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Two-Dimensional Imaging of Intermodulation Distortions in a Superconductor Resonator

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Two-Dimensional Imaging of Intermodulation Distortions in a Superconductor Resonator

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Abstract

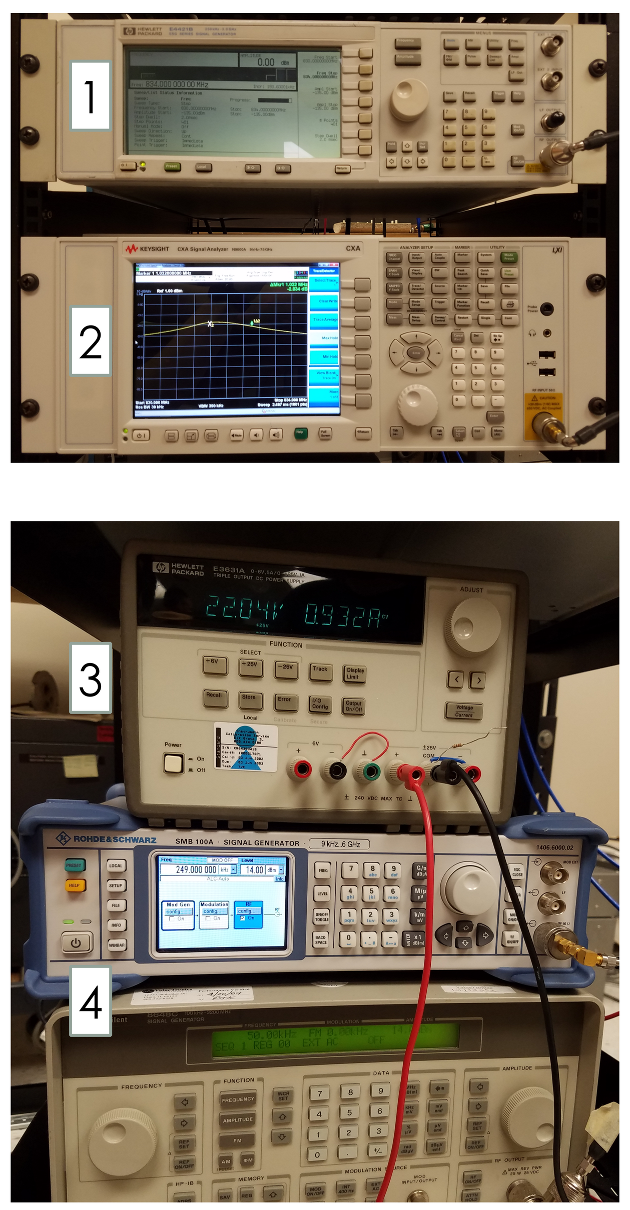
At the resonant frequency, superconducting resonators produce intermodulation distortion, smaller signals near the resonant frequency. By inducing external microwave signals, it is possible to analyse the patterns of intermodulation distortion (IMD) in several different types of superconducting resonators. These measurements can be used to complement the main peak values like quality factor and frequency shift in order to understand nonlinearities present in the material of the superconductor.

Motivation

Understanding the spatial distributions of IMD in superconducting resonators will aid device manufacturers to produce lower distortion superconducting devices.

Experimental Setup and Procedure

This experimental setup was based around a vacuum cryostat, held there by a rotary vane pump and turbomolecular pump. In addition to the heat lost from the vacuum, a cryopump brings the sample down past critical temperature in order to reach resonance. High vacuum also reduces the amount of thermal interference with air in the chamber.



1 ➔ Signal Generator
2 ➔ Signal Analyser
3 ➔ Power Supply for Amplifiers
4 ➔ Probe Signal Generators
5 ➔ Vacuum Cryostat w/ Cold Stage

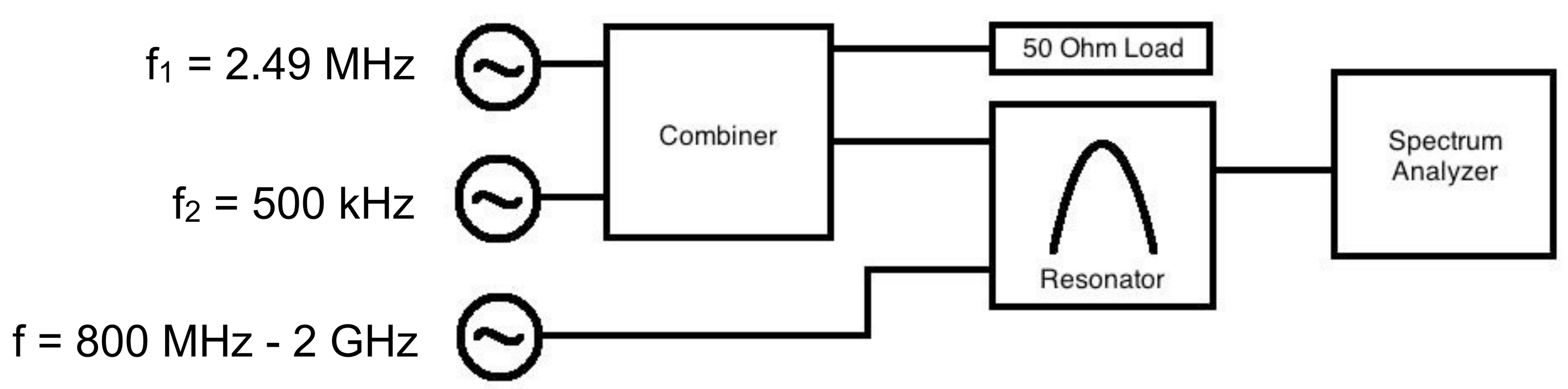
Procedure

1. Chamber brought to vacuum
2. Sample cooled to ~90 K
3. IMD induced in resonator by probe
4. Analyser measured IMD at a given point
5. Micrometers used to scan sample

Theory

Three-Tone Technique

When inducing a multi-tone signal in a device with nonlinearities, IMD spurs are produced near the resonant frequency of the resonator. [1]



IMD frequencies are a function of the resonant (or current input frequency, f) and the secondary input frequencies (f_1, f_2)

$$E(H) = E(0) + \frac{dE}{dH}\Big|_{H=0} H + \underbrace{\frac{d^2E}{dH^2}\Big|_{H=0}\frac{H^2}{2!}}_{2^{nd}\text{ Order}} + \underbrace{\frac{d^3E}{dH^3}\Big|_{H=0}\frac{H^3}{3!}}_{3^{rd}\text{ Order}} + \ldots$$

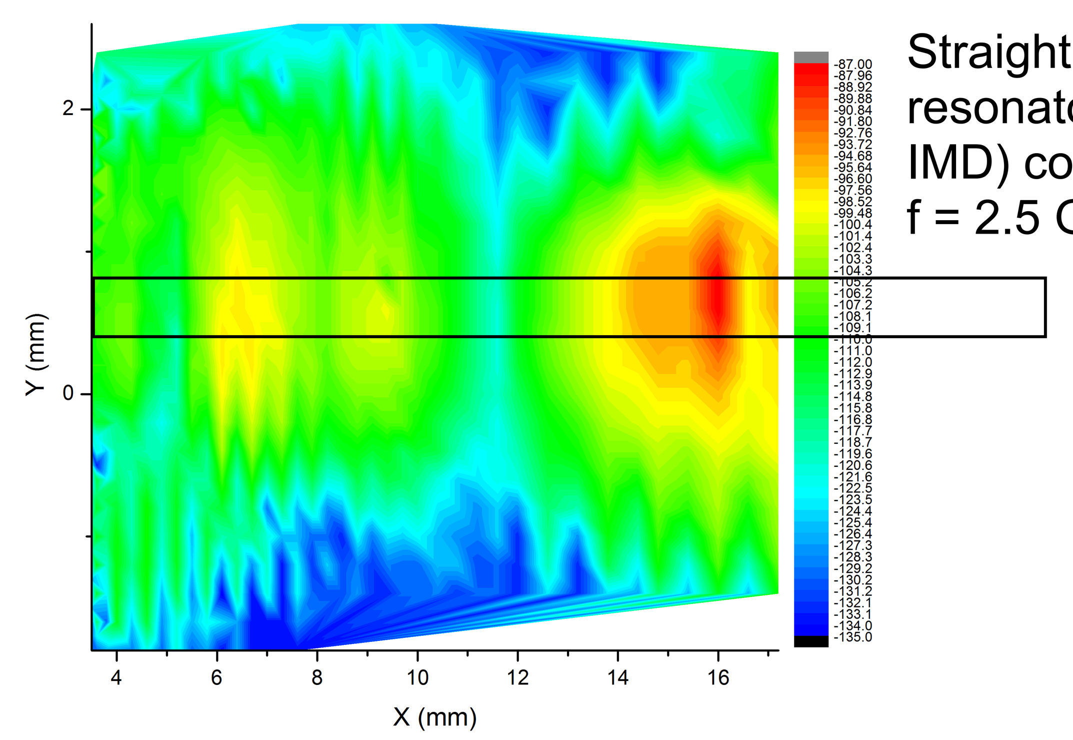
$$H^2 = \left(H_0 \sin(\omega_r t) + H_0 \sin(\omega_2 t)\right)^2$$

← Ex. The incident magnetic field is composed of multiple frequencies

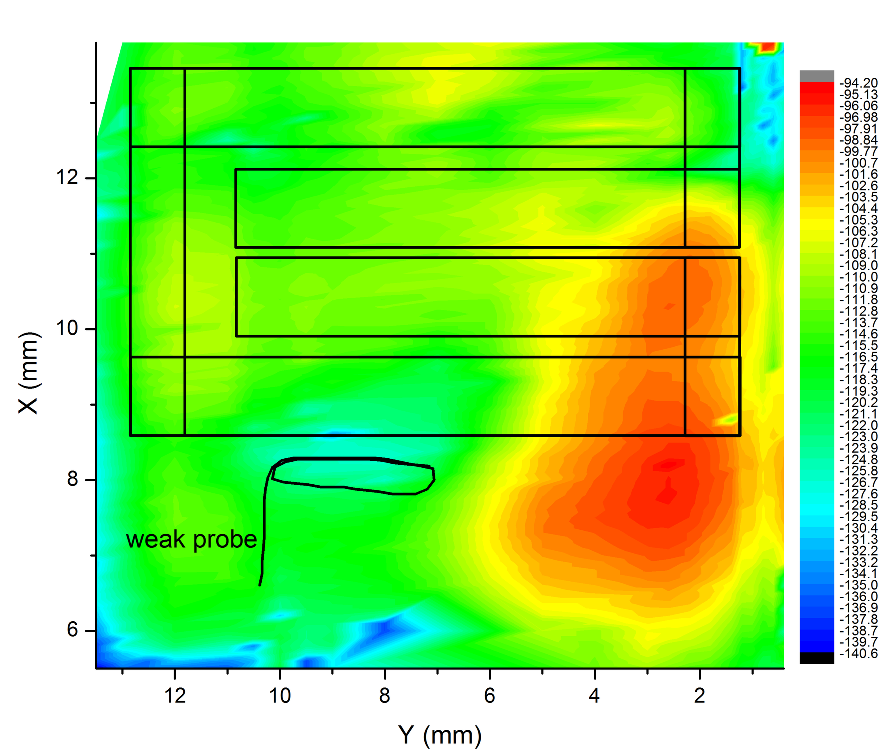
2nd order output:

$$H^2 = \underbrace{H_0^2 \frac{1-\cos(2\omega_r t)}{2} + H_0^2 \frac{1-\cos(2\omega_2 t)}{2}}_{\text{Harmonic Generation terms}} + 2H_0^2 \underbrace{\left[\sin(\omega_r + \omega_2) + \sin(\omega_r - \omega_2)\right]}_{\text{Intermodulation terms}}$$

Results

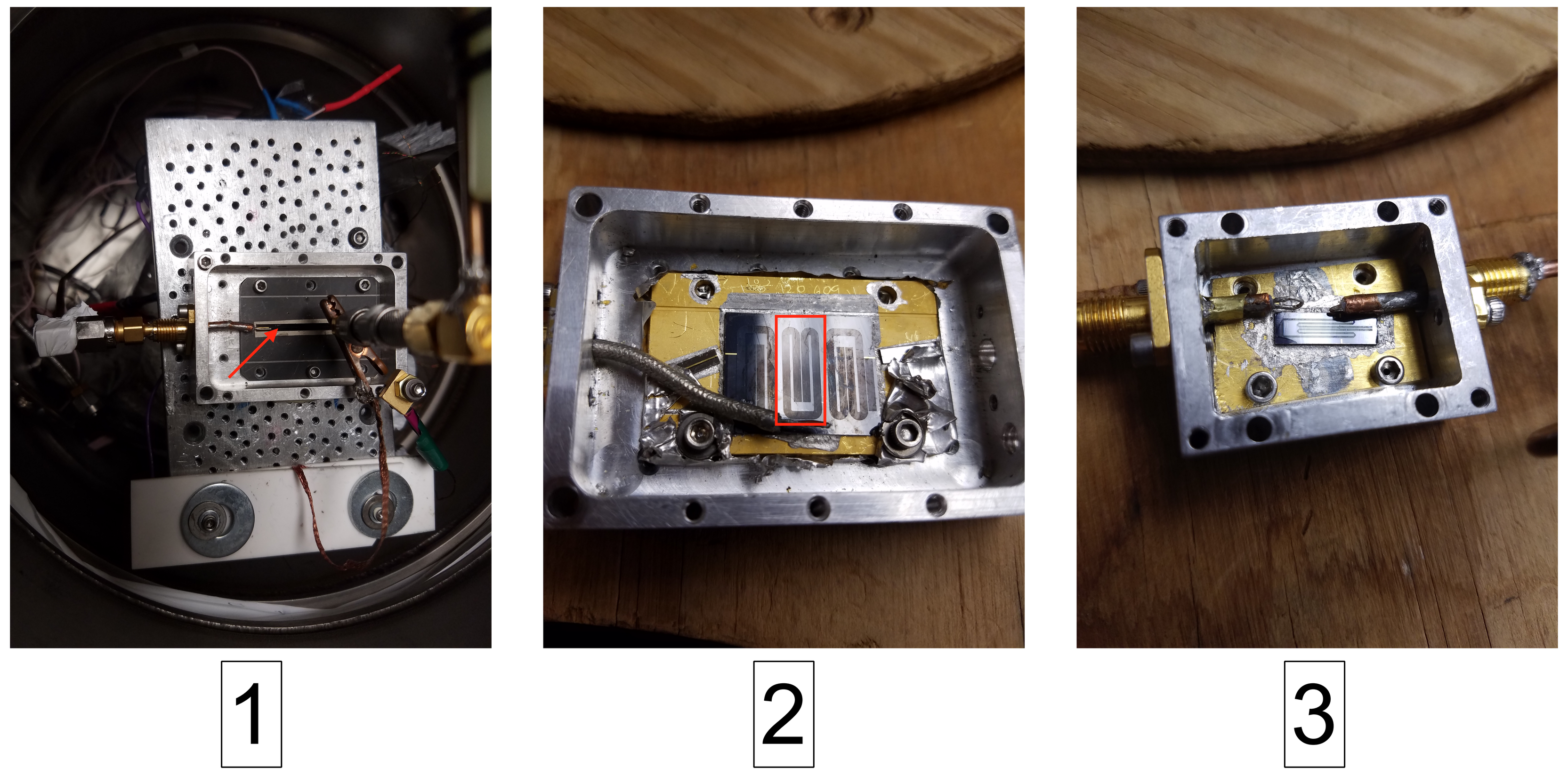


Straight line TBCCO resonator IMD2 (second order IMD) contour plot
f = 2.5 GHz



Wide-line YBCO resonator IMD2 contour plot
f = 835 MHz

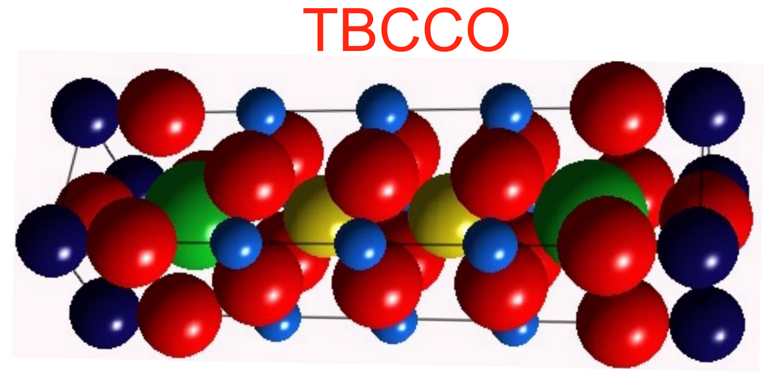
Sample

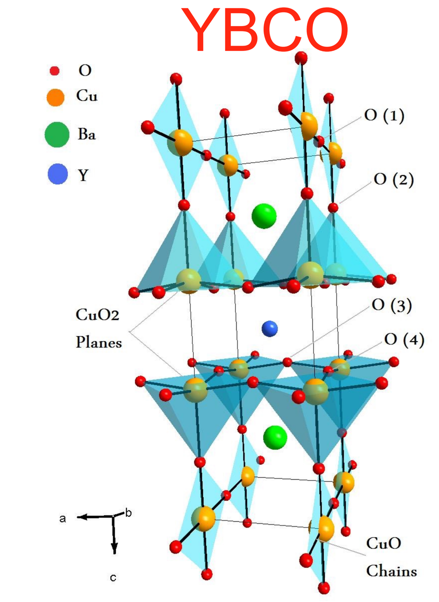


High-temperature superconductors (HTSC) are primarily made of two crystals, and they were the first to break the liquid nitrogen temperature barrier and become more accessible. $YBa_2Cu_3O_7$ (YBCO) is the most commonly used HTSC and is the makeup of most of the samples. $Tl_2Ba_2CaCu_2O_8$ (TBCCO) is the next most common HTSC used, and is present in one of the samples.

Several samples were analysed using these techniques:

- A large wide-line hairpin YBCO resonator (1)
- A small thin-line hairpin YBCO resonator (2)
- A thin straight line TBCCO resonator (3)





Conclusions

As the external probe approaches the location of current maxima, IMD power reaches a peak, confirming that high current is the source of IMD generation in a superconducting device. With further analysis of the patterns that arise from resonators' nonlinearities, it will be possible to identify resonators with both intrinsic and engineered nonlinearities.

Acknowledgements

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Sources:
[1] Eben, Anelle M. et. al, (June 2011). "Even and Odd Order Intermodulation Nonlinearity From Superconductive Microstrip Lines." IEEE Transactions on Applied Superconductivity. Vol 21, No.3