Back-end Design of the Read-Out System for the QUBIC Experiment

7th Helmholtz Detectors Technology and Systems - 2021

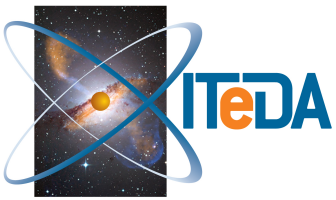
PhD Student:
Eng. Luciano Ferreyro

UNSAM Director:
Dr. Eng. Manuel Platino

Scientific Supervisor:
PD. Dr. Oliver Sander

KIT Director:
Prof. Marc Weber

ITeDA - Instituto de Tecnologías en Detección y Astropartículas, Buenos Aires, Argentina
UNSAM - Universidad Nacional de San Martín, Buenos Aires, Argentina
KIT - Karlsruher Institut für Technologie
IPE - Institut für Prozessdatenverarbeitung und Elektronik, Karlsruhe, Germany



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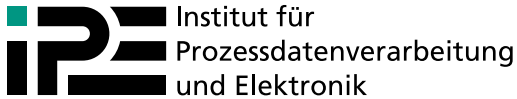
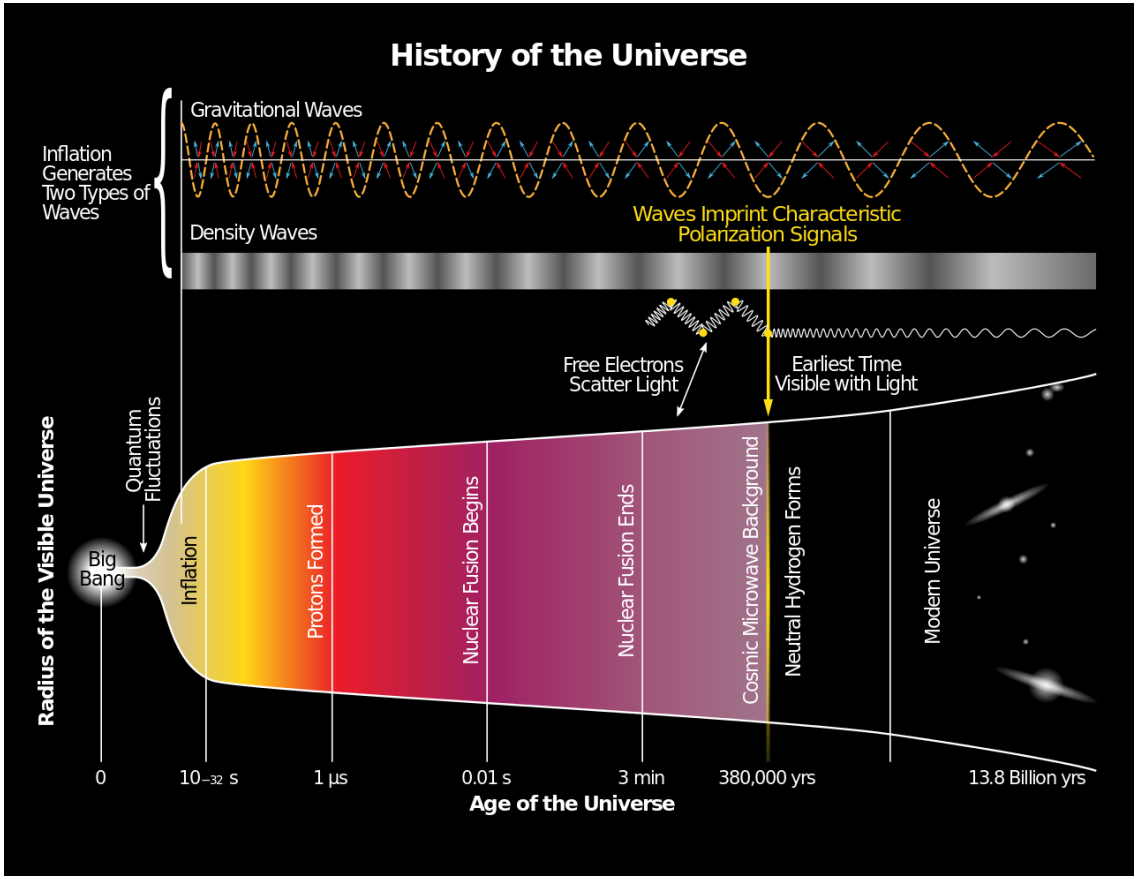


Schedule

Introduction

Cosmic Microwave Background radiation

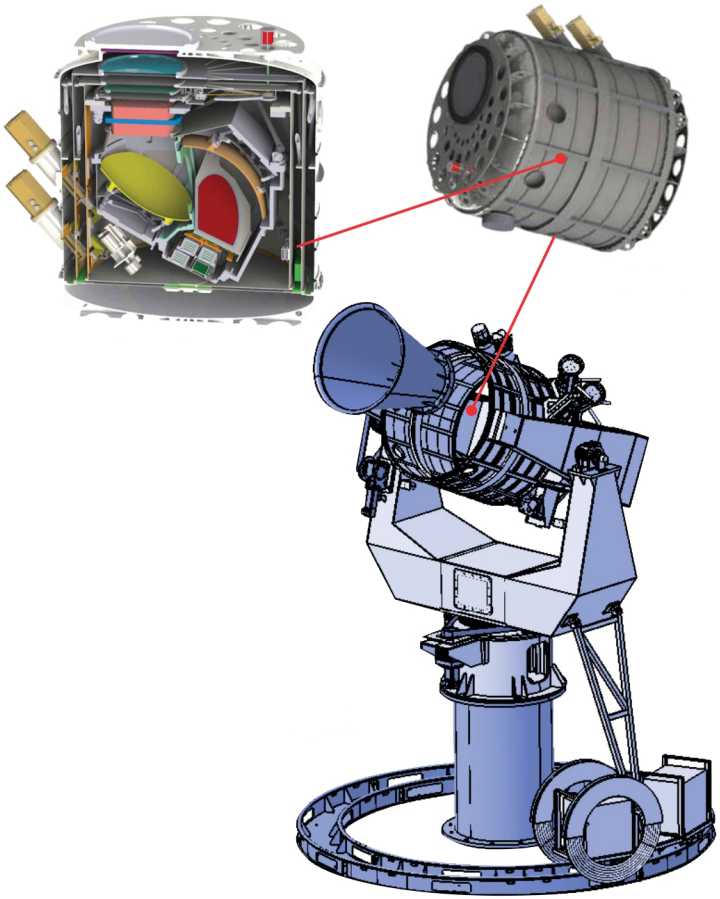


Confirmed by many experiments along the years:

Universe composition

- Dark Matter: 22%,
- Baryonic Matter: 4%,
- Dark Energy: 74%.

The QUBIC Project - Q&U Bolometric Interferometer for Cosmology

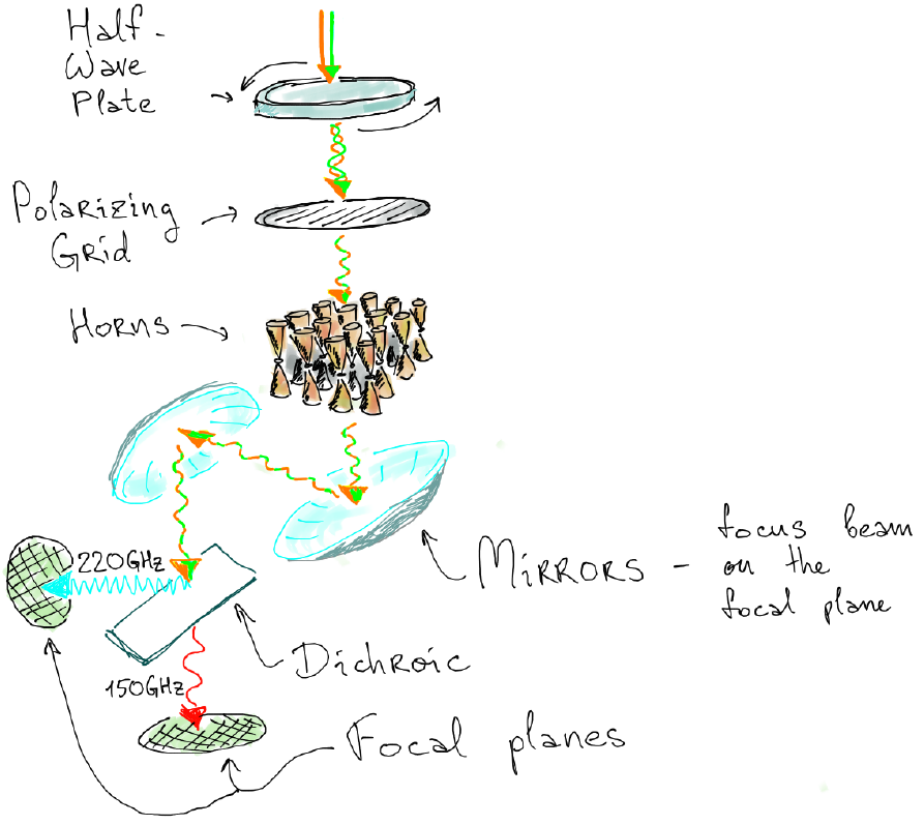


The QUBIC Instrument

- **QUBIC aims to measure the CMB B-modes polarization**,
- It's a ground based telescope which will work in the bands of 150 GHz and 220 GHz and implements a novel technique, combining a bolometric sensor (for sensitivity) and interferometry (for the control of systematics). The bolometers will be inside of a cryostat at 300 mK,
- The telescope and site constructions are carried out by **The QUBIC Collaboration**,
- Will be installed in San Antonio de los Cobres, Altos Chorrillos, in the province of Salta (Argentina), very near from the radio telescope LLAMA. It will travel between April and June 2021.

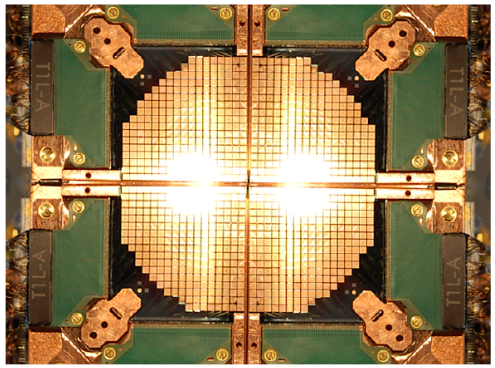
Current Read-Out electronics

The QUBIC Instrument



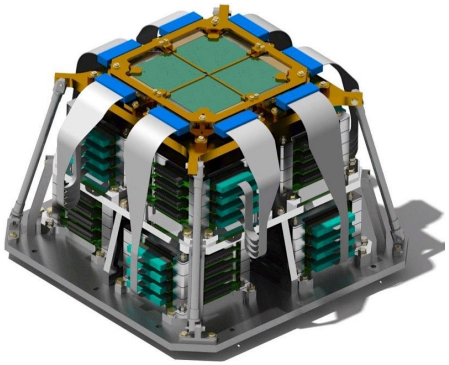
The QUBIC Instrument

- Used temperature sensor for the bolometers: TES (Transition Edge Sensors),
- Two focal planes, one for each band at 300 mK,

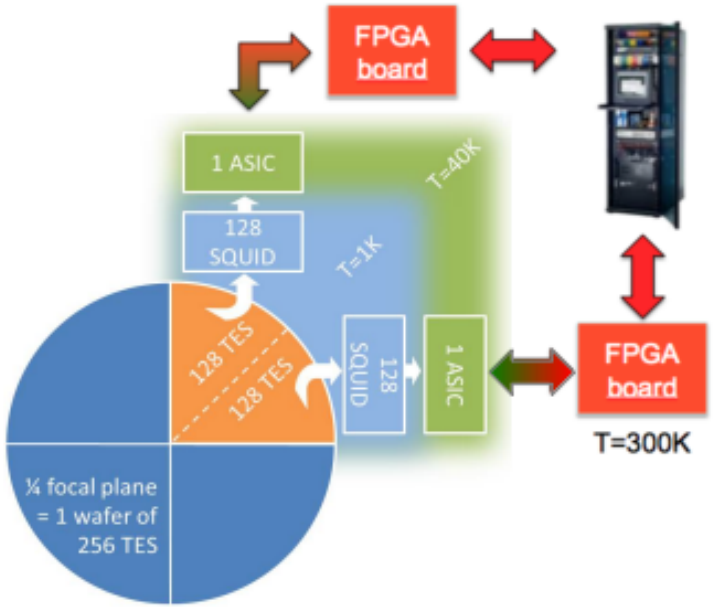


Focal plane

Time Domain Multiplexing Scheme



Focal plane electronics



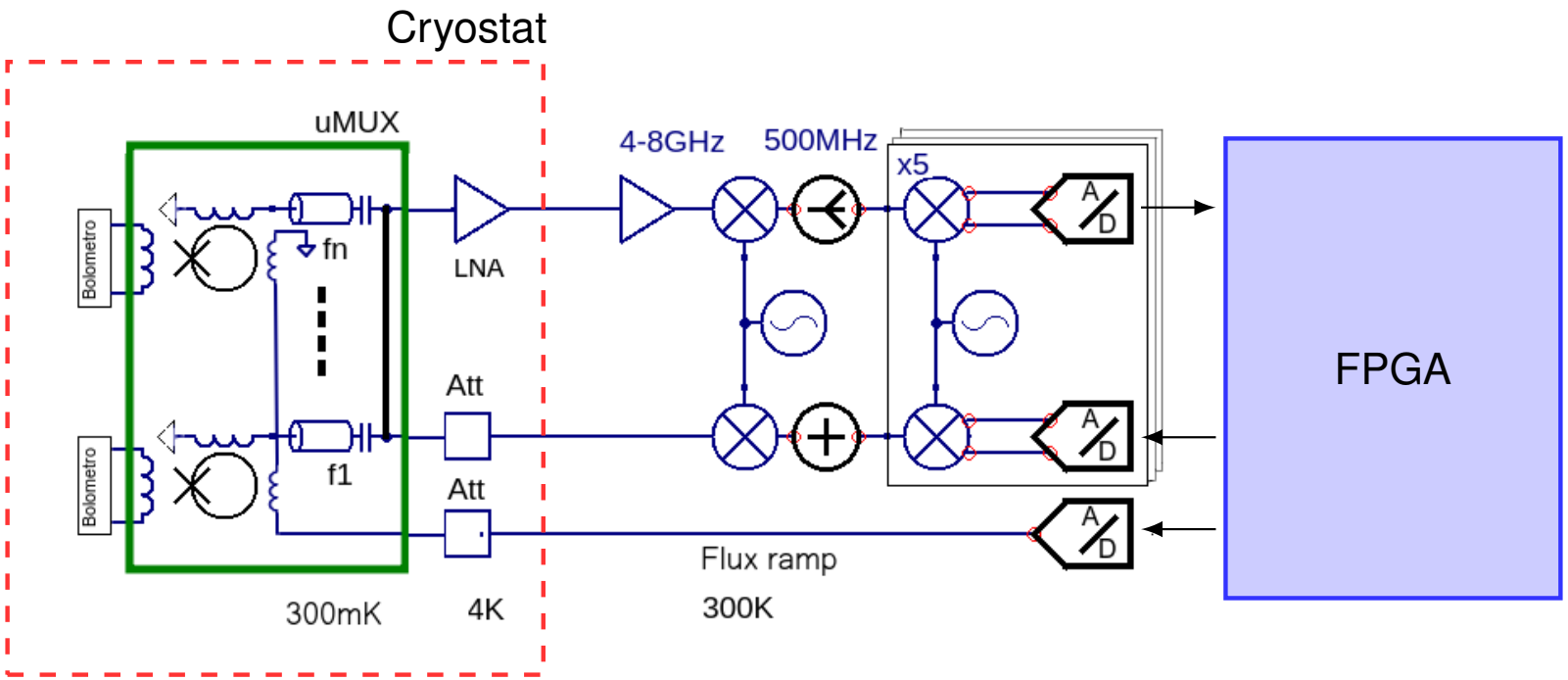
Read out

- Each focal plane is composed by 4 quarters (256 detectors per quarter, 1024 detectors per focal plane),
- The quarters are connected to a squid multiplexer (128:1), and afterwards connected to an ASIC.

- Time-Domain Multiplexing (TDM) scheme,
- Several electronic stages inside the cryostat: TES, SQUIDs and ASICs,
- Many connection cables going inside the cryostat.

The new approach for the future of QUBIC

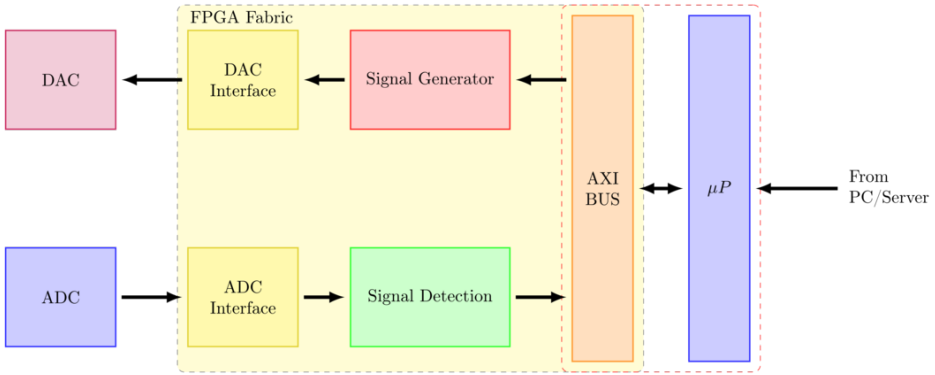
Frequency-Domain Multiplexing Scheme



Approach

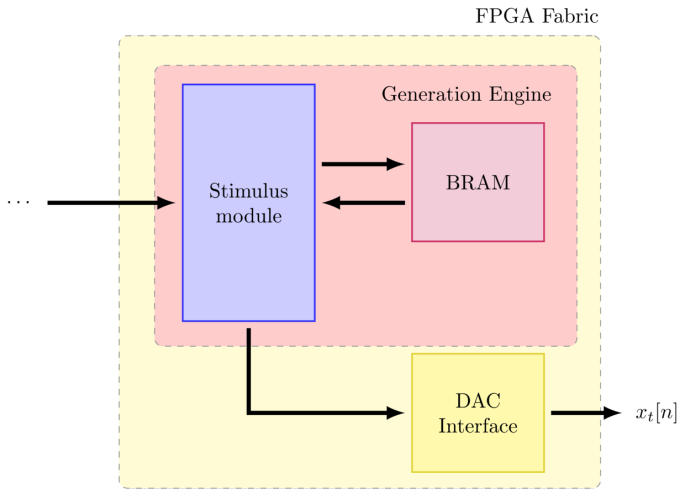
A high scalability and high performance FDM scheme for parallel processing of several number of detectors, using a flux-ramp SQUID's modulation technique and paramagnetic sensors to measure the temperature in the bolometers.

Digital Backend

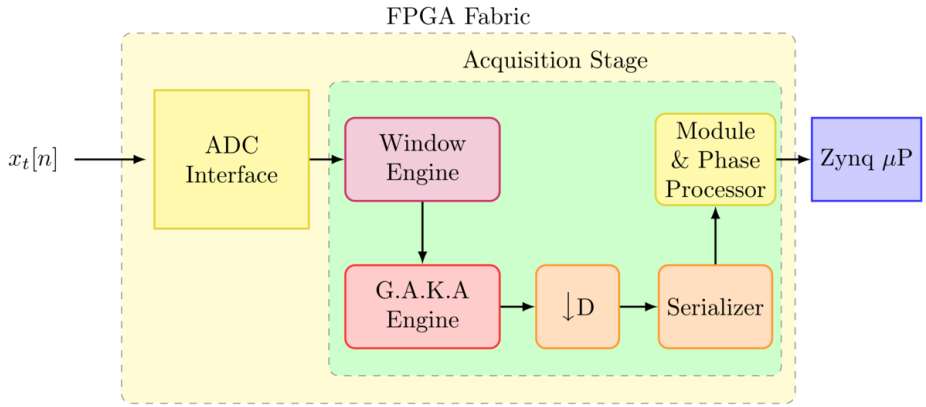


Digital Backend block diagram

- Consists of two well defined stages: generation and acquisition,
- Prototype based on:
  - ZCU102 (Zynq UltraScale+ from Xilinx): ZU9EG,
  - ADC AD9680-1000,
  - DAC AD9144.

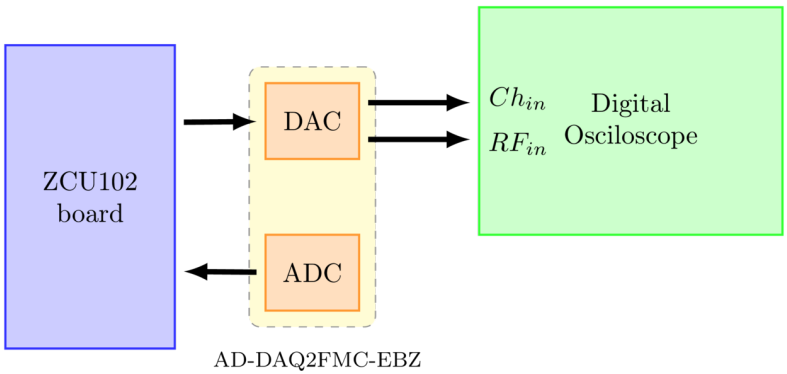


Generation Stage block diagram

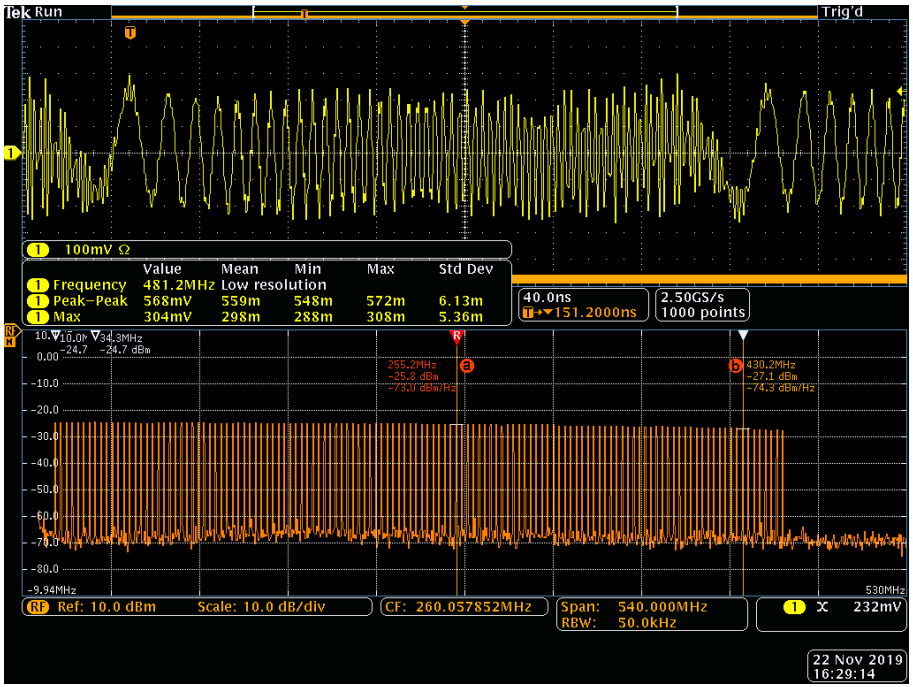


Acquisition Stage block diagram

Results: generation stage



Connection diagram for generation stage measurement. **Configuration**: DAC@1 GSPS and the ADC@1 GSPS.



DSO screen showing a *real* signal with 128 components: from 10MHz to 451MHz,$\Delta f = 3.5MHz$. **Top** (yellow) time-domain, **bottom** (orange) frequency-domain.

- $DSO_{\text{time-domain}}$: full-bandwidth, 100mV/div,
- DSO_{FFT}: **Span** = 540 MHz, **Center Freq.**: 260 MHz, $\mathbf{F_s}$ = 2.5 GSPS, **Memory**: 1000 points, **Ref. Level**: 10 dBm, **scale**: 10 dB/div

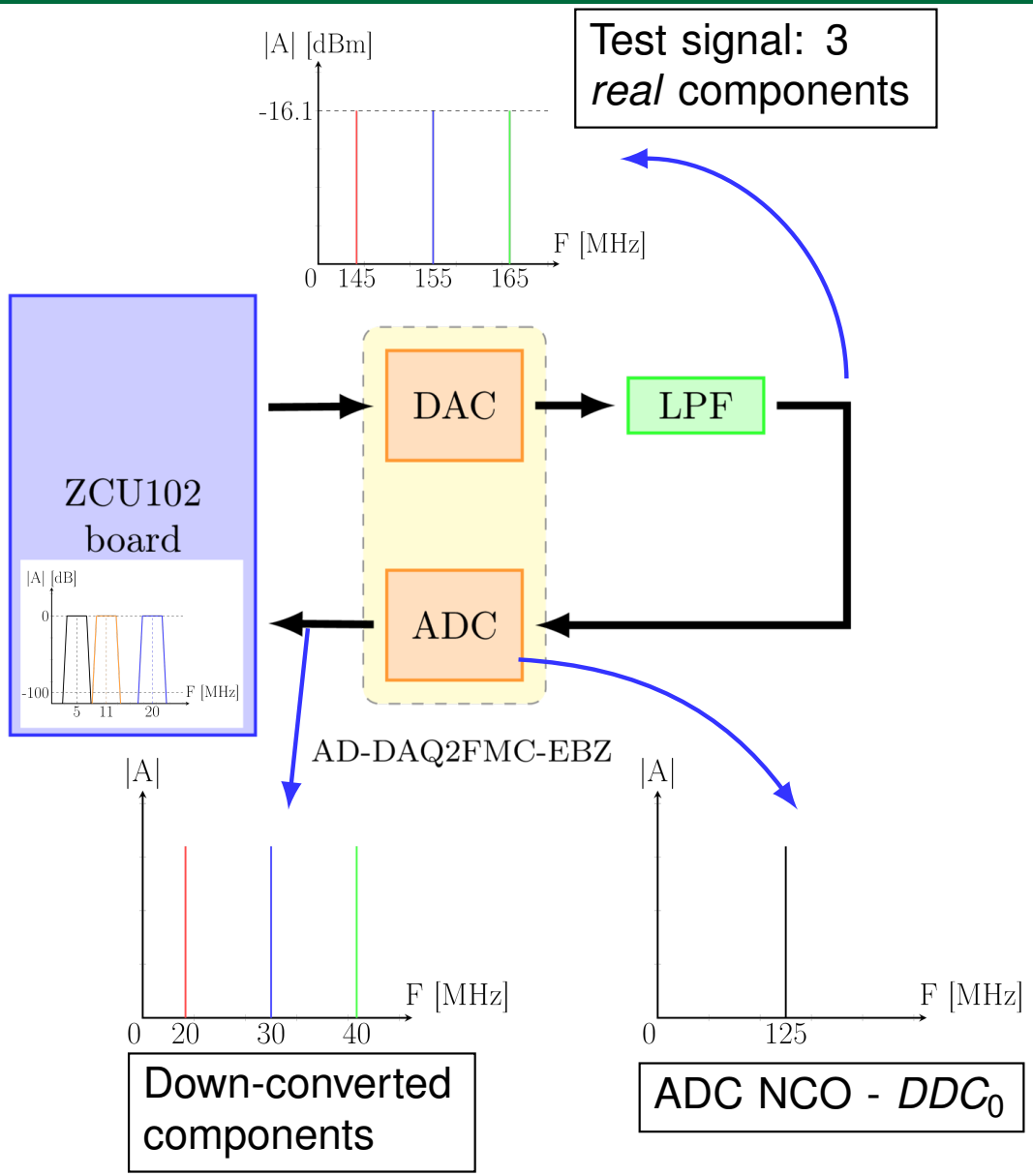
Results: acquisition stage

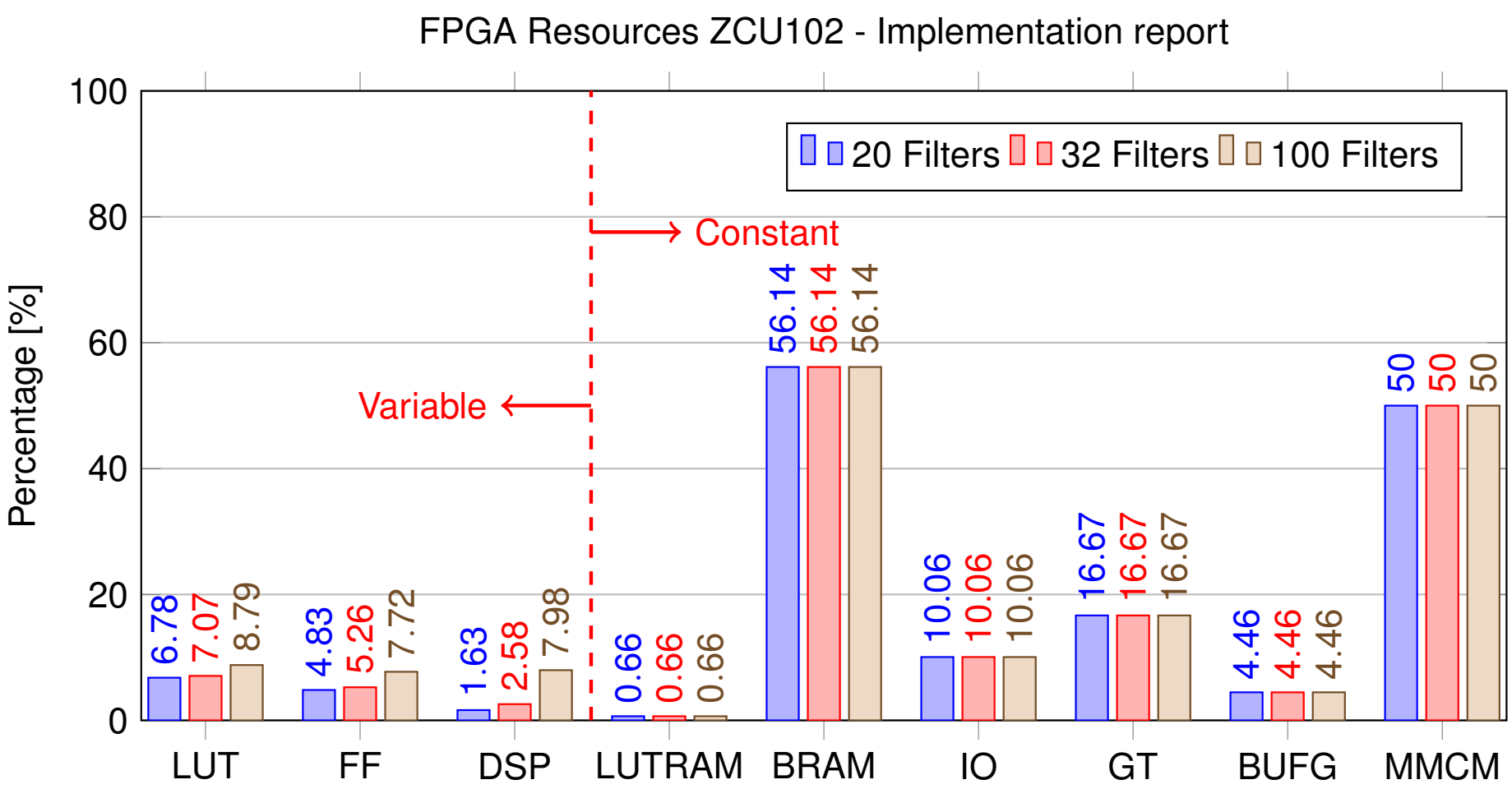
Loopback measurement setup:

- ADC@1 GSPS
- DAC@1 GSPS (max. 2.8 GSPS)
- FPGA DSP slices@500 MHz

Preliminary results shows:

- Activity in the 20 MHz channel ✓
- **NO** activity in the 5 MHz and 11 MHz channel ✓





Used resources seems to be:

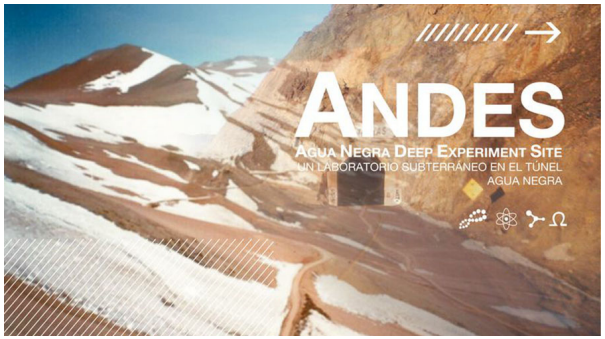
- moderate and in accordance with the state of the art ✓
- scales very well as long as the number of filters is increased (the current benchmark is 2 DSP slices per filter) ✓

Possible applications

Possible applications

LLAMA: Large Latin America Millimeter-Array. Radio astronomy and neutrino mass studies.

ECHo: Electron Capture ^{163}Holmium. A experiment for investigates the electron neutrino mass in the sub-eV range.



ANDES Laboratory: Agua Negra Deep Experiment Site. A future underground laboratory. Dark matter and neutrinos.

Summary and conclusions

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For the goal of developing a new DAQ system for the read-out of cryogenic sensors for CMB experiments, **preliminary results** are promising.

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Achieved goals

- Successfully implemented a stage for signal generation ✓
- Successfully implemented a stage with 100 filters which allows the processing of 100 real frequency components or 50 complex signals (I/Q modulation) ✓

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Upgrades

- A new version of the filter's kernel is under test improving in a factor of two the number of frequency tones

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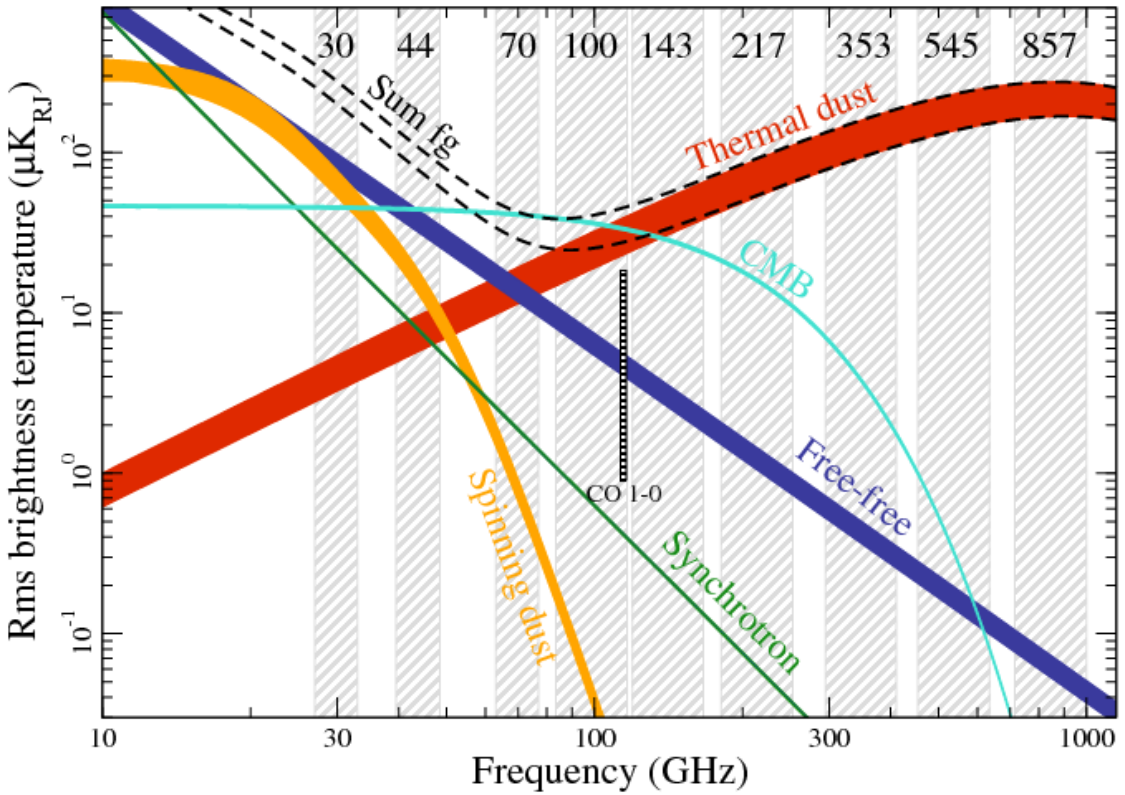
Future work

- Further measurements,
- Validate the filter's new version,
- Achieve timing closure for increase the number of filters in a factor of 10.

Vielen Dank!

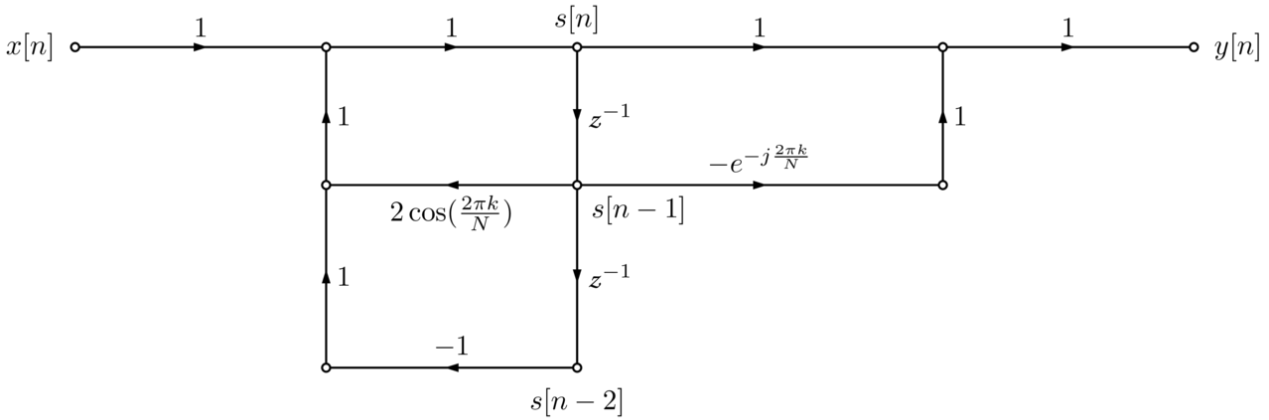
Backup

QUBIC - 150 GHz and 220 GHz

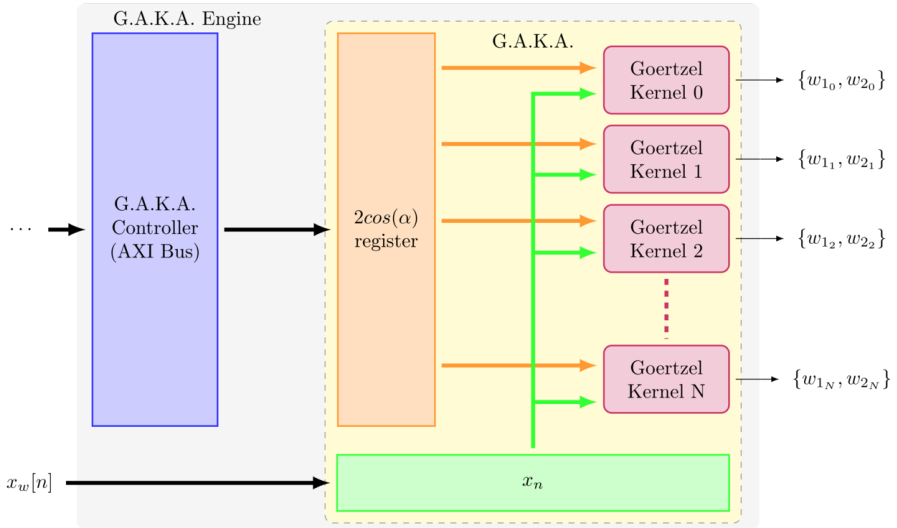


CMB spectrum component

G.A.K.A.: Goertzel Algorithm Kernel Array



Goertzel Kernel state-variables signal flow diagram

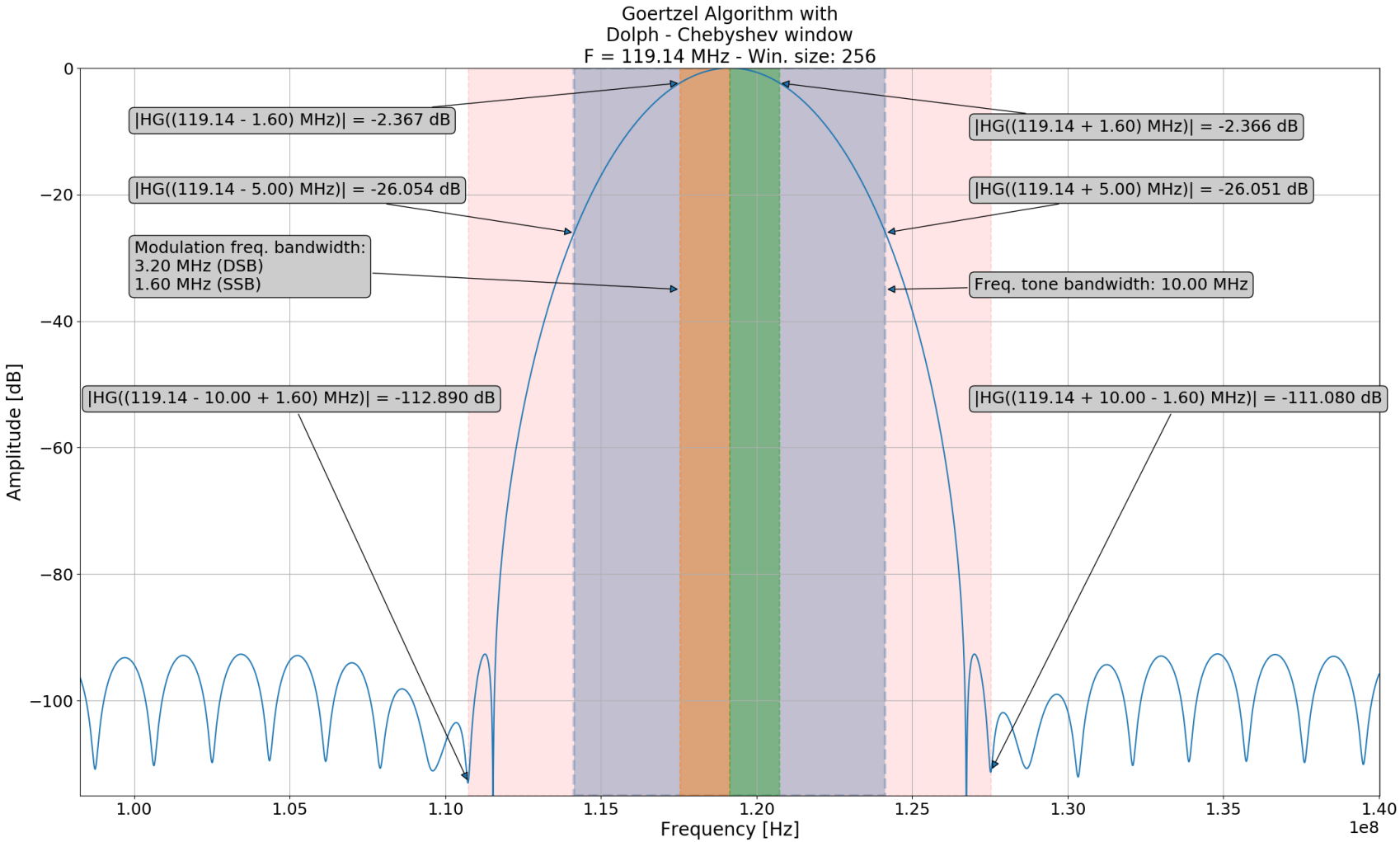


G.A.K.A.: Goertzel Algorithm Kernel Array

Second order IIR transfer function:

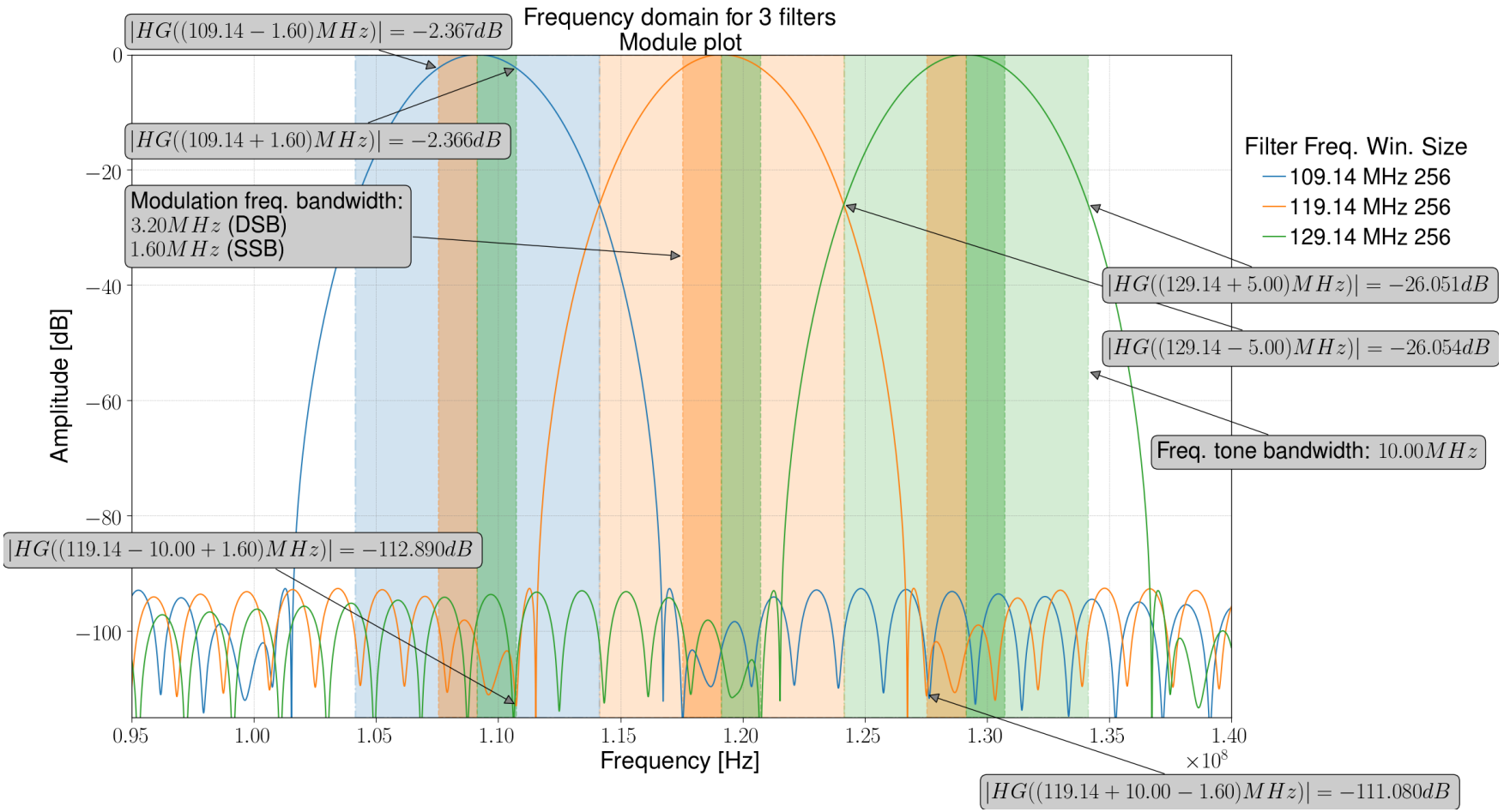
$$H_k(z) = \frac{1 - e^{-j\frac{2\pi k}{N}} z^{-1}}{1 - 2\cos(\frac{2\pi k}{N}) z^{-1} + z^{-2}} \quad (1)$$

G.A.K.A.: Goertzel Algorithm Kernel Array



Goertzel Filter with a Dolph-Chebyshev window. Configuration is based on ECHo's requirements

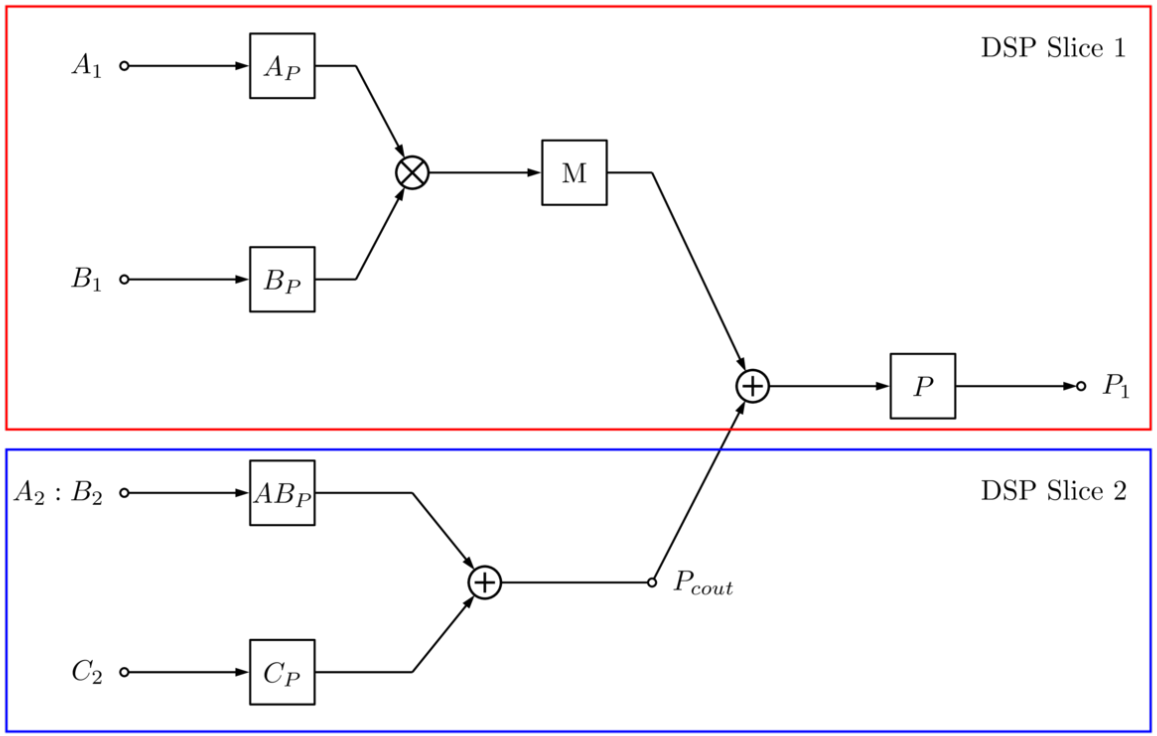
G.A.K.A.: Goertzel Algorithm Kernel Array



3 Goertzel Filters, with 10 MHz separation. ECHo's requirements.

Goertzel Algorithm implementation

HDL implementation with 2 DSP Slices



Goertzel Filter: DSP Slices implementation