Harmonic and Intermodulation Distortion in a Superconducting Microwave Resonator

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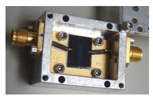
A $Tl_2Ba_2CaCu_2O_{8-y}$ microstrip resonator

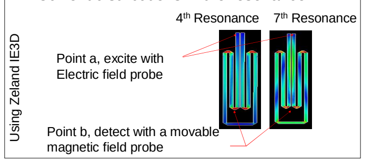


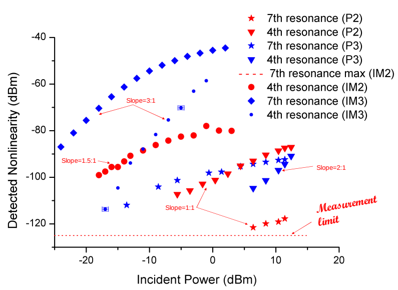
400 nm thick TBCCO film patterned on a 0.5 mm thick LAO substrate by Argon ion beam milling.

Measured Resonances

n	Resonant Freq.	Q_u
2	1.5640 GHz	
3	2.2178 GHz	6,000
4	2.8700 GHz	11,000
5	3.5240 GHz	15,400
6	4.3722 GHz	2,700
7	4.5885 GHz	8,500

Current distributions in the resonance





The 7th resonance of this structure exhibits very little time reversal symmetry breaking, when compared to the 4th resonance.

Objective

To observe the conditions for, and seek explanations of, even and odd order nonlinearity

Harmonic distortion is the production of outputs at an integer multiple of the input frequency. For example,

Even order (P2, P4…): f_1 input, $2f_1$, $4f_1$, $6f_1$… output.
Odd order (P3,P5…): f_1 input, $3f_1$, $5f_1$, $7f_1$… output.

Intermodulation Distortion (IMD) is the mixing of two or more signals in a nonlinear device. For example,

2nd order (IM2): f_1 and f_2 input, f_1+f_2 output.
3rd order (IM3): f_1 and f_2 input, $2f_1-f_2$ output.

Even versus Odd Order Nonlinear Distortion

Taylor expand the electric field, E, in a magnetic field $H = H_o\left(\cos(2\pi f_1 t)+\cos(2\pi f_2 t)\right)$ with 2 tones

$$E(H) = E(0) + \left.\frac{dE}{dH}\right|_{H=0} H + \left.\frac{d^2E}{dH^2}\right|_{H=0} \frac{H^2}{2!} + \left.\frac{d^3E}{dH^3}\right|_{H=0} \frac{H^3}{3!} + \cdots$$

See Remillard (1995)

1st order term at f_1 and f_2
➔Preserves time reversal symmetry

3rd order terms at such frequencies as $3f_1$, $2f_2 \pm f_1$
➔Preserves time reversal symmetry

2nd order terms at such frequencies as $2f_1$, $f_2 \pm f_1$
➔ Breaks time reversal symmetry

Time reversal symmetry (TRS) is determined by constitutive relations

See Lee (2005)

$$\vec{E}_{\|} = -L(H)\frac{dH_{\|}}{dt}\cdot \text{width}$$

Where L depends on $H=H_o sin(\omega t)$. e.g. L is nonlinear.

Even time reversal symmetry

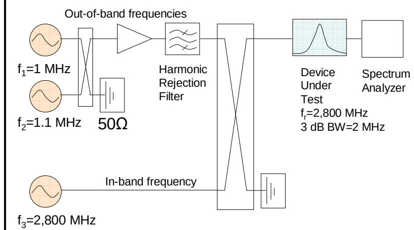
$$L(H) = L_o + \sum_m L(H^m)$$

Inductance per unit length

E and dH/dt have even TRS. H has odd TRS.

- m even ➔ TRS is preserved, and odd order harmonics occur.
- m odd ➔ TRS is broken, and harmonics in E with $\sin((m+1)\omega t)$, where m+1 is even, occur.

Next Step: 3-Tone IMD



All nonlinearities are on-resonance and share the field distribution and coupling coefficient of the resonant mode.

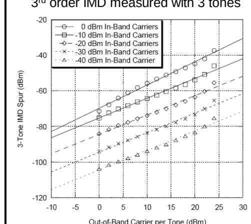
Advantages of 3-tone IMD

1) All measured nonlinearities are on resonance, permitting the use of a single, easily measured, reflection coefficient, ΔS_{11}, and correlation of nonlinearity current to circulating power.

3rd order is at $f_3 \pm (f_2-f_1)$
2nd order is at f_3-f_2 and f_3-f_1

2) High power is out of band resulting in enhanced test system sensitivity and minimizing peak distortion.

3rd order IMD measured with 3 tones



The 3-tone IMD measured for an 8-pole, 7.5 MHz wide filter centered at 903.75 MHz fabricated from 400 nm thick $Tl_2BaCa_2Cu_2O_8$ thin film on a Lanthanum Aluminate (LAO) substrate was measured at 75 Kelvin. The two out-of-band carriers were spaced 0.5 MHz apart.
(Figure from Remillard, et al., IEEE Trans. Appl. Supercond. **13**, no. 3, Sept. 2003.)

References

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Acknowledgements

This material is based upon work supported by the National Science Foundation under NSF-REU Grant No. 0452206