

# SDR-based readout electronics for the ECHo experiment

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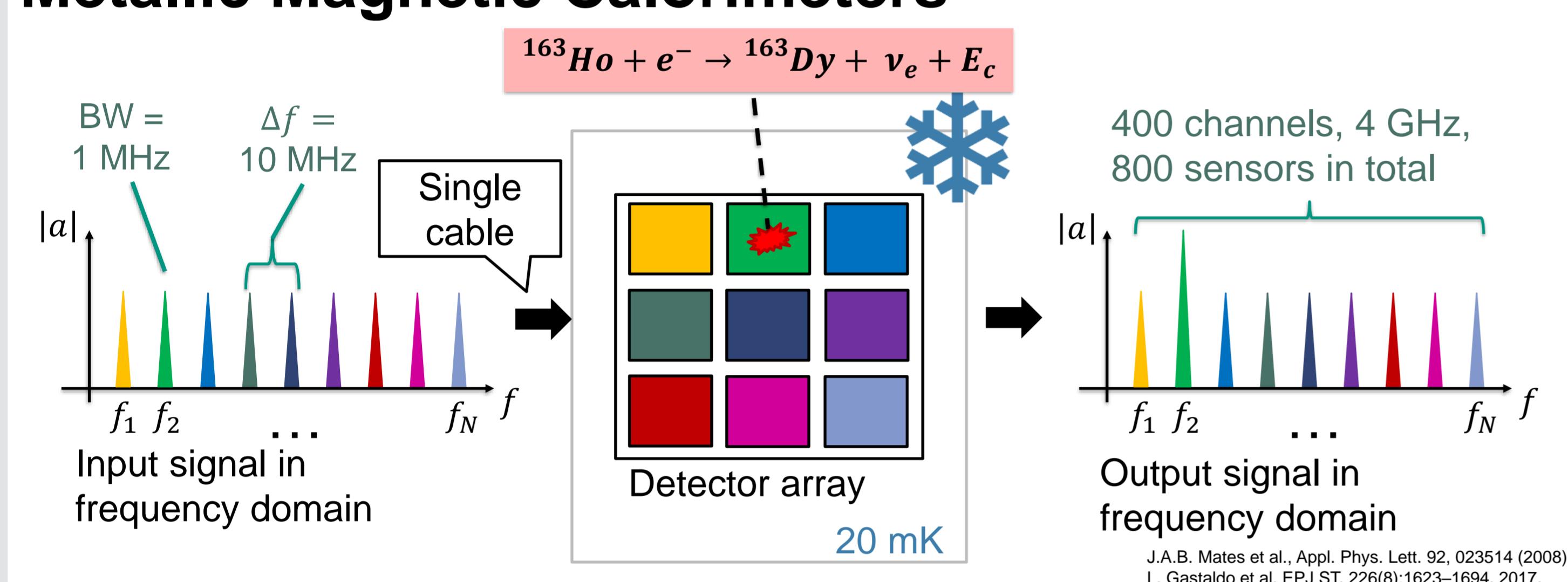
## ECHo-100k experiment

The Electron Capture  $^{163}\text{Ho}$  experiment **ECHo** will investigate the electron neutrino mass with sub-eV/c<sup>2</sup> sensitivity by analyzing the energy spectrum in the electron capture process of  $^{163}\text{Ho}$ .

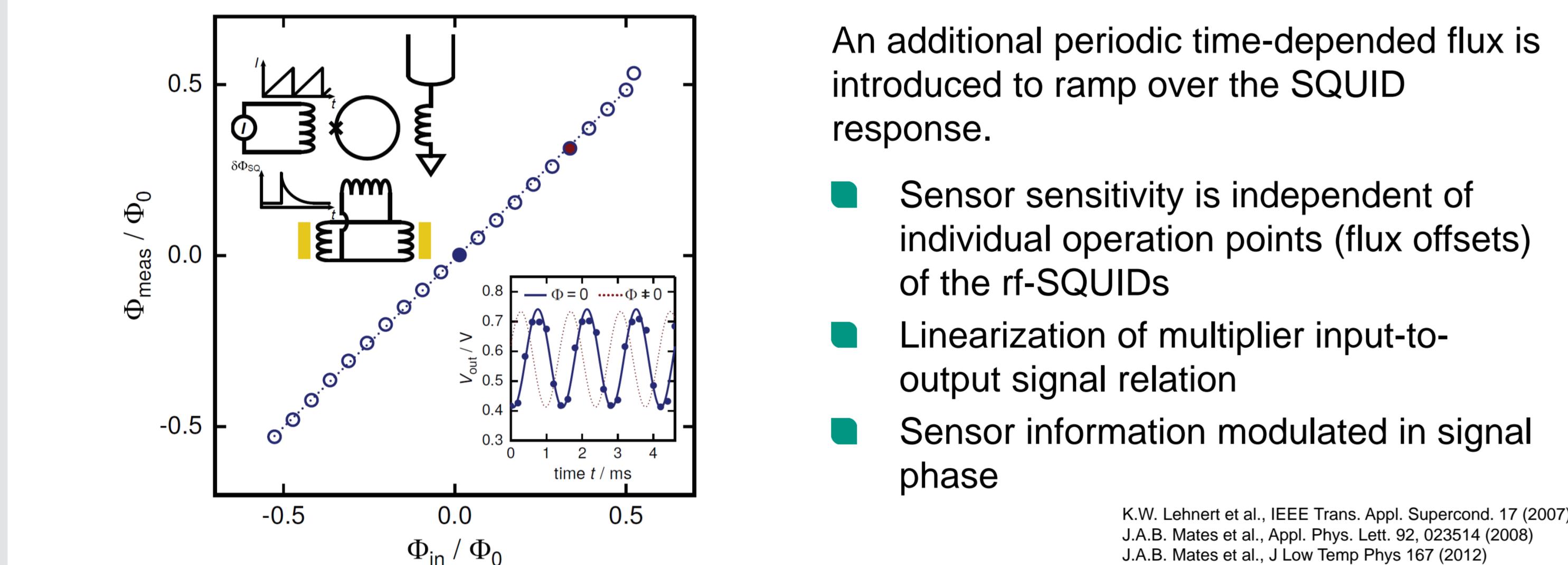
ECHo-100k is the second generation targeting a decay rate of  $10^5$  events per second. To achieve this rate at least  $10^4$  sensors are needed. If two sensors are associated with one readout channel this leads to a total of **5000 channels**.

L. Gastaldo et al. EPJ ST, 226(8):1623–1694, 2017.

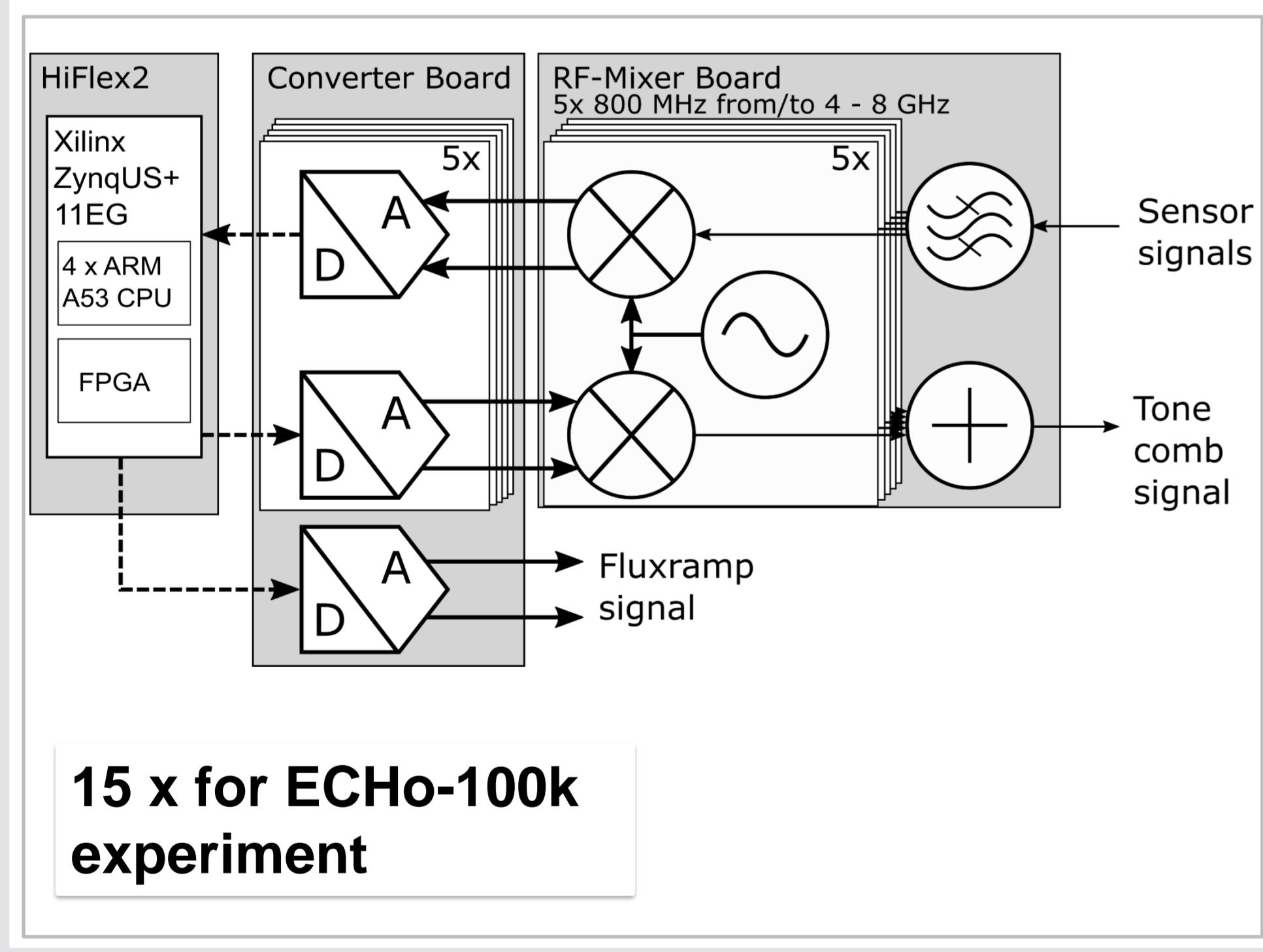
## Frequency division multiplex readout of Metallic Magnetic Calorimeters



## Flux ramp modulation for MMCs



## Software-defined radio hardware



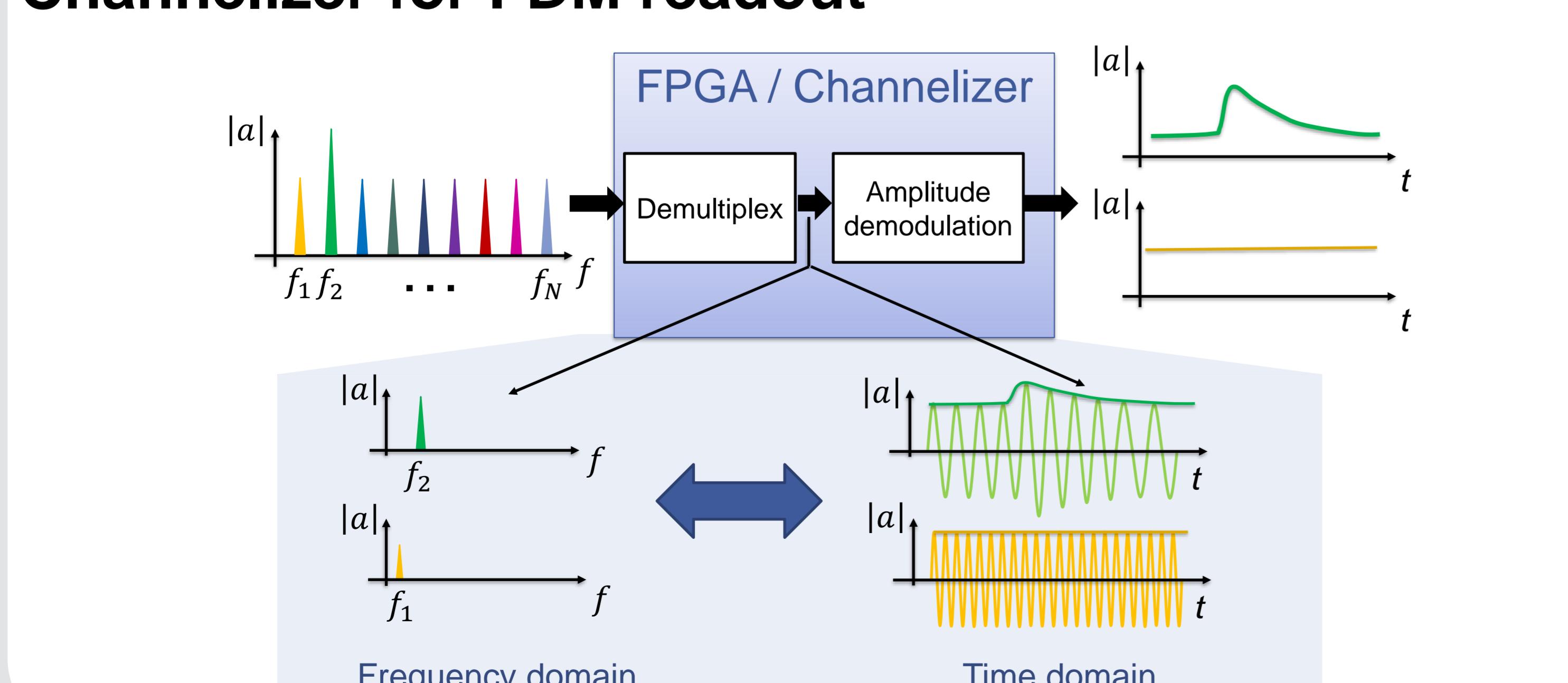
### RF frontend and ADC/DAC

- 5x 1 GS/s 14 Bit I/Q ADC (AD9680, 800 MHz BW)
- 3x 1 GS/s 16 Bit 2x I/Q DAC (AD9144, 2\*800 MHz BW)
- 2x < 500 MS/s DAC for Flux ramp generation
- Integrated PCB based approach for rf-conversion

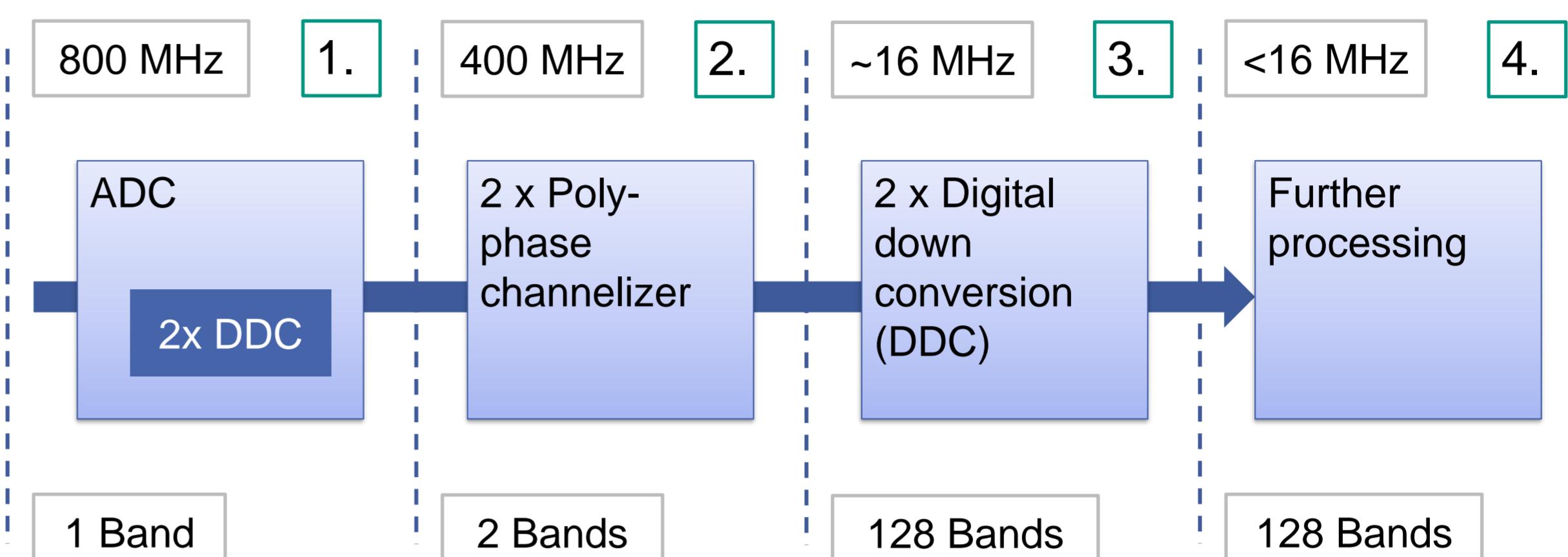
### Digital electronics

- Custom FPGA board HiFlex2 with Xilinx Zynq US+ 11EG

## Channelizer for FDM readout



## Channelizer cascade



### 1. ADC – AD9680

- 2 DDC with 400 MHz BW each

### 2. Interleaved poly-phase channelizer (PPC)

- Overlapping to avoid blind intervals
- 32 bands, 521 coefficients
- 6.1 / 10 MHz pass- / stop-band
- >80 dB stop-band attenuation

### 3. Digital down conversion (DDC)

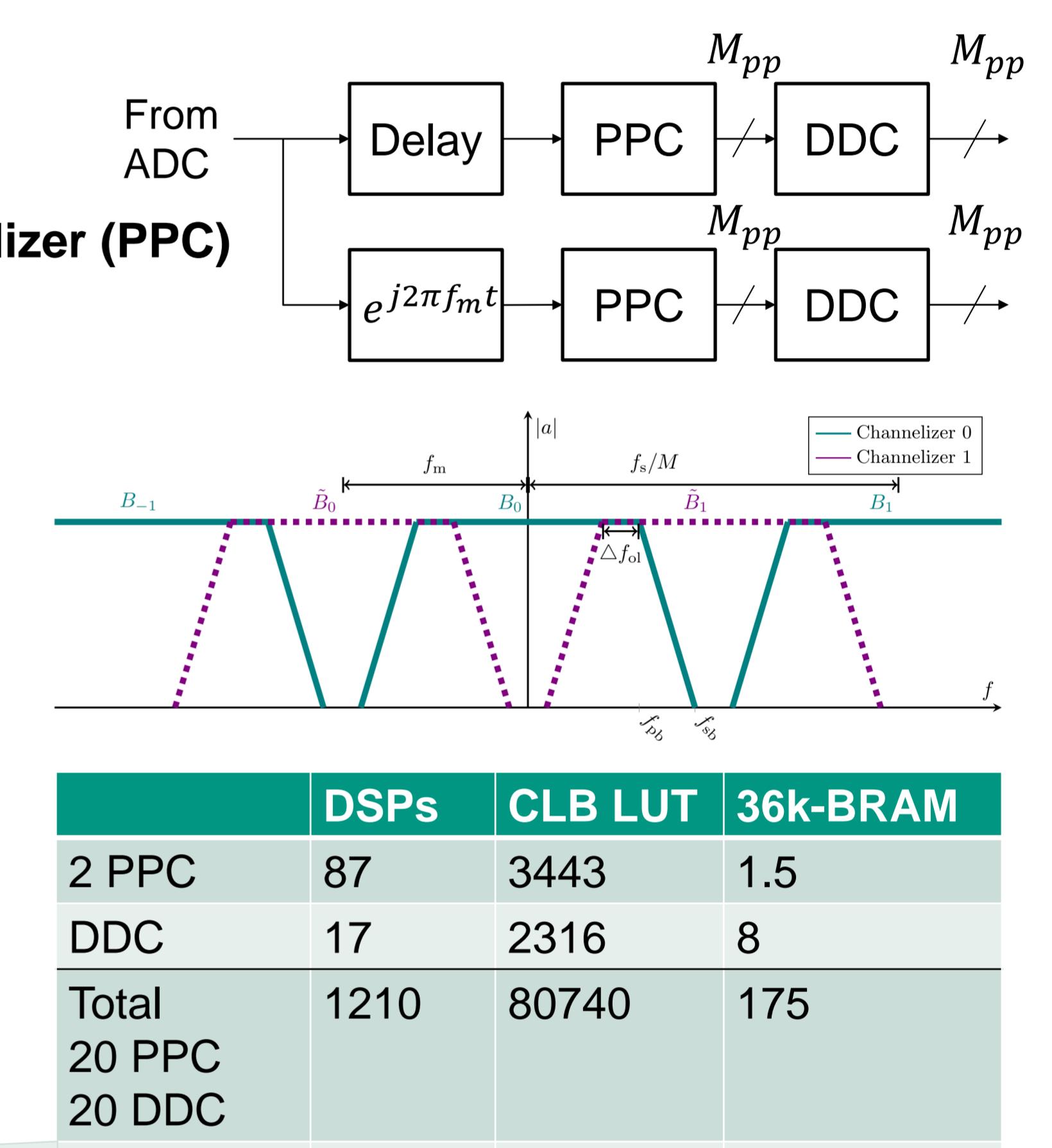
- 32 Channels TDM, 12 coefficients
- 1 / 4 MHz pass- / stop-band FIR
- Digital mixer for tuning

### 4. Further processing

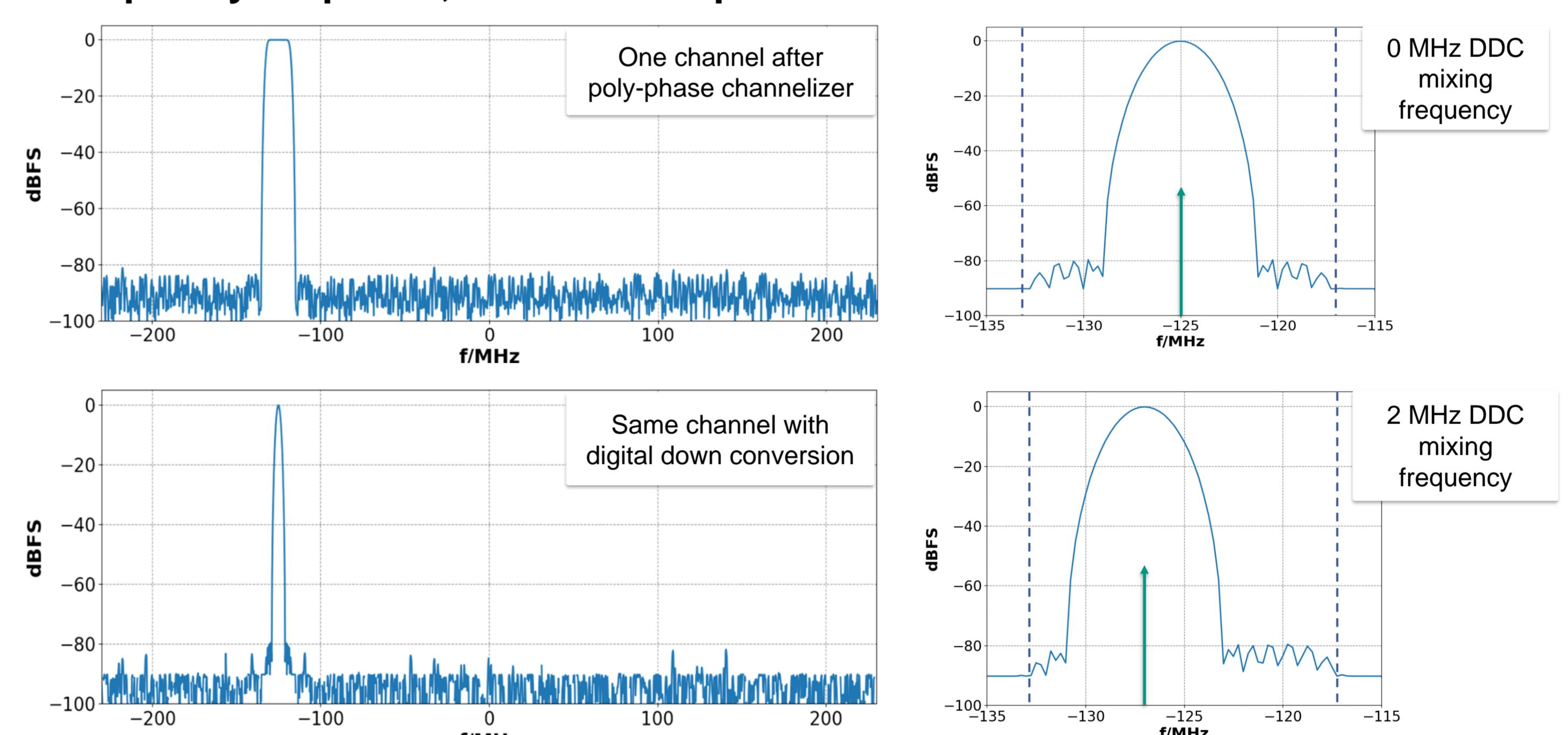
- Flux ramp demodulation
- ...

### Scale-up for ECHo

5 ADCs → 2 x 10 chains



## Frequency response, hardware loopback

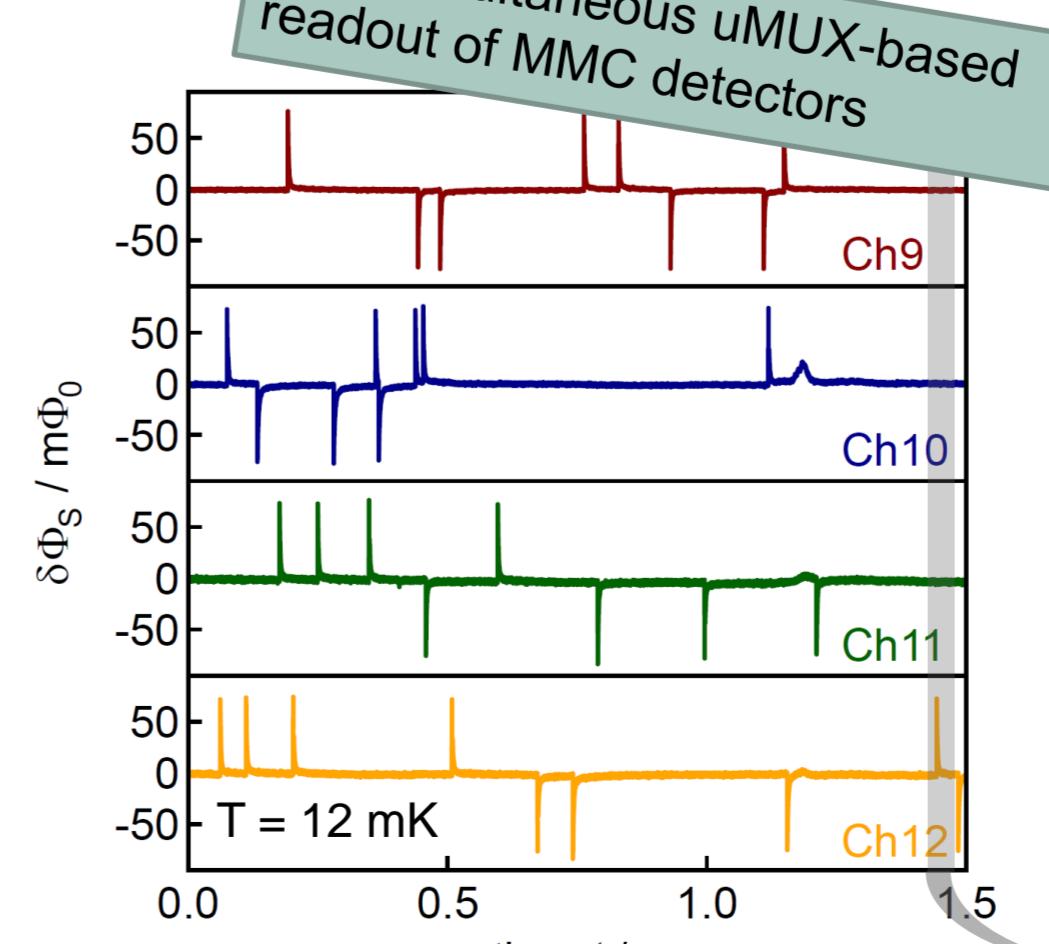


## Prototype measurement with channelization

### Prototype hardware

- ADC: ADS54J69, 500 MS/s, 16 Bit
- DAC: DAC38J84, 2.5 GS/s, 16 Bit
- Xilinx ZCU102 SoC Board
- Custom HF-Frontend
- Poly-phase channelizer and time sequential digital down conversion

First simultaneous readout of MMC detectors



### Measurement type

- Four channels  $f_{LO} = 4.51$  GHz (-30.2, -5.2, 18.9, 45.6 MHz)
- Gradiometric MMC sensor pixels
- Flux ramp modulation 62.5 kHz with HMF2550
- Amplitude modulated data was acquired
- Offline flux ramp demodulation