A 16 channel frequency domain modulation readout system with custom superconducting LC filters for the SWIPE instrument of the balloon-borne LSPE experiment

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SUMMARY: We present the design, implementation and first tests of the superconducting LC filters for the frequency domain readout of spiderweb TES bolometers of the SWIPE experiment on the balloon-borne LSPE mission [1] [2]. LSPE is optimized to measure the linear polarization of the Cosmic Microwave Background at large angular scales to find the imprint of inflation on the B-mode CMB polarization.

The Short Wavelength Instrument for the Polarization Explorer (SWIPE) is composed of 3 arrays of multi-mode bolometers cooled at 0.3K, with optical components and filters cryogenically cooled below 4K to reduce the background of the detectors. Polarimetry is achieved by means of large rotating half-wave plates and wire-grid polarizers in front of the arrays. In SWIPE angular resolution is traded off for sensitivity. Microwave radiation will be detected at the three frequencies of 140, 220 and 240 GHz to disentangle the expected cosmological signal from inflation from the galactic and extragalactic background, for a 13 days survey covering 25% of the sky.

LC filters are designed, produced and tested at the INFN sections of Pisa and Genoa where thin film deposition and cryogenic test facilities are present, and where also the TES spiderweb bolometers are being produced.

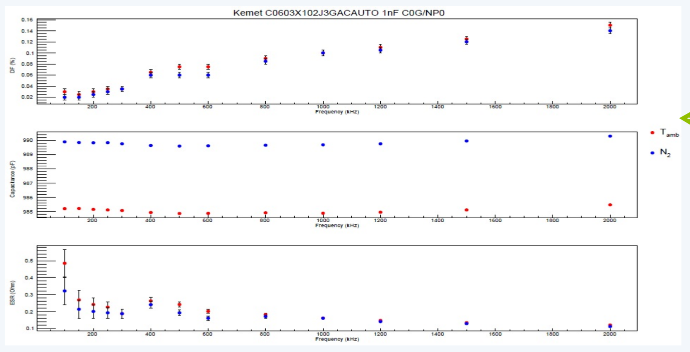
Multiplexing

Multiplexing technology is essential for large array of bolometers, both for reduction of costs and implementation simplicity. In frequency domain multiplexing (FDM), each detector in a set of N is biased with a sinusoidal bias at a unique frequency f_n.

A tuned filter consisting of a cold inductor and a cold capacitor is placed in series with each TES bolometer. The tuned filter has a double function: its bandwidth limits the current noise from the resistive TES bolometer and allows the N detector to be biased with a single pair of wires: a comb of N bias frequencies is sent down this single pair.

The tuned filter passes the appropriate bias carrier and suppresses the other N-1. The N sensors with their series filters are connected in parallel and the currents are summed and readout with a single SQUID. Warm demodulation electronics separate and recover the individual detector signals.

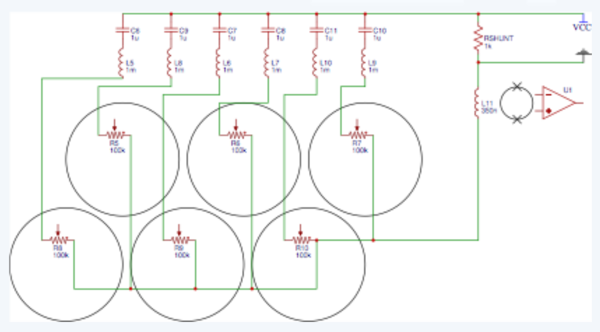
In LSPE we will use a 16-channel multiplexing in the range 200 KHz–1.8 MHz. To guarantee a constant filter bandwidth, L ≈ 20÷40 μH are designed. NP0/C0G capacitors of 220 pF÷30 nF are being tested at cryogenic temperatures for final design.

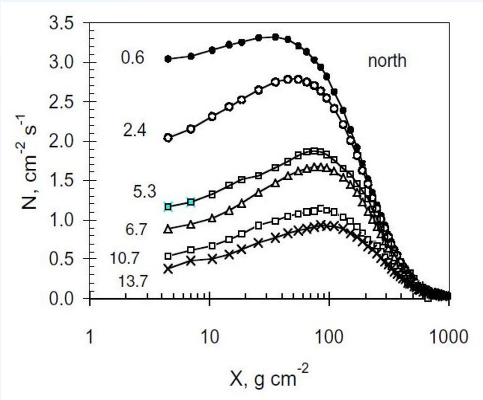


Test of a capacitor at room and cryogenic temperature. The first plot shows the dissipation factor, the second the capacitance, the third the equivalent series resistance as a function of the frequency

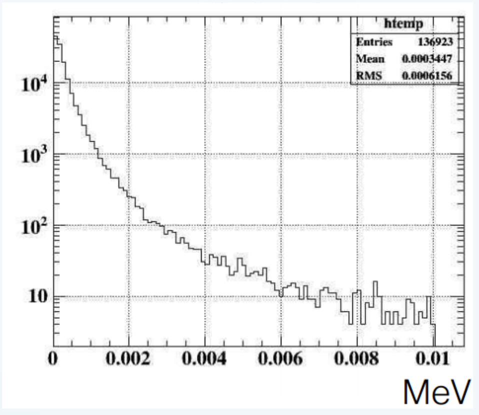
Nominal freq	L (H)	C (F)	C (nF)	Avail C (nF)	Freq (kHz)
200000	2.00E-05	3.17E-08	31.66	33	195.91
300000	2.00E-05	1.41E-08	14.07	15	290.58
400000	2.00E-05	7.92E-09	7.92	7.5	410.95
500000	2.00E-05	5.07E-09	5.07	5.1	498.35
600000	2.00E-05	3.52E-09	3.52	3.6	593.15
700000	2.00E-05	2.58E-09	2.58	2.7	684.91
800000	2.00E-05	1.98E-09	1.98	2	795.80
900000	2.00E-05	1.56E-09	1.56	1.6	889.73
1.00E+06	2.00E-05	1.27E-09	1.27	1.3	987.07
1.10E+06	2.00E-05	1.05E-09	1.05	1	1125.43
1.20E+06	2.00E-05	8.80E-10	0.88	0.9	1186.31
1.30E+06	2.00E-05	7.49E-10	0.75	0.75	1299.53
1.40E+06	2.00E-05	6.46E-10	0.65	0.68	1364.78
1.50E+06	2.00E-05	5.63E-10	0.56	0.56	1503.92
1.60E+06	2.00E-05	4.95E-10	0.49	0.47	1641.61
1.70E+06	2.00E-05	4.38E-10	0.44	0.44	1696.65
1.80E+06	2.00E-05	3.91E-10	0.39	0.39	1802.13

Schematics of the bolometers readout scheme

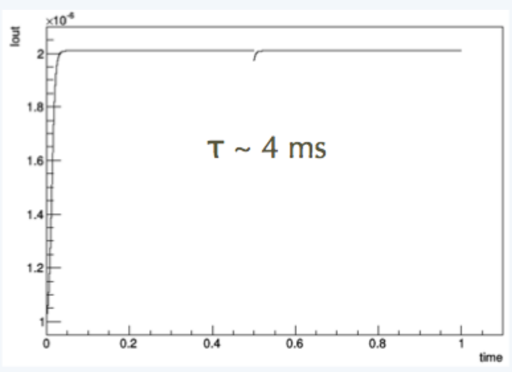




Cosmic ray flux in the stratosphere [3]



Energy deposit in TES induced by cosmic rays



Simulated signal of a cosmic ray depositing 1 keV energy in a LSPE TES

Transition-Edge Sensor

Bolometers are direct detectors which incoherently measure the power of the radiation, giving a signal proportional to the power of the input signal. They consist of an absorber with a heat capacity *C* which is thermally connected to a heat sink at T_0 through a thermal conductance *G*. Absorbers typically consist of a thin layer of metal deposited on a suspended backing structure.

A convenient geometry for the absorber is the spider-web: the geometry spacing is such that radiation can be effectively absorbed while simultaneously providing a very small cross-section for absorption of cosmic rays.

We simulated the effects of cosmic rays on the TES bolometer during LSPE circumpolar flight. The expected interaction rate is of the order of 0.4 Hz and makes the detector blind for ≈ 4 ms. Algorithms to eliminate cosmic rays interactions from the data stream are under development.

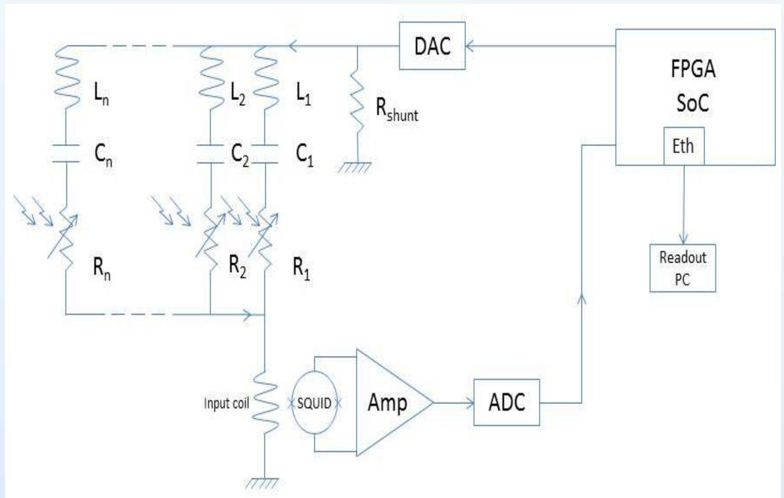
Readout electronics

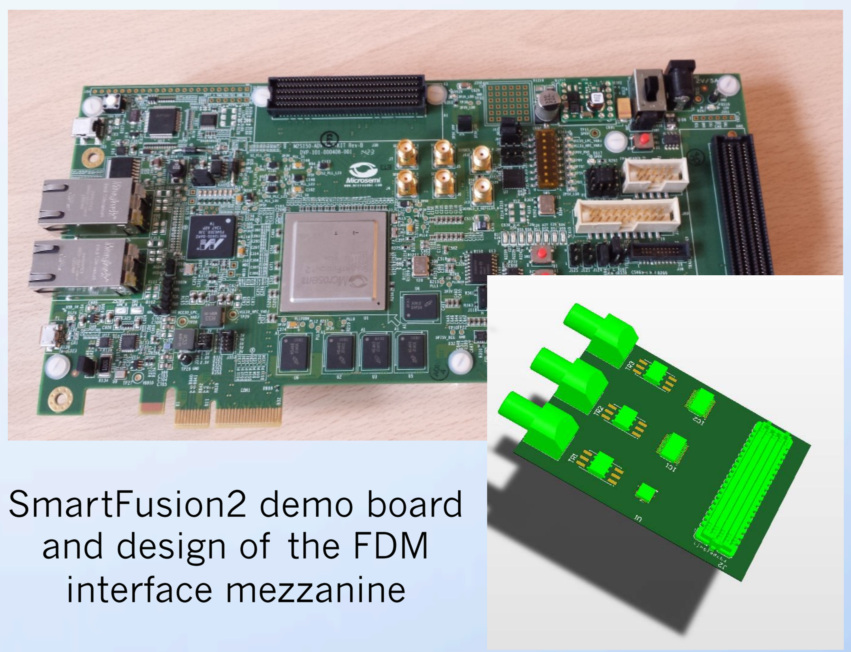
Bolometer bias carriers are synthesized on a FPGA, which also performs demodulation and digitization of the bolometer outputs. The comb of bias carriers is converted to analog through a DAC and then sent to the RLC. The signal is amplified by a SQUID, after that active nulling is performed by sending an identical comb with a displacement of 180° at the SQUID input. In this way only the physics signal is amplified.

After being digitized by an ADC, the FPGA demodulates the signal and sends it to the readout control computer via an Ethernet port. A first prototype to test the FDM algorithms is currently being built: it will handle a single comb generator and one ADC channel.

The core of the system is a MicroSemi SmartFusion2 SoC, model M2S150. It includes a powerful FPGA core with 150K LUT and an ARM processor with 167 MHz speed. The chosen DAC (LTC1668) was selected for its low noise and low power properties, while the ADC will be an AD9266 with a sampling speed of 20 MHz.

Schematics of the readout electronics



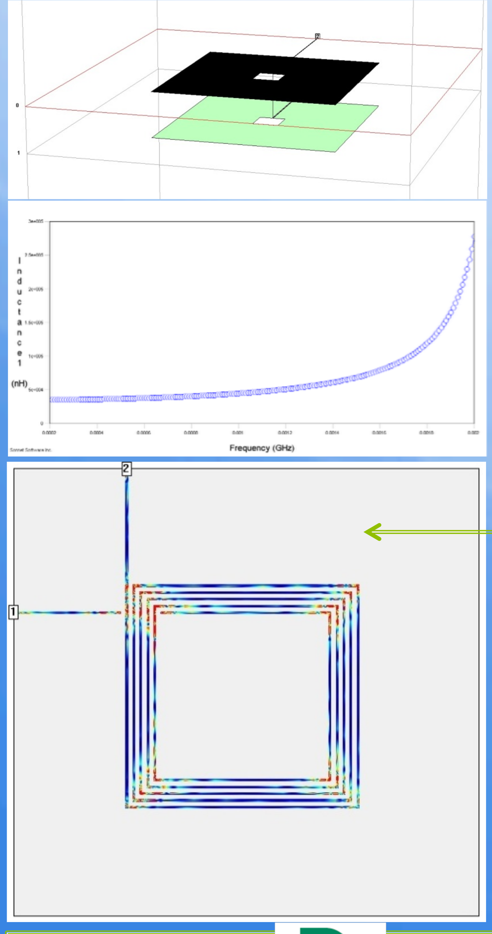


SmartFusion2 demo board and design of the FDM interface mezzanine

LC filters

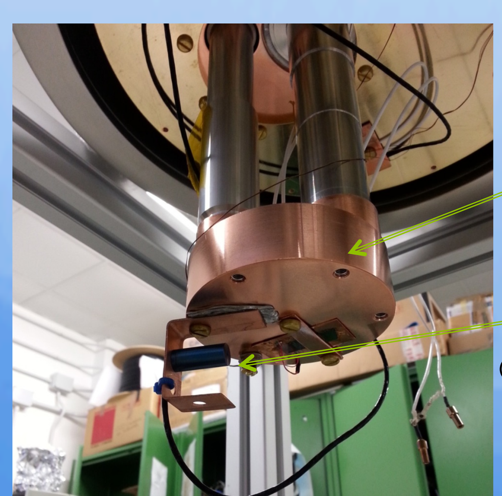
We designed and realized inductors consisting of a superconducting (Nb) coil deposited on and insulated from a slit square washer. This design leads to very low mutual inductances between adjacent coils. SMD capacitors with C0G/NP0 dielectric are chosen for their optimal performance and behavior at low temperatures.

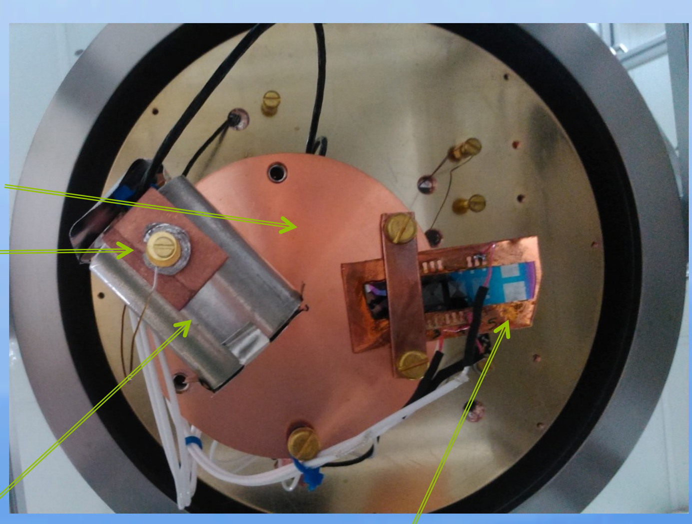
Detailed SONNET [4] simulations of spiral inductors showed that this design is suitable for our purpose. Prototype Nb/SiO_2/Nb inductors have been produced and are under test in our cryogenic facilities, where a complete readout chain (LC filter + SQUID amplification) is being set up.



SONNET simulation of a 5 μm niobium coil over a slit square washer showing the frequency dependent inductance and the maximum supercurrent

Test facility assembly





Cold head (4K stage)

Si sensor

SQUID (Supracon CE2 blue)

μ-metal shield containing the SQUID

LC filter

Microscope views of two prototype inductors realized at INFN Genova

References:

[1] P. de Bernardis *et al.*, *Proc.SPIE Int.Soc.Opt.Eng.* 8452 (2012) 3F

[2] S. Aiola *et al.*, arXiv:1208.0281 [astro-ph.IM]

[3] G. A. Bazilevskaya and A. K. Svirzhevskaya, Space Science Reviews 85: 431521, 1998.

[4] www.sonnetsoftware.it

FDFP FRONTIER DETECTORS FOR FRONTIER PHYSICS, La Biodola, Isola d'Elba, Italy, May 24–30 2015

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