Space Research Centre

Excess Noise in TESs – A comparison between theories

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Introduction – Excess Noise Theories

•Experiments have shown that the noise power spectrum of practical TES can not be explained by conventional noise sources.

•The excess noise observed appears to originate from inside the TES and behaves as a constant voltage noise source *(Takei et al.).*

•We will contrast and compare two theories describing the excess noise

Y. Takei et al., NIM A 523 (2004) 134

Introduction – Excess Noise Theories

Phase Slip Shot Noise

•Vortices moving perpendicular to bias current responsible for noise (*Fraser*)

•Vortex motion creates change in superconducting order parameter φ

•If dφ/dt is not zero a voltage appears across the TES

Percolation Noise

•The superconducting film consists of a number of domains of area (*coherence length)*^{2} *(Lindeman et al.)*

•In the transition these domains fluctuate randomly between their SC and normal states

•If by coincidence a set of SC domains forms a cluster linking both ends of the TES the device resistance is reduced until the cluster dissolves

M.A. Lindeman et al., NIM A 559 (2006) 715
G.W. Fraser, NIM A 523 (2004) 234

Noise vs. Resistance

Several experimenters report the excess noise to scale as R^{-1} *(Lindeman et al., Takei et al.)*

Phase Slip Shot Noise

$$i_n = \frac{\sqrt{S_v}}{R}$$

$$i_n \propto \frac{(VI)^{1/2}}{R}$$

✓PSSN meets the R^{-1} requirement

Percolation Noise

$$i_n = \frac{\sqrt{S_{RS}(f)}}{R_{rs}}$$

$$i_n \propto R_{RS}^{-0.9}$$ for a 2D Film *(Kiss et al.)*

✓Percolation Noise approximately meets the R^{-1} requirement

M.A. Lindeman et al., NIM A 559 (2006) 715

Y. Takei et al., NIM A 523 (2004) 134

L.B. Kiss et al., Phys. Rev. Lett. 71 (1993) 2817

Magnetic Field Dependence of Noise

To date, no quantitative predictions are made about the relation between excess noise and magnetic field by either theory.

Magnetic Field Dependence of PSSN

•Using the PSSN equations derived by *Fraser, 2003* and using the vortex dynamics results from *Minnhagen, 1981* the magnetic field dependence of PSSN was derived *(Brandt et al., in preparation)*.

$$i_n^2 \propto \frac{\varphi_0}{2\pi B}\left(\frac{R_{TES}}{R_N}\right)$$

$$i_n \propto B^{-0.5}$$

P. Minnhagen, Phys.Rev.B 23 (1981)

D.Brandt et al., NIM A, *in preparation*

Field Dependence of Percolation Noise

- Using energy arguments it is possible to demonstrate a ~linear dependence of superconducting domain density on H^2.

- Using the dependence of R on sc domain density we deriver an approximate quantitative prediction for variation of noise with magnetic field *(Brandt et al., in preparation).*

$$i_n \propto R_{rs}^{-0.9}$$

$$R_{rs}^{-0.9} \propto H^{-2.34}$$

$$\Rightarrow i_n \propto H^{-2.34}$$

D.Brandt et al., NIM A, *in preparation*

Magnetic Field Dependence of Noise

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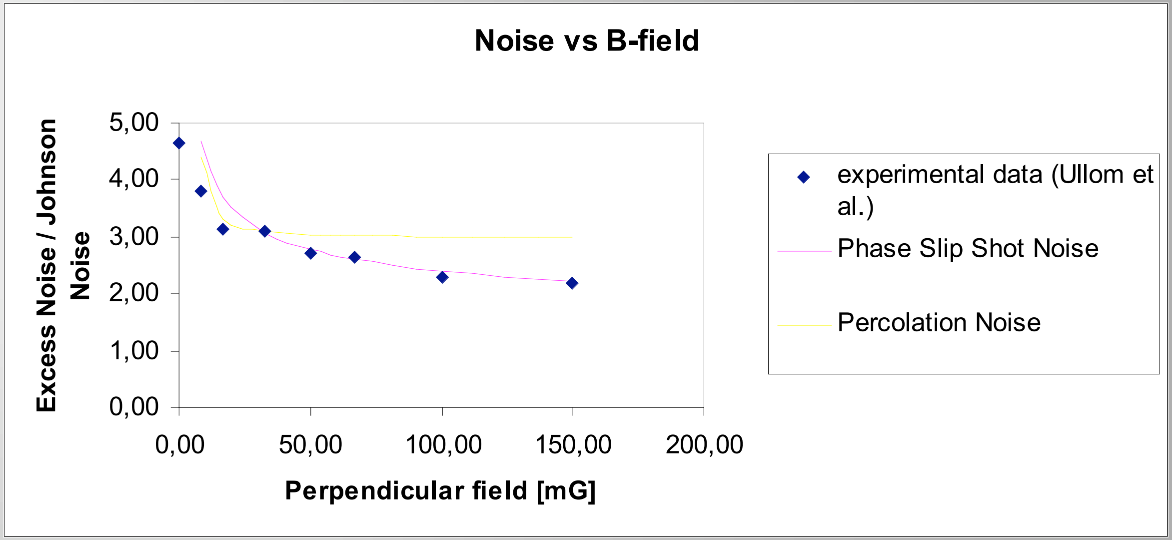
- The graph to the right shows data re-plotted from *Ullom et al.*
- This fits approximately with the expression we derived for Phase Slip Shot noise
- For fields >30 mG it does not agree with the expression derived for percolation noise



Data points re-plotted from data recorded by *Ullom et al.*

J. N. Ullom et al., Appl. Phys. Lett. 84 (2004) 4206

Geometry Dependence of Noise

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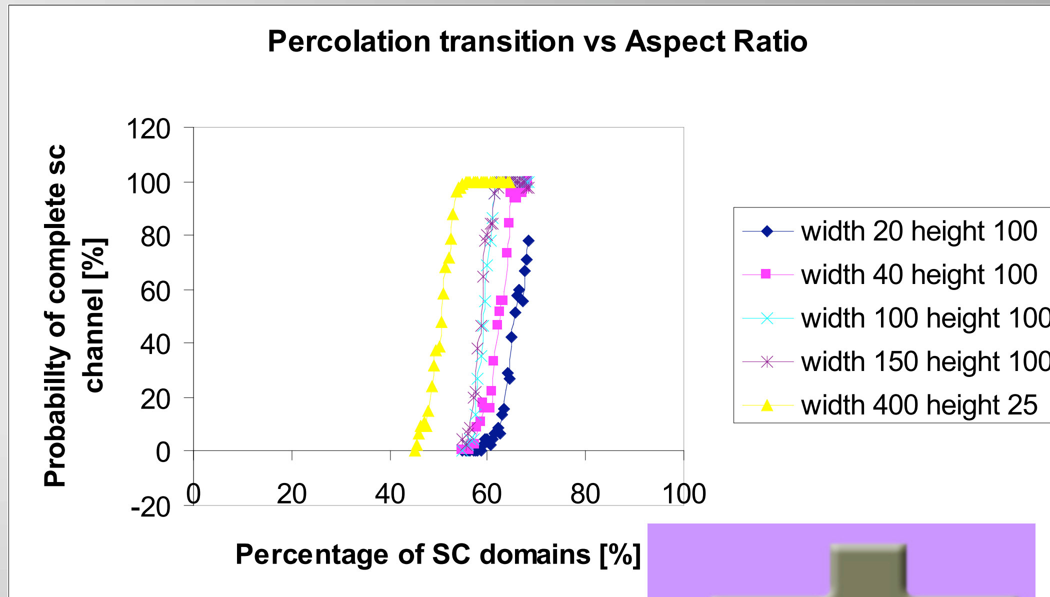
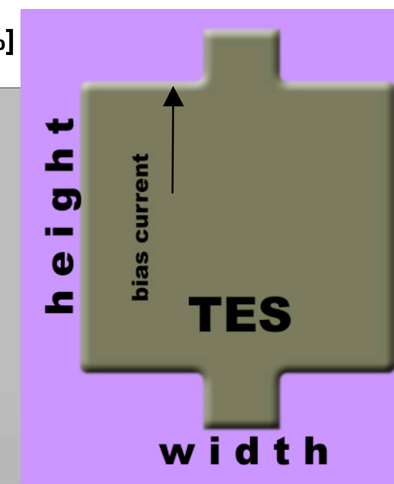
The magnitude of **phase slip shot noise** varies as **~area$^{-0.5}$**

Percolation noise should scale with device **length-to-width ratio** for small devices (smallest dimension << 500 domains)

Percolation noise should be approximately **independent of geometry for large devices**



Simulation data recorded at Leicester

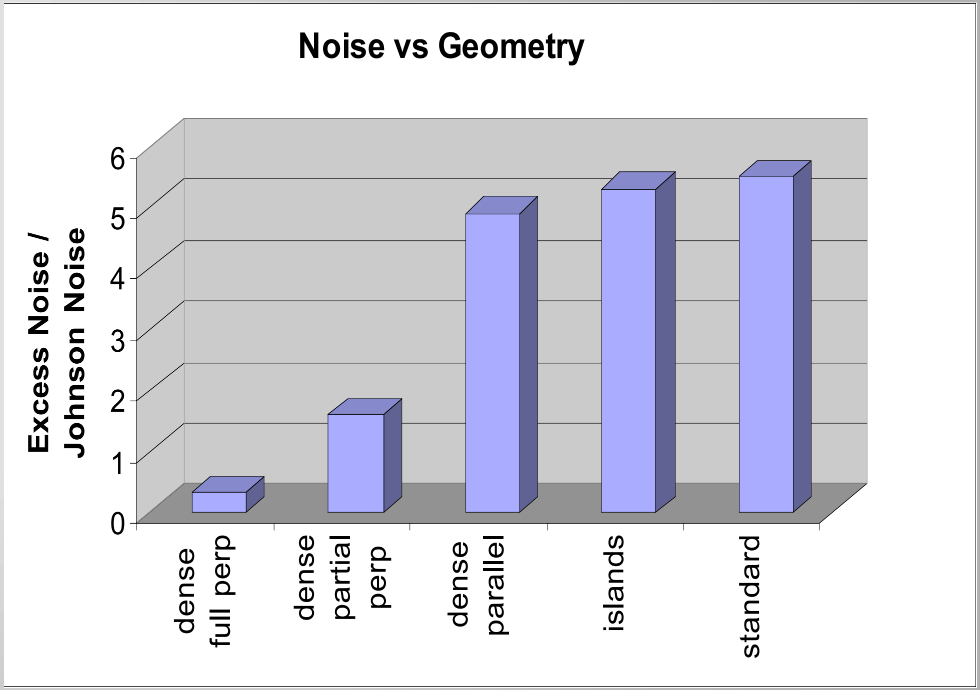


Geometry Dependence of Noise

- The deposition of normal material geometries on top of the TES can have a strong effect on excess noise.

- Dense stripes normal to the bias current yield the best results

- Dense full perpendicular stripes turn the device into a series of short wide TES which should be susceptible to Percolation Noise



J. N. Ullom et al., Appl. Phys. Lett. 84 (2004) 4206

Threshold Current

Voss et al. report the excess noise to scale strongly with bias current/voltage. *Takei et al.* report an absence of excess noise for low (< *10 μA*) bias current.

- Phase Slip Shot Noise explains threshold current with vortex dynamics
- Bias current creates driving force
- Lattice defects and impurities create vortex pinning sites
- At sufficiently high driving forces vortices become unpinned

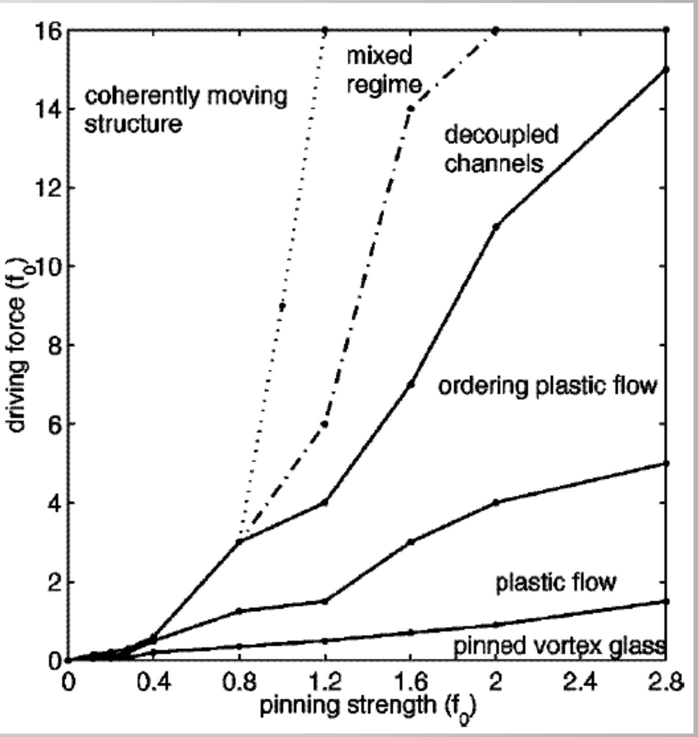
- Percolation Theory finds it difficult to explain the threshold current

R.F. Voss, C.M. Knoedler, P.M. Horn, Phys. Rev. Lett. 45 (1980) 1523.

Y. Takei et al., NIM A 523 (2004) 134

Threshold Current - Predictions

- Vortices interact to form a glass phase
- According to *Fangohr et al.* the vortex glass undergoes a series of phase transitions with increasing driving force
- We predict a change in spectral composition of noise with phase change



Graph taken from *Fangohr et al.*

H. Fangohr et al., Phys. Rev. B. 64 (2001)

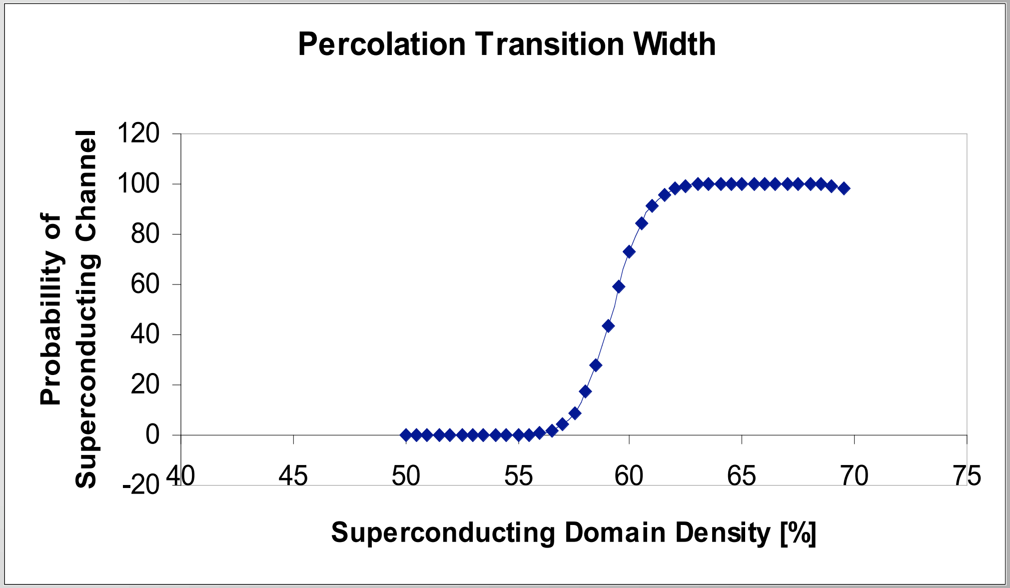
Validity of Models

The Phase Slip Shot Noise model uses single vortex dynamics in the KTB-transition

Therefore the model is valid for lower part of transition

Percolation Noise is only valid in the percolation region (p_{sc} *~ 56.3%*)

Therefore it is only valid near the centre of the transition



Summary

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	Phase Slip Shot Noise Predictions	Percolation Noise Predictions
Noise vs. Resistance	✓	✓
Noise vs. Magnetic Field	✓	Approximate agreement for fields < 30 mG
Noise vs. Geometry	✓	✓
Threshold Current	✓	Currently inexplicable by percolation theory
Validity of Model	Low part of transition	High part of transition

Combination of Models

- Since noise is observed almost everywhere in the s-n transition both models are necessarily incomplete

- We conclude that a complete description of excess noise contains both models