New Correlator Description
IRAM Plateau de Bure Interferometer

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October 1, 1999

Version 1.2

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This document is intended for IRAM astronomers to provide information about the new correlator and the modifications made in CLIC and OBS to support it. Details of the correlator architecture can be found in the backend group technical manuals.

Related information is available in:

- IRAM Plateau de Bure Interferometer: Introduction
- IRAM Plateau de Bure Interferometer: OBS Users Guide
- IRAM Plateau de Bure Interferometer: Atmospheric Calibration
- CLIC: Continuum and Line Interferometer Calibration

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1 Introduction

The "new" correlator, or "`CAMEMBERT`" (standing for Correlator Architecture for Multi-Element or Multi-BEam Radio-Telescopes), replaces the previous backends on the Plateau de Bure. The "old" continuum correlator, Berkeley spectral correlator and analog filter bank have been retired from service, and most (if not all) their functionalities are now available through the `CAMEMBERT`.

2 Description

2.1 Hardware

The `CAMEMBERT` is made of 6 fully independent units, connected to the IF system through a software configurable distribution system. Each unit processes 5 antennas and 10 baselines. The 6 units are totally independent from each other

Each unit is divided into three parts: the IF processor, controlled by a simple micro-controller (IF-micro), the master digital processor, controlled by a 68040 microprocessor, and the satellite digital processor, controlled by a 68030 microprocessor. The "master" crate contains all samplers, the main control board, correlator board, and a high speed (1 Gbit) serial link emitter to transmit the samples to the "satellite" crate. The "satellite" crate contain a high speed receiver, and correlator board to process the remaining correlations.

The "master" micros communicate to the IF-micro through a serial link. All 68xxx processors are linked to the main acquisition computer of the PdBI by a dedicated Ethernet link. The IF-micro controls all the low-level functions required in the analog part: frequency setting, low-pass filter selection, oscillator phase control (value and rate). The "master" microprocessors control all the digital parts: multiplex factor, delay steps, correlator board readout, Fast Fourier Transform, small delay correction, bandpass correction, frequency and time averaging, etc... The "satellite" micros do not handle any IF or sampling operation: only correlator board readout and subsequent calculations are performed here.

2.2 Functionalities

Each unit can operate in the following modes:

Mode	Band (MHz)	Channels	Spacing (MHz)
1	160	64	2.500
2	80	128	0.625
3	40	256	0.156
4	20	256	0.078
5	10	256	0.039

The effective resolution is 1.2 or 1.6 times the channel spacing, depending upon the apodization function.

Each unit can be placed anywhere in the [100,600] MHz IF band, by steps of 0.625 MHz using a local oscillator referred to as the LO3. Extension slightly upwards of 600 MHz are possible.

The 40, 80 and 160 MHz bandwidth are synthesized by the upper and lower sidebands of an IRM (Image Rejection Mixer) which converts the band around the LO3 frequency to baseband. Low pass filters of 20, 40 and 80 MHz allow to select the desired bandwidth.

The 20 MHz band is produced by analyzing only the upper sideband of the IRM, but with two correlator boards in pass-along to improve spectral resolution.

The 10 MHz bandwidth is available only on unit 5. It is produced by by slowing the clock rate to 20 MHz instead of 40 MHz. The input level is however somewhat lower than on other bandwidths, so that one should avoid placing this subband too close to the receiver band edges.

2.3 Data Types

The basic integration step (dump) of the `CAMEMBERT` is 1 second. Transmitting a full spectrum is impossible at such a rate: there are too many channels... Available integration times usually range from 15 to 240 seconds, although a few specific observing procedures have a shorter duration (5 seconds). However, the `CAMEMBERT` produces two types of data:

- the Time data, which is a frequency averaged data computed every second. Each unit produces its time data, by averaging the results of an integration step over a user-defined frequency band (to be selected within the IF band of the unit, of course). This data is also called the "Continuum" data.
- the Spectral data, i.e. the time averaged spectrum for the whole integration. This data is also called the "Line" data.

2.4 Software

The whole `CAMEMBERT` is controlled from the host computer by a program named "`correl`", which communicates with all 6 units every second.

Every second, `correl` sends to all connected units the desired observing mode, the rate and phases for the LO3, the delays, etc..., and retrieves Continuum data from the previous second. This is done by scanning sequentially the connected units.

Every second, the units perform the FFT of the lag data, apply the "IF Pass Band" correction, correct the phases for small delay offsets, and compute the Continuum data by averaging over a frequency band specified by `correl`.

At the end of an observation, `correl` instruct a second program, `correl_spectra` to read sequentially all connected units to recover the Line data, cross or auto-correlation spectra on all baselines or all antennas.

After some reordering, `correl` transmits the data (Continuum and Line) to "`RDI_PROGRAM`" which computes and applies atmospheric calibration before writing it on disk.

3 OBS

OBS has been modified to handle the new possibilities of the `CAMEMBERT`. A number of commands had small changes, mostly concerning integration times. Major modifications are:

- Display:
  New display layout, to have the `CAMEMBERT` configuration
- `SPECTRAL`
  The syntax of the `SPECTRAL` command has been changed:
  `SPECTRAL Iunit Band Center/CONTINUUM Band Center`
  See the internal help for details

- `POINT`
  Accepts the `/FAST` option even in interferometry mode

- `POINT PSEUDO`
  A new command making a pointing in autocorrelation, with a pseudo-continuum mode using the correlator. Analysis is provided by **CLIC** command SOLVE PSEUDO.

- Single-Dish mode
  Single-dish mode has disappeared.

4 RDI and RED

Both programs have been extensively modified. RED has disappeared. RDI now only computes atmospheric calibration and writes data. An additional program (named AFF) monitors the running acquisition (subscan number) and computes the real-time amplitude and phases for display by `STS C`.

In order to save time, RDI returns control to **OBS** immediately after data is read into memory. It then completes the calibration steps and writes up the data, while the acquisition of the next command is already started. This is normally OK because the computation time is less than the minimum integration time on the correlator (5 seconds + 3 seconds of setup or delays + 2-3 seconds to read the data) even in the worst cases.

An even faster automatic mode is available for cross-correlation loops, using the `SET SCAN Nscans`) command. In this mode, acquisition continues even while RDI reads, calibrates and stores the previous scan. The minimum integration time is 30 seconds in this case.

5 CLIC

CLIC has been significantly modified to handle the `CAMEMBERT` architecture, and specially because of the introduction of the Time data. The major modification indeed concerns the content of "records" in an observation: "records" now contain only the Time data and associated parameters. Only one set of spectral data is available per scan. In addition, a special record (the "average record") containing the average over the whole scan of the time data is available.

CLIC can then plot in two modes: Time or Spectral mode.

In a funny way, **CLIC** and `CAMEMBERT` are good examples of the uncertainty principle: you can have finely sampled data in time **or** in frequency, but not both at the same time (though $\Delta\nu.\Delta t >> h$)!

5.1 Time mode

In Time mode, **CLIC** plots by default the "Continuum" subbands C01 to C06 (each "Continuum" subband being a frequency-averaged data over part of the spectral band). This can be plotted as a function of time, record by record (`SET AVER NONE`), or with any integration time shorter than the scan duration (`SET AVER Atime`), or by scan average (`SET AVER SCAN`). In the latter case, **CLIC** does not recompute the time-averaged continuum data, but reads it directly from the "average record" in the input file: this mode is thus specially fast.

Time mode is selected whenever the X coordinate is a time-like variable: `SET X TIME, SET X HOUR, SET X DEC, SET X RA, SET X SCAN`, etc...result in time mode display for **CLIC**.

It is possible to plot spectral data (subbands L01 to L06) as a function of time, but only by scan average of course, since no other information is available. To do so, the `SET SUBBAND` command must be typed after the `SET X` command.

5.2 Spectral Mode

In Spectral mode, **CLIC** plots spectral data, the subbands L01 to L06, as a function of a frequency variable. Only one spectrum per subband and per scan is available.

Spectral mode is selected whenever the X coordinate is a frequency-like variable: `SET X I_FREQ`, `SET X CHANNEL`, `SET X VELOCITY`, `SET X SKY_F` result in spectral mode display.

It is possible to plot Continuum data (C01 to C06) as a function of frequency, but of course, each continuum subband is only ONE frequency point.

5.3 Other Commands

A few data reduction commands have been modified because of the new functionnality offered by the Time data. Major commands include

- `SPECTRUM`
  `SPECTRUM` has disappeared, because the `CAMEMBERT` data is already pre-calibrated. There is no longer any raw data.

- `COMPRESS`
  `COMPRESS` now only works on Time data, since the Spectral data is always scan averaged.

- `ATMOSPHERE`
  `ATMOSPHERE` is a new command to recompute the atmospheric calibration. This could formerly be done using the old `SPECTRUM` command.

- `SOLVE FOCUS`
  The `FOCUS` scans are now much like the `POINTING` scans: 3 scans are produced instead of 1 previously. The `SOLVE FOCUS` command accepts a `/COMPRESS` option to change the integration time of the Time data.

- `SOLVE POINT`
  The basic integration step being now 1 second, the sensitivity may be insufficient in such a time to allow the derivation of antenna based quantities from baseline visibilities in a pointing. `SOLVE POINT` command now accepts a `/COMPRESS Time` option to allow adjustment of the integration time of each dump to the source intensity. The default is `/COMPRESS 4`, producing something similar to the old correlator.

- `SOLVE PSEUDO`
  Because Time data can correspond to narrow bands, a pseudo-continuum mode is available for total-power pointing on strong line sources (SiO masers usually). If one subband group has been selected using command SET SUB, the signal is the intensity measured by this subband group. If two subband groups have bean selected (e.g. `SET SUB C01 C02 TO C06` the signal from the second group is subtracted from that of the first group (which should thus contain the line emission) to produce true pseudo-continuum data.

- `SOLVE DELAY`
  The delay is no longer measured by scanning the delay line, but by measuring the phase slope as a function of frequency in the line subbands. The `SOLVE DELAY/PLOT` command will fit a straight line to the phase versus frequency (allowing for 2π ambiguities).