.4.2. Definition of success

1. Adding channels and sub-bands should reduce noise as expected.
2. Noise should integrate down over time as expected.
3. Images from one-channel, one-sub-band, and full baseband should agree with expectations from old correlator, in terms of (i) off-source noise level, (ii) off-source noise characteristics, (iii) source structure, (iv) source flux densities, (v) lack of obvious artifacts.

2.5. Spectral line consistency check

New test, aimed at showing that a spectral line remains consistent when observed with different sub-band bandwidths.

2.5.1. Requirements

- Antenna/baseline: four antennas, for imaging, calibration, and sensitivity in a narrow bandwidth.
- Observing frequency: set by source, probably 22 GHz (for water masers) or 1.4 GHz (for HI absorption).
  Offset antennas by 10 kHz each.
- Source: strong, narrow spectral lines with simple structure – probably water masers or HI absorption. A 0.5 Jy continuum source would allow tracking the phase in line-free sub-bands without saturation.
  One hour at 1 km/s resolution with 4 antennas gives an expected rms noise level of 34 mJy/beam for HI (4.7 kHz), or 15–30 mJy/beam for water (78 kHz).
- Time required: set by sensitivity, but at least an hour.
- Correlator input
  - Delay tracking ON
  - Single polarization (or dual if we trust that)
  - 8-bit initial quantization
- Correlator setup
  - 4-bit re-quantization
  - A range of subband bandwidths (at least three settings, covering at least a factor 4 in subband bandwidth)
  - No recirculation
  - Integration time: ~ 1 second.
  - CBE: Fourier transform
- Correlator data products
  - Wideband and sub-band data quality indicators (state counts, power measurements, etc.)
  - Sub-band cross-correlation

- Post-processing
  - CASA/AIPS to calibrate and image spectral line data
- Comparison (old correlator) data
  - None required

2.5.2. Definition of success

1. Noise and signal should remain consistent for all subband bandwidths.
2. Images should agree with expectations from old correlator, in terms of (i) off-source noise level, (ii) off-source noise characteristics, (iii) source and spectral structure, (iv) source flux densities, (v) lack of obvious artifacts.

2.6. Sub-band aliasing check

New test, checking for aliasing of a strong spectral line into other sub-bands. Aliasing of one subband into another should be eliminated through LO offsetting (fringe washing) at the level indicated by Carlson (2001, 2006d), and vary with integration time and LO offsets as predicted by those references.

2.6.1. Requirements

- Antenna/baseline: at least one baseline
- Observing frequency: set by source, probably 1-2 GHz (for radio frequency interference) or 22 GHz (for water masers).
  Offset antennas by 0.1, 1, 10 kHz each, to check dependence of aliasing rejection on LO offset.
- Source: strong, narrow spectral line with simple structure – probably RFI or water masers – tuned to lie at the very edge of a subband.
  A 0.5 Jy continuum source would allow tracking the phase in line-free sub-bands without saturation.
  One hour at 1 km/s resolution with 4 antennas gives an expected rms noise level of 34 mJy/beam for HI (4.7 kHz), or 15–30 mJy/beam for water (78 kHz).
- Time required: set by spectral dynamic range – probably minutes to tens of minutes.
- Correlator input
  - Delay tracking ON
  - Single polarization
  - 8-bit initial quantization
- Correlator setup
  - 4-bit re-quantization
  - Any convenient bandwidth, but requires at least two (directly adjacent) subbands
  - No recirculation
  - Integration time: 0.1 to 1 second
  - CBE: Fourier transform
- Correlator data products
  - Wideband and sub-band data quality indicators (state counts, power measurements, etc.)

  - Sub-band cross-correlation
- Post-processing
  - CASA/AIPS to examine spectral line data
- Comparison (old correlator) data
  - None required

2.6.2. Definition of success

1. Aliasing of one subband into another should be eliminated through LO offsetting (fringe washing) at the expected level, as seen in (i) spectra on individual baselines, (ii) the vector sum of spectra taken on all available baselines, (iii) the noise level in the image plane.

2.7. Recirculation check

New test, motivated by the perception that recirculation is important and complex.

2.7.1. Requirements

- Antenna/baseline: four antennas for closure. Slight preference for longer baselines.
- Observing frequency: Would like set of reasonably strong, partly and unresolved spectral lines. Continuum is not so important.
  ⇒ L band for HI, or K band for water masers
- Source: see above. Orion or W3 OH might be good choices.
- Time required: full track (6-8 hours on-source).
- Correlator input
  - Delay tracking ON
  - Single polarization (or dual if we trust that)
  - 8-bit initial quantization
- Correlator setup
  - 4-bit re-quantization
  - At least one sub-band.
  - Compare results with and without recirculation. Exact recirculation factor used is arbitrary.
  - Integration time: ~ 10 seconds.
  - CBE: Fourier transform
- Correlator data products
  - Wideband and sub-band data quality indicators (state counts, power measurements, etc.)
  - Sub-band auto- and cross-correlation
- Post-processing
  - CASA/AIPS to calibrate and image.
  - Must handle Doppler shift.
- Comparison (old correlator) data
  - Identical observation with comparable spectral resolution (and much narrower total bandwidth).

2.7.2. Definition of success

1. Noise should integrate down over time as expected.

2. Results should be consistent with old correlator and with WIDAR without recirculation, in terms of (i) statistical noise, (ii) flatness and stability of bandpass, (iii) spectral response for both unresolved and resolved lines.

2.8. Deep spectral line integration

Part of Brent's test 22. Here we are interested in (i) the flatness of the bandpass and (ii) the ability to detect very weak lines.

2.8.1. Requirements

- Antenna/baseline: four antennas for closure. Slight preference for longer baselines.
- Observing frequency: ideally would like two different sub-bands on the same source at once, providing one sub-band with no spectral features, and one with a weak line
  ⇒ probably L-band, with weak HI absorption and sub-bands centered at and some frequency above that absorption line
- Source: as strong as possible, with line characteristics as above
- Time required: full track (6-8 hours on-source).
- Correlator input
  - Delay tracking ON
  - Single polarization (or dual if we trust that)
  - 8-bit initial quantization
- Correlator setup
  - 4-bit re-quantization
  - Ideally two sub-bands, with identical setups. Should run test twice, once with minimal filtering (128 MHz sub-bands), once with multiple filter stages to allow high spectral resolution without recirculation.
  - Recirculation useful but not absolutely required
  - Spectral resolution should provide at least five channels across the line, with a substantial number of line-free channels in the same subband.
  - Integration time: ~ 10 second.
  - CBE: Fourier transform
- Correlator data products
  - Wideband and sub-band data quality indicators (state counts, power measurements, etc.)
  - Sub-band auto- and cross-correlation

- Post-processing
  - CASA/AIPS to calibrate and image.
  - Must handle Doppler shift.
- Comparison (old correlator) data
  - Identical observation with comparable spectral resolution (and much narrower total bandwidth).

2.8.2. Definition of success

1. Noise should integrate down over time as expected.
2. Results should be consistent with old correlator, in terms of statistical noise, flatness and stability of bandpass, and any line(s) seen.
3. For line-free sub-band: no spectral features should be seen down to the expected thermal noise level, either in single channels or in spectra smoothed to a resolution as low as 1/5th of the sub-band bandwidth. The corresponding spectral dynamic range must be as high as possible, and at least $\sim 10^4 : 1$ for 1 MHz channels (at L band, for 7 hours on-source, this requires a source flux density $\gtrsim 9$ Jy). The lack of false features should be checked through lack of lines at non-physical locations, and the consistency of any feature(s) seen on different days (Doppler shift).
4. For weak absorption line: line strength and structure should agree with previous observations, at the VLA and/or elsewhere. Again "weak" means a spectral feature at least 10^4 times weaker than the continuum, i.e., an opacity $\lesssim 10^{-4}$.

3. Test Results

The results of each test should be distributed in the form of a memo, with all input and output scripts and data preserved in the permanent archive. At minimum this includes:

- a description of the test, giving the rationale for choices of observing frequency, astronomical source, etc.;
- the executor script and WIDAR configuration files;
- the Science Data Model (including binary data), plus all ancillary data where appropriate and available;
- the Measurement Set and UVFITS files used in the data analysis;
- the script used for post-processing analysis (if applicable);
- discussion of test results and a clear overall evaluation of its success or failure.

This series of critical WIDAR on-the-sky test memos constitutes one major set of inputs to the WIDAR Critical Design Reviews, and to the decision whether and when to proceed to full production.

4. General Notes

Here I point out a few interesting features of the suite of critical tests, taken as a whole.

- None of the critical tests require dual polarization inputs.
- Several tests require 4 antennas.
- A couple of the tests require comparison observations with the current VLA correlator.
- All but two of the critical tests do *not* require recirculation. The exceptions are the recirculation test and possibly the deep spectral line integration.
- Only one of the critical tests requires more than one sub-band, although (i) the deep "continuum" integration is more meaningful with more bandwidth, and (ii) two sub-bands would make the spectral line test more efficient.
- The scientific post-processing demands are not extreme. The main modifications needed are:
  - CASA filler (sdm2MS) – exists, but should check compatibility with EVLA version of Science Data Model (SDM)

  - CASA-to-AIPS conversion (CASA UVFITS writer compatible with AIPS) – exists, but requires some modification
  - Data examination facilities, capable of handling at minimum some hundreds of channels – should be there already

- Scientists will need to examine ancillary data (e.g., state counts) as well as more usual visibilities. Note however that the current plan does not require Tsys, on-line flags, etc. to appear in the post-processing environment. Rather, one will deal directly with raw correlation coefficients. The ancillary data will be available primarily through the RTDD. These data include:
  - Wideband state counts
  - Sub-band clip counts
  - Sub-band power counts (pre- and post-re-quantization)
  - Sub-band RFI counts
  - Sub-band state counts
  - Sub-band zero lags
  - Wideband auto-correlations

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REFERENCES

Carlson, B. 2001, *Refined EVLA WIDAR Correlator Architecture* (Memo #014)

Carlson, B. 2006a, *EVLA Correlator Prototype On-the-Sky Test Plan*

Carlson, B. 2006b, *EVLA Correlator Chip Prototype Test Plan*

Carlson, B. 2006c, *EVLA Correlator Chip Prototype Verification Matrix*

Carlson, B. 2006d, *Programmer's Guide to EVLA Correlator System Timing, Synchronization, Data Products, and Operation*

Fort, D. 2006, *Test and Verification Plan: Station Board*

Fort, D. 2007, *Test and Verification Plan: Prototype Station Board*