Front-end Design of the Read-Out System for Micromachined Sensors

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Work Plan

The CMB Challenge and QUBIC

We need

- BLIP Detectors (LTD).
- Fast Detectors.
- Both Polarization.
- Large Bandwidth.
- Multiple Bands.
- Systematic effects Control.

Figure: QUBIC Instrument (5)

BLIP Detectors and Multiplexing

(a) MKID Detectors (4)

(b) MMB or TES with uMUx (4; 6)

Objectives

Main Objective

Design a compact, scalable and universal RF Analog Front-End for the readout system of Low Temperature Detectors using frequency division multiplexing in the range of GHz.

Current Work

Organization

Organization

Small Scale MKID Array

(a) Cryogenic Set Up (9)

(b) Prototype RF Front-End

(c) Sample Holder (9)

Large Scale MMB Array

(a) Power and Control Board

(b) RF Variable Attenuator

(c) ECHo SDR Concept (10)

Future Work

RF Front-end Requirements

Parameter	***Minimum***	***Step***	***Maximum***	***Units***	***Description***
DAC Number	5	-	-	Units	
DAC Sampling frequency	1	-	-	GHz	
DAC ENOB	12	-	-	Bits	2 bits higher than ADC
ADC Number	5	-	-	Units	Plate Temperature
ADC Sampling frequency	1	-	-	GHz	
ADC ENOB	10.6	-	-	Bits	
Rx Power	-60	-	-20	dBm	
Tx Power	-30	-	-10	dBm	
Clock Jitter	-	-	180	fs	SNR Clock
LO Frequency	4000	$3\ 3 \cdot 10^{-3}$	8000	MHz	LNA Bandwidth
LO Phase Noise	-	-	-90	dBc/Hz	SNR LO
LO Stability	1	-	-	ppm	SNR LO
Tx IQ Phase Control	0	0.1	10	degree	IMRR
Tx IQ Amplitude Control	0	0.1	3	dB	IMRR
TX IQ DC Offset Control	0	2	200	*uV*	LO Leakage
Rx IQ Phase Control	0	0.1	10	degree	IMRR
Rx IQ Amplitude Control	0	0.1	3	dB	IMRR
Tx Gain		40	40	dB	
Tx NF	-	-	10	dB	
Tx IIP3	20	-	-	dBm	
Rx Gain		40	40	dB	
Rx NF	-	-	5	dB	
Rx IIP3	20	-	-	dBm	

Expected Results

(a) Noise PSD MKID (12)

(b) Noise FSD muMUX (11; 7)

Projects

(a) QUBIC (1)

(b) LLAMA

(c) ECHo (2)

Summary

Superconducting Thin Films - TPA
Single Photon Detectors
Radio-Frequency Integrated Circuits
March
KIT & ITeDA Large Scale Experiment (MMB)
LT lab & ITeDA Low Scale Experiments (KIDS)
Deutsch A1.1
Deutsch A1.2
HIRSAP 2019
HIRSAP 2020
KSETA Meeting
Kinetic Inductance Seminar

Collaborators

Salum Juan, Geria Juan, Ferreyro Luciano, Almela Alejandro, Hampel Matias, Bonaparte Juan, Gutierrez Silvina, Tosi Leandro, Platino Manuel, Gomez Berisso Mariano, Lipovetzky José, Etchegoyen Alberto.

Weber Marc ,Sander Oliver, Enss Christian, Kempf Sebastian, Karcher Nick, Gebauer Richard, Gartmann Robert, Mathias Kleifges, Kopmann Andreas, Balzer Matthias, Ulusoy Cagri, Konstantin Illin, Valenti Francesco, Ardila Perez Luis, Wang Weijia, Patil Meghana, Kleiffges Matthias, Pulch Saskia, Martin Antje, Caselle Michele, Bacher Alexander, Bauer Uwe.

Hamilton Christophe, Piat Michel, Guillaume Stankowiak, Fabrice Voisin.

Thanks!

Questions?

References

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Backup - Telescope

Backup - Cosmic Variance[1,2]

$$\Delta C_\ell^{BI} = \sqrt{\frac{2\kappa_1}{2\ell\Delta\ell f_{sky}}}\left(C_\ell + 2\frac{N_h}{N_{eq}^2}\frac{NET_{BI}^2\Omega}{t}\kappa_1\right) \tag{1}$$

1. Hamilton, J.-C., Charlassier, R., Cressiot, C., Kaplan, J., Piat, M., and Rosset, C. (2008). Sensitivity of a bolometric interferometer to the cosmic microwave backgroud power spectrum
2. Charlassier, R., Bunn, E. F., Hamilton, J.-C., Kaplan, J., and Malu, S. (2010). Bandwidth in bolometric interferometry

Backup - Photon Sources

Source	*Power*	*NEP*	%
Atmosphere	$1.6pW$	$2.14 \cdot 10^{-17} W/\sqrt{Hz}$	36
Cold Box	$0.42pW$	$0.95 \cdot 10^{-17} W/\sqrt{Hz}$	9.2
Telescope	$1.4pW$	$1.96 \cdot 10^{-17} W/\sqrt{Hz}$	31
Excess	$1pW$	$- \cdot 10^{-17} W/\sqrt{Hz}$	22
CMB	$0.08pW$	$1 \cdot 10^{-17} W/\sqrt{Hz}$	1.8
Detectors	-	$1 \cdot 10^{-17} W/\sqrt{Hz}$	12
Total	$4.5pW$	$5 \cdot 10^{-17} W/\sqrt{Hz}$	100

Backup - Noise Budget

Noise Source	*NEP*	$S_\Phi(f)$	T_n
Photons	$5 \cdot 10^{-17} W/\sqrt{Hz}$	$1.74 \cdot \mu\Phi_0/\sqrt{Hz}$	$11K$
Thermodynamic Fluc.	$3 \cdot 10^{-17} W/\sqrt{Hz}$	$1.05 \cdot \mu\Phi_0/\sqrt{Hz}$	$4K$
Johnson Electrical		$0.1 \cdot \mu\Phi_0/\sqrt{Hz}$	$0.03K$
Johnson Magnetic		$0.2 \cdot \mu\Phi_0/\sqrt{Hz}$	$0.3K$
SQUID		$0.6 \cdot \mu\Phi_0/\sqrt{Hz}$	$1.3K$
TLS		$0.2 \cdot \mu\Phi_0/\sqrt{Hz}$	$0.2K$
Flux Ramp	-	$0.9 \cdot \mu\Phi_0/\sqrt{Hz}$	$2.9K$
Cold Coupler	-	-	$0.1K$
HEMT	-	-	$2K$
Rx		-	$0.5K$
Total	$6.92 \cdot 10^{-17} W/\sqrt{Hz}$	$2.39 \cdot \mu\Phi_0/\sqrt{Hz}$	$21K$

Backup - TES

Parameter	***Band 1***	***Band 2***	***Band 3***	***Units***	***Description***	***References***
P_{ray}		4.5	7	pW	Incident Power	3 bands
P_{sat}		12.5	17.5	pW	Saturation Power	3 focal planes
ν	90	150	220	GHz	Radiation frequency	3 bands
$\Delta\nu/\nu$	25	25	25	%	Relative Bandwidth	3 focal planes
NEP	5	4.4	6.2	$1 \cdot 10 - 17 W/\sqrt{Hz}$	Noise Equivalent Power	Qubic TDR - TES Thesis
C_{max}		140	140	pJ/K	Maximum Heat Capacitance	Qubic TDR - TES Thesis
G		300	300	pW/K	Thermal Conductance	Qubic TDR - TES Thesis
$\boldsymbol{L}$		10	10	Unit	Loop Gain	Qubic TDR - TES Thesis
G_{eff}		3300	3300	pW/K	Effective Thermal Conductance	Voltage biased, strong ETF
τ_{max}		62	42	mS	Maximun time constant	Qubic TDR
R_{det}		330	330	KA/W	Detector Responsivity	TES Voltage biased, strong ETF
V_{bias}		3	3	μV	Voltage Bias	TES Voltage biased, strong ETF
$S_I(f)$		14.5	20.5	$pA/\sqrt{Hz}$	Noise Equivalent Current TES	Mates Thesis - TES Tesis
M_{in}		80	80	pHy	TES Coupling Inductance	Coupling to SQUID
T_{op}		300	300	mK	Operating temperature	Based on Qubic Cryo
η		0.9	0.9	Units	Radiation Coupling Efficiency	Qubic TDR
$l * w$		3x3	3x3	mm	Squared size	Qubic TDR
BW_{det}		100	100	Hz	Detector Bandwidth	Bolometer signal

Backup - uMUX

Parameter	***Band 1***	***Band 2***	***Band 3***	***Units***	***Description***	***References***
N_{det}		1024	1024	Units	Number of Sensors	Per focal plane
Δf		6	6	MHz	Resonators Spacing	20 times Res BW - Mates Thesis
BW_{det}		100	100	Hz	Detector Bandwidth	Bolometer signal
$BW_{channel}$		300	300	KHz	Resonator Bandwidth	Mates Thesis - FRM
BW_{mux}		4-8	4-8	GHz	Coaxial Lines	ECHo Project
Q_i		1×10^6	1×10^6	Units	Intrisic quality factor	Mates thesis - SOI high-resistivity silicon
η_m		1	1	Units	Bandwidth to Frequency Shift	Mates Tesis
L_s		20	20	*pHy*	Screening Inductance	$J_c = 0.5\mu A/\mu m^2$ Nb trilayer
C_J		100	100	*fF*	Josephson Capacitance	$J_c = 0.5\mu A/\mu m^2$ Nb trilayer
R_J		100	100	Ohms	Josephson Resistance	$J_c = 0.5\mu A/\mu m^2$ Nb trilayer
M_c		1.65	1.65	*pHy*	Squid Coupling Inductance	$J_c = 0.5\mu A/\mu m^2$ Nb trilayer
M_{fr}		24	24	*pHy*	Flux Ramp Coupling Inductance	$J_c = 0.5\mu A/\mu m^2$ Nb trilayer
λ		1/3	1/3	Unit	Non-Hysteretic Parameter	Mates Thesis
p		$1/\pi$	$1/\pi$	Unit	Flux amplitude	Mates Thesis
C_p		10	10	*fF*	Resonator Coupling Capacitance	Mates Thesis
Z_1		50	50	Ohms	Resonator Impedance	Mates Thesis
Z_0		50	50	Ohms	Feedline Impedance	Mates Thesis
$S_\Phi(f)$		1	1	$\mu\Phi_0/\sqrt{Hz}$	Noise Equivalent Flux - SQUID	Mates Thesis
T_{op}		300	300	mK	Operating temperature	Mates Thesis ADR 50mk to 350mk
T_{read}		6	6	K	Noise Equivalent Temperature - Readout	Mates Thesis
f_{rm}		50	50	KHz	Flux Ramp Modulation Frequency	Mates Thesis

Backup - Cryo Setup

Parameter	***Minimum***	***Step***	***Maximum***	***Units***	***Description***
T_{stage1}		300	300	mK	Plate Temperature
T_{stage2}		4	4	K	Plate Temperature
P_{stage1}		300	300	mW	Cooling Power Detectors Plate
P_{stage2}		1	1	W	Cooling Power LNA Plate
A_{stage1}	15	-	20	dB	Cold Coulpler
A_{stage2}	20	-	30	dB	Cold Attenuator
G_{LNA-1}	35	-	4	dB	First LNA Gain
G_{LNA-2}	15	-	-	dB	Second LNA Gain
Tn_{LNA-1}	2	-	4	K	First LNA Noise Temperature
Tn_{LNA-2}	20	-	-	K	Second LNA Noise Temperature
$IIP3_{LNA-1}$	-40	-	-	dBm	First LNA IIP3
$IIP3_{LNA-2}$	-10		25	dBm	Second LNA IIP3

Backup - System Req

Parameter	***Minimum***	***Step***	***Maximum***	***Units***	***Description***
Operation Frequency	4000	-	8000	*MHz*	LNA Bandwidth
Tx SNR	75	-	-	dB	
Rx SNR	65	-	-	dB	Plate Temperature
Rx Power	-55	-	-35	dBm	Plate Temperature
Tx Power	-35	-	-65	dBm	Plate Temperature
SNR Jitter	65	-	-	dB	SNR Clock
SNR Phase Noise	65	-	-	dB	SNR LO
LO Stability	1	-	-	ppm	SNR LO
IMRR	60	-	-	dB	IMRR
LO leakage	40	-	-	dB	LO Leakage
Tx Spurious	-60	-	-	dBc	
Rx Spurious	-60	-	-	dBc	

Backup - RF Front End Req

Parameter	***Minimum***	***Step***	***Maximum***	***Units***	***Description***
DAC Number	5	-	-	Units	
DAC Sampling frequency	1	-	-	GHz	
DAC ENOB	12	-	-	Bits	2 bits higher than ADC
ADC Number	5	-	-	Units	
ADC Sampling frequency	1	-	-	GHz	
ADC ENOB	10.6	-	-	Bits	
Rx Power	-60	-	-20	dBm	
Tx Power	-30	-	-10	dBm	
Clock Jitter	-	-	180	fs	SNR Clock
LO Frequency	4000	$3\ 3 \cdot 10^{-3}$	8000	MHz	LNA Bandwidth
LO Phase Noise	-	-	-90	dBc/Hz	SNR LO
LO Stability	1	-	-	ppm	SNR LO
Tx IQ Phase Control	0	0.1	10	degree	IMRR
Tx IQ Amplitude Control	0	0.1	3	dB	IMRR
TX IQ DC Offset Control	0	2	200		LO Leakage
Rx IQ Phase Control	0	0.1	10	degree	IMRR
Rx IQ Amplitude Control	0	0.1	3	dB	IMRR
Tx Gain		40	40	dB	
Tx NF	-	-	10	dB	
Tx IIP3	20	-	-	dBm	
Rx Gain		40	40	dB	
Rx NF	-	-	5	dB	
Rx IIP3	20	-	-	dBm	