Characterising Superconducting lumped element resonators by Pound locking

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Pound lock: Original & Adaptation

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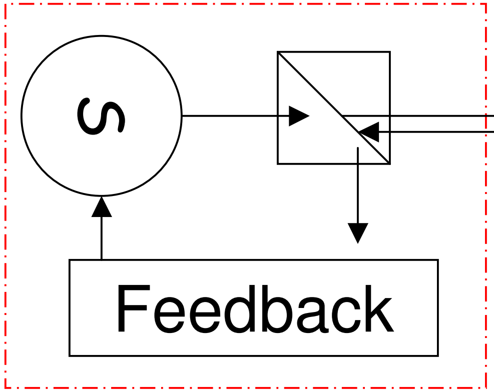
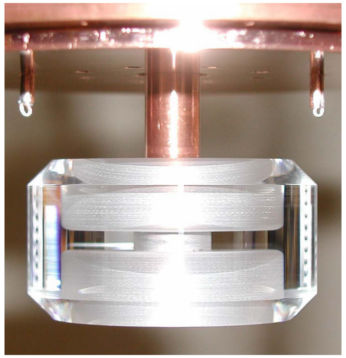
Original

- Oscillator (loop) stabilised by ultra-high $Q>10^9$ resonator
- High power technique – no amplification

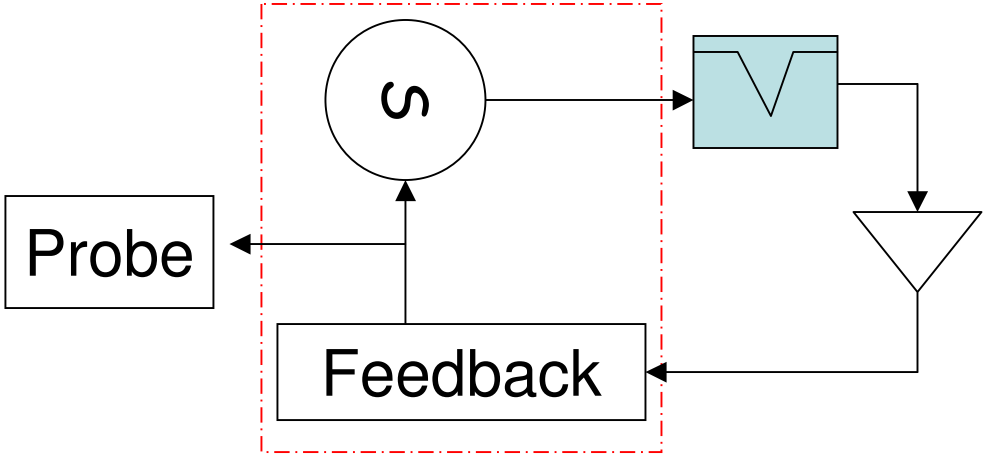


Feedback



Adaptation

- Stable microwave oscillator probes unstable $Q>10^4$ resonator
- Low power technique – needs amplification

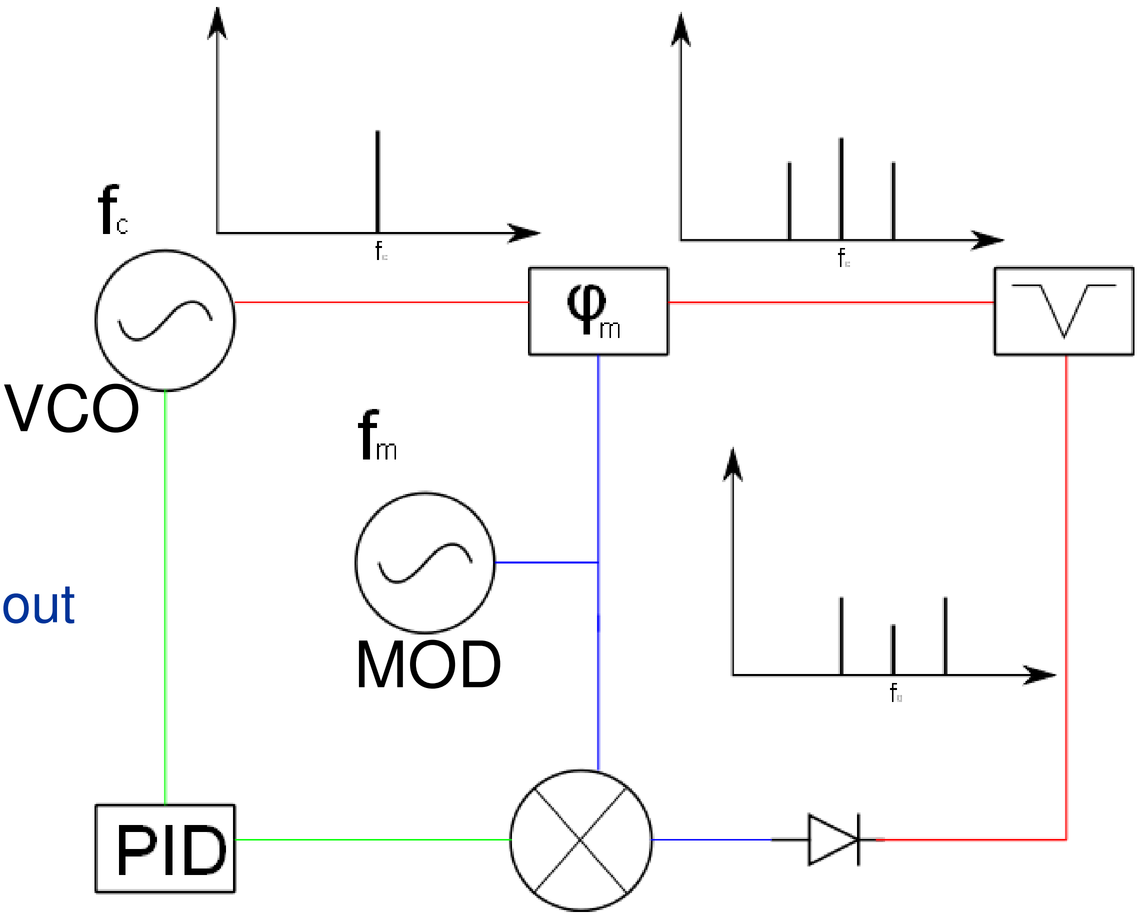


Probe

Feedback

Pound lock: Concept

- $f_c \sim f_o$
- $f_m >> \Delta f$
- Side bands reflect
  Carrier interacts
- Error signal at f_m but contains information about resonance!



Pound lock: Error signal

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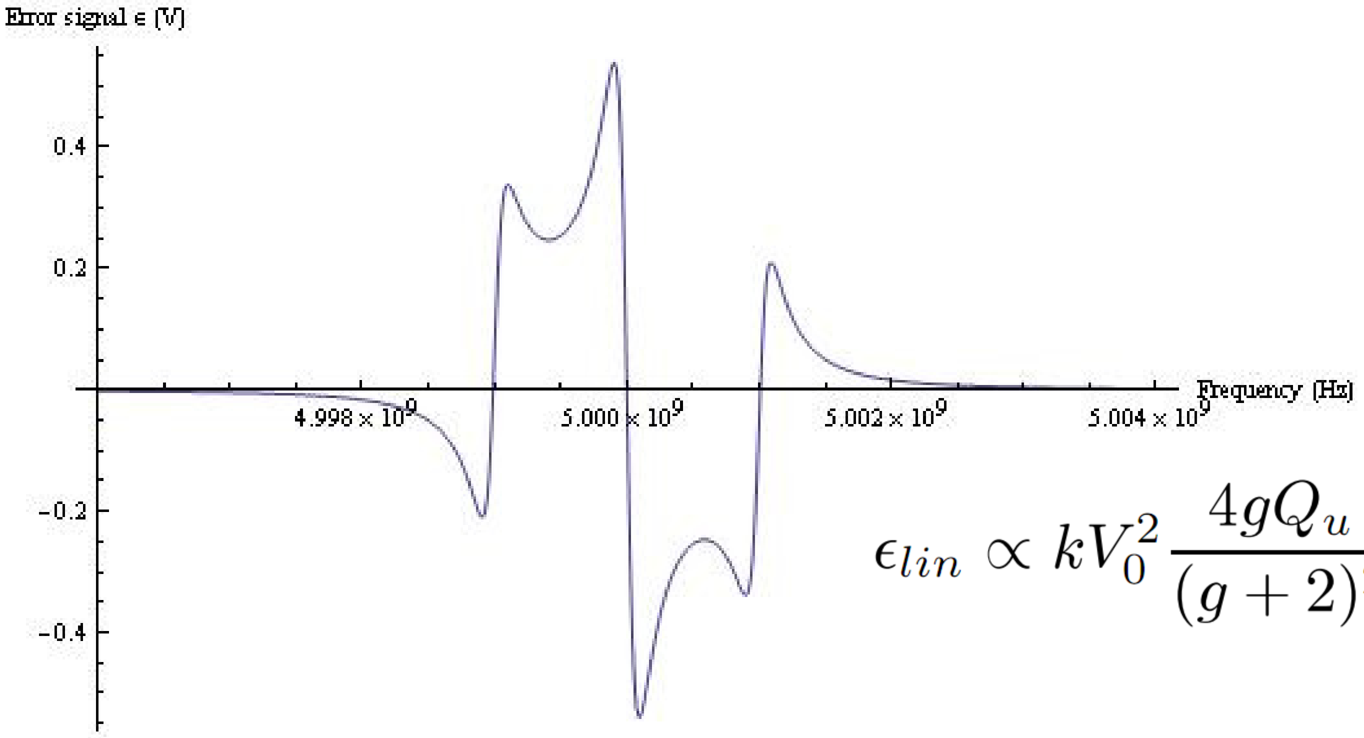
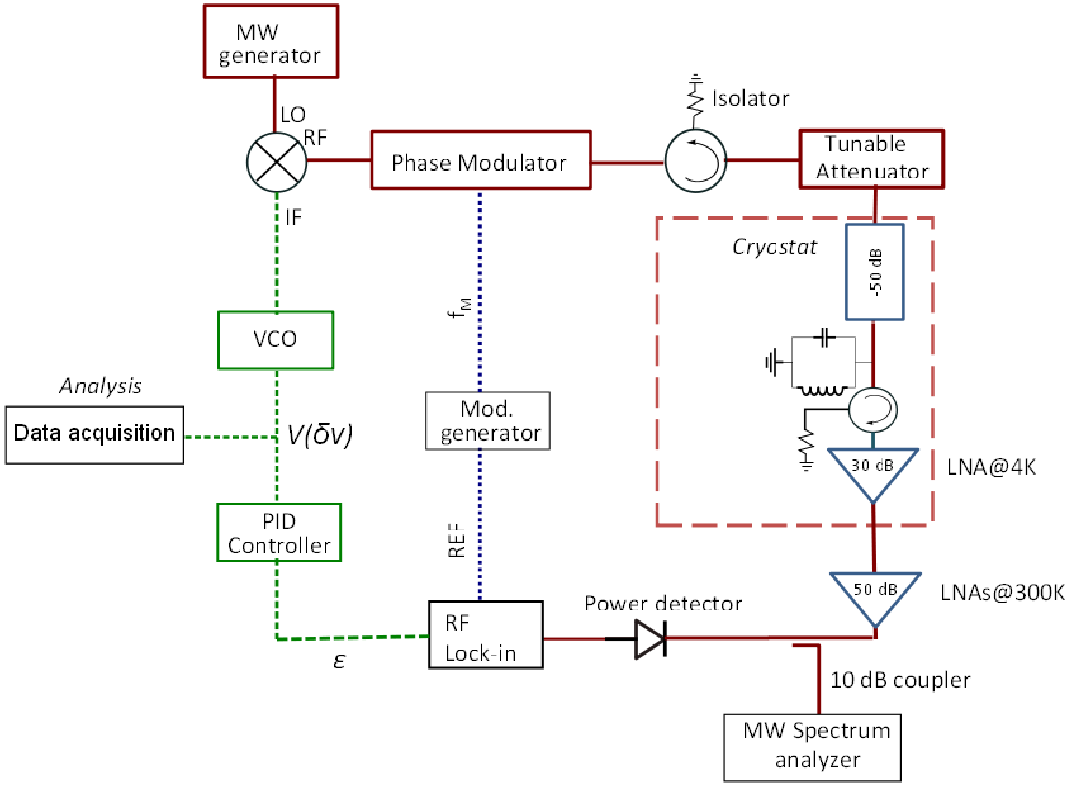


$$\epsilon_{lin} \propto kV_0^2 \frac{4gQ_u}{(g+2)^2} y$$

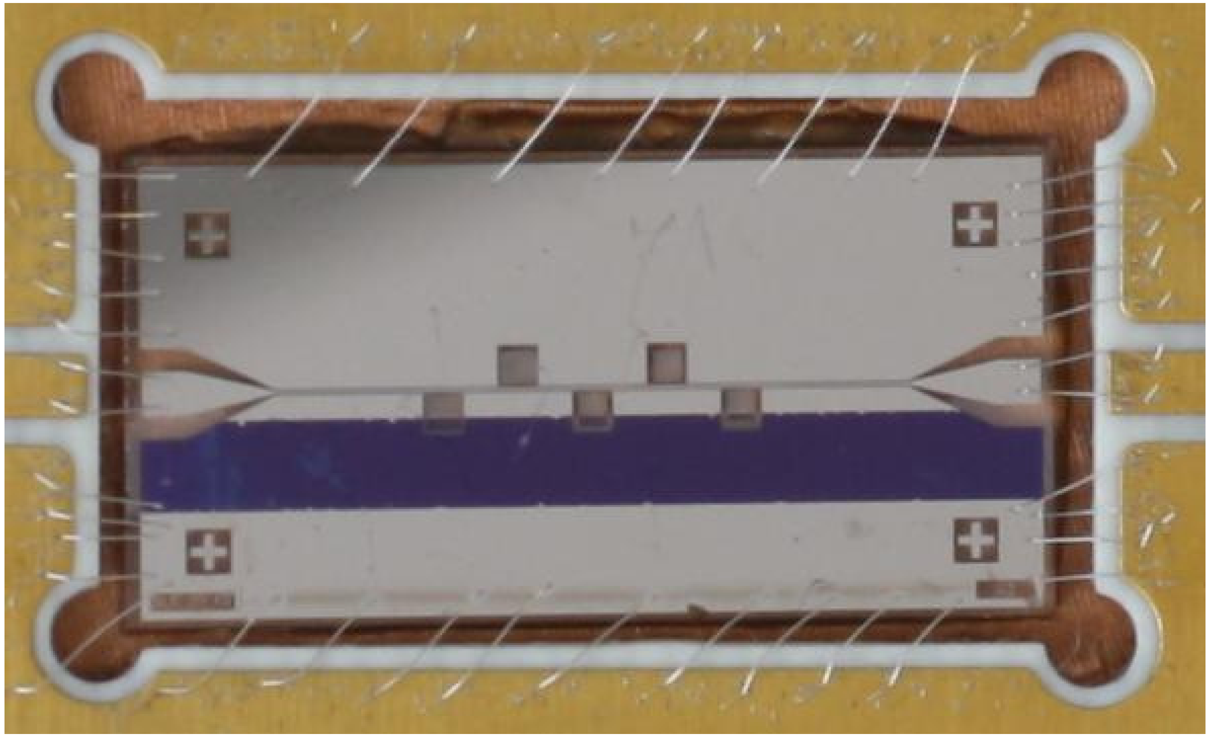
- Zero crossings correspond to each signal being at resonance
- Gradient of carrier maximal when power in sidebands is half that of carrier

Pound Lock: Implementation

- Improved carrier stability from function generator
- Tuneable attenuator maintains control of microwave input power
- Lock in used as down mixer with gain
- Data acquisition by DAQ-ADC and FFT analyser



Sample overview

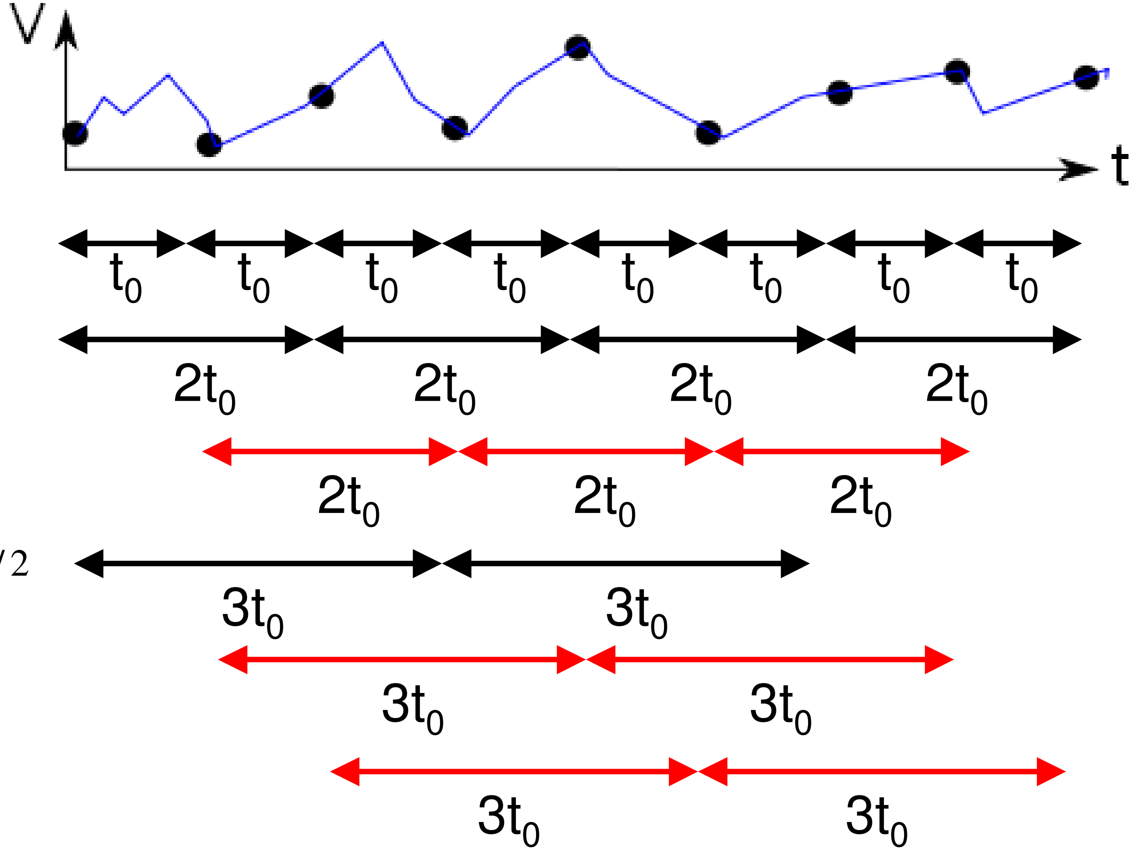


- Nb on Sapphire
- 5 Lumped element resonators
- f_0 range 4-8 GHz
- Additional dielectric layer over capacitive region of three resonators (blue strip)

Allan deviation: Introduction

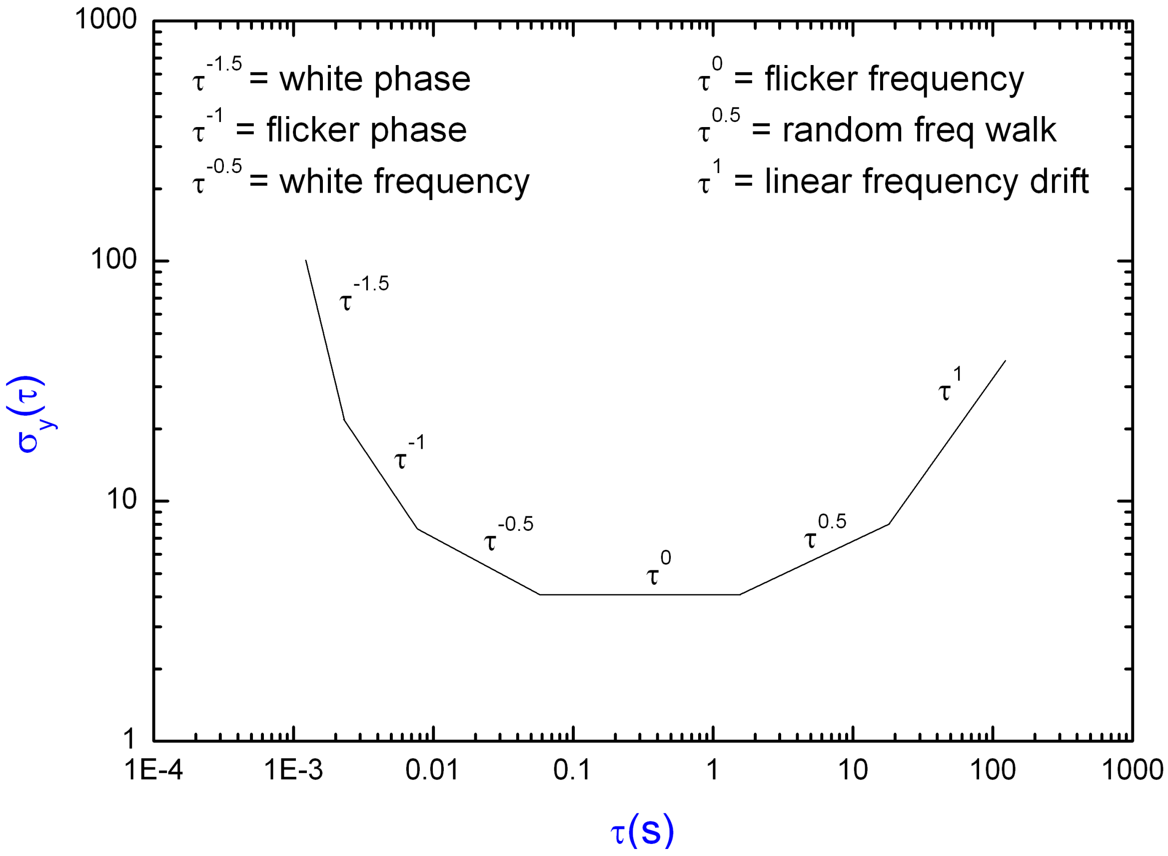
- Deviation of points equally separated in time
- Estimator of Allan deviation converges for all power law noise processes.

$$\sigma_y(\tau) = \frac{1}{\sqrt{2}} \left\langle \left(\bar{y}_{i+1} - \bar{y}_i\right)^2 \right\rangle^{1/2}$$



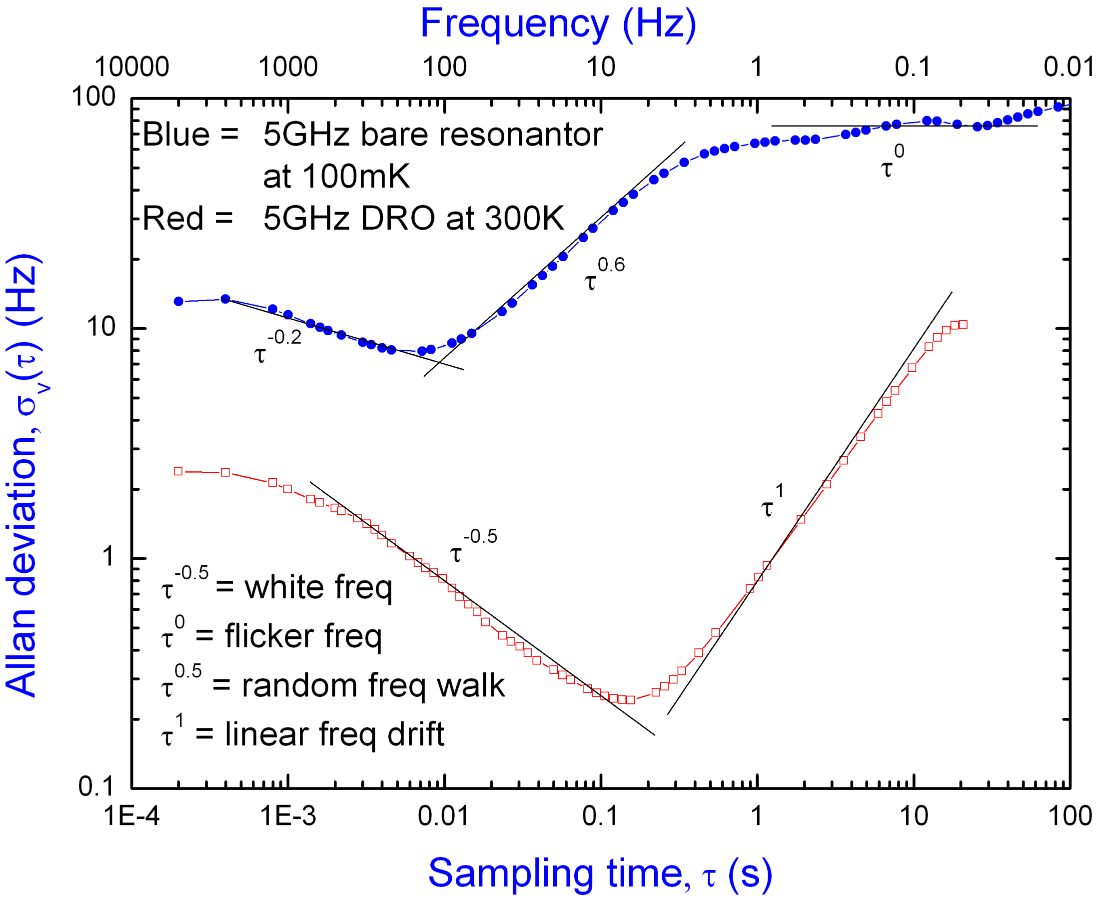
Allan deviation: Introduction cont.

- Plot of stability within a measurement time τ
- Stability can be considered as read ou resolution in Hz
- Power law noise processes can be fit as $\sigma_y \propto \tau^\alpha$



Characterising the loop

- 10 Hz readout resolution at 10 ms
- DRO 100 times more stable than superconducting resonator
- Between 5-100 Hz dominant noise in superconducting resonator is random frequency walk ($1/f^2$)



Preliminary results: Loss tangent

50 nm Al_2O_3

f_0(MHz)	F*tan d_i*1e6
4322	26
5004	3.0
6248	27
7091	13
7764	27

50 nm HfO_2

f_0(MHz)	F*tan d_i*1e6
4946	4.8
6125	24
7045	6.0
7588	15

- Measure centre frequency with changing temperature

$$F \tan \delta_i = \frac{F \pi d^2 n}{3\varepsilon}$$

- Loss tangent approximately 10x larger for Al_2O_3 layer
- Loss tangent approximately 5x larger for HfO_2 layer

Preliminary result: Noise

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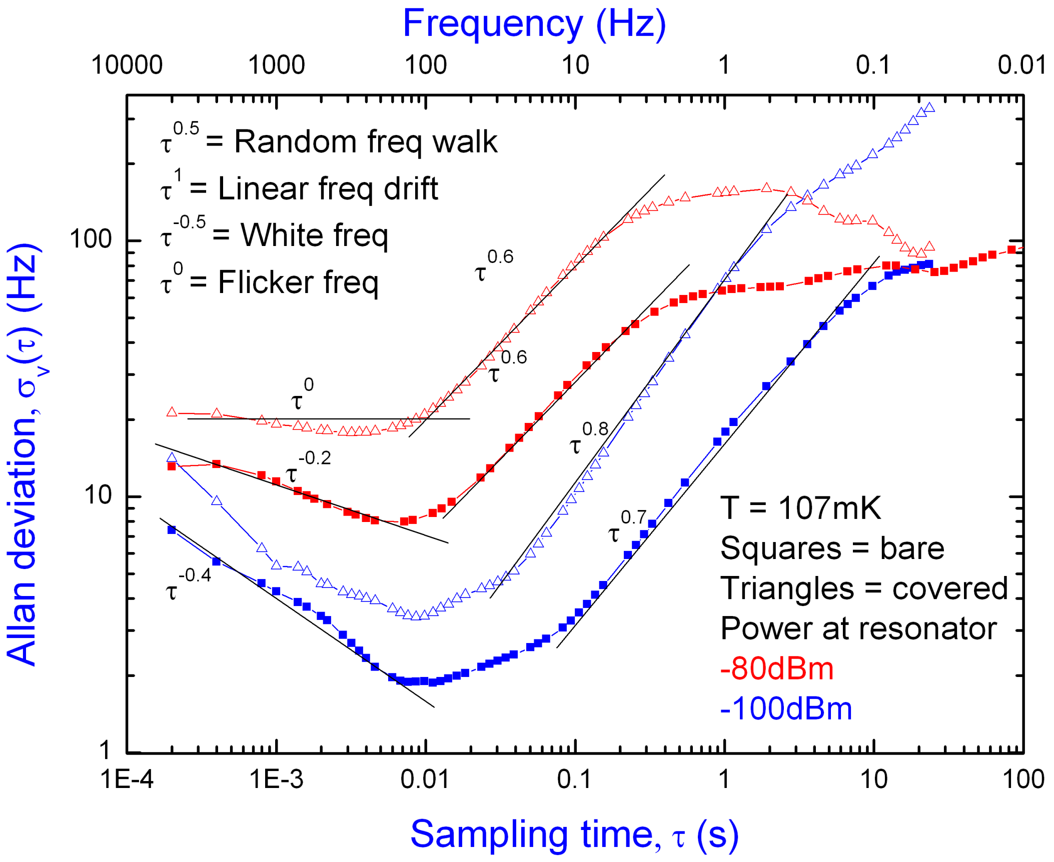
- Covered resonators always noisier than uncovered
- Noise level decreases at lower powers
- Between 5-100 Hz random frequency walk (1/f²) is dominant noise
- Between 100-10000Hz noise type varies with power



Summary

- Direct probe of resonant frequency fluctuations
- Measurements possible between –80dBm and –100dBm
- Pound loop read out resolution of 10 Hz within 10 ms
- Read out resolution down to 0.2 Hz has been demonstrated in “clean” DRO
- Covered resonators are noisier and have higher loss tangent.
- Dominant random frequency walk noise in the 5-100 Hz range
- Flicker frequency noise only dominates at sub 1 Hz

http://arxiv.org/abs/1106.5396

Further loop characterisations

- Thermal or mechanica instability produces frequency drift
- DRO 100 times more stable than superconducting resonator
- Between 5-100 Hz dominant noise in superconducting resonator is random frequency walk ($1/f^2$)