A FUTURE CORRELATOR
for
IMPROVED *ALMA* SCIENCE RETURNS

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Ongoing Correlator Studies

Why a Future Correlator?

Additional Science with ALMA FC

Organization of European Backend Team & Schedule

FC Top Level Specifications

Digital Hybrid Architecture & Flexibility

Questions to the ASAC

Ongoing Correlator Studies

- Europe initiated studies for a *Future Correlator* by ~ late 1999
- Japan proceeds with an *FX correlator* plan
- NRAO proceeds with *Baseline Correlator* design (XF, time multiplexing)

Harmonization to reach full decision point & prepare the future

Preliminary Design Reviews & Recommendations

- Correlator PDR (Charlottesville, Jan. 2000) :
  - ° Europe prepares a digitizer development plan
  - ° Primary responsibility
    - Baseline correlator, NRAO
    - Future possibilities, Europe
  - ° Decision point for ALMA correlator construction ~ 2003
- ALMA System PDR (Garching, Febr. 2000)
  - ° European & Japanese development plans for Digitizers

Europe Proposes a Digital Hybrid Correlator (XF…FX)

- Lag correlator based on frequency-division into sub-bands
- Major issues : Cost, flexibility, more scientific options

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- *Increase scientific performances*

  Main goals :

  ° Higher correlation efficiency

  ° Higher Flexibility: spectral, reconfiguration, etc.

  ° Optimize "Performances / Cost" ratio

  … higher with advanced technology… attract more scientists

- *Full array ready by ~ 2010*

  => *anticipate / benefit from technical advances*

  ° Computer processing power

  ° Microelectronics: chip gate density & implications (correlator chip, digitizer…)

  ° Fast interconnection board schemes

- *Intellectual resources, experience and desire in Europe to propose a new design* … before decision for full ≥ 64-antenna correlator

- *New designs desirable*

  ° Wise to consider alternatives: no such huge correlator has ever been made operational for radio astronomy

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<u>High Digitizer and Correlator Efficiency</u>

- Multi-bit Correlator **beneficial to *all* types of observations**

  Going from full 2 bits to full 3 bits => 9% sensitivity gain

  Speeds up all programs by 19% or adds 9% more collecting area

- FC plan : 4-bit correlation format, ≥ 3-bit digitizers

<u>Sub-Band Flexibility</u>

- More sub-bands with 16 FIR filters per baseband
- **Many advantages**: simultaneaous wide and narrow band observations, high spectral resolution in several narrow bands, accurate 'line / continuum' ratios and spectral index measurements, select sub-bands to avoid contamination, etc.

<u>Configuration Flexibility versus Number of Channels</u>

- Number of channels can be high in the FC design due to number of lags in each correlator board divided by 16 per 2 GHz baseband

  - ~10 kHz resolution achievable

- easier to get all cross-products
  e.g. Zeeman effect projects

- large total number of channels important
  in several projects
  e.g. spectral line surveys ~ 4000 chann. over 4 GHz
  CO search in distant galaxy clusters

- In all cases **easy sub-band reconfiguration** is a major goal
  => several types of observations concerned

Flexible Sub-Arraying

- **FC design is modular & subarraying** to be included in the architecture
  => easy definition of antenna subsets
  => easy insertion of additional antenna(s) into a subset

  Major goal:
  - flexible scheduling (weather, maintenance, etc.)
  - different types of observations running simultaneously
    e.g. sub-array work + tied sub-array + VLBI
    sub-arrays working at different frequencies

  (work needed on definition and number of sub-arrays)

Local Processing

- Included from the start in FC design
  - to reconstruct wideband spectra & to lower output data rates
    e.g. ~ 30 000 chips, 8 klags/chip, 4 bytes every 10 msec
    => 100 Gbytes/sec
  - to improve *Scientific Options*

- *Scientific Options* with high data rate processing
  - Good atmospheric subtraction
  - On-the-fly mapping
  - Fast interferometer readouts to survey large sources
    e.g. Magellanic Clouds
  - On-line processing of Water Vapour Radiometry ?

WVR (together with fast switching), would be important for precise atmospheric phase calibration required in :

- High fidelity imaging
- Precise imaging at high spatial resolution
- Submm projects

Organization of Europe's Backend Team

Future Correlator Model

headedy by ASTRON/NFRA

- System architecture
- Chip development subcontracted to Haystack/MIT
- Simulation
- Prototypes of critical subsystems

FIR Filter & Digital LOs

headed by Jodrell Bank & Arcetri

- Simulation
  - Downconversion, IMR filters
- Digital LOs
  - Harmonics

FIR Filter Fabrication

headed by Bordeaux and ENSERB

- Demonstrator (FPGA)
- ASIC prototype (CMOS technology)

Fast Digitizers

headed by Bordeaux/IXL

- First generation ASIC: amplifier/adaptator & comparators
- Second generation ASIC: broad band, n-level digitizers

Test Autocorrelator

headed by IRAM

- Simplified 4-bit AC to test fabricated digitizers

Agreements Prepared for Phase 1

Correlator
Samplers & test machine
FIR filter fabrication

December 2001, Report on Preliminary Design Phase of FC

Design & development documents
Identify risk areas & technical options
Pre-protos of selected subsystems
Cost & manpower estimates

OVERALL PLANNING & HARMONIZATION

- *December 2001* : Preliminary Design Report on FC
- *End of 2003 :* FC Prototype
- *Mid-2003 ?* Baseline Correlator Prototype
- *Mid-2004* : NRAO delivers first quadrant of Baseline Correlator
- *2003-2004* : Full Construction Decision Point

Joint/Parallel Tasks

Reviews
Parallel studies on FIRs
Digitizers for both FC and Baseline Correlator

ALMA FUTURE CORRELATOR TOP LEVEL SPECIFICATIONS

Goal

Digital hybrid lag correlator
System clock rate = 250 MHz
≥ 64 antennas (≥ 2016 baselines)
Baseband = 2 GHz
16 independent sub-bands per Baseband
Maximum bandwidth = 16 GHz / antenna
Max sampling rate = 4 GHz / Baseband input
≥ 3-bit, *n*-level sampling
4-bit correlation format
30 km max baseline delay range
Cross- and auto-correlation modes
1, 2 or 4 product pairs for polarization
≥ 1024 channels / baseline at 4 GHz clock rate
On-line apodisation schemes
Minimum dump time in auto-correlation = 1 ms (OTF mode)
Fastest integration period (cross-correlation mapping) = 10 ms
Full sub-arraying capabilities (sub-band independent)
Phased sub-array for VLBI
Large output rate (N_chann x N_base / Shortest_dump_time > 2 10^8 s^{-1})
Local processing

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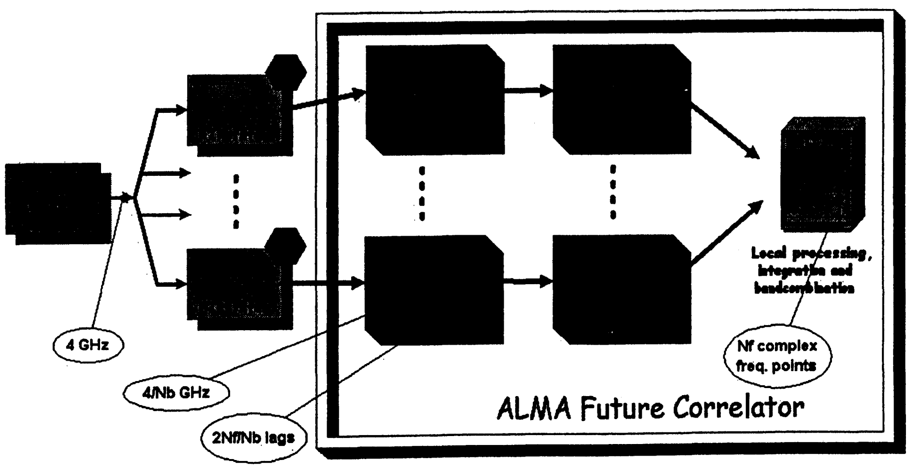


ASAC meeting, Berkeley, 2000-09-09

Basic architect... e

- Each of ALMA's eight 2 GHz bands (sampled at 4 GHz) is separated into a number of sub-bands using programmable digital filters
  => 8 * Nb sub-bands can be selected independently

- In each sub-band all correlation products are formed by a 3..4 bit lag-correlator.
  Since the correlator runs at reduced clockspeed no time-multiplexing is needed
  => highly flexible interconnection scheme

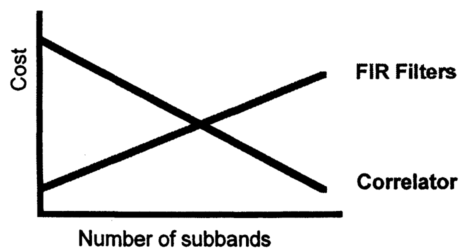
- The resulting data is converted to a sub-band spectrum. Powerful local processing handles integration and combination of sub-bands, and allows for on-line calibration (e.g. removing atmospheric phase slopes based on WVR information)
  => manageable output datarates

ALMA Future Correlator: some highlights
Spectral flexibility

FIR filters can be reconfigured. For many applications they will be set to cover the full input band (left).

They can also be used to get data with very high spectral resolution at several frequencies within the band, including additional continuum band (right).

Optimising cost/performance



The number of sub-bands is a free design parameter in the digital hybrid architecture and can be used to optimise the total cost of the system.

With more sub-bands, the correlator can operate on lower clockrates, so the cost becomes less. On the other hand, more high speed FIR filters are needed, so their contribution to the total cost becomes higher.

QUESTIONS to the ASAC

- Is 5-10 kHz max resolution appropriate ?
- Required number of channels over 8 GHz ? (more channels possible at increased cost)
- Minimum acceptable dump time for OTF ?
- Fastest integration period in X-correlation ?
- Need for on-line WVRadiometer corrections ?
- Sub-arraying

  Significance:

  - Number of antenna subsets the X-correlator *and* the software has to accomodate: 4, more ?

Functionality:

- Simultaneous observational modes
- Moving telescopes between sub-arrays
- Multi-frequency sub-arrays

- Importance of lower correlator power consumption :
  - Impact on ALMA operations ?
  - Less operation cost => more science contracts ?