Readout electronics for NIKA

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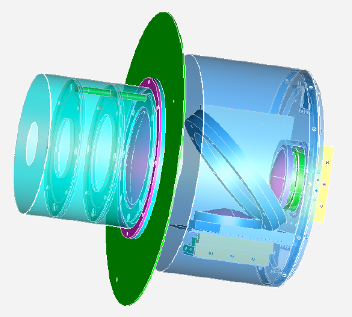
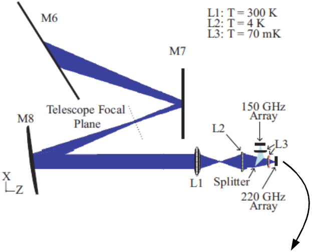
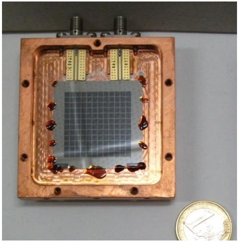
NIKA camera



Camera
Field of view 2 arc-min
112 + 72 pixel readout

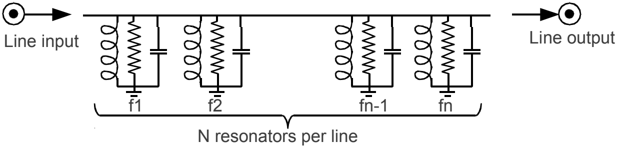




144 pixels array

MKID: reminders

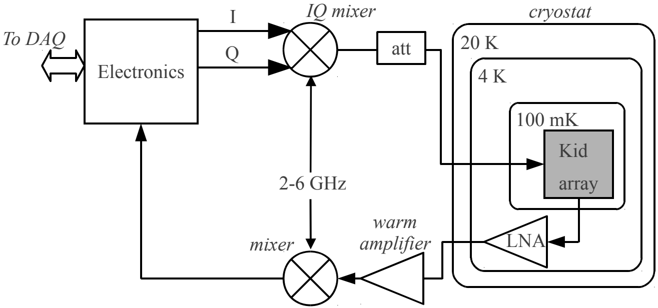
- Bolometer array = line with n high Q resonators
  - Bolometer array built by microlithography
  - **Average** resonator self resonant frequency spacing of 2 MHz.
  - Resonance frequency at several GHz



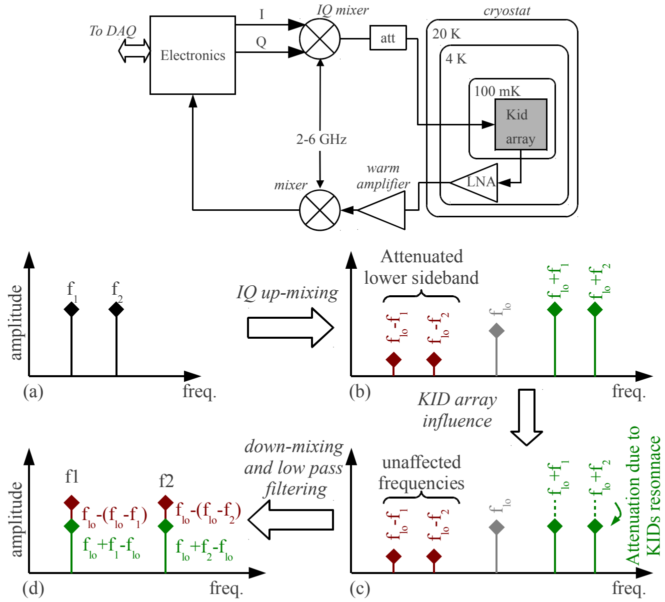
- Detection principle → shift of the resonator self resonant frequency when illuminated.
- Constraints:
  - Array at very low temperature (cryostat at 100 mK)
  - Cable feedthrough must be kept to a minimum
  - Work in RF domain
  - Full array readout at several Hertz

Array instrumentation method (1/2)

1. Generation of a frequency comb (frequency multiplexing):
   - Containing the largest possible number of frequency (→ Output analog frequency (Shannon))
   - Each frequency adjustable at a kHz resolution.
2. Up-mixing of the baseband generated frequency comb
3. The signal passes through the array and is eventually modified
4. At the array's output, down-mixing to baseband
5. Signal processing: determine each tone amplitude and phase

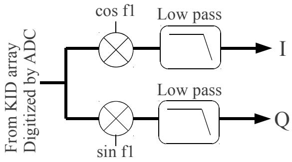


Array instrumentation method (2/2)



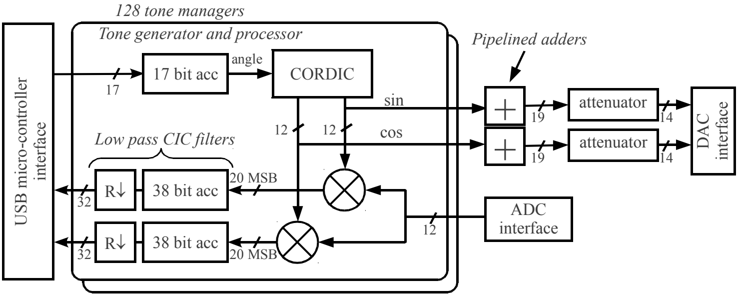
1. Sine and cosine waves generated by CORDIC (COordinate Rotation DIgital Computer)
   - Using only adder/subtracters and a small precomputed arc tangent table
   - Easily algorithm "pipelining"
   - Can reach sine and cosine resolution of $1/2^{n-1}$, where n is the number of +/- stages and atan constants
2. Line output signal analyzed by Digital Down Conversion (DDC)
   - As much processors as spectral rays to analyze

- Principle: signal is shifted to baseband and projected on I, Q axis by multiplying the returning signal by the original sine and cosine wave
- Low pass filter actually implemented by 1 ms signal averaging (not moving average →CIC!!)
- For $\mathrm{A} \times \sin(\omega t + \phi) \Rightarrow |\mathrm{A}| = \sqrt{\mathrm{I}^2 + \mathrm{Q}^2}$ and $\phi = \arctan \frac{\mathrm{Q}}{\mathrm{I}}$



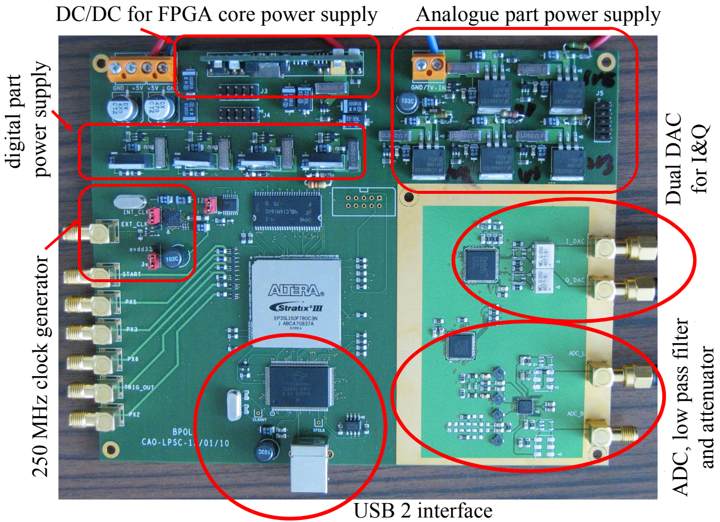
FPGA content

- 128 CORDIC generators
- 128 DDC



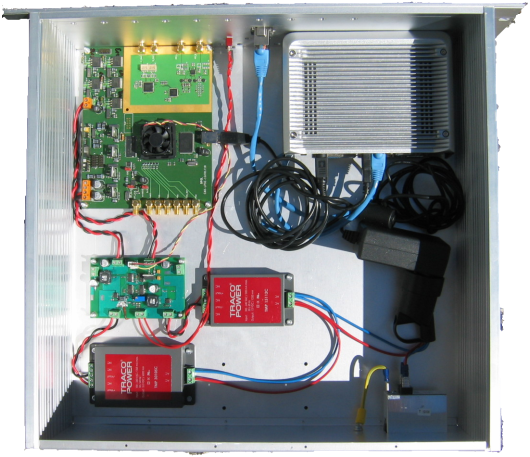
First prototype

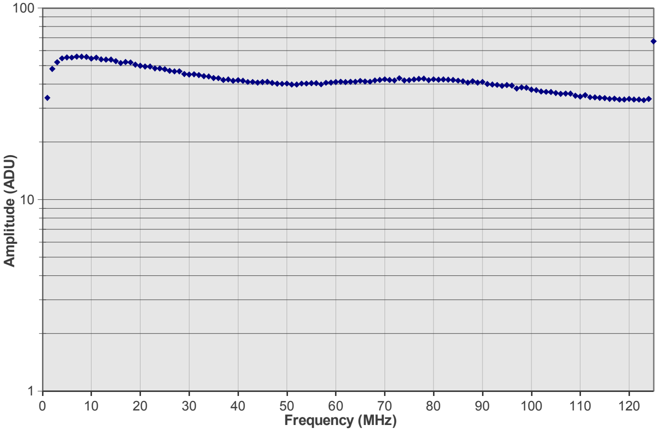
- Fadc=FDAC=250 MHz, fanalog max 125 MHz



Equipped rack

- Electronic board
- Data server PC (Ubuntu) for Ethernet interfacing
- AC/DC power supplies + fan control

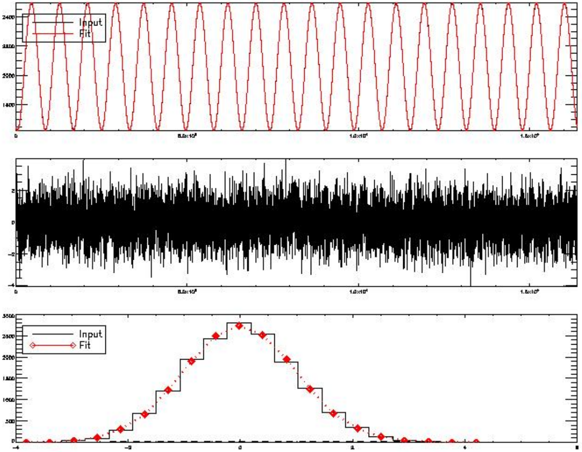




- Flat response over the whole bandwidth (-20 dB over 125 MHz).
- Attenuation mostly due the input Variable Gain Amplifier.

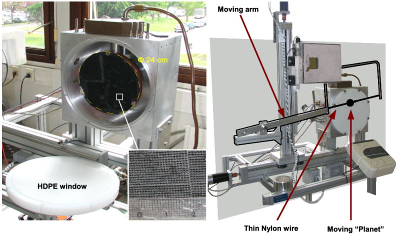
Signal to Noise in loopback mode

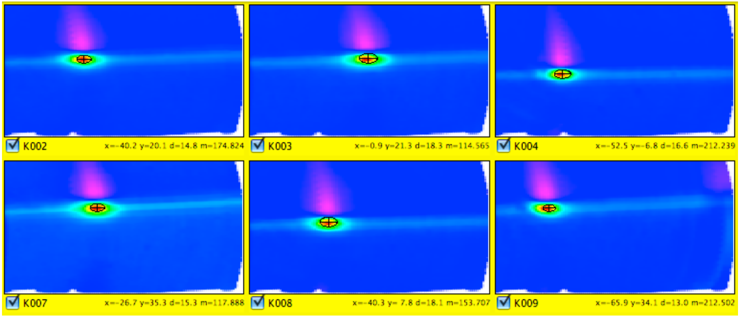
- Sine wave at $\sim$ 300 kHz
- Fiiting of a perfect sine wave $\rightarrow$ RMS=1.1
- Electronic chain allows to recover up to $\sim$11 effective bit (out of 12)



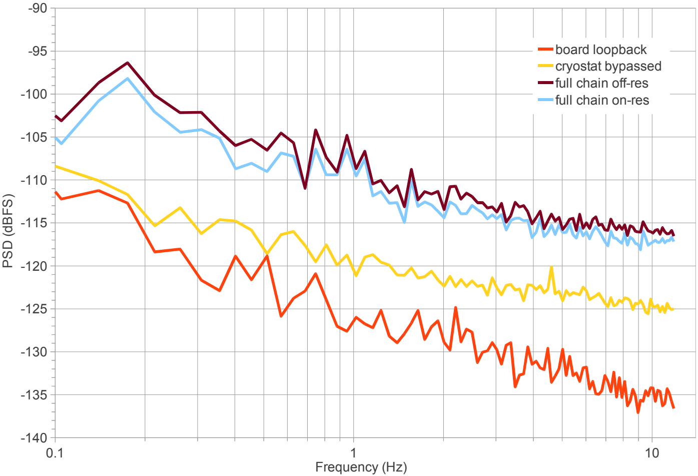
First images with the sky simulator

- A source at ambient temperature is placed between a cold plate and the MKID array and moved in 2D





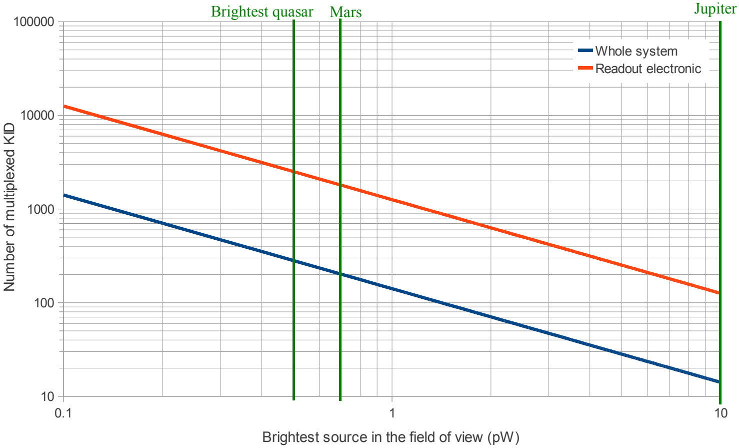
- The “planet” is seen when passing in front of a MKID pixel.



1. Noise is not due to the MKIDs themselves (see off/on resonance)
2. Noise floor electronic alone at -135 dB
3. Noise added by mixing electronics is +10 dB
4. Cold amplifier adds 10 dB of noise

Multiplexing limit

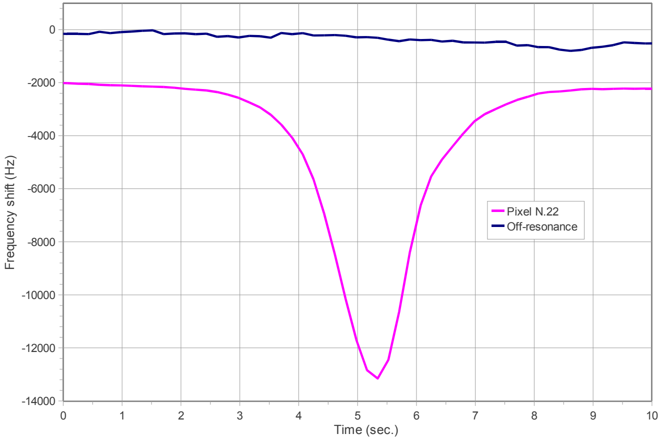
- When targeting a constant resolution of $50\ \mathrm{aW}/\sqrt{\mathrm{Hz}}$ at an acquisition rate of 20 Hz with a fixed dynamic range of 115/135 dB, the multiplexing limit is fixed by the brightest spot in the FOV



- Mars in FOV → 110 MKIDs, Jupiter in FOV → 10 MKIDs!!

Crosstalk between MKIDs

- Using sky simulator with cold plate at 50 K
- Highly emissivity ball simulating the planet at 300 K



Status

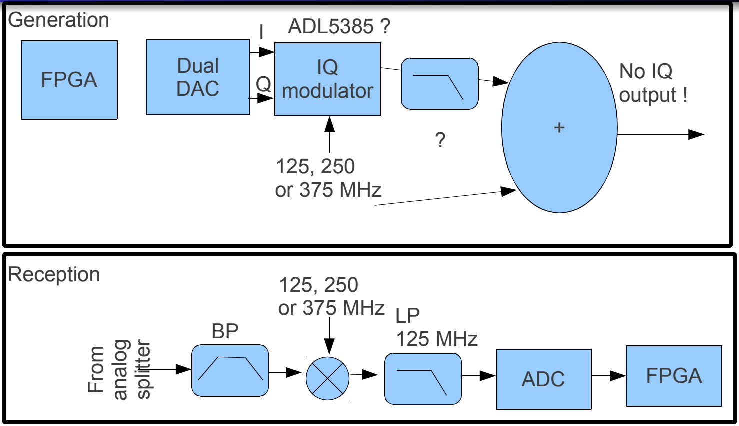
Summary 1st prototype

- Technology and know-how validated for 128 spectral rays fitting in a bandwidth of 125 MHz
  - Validation done with 64 bands separated in average by 2 MHz
- see **2011 JINST 6 P06012**, also available at arXiv:1102.1314

Future

- Equip arrays featuring 2000+4000 pixels
- Design and construct electronic boards able to manage 256 spectral rays over a bandwidth of 500 MHz
  - Limited by trade off between number of spectral rays and multiplexing limit
  - Technical difficulty (computing power/FPGA size, bandwidth, ...)

Obvious (?) "analog" solution



- Idea: split the 500 MHz bandwidth in 4 bands: 0→125, 125→250, 250→375, 375→500 MHz
- 1^{st}drawback: impossible to build directly the comb in IQ
- 2^{nd} drawback: practically impossibility to have highly selective filters massive crosstalk due to image frequencies!!

All “digital” solution

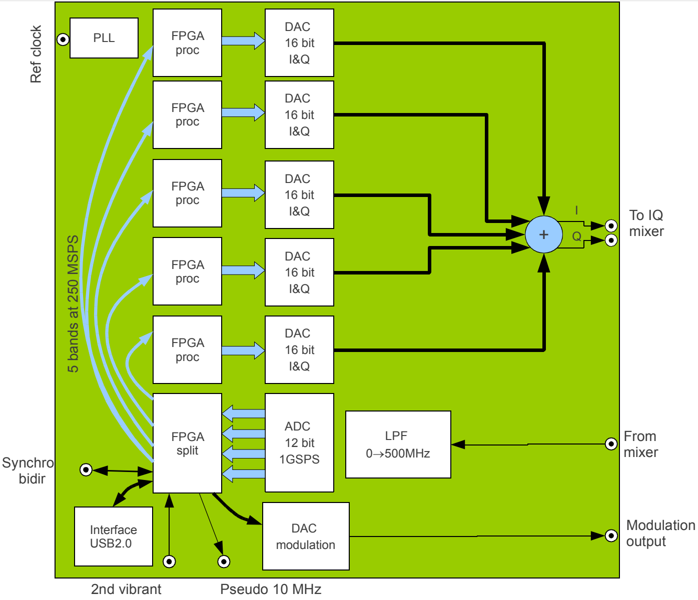
Frequency comb generation

- Nowadays DAC providing analog samples at 1 GSPS while receiving digital inputs at 250 MSPS exist off the shelves
- **Principle**: features digital modulators, interpolators and very steep (high order) filters
- ⇒ Use 5 DACs to build 5 100 MHz wide bands to generate the excitation comb

Returning signal digitization and processing

- ADC running at 1 GSPS exist but impossible to manage so many spectral rays in a single FPGA
- Using polyphase filtering and digital demodulation, it is possible to separate the 5 bands and bring them back in baseband for a “regular” processing.
- Becomes almost identical to 5 times the processing developed and implemented in version 1

Board block diagram



Conclusion

- One board will instrument between 256 (2 MHz spacing) and 500 pixels (1 MHz spacing)
- $\Rightarrow$ For 4000 pixels, less than 16 boards required
- Algorithms of the frequency band separator developed and coded in VHDL
- New board available and in debug