EURECA: EURopean–JapanEse Calorimeter Array

A technology demonstrator and contribution to the combined US, Japanese, and European

Cryogenic Imaging Spectrometer onboard IXO

Piet de Korte, Dick Boersma, Marcel Bruijn, Bob Dirks, Luciano Gottardi, Roland den Hartog, Jan-Willem den Herder,
Henk Hoevers, Jan van der Kuur, Bert-Joost van Leeuwen, Ad Nieuwenhuizen, Manuela Popescu, Marcel Ridder, Henk van Weers

SRON Netherlands Institute for Space Research, Utrecht, The Netherlands

Collaborators	Institutes
Jose Anquita, Fernando Briones, and Raqual Gonzalez-Arrabal	**IMM-Instituto de Microelectronica de Madrid, Madrid Spain**
Xavier Barcons, Beatriz Cobo, Francisco Carrera, Maite Ceballos, Raquel Fraga	**Instituto de Fisica de Cantabria, Santander, Spain**
Augustin Camòn, Maria Parra	**ICMA, Zaragoza, Spain**
Javier Sese	**INA-Instituto Universitario de Investigatión en Nanociencia de Aragón, Zaragoza, Spain**
Lourdes Fabrega	**Institut de Ciència de Materials de Barcelona (CSIC), Barcelona, Spain**
Reiner Rohlfs, Stephane Paltani	**ISDC, Versoix, Villigen, Switzerland**
Lorenza Ferrari, Flavio Gatti	**INFN and University Genua, Genua, Italy**
Paolo Bastia	**ThalesAlenia Space, Vimodrone, Italy**
Luca Colasanti, Claudio Macculi, Luigi Piro	**Istituto Astrofisica Spaziale Fisica Cosmica (INAF), Rome**
Guido Torrioli	**IFN/CNR Rome, Italy**
Panu Helistö, Mikko Kiviranta	**VTT Sensors, Finland**
Jörn Beyer, Dietmar Drung	**Physikalisch-Technische Bundesanstalt (PTB), Berlin**
Yoshitaka Ishisaki, Takaya Ohashi	**Tokyo Metropolitan University, Tokyo, Japan**
Kazuhisa Mitsuda, Yoh Takei, Noriko Yamasaki	**Institute of Space and Astronautical Science (ISAS,YAXA), Sagamihara, Japan**
Bert Monna	**Systematic Design B.V., Delft, The Netherlands**

GOAL

- Demonstrate technology readiness of a TES-based cryogenic instrument for future X-ray astronomy missions like the IXO, DIOS, XENIA, and IR-missions like SPICA.
- Build an international consortium to develop and deliver such an instrument.

EURECA – BASELINE

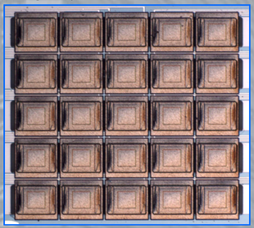
- 5 x 5 pixel array
- 2 SQUID-amplifier read-out channels using Frequency Domain Multiplexing (FDM) and base-band feedback
- Cryogen-free cooler based on 4K pulse tube and 50 mK dADR

EURECA – REQUIREMENTS

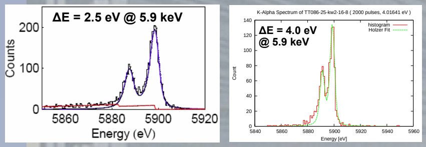
- ΔE = 2 eV FWHM @ 1 keV and 5 eV @ 6 keV with high efficiency for $0.1 < E < 10$ keV
- Pixel size of 250 x 250 μm^2
- Signal decay time < 100 μs, countrate > 500 c/s
- Electronics dynamic range +/- 2.5 10^6 √Hz
- Inter-pixel crosstalk < 5.10^{-3}
- Multiplexer suitable for 32 x 32 pixel array

Single Pixel Performance of 5 x 5 arrays

Successful fabrication of 5 x 5 pixel arrays with Ti/AU transition-edge-thermometers and Cu/Bi (3/0.15 μm) absorbers Qualification for thermal cycling, launch vibrations, and radiation damage is planned for the 1st half of 2009.



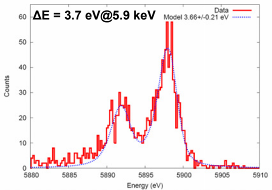
The science performance equals < 2 eV for E < 2 keV and 2.5 eV @ 6 keV with Cu-stem of representative heat capacity and 4 eV @ 6 keV with full mushroom (Cu/BI) absorber.



Cu-stem absorber **Cu/Bi mushroom absorber**

Single pixel AC-bias performance

Verification of the pixel read-out under FDM by comparison of pixel performance under AC- and DC-bias. Within the present error bars of the measurements the I – V's, complex impedance, and noise characteristics are equal. Notwithstanding that the X-ray performance is still lagging behind, i.e 3.7 eV instead of 2.5 eV. At this moment the set-up still suffers from drifts and rather low FLL-gain



Energy resolution of a pixel with Cu-stem absorber under AC-bias (370 kHz)

FDM Frequency Range, Frequency seperation, and number of pixels/channel

The frequency range that can be used for FDM is set by:

- LC capacitor size at low-frequency end, i.e. 3.5 x 3.5 mm^2 at 1 MHz
- Voltage bias requires Q >> 170 f (MHz). Q > 4000 demonstrated
- SQUID back-action noise. For $\omega = R_{TES}.L_{SQ}/N.M^2$ back action noise equals input noise. About 10 MHz for PTB-SQUID array.

So multiplexing range is: $1 < f < 10$ MHz

The frequency separation required for FDM is set by:

- The information bandwidth (about 10 kHz for EURECA)
- Enough baseband gain-bandwidth (GBW ≈ Δf /6)
- The requirements on crosstalk between pixels (< 5.10^{-3})

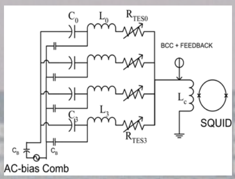
So frequency seperation is: $200 < \Delta f < 300$ kHz

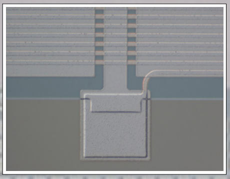
Using frequency-comb with 200 kHz channel separation 45 pixels can be read-out by one SQUID-channel.

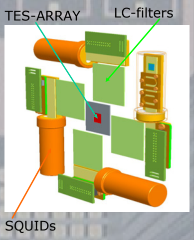
Frequency Domain Multiplexing

Signal Summing and TES-bias Topology

The baseline summing topology used for EURECA is current summing on the input coil of the read-out SQUID.







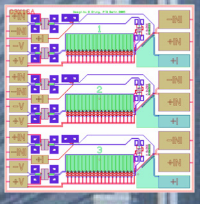
Current summing	**LC-filter (close-up coil)**	**EURECA Cold Head**
- AC-bias comb with capacitive divider	Q >> 170 f (MHz)	Design
- Feedback to input or feedback coil	Q > 4000 measured	

- FDM requires that each pixel has its own LC-filter to limit the contribution of wide-band Johnson noise from neighbour pixels and to enable voltage bias.
- Voltage bias requires Ohmic filterloss $R_{ESR} << R_{TES}$, and therefore LC-filters $Q >> \omega\tau_{RISE}$. For τ_{RISE} = 25 μs we require Q >> 170 f (MHz)
- The SQUID input inductance for current summing is the common impedance at the summing point and has to be small to circumvent crosstalk between pixels. The current crosstalk level equals $(L_C/2L)x(f/\Delta f)$. For our case L_C < 2.8 nH (@10 MHz) for a power crosstalk in the sensor < 5.10^{-3}. Typical SQUIDs will have an input inductance of at least 3 nH.
- AC-biasing by a comb results in predictable and correctible crosstalk levels between pixels at neighboring frequencies, which can be reduced by use of more than one bias wire pair.

SQUIDS

For now our baseline is the PTB 16-SQUID array

Its characteristic:
Lin ≈ 3 nH
I_N = 4.5 pA/√Hz
T_N = 20 K



The dynamic range of this SQUID with sufficient linearity is about 10^5 √Hz, requiring significant feedback gain.

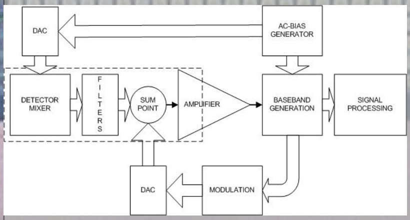
Both VTT and PTB are working on SQUIDs with a significant larger dynamic range (5.10^5 √Hz) using local feedback. Also 2nd stage SQUID drivers with T_N = 100 K, allowing for higher resistive harness and lower power LNA, are under development at VTT.

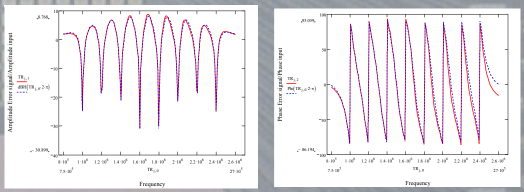
Dynamic Range and Linearity

- X-ray micro-calorimeters do require a large dynamic range for its electronics. For EURECA a dynamic range of +/- 2.5 10^6 √Hz is needed.
- Good SQUIDs have a typical flux noise of 0.2 $\mu\text{Ø}_0$/√Hz and a maximum range of +/- 0.2 Ø_0, giving a full dynamic range of about +/- 10^6 √Hz. (Our presently used PTB-SQUID has a 10x smaller dynamic range)
- So feedback is required to increase the SQUID dynamic range, as well as to linearize its response.

Baseband Feedback

- Since a feedback system has a limited gain-bandwidth product, high FLL-gains are not possible at carrier frequencies in the MHz range.
- So a base-band feedback system is required in which the gain-bandwidth of the FLL is optimized for the information bandwidth of about 10 kHz around each carrier. This can actually be done by de-modulation and re-modulation of the signal before feedback, so that the phase difference of the carriers can be compensated for.

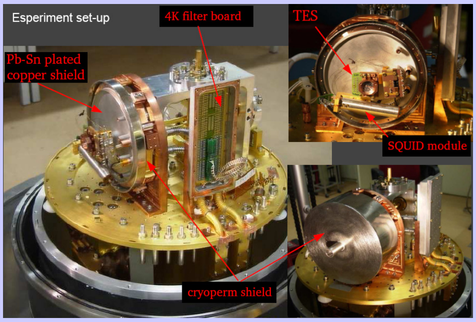




Measured (red) amplitude and phase of the error signal at the SQUID input for 8-channel baseband feedback with 35 kHZ gain-bandwidth and with model (blue)

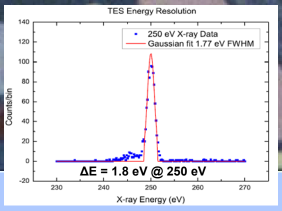
In this system the FLL-gain at each carrier frequency will be extremely high (60 dB measured) thereby effectively nulling the carriers at the input of the SQUID. The gain-bandwidth around each carrier is set by the didtances between carriers. For a typical 200 kHz separation the gain-bandwidth equals 32 kHz, giving a FLL-gain of 3x at the signal risetime (10kHz) and about 20x at the signal decaytime (100 μs)

HARDWARE FOR PTB/BESSY TEST



Measurements at the BESSY synchrotron indicate low susceptibility to EMI and ADR magnet. Suppression of microphony has been achieved by isolating the pulse tube valve head from the cryostat and by fixation of the high pressure tubing before reaching the pulse tube cooler.

Low Energy (250 eV)



Measurements show that this has been successful down to the 1.8 eV energy resolution level. Up to countrates of 800 c/s more than 30% of the events have < 2 eV energy resolution.

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