Multiplexed readout of kinetic inductance bolometer arrays

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Introduction

Kinetic inductance bolometers (KIBs) [1] can be constructed into kilo-pixel detector arrays [2], allowing them to be used in passive sub-millimeter and terahertz imaging systems that operate above 5 K. Just like their millikelvin counterparts, kinetic inductance detectors, KIBs can be read out using frequency-division multiplexing (FDM) techniques. However, to avoid the use of expensive high-speed digital electronics, we present a new readout scheme called serial addressed frequency excitation (SAFE) [3], which combines features from both FDM and time-division multiplexing.

SAFE concept

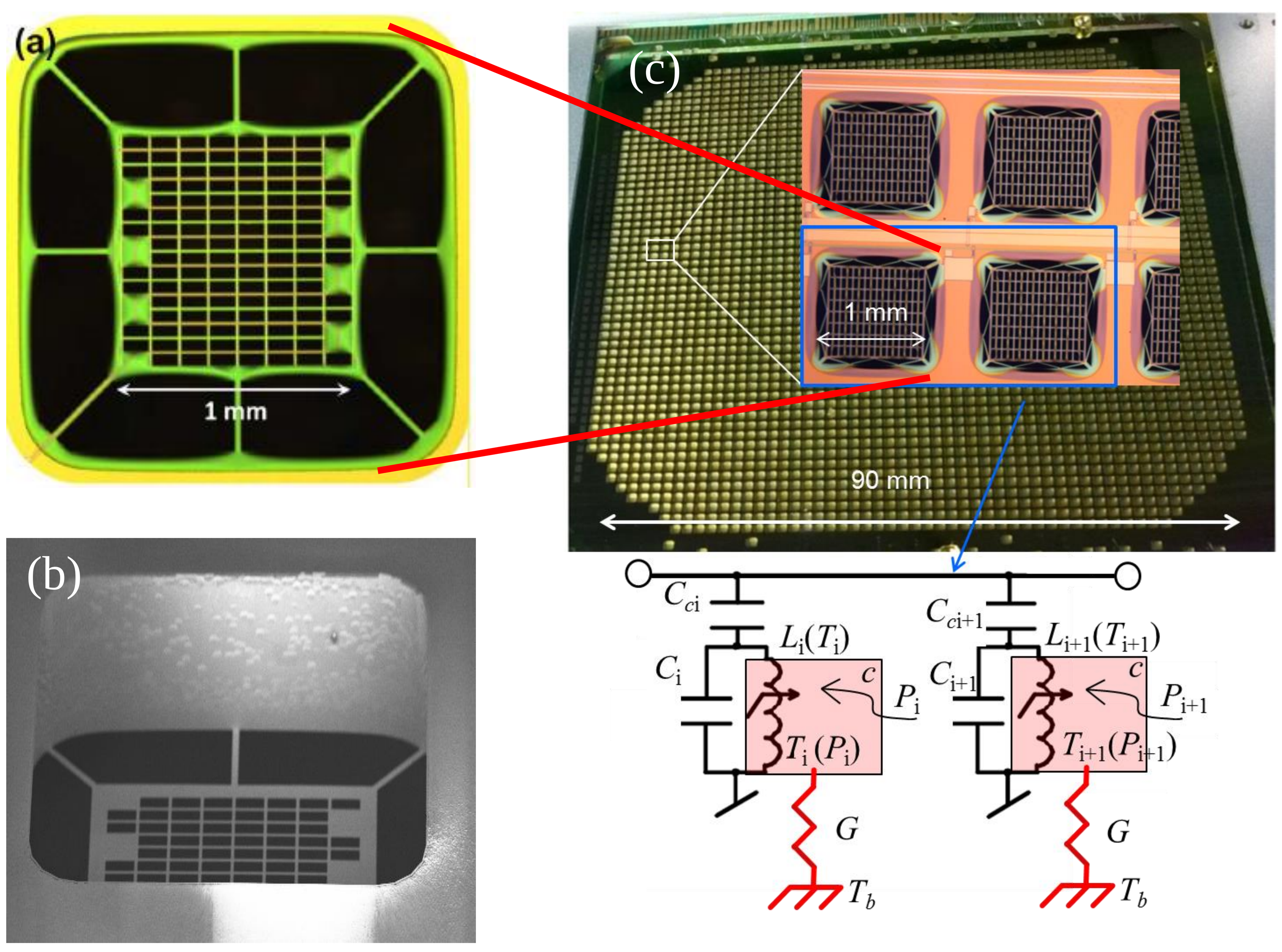

Figure 1. *(a) Microphotograph of the detector patterned (b) on a nanomembrane for thermal isolation. (c) A detector array with 2500 pixels together with electrothermal schematic of a part of the array. The absorbed radiation power P_i at ith detector heats the thermal volume to temperature T_i (heat capacity c and thermal conductance G at constant bath temperature T_b). The temperature change is recorded via the change of L_i converting to the change of resonant frequency f_i of L_i–C_i resonator.*

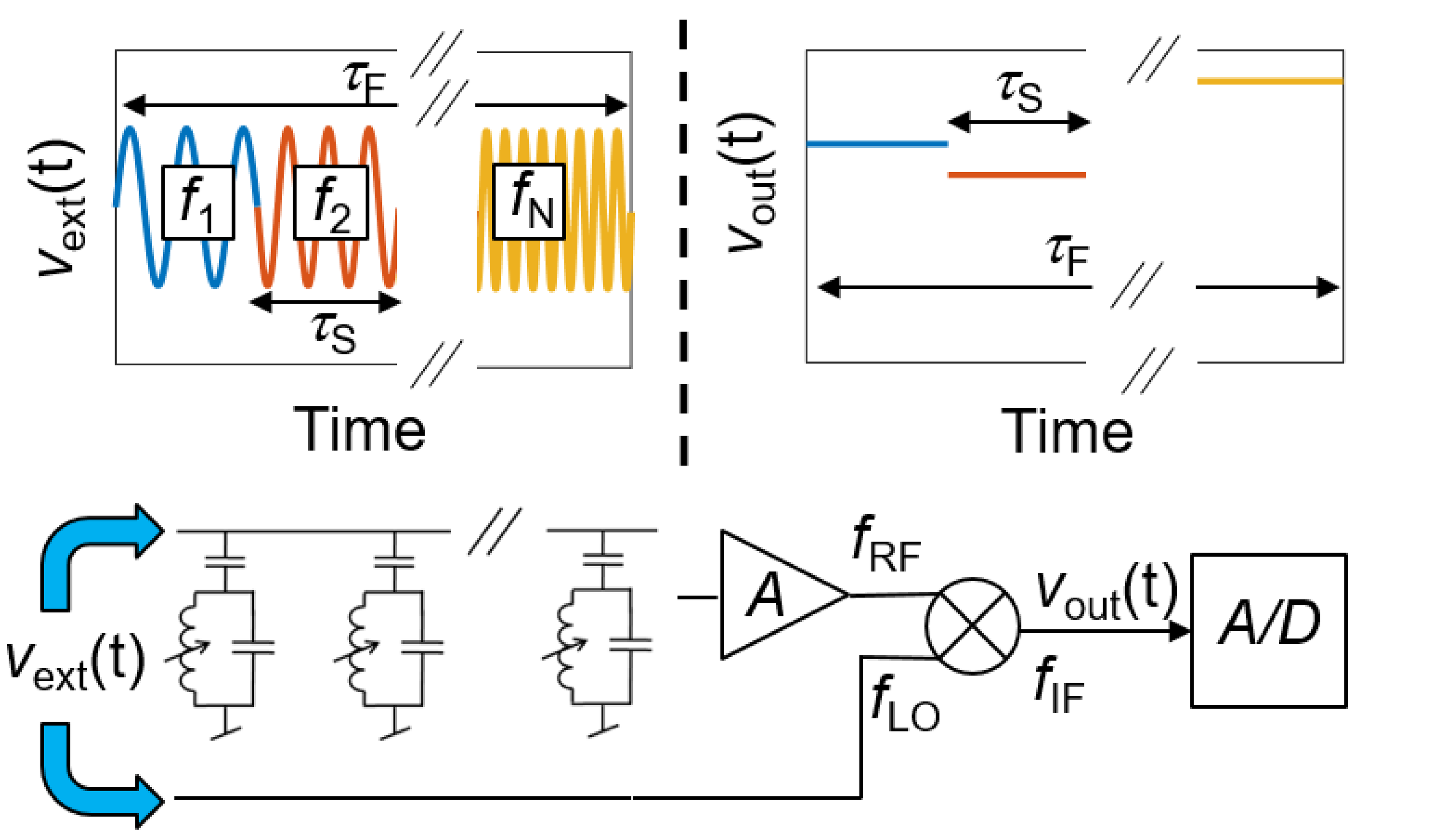

Figure 2. A conceptual illustration of SAFE. During frame rate τ_F all N detectors are probed by individual readout tones f_i for a duration of $\tau_S = \tau_F/N$. After passing through the resonator network, the signal-modulated rf signal is amplified and demodulated to the baseband with a mixer, thus containing the time-multiplexed detector signals that are A/D-converted.

Implementation

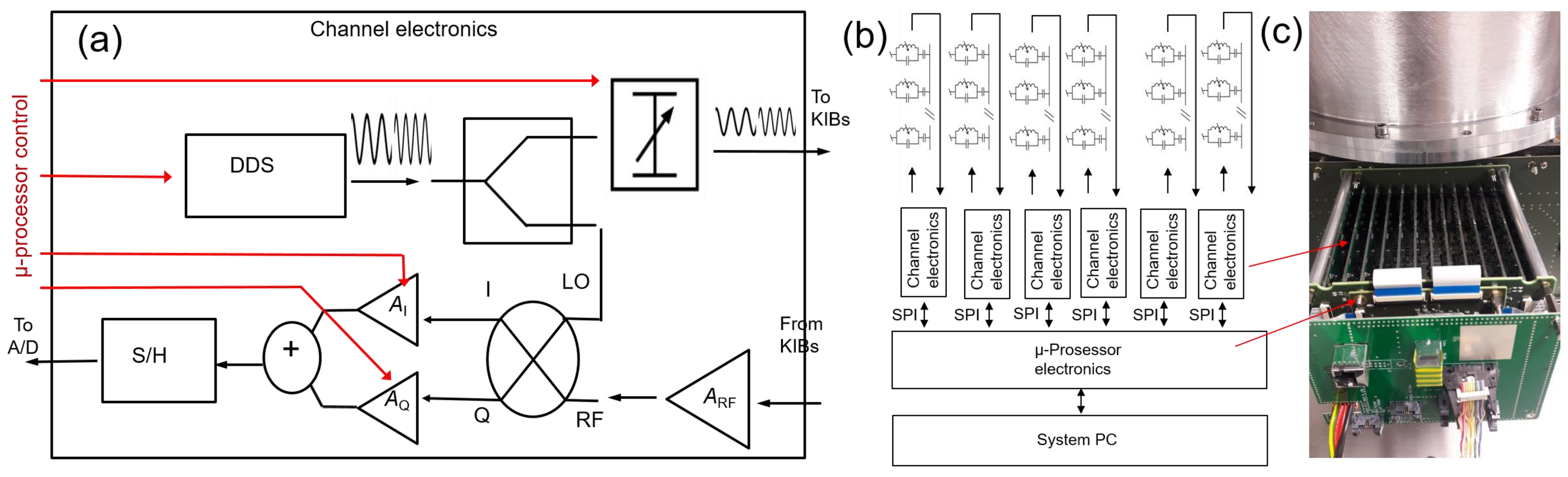

Figure 3. (a) The signal flow in channel electronics which hosts the main functionalities of the readout sequence, i.e., RF excitation, RF preamplification, and demodulation. (b) The electronics block diagram of the implementation as well as (c) a photograph of an electronics block.

Noise dynamics

- We express the total noise $S(N) = S_{\mathrm{BLW}}(N) + S_{\mathrm{W}}(N)$, where N is the multiplexing ratio, S_{BLW} band-limited white noise and S_{W} wide-band white noise components.
- Multiplexing penalty reads
$$\frac{S(N)}{S(1)} = \frac{1}{\gamma+1}\left(\frac{S_{\mathrm{BLW}}(N)}{S_{\mathrm{BLW}}(1)} + \gamma N\right),$$
where $\gamma = S_{\mathrm{W}}(1)/S_{\mathrm{BLW}}(1)$.
- In theory, there is no noise penalty for ideal band-limited white noise ($\gamma = 0$) and sampling that fulfills the Nyquist criterion $f_{\mathrm{F}} = \frac{1}{\tau_{\mathrm{F}}} > 2f_{\mathrm{c}}$, i.e., $\frac{S_{\mathrm{BLW}}(N)}{S_{\mathrm{BLW}}(1)} = 1$.
- Non-multiplexed detector noise is dominated by the band-limited phonon noise $S_{\mathrm{BLW}}(1) = \sqrt{4kBT^2G}$ with $f_{\mathrm{c}} = G/(2\pi c)$ being the cut-off frequency although there exists also a smaller (wide-band) noise contribution stemming from the excitation and readout electronics.

Imaging example

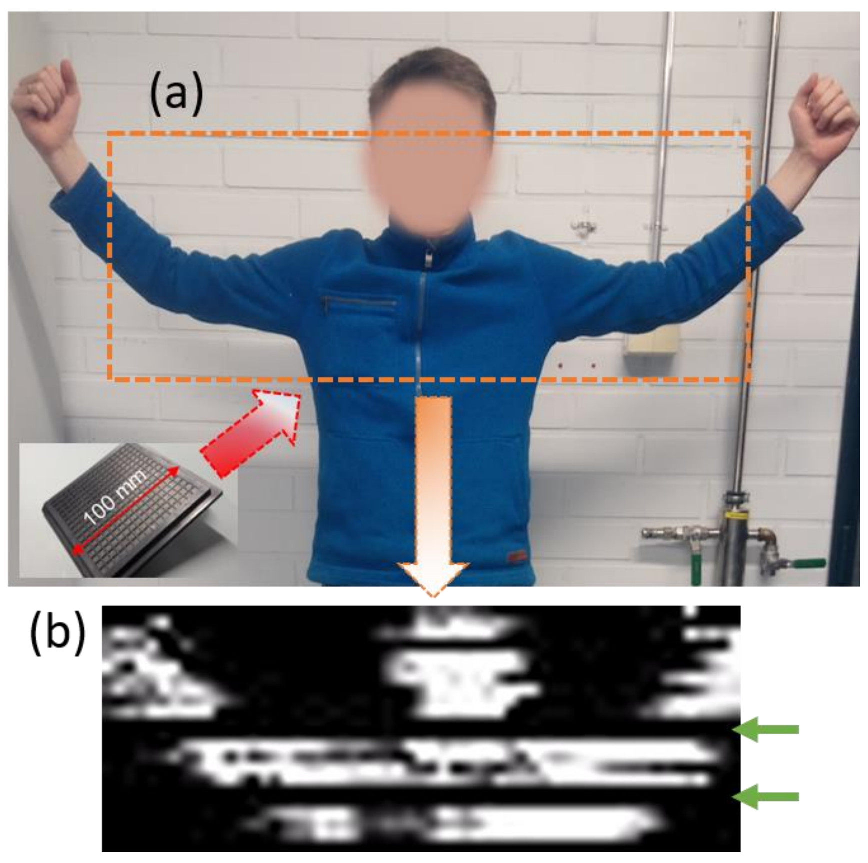

Figure 4. (a) An optical photograph imitating the actual imaging situation. (b) A snapshot from a video acquired with > 1000 detectors and post-integrated into a 10-Hz frame rate. A plastic object depicted in the inset of (a) is hidden in the pocket of the fleece jacket and the corresponding feature is also visible in (b). The detector yield in this case was > 97% leading to 2-3 dead pixels per channel on average and inaccuracy in spatial mapping of some pixels. Also the two channels indicated with green arrows in (b) were not available for the measurement.

Conclusions

- **A new multiplexing scheme presented to read out large arrays of KIBs that avoids the multiplexing penalty partially or even completely.**
- **High-speed digital electronics limited to a controlable RF source only.**

[1] A. V. Timofeev *et al.*, *Supercond. Sci. Technol.* **27**, 025002 (2014).
[2] A, Timofeev *et al.*, *IEEE Trans. THz. Sci. Technol.* **7**, 218 (2017).
[3] H. Sipola *et al.*, *Rev. Sci. Instrum.* **90**, 074702 (2019).

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