The CARMA First-light Correlator – Revised Performance Estimates

A.J. Beasley, D.W. Hawkins, K. Rauch, D. Woody

4/29/2003

Background

In February 2002 a document describing the expected scientific performance of the COBRA-based CARMA First-light (CFL) correlator was distributed by the CARMA hardware group (http://www.mmarray.org/workinggroups/hardware/corrplan.pdf). The correlator described in that document was a 15-stn 4-GHz correlator, comprised of eight 500-MHz bands. The correlator hardware was assumed identical to that designed for the OVRO COBRA correlator; the channelization (velocity resolution and total velocity coverage) was theoretically estimated at that time (Table 1). These numbers were derived for observing frequencies of 100 and 300 GHz.

Bandwidth (MHz)	Channels	3 mm channel spacing (km/s)	3 mm total velocity width (km/s)	1 mm channel spacing (km/s)	1 mm total velocity width (km/s)
512	16	96	1536	32	512
256	32	24	768	8	128
128	64	6	384	2	128
64	128	1.5	192	0.5	64
32	128	0.75	96	0.25	32
8	128	0.18	24	0.06	8
2	128	0.05	6	0.01	2

Table 1 – Anticipated CFL correlator performance, based on 2002 COBRA analysis.

Table 1 shows the 2002 anticipated channelization for a single 500 MHz band; in operation, there could be as many as eight tunable bands available, each band producing both upper and lower sideband (the sidebands will be separated by 2 GHz, i.e. the highest frequency in the lower sideband will be 2 GHz below the lowest frequency in upper sideband).

At the time the CARMA Science Steering Committee accepted these proposed specifications for the CFL correlator as consistent with the science priorities for first-light, however a number of milestones were identified, and significant simulation and testing was required before this plan could be adopted. In a related Work Package (Spectral-line Downconverter) additional analysis was also required to understand if (a) all eight 500-MHz bands would be fully tunable (leading to additional cost), and (b) if digital FIR filtering in the digitizers could remove the need for the narrow bandwidth analog filters.

Update

Early in 2003, detailed correlator field-programmable gate array (FPGA) simulations were completed by Kevin Rauch (http://www.mmarray.org/memos/carma_memo9.pdf). Analysis of the COBRA correlator board's ability to process 10 baselines per card (COBRA boards currently only handle 5), and details of how information is stored and routed through the correlator, have led to a reassessment of the expected spectral-line performance of the correlator. The revised parameters are shown in Table 2; this table incorporates the expected channelizations for this hardware, and has been calculated for observing frequencies of 100 and 230 GHz (CARMA first-light receivers will not observe at 1mm), with no spectral smoothing.

Bandwidth (MHz)	Channels	3 mm channel spacing (km/s)	3 mm total velocity width (km/s)	1.3 mm channel spacing (km/s)	1.3 mm total velocity width (km/s)
500	16	93.8	1500	40.8	652
250	32	23.5	750	10.2	326
125	40	9.4	375	4.1	163
62	48	3.9	186	1.7	80
31	56	1.7	93	0.7	40
8	64	0.4	24	0.16	10
2	64	0.09	6	0.04	2

Table 2 – Predicted CFL correlator performance, based on Rauch simulations

The primary change is a loss of a factor of ~two in the velocity resolution at or below 10 km/s (3mm) or 4 km/s (1.3mm) for a given configuration; total velocity coverages remain unchanged (although the numbers reflect the shift from 1mm to 1.3mm as the reference wavelength). Again, it is important to remember that Table 2 indicates the performance for one band; during operations, eight bands identically channelized can be placed contiguously, leading to a total velocity coverage eight times that indicated in columns 4 & 6. For example, at 3mm the highest velocity resolution (0.09 km/s) could be obtained over a total velocity range of 48 km/s (eight x 6 km/s).

Spectral-Line Downconverter

The preliminary design review for the Spectral-line Downconverter (SLD) was held during the April 2003 f2f3 meeting. Dave Woody addressed questions raised during 2002 about the cost of implementing all eight correlator bands with frequency flexibility; the discovery of cheap ceramic filters capable of meeting our specifications suggests that all eight bands can be implemented as tunable. A simple approach would be to implement the specified 7 bandwidths by laying out the analog filters as two banks of four filters each (one slot unused) – this appears possible with the ceramic filters, but has implications for board layout.

Related to this hardware work were the results of Kevin Rauch's analysis of digital FIR filtering options for CARMA. These results will be described in a separate memo – of relevance here, he believes that the two narrowest bandwidths (8 and 2 MHz) can be implemented in the existing digitizer FPGAs. This raises an interesting possibility: if a single row from the top half of Table 2 can be eliminated (e.g. 64 MHz), then the SLD could be implemented as a single bank of four filters (500 MHz, 250 MHz, 125 MHz, 31 MHz), with lower bandwidths implemented using the digital FIR filtering on the digitizers. This would lead to considerable savings (tens of $k) and simplification of the SLD design and implementation.

CFL Correlator Options

In general, the decreases in channel velocity resolution for a desired total velocity coverage between Table 1 and Table 2 may be avoided by observing in a higher-resolution correlator mode, with four caveats:

- If all 8 bands were required previously to provide a specific total velocity coverage, then the observations would likely need ~two tracks (i.e. separate observation of the two halves of the total velocity coverage desired). This would be an operational limitation of the first-light system.
- If only half (or less) of the eight available bands were required previously, then using all eight bands will approximately recover or exceed the original combination of resolution & velocity coverage.
- Line resolutions higher than 0.09 km/s (3mm) and 0.04 km/s (1.3mm) are not possible, although additional narrower FIR filters may be possible (Rauch, priv. comm.)
- The correlator is capable of simultaneous spectral-line and continuum observations (e.g. four bands allocated to spectral line – 4 x 2 MHz – plus four bands allocated to continuum – 4 x 500 MHz). More bands allocated to spectral line correlation obviously decreases the bandwidth of any simultaneous continuum setup.

It is important for the CARMA SSC and the broader user community to review the correlator parameters indicated in Table 2 and identify first-light science requirements that will not be met.

Another option to consider is the possibility of dropping one of the large bandwidth modes. For example, the 62 MHz mode provides 4 km/s resolution over 186 km/s per band (1488 km/s total) at 3mm, 1.7 km/s over 80 km/s (640 km/s total) at 1.3mm. Observations requiring a similar combination of resolution & coverage could also be produced using the 31 MHz configuration if total velocity coverages of less than 744 km/s (3mm) or 320 km/s (1.3mm) were required. If these coverages were required, two separate observations could be used to gather the data.

Early identification of science requirements that would not be met if the 62 MHz bandwidth configuration were removed from correlator specifications is critical. Other large bandwidth configurations (e.g. 128 MHz) should also be considered as alternatives for removal.

Residual Technical Issues

In adopting the existing design COBRA correlator hardware for the CFL correlator, there remain a number of hardware issues to address. The two most serious to be addressed in the CDR in September 2003 are:

- *DSP Utilization*. The COBRA correlator cards have been found to use significantly more DSP processing power than anticipated. At present, this problem would severely affect any future spectral line CFL correlator implementation. Kevin Rauch and Dave Hawkins are about to start work on identifying the problems and addressing them. Implementing more spectral channels and 1ms phase-switching (required for CARMA) on the boards will additionally strain DSP performance, and these impacts must be analyzed.

- *Data fan-out*. The COBRA digitizer cards accept two input analog signals, each of which can be routed to two 32-bit digital output connectors on the front panel (four connectors, total). Each of these connectors can distribute either one antennas digitized output (32 bits at 62.5 MHz, a time demultiplex of 16) or two antennas (16 bits at 125 MHz, time demultiplex of 8). Therefore, the maximum antenna data fan-out per digitizer board is a factor of 4. To implement the CFL correlator from the COBRA hardware, a fan-out of greater than 4 is required, implying that (a) a special-purpose digital fan-out cards needs to be designed/implemented, (b) an analog fan-out solution followed by additional digitizers should be used. Dave Hawkins will examine this issue in June 2003.

Future Reviews

There will be two CFL correlator design reviews:

- A <u>Preliminary Design Review (PDR);</u> this was held in April 2003.
- A <u>Critical Design Review (CDR)</u> planned for September 2003. This review would examine the design of the CFL correlator and all related hardware/software developments in detail, including issues such as DSP utilization, fan-out board design, crate configuration and digital delay lines (needed for SZA first light). At the same time, the SLD CDR would occur, with a decision made on how to implement the analog & digital filtering in the system.

Schedule

Adopting this plan would lead to the following timeline:

- CFL Correlator Critical Design Review – September 2003
- SZA correlator production – June 2003 – December 2003
- CFL correlator production – December 2003 – June 2004