FAIRTEL

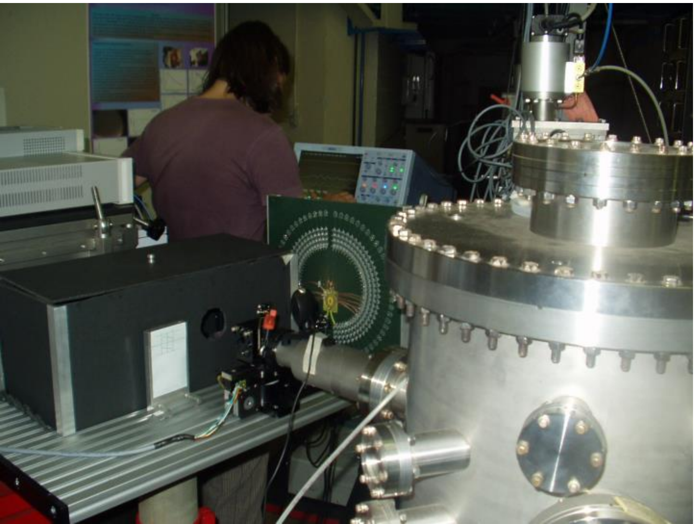
ultra-FAst InfraRed TELescope

a new proposal for the years 2022-23

Simone Bini, Mariangela Cestelli Guidi, Alessandro Drago, Augusto Marcelli, Rossano Sorchetti, Raffaele Zarlenga (LNF),

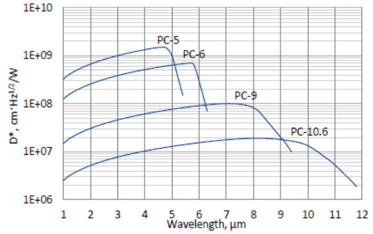
Emanuele Pace (UNI-FI, Arcetri Astronomy Department),

Valerio Bocci (INFN-RM1)



Consiglio di Laboratorio "Preventivi"

6^{th} July 2021



VIGO SYSTEM

PC series HgCdTe detectors datasheet

PC series

1.0 – 12.0 µm HgCdTe ambient temperature photoconductive detectors

PC series features uncooled IR photoconductive detectors based on sophisticated HgCdTe heterostructures for the best performance and stability. The devices are optimized for the maximum performance at λ_{opt}. The devices should operate in optimum bias voltage and current readout mode. Performance at low frequencies is reduced due to 1/f noise. The 1/f noise corner frequency increases with the cut-off wavelength.

Spectral response (T_a = 20°C)

Exemplary spectral detectivity, the spectral response of delivered devices may differ.

Topics

- Preliminary considerations
- Scientific context
- Competitors
- Technological proposal and design scheme
- Working program & budget
- Personnel
- Conclusion / comments

Preliminary considerations

- GOAL 1: Design an ultra fast infrared detector with rise time / fall time < 1ns (working from DC to 400 MHz) to be used in astronomy for ground based infrared telescopes. The proposal is based on the experience done with HgCdTe solid state detectors studied by the 3+L and 3L_2D experiments approved by 5th National Scientific Committee in the last years .
- GOAL 2: evaluation and test on astronomical sources.
- GOAL 3: If all the tests will give positive answers, at the end of the two years the experiment will look for a European funding that will be necessary to build an engineered system for use in ground-based astronomical observatories, satellites or on the moon.

Scientific context: the multi-messenger astronomy

- The discovery of the first gravitational wave in 2017 by the LIGO-VIRGO collaboration has opened a new era for the astronomy, that now can correlate even more types of signals from the space. After the classic and historical astronomy in the visible, after gamma rays and the other electromagnetic waves detection, after neutrinos and cosmic rays, now It is possible to consider the multi-messenger astronomy to have a new and deeper vision of the universe.

- Goal of this new and more sophisticated approach is to evaluate how the synchronized arrival of quite different signals from the same astronomical source can give us a more complete description of the events. Furthermore, as it has been demonstrated in the radioastronomy with the discover of Fast Radio Burst, the ultra-fast detection can be extremely useful. Also in the *infrared* astronomy, a fast detector could be a very interesting and eclectic instrument that can open new fields of research in exo-planet, solar and milk-way fast events as well as in new SETI possible activities.

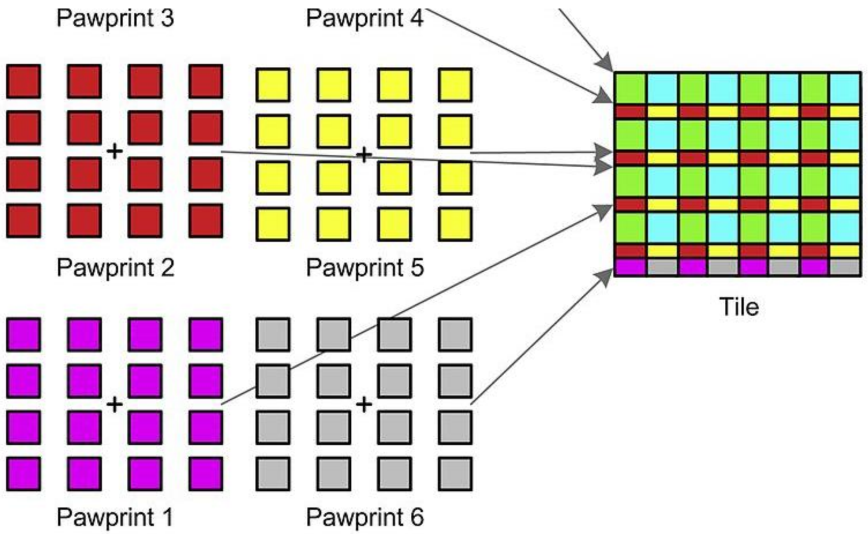
- Considering the multi-messenger astronomy, the detectors and telescopes, from the point of view of the location, are very varied. Nowadays, observatories are placed both on the earth and in the space. On the ground the preferred sites are on plateaus like Atacama or high mountains like Mauna Kea, or underground, like the Gran Sasso INFN Laboratory, under see, or even in the Antarctica for neutrinos. In addition, of course many artificial satellites, first the Hubble Space Telescope, are dedicated to astronomical observations.

- About the infrared astronomy, it must be considered that the terrestrial atmosphere shows a window basically between 8 and 14 micrometres. However, in the satellite, where the radiation is not screened by the atmosphere, the infrared detection activity is often limited in time because the IR detectors need to be cooled by cryogenic system to maintain the detector noise to a low level. This can be done usually by liquefied He that, after some month, finishes. For example, the IRAS telescope satellite worked for 8 months. Of course, ground-based IR telescope can bypass this kind of time limit.

Scientific context: competitors

The most modern (even if not ultra-fast) competitors are on satellite, like the James Webb Space Telescope (still to be launched), or ground based, like three infrared recent instruments: VIRCAM (the VISTA InfraRed Camera), MOONS (The Multi-Object Optical and Near-infrared Spectrograph) by ESO and ERIS-NIX for the European Southern Observatory (ESO)'s Very Large Telescope (VLT). In particular, the experiment MOONS uses the HAWAII-4RG detector by Teledyne Technologies (16,7 Megapixel of 15 square micron each). These instruments can work up to 5 / 10 MHz, so much slowly than the detector proposed here.

The three-tons VISTA infrared camera hangs in the air in front of the telescope.

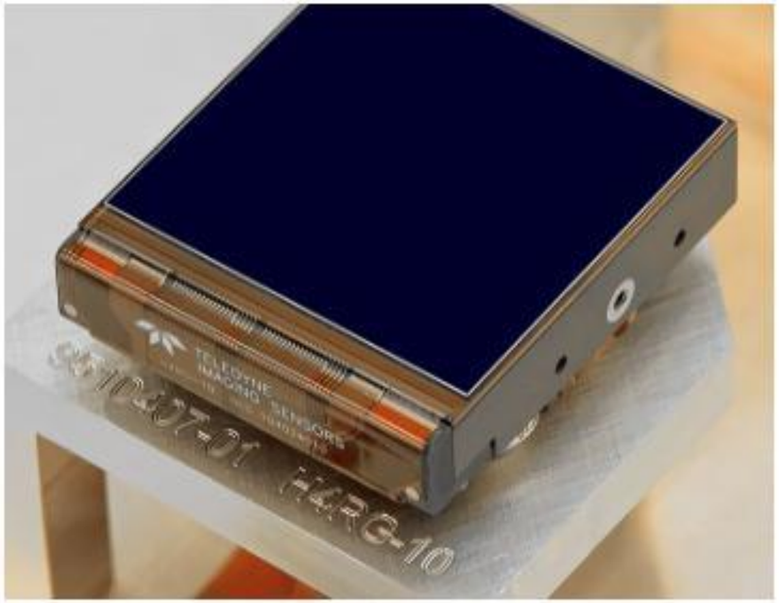


Scientific context: competitors

TELEDYNE
SCIENTIFIC & IMAGING
Everywhereyoulook™

HAWAII 4RG™

IR and Visible FPAs



The 4096×4096 pixel HAWAII-4RG™ (H4RG) is the next generation, state-of-the-art readout integrated circuit for visible and infrared instrumentation in ground-based and space telescope applications.

- Large (4096×4096 pixel) array with either 10 µm or 15 µm pixel pitch.
- Compatible with Teledyne Imaging Sensors (TIS) HgCdTe infrared (IR) and silicon PIN HyViSI™ visible detectors, providing sensing of any spectral band from soft X-ray to 5.5 µm.
- Substrate-removed HgCdTe enhances the J-band QE, enables response into the visible spectrum (70% QE down to 400 nm) and eliminates fluorescence from cosmic radiation absorbed in the substrate.
- Reference rows and columns for common-mode noise rejection.
- Guide window output – windowing with simultaneous science date acquisition of full array. Programmable window which may be read out at up to 5 MHz pixel rate for guiding. Readout is designed to allow interleaved readout of the guide window and the full frame science data.
- Selectable number of outputs (1, 4, 16, 32 or 64) and user-selectable scan directions provide complete flexibility in data acquisition.
- Built with modularity in mind – the array is 4-side-buttable to allow assembly of large mosaics of 4096×4096 H4RG modules.
- Fully compatible with the TIS SIDECAR™ ASIC Focal Plane Electronics

Published Information – Cleared for Public Release by the DoD´s Office of Security Review (Case #12-S-1869).

FAIRTEL, an ultra-FAST InfraRed Telescope

As it is well known, the atmospheric IR transmittance window can be used to make astronomic signal detection. Moreover, a particular case of interest could be the fast and ultra-fast infrared detection. How fast? The studies about astrophysical signals with fast transient are everyday more interesting. In this research proposal, the authors aim for designing an infrared detector potentially working up to 400 MHz. The semiconductor technology has been proved that this bandwidth can be achieved as it was shown at in the last years with the 5th National Scientific Committee experiments 3L and 3L_2D [see the Reference at the end].

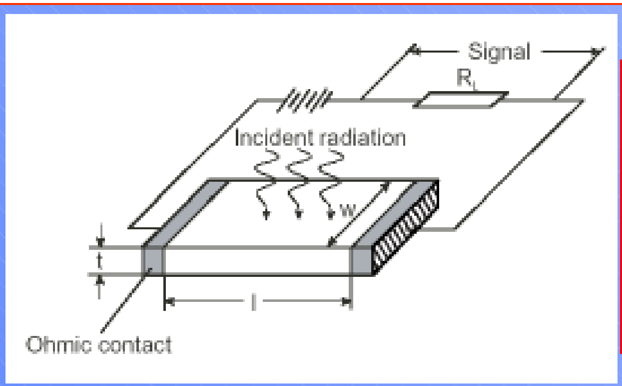
A multipixel prototype can be designed and based on HgCdTe (MCT) photovoltaic or photoconductor devices with 0.1x0.1 mm^2 area for each pixel. They could be arranged on a small board with 5x5 pixels located on the focus of a standard telescope for infrared observations. The small number of pixels is convenient to carry on preliminary feasibility studies and evaluations with reasonable budget requests. The competitors can manage a bigger number of pixels, but they cannot achieve the same speed. During the work, the sensibility, the linearity, and the noise level shall be evaluated making comparisons of different single pixel HgCdTe (MCT) photoconductor and photovoltaic detectors. Rise time and fall time, both foreseen <1ns, can be evaluate at SINBAD.

A cooling system should be considered (only if necessary) to decrease the semiconductor noise level. The interface electronics shall be designed to be able to maintain the photodetector bandwidth. Great care is necessary to design a correct synchronization and acquisition system.

IR PHOTODETECTORS

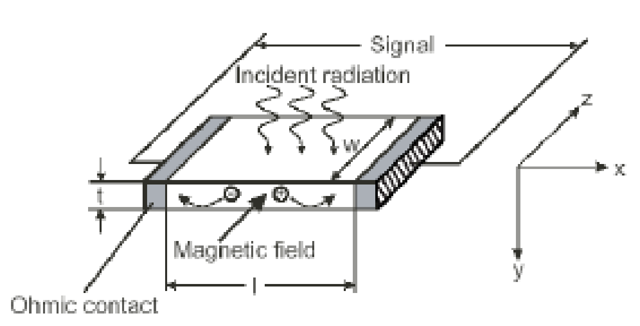
MAIN PRINCIPLES OF GENERATION OF OPTICALLY CARRIERS IN PHOTODETECTORS

PHOTOCONDUCTIVE
PC
detectors



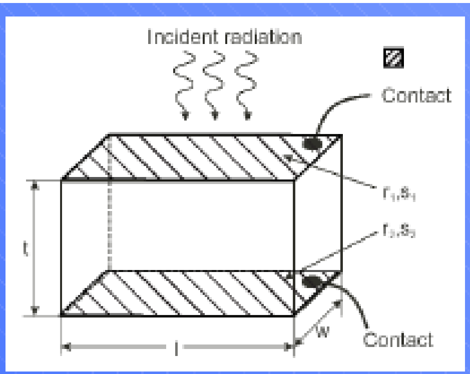
ELECTRICALLY BIASED DEVICES
SIGNAL GENERATED IN THE ABSORBER
BY CHANGE OF ITS RESISTENCE
OR
CONDUCTANCE

PHOTOELECROMAGNETIC
PEM
detectors



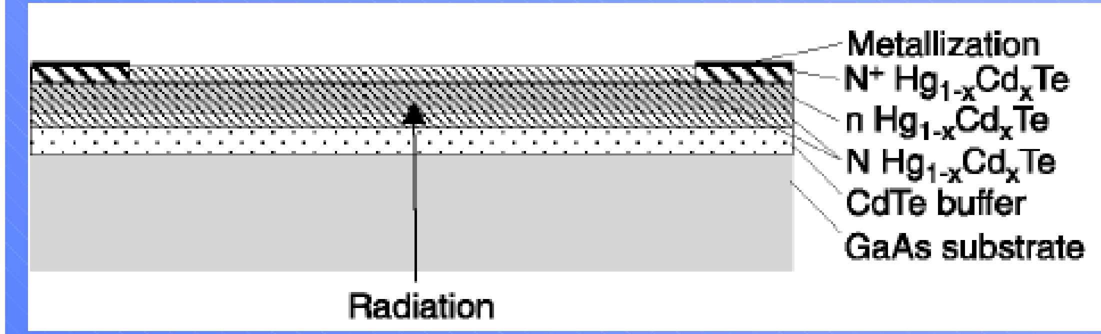
SIGNAL GENERATED
BY DIFFUSION OF
PHOTOGENERATED CARRIERS
DEFLECTED
BY A MAGNETIC FIELD
(2T, PERMANENT MAGNETS)

PHOTOVOLTAIC
PV
detectors



PHOTOVOLTAIC EFFECT
IN BIAS OR UNBIASED
HOMO OR HETEROJUNCTION

PHOTOCONDUCTIVE DETECTORS



ADVANTAGES	DISADVANTAGE
LOW COST TECHNOLOGY 1/f NOISE (f<20kHz) HIGH RESPONSIVITY	BIAS REQUIRED

MWIR PC-IMMERSED @230K APPROCCHING BLIP LIMIT

MWIR PC @300K limited by G-R noise at f>20kHz SUB-BLIP devices

LWIR PC-PC-IMMERSED @230K limited by G-R noise at f>20kHz SUB-BLIP

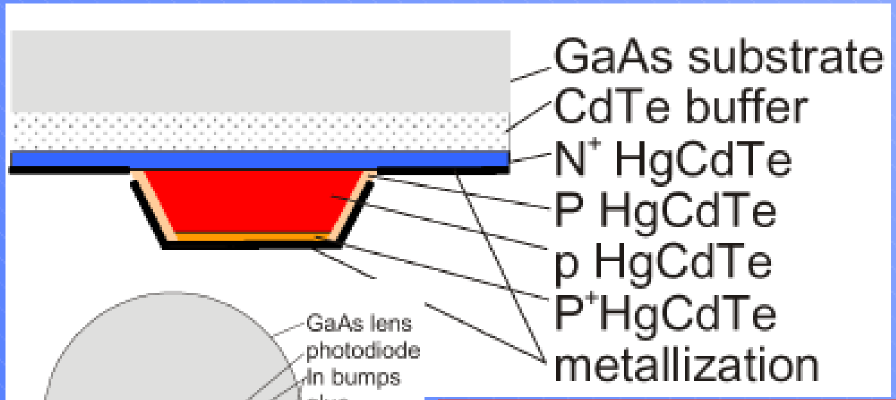
LWIR PC @300K limited by JOHNSON-noise at f>20kHz BELOW-BLIP

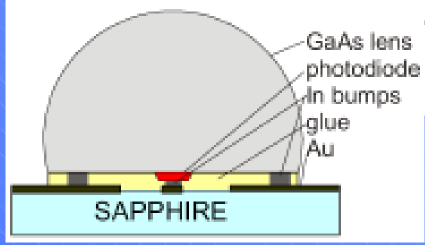
MINIMUN RESPONSE TIME
DETERMINATED BY RECOMBINATION TIME OF CHARGES
IN THE ABSORBER

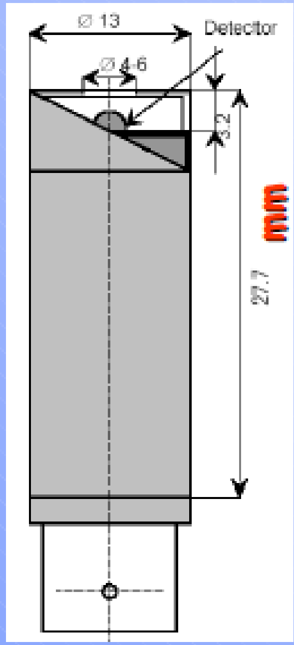
τ~500 ps

J. PIOTROWSKI, OPTO-ELECTRONICS REVIEW 12(1), 111-122 (2004)

PHOTOVOLTAIC DETECTORS







ADVANTAGES	DISADVANTAGES
NO BIAS	LOW RESISTENCE
FAST RESPONSE TIME	LOW QE
FROM DC to VHF	

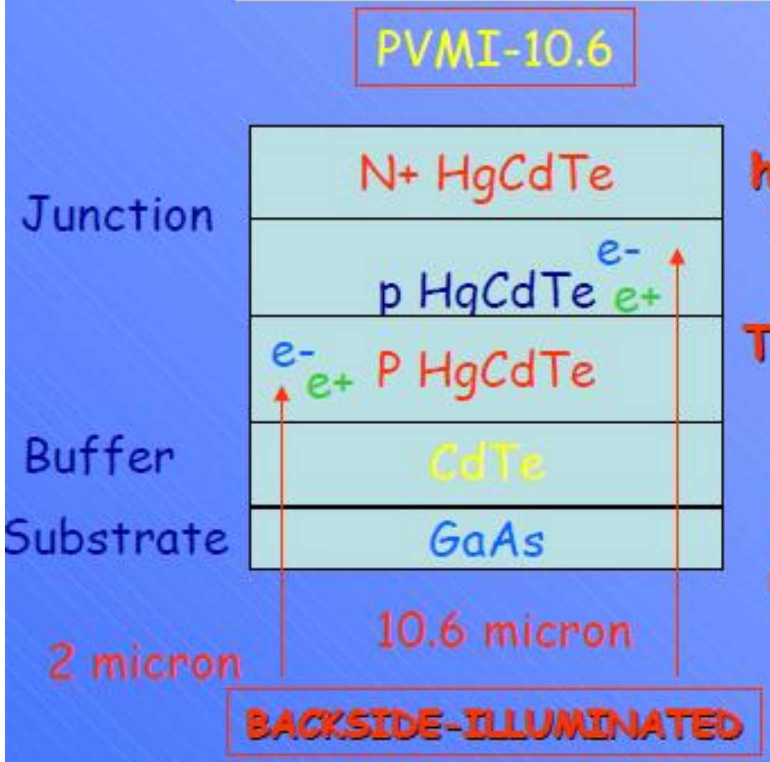
UNCOOLED OR PELTIER COOLED

LWIR - PV-IMMERSED - 2TECOOLED
ONE ORDER OF MAGNITUNE BELOW
BLIP PERFORMANCE

RESPONSE TIME
LIMITED BY TRANSPORT (DIFFUSION AND DRIFT) THROUGH
THE ABSORBER REGION
RC TIME CONSTANT (C OF JUNCTION AND PHOTODIODE SERIES R)

$\tau < 1ns$

IMPROVMENTS IN THE MEASUREMENT



Most of the incident radiation on the detector has wavelength shorter than those optimized for the detector. As a consequence an increase of the response time is expected.

The absorption of short ($\lambda < \lambda max/2$) wavelength radiation in PVM and some other detectors backside illuminated occurs at large distance from the junction plane. Therefore, the time necessary to photogenerated carriers to travel towards the junction is long.

NEW PHOTOCONDUCTIVE DETECTOR FRONT-SIDE ILLUMINATED WILL BE TESTED

RESPONSE TIME ~500ps

SUITABLE TO OBSERVE THE DISTANCE BEETWEEN TWO BUNCHES AND TO OBSERVE THE RISE TIME OF EACH BUNCH

COLLABORATION WITH Prof. JOZEF PIOTROWSKI (Chief Scientist VIGO SYSTEM S.A. COMPANY)

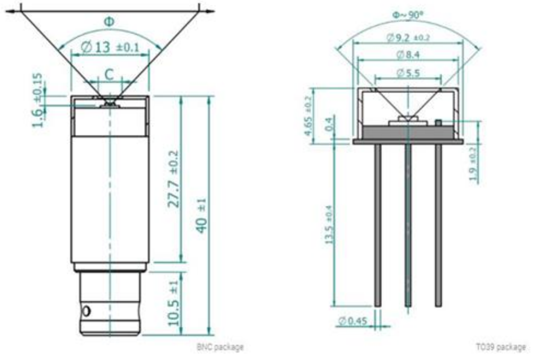
MOCVD SYSTEM @ VIGO

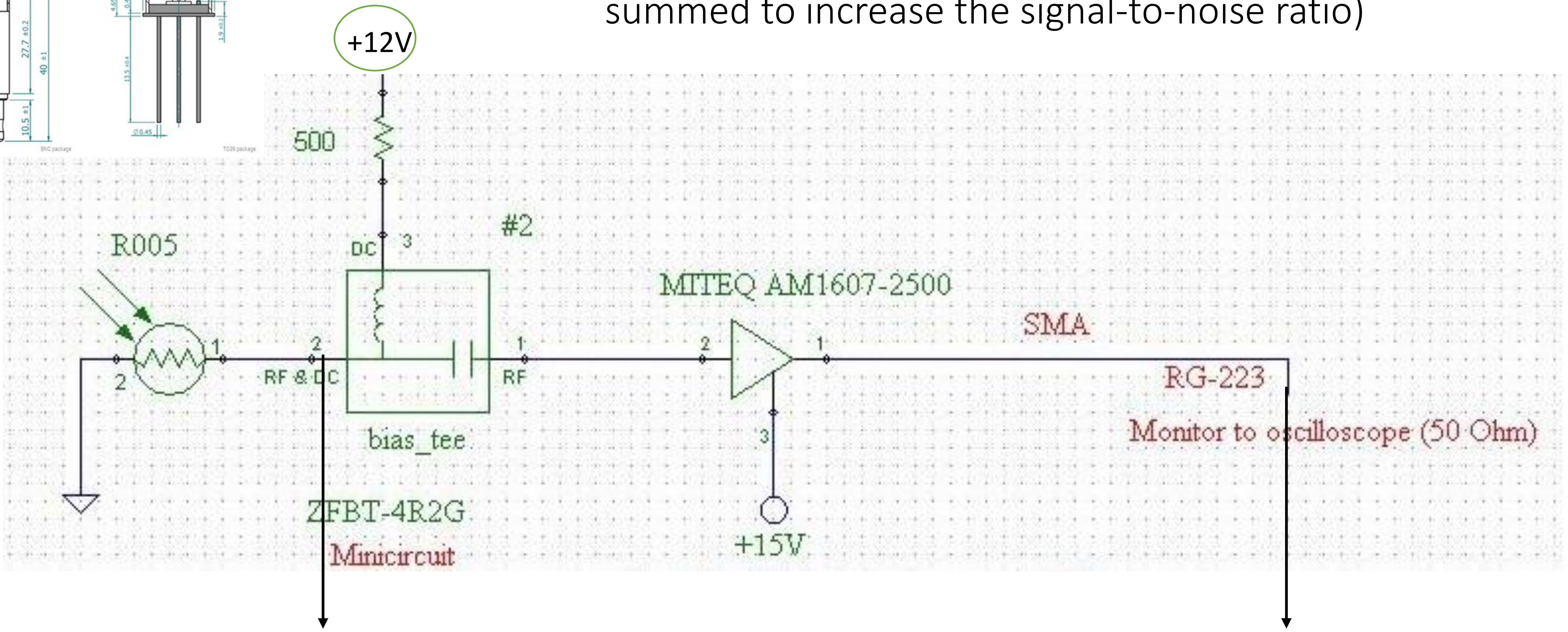
A.PIOTROWSKI et al.,
OPTO-ELECTRONICS REVIEW 12(4) (2004)

MOCVD
METALLORGANIC CHEMICAL VAPOUR DEPOSITION
Epitaxial growth
of multilayer heterostructures
of Hg1-xCdxTe on GaAs, Si, sapphire
SUBSTRATES

Collaboration with
Univ. Firenze and LNF-INFN
to develop, optimize and test
fast uncooled and Peltier
cooled IR detectors for high
frequeny applications
(λopt.2-14 micron)
Few picosecond response time

Front-end basic scheme for each pixel
(to be repeated for 25: the outputs will be summed to increase the signal-to-noise ratio)





DC signal output
(0-10kHz)

AC signal output
(10kHz-1GHz)

FAIRTEL, an ultra-fast infrared telescope design for ground-based astronomy

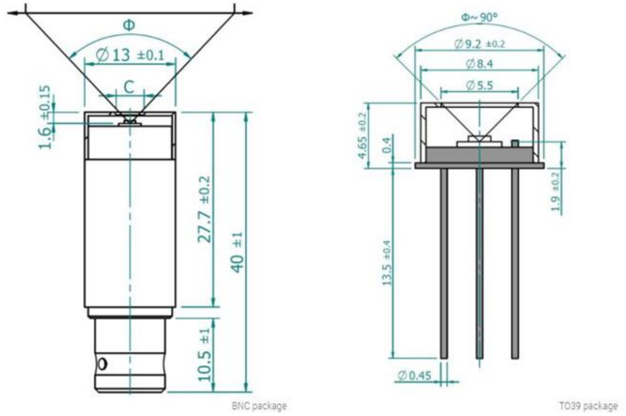
- First year activities: evaluation and comparison of the available HgCdTe detectors performance (both photovoltaic and photoconductive devices). Evaluation of the sensibility needed for the different astrophysical events. Design of 5x5 pixel device. Test at Sinbad, the DAFNE IR beamline (resp. Mariangela Cestelli Guidi).

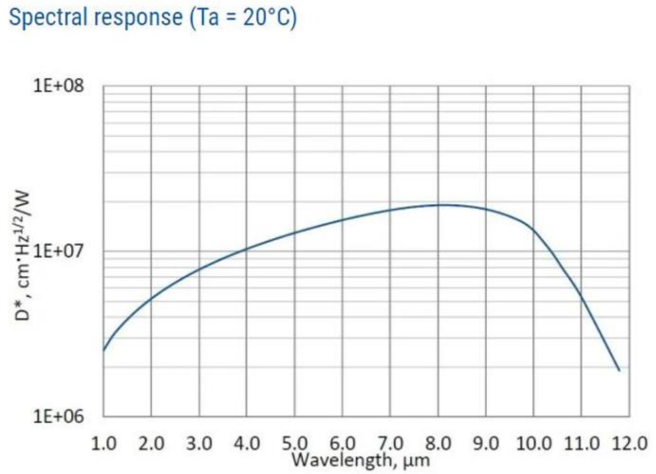
- Second year activities: build of the detector. Test of the 5x5 pixel device at Sinbad. Test of the needed interface electronics and software on real infrared telescopes (resp. Emanuele Pace).

- Duration: 2 years, 2022 -2023
- Budget request: 15k€ per year
- First year (2022)
  - 15k€ consumo (non inventariabili) per componentistica elettronica e meccanica, e alcuni accessori per la linea Sinbad (due specchietti)
- Second year (2023)
  - 10k€ consumo (non inventariabili)
  - 5k€ missioni Italia

FAIRTEL, an ultra-fast infrared telescope design for ground-based astronomy

- The infrared telescope can be used for:
  - Studies on exo-planets
  - Studies for S.E.T.I.: to receive possible artificial messages coming from remote infrared lasers in exo-planets
  - Studies on very fast pulsars or other fast astronomical events.
  - Solar studies
- To be used for different astronomical sources, the infrared telescope will have:
  - A low frequency output (from 0 to 10kHz), called DC output
  - A high frequency output (from 10KHz to 400 MHz), called AC output





Participants

- LNF
  - Alessandro Drago (principal investigator), LNF senior associate, 90%
  - Simone Bini (resp.naz./loc.), technologist, 40%
  - Mariangela Cestelli Guidi, technologist, 20%
  - Augusto Marcelli, prime researcher, 20%
  - Rossano Sorchetti, technician, 10%
  - Raffaele Zarlenga, technician, 10%

- Florence University / Arcetri astronomy department
  - Emanuele Pace (university researcher), Director of the OPC - Osservatorio Polifunzionale del Chianti

- La Sapienza Rome University
  - Valerio Bocci (prime technologist) 0%, available to loan electronics from MICRO experiment (5th NSC)

Total F.T.E. 1.9 + UNI-FI

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PUBLISHED BY IOP PUBLISHING FOR SISSA MEDIALAB
RECEIVED: *May 9, 2016*
ACCEPTED: *June 23, 2016*
PUBLISHED: *July 7, 2016*

4TH INTERNATIONAL CONFERENCE FRONTIERS IN DIAGNOSTICS TECHNOLOGIES
30 MARCH 2016 TO 1 APRIL 2016
FRASCATI, ROME, ITALY

Fast rise time IR detectors for lepton colliders

A. Drago,[a,1] S. Bini,[a] M. Cestelli Guidi,[a] A. Marcelli[a,b] and E. Pace[c]

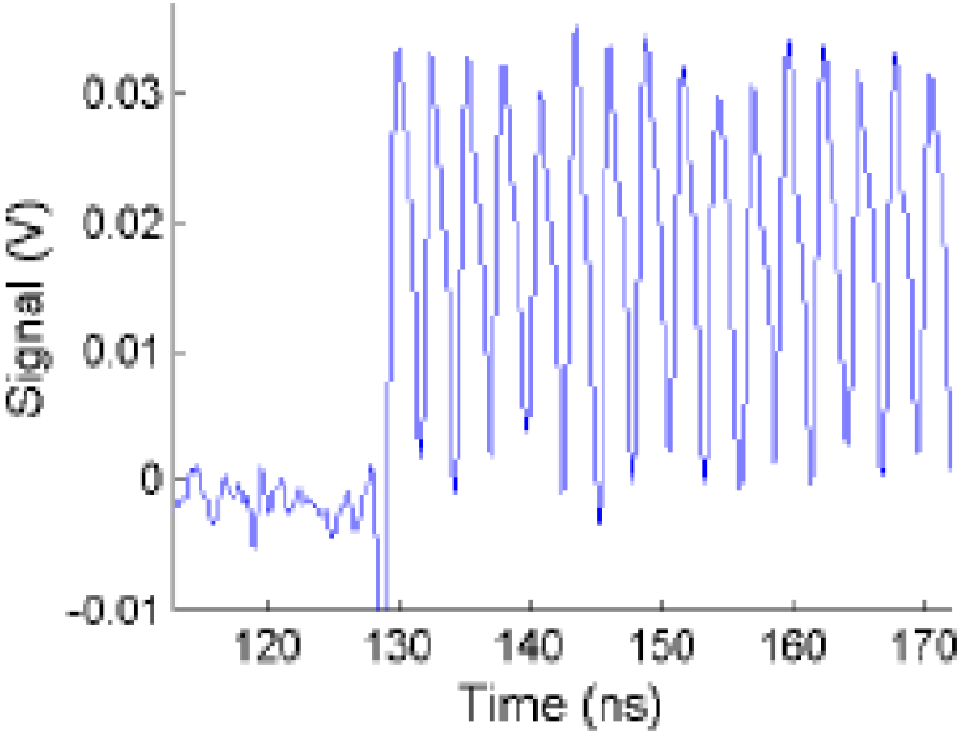

Figure 2. Longitudinal bunch signal is converted by the HgCdTe detector and acquired by the 3L and 3L_2D instrumentation. The bunch separation is 2.7 ns and the bunch train following the gap (after 130 ns in this plot) is well reproduced by the detector rise time.

Conclusion / comments

- The FAIRTEL approach is very different from the competitors: it does not look for an IR picture, it looks for IR signal time variations.
- Big opportunity to prepare the technological and scientific experience necessary for asking a European funding in 2024
- Low budget requested and low risks, because it will <u>use a standard telescope for IR</u>
- Why the 5x5 pixels ? To decrease the noise by using autocorrelation software techniques and to have good amplification by summing the 25 synchronized signals making a better signal-to-noise ratio
- A cryogenic system could be considered, even if most likely it will not be necessary
- Detector outputs must be studied both in DC (at very low frequency) to evaluate the sensitivity to the different astronomical source and in AC by using RF amplifier(s) to discover possible transients

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