Test Plan for the VLBA-DiFX Correlator and Other VLBA Sensitivity Upgrade Equipment

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Introduction

This document outlines a multi-purpose suite of tests for validation and comparison of VLBI equipment. Although developed for a transition from the original VLBA correlator to the VLBA implementation of the DiFX software correlator, it has been generalized here to include tests of other new components of the VLBA Sensitivity Upgrade data-path, as well as other, similar equipment under development elsewhere.

The various tests address six separate purposes, which are introduced here, with short formulations to facilitate references to them within the subsequent text.

- **VLBA-DiFX:** Comparison of the VLBA DiFX software correlator to the original ASIC-based VLBA correlator. The goal is to establish correctness of results, and continuity within long-term observational sequences. These tests are necessarily restricted to the capabilities of original correlator. Tests for this purpose will be conducted in the very near future, when commissioning of the DiFX correlator is planned to begin..
- **DiFX-Ext:** Evaluation of the VLBA DiFX correlator's results in modes that extend beyond the capabilities of the original ASIC-based VLBA correlator. The goal is to verify that DiFX performs as one might reasonably expect, possibly on the basis of published non-VLBI observations. Tests for this purpose will be conducted in the very near future, when commissioning of the DiFX correlator is planned to begin..
- **VLBA-DBE:** Comparison of the VLBA Digital Backend (VDBE) to the original, analog VLBA BBC/Sampler/Formatter equipment. The goal is to establish correctness of results, and continuity within long-term observational sequences. These tests are necessarily restricted to the capabilities of the original equipment. Tests for this purpose cannot be conducted until the new VDBE *and* the new Mark 5C recording system are operational.
- **DBE-Ext:** Evaluation of the VDBE's performance in modes that cover the full range of VDBE performance, extending beyond the capabilities of the original analog equipment. The goal is to verify that the VDBE performs as one might reasonably expect in these modes. Tests for this purpose cannot be conducted until the new VDBE *and* the new Mark 5C recording system are operational. Test observations scheduled in support of this goal should exploit the parallel analog/digital data paths planned for the Pie Town station while this capability exists.
- **Golden Data:** Establishment of new "golden data" for DiFX, and possibly other correlators. Tests using these recordings are the only cases where the same correlator is compared between current and earlier epochs. The goal of such comparisons is periodic revalidation of DiFX through a series of subsequent updates. New golden data are required to span the range of new capabilities supported by both the VDBE (and other, similar equipment) and DiFX.

- **Re-verification:** Comparison of both VLBA correlators against one or more Mark 4 correlator(s). The primary goal is to re-create the connection first established in the VSOP correlator-comparison project of 2001. It is believed that the original VLBA correlator maintained this connection through the many changes required to implement playback of Mark 5 recordings, but this can no longer be demonstrated unambiguously for the final stages, due to an unfortunate accidental erasure of previous golden data. These tests are necessarily restricted to the lesser capabilities of Mark 4 correlator(s).

The test suite is organized into two primary groups, functional tests and science use cases, described in detail in the following sections.

1. Functional Tests

Functional tests are designed to demonstrate correct and consistent results, in a sequence of brief observations covering a range of observational parameters. They are designed to require only limited observing time, storage media, and data analysis. Recordings of the entire set of functional tests, and all required correlator control scripts, will be retained permanently, for long-term re-verification and expeditious test correlations whenever required. Four categories are outlined below.

The tests cover ranges of various important observational parameters. However, the comprehensive "all [recording] modes" test approach used for the original VLBA are neither feasible nor desirable for the flexible, wideband equipment being developed for the VLBA Sensitivity Upgrade. Instead, the tests in each category are organized around a "spine" which covers the full range(s) of one or two crucial parameters that are supported by the new equipment. Other parameter values remain fixed for most of the tests, except for a few excursions away from the "spine", included to sample the full multi-dimensional parameter space. Expanded ranges that may be appropriate to other new equipment will be included on request.

Boldface test numbers in the following subsections indicate "restricted" tests in each category that can be carried out with the original VLBA analog BBC/Sampler/Formatter data-acquisition equipment and the original VLBA correlator. For some test purposes, only this subset of restricted tests will be applicable.

Functional tests require only limited observing arrays. A minimum of four stations, including at least three relatively long baselines, is sufficient; five stations are planned here. Most of these tests also require only short observations. It should be possible to accommodate all the individual tests enumerated below in a reasonable time, comparable to the four hours scheduled for the old "all modes" tests.

Generally, the analysis of functional-test results is limited to verifying equality of the direct correlator outputs, including the auxiliary tables, as appropriate. Some tests involve integrations over extended time intervals, or averaging across high-resolution spectra, to investigate noise statistics. Further data analysis such as imaging is not necessary for functional tests.

Observing time and storage requirements for the functional tests are modest. Assuming a five-station observing array, the tests outlined in the following subsections would require these resources:

- The 28 restricted tests would take about 2.5 hours, and require storage of only 153 GB per station.
- The full set of 64 functional tests would take 6.5 hours, and occupy about 2 TB per station.

Since these data are to be kept permanently, they should be recorded using modern, SATA-interface disk drives. Such modules are available from Conduant Corporation in sizes as small as 2 TB, although current pricing is uneconomical below 6 TB. Five 6-TB modules would cost about $12K; five 2-TB modules $9K. The restricted tests could be recorded on exiting 2-TB modules at first, and then replaced by the full test set, recorded on new SATA modules, when the DBE and Mark 5C become available.

1.1] Basic Continuum Tests

These tests observe moderately strong, reasonably compact, somewhat polarized sources. Dual-polar observing and correlation are used whenever two or more channels are indicated. Correlation uses normal integrations, with spectral points specified to maintain a uniform resolution of 500 kHz, with a fixed corresponding spanned delay of 2 microseconds. A duration of 5 minutes per test is suggested.

This most fundamental test category addresses all six of the purposes enumerated in the Introduction. Only the restricted subset of tests with boldface numbers are suitable for the VLBA-DiFX, VLBA-DBE, and Re-verification purposes.

In acquiring data for these tests, the schedule should include changes among sources, frequencies, and (where possible within restrictions of the scheduling and correlator output formats) observing modes, as well as combinations of such changes.

Test	Channel BW [MHz]	Channels	Bits / Sample	Spectral Points	Aggregate Mbps
1.01	4	1	2	8	16
1.02	4	2	1	8	16
1.03	4	2	2	8	32
1.04	4	4	2	8	64
1.05	4	8	2	8	128
1.06	4	16	2	8	256
1.07	4	32	2	8	512
1.08	4	2	4	8	64
1.09	4	2	8	8	128
1.10	8	2	2	16	64
1.11	16	1	2	32	64
1.12	16	2	1	32	64
1.13	16	2	2	32	128
1.14	16	4	2	32	256
1.15	16	8	2	32	512
1.16	16	16	2	32	1024
1.17	16	32	2	32	2048
1.18	16	2	4	32	256
1.19	16	2	8	32	512
1.20	32	2	2	64	256
1.21	64	2	2	128	512
1.22	128	1	2	256	512
1.23	128	2	1	256	512
1.24	128	2	2	256	1024
1.25	128	4	2	256	2048
1.26	128	8	2	256	4096
1.27	128	2	4	256	2048
1.28	128	2	8	256	4096

1.2] High-Sensitivity Continuum Tests

These tests observe faint, very compact sources, in dual-polar mode. The observing frequency should be optimized for the longest coherence time. Correlation can use long integrations. Further off-line integrations, up to and beyond the coherence time, are studied to compare the reduction in noise level to theoretical prediction. A duration of 20 minutes per test is suggested to accommodate the long integrations.

This category is most useful in addressing the VLBA-DiFX, DiFX-Ext, and Golden purposes. Only the single test 2.01 is suitable for the first of these purposes.

Test	Channel BW [MHz]	Channels	Bits / Sample	Spectral Points	Aggregate Mbps
2.01	16	8	2	16	512
2.02	32	8	2	16	1024
2.03	64	8	2	16	2048
2.04	128	8	2	16	4096

1.3] High-Resolution Continuum Tests

These tests observe moderately strong, reasonably compact sources, in single-polar mode. Correlation uses high spectral resolution and normal integrations. A continuum source is observed to illuminate all spectral points in the correlator results. Varying high-resolution cases, with increasing number of spectral points and proportionally increasing channel bandwidth (and thus fixed frequency spacing of spectral points) allow the noise performance to be compared with theoretical predictions. These comparisons can be extended by off-line spectral averaging. A duration of 5 minutes per test is suggested.

This test category is most applicable to the VLBA-DiFX, DiFX-Ext, VLBA-DBE, and Golden purposes. Only the restricted subset comprising the first two tests is suitable for VLBA-DiFX and VLBA-DBE purposes.

Test	Channel BW [MHz]	Channels	Bits / Sample	Spectral Points	Resolution [kHz]	Aggregate Mbps
3.01	4	1	2	1024	3.9	16
3.02	8	1	2	2048	3.9	32
3.03	16	1	2	4096	3.9	64
3.04	32	1	2	8192	3.9	128
3.05	64	1	2	16384	3.9	256
3.06	128	1	2	32768	3.9	512
3.07	4	1	2	4096	1.0	16
3.08	8	1	2	8192	1.0	32
3.09	16	1	2	16384	1.0	64
3.10	32	1	2	32768	1.0	128

1.4] Spectroscopic Tests

These tests observe an artificial spectral line, in dual-polar mode. The line is generated by the phase-cal pulse generator, and the observing channels are shifted to scan its frequency across the central spectral point of the correlator output in several sub-tests. Actual antenna pointing in not required. Correlation uses a North Celestial Pole position with fixed LO offsets, to disable baseline fringe rotation while avoiding artifacts from stopped (hardware) fringe rotators. A duration of 5 minutes per test is suggested.

This test category is most useful in addressing the VLBA-DiFX, VLBA-DBE, DBE-Ext, and Golden purposes. Only the restricted subset of tests with boldface numbers are suitable for the VLBA-DiFX and VLBA-DBE purposes.

The artificial spectral lines described above appear to be the only line sources sufficiently narrow – and reproducible – to accomplish the test purposes. Nevertheless, the accompanying necessity for disabled baseline fringe rotation also exposes the results to potential interference from correlated DC and other signals. These are expected to appear only at the DC edge of the original sampling process. Vigilance for the impact of such interference must be maintained in the analysis of these tests.

Test	Channel BW [MHz]	Channels	Bits / Sample	Spectral Points	Resolution [kHz]	Aggregate Mbps
4.01	0.5	2	2	256	1.95	4
4.02	0.5	2	2	512	0.98	4
4.03	0.5	2	2	1024	0.49	4
4.04	0.5	2	2	2048	0.24	4
4.05	0.5	2	2	4096	0.12	4
4.06	1	2	2	256	3.91	8
4.07	1	2	2	1024	0.98	8
4.08	1	2	2	4096	0.24	8
4.09	2	2	2	256	7.81	16
4.10	2	2	2	1024	1.95	16
4.11	2	2	2	4096	0.49	16
4.12	4	2	2	256	15.63	32
4.13	4	2	2	1024	3.91	32
4.14	4	2	2	4096	0.98	32
4.15	8	2	2	256	31.25	64
4.16	8	2	2	1024	7.81	64
4.17	8	2	2	4096	1.95	64
4.18	16	2	2	256	62.50	128
4.19	16	2	2	512	31.25	128
4.20	16	2	2	1024	15.63	128
4.21	16	2	2	2048	7.81	128
4.22	16	2	2	4096	3.91	128

2. Science Use Cases

Science use cases are a group of typical scientific observations, selected to stress various aspects of the upgraded VLBA subsystems. Each of these tests will require a commitment of observing time and storage media similar to an ordinary VLBA project, using at least most of the full VLBA, and possibly some stations of the High Sensitivity Array. Thus, to limit the impact, the following cases have been selected so that as many as possible exercise multiple features of the overall system.

Science use case tests involving comparison generally require both direct comparison of the correlator outputs, as for the functional tests, and also imaging or other data analysis, carried out on at least one of the data sets.

It seems unrealistic to include the full sets of raw data for all nine cases as "golden data", but possibly some of the less-voluminous observations – one or two spectroscopic and/or a pulsar case, perhaps – could be recorded on small modules that the VLBA may no longer need to use in the future. Since the science use cases require additional processing beyond comparison of the raw correlator output, they are likely to be more useful as one-time verifications of performance, than as long-term golden data.

- **Unresolved Continuum Source.** No end of possible sources! Include one case at W-band.
- **Complex Continuum Source.** Suggestions: 3C84, Arp 220.
- **Un- or Minimally Resolved Emission Line.**
- **Complex Emission-Line Region.** Suggestion: W49.
- **Un- or Minimally Resolved Absorption Line.**
- **Phase-Referenced Blank-Sky Observation.**
- **Phase-Referenced Relative Astrometry.**
- **Full Astrometric Sequence.** Include subarrays and dual-frequency S/X bands
- **Pulsar Gating.** The following pulsars are proposed, to cover adequate ranges of pulse period and dispersion:

Pulsar	Period [s]	DM [cm^{-3} pc]	S_1400 [mJy]	Observing Frequency
B0329+54	0.715	26.833	203	1.5 GHz
B0950+08	0.253	2.958	84	1.5 GHz
B1933+16	0.359	158.5	42	1.5 GHz
B1937+21	0.00155	71.04	5	330 MHz

A. Appendix: Prerequisites for the Tests

The following capabilities are being added currently to DiFX or its peripheral software. They must be in place before the VLBA-DiFX comparison purpose described on page 1 can be completed, although early test runs can and will begin earlier. Most are necessary for the entire test suite; the one exception is noted below. Items, and eventually the entire Appendix, will be deleted as they are completed.

- Operator GUI. "Completion" requires the GUI to be functional at a level judged adequate for routine processing by VLBA Operations.
- Vex control. It was decided recently to move the branch point earlier, so as to include this nearly-complete capability in the tests.
- Matched, equal-length, simultaneous integration intervals. This requirement was the original point of this Appendix, but with its development now underway, it has been subsumed into the current, larger scope.
- LO offsets. These are necessary only for the Spectroscopic Tests of subsection 1.4.