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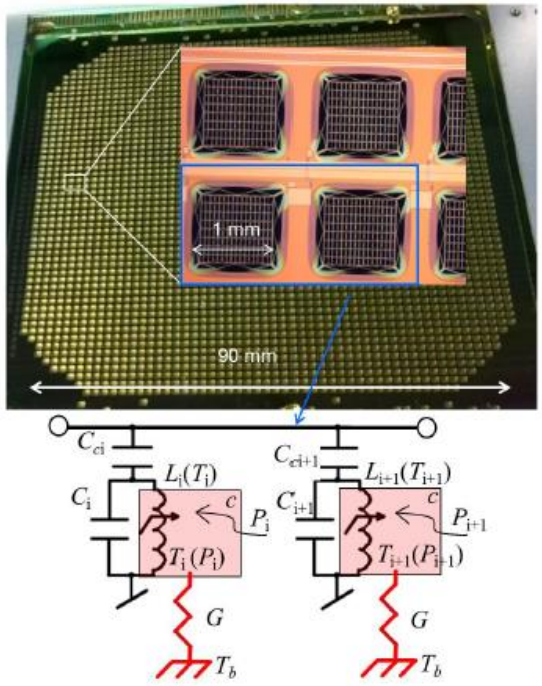

Kinetic inductance bolometers for security screening applications

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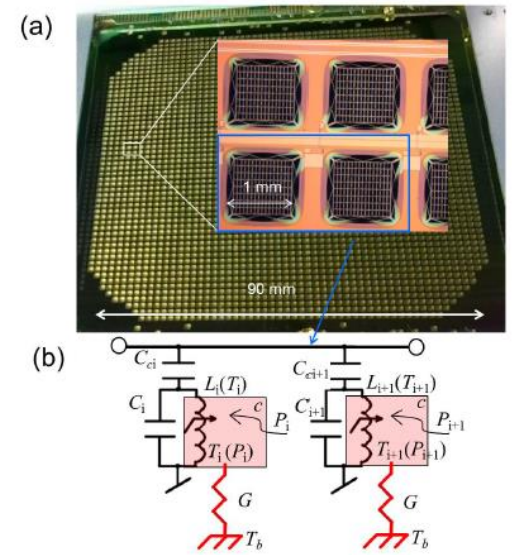
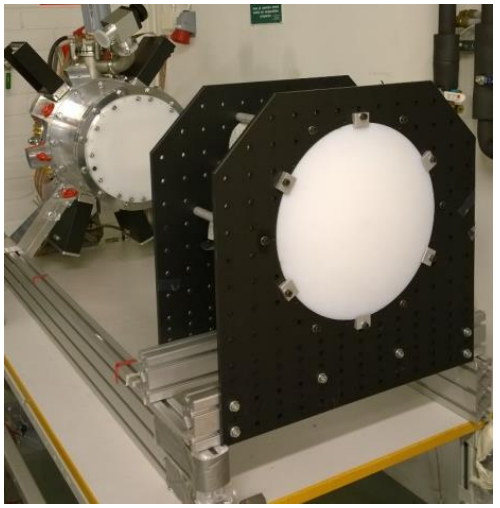
Introduction

- **Passive sub-THz band imaging technology with**
  - Relatively light cryogenics (5 – 10 K)
  - Sufficient radiometric resolution for contraband detection
  - Scalability of detector arrays
- **Kinetic inductance bolometer (KIB) technology**
  - Equilibrium mode KI detection enabling higher-temperature operation
  - RF coupled readout enabling multiplexing of large arrays
- **Topics:**
  - Basic operation of KIBs
  - Imaging system development based on KIBs

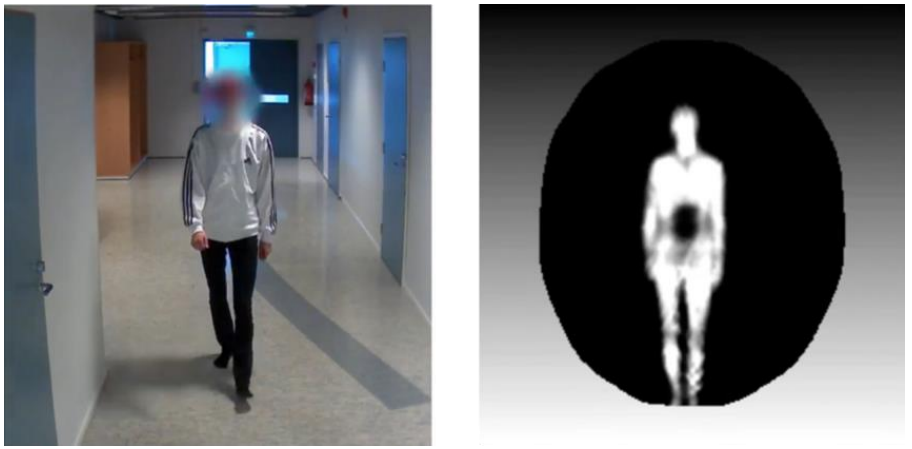




Background

- **VTT's THz imaging technology commercialized by Asqella Oy:**
  - Large FOV video-rate imager commercially available.
- **KIBs aimed as the second-generation technology:**
  - Larger detector arrays enabling improved spatial/radiometric resolution and relaxed requirements of optomechanics.

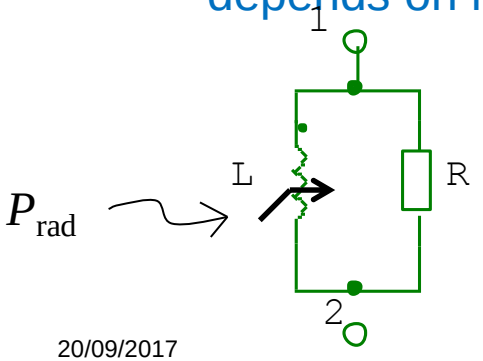
ARGON imager by Asqella Ltd.



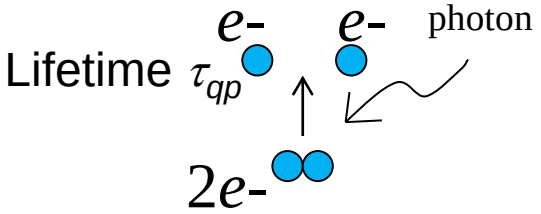
Video-frame illustrating concealed object detection.

Kinetic inductance for radiation detection

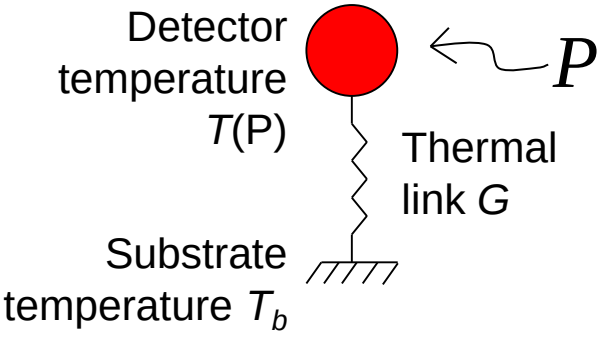
- In a low-loss medium charge carrier inertia shows as inductance
- Incoming power affects carrier (Cooper pair 2e) density n_s
  - Nonequilibrium mechanism: incoming photons break Cooper pairs. Excitation has finite lifetime τ_{qp} at very low (<1 K) temperatures.
  - Equilibrium (bolometer) mechanism: density n_s depends on temperature which in turn depends on incoming power.



$$L = \frac{m_0}{q_0^2 n_s} \frac{\ell}{A}$$



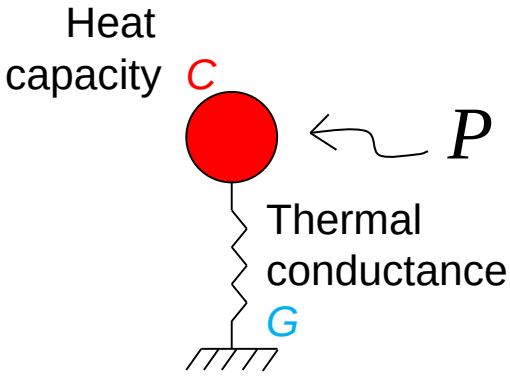
Nonequilibrium.



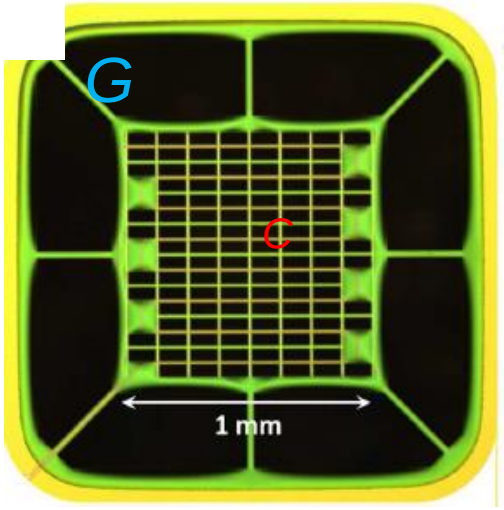
Equilibrium.

Kinetic inductance bolometer

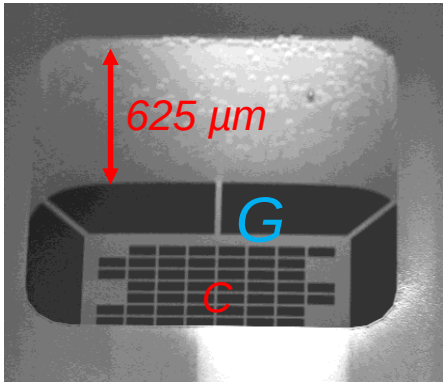
- **Bolometric mechanism**
  - works basically up to superconducting critical temperature T_c
  - In our case $T_c(\mathrm{NbN})$ up to about 14 K
  - In practice operation temperature 5 – 7 K.
- **Challenge: engineering of thermal confinement.**
  - Integration into nanomembrane technology
  - Micromachining to form perforated through-wafer membranes



Conceptual thermal model.

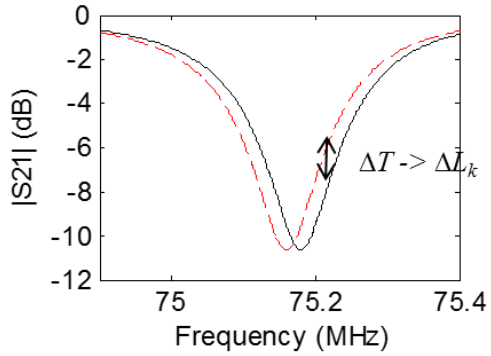


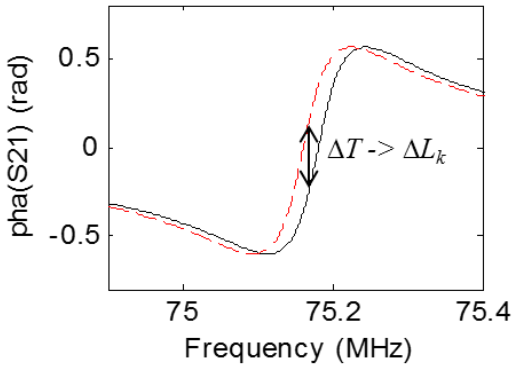
Microphotograph (front side).



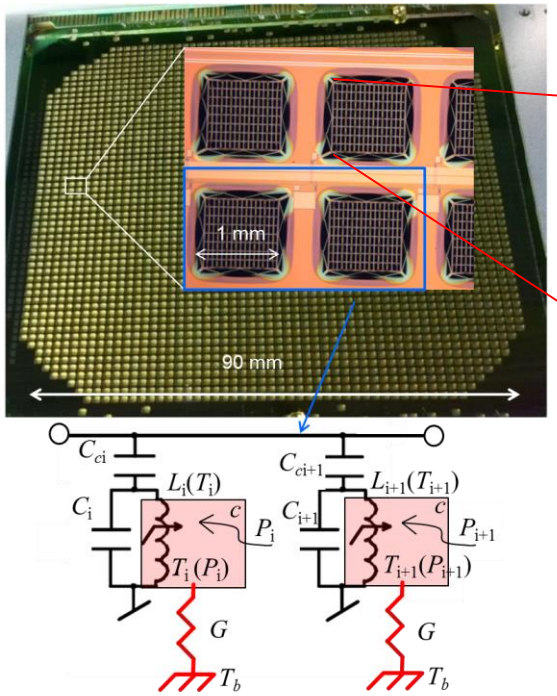
KIB readout coupling

- Individual RF resonance tuning for each detector within a readout channel
- Record the frequency shifted by the signal.

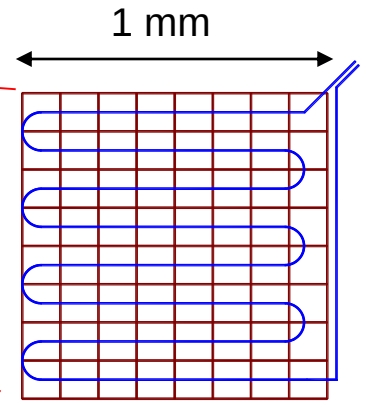




Effect of signal-induced resonance shift.

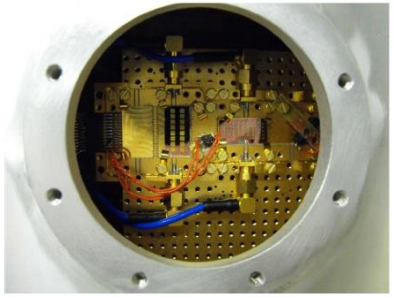


Matrix of ~2500 detectors and electrothermal equivalent of readout coupling.

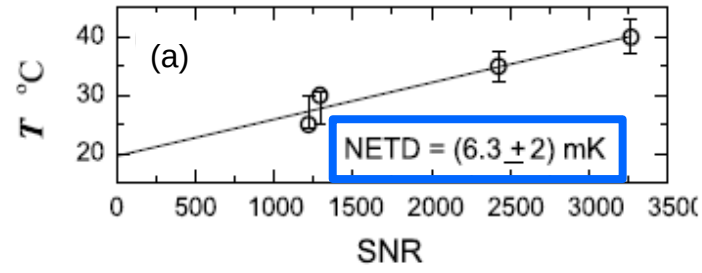


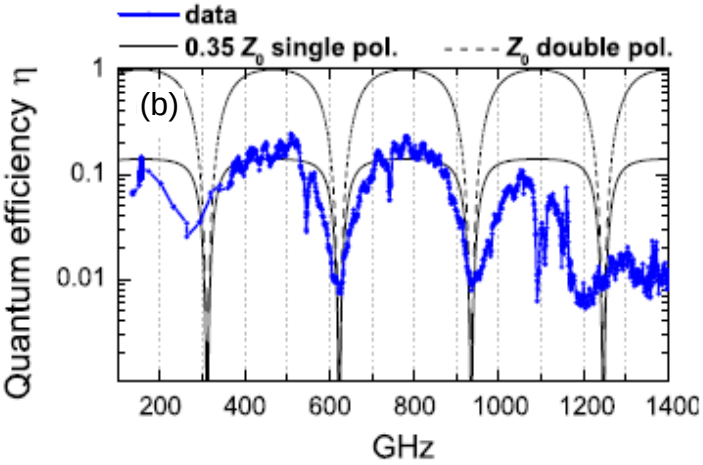
On-membrane structures: inductive meander strip $L_i(T_i)$ and resistive THz absorber

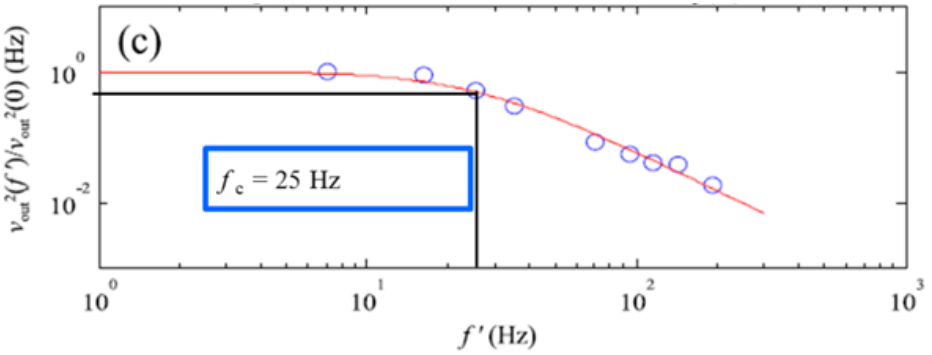
Electrical characteristics

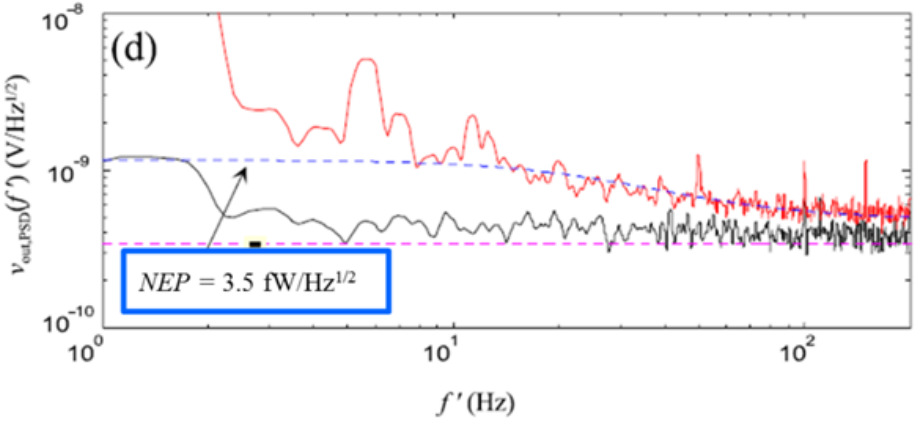


- **Single pixels and small arrays [1]:**
  - Phonon-noise limited NEP = 3.5 fW/Hz$^{1/2}$.
  - Thermal band sufficient for video-rate imaging, f_c = 25 Hz.
  - Radiometric contrast in line with requirements, NETD = 6.3 mK
  - Signal band as expected for back-cavity coupled absorber.





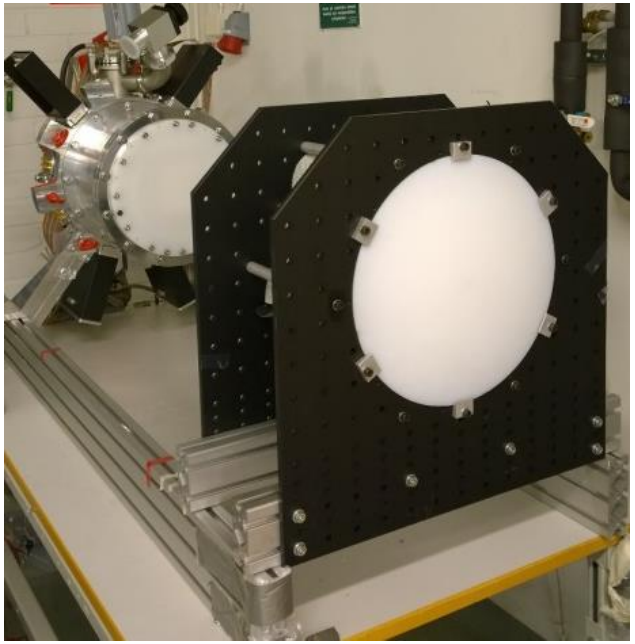




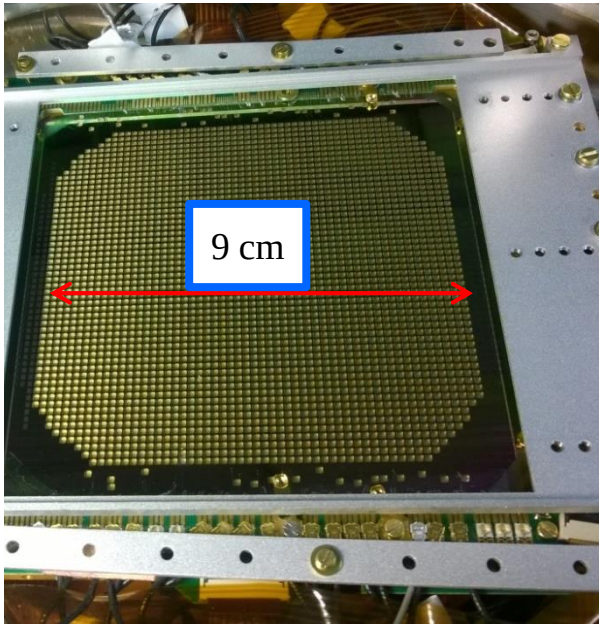
[1] A. Timofeev et al, Supercond. Sci. Technol. 27, 025002, 2014.

Scalability and system integration

- A small test system constructed for an experimental feasibility study [2]
  - 5 m standoff, optics limited FOV with 2 m radius.
  - ~2500 detectors, FOV limited to ~60 cm square.



Prototype imager with optics and vacuum system.

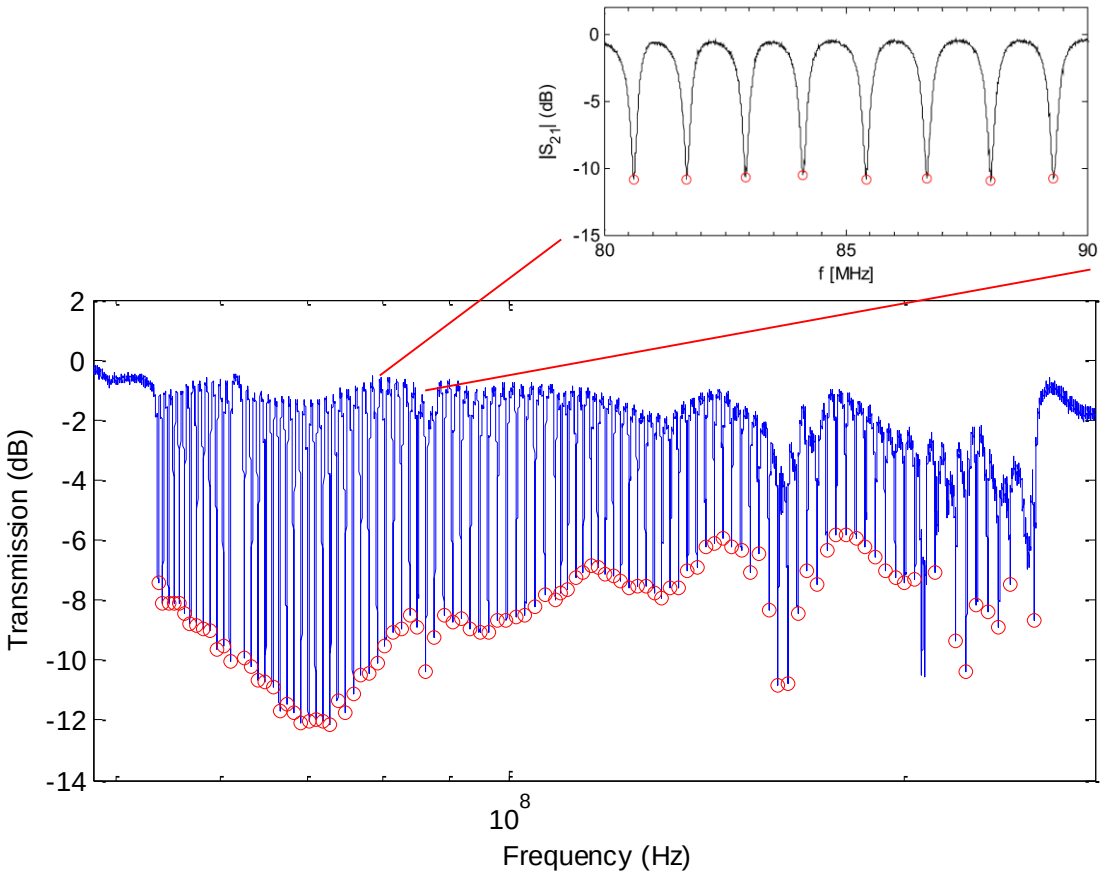


Focal plane array installed in the cryostat.

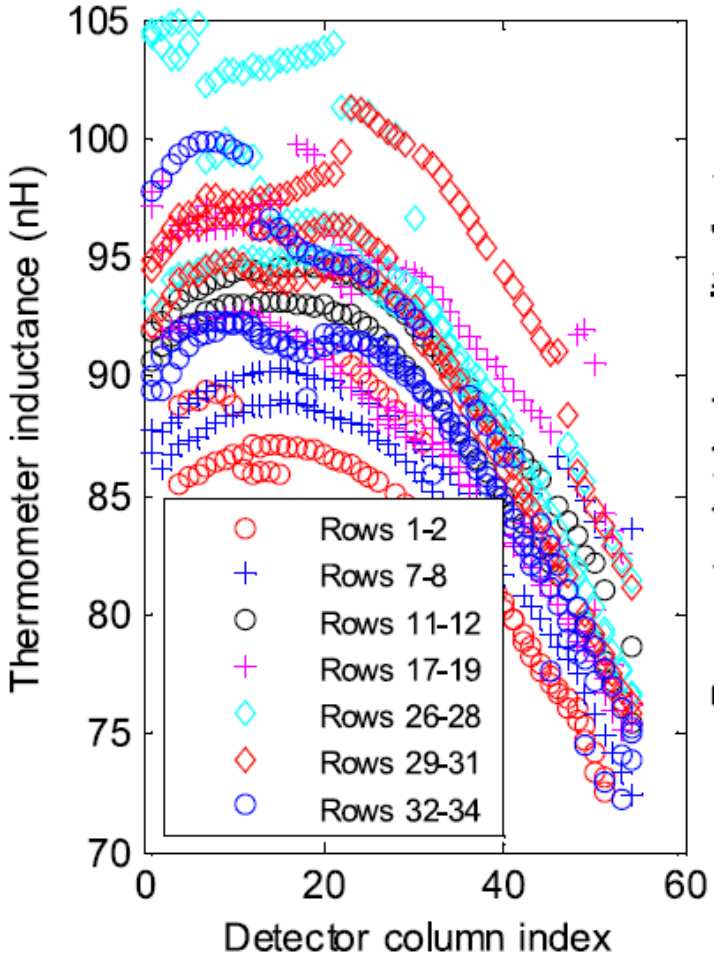
[2] A. Timofeev et al, IEEE Trans. Thz Sci. Technol. 025002, 2017.

Test system electrical characterization

- **Readout band characteirzation**
  - Pixel yield >95%.
  - Parameter variation tolerable.



Readout band transmission of one readout channel.

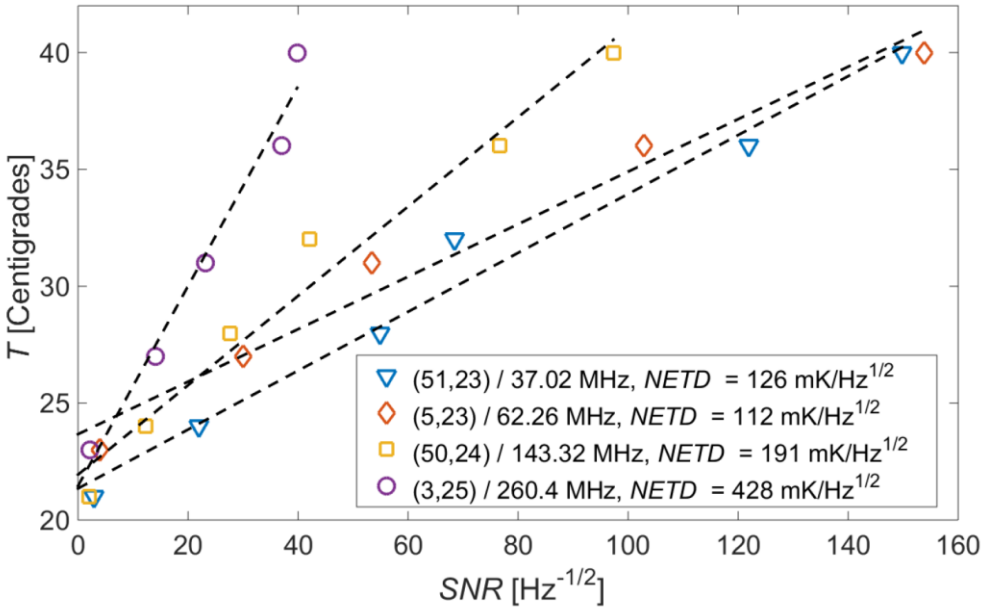


Extracted inductance spread from ~1000 detectors.

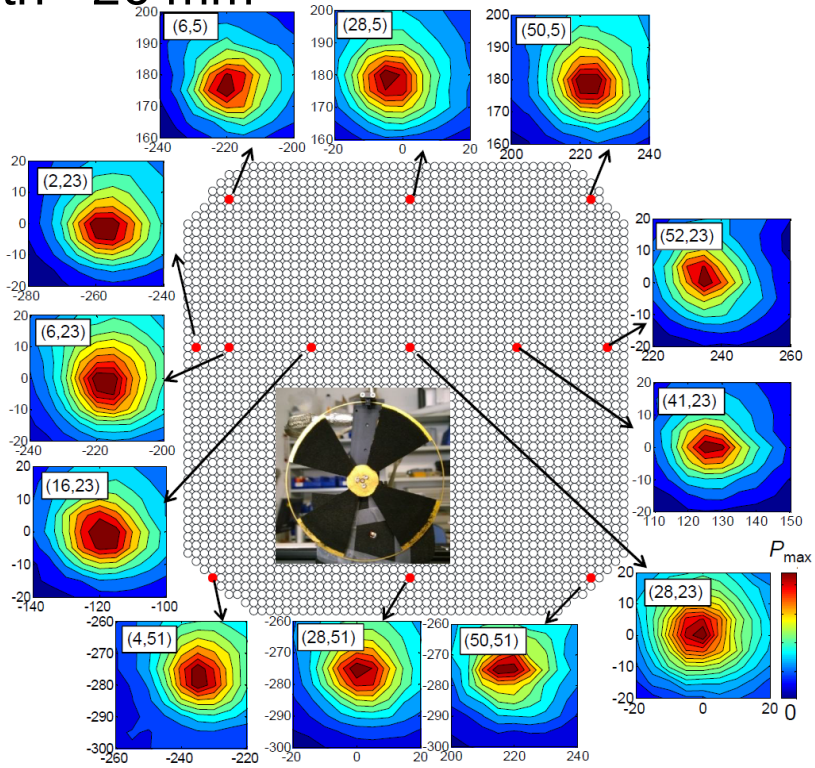
[2] A. Timofeev et al, IEEE Trans. Thz Sci. Technol. 025002, 2017.

Test system optical characterization

- Radiometric contrast and PSF measured with phantoms at 5 m standoff
  - NETD down to ~110 mK/Hz$^{1/2}$; PSF width ~26 mm



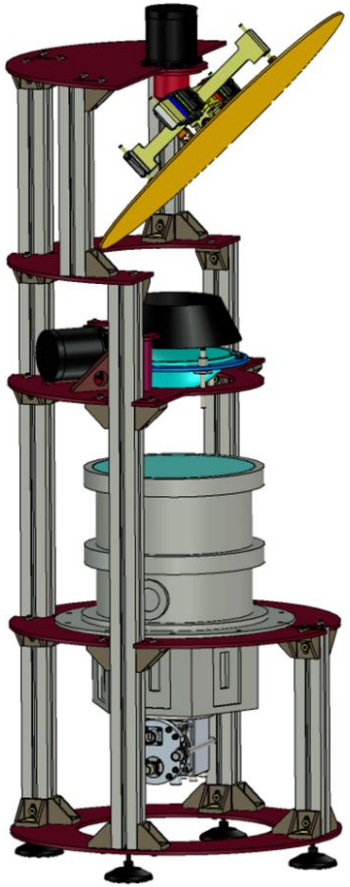
Radiometric contrast measured with acqueous blackbody calibrator.



Point spread functions across the FOV..

Construction of full-person imaging system

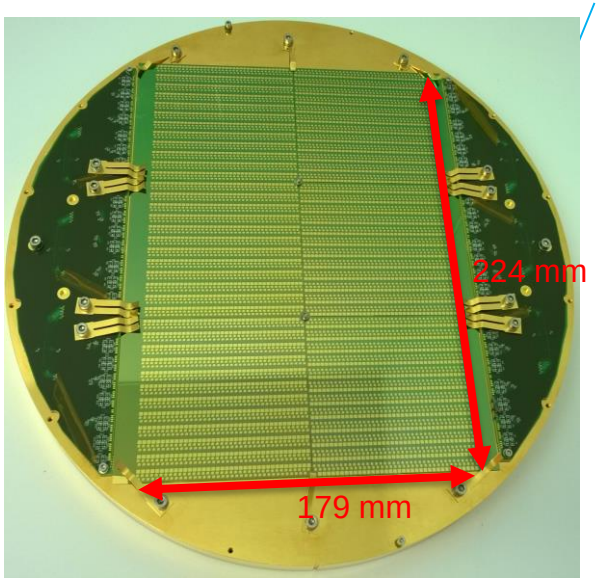
- Ongoing construction of full-person imaging system
  - CONSORTIS: dual modality active-passive imager [3].
  - KIBs to perform the passive imaging modality.
  - Optimised for walk-by system.
  - Full-person imaging with stand-off 1.6 m – 2.3 m



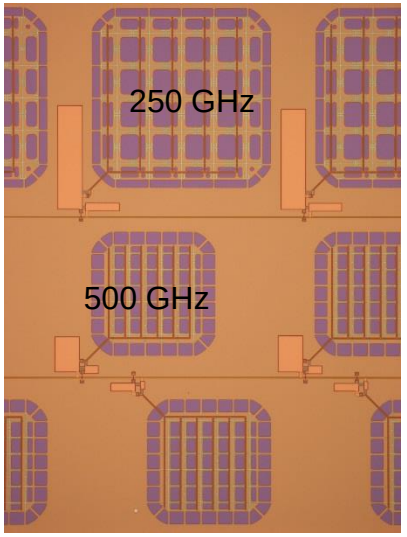
[3] Consortis collaboration, see www.consortis.eu.

CONSORTIS focal plane array

- Dual-band KIB matrix (250 GHz, 500 GHz) and wide-field-of-view optics designed by TU Delft.
- Focal plane array with 8208 detectors
- Dither scan to form 16416 image pixels @ 250 GHz and 65664 image pixels @ 500 GHz.

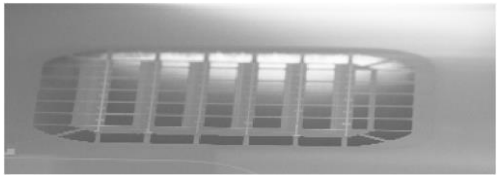


CONSORTIS passive focal plane.



Focal plane zoomup.

Scanning electron micrograph on 250 GHz detector.

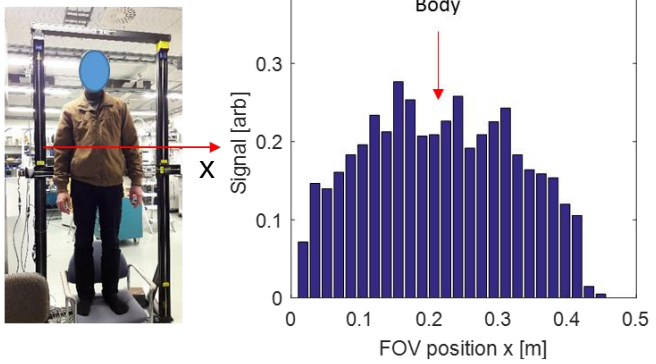


Scanning electron micrograph on 500 GHz detector.

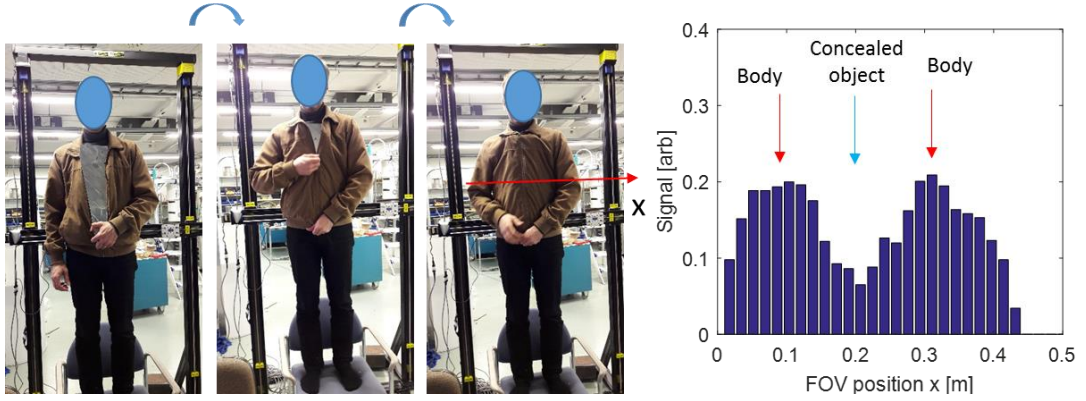
CONSORTIS passive system status

- Cryogenics and optics set up
- FPA and optics functionality observed with electrical and optical tests
- Electronics scale-up and software development ongoing.
- First video-rate concealed objects detection experiments performed.

Without concealed objects.



With metallic concealed object.



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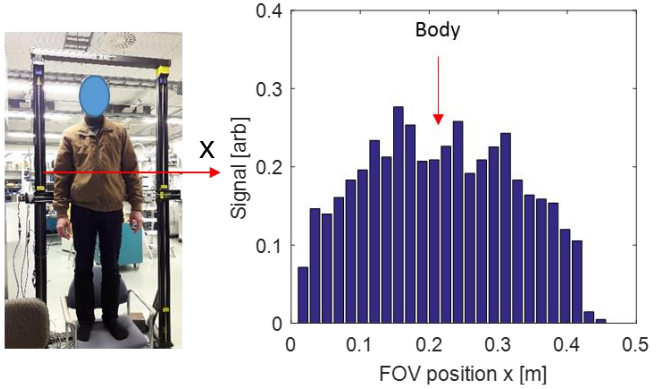
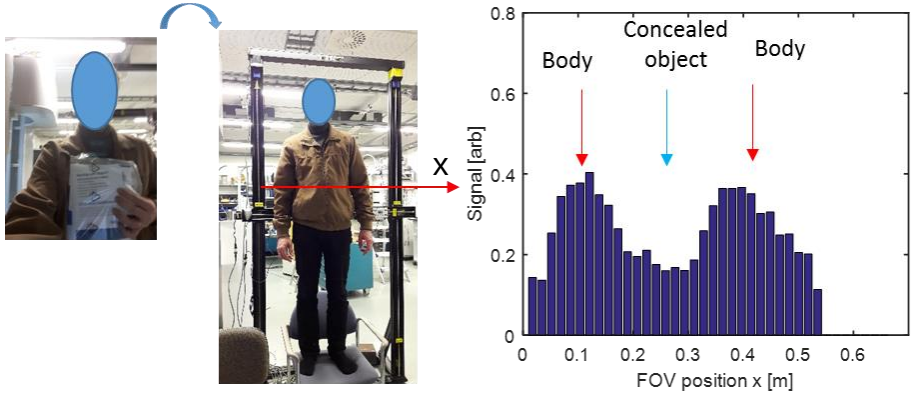
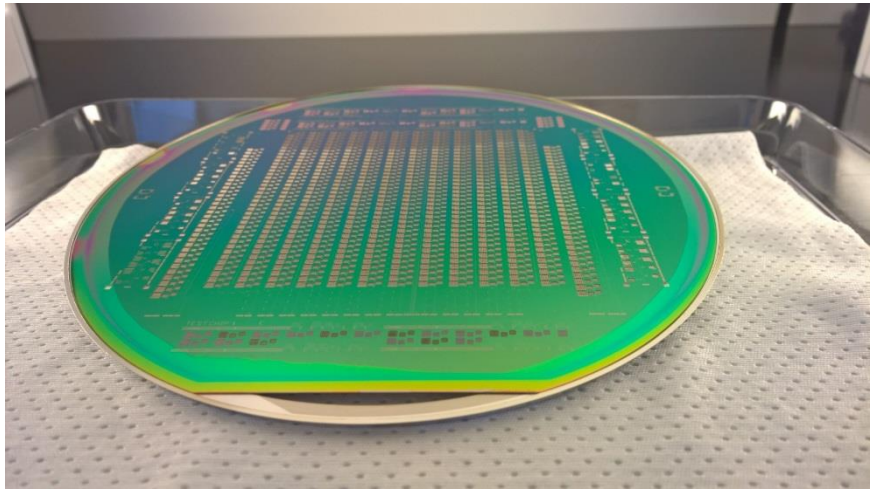


With dielectric concealed object.



Summary

- Kinetic inductance bolometers appear as a feasible technology in passive contraband detection.
  - Conclusion supported by electrical and optical characterization.
- Full-scale CONSORTIS radiometer mainly constructed and undergoing tests:
  - Concealed object detection capacity verified.
  - Certain electronics and software aspects still to be addressed.



Thank you!

Contributions

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