**Magnetic flux noise in SQUIDs and qubits**

Our understanding of flux noise before thesis work:

* All SQUIDs and qubits exhibit a real effective flux noise that is intrinsic to the loop and not due to external fields or parameter variations.
* Magnitudes of noise SΦ(1 Hz) are remarkably uniform between devices of greatly varying geometries and fabrication processes and materials.
* Models assuming independent surface spins predict a particular scaling of the noise magnitude with geometry, but this scaling had not been systematically and experimentally studied.

Our understanding of flux noise as a result of this thesis work:

* Dephasing:
  + The slope α greatly affects qubit dephasing times, making it perhaps more important even than the magnitude A2.
* Numerical calculations of 〈Φ2〉:
  + Indicate that the potential contribution of edge spins is significant.
* Temperature dependence:
  + The slope α varies greatly with temperature.
  + The spectra of any particular device tend to pivot about a single frequency as the temperature is varied.
  + Our data (strongly temperature-dependent inferred 〈Φ2〉) are inconsistent with the independent single-electron fluctuator model.
    - Simple cluster model is unable to reconcile the discrepancies
* Geometry dependence:
  + The slope α can vary systematically with geometry
  + SΦ(1 Hz) tends to scale with geometry, but 〈Φ2〉 does not [MIT devices]
  + Other devices?
* Material dependence:
  + The native surface oxide is not a major factor in flux noise [Au-capped measurements].
  + The slope α can vary with capping materials.

Principal conclusions:

* We have compelling evidence that the flux noise is caused by spins that exist at the upper and lower surfaces of the loop.
* The independent single-electron fluctuator model is not consistent with our data, even if one extends the model to include independent clusters that change size with temperature. The likely interpretation is that spin-spin interactions are significant.
* The material of the loop as well as capping layers above and below the loop can significantly influence the value of A2 and α in a device. Although this point is poorly understood, it provides a promising avenue towards lowering the flux noise and better understanding its nature.

1. **Introduction**
   1. Low-noise measurements and devices?
   2. SQUIDs
   3. Qubits
   4. Types of noise: critical current and flux noise
   5. Flux noise
      1. Fred’s measurements
      2. Koch’s calculations and surface spins
      3. Surface density of spins (Bluhm, McDermott, etc.)
      4. Reciprocity and analytic calculations
      5. MIGS
2. **Dephasing in qubits due to flux noise [PRB]**
   1. Decoherence and dephasing in qubits
   2. Model for dephasing due to flux noise
   3. Various calculations as α is varied
   4. Redo some calculations using 1/f2 falloff for f2 instead of brick wall?
3. **Numerical calculations of the mean square flux noise [paper in progress]**
   1. General method of calculation
   2. Previous methods and their respective shortcomings
   3. Our new method
      1. Results
4. **Experimental measurement system and procedures**
   1. Overview

* Low noise, stable, multiple SQUIDs,
  1. Measurement overview
* SQUID in normal state generates fluctuations that are read by a readout SQUID
* Bias the SQUID and null the circulating current
  + 1. Optimal circuit and device parameters
* Load line picture to determine value of Rc (small); voltage biased
* Large input coil mutual inductance, smaller feedback coil M
* ~~Feedback resistor?~~
* Large junction critical current
  1. Implementation
* Sample box
* Fridge + filters
* Electronics (custom, StarCryo, signal analyzer, lock-ins, etc.)
  + Figure?
  1. Calibration and validation
* Noise budget?
* dVfll/dPhi – Fred’s method
* Noise of Rc
  1. Measurement process
* Measure at 0 Phi0
* Sensitivity to flux
* Measure at ¼ Phi0
* Verify that noise scales as flux, 1/8 Phi0
  1. Low-frequency critical current noise [APL]
     1. Low in our devices, except for…
     2. Temperature-induced fluctuations

1. **Scaling of flux noise with temperature [PRL in review]**
   1. Spectral pivoting
      1. Experimental data
      2. Conjectures and implications?
   2. Fit coefficients vs. T
   3. Discrepancy between predicted and inferred MSFN
   4. Clusters?
2. **Scaling of flux noise with SQUID loop dimensions [PRL in review]**
   1. MSFN of MIT devices don’t scale with R
   2. Other devices with numerical MSFN?
3. **Second spectrum?**
   1. Do we include this?
4. **Effects of materials and interface engineering**
   1. Why interface is important?
   2. Descriptions of fab
   3. Tables listing experiments
      1. NIST SQUIDs (SiNx)
      2. UIUC SQUIDs (Au, top nitrides, NbNx, top/bottom SiNx)
5. **Concluding remarks**
   1. Uncorrelated single-electron model doesn’t fit data
   2. Interfaces and materials are important
      1. Evidence that spins are at the surface
6. **Device overview**
   1. Design, fabrication, capping layers, etc.
   2. A^2 and α vs. T for all measured devices in a standard format

Still to add:

* Second spectra