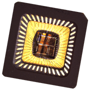


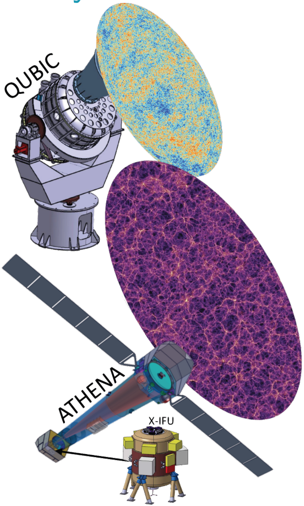
SiGe **ASIC** Developments for SQUID/TES Readout

D. Prêle, F. Voisin, C. Beillimaz, S. Chen, M. Piat, A. Goldwurm

July 17-21, 2017
Kurume, Fukuoka, Japan

Introduction - on the use of large TES arrays

- Cosmic Microwave Background (CMB) observations - **QUBIC** ground based experiment - mm range
  - 2 k pixels TES focal plans (150 & 220 GHz)
  - **TDM** cryogenic readout with SQUIDs and LNA
- Hot and Energetic Universe science theme - **X-IFU** instrument on-board of ATHENA space mission - X-ray range
  - 4 k pixels micro-calorimeter/TES focal plan
  - **FDM** cryogenic readout with LC and SQUID



$\Rightarrow$ *TES + Time or Frequency Domain Multiplexers*

Outline

SQUID/TES Readout

LNA design using BiCMOS SiGe technology

*SQmux*128, cryogenic ASIC for the TDM of QUBIC

AwaXe, Warm Front End Electronics for the FDM of ATHENA X-IFU

Outlook

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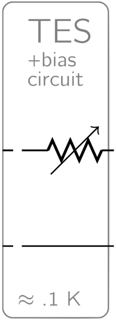
SQUID/TES Readout

- Voltage biased TES (for ETF) ⇒ **current readout**
- SQUID (**S**uperconducting **QU**antum **I**nterference **D**evices) + supercon. L_{in}
  ⇒ **cryogenic trans-impedance amplifiers** & multiplexer
- SQUID **amplification** and **biasing** I_{SQ} and **offset** adjustment



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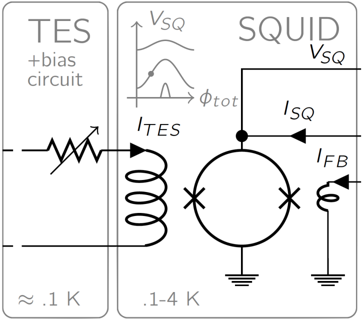

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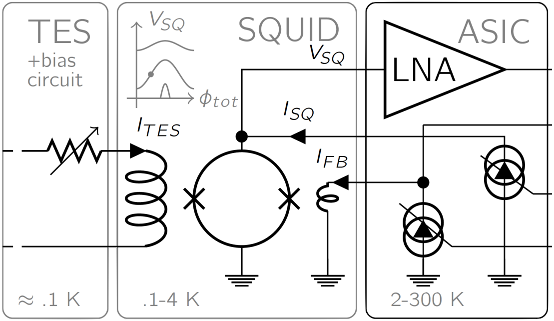

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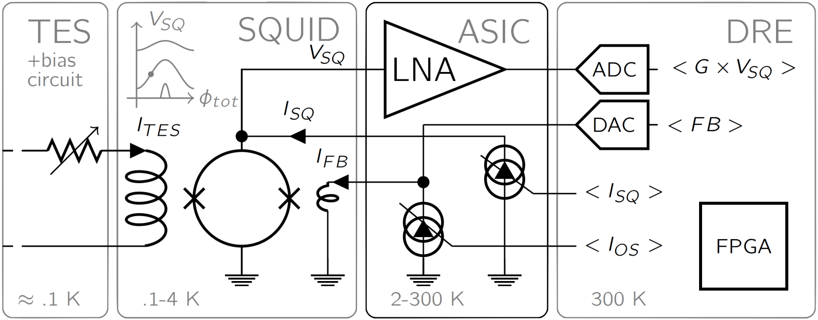

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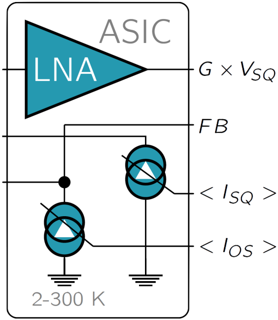

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SQUID/TES Readout

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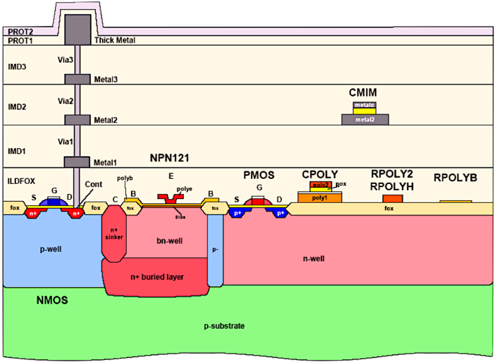
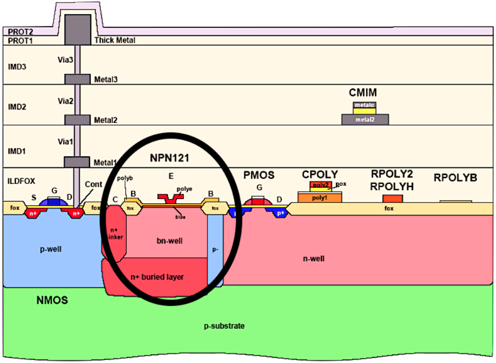
Outlook

ASIC technology

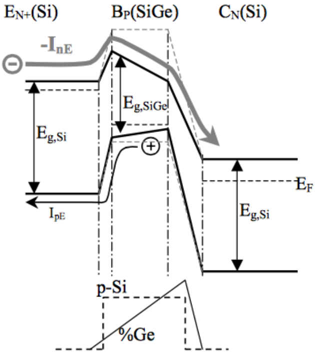


AMS 0.35 BiCMOS SiGe

ASIC technology

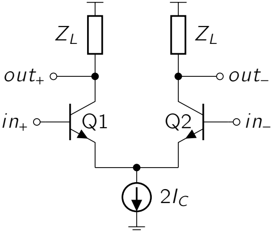


AMS 0.35 BiCMOS SiGe



Bipolar differential pair

Amplifier stage:

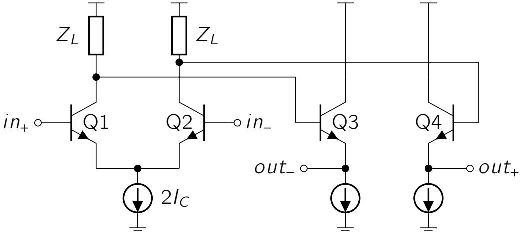


$$A_V \approx g_m \times Z_L \quad \text{and} \quad e_n \approx \sqrt{4qI_C}/g_m \quad \text{with} \quad g_m = \frac{\partial I_C}{\partial V_{BE}} = \frac{qI_C}{k_B T}$$

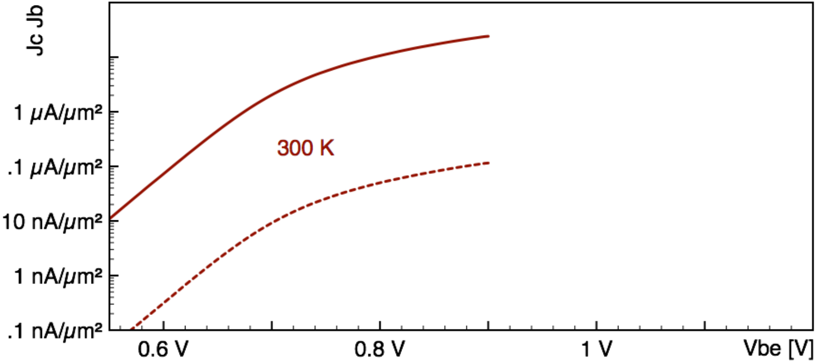
Z_L could be simple resistances ($Z_L = R_L$)
or diodes ($Z_L \propto 1/g_m$)

Bipolar differential pair

Amplifier stage with buffer stage:



Sizing the bipolar transistor using Gummel Plot



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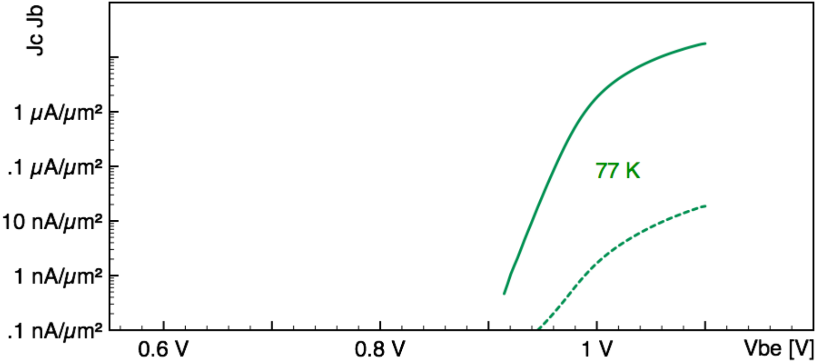

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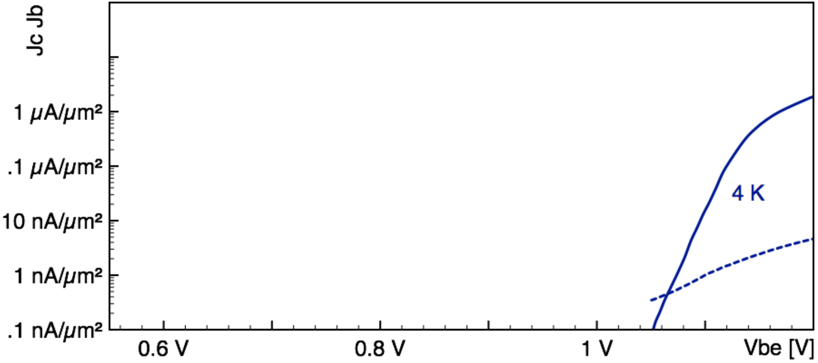

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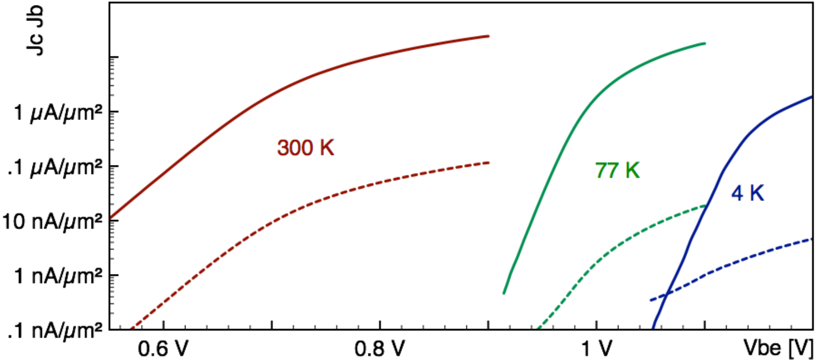

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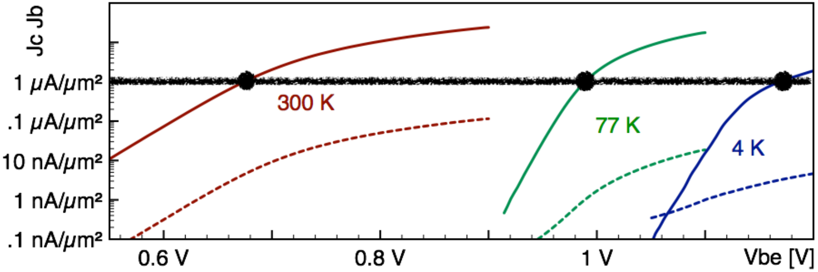

*	300 K	77 K	4.2 K
$\beta = \frac{\partial I_C}{\partial I_B} \approx \frac{I_C}{I_B}$	180	1400	900
$g_m = \frac{\partial I_C}{\partial V_{BE}} \approx \frac{qI_C}{k_B T}$	30 mS	100 mS	150 mS
$h_{11} = \frac{\partial V_{BE}}{\partial I_B} = \frac{\beta}{g_m}$	6 kΩ	14 kΩ	6 kΩ

* *Considering a HBT SiGe with $\underline{1000\mu m^2}$ area and $\underline{I_C = 1\ mA}$;*
J_C is thus equal to $1\mu A/\mu m^2$ ($1mA/1000\mu m^2$)

$I_c = 1\ mA \Rightarrow$ Power consumption $>$ 10 mW / amplifier

Outline

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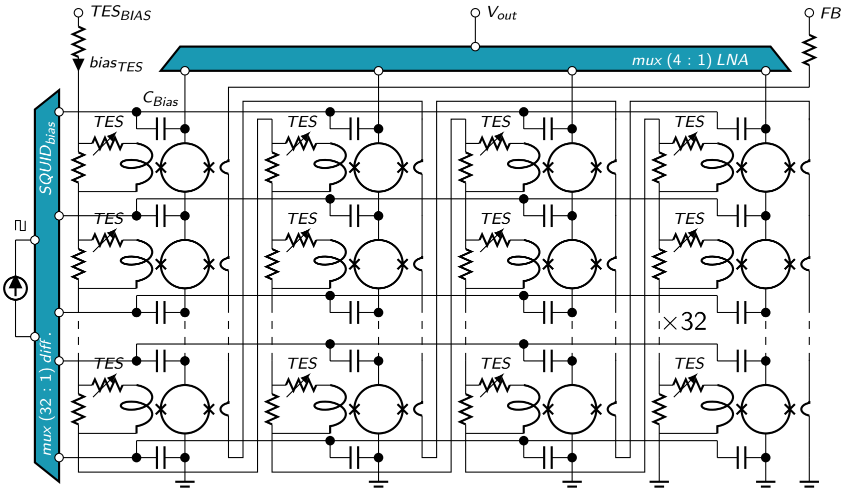
*SQmux*128, cryogenic ASIC for the TDM of QUBIC

AwaXe, Warm Front End Electronics for the FDM of ATHENA X-IFU

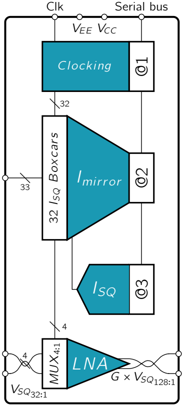
Outlook

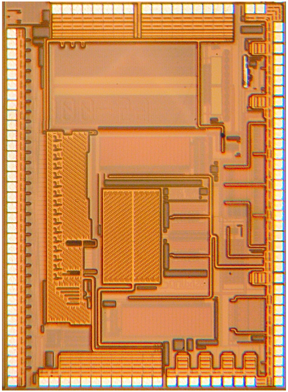
QUBIC readout chain (simplified)



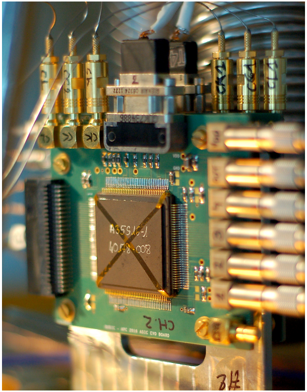
D. Prêle et al, "Capacitively-coupled SQUID Bias for Time Division Multiplexing", JLTP 2014
D. Prêle et al, "A 128Multiplexing Factor Time-Domain SQUID Multiplexer", JLTP 2016

SQmux128 ASIC (77 K)





Chip size 2 mm × 4 mm



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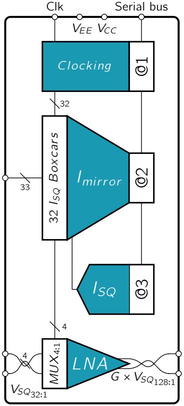
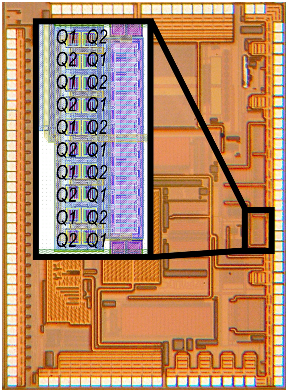
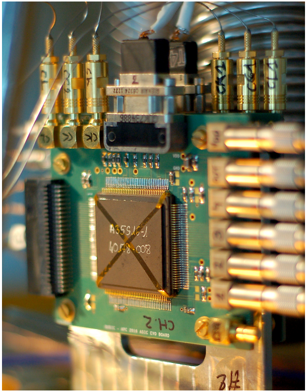
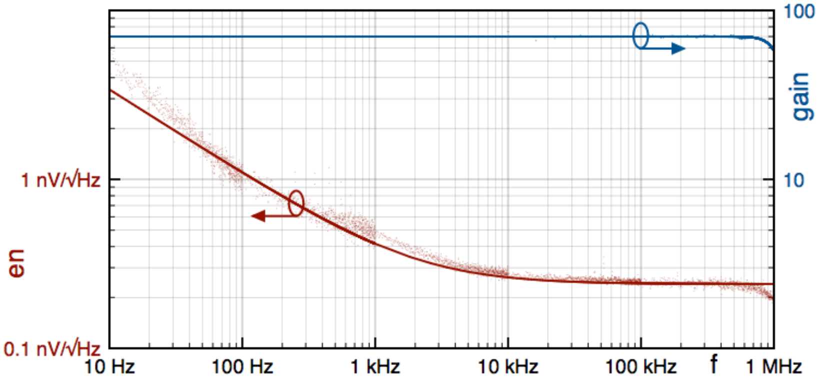






Q1 and Q2 input transistors are subdivided and mixed in a common centroid topology to well match the pair.

SQmux128 LNA performances at 77 K



* *the cutoff frequency is due to a 1 MHz "antialiasing filter" in the QUBIC readout chain*

** *corner frequency increase at low temperatures is potentially due to increase sensitivity to thermal fluctuations of transistor parameters g_m, β, h_{11} (?)*

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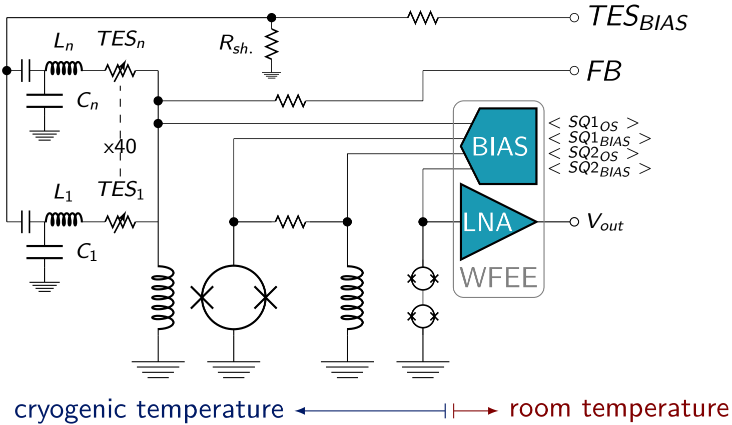
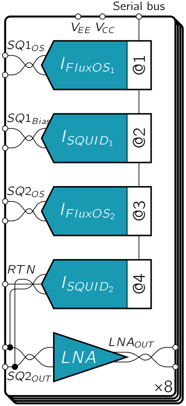
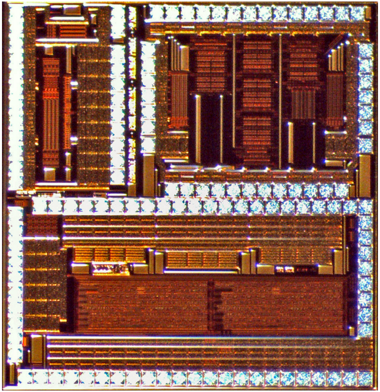
Outlook

ATHENA X-IFU readout chain (simplified)

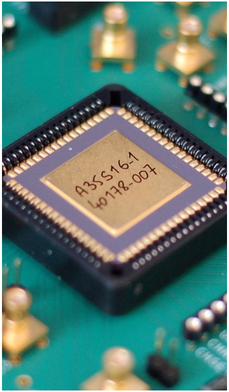


AwaXe ASIC (operated at 300 K)





Chip size 2.5 mm × 2.5 mm



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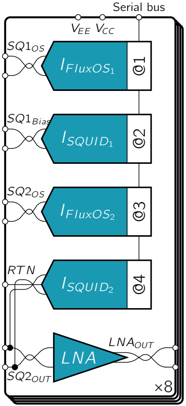
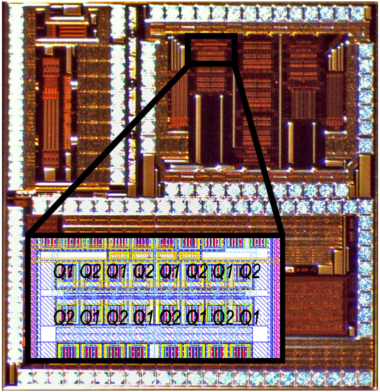
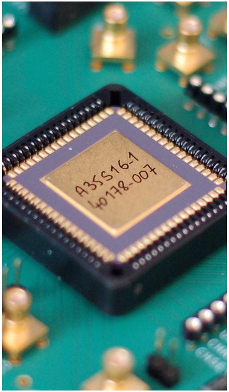
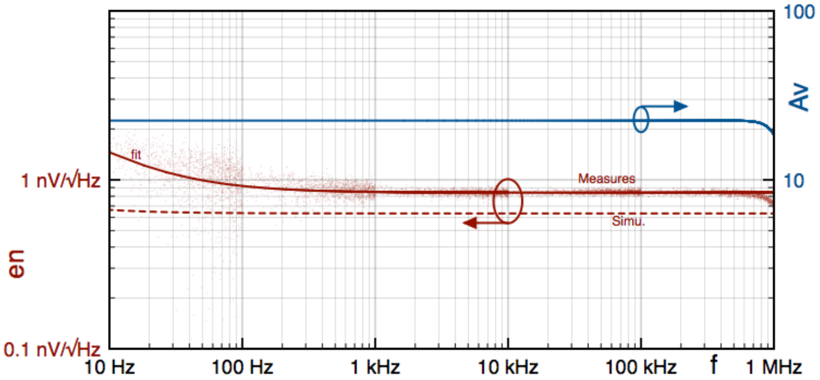






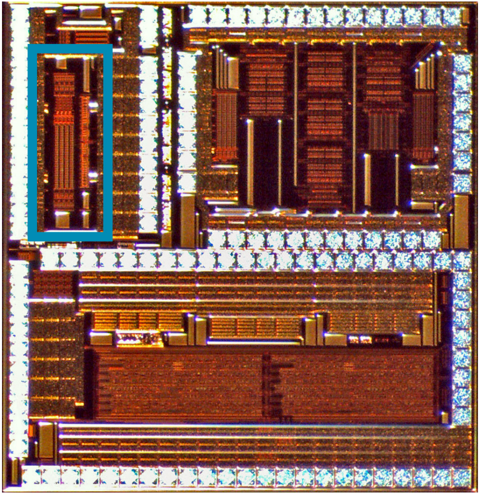
D. Prêle et al, "Gain drift compensation with no feedback-loop developed for the X-Ray Integral Field Unit/ATHENA readout chain", JATIS 2016

AwaXe LNA performances at 300 K

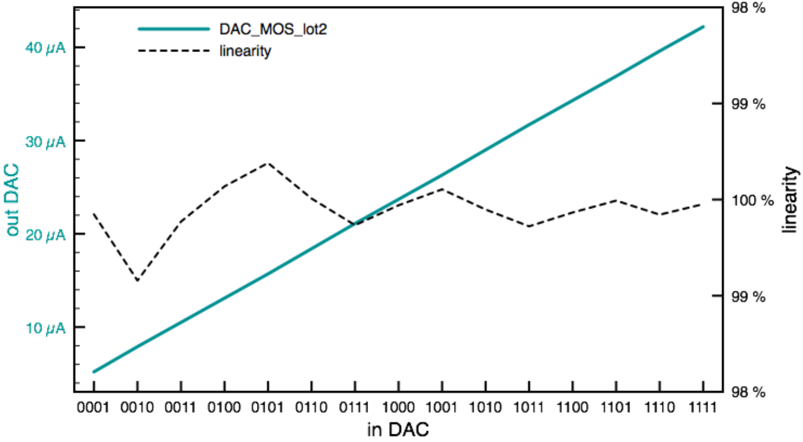


* *the 1MHz cutoff frequency is due to the test set-up, the expected LNA bandwidth is > 20 MHz*

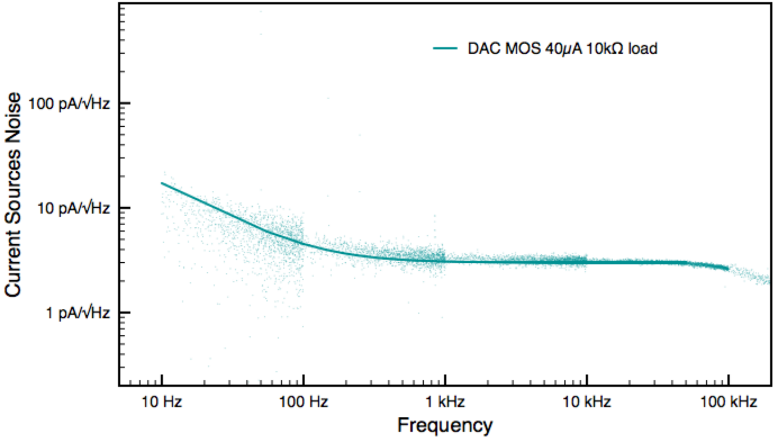
Current sources in the ASIC *AwaXe_v1*



Current sources linearity measurements



Current sources noise measurements



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Outlook

- We are developing **ASIC** using **SiGe BiCMOS** technology for the readout of SQUID/TES devices.

- ASIC ⇒ **Small, lightweight and efficient**
  - **LNA**
  - **Biasing SQUID** (current DAC)
  - **serial decoder**
  - **sequencing** SQUID turning on for TDM

So it is suitable for **whatever the multiplexing** *scheme and at whatever the needed* **temperature**

- *One is used in the* **QUBIC** *instrument (***TDM***)*
- *One is currently optimised for the* **X-IFU** *instruments (***FDM***)*

This last ASIC has been also "space qualified" up to 100 kRad TID and is Latchup free up to a LET > 120 MeV/mg/cm^2 (heavy ion $^{124}Xe^{35+}$ tilt at 60°)