Lumped Element Kinetic Inductance Detectors for the W Band

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Planck Collaboration 2015, *Planck 2015 results. XIII.*
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Thanks to Luca Pagano
**Why the W Band?**

- The W-band lies at an interesting transition between frequencies where Galactic emission is dominated by free-free and synchrotron, and frequencies where it is dominated by dust.
- In this band, the atmosphere is quite transparent, and then we can perform ground-based observations, avoiding the costs, complications and size limitations of balloon-borne and space-based missions.
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What KIDs are

Feedline

- Inductive
- Meander
- Inductive Coupling

\( M \)
\( R \)
\( L_m \)
\( L_k \)
\( C \)
What KIDs are

Inductive Meander

Feedline

\[ M \]

\[ R \]

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- Inductive Meander
- Interdigital Capacitor

\[ M, R, L, C \]
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Mathematical equations:
\[ M \]
\[ R \]
\[ L \]
\[ k \]
\[ L_m \]
\[ L_k \]
\[ C \]
**Which are the effects of incoming radiation?**

- A Kinetic Inductance Detector works on the principle that incident photons, with enough energy to break Cooper pairs \( (h\nu > 2\Delta) \), change the surface impedance of a superconductor \( (Z_s) \).

- In particular, the photons absorbed in the superconductor break the Cooper pairs producing quasi-particles \( (n_{qp}) \), and the rise in quasi-particle density results in a change of the kinetic inductance \( (L_k) \).

- This change can be accurately measured using a thin film superconducting resonant circuit, and sensing the change in amplitude and in phase of a microwave signal transmitted through the resonator.
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When photons, with $h\nu > 2\Delta$, hit the KID ...
\[ \ldots n_{qp} \uparrow \Rightarrow \begin{cases} L_k \uparrow \\ R_s \uparrow \end{cases} \Rightarrow \begin{cases} \nu_{\text{res}} \propto \frac{1}{\sqrt{LC}} \\ Q \propto \frac{1}{R_s} \sqrt{\frac{L}{C}} \end{cases} \ldots \]
How KIDs work

\[ \frac{\delta \varphi}{dN_{qp}} = \text{responsivity}. \]
Our prototypes are fabricated at the Istituto di fotonica e nanotecnologie (IFN), of the Consiglio Nazionale delle Ricerche (CNR).
The experimental setup is composed of

- the cryogenic system, necessary to reach the optimum working temperature;
- the optical system, necessary to remove the non interesting radiation and to focus the interesting radiation on the detectors;
- the data acquisition system, with which we can investigate the electrical and the optical characteristics of the resonators;
- the thermometers and the control unit, with which we can read the temperature and power the heaters.
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We measured the **critical temperature** to know if our detectors work in the W-band:

\[ h\nu = 2\Delta \approx 3.5k_B T_c ; \]

- we performed **electrical tests** in order to find the resonance frequency and the quality factors of our detectors;
- we performed **optical tests** in order to measure the responsivity and the noise.
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Critical Temperature

Setup

- 90 GHz Horn
- mm-wave Source
- Baffle
- Radiation
- Black sheet
- Lens
- Mirror
- Vector Network Analyzer
- Cryostat
- KIDs
- 16 dBm
- Att.
- 300 K
- 45 K
- 3.5 K
- 1 K
- 0.18 K
- 0.20 K
Critical Temperature: Al 40 nm

![Critical Temperature Graph](image)

- 95.50 GHz, 1.308 K
- 98.70 GHz, 1.352 K
Critical Temperature: Al 80 nm

93.20 GHz, 1.277 K
93.73 GHz, 1.284 K
Critical Temperature: 10 nm Ti + 25 nm Al
Electrical Test

Material | Thickness | $Q_i$ | $Q_e$
--- | --- | --- | ---
Al | 40 nm | 82 958 | 26 447
Ti-Al | 10+25 nm | 28 632 | 22 144

Figure: Electrical Test setup with data fit and material thickness values.
Optical Test

### Material Thickness

<table>
<thead>
<tr>
<th>Material</th>
<th>Thickness</th>
<th>NEP</th>
<th>NET</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al</td>
<td>40 nm</td>
<td>0.21</td>
<td>1.2</td>
</tr>
<tr>
<td>Ti-Al</td>
<td>10+25 nm</td>
<td>in progress</td>
<td></td>
</tr>
</tbody>
</table>

**NEP**: $\frac{fW}{\sqrt{Hz}}$

**NET**: $\frac{mK}{\sqrt{Hz}}$

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**Cryostat**

**Source**: BB @300K BB @77K

**Local Oscillator**: $-14\text{dBm, } \nu_{res}$

**Oscilloscope/Spectrum Analyzer**

**IQ Mixer**

**Splitter**

**16 dBm**

**Att.**

300 K 45 K 3.5 K 1 K 0.20 K 0.18 K
We have studied the possibility to integrate an array in the focal plane of the 64 m—Sardinia Radio Telescope (SRT).

In order to define the main requirements of the detectors, it is necessary to characterize the background on the devices and the consequent Noise Equivalent Power (NEP).

We estimated the background emission in a band between 80 and 100 GHz considering different contributions:

- the atmosphere,
- the mirrors,
- the optical window of the experiment and the CMB.
The main requirement is that the detector should have $\text{NEP} \sim 0.1 \text{fW}/\sqrt{\text{Hz}}$. 

\[ \text{Cumulative distribution function} \]

\[ \text{Background NEP [fW/Hz}^{1/2}] \]
Conclusions

- Our purposes are to design, fabricate and test LEKIDs able to work in the W-Band (75 ÷ 110 GHz).
- We tested prototype with different Al thickness (40 and 80 nm): these are not suitable to cover the whole W-band.
- The use of Ti-Al bi-layer allows us to cover frequencies greater than 60 GHz.
- We are now performing the optical characterization of Ti-Al LEKID.
- In the same time, we are developing LEKIDs for the D-Band (110 ÷ 170 GHz).
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thank you