MKID large format array testbed

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***Abstract*— The development of an astrophysics kilo-pixel imaging instrument requires a dedicated cryogenics and optics setup to measure the expected performance of the detector arrays in terms of sensitivity and optical response.**

We have developed a testbed for the characterization of MKID large format arrays (6 cm x 6 cm) in the 350 GHz and 850 GHz band. The testbed is a wide field camera, allowing full optical tests in a realistic environment. The cryostat is based upon a commercial pulse-tube cooled 3K system with a He10 sorption cooler to reach base temperature below 250 mK. We will describe the thermo-mechanical solutions implemented in our system to minimize the thermal loading on the cold stage allowing a base temperature of 250 mK in combination with a large focal plane. The optics design and the stray light philosophy will also be presented.

I. INTRODUCTION

Microwave Kinetic Inductance Detectors (MKIDs) have matured in the last decade and have become an excellent detector choice for future submm and mm astronomical instruments. Their intrinsic multiplexing capability makes the readout of kilopixels arrays relatively cheap and easy compared to other technologies [2] [3]. At SRON we are developing antenna coupled KIDs for a KID camera called AMKID to be deployed at the APEX telescope in Chile [4]. Our design is targeting two of the atmospheric windows available at the telescope centered at 350 and at 85O GHz [5][6] . The detector arrays before deployment to the telescope need a full optical and electrical characterization. The array performance verification can only be realized using a wide field camera which simulates the thermal and optical properties of the telescope instrument. For this goal we have designed and built such testbed. The cryostat requirement specification derived from the telescope instrument and the detector design are:

1) 2 bands of operation: 350 GHz and 850 GHz;
2) Use of reimaging optics with F#=2 at the detector, Strehl ratio better than 95%, near telecentric behavior and a band transmission better than 30%;
3) Stray light and spillover rejection better than 60 dB;
4) Base temperature of 250 mK or lower;
5) A turn-around of roughly a week.

In this paper we will describe the thermal, optical and mechanical solutions implemented to meet the specified requirement.

II. CAMERA DESIGN

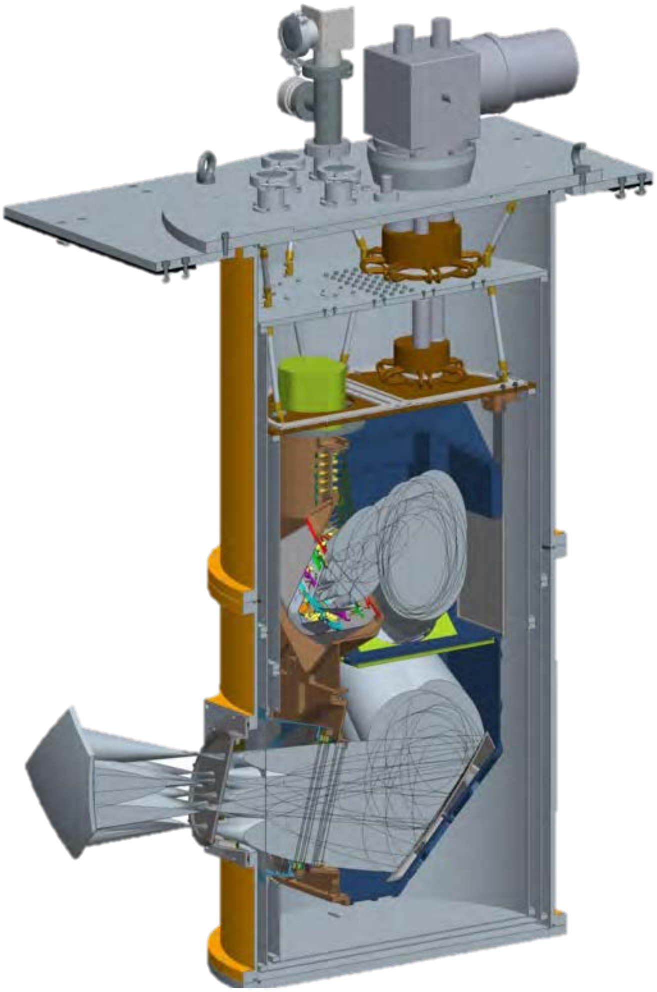

Fig. 1. Schematic of our wide field camera. For simplicity the warm optics is omitted. The light enters via the cryostat window and is reimaged via the optics onto the array, mounted on a thermal suspension unit. The cold optics is mounted inside an enclosed box connected to the 4 K plate via spring leafs. The detector array is cooled down to base temperature via a He10 cooling unit.

The camera design is shown in Fig. 2. The cryostat cooling unit is based on a commercial Pulse tube cooler (PTC) and an extra He3-He3-He4 sorption cooler [7] used to reach the base temperature at the detector array. A liquid nitrogen LN2 precooling unit allows fast turnaround of the system, speeding up the first part of the cool-down to roughly 80 K. The radiation enters the cryostat via an HDPE window and travels via the optics to the detector array mounted inside a thermal suspension unit. The cold optics are enclosed in a box mounted on the 4 K cryostat plate via spring-leaves.

In the following subsections each component is described in more detail.

A. Re-imaging optics and optics box

The camera optics create an image of the detector array at a warm focal plane outside the cryostat using a seven mirror system with a total magnification of 3. The optical design is based on two parabolic relays, one in the cold at 4 K and one outside the cryostat. The optical design is based on aberration compensation [8] that cancels out the aberrations and cross-polarization of the optics near the optical axis. All mirrors were modelled as biconics, allowing different curvature and conic constants in the x and y direction. An angular limiting aperturein the pupil limits the beam to F#=2 and is placed between the 4 K active mirrors where all the different pixel beams overlap. The design was simulated using the Zemax software [9] (see Fig. 2 for the final design). The cold optics are mounted inside an enclosed 3K box (800 X 425 X 400 mm^3) using three mounting pads for each mirror that allow fine positioning. The alignment of all mirrors was verified by measuring their position with a 3D measuring machine and found to be within tolerances. The optics box provides also the mounting interface for the He10 and the detector thermal suspension unit and baffles. The inside of the box is coated with radiation absorbing coating made of a mixture of 1 mm SiC grains and Stycast 2850 [10]. The box is equipped with flexible thermal straps to ensure a good thermal contact and evenly cool down the big structure.

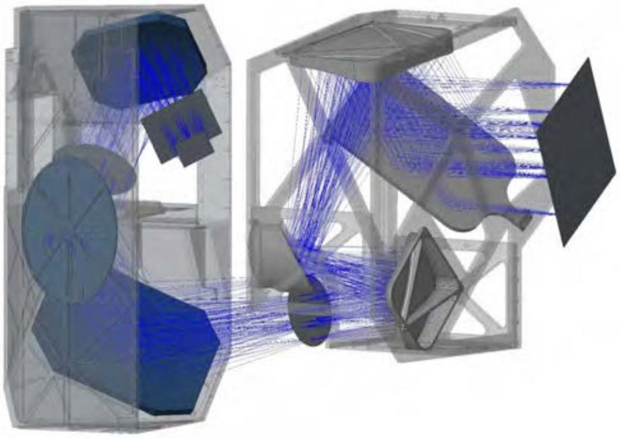

Fig. 2. Scheme of the cold and warm optics. The cold optics is mounted inside an enclosed 4 K box. The warm optics is mounted outside the cryostat.

B. Radiation filtering

The optical measurement band is defined by a set of quasi optical filters [11]. More than 60 dB out of band rejection is needed to suppress the out of band 300 K blackbody spectrum and self-emission of the windows and filters. A known problem is the filter heating due to the fact that the filters are large and made of plastic (mostly mylar) so poorly thermalized [12]. This issues requires additional filters to block the reradiated heat. In Fig. 3 the spectral transmission of the filters is shown and in Table I the filter stack overview for the 350 GHz band is summarized including the main task of each filter.

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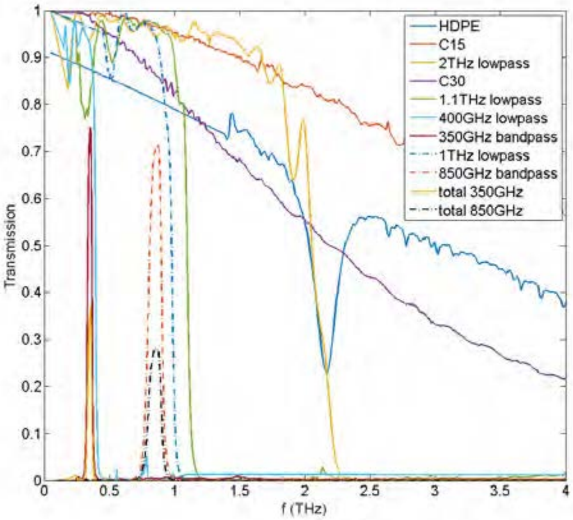

Fig. 3 Spectral transmission of the filters used in our system.

TABLE I
FILTER STACK OVERVIEW FOR THE 350 GHZ BAND

Name	Position and minimal T	Task
HDPE window	Window 300 K	Absorbs IR
Scatterer	300 K	Scatters near IR radiation, reduce condensation on the window
Shader 15 µm	50 K	Reflects near to mid -IR power back
Scatterer	50 K	Scatters near IR radiation, reduce condensation on the window
Shader 15 µm	50 K	Reflects power back
LP 3 THz	50 K	
Shader (2x) 30 µm	Window 4 K	Reflects near to mid-IR power back
LP 1.1 THz	Window 4 K	Reflects far IR and out of band mm wave but absorbs mid-IR
Goretex sheet	Pupil 4 K	Absorbs IR
LP 400 GHz	850 mK	Reflects far IR and out of band mm wave but absorbs mid-IR
BP 350 GHz	250 mK	Defines measurement band

C. MKID Readout

The MKID readout is fed into the cryostat by standard coaxial cables with SMA connectors with double DC blocks at the input to prevent ground loops. The signals runs from 300 K to the detector array and back. From 300 K to 4 K we use CuNi coax cables with Ag cladding on the central conductor [13]. From 4 K to the optics box we use copper coax and from the inner side of the box and in the suspension unit we use 0.86 mm CuNi coax cables with Ag cladding. The signal is attenuated on its way to the detector array and on the way back is amplified by 4-8 GHz Low Noise Amplifier. The loading of the cables has been designed to be well below the cooling power of the He10 unit.

D. Thermo-mechanical suspension unit

The detector array is mounted inside a suspension unit (see Fig. 4) which provides the thermal interface to the optics box and the intermediate thermal steps going from 3K to the 250 mK base temperature. The temperature levels are provided by the He10 cooler via flexible thermal straps. All temperature stages consist of a square annular deck, that are separated using three Vespel SP1 supports. The inner side has baffles coated with absorbing coating. The coaxial harness is thermally coupled to each deck to reduce the thermal load at the detector unit. The attenuators and Dc blocks and SMA connectors are used to rigidly clamp the coaxial harness. To attenuate magnetic fields the whole thermal suspension unit is surrounded by a niobium superconducting shield.

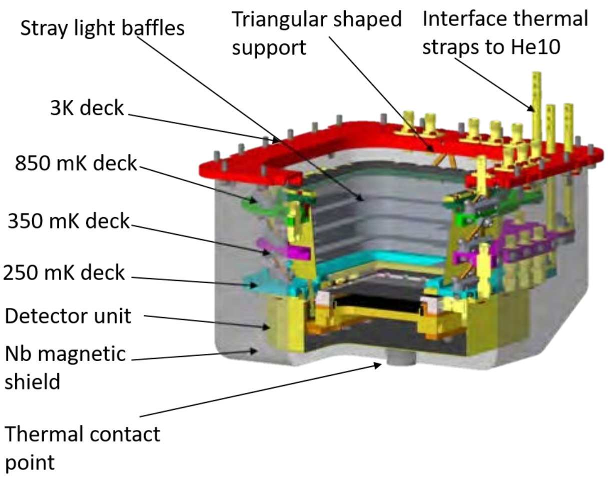

Fig. 4 Schematic of the thermo-mechanical suspension unit.

III. VERIFICATION

The thermal operation of the cryostat shows excellent performance: the base temperature of 250 mK is reached in roughly two days and an the hold time is about 30 hours with an addition recharge of the He4 buffer head of the He10 cooler.

The detectors show photon noise background operation and the optics quality is verified by the comparison of the simulated beam pattern using the Zemax physics optics tool and the measured beam patterns [14]. The agreement is excellent.

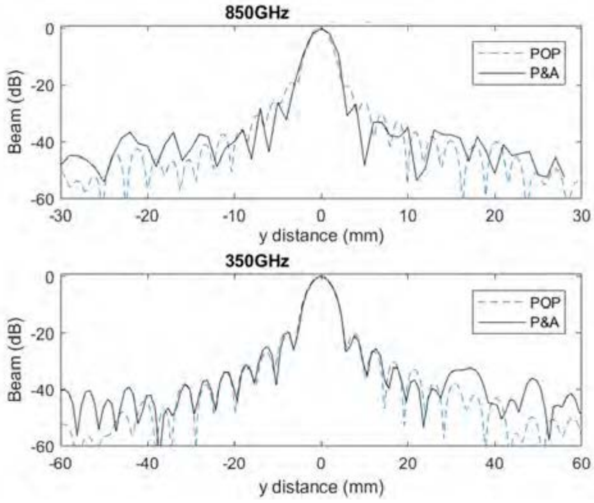

Fig. 5 Comparison between simulated and measured beam patterns.

CONCLUSIONS

We have successfully designed, build and verified a wide field camera testbed for the development of large format KID arrays. It mimics the conditions found in typical submm telescope instruments (APEX).

REFERENCES

[1] P. K. Day, H. G. Leduc, B. A. Mazin, A. Vayonokis and J. Zmuidzinas, "A broadband superconducting detector suitable for large arrays", *Nature*, vol. 425, 817, 2003.

[2] W. S. Holland et al, "SCUBA-2: the 10 000 pixel bolometer camera on the James Clerk Maxwell Telescope", *MNRAS*, vol. 430, Issue 4, pp..2513-2533, 2013.

[3] V. Reveret et al, "The ArTéMiS wide-field submillimeter camera: preliminary on-sky performances at 350 microns", Proc. SPIE 9153, doi:10.1117/12.2055985, June 2014.

[4] APEX telescope [Online]. Available:http://www.apex-telescope.org/.

[5] R. M. J. Janssen, J. J. A. Baselmans, A. Endo, L. Ferrari, S. J. C. Yates, A. M. Baryshev and T. M. Klapwijk,, "High optical efficiency and photon noise limited sensitivity of microwave kinetic inductance detectors using phase readout", *Appl. Phys. Letter*, 103, 203503, 2013.

[6] L. Ferrari, O. Yurduseven, N. Llombart, S. J. C. Yates, J. Bueno, V. Murugesan, D. J. Thoen, A. Endo, A. M. Baryshev, J. J. A. Baselmans, Äntenna coupled MKID Performance verification at 850 GHz for large Format Astrophysics Array", *IEEE Transactions on Terahertz Science and Technology*, Volume 8, Issue 1, pp. 127-139, Jan. 2018.

[7] Chase Research Cryogenics [Online]. Available: http://www.chasecryogenics.com/

[8] J. A. Murphy, "Distortion of a simple Gaussian beam on reflection from off-axis ellipsoidal mirrors*", Int. J. Infrared and Milli. Waves*, Vol. 8, no. 9, pp. 1165-1187, Sep. 1987.

[9] Zemax LLC, "Zemax optical studio", 2013 . [Online] Available: www.zemax.com.

[10] J. J. A. Baselmans, S. J. C. Yates, P. Diener, P. J. de Visser, *J. Low Temp. Phys.* , vol. 167, 360, 2012.

[11] QMC Instruments Ltd, 2008. [Online] Available: www.terahertz.co.uk/qmc-instruments-ltd

[12] C. E. Tucker, P. A. R. Ade, "thermal filtering for large aperture cryogenic detector arrays", *Proc. SPIE.* , vol. 6275, 2006.

[13] COAX Co. Ltd., [Online] Available: www.coax-co.jp/en

[14] K. K. Davis, W. Jellema, S. J. C. Yates, L. Ferrari, J. J. A. Baselmans, K. Kohno, D. Thoen, V. Murugesan and A. M. Baryshev, "Proof of concept demonstration of vector beam pattern measurements of kinetic inductance detectors*", IEEE Trans. THz Sci. Technology*, vol. 7, no. 1, pp. 98-106, Jan. 2017.