Fringe stopping in for Apertif

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**Terminology:**

ADC Analogue to Digital Conversion

ADU Analogue to Digital Unit (board with 8 ADC)  
Apertif APERture Tile In Focus

Arts Apertif Radio Transient System

beam Group of beamlets that point in the same direction

beamlet Beam formed subband, a small beam spanning one subband

BF BeamFormer

BG Block Generator

BN Back Node FPGA on UniBoard

bps Bits per second

BSN Block Sequence Number (time stamp)

BW BandWidth

CB Compound Beam, formed at dish level over the FPA  
channel Unit frequency band within a beamlet

CoBI Correlator Backplane Interface board (connects 8 Uniboards with 8 OEB)

DB Data Buffer

DT Delay Tracking

FF Flip Flop  
FN Front Node FPGA on UniBoard

FoV Field of View

FPGA Field Programmable Gate Array

FS Fringe Stopping (is DT + PT)

GbE Gigabit Ethernet

GPU Graphics Processing Unit

HEM HMC Extension Module (provides UniBoard2 with one HMC and extra optical IO per PN)

HMC Hybrid Memory Cube  
IAB Incoherent array beam, formed by incoherently combining dishes

IO Input Output

LE Logic Element

MAC Multiply and Accumulate, Medium Access, Monitoring and Control

NIC Network Interface Card for 10GbE

node Processing node (PN), typically one FPGA chip  
Nof Number of

OEB Optical-Electrical Board (provides UniBoard BN with same optical IO as the FN)

PAC Power and Control board

power beam Full Stokes power values: I, Q, U, V

PL Pipeline processing  
PN Processing Node (FN or BN), PN0:3 = FN0:3, PN4:7=BN0:3

PT Phase Tracking

RF Radio Frequency

SC Science Case  
SP Signal Path, 1 CB consists of Npol = 2 SP, 1 SP per Apertif BF subrack

SR Science Requirement

sps Samples per second

subband Frequency band, unit output of the filterbank

TAB Tied array beam, formed by coherently combining dishes  
Tant Transpose to group data from all S = 64 (≥ Nant) antenna elements in the FPA  
Tdish Transpose to group data from all Ndish = 12 dishes  
Tpol Transpose to group data from both Npol = 2 polarizations  
Tsp Transpose to group data from all Nsp = Npol \* Ndish signal paths, so combines Tdish and Tpol   
Tband Transpose to group data from all Nband = 16 bands

Tintegration Transpose to group data from an integration interval of Nint\_x values in time  
TFoV Transpose to group data from all NCB = 37 beams for the full FoV

VLBI Very Large Baseline Interferometry  
voltage beam Dual polarization sample values with phase information: Xre, Xim, Yre, Yim

WSRT Westerbork Synthesis Radio Telescope  
X Correlator

**Definitions:**

Ncomplex 2 Two part of a complex number, the real and imaginary part   
Npol 2 Number of polarizations, X and Y  
NStokes 4 Number of power values in the Stokes vector [I, Q, U, V]  
Ndish 12 Number of WSRT dishes in Apertif  
Nsp 24 Number of signal paths = Ndish \* Npol at the output of the Apertif BF  
CBBW 300 MHz Full bandwidth of the CB and also of the TAB and IAB (SR-0.2)  
Bsub 781250 Hz Subband bandwidth in Apertif BF, = beamlet bandwidth  
Nband 16 = nof\_fn\_bf, Number of bands in the Apertif BF to process the full CBBWNCB 37 Required number of compound beams  
Ngr 12 Required number of TAB grating lobe patterns to cover the full CB (SR-0.41)  
NVLBI 12 Required number of TABs in the central CB for VLBI, choose = Ngr (SR-0.23)  
KTAB 12 Implemented number of TABs per beamlet (≥ Ngr)

NTAB 444 = NCB\*KTAB, number of TABs   
NIAB 37 = NCB, number of IABs   
Nlink 384 = NPN, number of physical 10G output links of the Apertif BF, so 1 link per PN  
NPN 384 = Nsp \* Nband, total number of parallel processing nodes in the Apertif BF  
MPN 128 = Nband \* nof\_un, total number of parallel processing nodes in the Arts

Muni 16 = Nband = nof\_fn\_bf, total number UniBoards in the Arts BF and in Apertif X

Muni2 4 Total number UniBoard2 in the Arts BF

Nchan 4 Number of channels per beamlet, for SC3 and SC4  
Bchan = Bsub/Nchan, channel bandwidth within a beamlet, for SC3 and SC4

Nint ≈ 10 Number of Stokes channel power values that are integrated in Arts  
TStokes ≈ 50 μs Minimum required sample period for the Stokes power values  
fStokes ≈ 20 kHz = 1/TStokes, minimum required sample frequency for the Stokes power values  
nof\_uni 4 Number of UniBoards per polarization and dish in the Apertif BF

nof\_bn 4 Number of back node FPGAs (BN) per UniBoard

nof\_fn 4 Number of front node FPGAs (FN) per UniBoard

nof\_un 8 = nof\_fn + nof\_bn, number of processing node FPGAs per UniBoard

nof\_10g 3 Number of 10G links per FPGA node on UniBoard

nof\_pn Number of processing nodes (BN or FN on UniBoard or PN on UniBoard2)

nof\_bn\_fb 16 = nof\_uni\*nof\_bn, number of subband filterbank BN per SP in the Apertif BF

nof\_fn\_bf 16 = nof\_uni\*nof\_fn, number of beamformer FN per SP in the Apertif BF

Wbeamlet 6 Word width in number of bits of a beamlet voltage sample  
Wtab 6 Word width in number of bits of a TAB voltage sample  
Wpower 8 Word width in number of bits of a IAB or TAB power sample

# Introduction

## Purpose

## Scope

The fringe stopping applies to both Apertif and Arts.

Geometrical delay

* τg = τd + τr
* The τg is a physical path length delay, the FS is applied after the signal is mixed down by a LO and down sampling.
* DT compensates τd in steps of the ADC sample period Ts.
* PT compensates the residual delay τr using a complex phase rotation per frequency channel
* DT occurs before filterbank on the full bandwidth input samples and PT occurs after filterbank per frequency channel

FS = DT + PT

* DT : Delay tracking for central direction of the central compound beam
* PT : Phase tracking for each compound beam in the FoV

Delay rate

* DT update rate 🡪 PT phase step adjust per frequency channel
* PT update rate during steady DT set by linear relation po + p1\*t

Decorrelation

* In time due to rotation of earth
* In frequency across a channel due to compensation for central frequency 🡪 maximum Bchan
* In space angle across the a compound beam due to compensation for central direction

Smooth delay tracking

* DT step 🡪 rerun subband filterbank for impulse response

# Fringe stopping

Fringe stopping (FS) applies to both Apertix X and Arts BF and is a task that can be done in the Apertif BF. Typically fringe stopping is a two-step process that consists of a true sample delay before a filterbank and phase tracking per frequency channel after the filterbank. For the Apertif the true sample delay tracking (DT) occurs on the ADC samples at the input of the Apertif BF followed by phase tracking (PT) of the beamlet data to stop the residual fringe. The phase tracking needs to be done per beamlet, because it depends on the subband frequency and on the CB direction.

The delay tracking involves duplicating an input sample or skipping an input sample. The phase tracking involves phase rotation by a complex multiplication. The phase tracking must be synchronous to the delay tracking, because a delay step causes a phase step. For the Nyquist frequency a delay step of one sample causes a phase step of 180 degrees. The delay step also disturbs the subband filtering if it is not accounted for. To have a smooth delay tracking the ADC data with the extra sample or the skipped sample needs to be reprocessed by the subband filterbank for the duration of the filterbank impulse response. The subband filterbank in the Apertif BF has 16 taps and an FFT size of 1024, so with 8 bit ADC samples this requires storing at least 16 kByte per ADC input.

Currently the delay tracking is implemented in RAM in the Apertif BF, but only accounts for buffering the number of samples that are expected for the maximum geometrical delay difference between dishes. The phase tracking is not implemented yet in the Apertif BF. The smooth delay tracking to recalculate the subbands after each delay step is also not implemented yet in the Apertif BF. If the internal RAM is limited, then the delay tracking may require using external memory DDR3. After every delay step the data subband filterbank processing needs to catch up with the input data rate of 200 MHz. This implies that for smooth delay tracking the subband filterbank will need to run at slightly more than 200 MHz. An alternative to smooth delay tracking is to flag the 16 beamlet time samples as being disturbed by the delay step. However for each dish the delay step is typically applied at a different instant, so this then causes quite some flagging. For initial measurements it may be suitable to just ignore the effect of the delay steps. The smooth delay tracking can then be added in a later stage of the development.

The fringe stopping should best be implemented in the Apertif BF, because that is the central location. When the fringe is stopped then all user applications of the Apertif BF output data can then rely on it.

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