# COBRA Correlator Configurations

D. W. Hawkins

August 28, 2000

## Contents

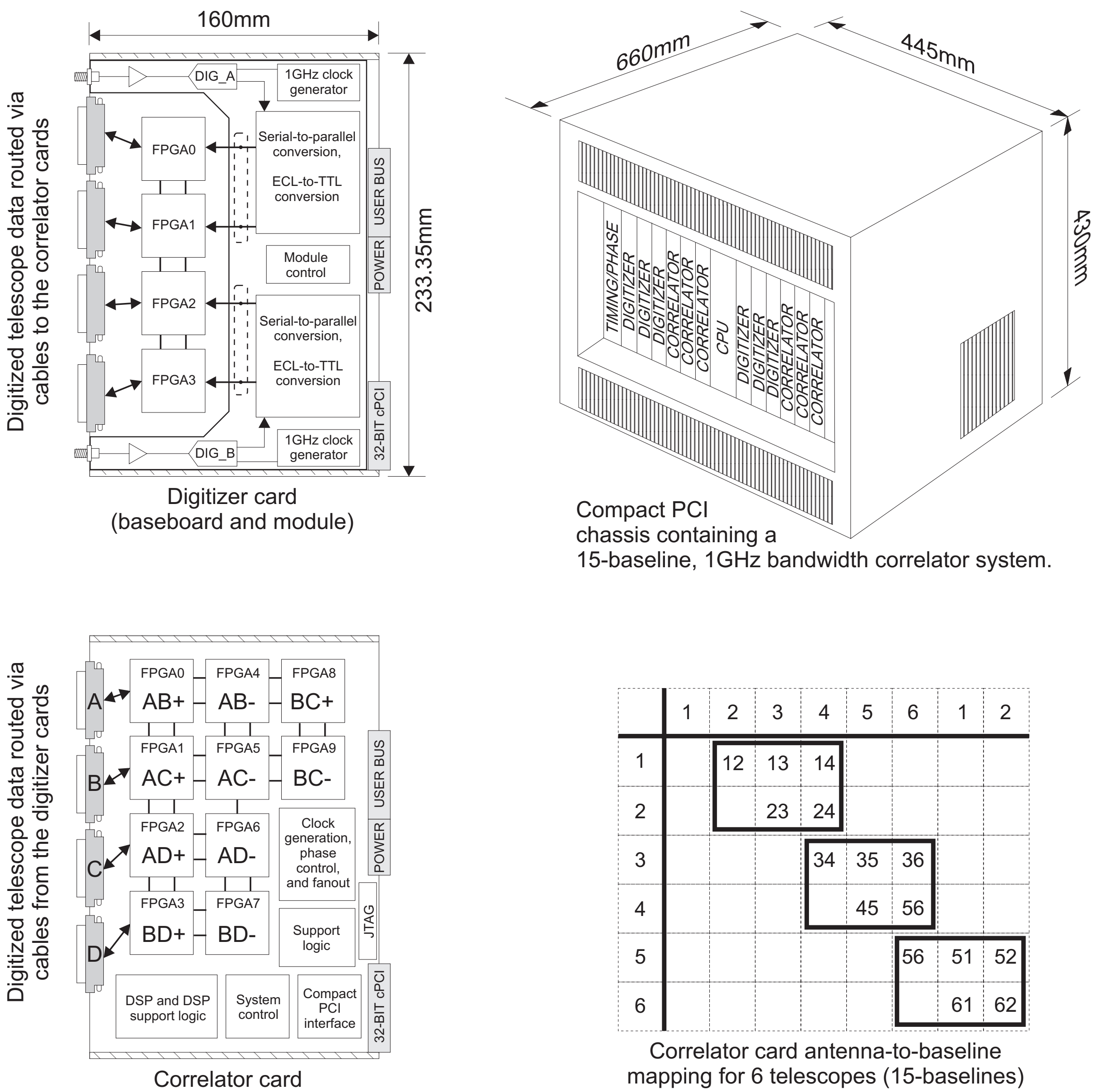


Figure 1: Major components in the correlator system.

# 1 Introduction

This document reviews some of the configurations possible with the COBRA correlator system. Figure 1 provides an overview of the COBRA system. The correlator system is composed of varying numbers of four compact PCI (cPCI) boards; correlator boards, digitizer boards, system timing cards, and a host CPU. Each correlator board (bottom left of Figure 1) contains ten reconfigurable FPGAs, a DSP, RAM, PCI core, and associated control logic. Each digitizer board (top left of Figure 1) is composed of a cPCI base board containing FPGAs, a DSP, RAM, PCI core, and associated control logic, and a module board containing two 1GHz digitizers, and time demultiplexing logic. The host CPU is a commercially available Pentium-based board. The top right of Figure 1 shows an example of the correlator system boards housed in a cPCI crate.

The COBRA correlator design provides flexibility in terms of the clock rates that it can operate at, the time-demultiplexing of the digitized data, and the number of baselines each correlator card can calculate. This document presents example configurations of the correlator system.

The configuration of the COBRA system shown mounted in the chassis in Figure 1 is part of the new continuum correlator for the Owens Valley Radio Observatory (OVRO). The correlator system is used to digitize and process the radio-frequency (RF) signals from OVRO's six telescope radio interferometer. RF signals from OVRO's six telescopes are downconverted, band-limited, and routed to three digitizer boards (each board contains 2 digitizers). The digitizer boards outputs are routed to three correlator boards. The FPGAs on the correlator boards calculate the average cross-correlation between pairs of telescopes. Each board calculates 5 baselines, so the three boards process 15 baselines. A DSP on the correlator boards reads the average cross-correlation from the FPGAs, and performs an FFT to generate cross-power spectra. The DSP applies phase corrections to the data and performs further accumulation. The DSP stores the cross-power spectra in the on-board SDRAM for the host cPCI CPU to access. The host CPU reads the data and transfers it to a database for post-processing. The bottom right of Figure 1 shows the mapping of digitized telescope signals (the numbers) to correlator cards (the bold outlines).

The RF signals from the telescopes are many gigahertz wide. The RF signals are down-converted and filtered into multiple 500MHz bandwidth (or smaller) sub-bands before being routed to the digitizer boards. A set of three digitizer cards and three correlator cards constitutes one processing band in the OVRO continuum correlator system. Each processing band calculates the averaged cross-power spectra for 500MHz bandwidth signals from six telescopes. The top right of Figure 1 shows that each cPCI crate can house two such processing bands (for a total of 1GHz processed bandwidth). The OVRO continuum system is composed of many copies of this system.

The major components in the correlator system are:

- **Downconverter:** Filters and downconverts the 4GHz IF signal into 500MHz bands suitable for digitization.
- **Digitizer board (base + module):**
  - Digitizes the RF signal.
  - Performs Time Division Multiplexing (TDM) of the high speed data before routing it to the on-board FPGAs.
  - The FPGAs perform quantization state monitoring, autocorrelation, and data delay before transmitting the data to the correlator boards over the front panel LVDS interface.
- **Correlator board:**
  - Calculation of 5 correlation functions with data received from digitizer boards.
  - PCI interface for reading the average cross-power spectra.
  - DSP for real-time control and Fast Fourier Transform (FFT) calculations.
  - A reprogrammable block of 10 Altera 100KA or 100KE FPGAs for the calculation of average cross-correlations.
- **Host PC:** Reads the power spectrum calculated in the correlator boards through the PCI bus interface, and performs all non-real-time control of the system.
- **System timing board:** Generates the reference clock to which the correlator and digitizer board FPGA and digitizer clocks are phase locked. Provides the front panel interface for the 40-bit general purpose user bus.

# 2 System parameters

## 2.1 The digitizer boards

The digitizers used in the COBRA system operate at 1GHz and digitize the data to 2-bits. The time-demultiplexing circuits serial-to-parallel convert the 2-bit data into either 16-bits at 125MHz (a time demultiplexing factor of 8) or 32-bits at 62.5MHz (a time demultiplexing factor of 16). The clock rate of the time demultiplexed data is the clock rate at which the digitizer and correlator FPGAs must operate. The two clock rate options exist, to allow for the use of lower performance FPGAs and for configurations that require few lags or few baselines per card, a lower clock rate offers reduced power consumption in the FPGAs.

The digitizer boards have four front panel connectors each able to transmit 32-bits of data. At a time demultipex factor of 8, i.e., 16-bits at 125MHz, each cable can distribute the data from both digitizers, i.e., each telescope's digitized data is fanned out by 4. At a time demultipex factor of 16, i.e., 32-bits at 62.5MHz, each cable can distribute the data from one digitizer, i.e., each telescope's digitized data is fanned out by 2.

This fanout limitation places limits on the number of correlator cards the signals can be routed to, i.e., 4 cards at demux-by-8 and 2 cards at demux-by-16.

The OVRO continuum correlator operates at a time demultiplexing factor of 16, and requires a fanout of 2 from each digitizer, i.e., all front panel connectors are used.

## 2.2 The correlator boards

The correlator boards contain four front panel connectors capable of receiving 32-bits of data each, and 10 FPGAs for calculating cross-correlations. In the OVRO continuum correlator system the data from the digitizers is 32-bits wide at 62.5MHz. With 6 telescopes, there are 15 baselines. These 15 baselines are calculated by 3 cards, each calculating 5 baselines. Since there are 10 FPGAs per card, 2 FPGAs are used per baseline.

At a digitizer time demultiplexing factor of 16, the correlator front panel connectors can receive a maximum of 4 telescopes worth of digitized data. Hence at demux-by-16, a correlator card can calculate a maximum of 6 baselines.

At a digitizer time demultiplexing factor of 8, the correlator front panel connectors can receive a maximum of 8 telescopes worth of digitized data. Hence at demux-by-8, a correlator card can calculate a maximum of 28 baselines.

However, since there are 10 FPGAs on a correlator card, the development of the FPGA configuration files is simpler if a correlator board calculates either 5, 10, or 20 baselines of data. Any baseline requirement that falls between these levels can be handled by a configuration that is similar to the next higher configuration. For example, 9 baselines per card would use a configuration file similar to that used for 10 baselines per card: 1 FPGA would not be used for correlation, while the other 9 FPGAs would calculate plus and minus lags for a baseline.

## 3 Correlator Configurations: 6, 8, 10, and 12 telescopes

This section presents configurations for 6, 8, 10, and 12 telescopes. The number of telescopes increases by two each time, as there are two digitizers per digitizer board, and so the mapping of telescopes to digitizer boards is clearer. An odd number of telescopes can be used, however, in that case some digitizer boards will handle signals from different 500MHz bands.

Figures 2 to 8 show the mapping of telescopes to correlator cards, and Tables 1 and 2 summarize the system parameters for the different configurations. Table 1 and Figure 2 show that at a digitizer demux-by-16 setting, only the 6 telescope system can be configured without requiring additional fanout hardware. For a 6 telescope interferometer operating at demux-by-16, the cabling between the digitizer and correlator cards is fully utilized. For 8, 10, and 12 telescopes, extra fanout of the digitizer data is required.

At the higher clock rate provided by the demux-by-8 setting, the system becomes extremely flexible. For example, because the digitized data can now be fanned out by 4 at the digitizer cards, the 6, 8, and 10 telescope configurations shown in Table 1 can be implemented. These configurations would be used when maximum spectral resolution is required.

Since the demux-by-8 setting allows more telescopes to be routed to a correlator card, it makes sence to reduce the number of correlator cards required by increasing the number of baselines calculated per card. Table 2 and Figures 3 to 8 show some possible configurations.

The 6 telescope configuration in Figure 3 shows one card calculating 5 baselines. These baselines are calculated using the signals arriving on two front panel connectors (3 and 4 on one cable, 5 and 6 on the other). This leaves two other front panel connectors and 5 FPGAs available for calculating the same set of 5 baselines from another band.

The 12 telescope configuration in Figure 8 is shown to calculate 11 baselines per correlator card. As mentioned earlier, this is an inconventient number of baselines to calculate, as there are only 10 FPGAs available. For this configuration, it is possible to calculate the 6 baselines 12, 34, 56, 78, 9A, and BC back on the digitizer boards. This reduces the load on the correlator card to 10 baselines per correlator board.

Table 1: Parameters for 500MHz bandwidth / demux-by-16 (62.5MHz) data correlator systems.

| Telescopes | Baselines | Digitizer Boards | Required Fanout | Correlator Boards | Max. Baselines per card |
|---|---|---|---|---|---|
| 6 | 15 | 3 | 2 | 3 | 5 |
| 8 | 28 | 4 | 3 | 6 | 5 |
| 10 | 45 | 5 | 4 | 10 | 5 |
| 12 | 66 | 6 | 5 | 15 | 5 |

Table 2: Parameters for 500MHz bandwidth / demux-by-8 (125MHz) data correlator systems.

| Telescopes | Baselines | Digitizer Boards | Required Fanout | Correlator Boards | Max. Baselines per card |
|---|---|---|---|---|---|
| 6 | 15 | 3 | 2 | 1.5 | 10 |
| 8 | 28 | 4 | 3 | 3 | 10 |
| 10 | 45 | 5 | 3 | 5 | 9 |
| 12 | 66 | 6 | 4 | 6 | 11 |
| 12 | 66 | 6 | 2 | 3 | 22 |

| Telescope Number | 1 | 2 | 3 | 4 | 5 | 6 | 1 | 2 |
|---|---|---|---|---|---|---|---|---|
| 1 | | 12 | 13 | 14 | 15 | 16 | | |
| 2 | | | 23 | 24 | 25 | 26 | | |
| 3 | | | | 34 | 35 | 36 | | |
| 4 | | | | | 45 | 46 | | |
| 5 | | | | | | 56 | 51 | 52 |
| 6 | | | | | | | 61 | 62 |

Figure 2: Telescope to baseline mapping: 6 telescopes, 15 baselines, 5 baselines per correlator card (demux-by-16 or 8).

| Telescope Number | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | | 12 | 13 | 14 | 15 | 16 |
| | | | | | | 56 |
| 2 | | | 23 | 24 | 25 | 26 |
| 3 | | | | 34 | 35 | 36 |
| 4 | | | | | 45 | 46 |
| 5 | | | | | | 56 |
| 6 | | | | | | |

Figure 3: Telescope to baseline mapping: 6 telescopes, 15 baselines, $10 + 5$ baselines per correlator card (demux-by-8).

| Telescope Number | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 1 | 2 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | 12 | 13 | 14 | 15 | 16 | 17 | 18 | | |
| 2 | | | 23 | 24 | 25 | 26 | 27 | 28 | | |
| 3 | | | | 34 | 35 | 36 | 37 | 38 | | |
| 4 | | | | | 45 | 46 | 47 | 48 | | |
| 5 | | | | | | 56 | 57 | 58 | | |
| 6 | | | | | | | 67 | 68 | | |
| 7 | | | | | | | | 78 | 71 | 72 |
| 8 | | | | | | | | | 81 | 82 |

Figure 4: Telescope to baseline mapping: 8 telescopes, 28 baselines, 5 baselines per correlator board (demux-by-8).

| Telescope Number | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| 1 | | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
| 2 | | | 23 | 24 | 25 | 26 | 27 | 28 |
| 3 | | | | 34 | 35 | 36 | 37 | 38 |
| 4 | | | | | 45 | 46 | 47 | 48 |
| 5 | | | | | | 56 | 57 | 58 |
| 6 | | | | | | | 67 | 68 |
| 7 | | | | | | | | 78 |
| 8 | | | | | | | | |

Figure 5: Telescope to baseline mapping: 8 telescopes, 28 baselines, 10+9+9 baselines per correlator board (demux-by-8).

| Telescope Number | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | A | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 1A | | | | |
| 2 | | | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 2A | | | | |
| 3 | | | | 34 | 35 | 36 | 37 | 38 | 39 | 3A | | | | |
| 4 | | | | | 45 | 46 | 47 | 48 | 49 | 4A | | | | |
| 5 | | | | | | 56 | 57 | 58 | 59 | 5A | | | | |
| 6 | | | | | | | 67 | 68 | 69 | 6A | | | | |
| 7 | | | | | | | | 78 | 79 | 7A | 71 | 72 | | |
| 8 | | | | | | | | | 89 | 8A | 81 | 82 | | |
| 9 | | | | | | | | | | 9A | 91 | 92 | 93 | 94 |
| A | | | | | | | | | | | A1 | A2 | A3 | A4 |

Figure 6: Telescope to baseline mapping: 10 telescopes, 45 baselines, 9 baselines per correlator board (demux-by-8).

| Telescope Number | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | A | B | C | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 1A | 1B | 1C | | | | | | |
| 2 | | | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 2A | 2B | 2C | | | | | | |
| 3 | | | | 34 | 35 | 36 | 37 | 38 | 39 | 3A | 3B | 3C | | | | | | |
| 4 | | | | | 45 | 46 | 47 | 48 | 49 | 4A | 4B | 4C | | | | | | |
| 5 | | | | | | 56 | 57 | 58 | 59 | 5A | 5B | 5C | | | | | | |
| 6 | | | | | | | 67 | 68 | 69 | 6A | 6B | 6C | | | | | | |
| 7 | | | | | | | | 78 | 79 | 7A | 7B | 7C | | | | | | |
| 8 | | | | | | | | | 89 | 8A | 8B | 8C | 81 | 82 | | | | |
| 9 | | | | | | | | | | 9A | 9B | 9C | 91 | 92 | | | | |
| A | | | | | | | | | | | AB | AC | A1 | A2 | A3 | A4 | | |
| B | | | | | | | | | | | | BC | B1 | B2 | B3 | B4 | | |
| C | | | | | | | | | | | | | C1 | C2 | C3 | C4 | C5 | C6 |

Figure 7: Telescope to baseline mapping: 12 telescopes, 66 baselines, 11 baselines per correlator card (demux-by-8).

| Telescope Number | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | A | B | C | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 1A | 1B | 1C | | | | |
| 2 | | | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 2A | 2B | 2C | | | | |
| 3 | | | | 34 | 35 | 36 | 37 | 38 | 39 | 3A | 3B | 3C | | | | |
| 4 | | | | | 45 | 46 | 47 | 48 | 49 | 4A | 4B | 4C | | | | |
| 5 | | | | | | 56 | 57 | 58 | 59 | 5A | 5B | 5C | | | | |
| 6 | | | | | | | 67 | 68 | 69 | 6A | 6B | 6C | | | | |
| 7 | | | | | | | | 78 | 79 | 7A | 7B | 7C | | | | |
| 8 | | | | | | | | | 89 | 8A | 8B | 8C | | | | |
| 9 | | | | | | | | | | 9A | 9B | 9C | 91 | 92 | 93 | 94 |
| A | | | | | | | | | | | AB | AC | A1 | A2 | A3 | A4 |
| B | | | | | | | | | | | | BC | B1 | B2 | B3 | B4 |
| C | | | | | | | | | | | | | C1 | C2 | C3 | C4 |

Figure 8: Telescope to baseline mapping: 12 telescopes, 66 baselines, 22 baselines per correlator card (demux-by-8).

# 4 Suggested configurations for the OVRO/Carlstrom combined array

The Carlstrom array will be built using 6 3.5m dishes and will have a processing bandwidth of 8GHz. Based on Figure 3 and Table 2 each 500MHz band requires 3 digitizer boards and 1.5 correlator cards. The full 8GHz system can be built using 48 digitizers and 24 correlator boards.

For OVRO's 6-telescope interferometer, each 500MHz band in the 4GHz continuum correlator requires 3 digitizer boards and 3 correlator cards (see Figure 2 and Table 1), giving a total card count of 24 digitizers and 24 correlator boards for 4GHz.

A combined 12-element interferometer using the correlator mapping shown in Figure 7 requires 6 digitizer boards and 6 correlator cards per 500MHz. With the combined correlator resources of the OVRO continuum correlator and the Carlstrom array (72 digitizers and 48 correlators), we can easily implement a 4GHz continuum correlator (48 digitizers and 48 correlators). This under-utilizes the 72 digitizers available - these could give us a 6GHz continuum correlator. The configuration in Figure 7 would require 72 correlator cards to implement a 6GHz continuum correlator, however, using the configuration in Figure 8 would require only 36 correlator cards. The problem with the configuration shown in Figure 8 is that calculating 22 baselines per card efficiently would take some work. The configuration shown in Figure 7 is much easier - assuming that the digitizers each calculate 1 baseline and the correlators calculate 10.