Design Optimization of a 10 Kilopixel Optical Band Microwave Kinetic Inductance Detector

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Abstract: In order to make improved spectral imaging measurements in the ultraviolet, visible and near infrared bands, we investigated the design of a 10 kilopixel Microwave Kinetic Inductance Detector (MKID) sensitive in these bands. We evaluate design parameters for MKIDs arrays with equally spaced resonant frequencies and high intrinsic and coupling quality factors. Resonance frequencies were chosen in the range of 2.8-4.8 GHz with an average of 2 MHz intervals. We describe the optimization of our design, including reduced cross-coupling. Through simulations, we find the average intrinsic and coupling quality factors to be on the order of 10^7 and 3×10^4 respectively, which are good enough for our purposes.

Introduction

MKIDs are superconducting resonant LRC circuits whereby a photon absorption in the sensitive medium breaks cooper pairs leading to an increase in kinetic inductance, in turn causing changes in resonance phase and amplitude that can be used to sense the energy and time of arrival of each incoming photon [1,2]. In our designs, interdigitated capacitors are used to tune the resonant frequencies only, and meandered lines make up the changing value inductor. MKIDs can be tuned for performance across a wide range of frequency, currently from at least sub-mm to optical regimes [3]

Design

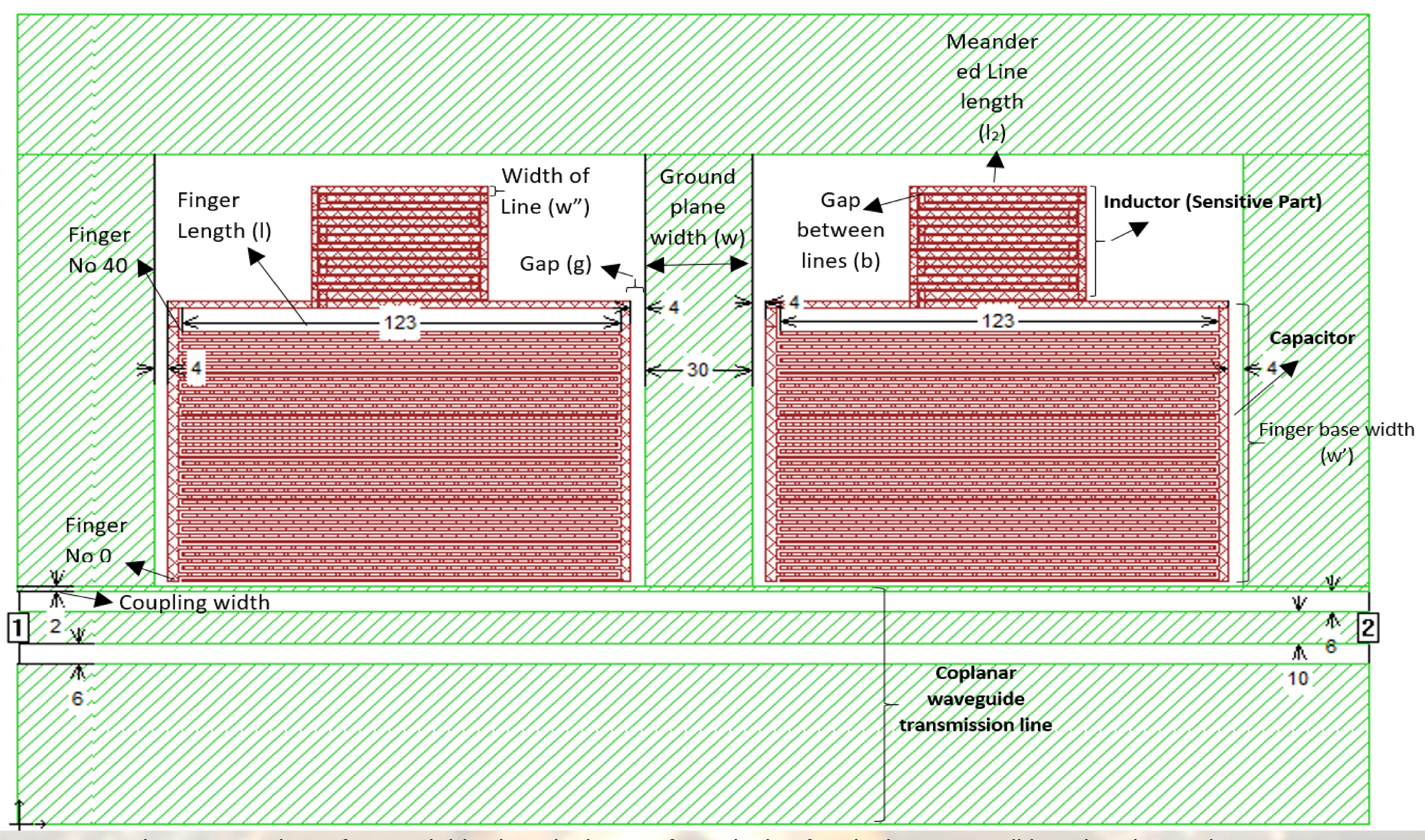


Figure 1. Design of two neighboring pixels out of 1K pixels of optical MKIDs, All length units are in μm.

We have readout electronics with a bandwidth of 2 GHz and frequency range of 0-6 GHz. 2 GHz bandwidth electronics, and the smallest practical regular frequency spacing, 2 MHz, gives 1 k pixels [4]. Simulating a design with these parameters yielded resonance frequencies in the range of 2.8-4.8 GHz. By considering 10 identical sets of MKIDs with 10 Input/output feedlines on the same Silicon wafer, we can obtain our 10kpixel MKIDs. In this design, we used 60 nm thick TiN with a kinetic inductance of 24pH/square for the resonators, 60 nm thick Nb with a kinetic inductance of 0.2 pH/square for the coplanar waveguide transmission lines and ground planes and 300 μm thick high resistivity (>15000 Ω.cm) Silicon as the substrate.

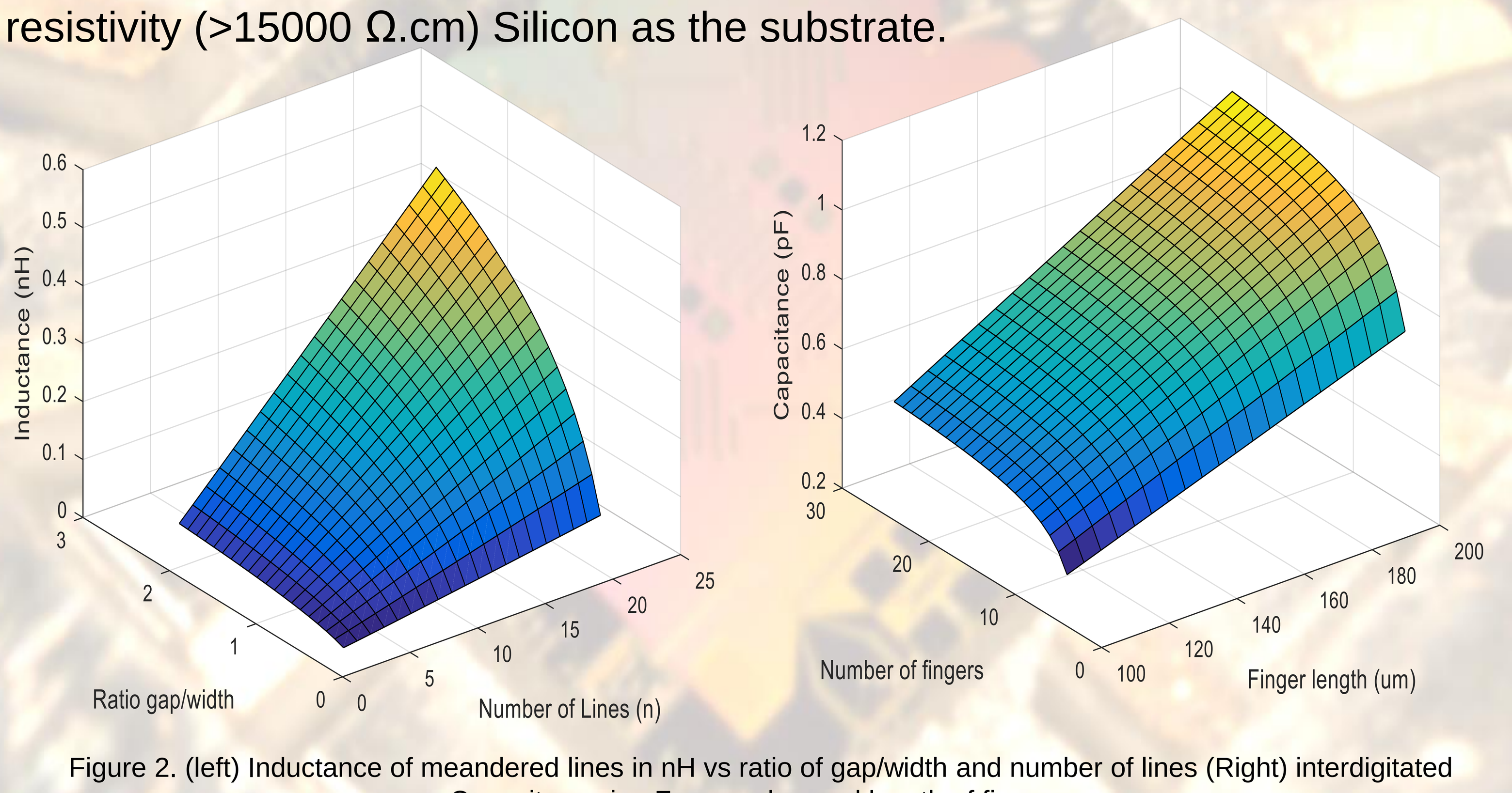


Figure 2. (left) Inductance of meandered lines in nH vs ratio of gap/width and number of lines (Right) interdigitated Capacitance in pF vs number and length of fingers.

Results

Coupling to the transmission line

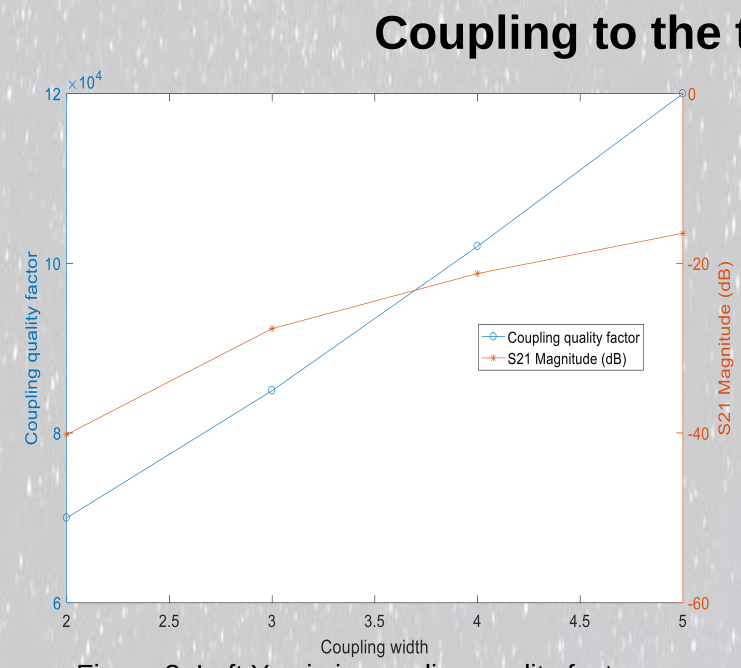


Figure 3. Left Y-axis is coupling quality factor and right Y-axis is depth of resonator (S21 magnitude in dB) for different coupling width in μm.

The total quality factor, Q, is given by:

$$\frac{1}{Q}=\frac{1}{Q_i}+\frac{1}{Q_c}$$

where the intrinsic and coupling quality factors are Q_c *and* Q_i, respectively. For very high intrinsic quality factors, $Q_{tot} \approx Q_c$

Resonator cross coupling and fill factor

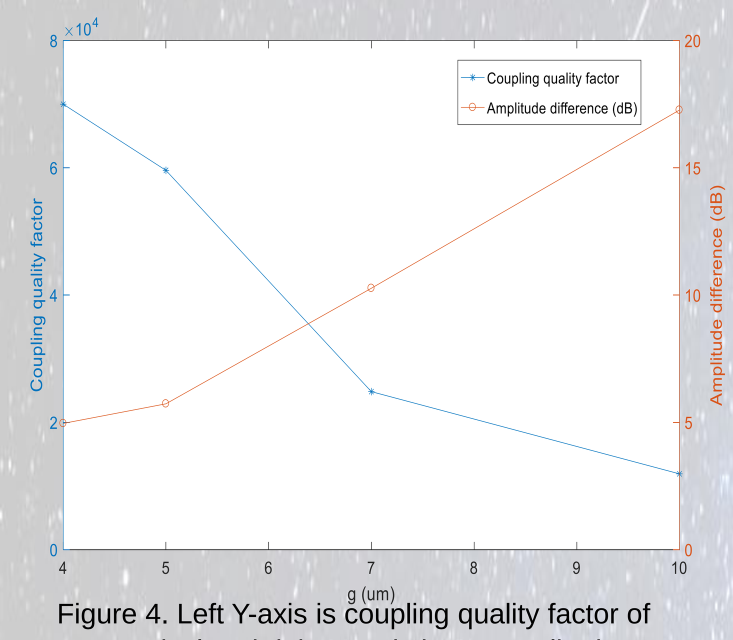


Figure 4. Left Y-axis is coupling quality factor of one pixel and right Y- axis is S_{21} amplitude difference of neighboring resonators (ΔA) at different *g* with fixed *w*=30μm.

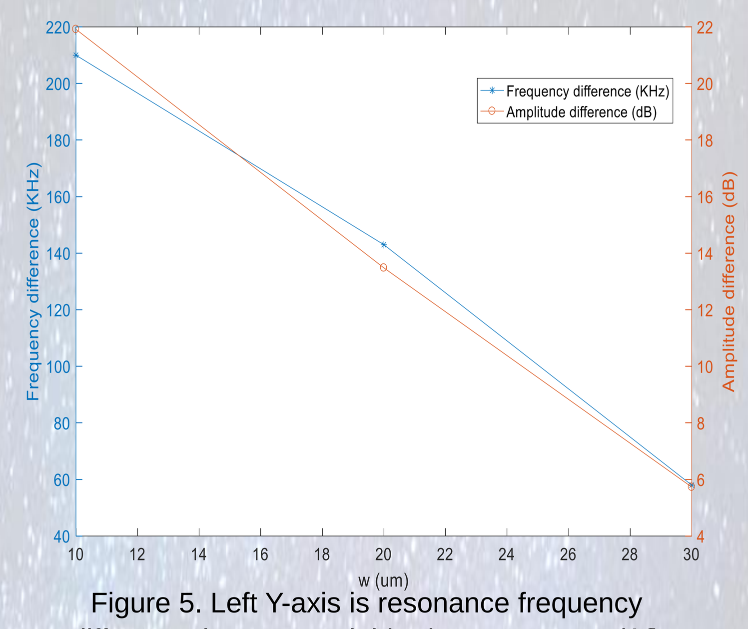


Figure 5. Left Y-axis is resonance frequency difference between neighboring resonators (Δf) and right Y- axis is S_{21} amplitude difference of neighboring resonators (ΔA) at different *w* with fixed *g* =4μm.

Tuning the Resonant Frequency Spacing by Varying the Finger Length

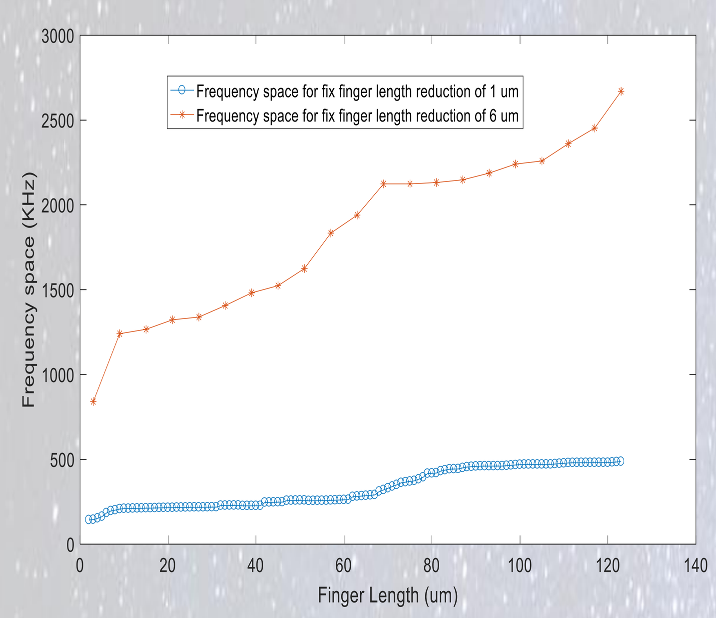


Figure 6. Resonance frequency spacing between successive pixels for reducing the length of finger number 40 by steps of *Δx*=1μm and *Δx*=6μm. For *Δx*=1μm we have 123 finger lengths (pixels) and for *Δx*=6μm we have 21 finger lengths (pixels) from 3 μm to 123 μm.

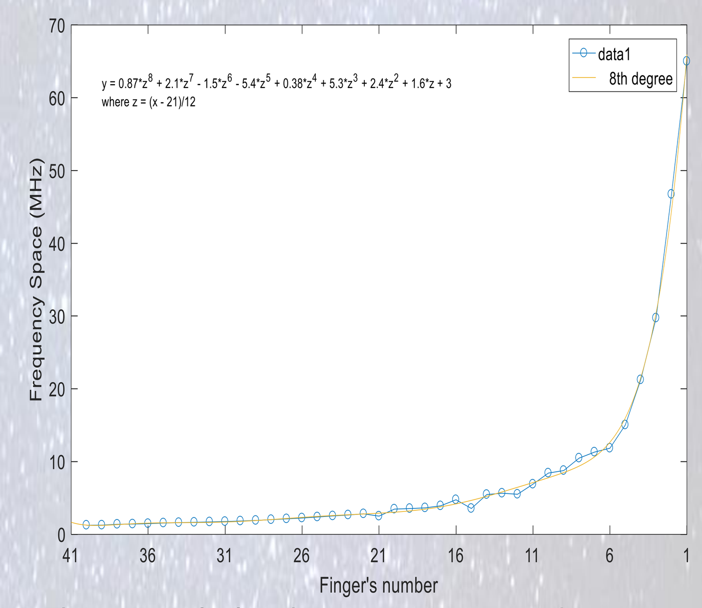


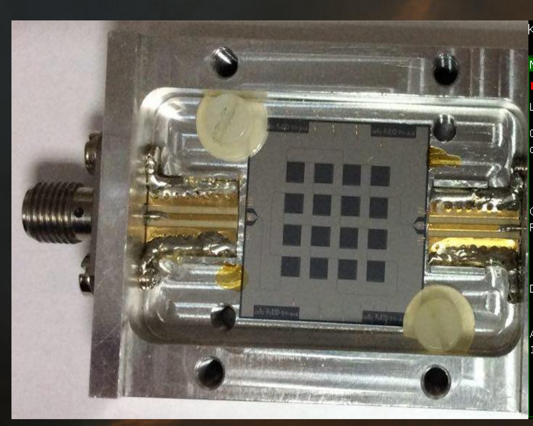
Figure 7. Calculated average resonance frequency spacing for each resonators with a finger length reduction of 6 μm, on different fingers.

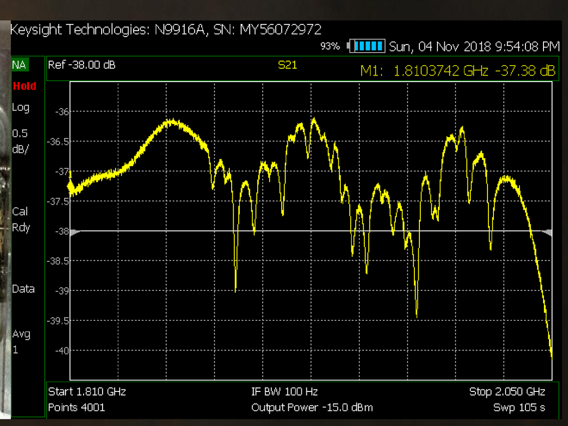
Conclusion

The proposed geometry can be used for making 1,000 pixels with resonance frequencies in the range of of 2.8-4.8 GHz with 2 MHz gap between resonance frequencies. To make 10,000 pixels we need to use 10 identical sets of MKIDs with 10 feedlines on the same Si wafer. In order to reduce the number of feed lines, we have to use wide band electronic readout system and use more fingers in our design to produce more pixels.

Our MKIDs Lab

Cryostat HPD Shasta 106 ADR 30 mK





10.5 GSPS ADC and 12.6 GSPS DAC with Ultra scale FPGA and GPU K80 as readout system

References

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