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VLBA & AT Long Baseline Array Correlator/LO Options

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This memo is meant to acquaint both AT and VLBA people with the possible overlap in the interests of the two projects in the area of VLBI correlators and LO systems.

I am currently evaluating several (at least two) correlator designs, looking at them as candidates for (1) the Australia Telescope Long Baseline Array (AT LBA) system, (2) a US Very Long Baseline Array (VLBA) Interim System, and (3) a VLBA Final System. The "VLBA Interim" correlator is a hypothetical "cheap" machine providing a useful subset of the full VLBA correlator functions. Obviously, the criteria for these 3 applications will be quite different, and it is not at all clear whether any design will be of interest for more than one. I think there is a chance that (1) and (2), however, might share a common design.

The compatibility of AT and VLBA correlator systems depends critically on the LO (phase tracking) schemes adopted by the two projects. Since important aspects of both the VLBA and AT LO systems are still not fully defined, I will elaborate somewhat on the consequences of LO specifications for the correlators and the prospects for AT-VLBA cooperation.

1 THE AT SITUATION

The AT LBA system will initially comprise up to 5 elements: Culgoora tied array (5-6 new 22 m antennas), Siding Spring (new 22 m), Parkes (64 m), Tidbinbilla (64 m or 34 m), and Hobart (26 m). Baselines range up to about 1300 km, mostly N-S. Initial operation will be up to X band, although Hobart may be available only at longer wavelengths. The new antennas will operate to 110 GHz, and Parkes and Tidbinbilla may go to 43 GHz. Receivers and feeds to support K band and higher have secondary priority, however.

The AT Compact Array (CA), like the VLA, steers its phase center through offsetting LOs and samplers. The CA correlator, based on the "XCELL" chip, has no lobe rotation or delay correction hardware. As we know from previous VLBA work, it is not easy to implement lobe rotation with the XCELL design.

The AT LBA will have a correlator separate from the CA. This permits simultaneous CA and LBA operation and simplifies scheduling of real-time and non-real-time operations. The present nominal design for the AT LBA correlator is simply a duplicate (subset) of the CA correlator. It is assumed that the LBA stations will have frequency/delay tracking similar to the CA antennas.

1.1 AT LBA And World VLBI Compatibility

There are several issues of compatibility of the AT LBA with overseas VLBI operations. These will have an impact on the AT LBA systems design, especially the data acquisition systems and the correlator.

- Should LBA stations be full-fledged Mk III/VLBA facilities, capable of making standard tapes for overseas correlators?

- Should the LBA use a VLBA standard tape format internally?

- Should the LBA and the VLBA use the same phase tracking scheme? (The presently proposed AT LO tracking range is only +/-1 kHz, which is not enough for all the planned baselines at X band.)

- Should the LBA correlator be compatible (at least as a subset) with other VLBI correlators, i.e., able to accept tapes from overseas stations?

I think that scientifically and technically such compatibility is very attractive. Of course, practical financial and manpower limitations may limit the feasible degree of compatibility.

1.2 Other AT LBA Issues

Even without the questions of global VLBI compatibility, I think there is a need to address some AT LBA issues before proceeding too far in defining the AT LBA hardware.

- Some 11 antennas in Australia and New Zealand have been identified as candidates for future LBA expansion. Map quality is a strongly increasing function of number of stations. Will there be a need to correlate more than 5 stations in the near term?

- Rightly or wrongly the VLBA project has determined that 512 frequency channels per baseline are adequate, especially considering that more can be achieved by reprocessing. The AT CA correlator provides up to 4,096 frequency channels; are these needed in the AT LBA, or would the money be better spent on more correlator inputs, computing, receivers, etc.?

- The AT LBA, unlike the VLBA, is planned to operate with a duty cycle << 100%. Having the data on tape, we can plan for multipass processing to increase frequency resolution, number of baselines, etc. (The effective number of stations can be increased by up to 50% by using three tape passes.) How does this affect the optimum specification of the LBA correlator?

2 THE VLBA: AN INTERIM CORRELATOR?

Because of the unfortunate funding stretchout, construction of the full VLBA correlator has been deferred for some years. This situation has stimulated discussions of possible interim correlators for the VLBA, but there is none in the current plan. There are several drivers for such a correlator:

-Another correlator may (or may not) be needed to provide enough capacity to handle VLBI observing until the VLBA is completed.

-If the "fringe tracking at antenna" (FTA) scheme is adopted, there will be a need for an "FTA-style" (non-complex, non-tracking) correlator to develop data-handling software, which will be somewhat different from previous VLBI software.

-In any case, it is desirable to have a "test bed" correlator to allow orderly development of database, archiving, and post-processing software, and operations procedures -- not bunched up at the end of the project.

If a design is available that can be inexpensively copied, it may be feasible for the VLBA project to make (or procure) a copy for interim operations. The interim machine need not be technically similar to the "final" correlator, but if it were there would be obvious benefits. The DPS units and (probably) the computer systems could be carried forward to the final system.

3 CORRELATOR OPTIONS

Various scenarios are possible for the LBA correlator and a possible VLBA interim correlator. I have only looked at two main variations: the AT Compact Array correlator and an 8-station, reduced frequency resolution correlator. I think these bracket a range of possible choices for the AT.

If the VLBA adopts the FTA scheme, the XCELL chip appears to be the most attractive basis for any near-term VLBA correlator. The correlator options described here would then be valid for the VLBA. (In fact, the savings available in correlator hardware is the chief driver for the FTA system.) On the other hand, if the "traditional" VLBI technique of lobe rotation in the correlator is adopted, it seems unlikely that any of these options would be useful for the VLBA.

Only outlines of the correlator designs are provided here. More detailed descriptions are in preparation.

3.1 Correlator Based On AT Compact Array For LBA Or VLBA Interim.

The currently proposed AT LBA correlator is a 6-station, 12-baseline version of the Compact Array correlator. It will contain 8 "products", capable of full polarisation observations at 2 frequencies. Each product works on a 16 MHz IF band. The tape system (Haystack / VLBA) will record up to a total of 64 MHz bandwidth with 2-bit sampling in four 32 Msample/sec channels. Up to 4,096 frequency channels are available (e.g., at 4 MHz BW). A total of 1,536 XCELL chips is required.

The main cost of the correlator is in the XCELL chips, which are already on hand at CSIRO for the LBA correlator. The full incremental parts and fabrication costs for building a new copy of the AT CA correlator, including new XCELLs, is about $230K (US) plus perhaps 2 man-years of labour. Data Playback Systems (6 DPS @ US$76K) are not included. This includes a MicroVAX with a small array processor for data handling. (Computing will be a performance bottleneck, I think.) A more detailed (believable?) estimate is in preparation.

It is very important to realise that nearly all the hardware design and debugging costs will have been borne by the AT CA project. Hardware risk seems very small. Control and data handling software, however, will have to be revised for the VLBI situation.

3.2 An 8x8 XCELL-based Correlator For LBA And VLBA Interim.

Taking the XCELL chip as a given, I have examined an alternative connection scheme for a VLBI correlator. Since the XCELL is an 8 by 8 array of correlator/accumulators, it is natural to consider an 8 station correlator composed of these chips. (Correlators for 16 or 24 stations are simple extensions.)

The elementary correlator works at 8 Msamples/sec in 2-bit mode or 16 Msamples/sec in 1-bit. A very straightforward connection would produce an 8 station by 16 channel correlator, with each channel corresponding to 4 MHz of bandwidth, 2 bits/sample. (Alternatively, one could have an 8 station by 8 channel correlator, 8 MHz BW/channel, 1 bit/sample. This gives similar sensitivity but requires only half the number of baseband converters.)

This correlator can be sized to meet the VLBA frequency channel requirements (512 per baseline) for 28 baselines using only 528 XCELLs. The replication costs, on a similar basis as for (1) above, are US$133K plus 2 Man-years. There would be additional design costs because a new module and interconnection scheme would have to be developed.

(The 8x8 approach uses no "bandwidth multiplication", i.e., the sample rate is equal to the clock rate, while the CA-based correlator uses 4:1 multiplication to achieve 32 Msample/sec [2-bit]. An alternative design, "4x4", would use 2:1 multiplication, support 16 Msample/sec, and be expandable in steps of 4 stations. A "2x2" design is also possible. One of these intermediate approaches may prove preferable when a full analysis is done.)

3.3 Expanded Versions For The Full VLBA.

Either of the correlators described above could be built up to provide a full-capability correlator for the complete VLBA, assuming, as always, that the FTA scheme is adopted. If there is sufficient time available, such an upgrade would most likely be accompanied by a significant redesign of the XCELL chip to achieve better cost performance.

4 DISCUSSION

The AT LBA correlator design could be used for an interim VLBA correlator, if the VLBA adopts fringe tracking at the antenna. Moreover, if the VLBA does adopt FTA, this will define a standard for the rest of the VLBI community, and all VLBI telescopes will probably gain the FTA capability over time.

If, then, the AT LBA fringe tracking is enhanced to permit an arbitrary terrestrial phase center, the AT stations could be compatible with overseas VLBI facilities. ("Compatibility" here refers to phase tracking, IF, and recording schemes. Frequency and polarisation compatibility are beyond the scope of this memo.)

If fringe tracking is <u>not</u> done at VLBA antennas, but in the VLBA correlator, the AT LBA stations can be run with zero LO offset in international VLBI experiments.

Even though geography prevents the AT from supporting much VLBI with the US or Europe, there should be a substantial technical and economic benefit from adhering to a common technical standard. Mutually exploiting the Haystack/VLBA recording system and the AT XCELL chip development are good examples. Having interoperable correlators and data recorders is a great advantage in debugging of VLBI hardware and software. Interoperability also maximises astronomical flexibility, since it is possible to correlate VLBI observations at several sites. Eventual VLBI expansion into space (e.g., Quasat) would be facilitated by a common global technical standard.

5 CONCLUSIONS

The thrust of this memo has been to point out the existence of a some overlapping interests between the AT and VLBA projects. As I see it, the extent of these interests depends on the answers to the following questions:

1. Will the VLBA project adopt fringe tracking at VLBA antennas (FTA)?

2. If FTA is selected by the VLBA, a "low cost" interim VLBA correlator is possible using the AT LBA development. Should such a correlator be built?

3. What number of frequency channels and baselines is best for the AT LBA correlator and the hypothetical VLBA interim machine? Can a common specification be agreed upon?

4. The AT project requires some 4-6 VLBA recording systems for the LBA and a similar number for playback; the VLBA needs correlator technology and possibly an interim correlator. Can a technology and/or hardware exchange be worked out to the mutual advantage of both the AT and VLBA?

Question #1 is actively being pursued at NRAO; a decision is expect by about March, 1986.