# Multi-Chroic Detectors for Observing the Cosmic Microwave Background

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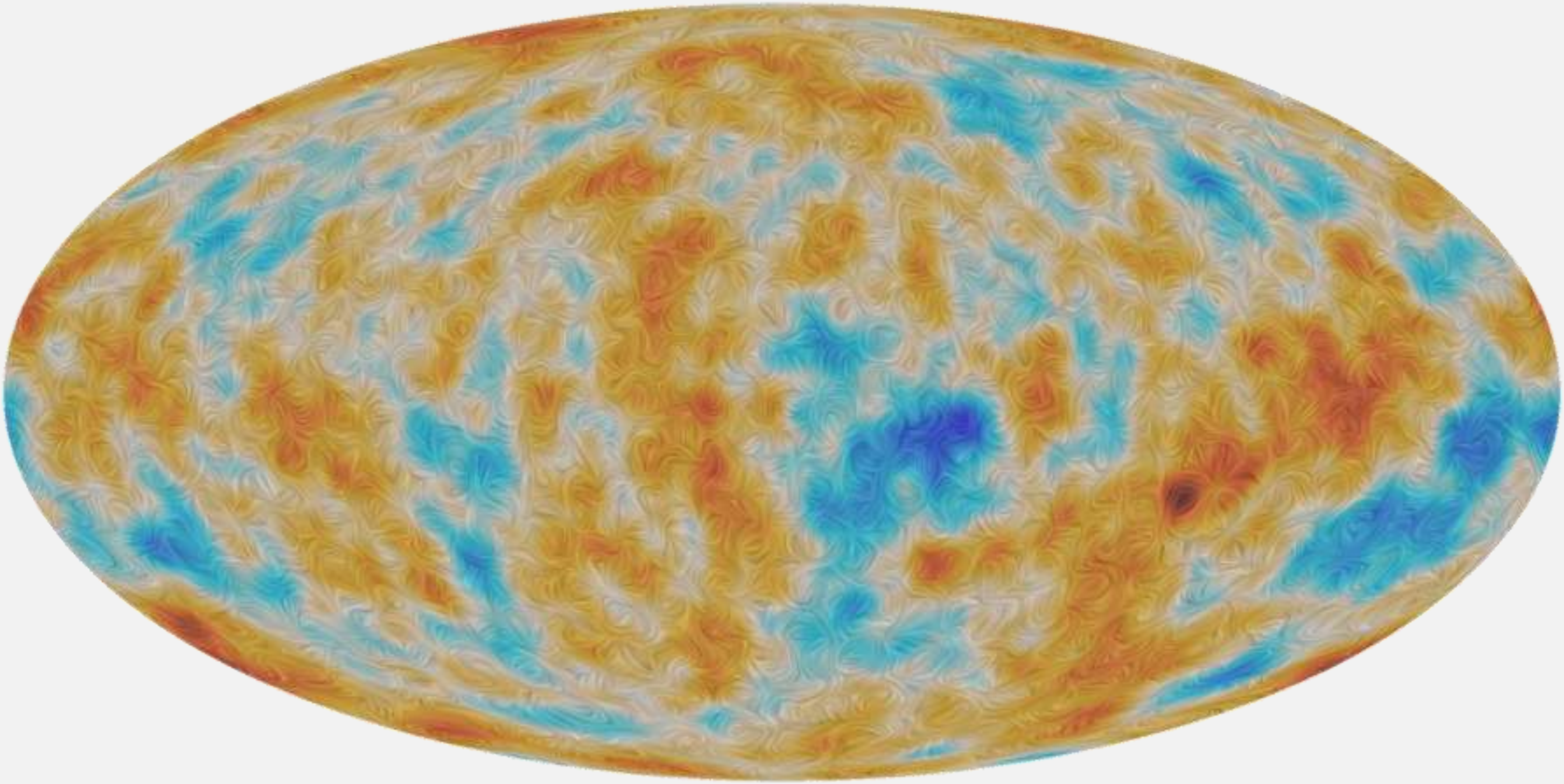
# Outline



- Motivation
- Kinetic Inductance Detectors (KIDs)
- Antenna-Coupled LEKID

# Motivation: B-Modes

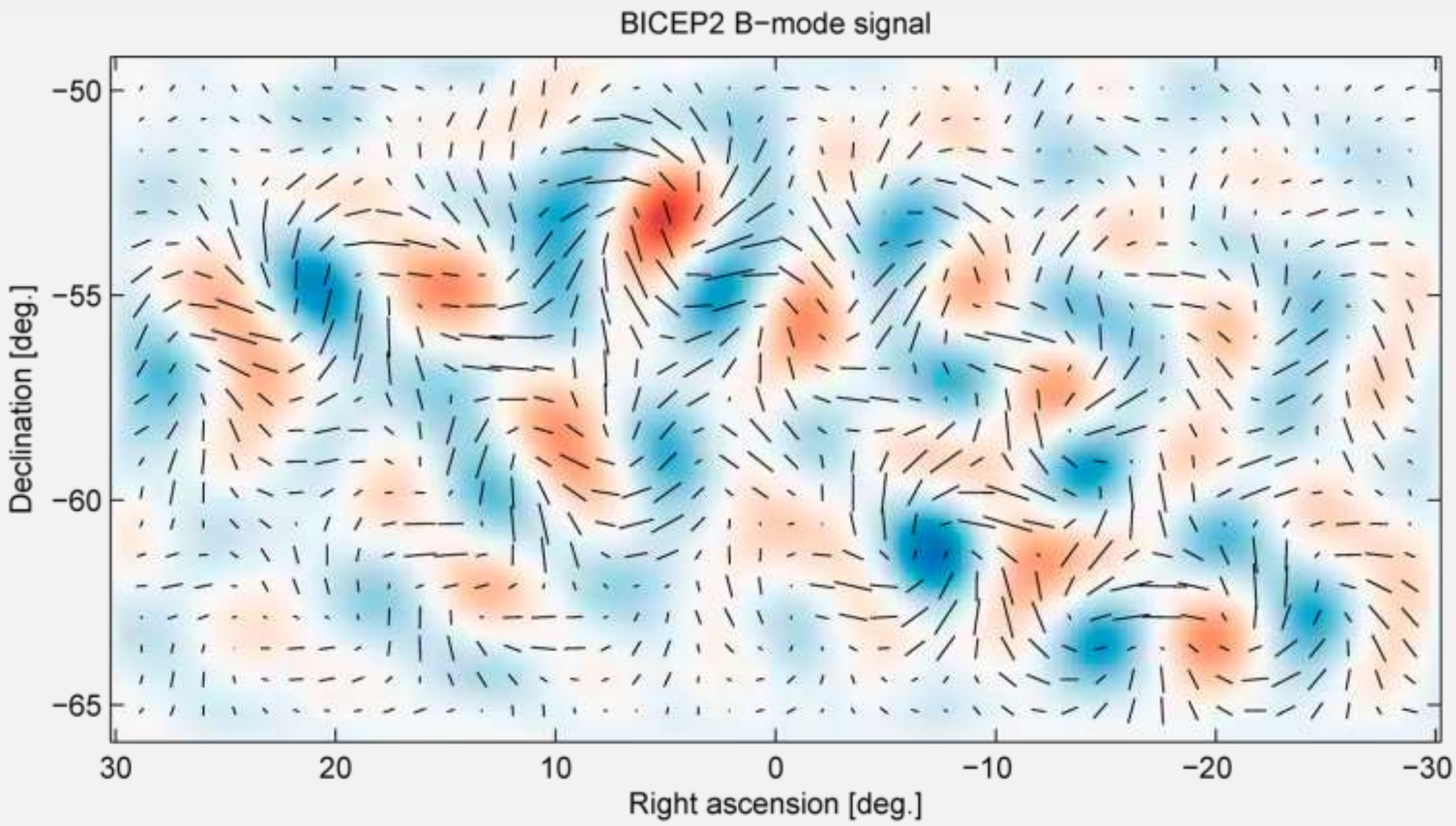


CMB as detected by ESA's Planck Space Telescope

Approximately the 10% of CMB is polarized

# Motivation: B-Modes






TENSOR to SCALAR ratio from Planck (and Bicep2)

$$r < 10^{-1}$$

# Future CMB Observations: Technological Challenges



- From Theory(ies): B-Modes 100 times fainter than Planck limit

↓

Detectors already photon noise limited

↓

About x100 number of detectors required ($\approx 10^4$)

- Foreground Contamination (Gravitational lensing, cosmic dust …)

↓

Wide spectral coverage - from 60 GHz to 600 GHz

Antenna Coupling:

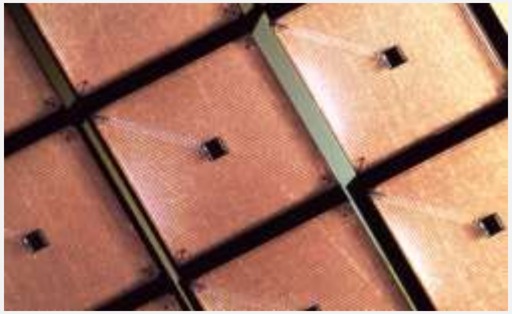
- Improving the area filling efficiency
- Polarization sensitive pixels

# Future CMB Observations – Detectors

## BOLOMETERS

- Photon noise limited
- Widely used on CMB telescopes
- High TRL

- Complex to fabricate (expensive)
- Complex readout (for large array)

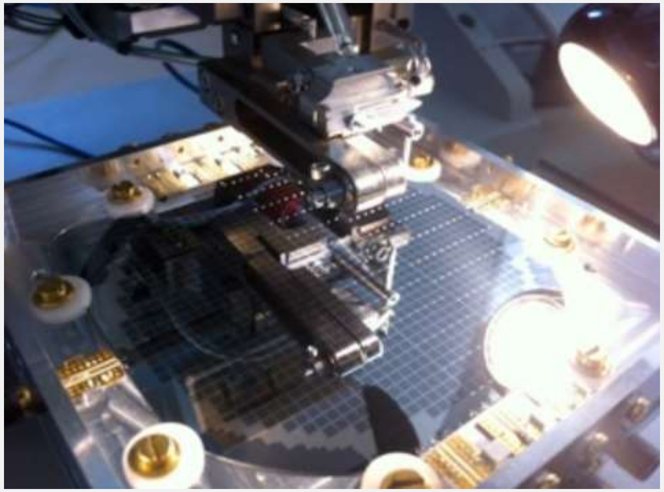


Credit: QUBIC collaboration

## KINETIC INDUCTANCE DETECTORS

- Naturally multiplexed
- Only planar structures (less expensive)
- Short time constant
- Less sensitive to temperature fluctuations
- Vibration insensitive

- Lower TRL
- Room temperature electronics
- Recent technology



Credit: Nika2 collaboration

# Outline



- Motivation
- **Kinetic Inductance Detectors (KIDs)**
- Dual-Color Antenna-Coupled LEKID

# Kinetic Inductance in Superconductors

## Normal state conductor

$$\sigma(\omega) = \frac{ne^2\tau}{m_e(1+\omega^2\tau^2)} - i\underbrace{\frac{ne^2\omega\tau^2}{m_e(1+\omega^2\tau^2)}}_{\text{Negligible}}$$

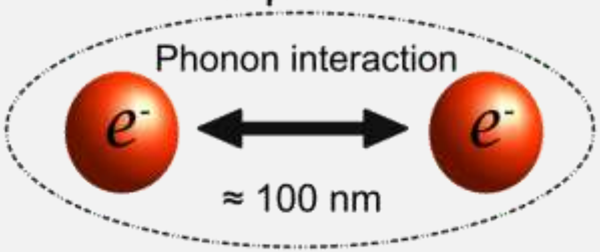
$$\sigma_i/\sigma_r = \omega\tau$$

$$f < 600\,GHz \;\downarrow\; \omega\tau \ll 1$$

## Superconductor (T=0)

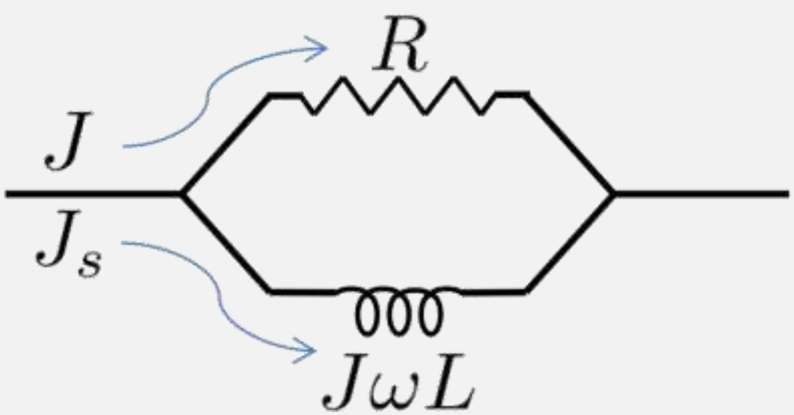
$$\sigma_{is} = \frac{n_s e^2}{m\omega}$$

Cooper Pair




## Total conductivity: $\sigma_t(\omega) = \sigma_r - \sigma_{is}$

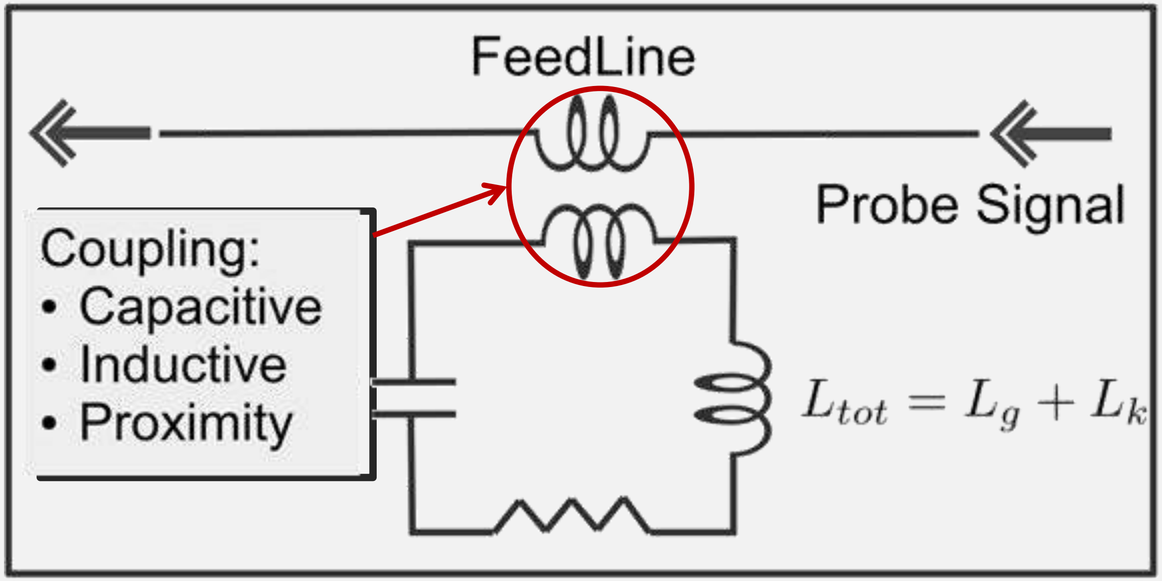
$$\sigma_t = \frac{n_n e^2\tau}{m_e} - i\frac{n_s e^2}{m\omega}$$

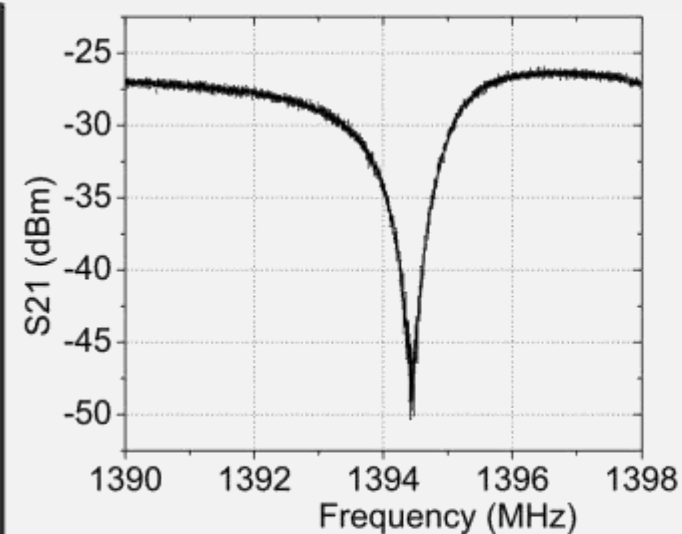


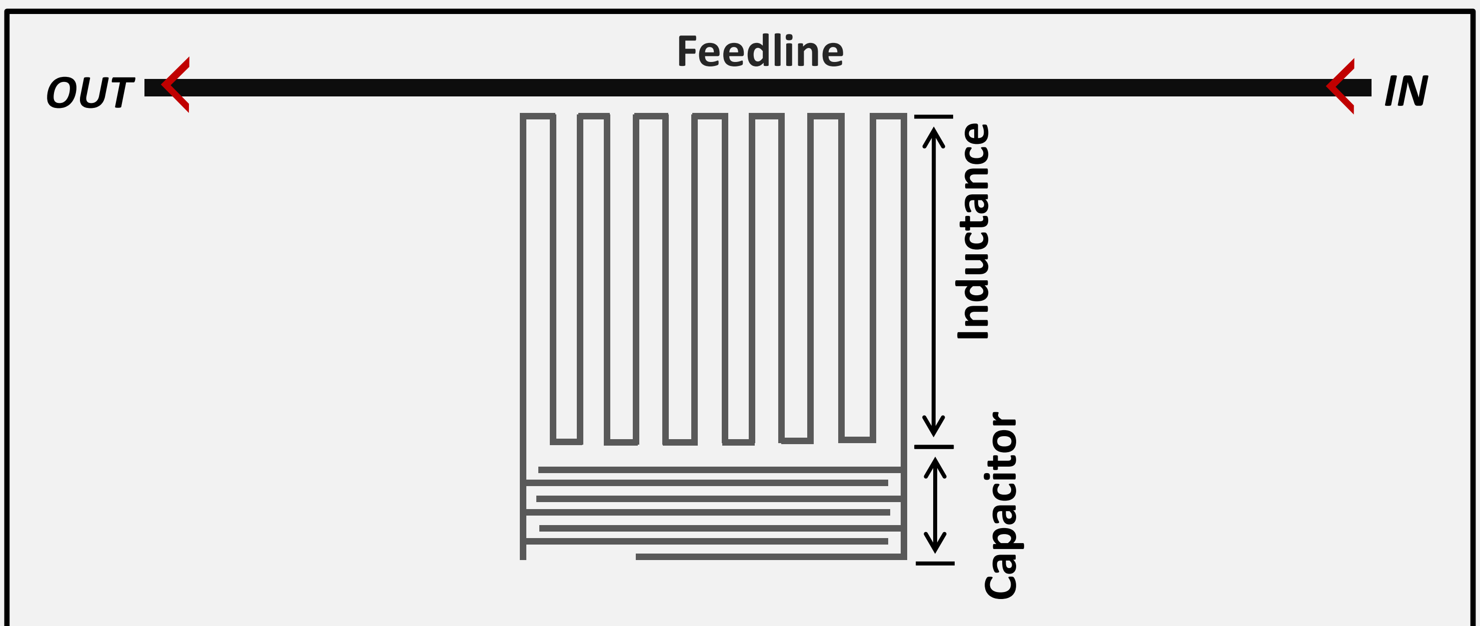
# Lumped Kinetic Inductance Detectors (LEKIDs)



RLC Circuit coupled to a readout line

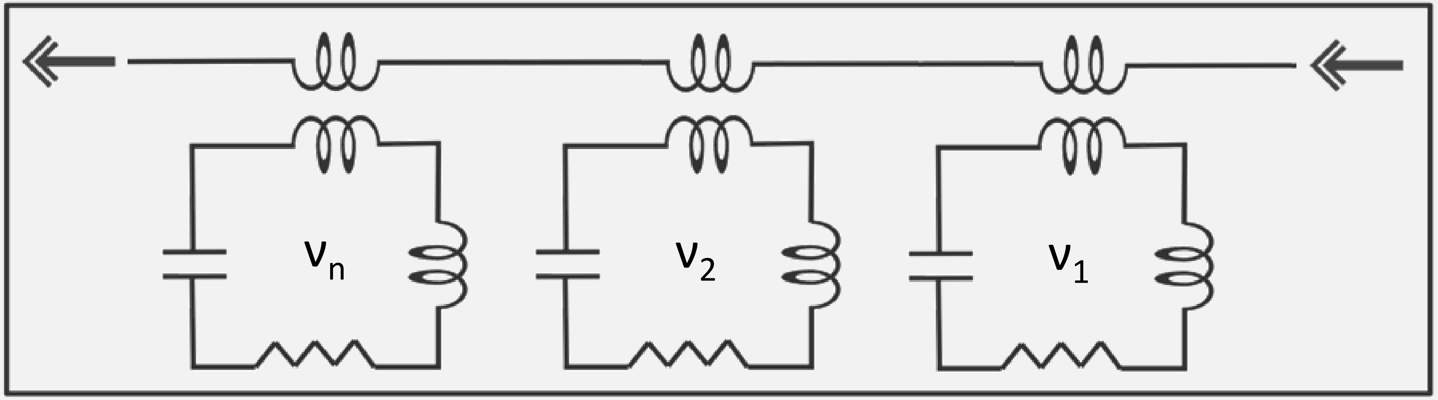


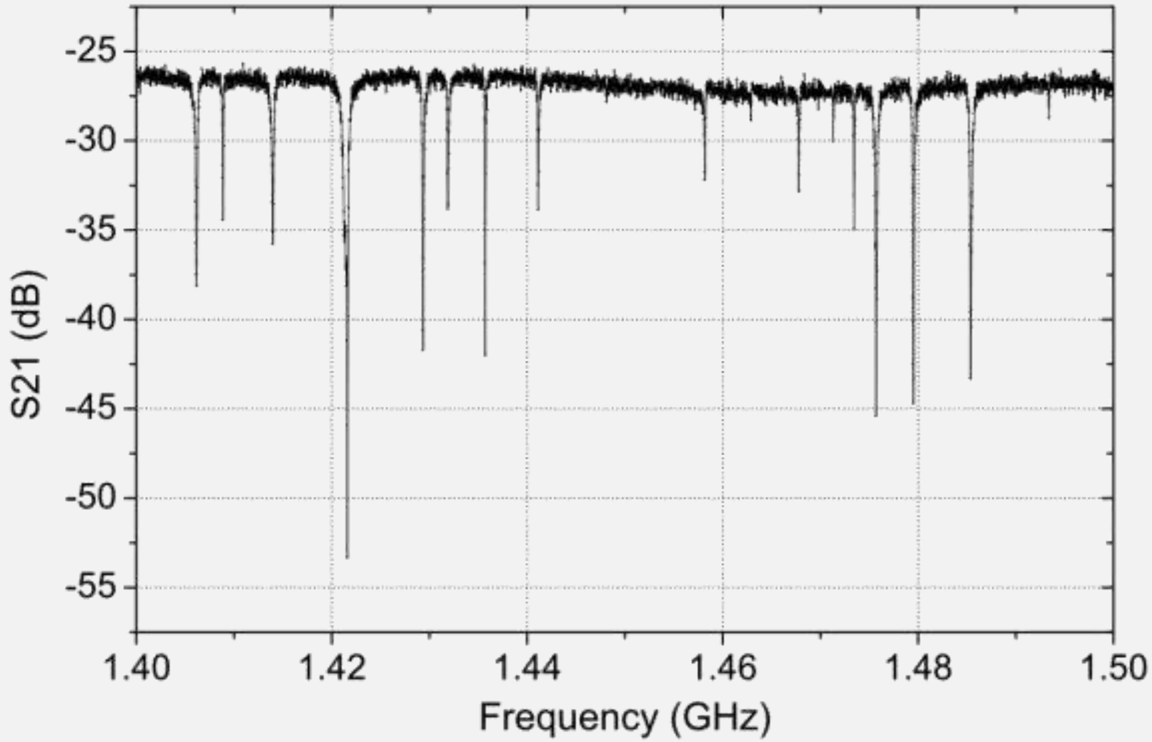



# KIDs multiplexing



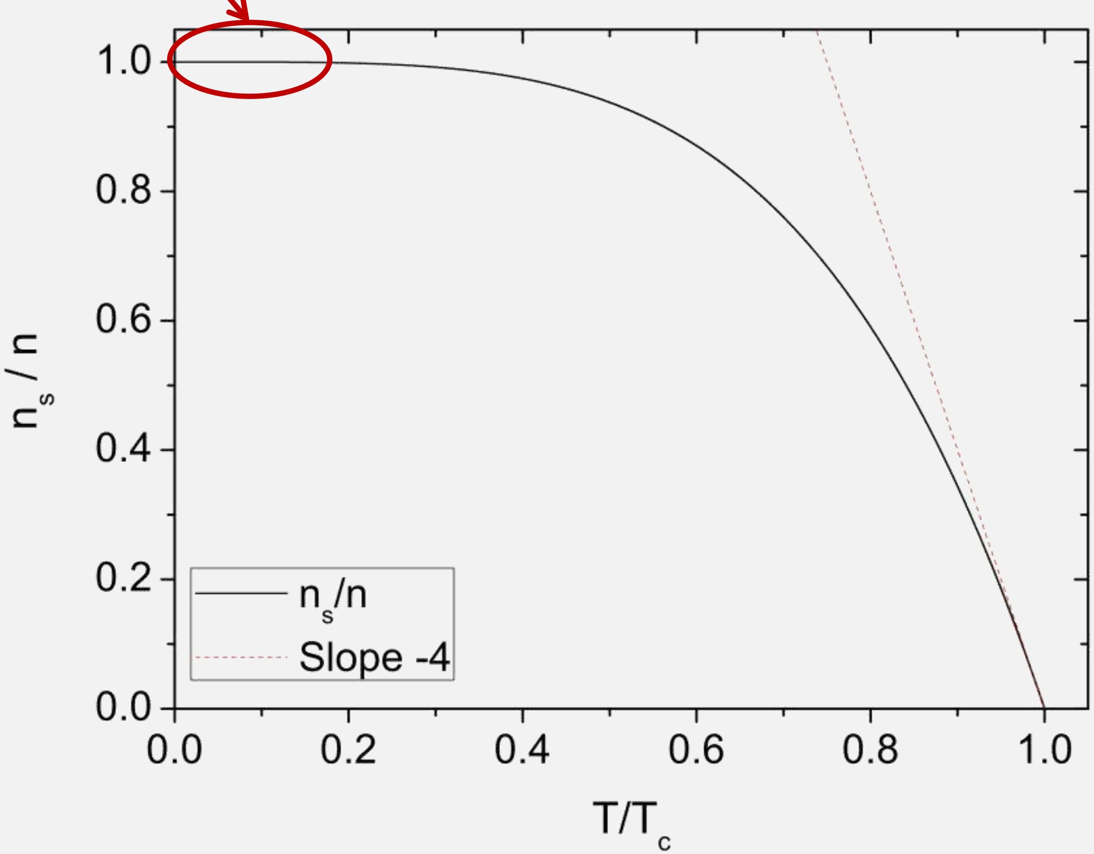


# Cooper Pair Density

Less sensitive to temperature

$$\frac{n_s(T)}{n} \sim \left[1 - \left(\frac{T}{T_c}\right)^4\right]$$



$$2\Delta(0) \approx 3.52\, k_b T_c$$

| MINIMUM FREQUENCY DETECTABLE | | | |
|---|---|---|---|
| *CONDUCTOR* | $T_c$ $[K]$ | $2\Delta$ $[meV]$ | $\nu_{min}$ $[GHz]$ |
| Titanium | 0.39 | 0.12 | 28.6 |
| Gallium | 1.1 | 0.33 | 80.7 |
| Aluminium | 1.2 | 0.36 | 88 |
| Indium | 3.4 | 1.03 | 249.4 |
| Tin | 3.7 | 1.12 | 271.4 |
| Mercury | 4.2 | 1.27 | 308 |
| Lead | 7.2 | 2.19 | 528 |
| Niobium | 9.3 | 2.82 | 682.1 |

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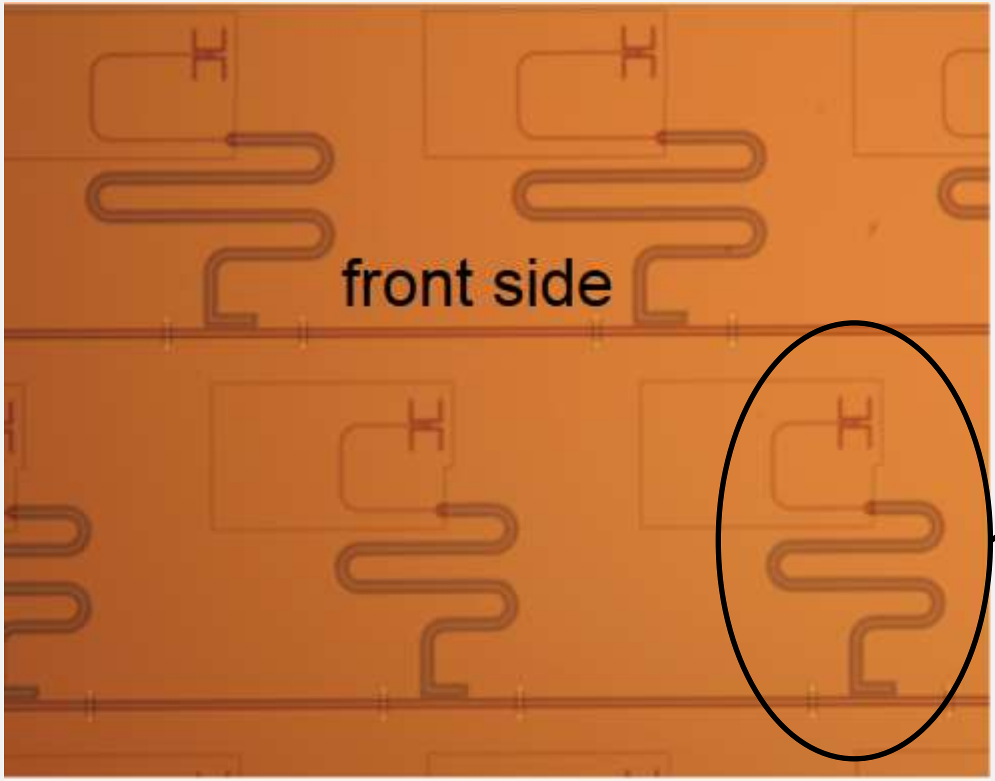
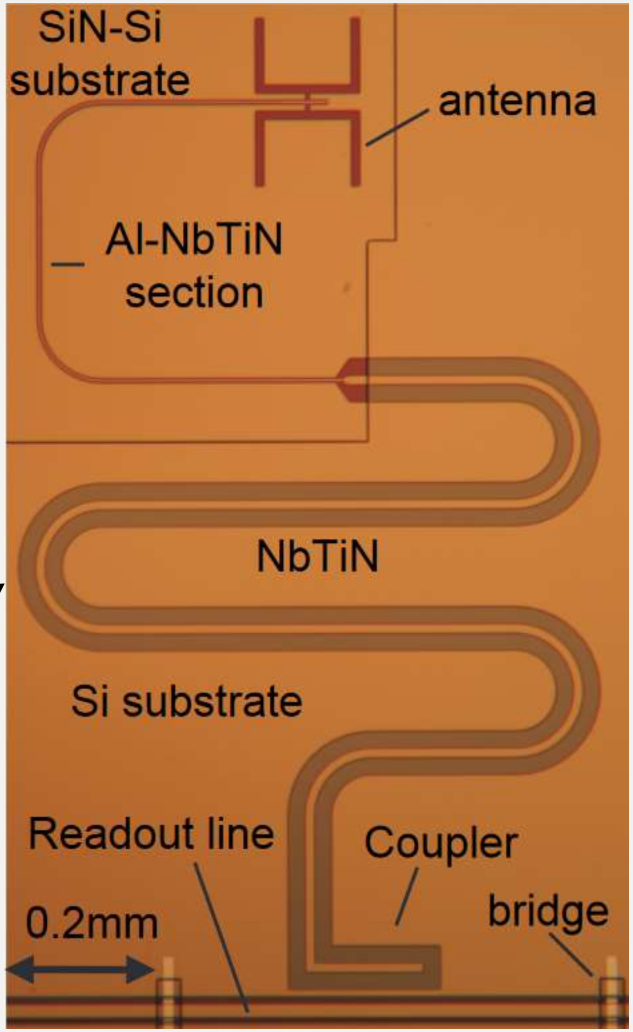
- **Dual-Color Antenna-Coupled LEKID**

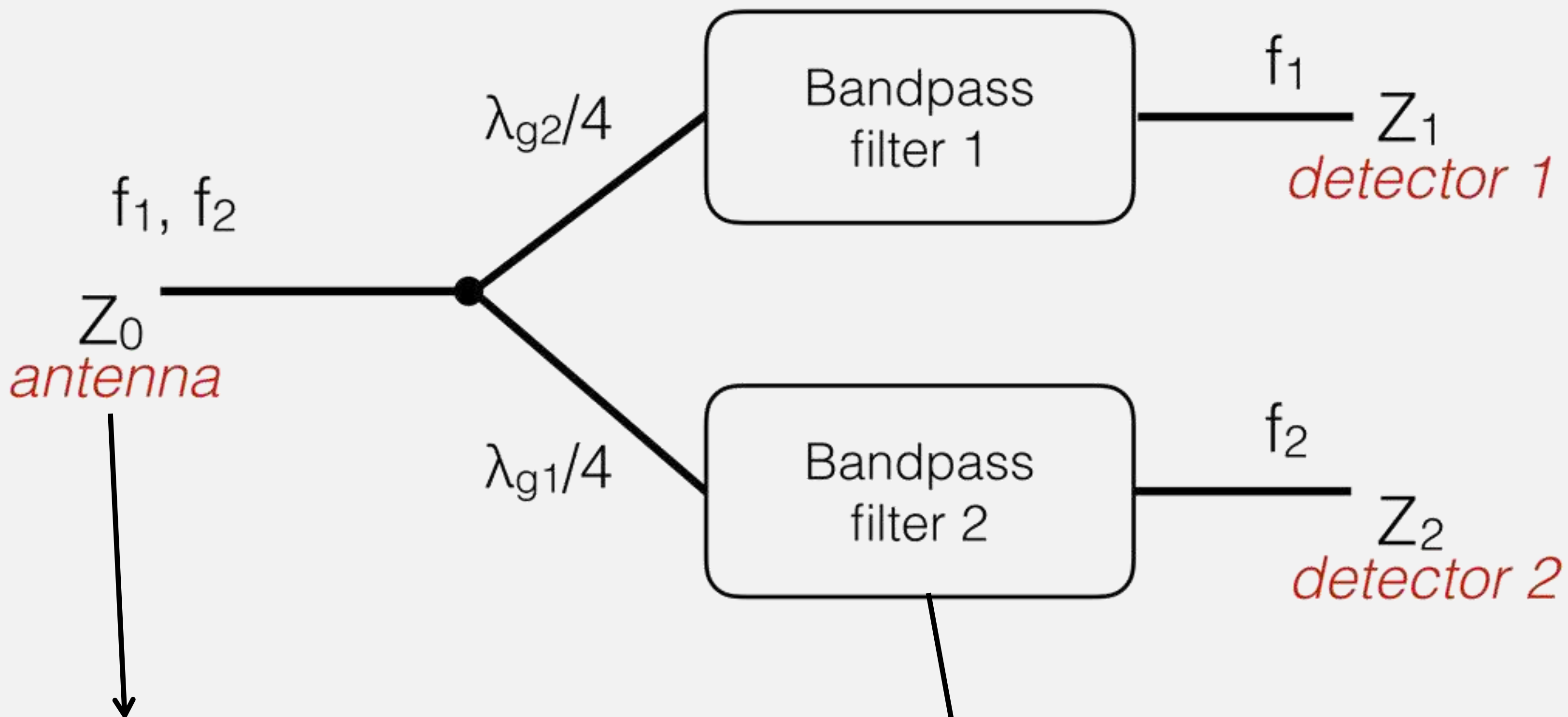
# Antenna Coupled MKID




S. Yates et al. (2017)

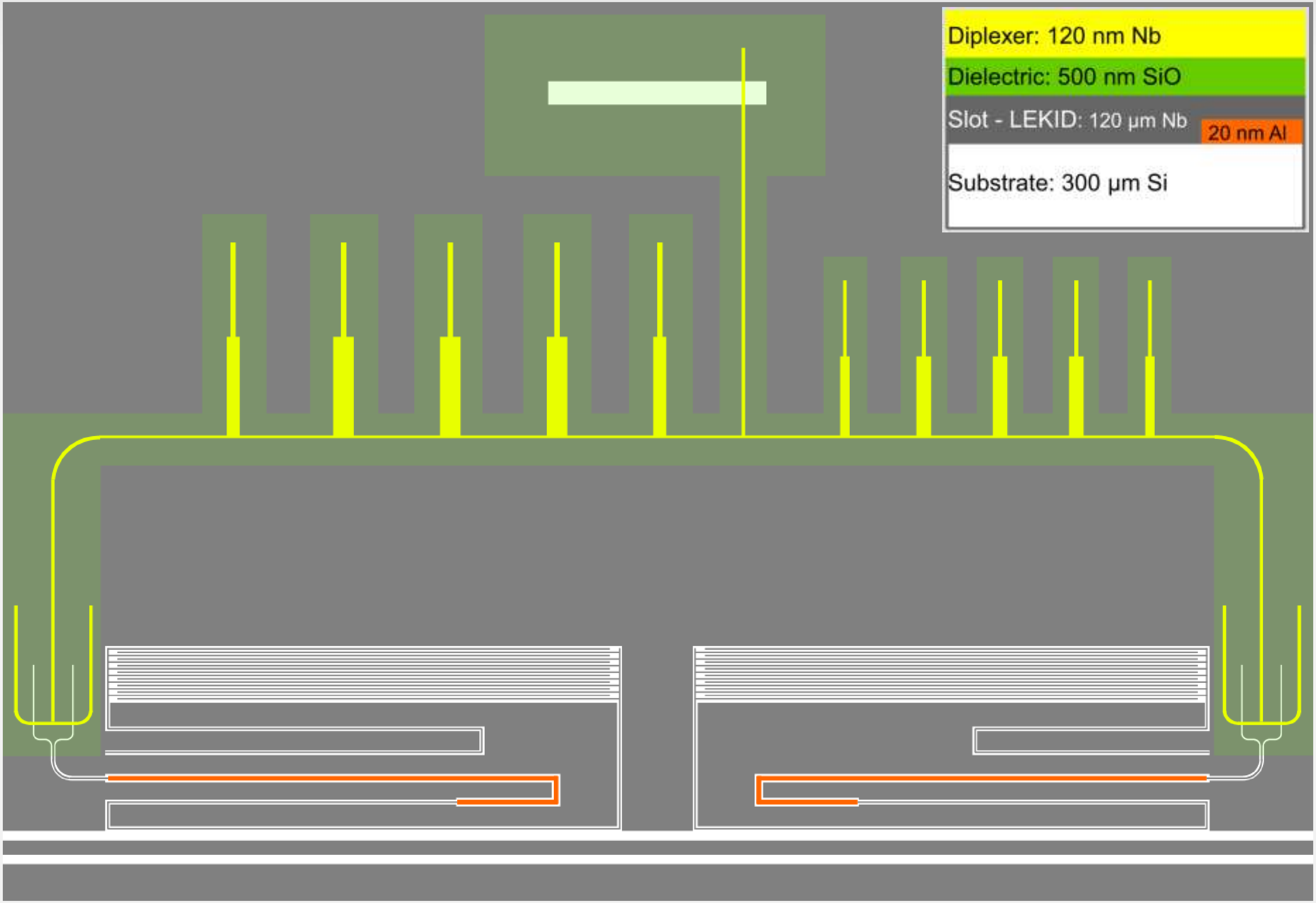
# Dual-Color Antenna-Coupled LEKIDs




**Slot Antenna:**
- Microstrip excited
- Basic element for more complex antennas
- Highly sensitive to linear polarization

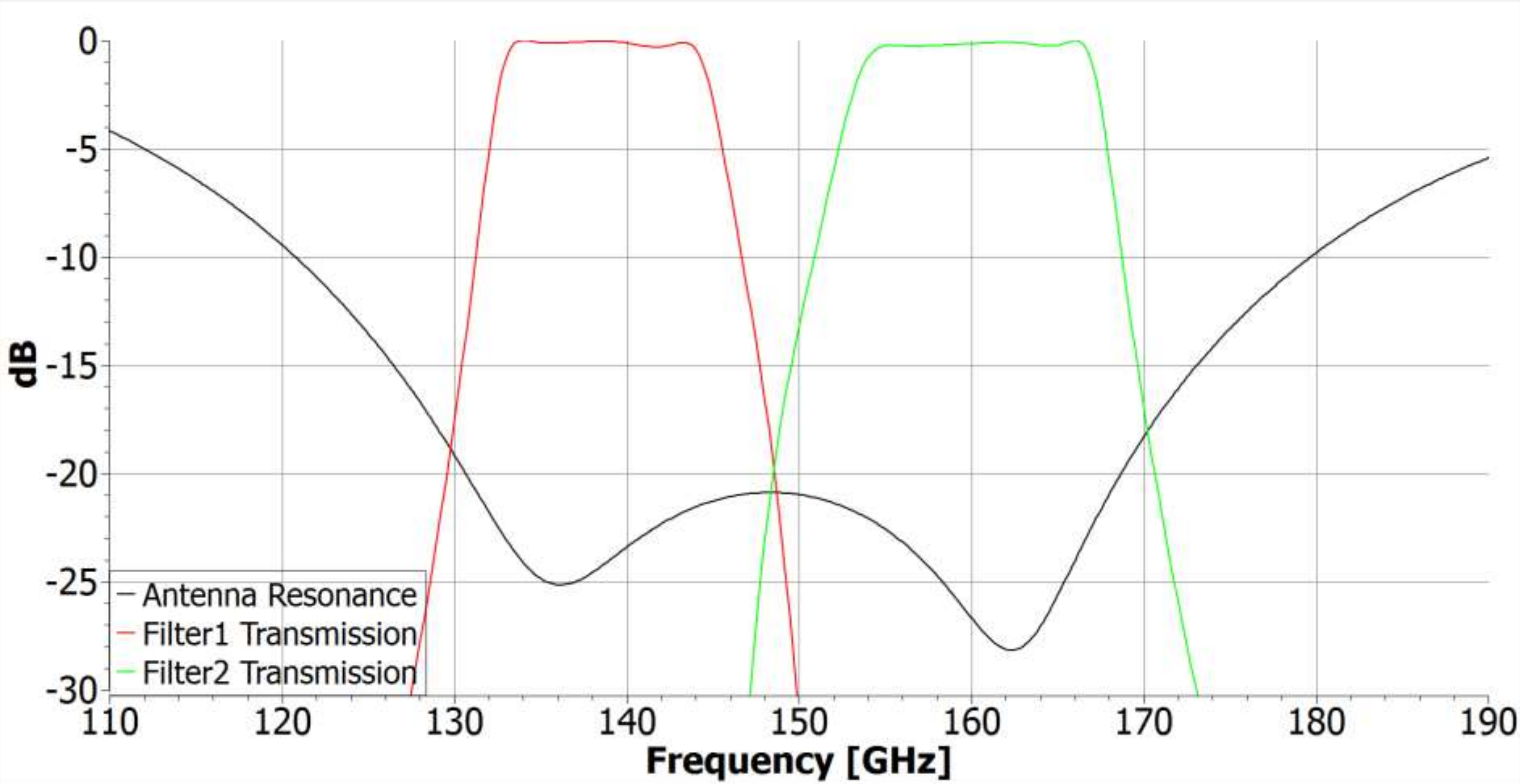
**N=5 Chebyshev open-stub Bandpass Filter:**
- No capacitive coupling
- Does not require a VIA

# Dual-band pixel



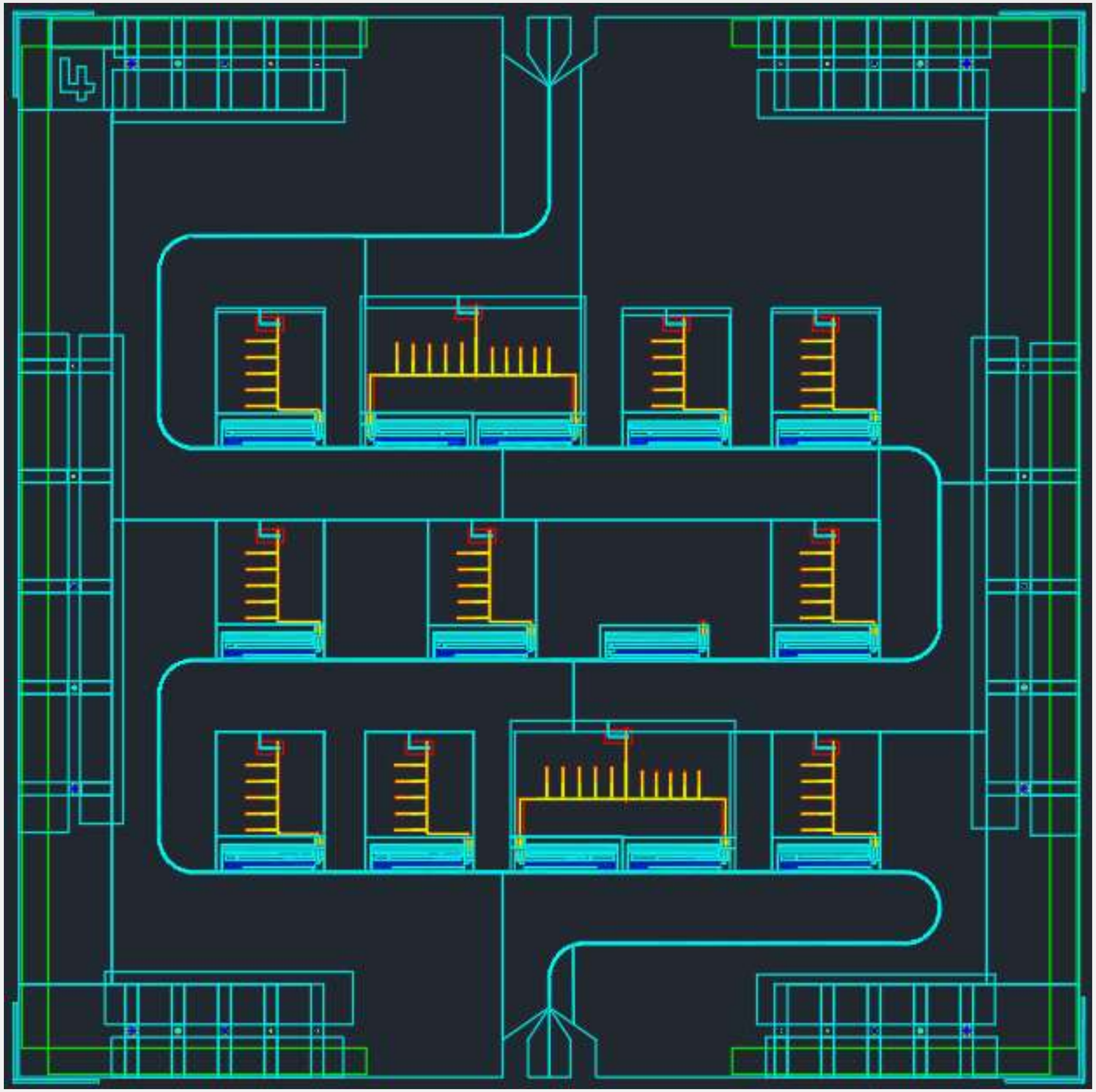
# Antenna + Diplexer





# Test Chip 14 Detectors





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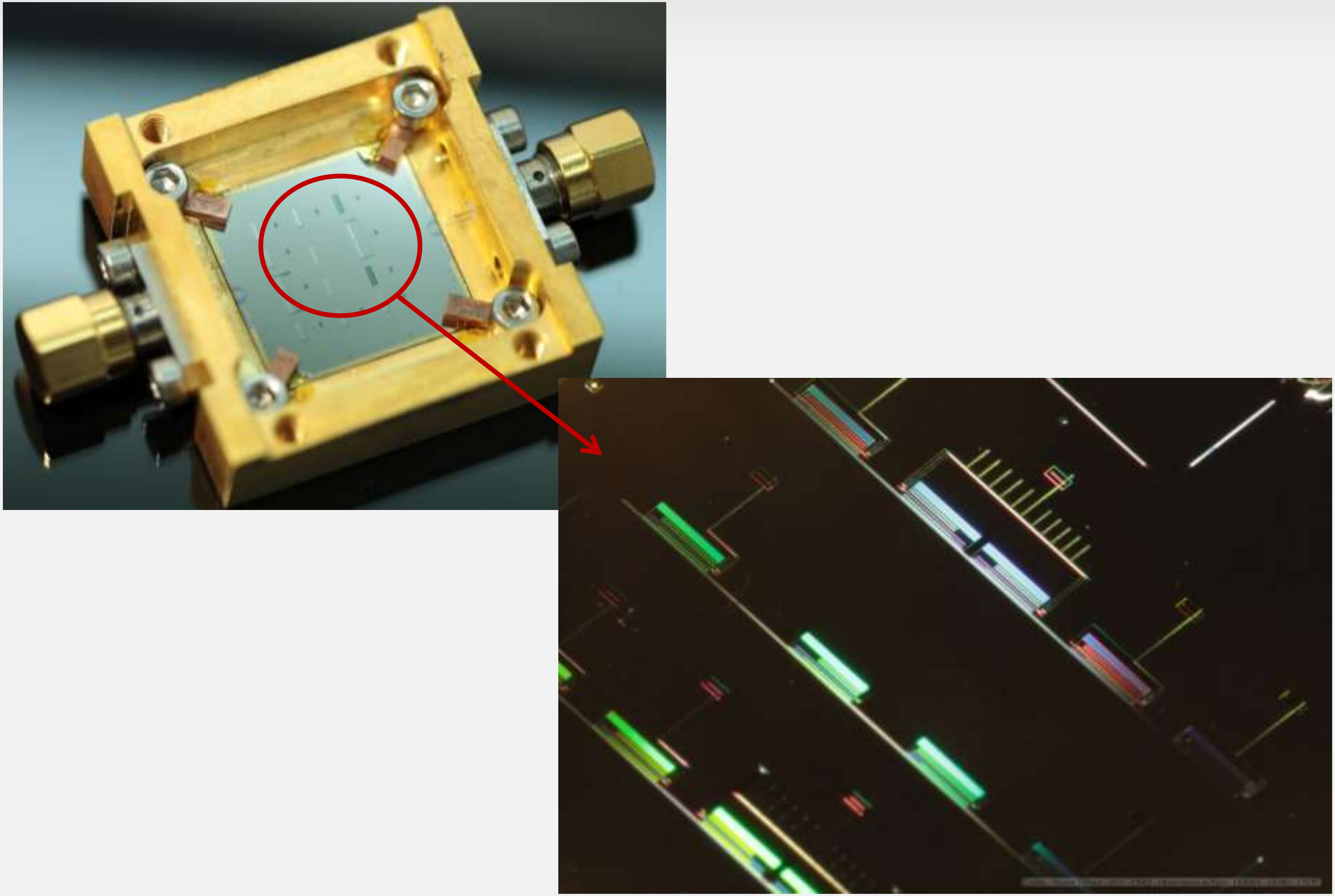

# Tests at APC



# Conclusion



## DESIGN

- Polarization sensitive slot antenna with 35% bandwidth
- Open-Stub Bandpass filter diplexer at 140 GHz and 160 GHz
- Lumped Element Kinetic Inductance Detector coupling

## FABRICATION STATUS AND TESTS

- Five chips fabricated at Paris Observatory - GEPI
- Preliminary tests at APC down to 300 mK currently ongoing
- Tests down to 100 mK at Institut NEEL to arrange

This project is part of an ESA TRP to develop pixels for future CMB focal planes.