Local Whole-Device Scanning of Distortion in Superconducting Microwave Resonators

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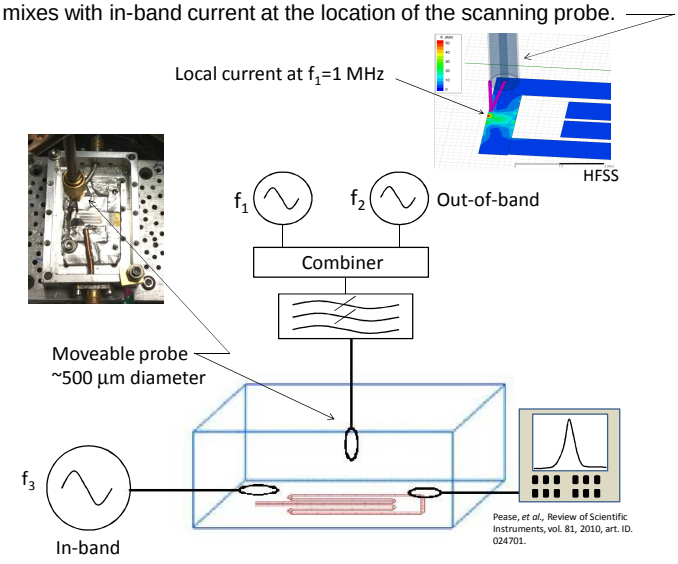
Motivation

Spatially resolved measurement of the nonlinearity inside a superconducting microwave device:

- Device physics without global averaging
- Pinpoint the location of nonlinearity phenomena
- Synchronous measurement of even and odd order nonlinearity
- Develop models for the distinct processes of even and odd order distortion
- Distinguish local from nonlocal electrodynamics

Intermodulation Distortion (IMD)

Out-of-band signals induce local, non-propagating current which mixes with in-band current at the location of the scanning probe.



Even and odd order distortion arise at a variety of frequencies, including:

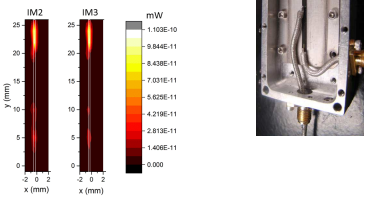
2nd Order IMD: f_3+f_1
3rd Order IMD: $f_3+(f_2-f_1)$

In this experiment: f_1=510 KHz, f_2=2.49 MHz, P_1=P_2=+20 dBm
f_3 is the resonant frequency, P_3=+5 dBm
T>77K and the 3dB bandwidth is > 1 MHz

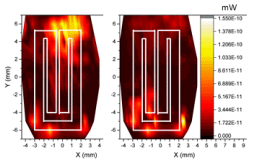
Picture of probe station

Raster Scans

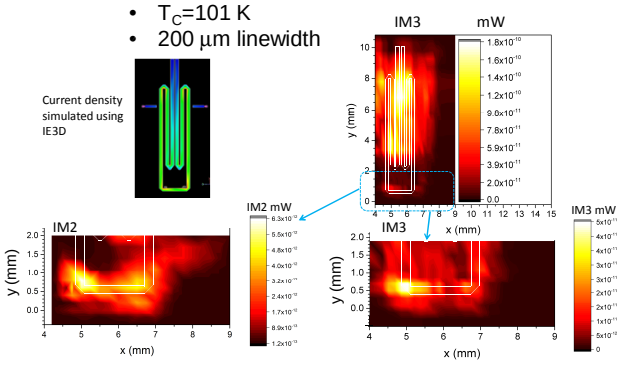
1. Straight-line resonator operated in its 2nd harmonic mode
   - 400 nm thick $Tl_2Ba_2CaCu_2O_8$/LAO
   - T_C=101 K
   - 160 µm linewidth
   - Operated in 2nd harmonic



2. Wide line resonator operated in its fundamental mode
   - $Tl_2Ba_2CaCu_2O_8$/LAO
   - 400 nm thick
   - T_C=101 K
   - 1 mm linewidth



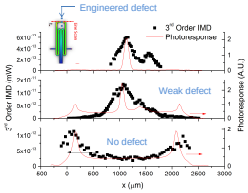
3. Thin line hairpin resonator operated in it fundamental mode
   - 400 nm thick $Tl_2Ba_2CaCu_2O_8$/LAO
   - T_C=101 K
   - 200 µm linewidth



Applications

- Localized probing of nonlinearity hot spots

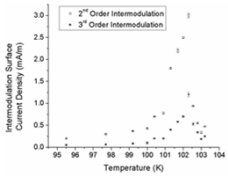
S.K. Remillard, Dustin Kirkendall, Gianluca Ghigo, Roberto Gerbaldo, Laura Gozzelino, Francesco Laviano, Zhili Yang, N.A. Mendelsohn, B.G. Ghamsari, B. Friedman, P. Jung, and S.M. Anlage "Microwave nonlinearity and photoresponse of superconducting resonators with columnar defect micro-channels." *Superconductor Science and Technology* 27, no. 9 (2014): 095006.



  - IMD corresponds to current density in the absence of defects.
  - Lossy defect is a local source of IMD.

- Synchronous comparison of even and odd order nonlinearity

Anelle M. Eben, V. Andrew Bunnell, Candace J. Goodson, Evan K. Pease, Sheng-ChiangLee, and Stephen K. Remillard. "Even and odd order intermodulation nonlinearity from superconductive microstrip lines." *IEEE Transactions on Applied Superconductivity* 21, no. 3 (2011): 595-598.

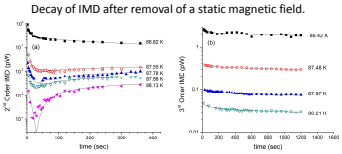


  - 2nd and 3rd order IMD both exhibit peaks just below T_C.
  - 2nd order IMD persists at lower temperature due to dissipation.

- Magnetic fluxon effect on even and odd order nonlinearity

Richard A. Huiżen, Sean L. Hamilton, Geoffrey T. Lenters, and Stephen K. Remillard. "Relaxation of Microwave Nonlinearity in a Cuprate Superconducting Resonator." *IEEE Transactions on Applied Superconductivity* 27, no. 4 (2017): 1-5.

Decay of IMD after removal of a static magnetic field.



  - 2nd order IMD is more influenced by fluxon density than 3rd order .
  -

$y(t) = y_0 + Ae^{-t/t_1} + A_2 \log_{10}(t/t_2)$ $y(t) = y_0 + A_2 \log_{10}(t/t_2)$