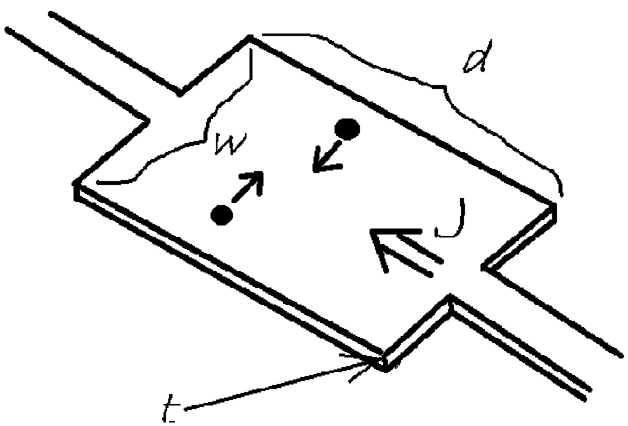
TES III Workshop
Gainesville, FL, 17-18 August 2006

Flux Flow noise in Transition Edge Sensors

UNIVERSITY OF MIAMI
DEPARTMENT OF PHYSICS

Massimiliano Galeazzi

Review of Flux Flow Noise



ALL expressions are in SI units

v = vortex speed

η = viscosity

ϕ_o = flux quantum

J = current density

μ_o = magnetization of vacuum

H_{C2} = critical field

ρ_n = normal state resistivity

V_1 = voltage generated by one vortex

V = voltage

I = current

N = average number of vortices

V_{RMS} = voltage noise root mean square

τ = vortex average lifetime

B = noise bandwidth

$S(f)$ = noise power density

e_{ff} = noise spectral density

l = vortex effective mean free path

V_o = "correlation" voltage

Review of Flux Flow Noise

Vortices move perpendicular to current flow with speed:

$$v = \frac{\phi_o J}{\eta}$$

Where

$$\eta = \frac{\phi_o \mu_o H_{C2}}{\rho_n}.$$

Each vortex generates a voltage

$$V_1 = \frac{v\phi_o}{w} = \frac{\phi_o}{w}\frac{\phi_o J}{\eta} = \frac{\phi_o}{w}\phi_o J \frac{\rho_n}{\phi_o \mu_o H_{C2}} = \frac{\phi_o}{\mu_o}\frac{IR_n}{wdH_{C2}}$$

v	=	*vortex speed*
η	=	*viscosity*
ϕ_o	=	*flux quantum*
J	=	*current density*
μ_o	=	*magnetization of vacuum*
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e_{ff}	=	*noise spectral density*
l	=	*vortex effective mean free path*
V_o	=	*"correlation" voltage*

Review of Flux Flow Noise

If the resistance at the transition is completely due to flux flow motion

➔ $$R = \frac{V}{I} = \frac{NV_1}{I}$$

➔ $$N = \frac{RI}{V_1} = \frac{\mu_o}{\phi_o}\frac{R}{R_n} w^2 H_{C2}$$

For SMALL N this generates a RMS voltage noise:

$$V_{RMS} = \sqrt{N} \cdot V_1 = \sqrt{RIV_1}$$

The average lifetime of each vortex is give by

$$\tau = \frac{w}{v}$$

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Review of Flux Flow Noise

➔ $$B = \frac{1}{\tau} = \frac{v}{w}$$

➔ $$S(f) = \frac{V_{RMS}^2}{B} = \frac{RIV_1}{v/w} = \phi_o V$$

➔ $$e_{ff} = \sqrt{\phi_o V}$$

This is the same result obtained by Knoedler and Voss [Phys. Rev. B 26, 449 (1982)] assuming "vortex" shot noise.

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Review of Flux Flow Noise

ISSUE #1: The observed noise is too small
➔ Introduction of vortex mean free path

➔ $$B = \frac{1}{\tau} = \frac{v}{l}$$

➔ $$S(f) = \frac{V_{RMS}^2}{B} = \frac{RIV_1}{l} = \phi_o V \frac{l}{w}$$

➔ $$e_{ff} = \sqrt{\phi_o V \frac{l}{w}}$$

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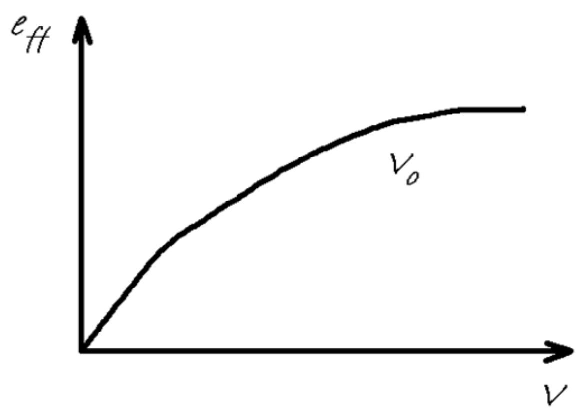
Review of Flux Flow Noise

ISSUE #2: For large N the vortexes are correlated
➔ e_{ff} is smaller

But $N = \frac{V}{V_1}$ ➔ for large voltage the noise is reduced due to the correlation (saturation effect).



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Review of Flux Flow Noise

FIRST ORDER APPROXIMATION:

Replace **V** with $\frac{V}{1+V/V_o}$, where $\mathbf{V_o}$=const. (dependent on $\mathbf{V_1}$)

$$\rightarrow \quad e_{ff} = \sqrt{\phi_o \frac{V}{1+V/V_o} \frac{l}{w}}$$

for $\mathbf{V<<V_o}$ $\rightarrow$ $e_{ff} = \sqrt{\phi_o V \frac{l}{w}}$

for $\mathbf{V>>V_o}$ $\rightarrow$ $e_{ff} = \sqrt{\phi_o V_o \frac{l}{w}}$

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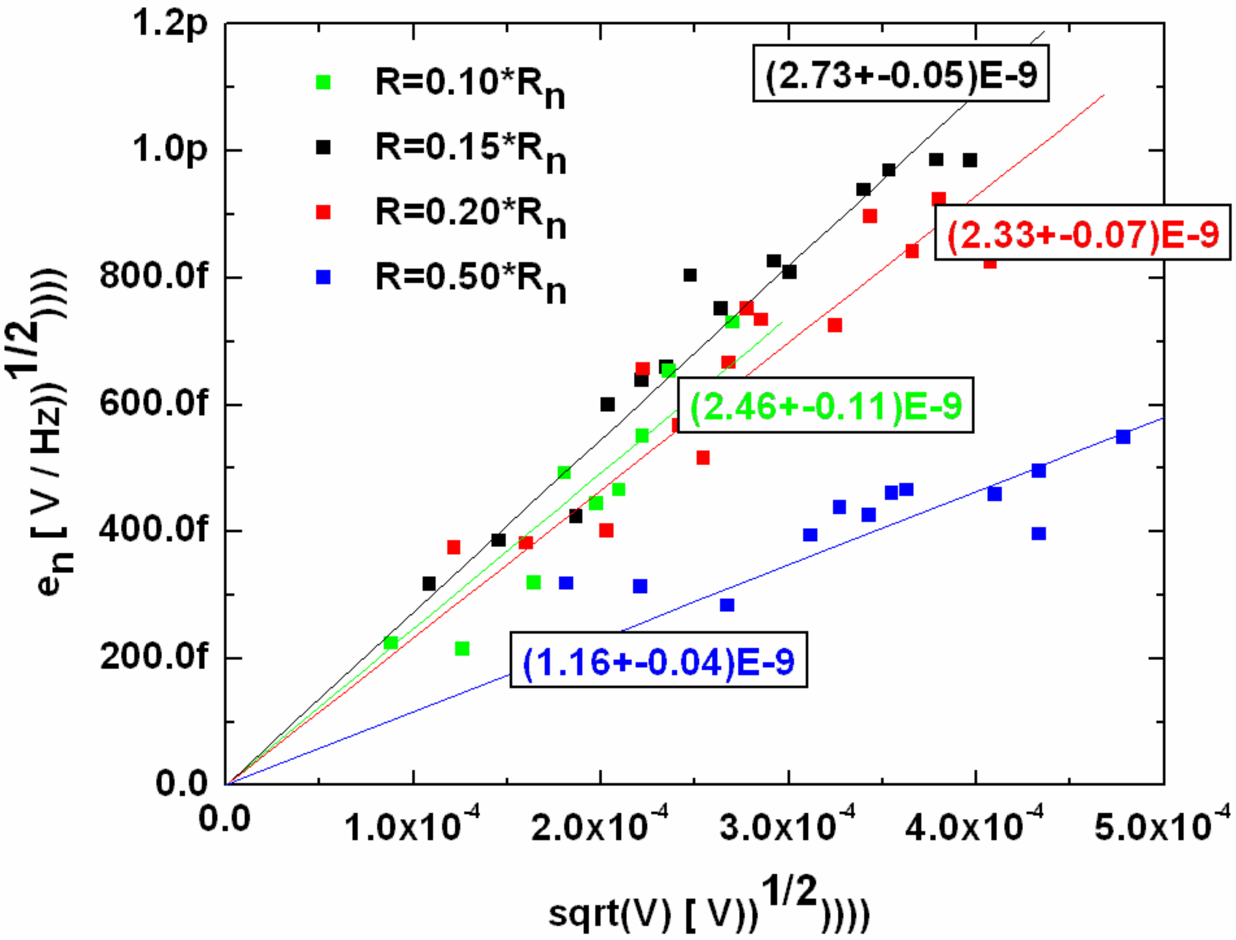
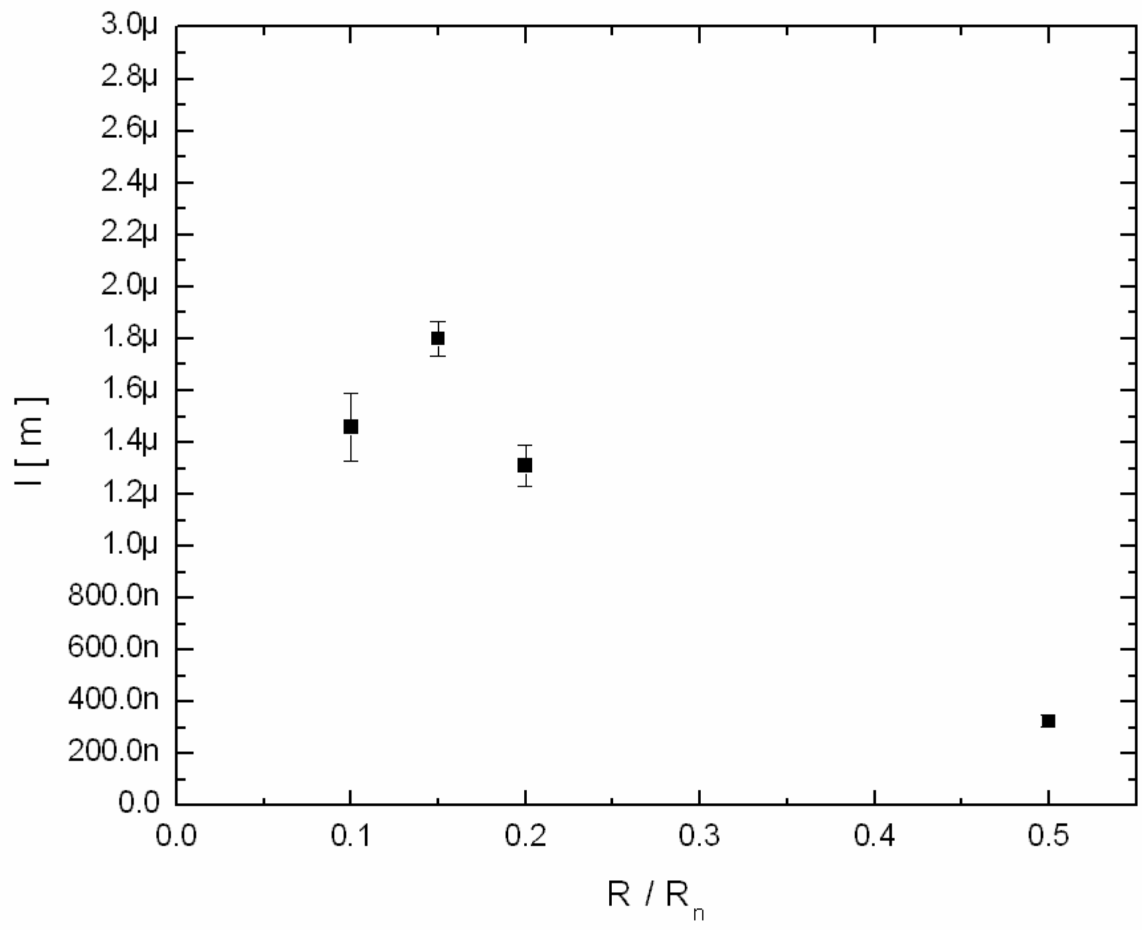
Experimental evidence

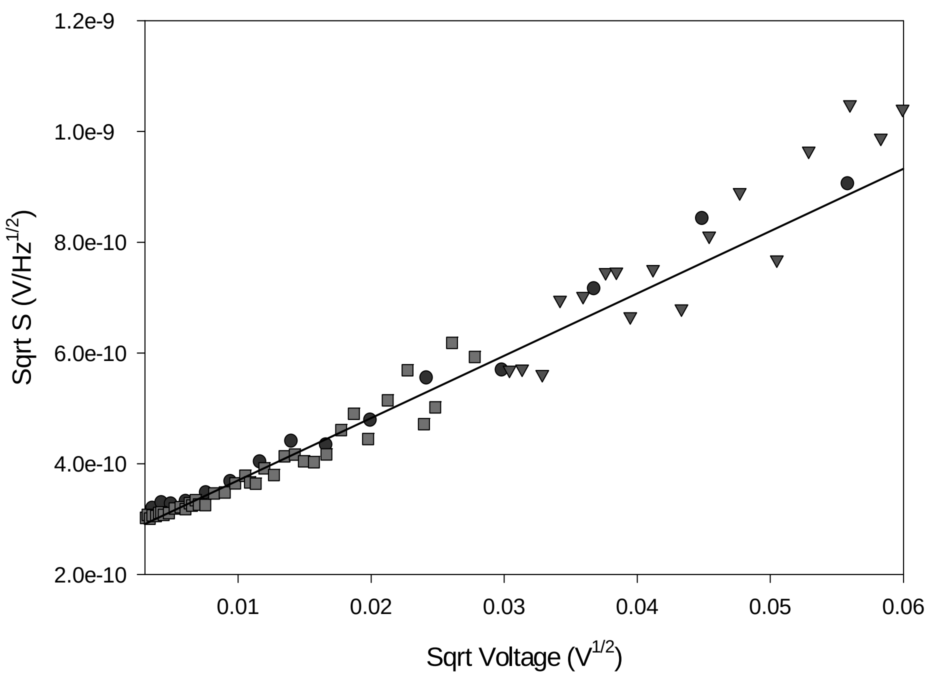


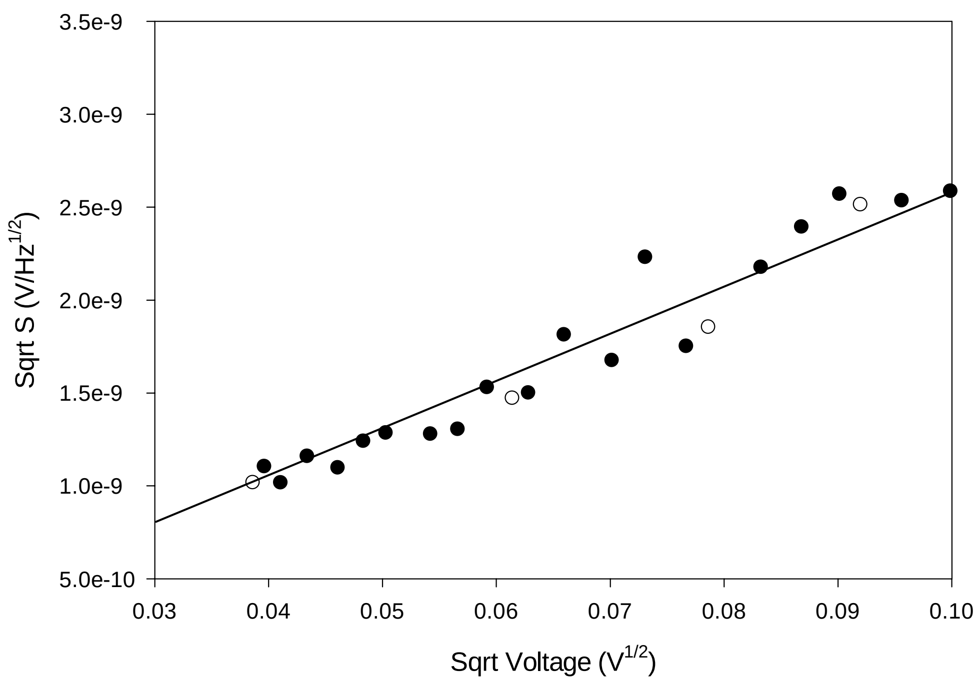
Data courtesy of the X-ray Astrophysics group at the NASA/GSFC

Mean Free Path



Experimental Evidence





UNIVERSITY OF Miami
DEPARTMENT OF PHYSICS

Hengsong Zhang, Qian Chen and Fulin Zuo (see poster for details)

Open Questions

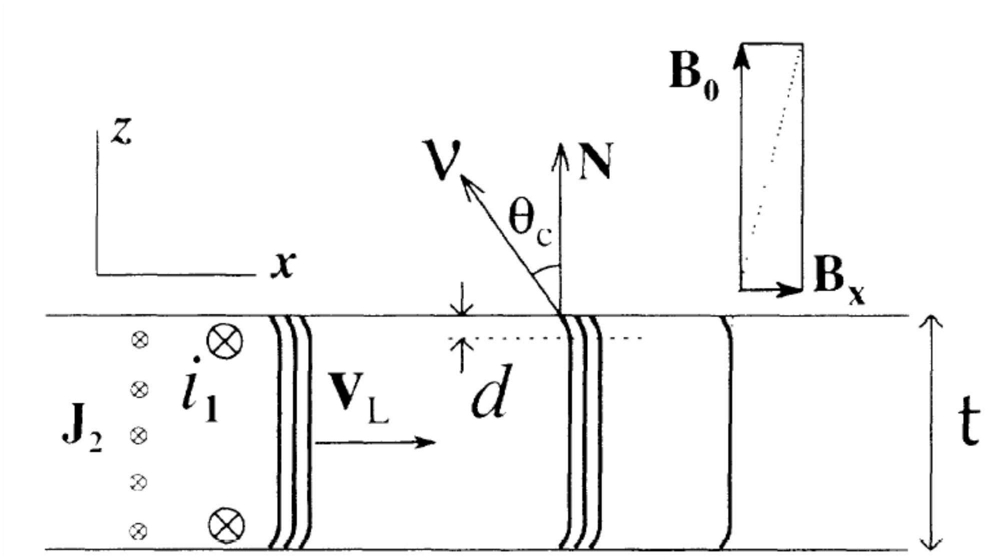
- **What is the mean free path *l*?**
- **Why do we have a dependence of the noise on α?**

➔ Different Approach to Flux Flow Noise

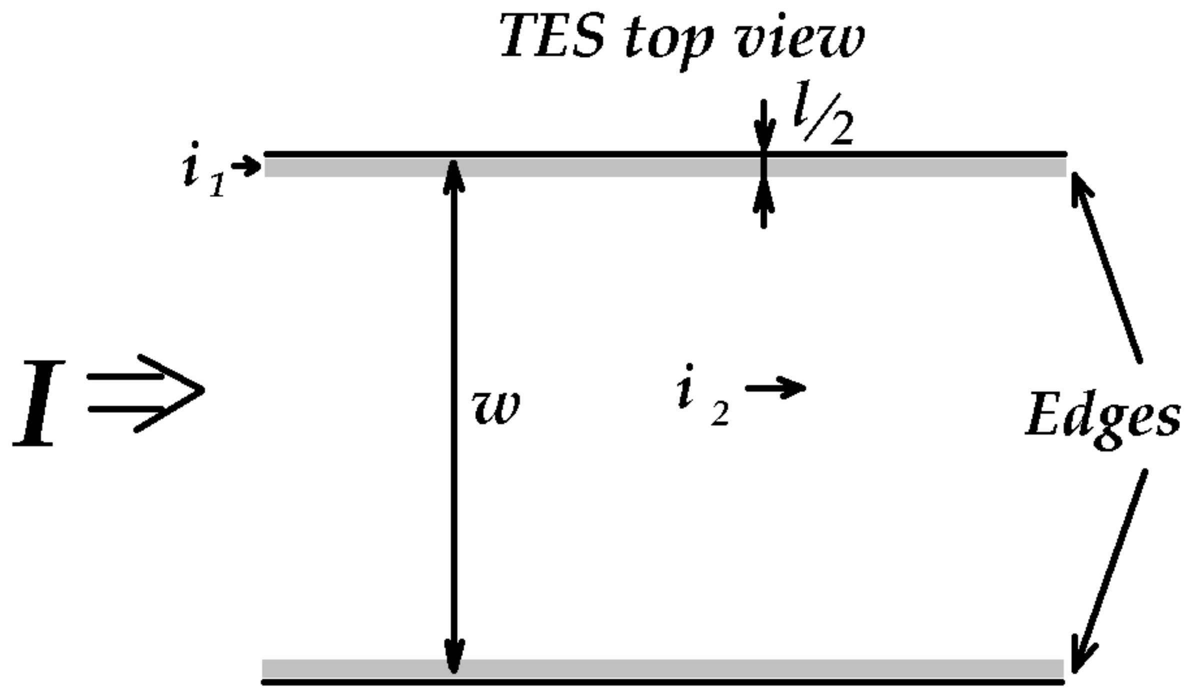
Flux Flow Noise Revisited

Placais, Matheiu, and Simon, PRB 49, 15815 (1994)

1. A 3D treatment is necessary
2. In the film there are two separate currents contributions: a non-dissipative current at the edges and a dissipative current in the bulk
3. The non-dissipative current at the edges is of the order of the critical current i_c (A/cm)
4. It is the non-dissipative term that generates the noise



Flux Flow Noise Revisited



i_1 = non-dissipative current per unit width

$i_1 \sim i_c$ (critical current per unit width)

i_2 = dissipative current per unit width

$\Rightarrow$ $\boldsymbol{I = i_1 \cdot l + i_2 \cdot w \sim i_2 \cdot w}$

Flux Flow Noise Revisited

Flux Flow Model

$$S(f) = \frac{V_{RMS}^2}{B} = \frac{RIV_1}{w} = \phi_o V$$

$$e_{ff} = \sqrt{\phi_o V}$$

Flux Flow Model Revisited

$$S(f) = \frac{V_{RMS}^2}{B} = \frac{R(i_1 l)V_1}{w} =$$

$$= \frac{R(i_1 l)V_1}{w} \cdot \frac{I}{I} = \frac{RIV_1}{w} \cdot \frac{(i_1 l)}{I} \approx \phi_o V \frac{i_1 l}{i_2 w}$$

$$e_{ff} = \sqrt{\phi_o V \frac{i_1 l}{i_2 w}} \approx \sqrt{\phi_o V \frac{i_C \cdot l}{i \cdot w}}$$

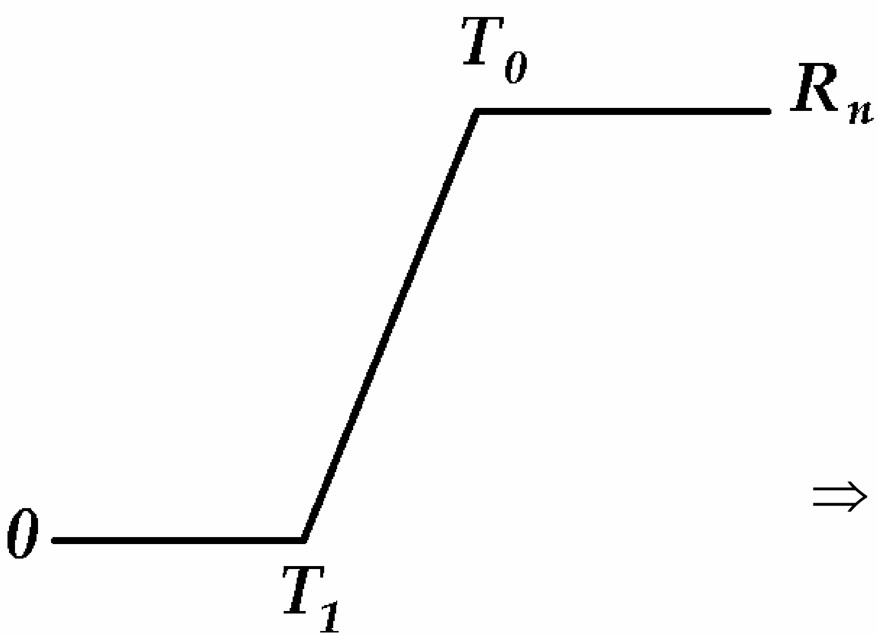
Detector sensitivity α

$$E_J = \frac{\hbar I_C}{2e}$$ Energy to break vortexes

$$k_B T_{KT} \sim E_J$$ Kosterlitz-Thouless Transition Temperature

$$T_{KT} \sim T_0$$ For low Resistance (Beaseley and Mooji, 1979)

$$k_B T_1 = E_J - E \approx kT_0 - E$$ E = Energy provided by current (or magnetic field)



$$\Rightarrow \Delta T = T_0 - T_1 = \frac{E}{k_B} \approx T_0 \frac{E}{E_J}$$

$$\Rightarrow \alpha = \frac{T}{R} \cdot \frac{\Delta R}{\Delta T} \sim \frac{T_0}{R} \cdot \frac{R_n}{T_0 \frac{E}{E_J}} = \frac{R_n}{R} \frac{E_J}{E} \propto \frac{I_C}{I}$$

Flux Flow Noise Revisited

$$e_{ff} \approx \sqrt{\phi_o V \frac{l}{w} \alpha}$$