The VLBI Mode of the Universal Effelsberg Direct Digitization (EDD) System

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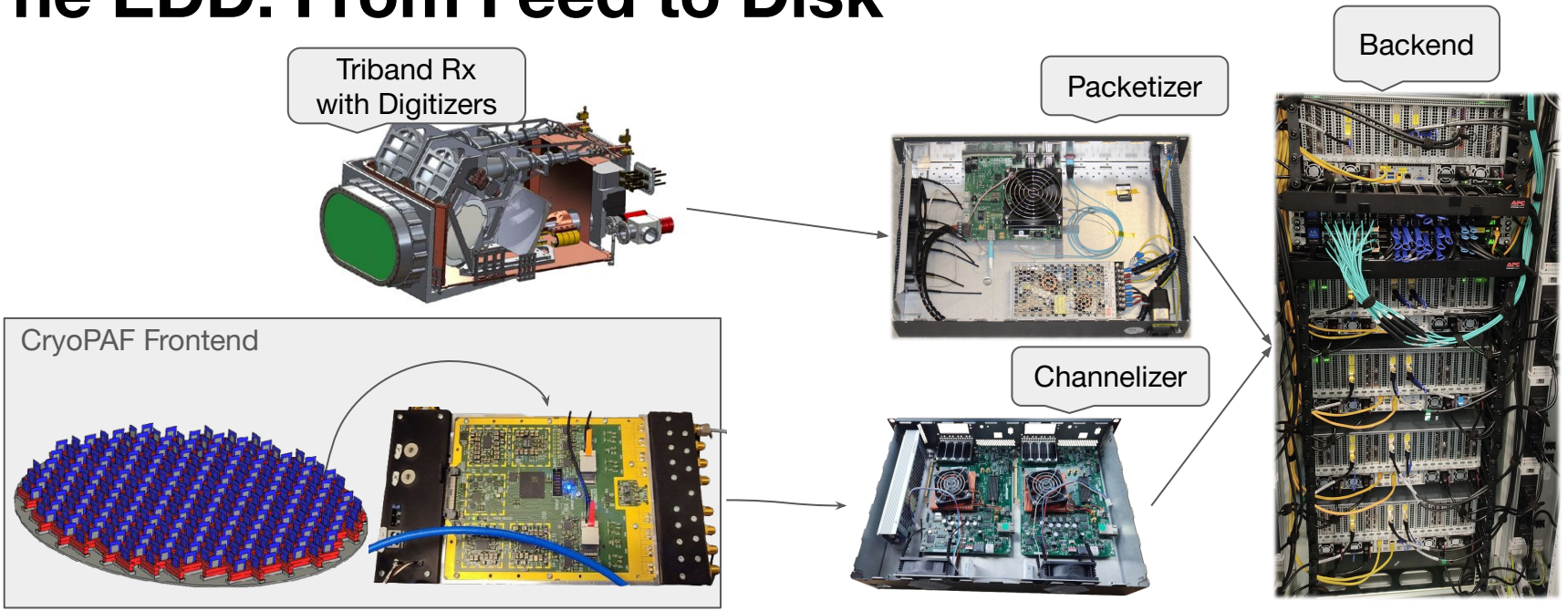
The EDD: From Feed to Disk



The EDD (Effelsberg Direct Digitization) is a modular framework for radio astronomy observing systems, covering receivers, analogue signal conditioning, time distribution units, digitization, packetization and backend signal processing.

Instruments operating with the EDD

Effelsberg Radio Telescope

- Diameter: 100m
- 4 EDD receivers (full)
- 11 other receivers are not direct digitized but can be fed into the EDD backend
- Specifications

SKA Prototype Dish

- aka SKAMPI
- Diameter: 6m
- robotic telescope
- 2 EDD receivers
- S-Band 1.8 - 3.6 GHz
- Ku-Band

Thai National Radio Telescope

- Diameter: 40m
- 2 EDD receivers
- L-Band 1 - 1.8 GHz
- K-Band
- EDD compatible Rx planned (Cx-Band)

Planned Instruments

Botswana Telescope

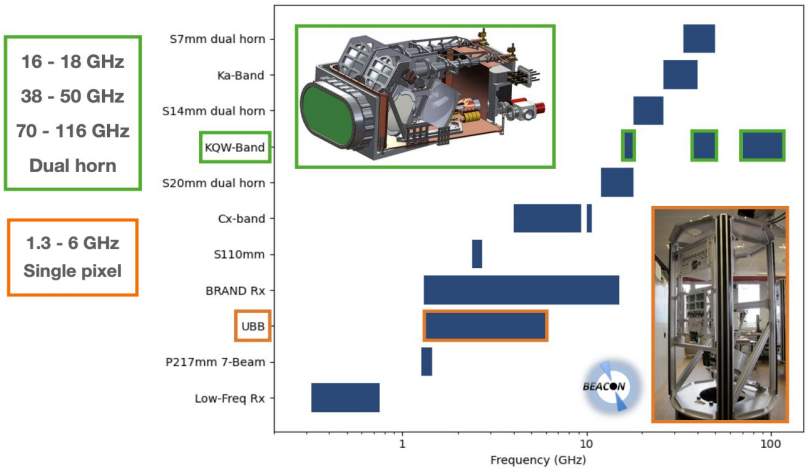
- SKAMPI Design
- 2 EDD Receiver
- S-Band (TBD)
- C-Band (TBD)

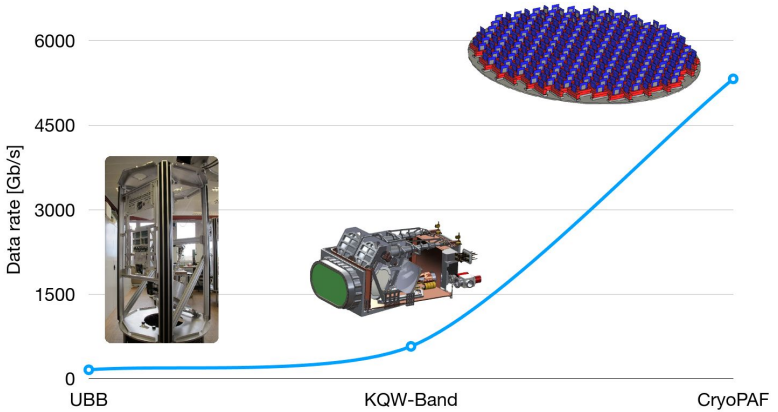
ARGOS (Prototype)

- First Interferometer using the EDD
- 5 Antennas
- Aimed bandwidth
- 1-2 GHz
- 2-3 GHz

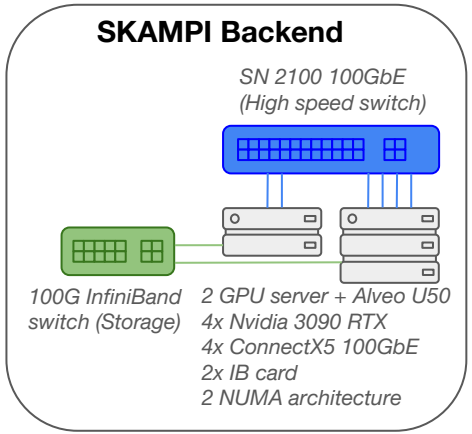
ARGOS

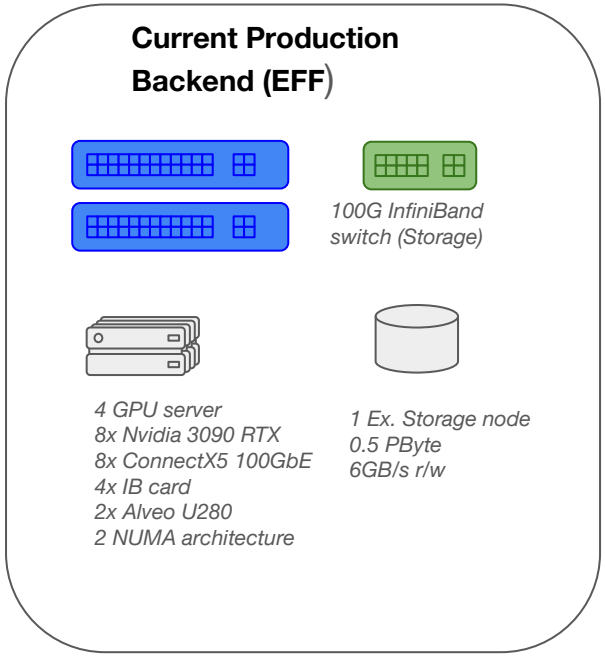
Challenging Future Rx Systems

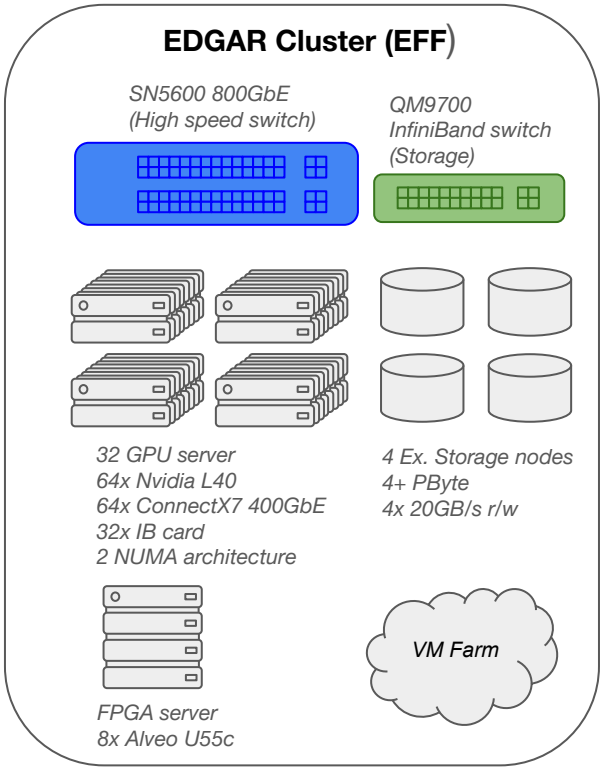




More Bandwidth, More Feeds
More Computing

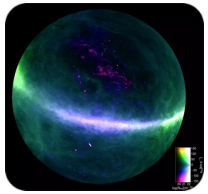


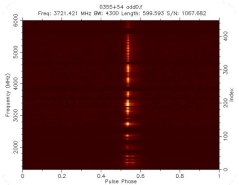


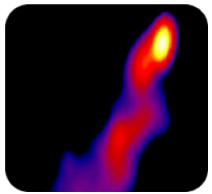


Scale the cluster to the demands of receivers, scientist and modes

What makes the EDD Backend ‘universal’?





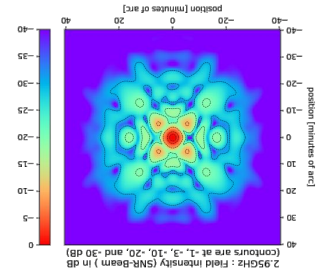


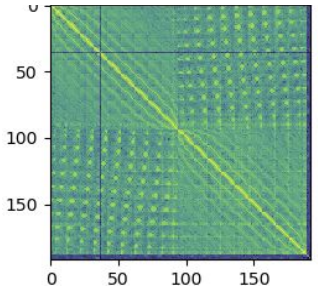
Science Modes

- Spectroscopy
- Pulsar timing
- Pulsar & Transient search recording
- VLBI recording

Instruments

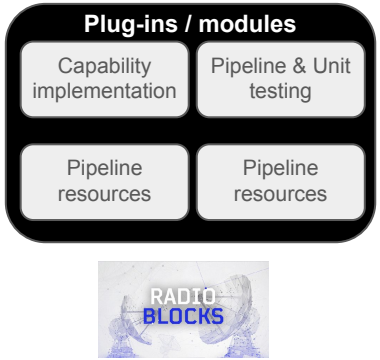
- Single pixel feeds
- Multi-pixel feeds
- Phased array feeds (in progress)
- Interferometer (in progress)



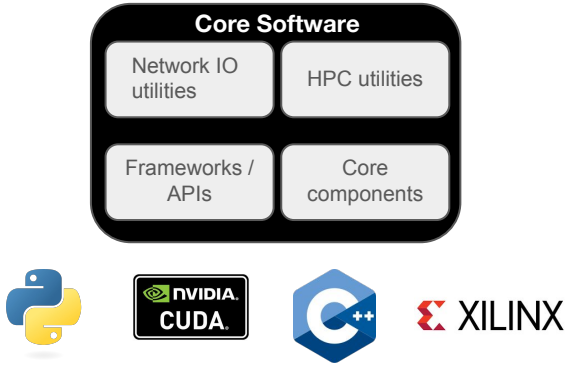


The “EDD backend” is not a specific instance of a backend, but a framework for the development, deployment and operation of radio astronomy backends on COTS hardware.

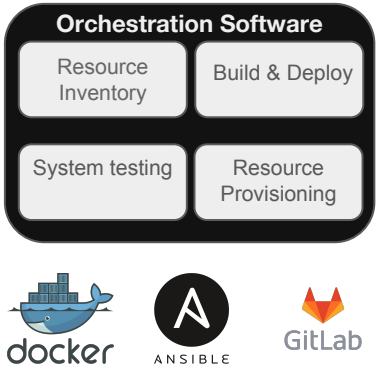
Overview of the EDD Backend Software



- edd_dbbc - VLBI processing
- edd_paf - Multi-antenna processing
- edd_pfb - Channelization / Synthesis
- edd_transient - Transient search
- edd_moonbounce - Educational



- psrdada_cpp - Graph processing and IPC
- mpikat - Python control framework with HPC utilities, CLI wrappers, process management
- mkrecv / mksend - CLIs for high speed data capture and transmission

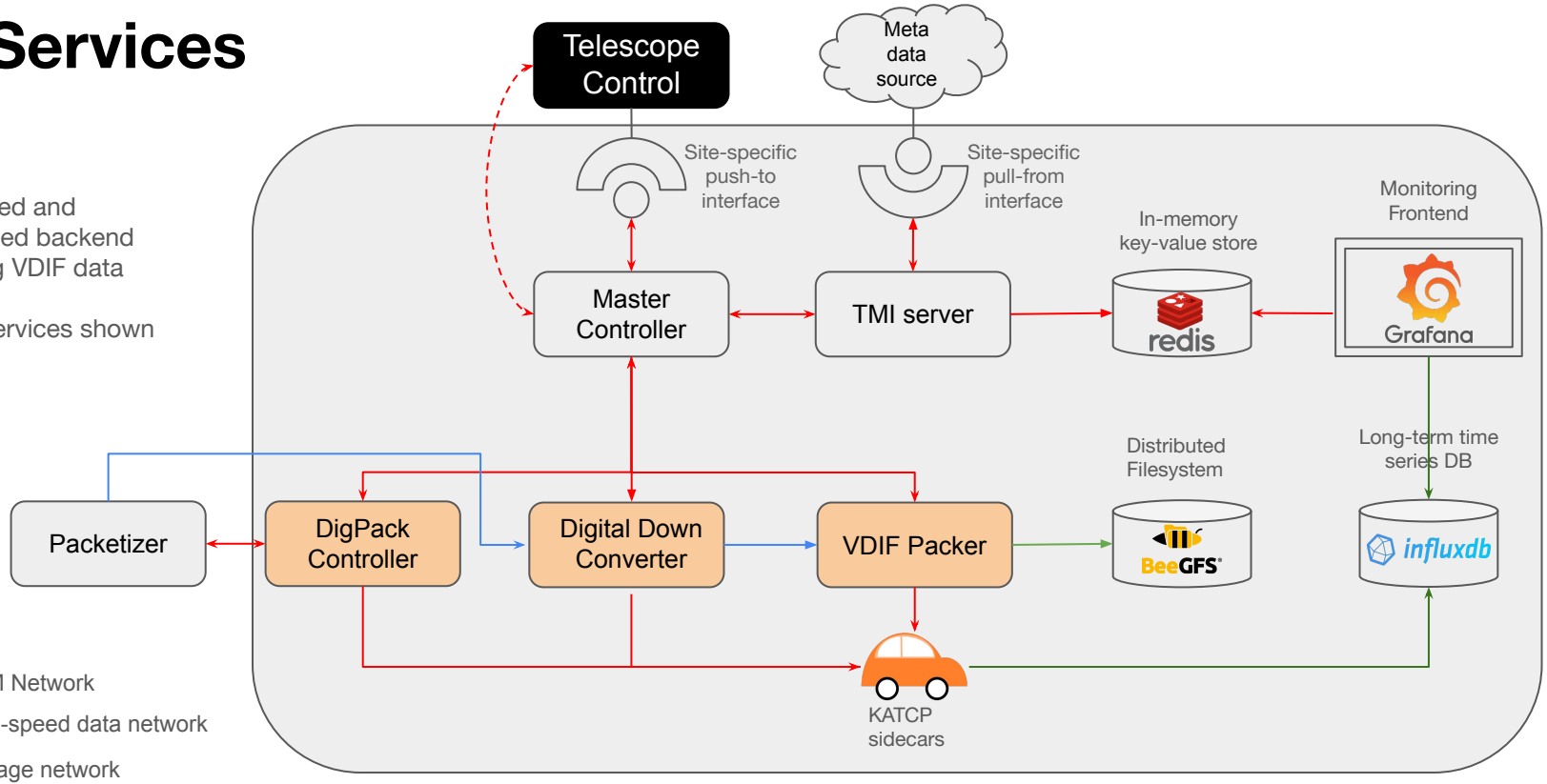


- Site-specific resource management
- Dockerized service deployment
- Automated CICD Docker image and Debian package builds

Communications and Services

A deployed and provisioned backend recording VDIF data

Not all services shown

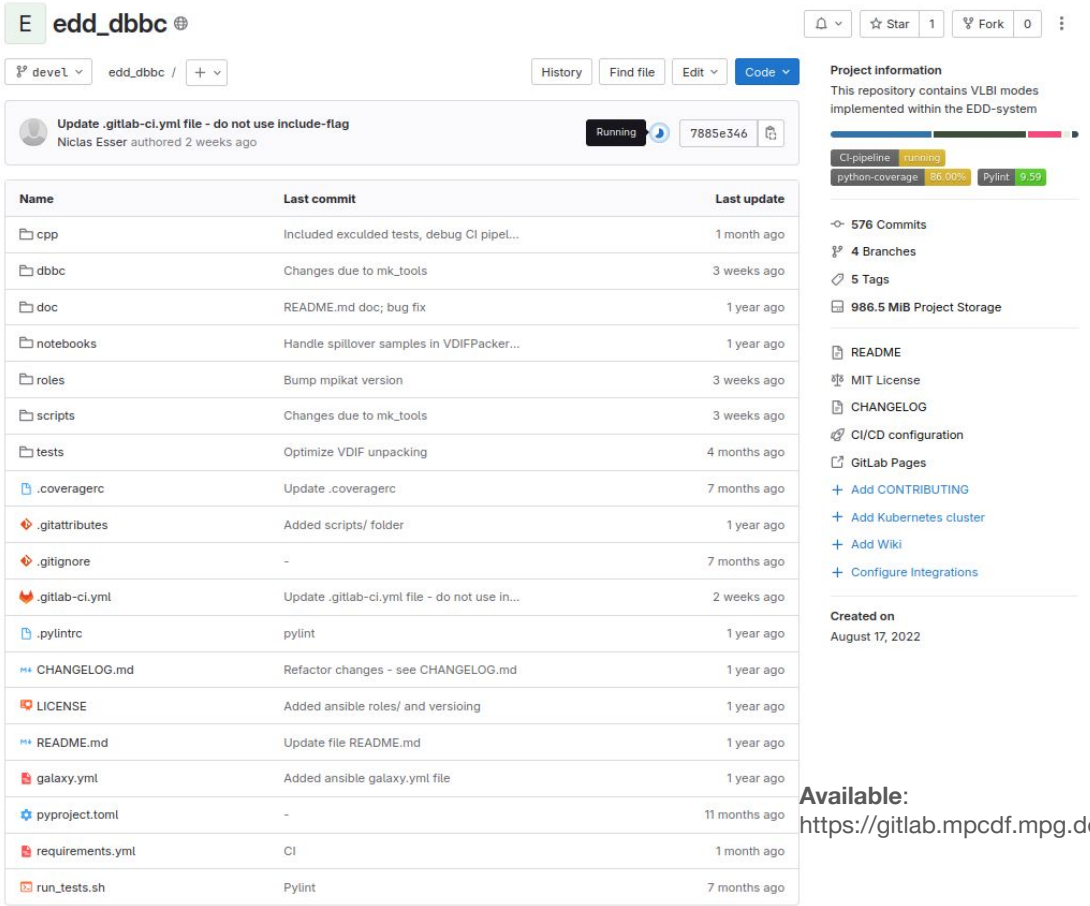


VLBI plug-in

EDD Pipelines for VLBI

- Digital down converter
- VDIF packer
- Real-time plotter
- Recorder / e-VLBI

Comprehensive CI Pipeline with build, testing, benchmarks, code quality metric and documentation

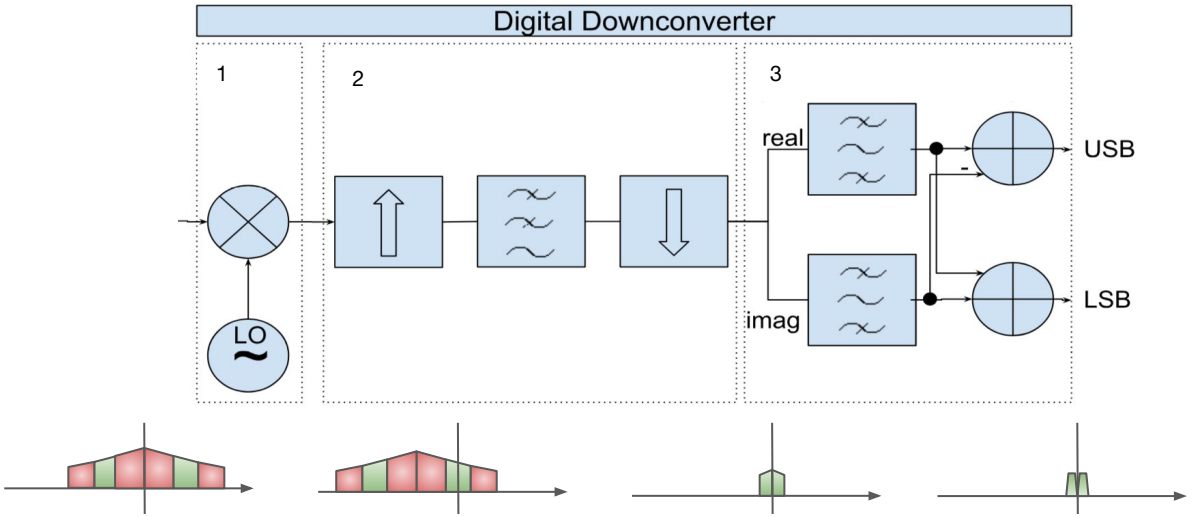


Available:
https://gitlab.mpcdf.mpg.de/mpifr-bdg/edd_dbbc

EDD Pipelines: Digital Down Converter I

An EDD Pipeline selecting arbitrary bands from the baseband signal

1. Mixing stage
2. Resampling: up-, filtering and downsampling
3. Hilbert bandpass filtering



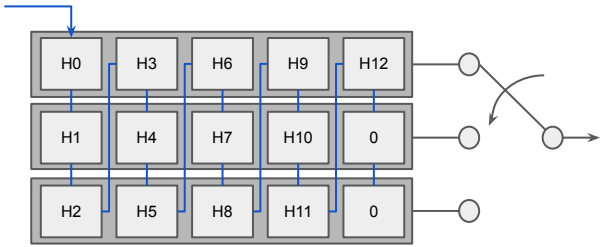
EDD Pipelines: Digital Down Converter II

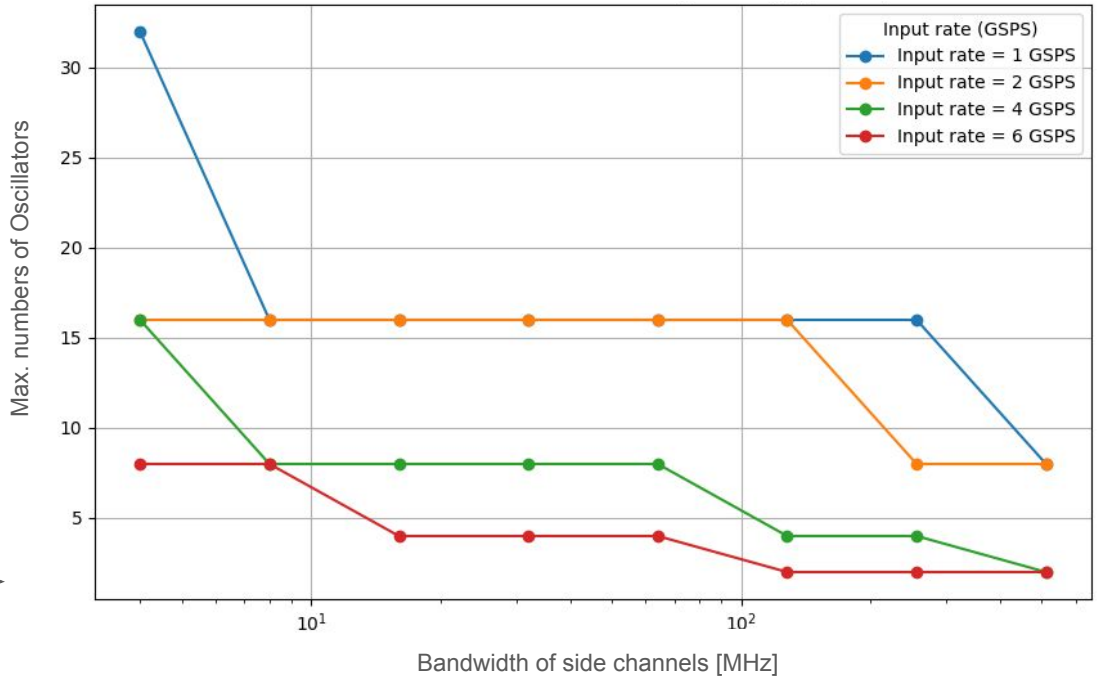
Just downsampling is not enough
→ EDD Rx not always aligned to VLBI bands
→ Upsampling is often required

Example SKAMPI S-Band:
- Initial sampling rate: 3.6 GHz
- Desired sampling rate: 512 MHz
- Upsample factor U = 32 = lcm(3600, 512) / 3600

Computational Costs:
- Naive FIR convolution: $\mathcal{O}(K \times U \times N)$
- Polyphase resample: $\mathcal{O}(K / U \times N)$, U^2 cheaper

→ Polyphase resampling saves a lot memory, too

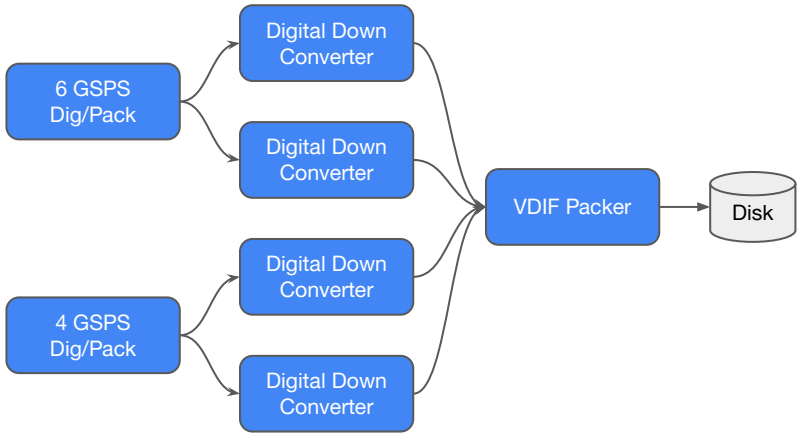




Benchmark carried out on a Nvidia L40

EDD Pipelines: VDIF Packer

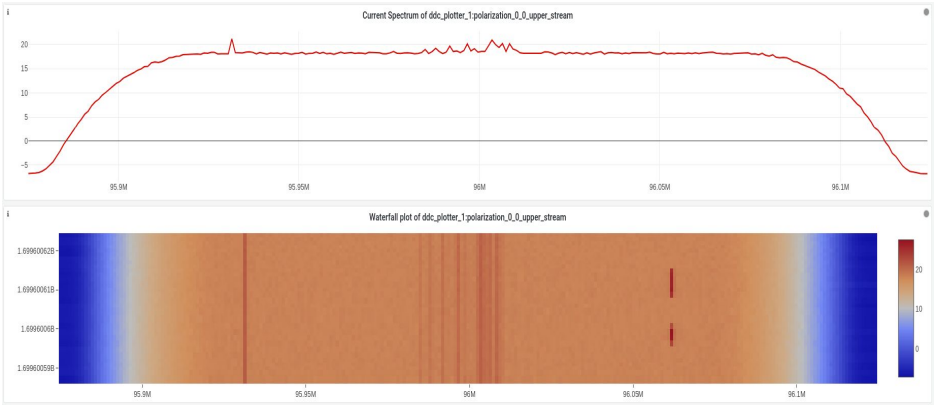
- Re-quantization from float32, 12,10,8-bit int to 2-bit
- Cheap and highly parallelizable operation
- GPU and multi-threaded CPU implementation
- A single VDIF Packer handles multiple DDC streams
- Rudimentary data dumps



Real-time Plotter

- FFTed snapshots from DDC streams
- Sends spectra to Redis
- Grafana live dashboard

redis Grafana



EDD Pipelines - Recorder and e-VLBI

We need a proper recording pipeline to fulfill VLBI recording standards

Running and commanding `jive5ab` from an EDD pipeline

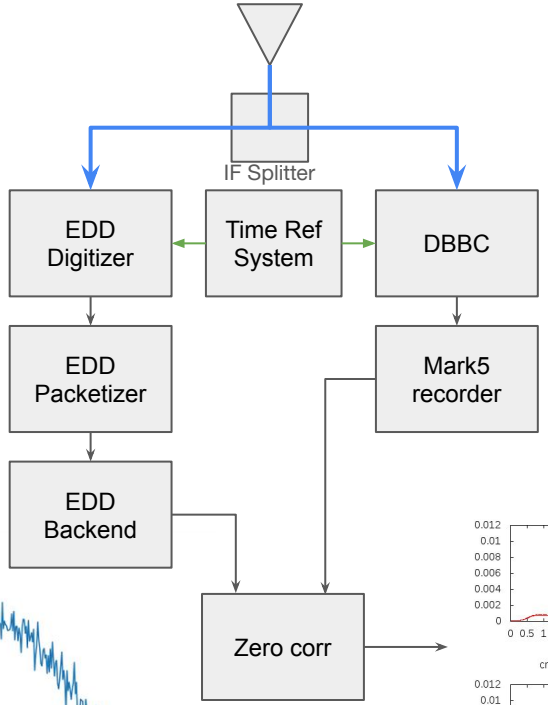
Potentially enables e-VLBI operations

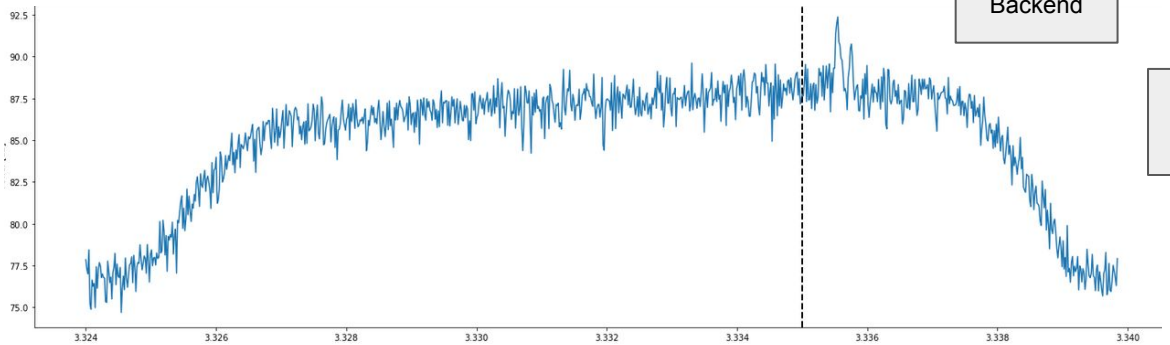
Under construction

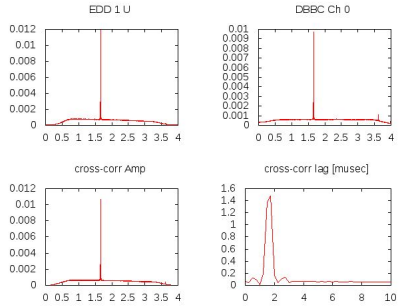
Testing and Verification

Comprehensive unit and system testing important
… but on-sky tests allow verification

- Zero-baseline test → run DBBC3 against EDD
- Frequency stability checks







Happy Niclas

Happy Uwe

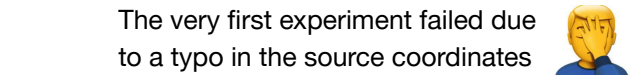
First Experiment

Participants

- SKAMPI
- Medicina
- Yebes
- Effelsberg (DBBC/EDD)

SKAMPI's clock offset 130 us
→ Under investigation

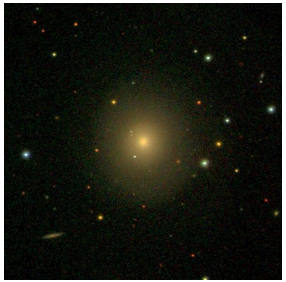
The very first experiment failed due to a typo in the source coordinates

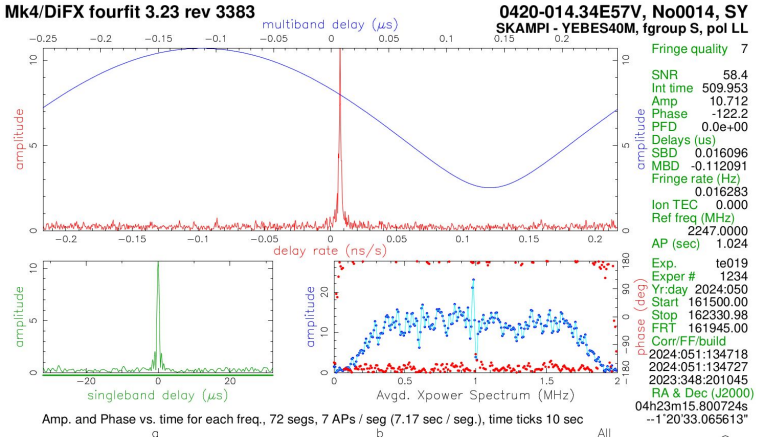


Fringes between all stations and backends!

Longest Baseline: 8800 km

Observed 2 x 4 MHz @ 2.25 GHz





Follow-up Experiments

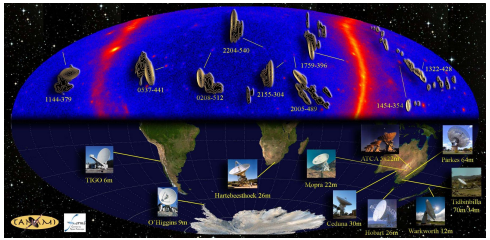
Fringe Detection Test with TNRT and EFF

- Observed various extra galactic sources
- Fringes in all scans
- Frist Fringe detected within Thailand
- Enables international collaborations with TNRT (e.g. EVN)

TANAMI with SKAMPI

- 24h test observation
- Fringes detected
- Only partially successful as full seconds offsets were found

→ Bug is fixed now



TNRT, FAST and Tianma

- Thai and Chinese collaboration
- Without support from MPIfR
- Fringes detected

Outlook

Planned Collaborations

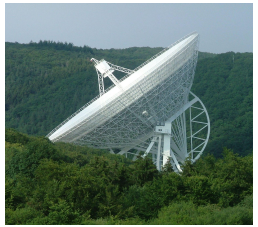
- **The Big Milestone:** Join the EVN with SKAMPI and EFF
- Contribution to the TANAMI project with SKAMPI

Further Developments (VLBI)

- Standardized recording with Field System-like meta data logging
- Support for e-VLBI
- Multi-beam VLBI with ARGOS and CryoPAF within RadioBlocks
- Various features…

Take away

- The EDD backend is ready for VLBI operations - even not completely automated
- Adaptable and scale computing hard- and software to fulfil the needs of high data rates Rx
- GPUs are suited for VLBI recording
- EDD has proven itself at various stations in different science modes



Thank you for listening

All EDD Software is open source, feel free to use
https://gitlab.mpcdf.mpg.de/mpifr-bdg

Ewan Barr | Wewei Chen | Jason Wu | Jan Behrend | Tobias Winchen | Niclas Esser | Yunpeng Men