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SMR/543 - 12

EXPERIMENTAL WORKSHOP ON HIGH TEMPERATURE SUPERCONDUCTORS AND RELATED MATERIALS (BASIC ACTIVITIES)

(11 February - 1 March 1991)

" High Temperature Superconducting Thin Films and Their Applications "

PART III

presented by:

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Building 309
DK-2800 Lyngby
Denmark

ELECTRONIC APPLICATIONS OF LOW T_c AND HIGH T_c SUPERCONDUCTORS

N.F. PEDERSEN,
TECHNICAL UNIV. OF DENMARK , LYNGBY.

PRESENTATION OF LABORATORY.
(PHYSICS LABORATORY I)

Low T_c	high T_c
since 1970	since 1987.
thin films	thin films
Niobium technology	YBCO , BSCCO
Josephson junctions	↓
Superconducting circuits	
samplers	to come
mixers	
paramps	
SQUIDS	

Related topics at this conference :
- films
- SQUIDS
- rf properties

Plan for this talk

1) General advantages of high T_c

2) Brief overviev of low T_c
- materials
- Josephson junctio
- devices
- performance

3) High T_c , no junctions
- shielding
- resonators
- bolometers
- ⋮

4) High T_c , junctions
- SQUIDS
- mixers
- ⋮

Future

General about high T_c

1) Cooling N_2 instead of He

N_2 cost $= \frac{1}{100}$ He cost, $\lambda_{N_2} = 100\, \lambda_{He}$

2) $$\gamma = \frac{I_t}{I_0} \sim \frac{2\pi}{\Phi_0} \frac{k_B T}{I_0}$$

thermal noise goes up factor 20.

3) Anisotropy in transport properties

4) Small coherence length ξ.

5) Low normal conductivity (R_s high)

6) Very sensitive surfaces / interfaces.

1) First requirement: High T_c :

YBCO
BSCCO
TlCaBaCuO

2) Second requirement: good film:

example YBCO

T_c 87 - 90 K
ΔT_c < 1 K
J_c $5 \cdot 10^6$ A/cm² 77K
$> 10^7$ A/cm² 4.2K
R_s (10 GHz) < 500 μΩ 77K
< 50 μΩ 4.2K
ρ < 300 μΩcm at 300K
ρ(T) extrapolates to zero
surface smoothness.

3) Third requirement: Josephson junctions.

BCS: $RI_c \propto \Delta \propto T_c$

RI_c is a quality measure

10 THz

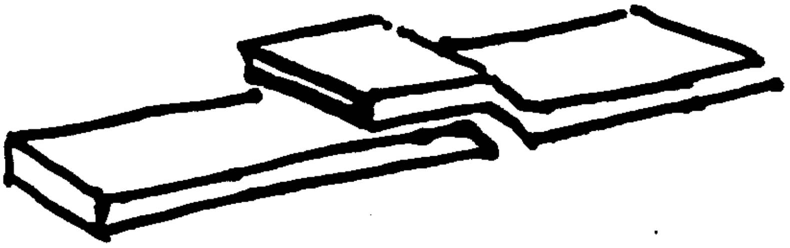
low T_c: $RI_c \sim 3\,mV$, high T_c: $RI_c \underset{\uparrow}{\sim} 25\,mV$

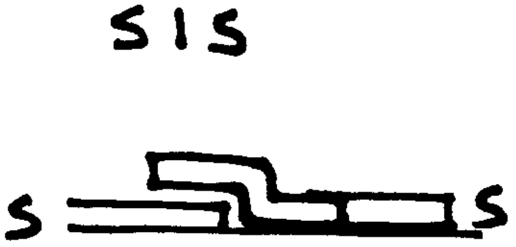
1 THz

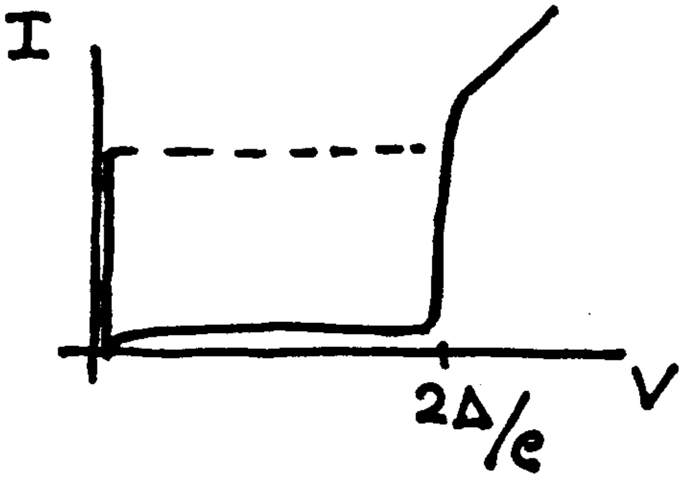
potentially

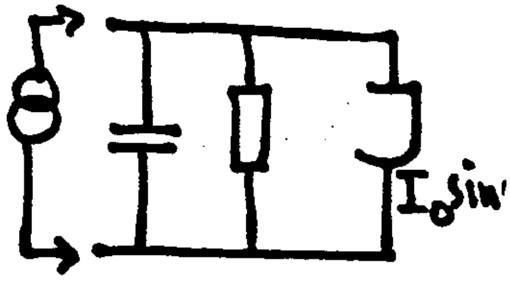
Low T_c Josephson junction achievements

- Technology : Niobium $T_c \sim 9.2K$
- chip fabrication , integration
- key element : Josephson junction









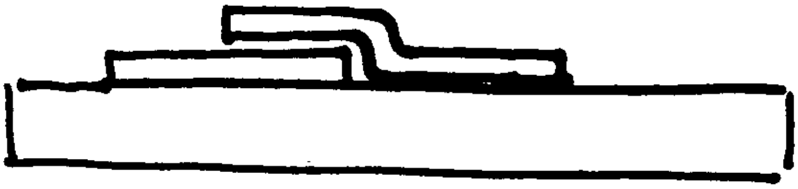
$$I = I_0 \sin\phi + \frac{V}{R} + C\frac{dV}{dt}$$

$$\frac{d\phi}{dt} = \frac{2e}{\hbar}V$$

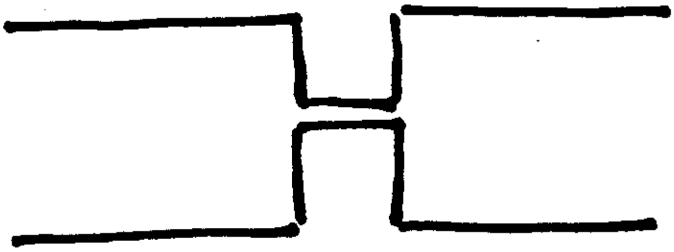
So far: no high T_c Josephson junctions of thin film sandwich type.

~

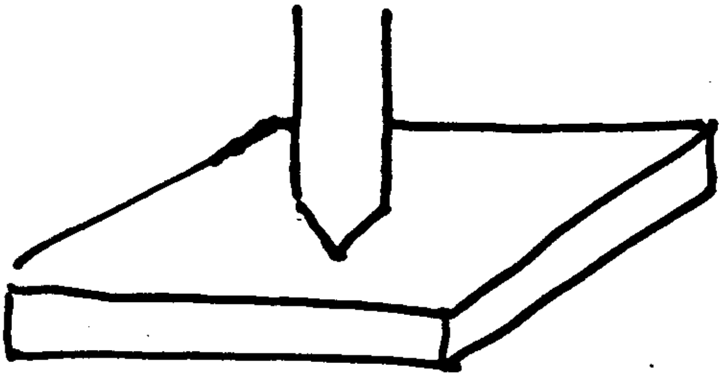
Types of junctions:



thin film sandwich



Weak link
microbridge



point contact.

Josephson junction

- rf - detection

  most sensitive detector 50 - 1000 GHz
  (near quantum limit / single foton detector)
  (standard in radio astronomy receivers)

- voltage standard.

  most precise (1: 10^9), commercial.

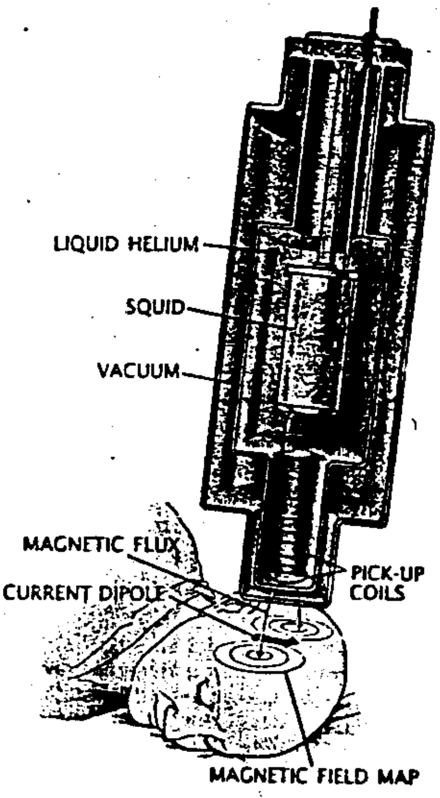
- sampling circuits.

  best time resolution (~ 1 pS), commercial.

- AD converters, computers, ...

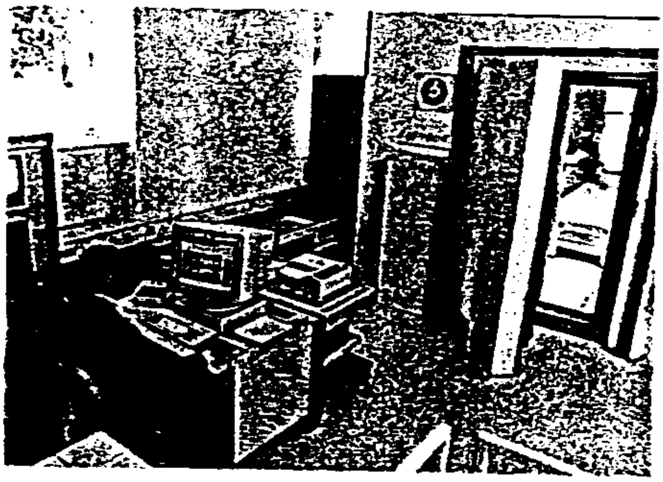
  oscillators

COMMERCIAL LOW T_c SQUID SYSTEMS ALREADY WORKING IN HOSPITALS



MAGNETOENCEPHALOGRAPHY employs

← Brain



View of the KRENIKON system from the operators position at
nputer workstation into the open door of the magnetically
d examination room.

IEMENS Corporate Research,
IEMENS Medical Engineering Group,
8520Erlangen, Germany

ript received September 24, 1990

Heart
↓

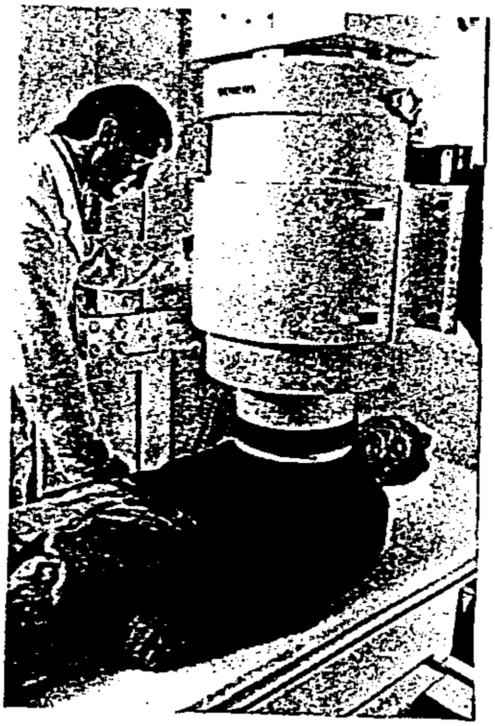


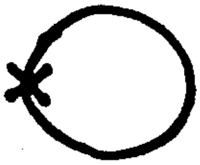
Fig. 2 A patient being prepared for an MCG investigation.

paper EK-2, Hoenig et al.

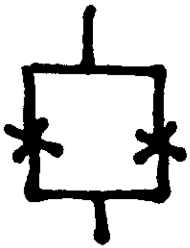
Low T_c Josephson junction achievements.

1) SQUIDS 10^{-34}

- Energy resolution ~ 10^{-31} J/Hz
(potential energy of an electron lifted 100 μ.v. 10 cm)
- Magnetic field sensitivity 10^{-14} Tesla
- Voltage 10^{-18} Volt
- Current 10^{-18} Amp.



rf SQUID



dc SQUID

Biomedical applications, commercial
BTI, Siemens.

NAKAJIMA et al.

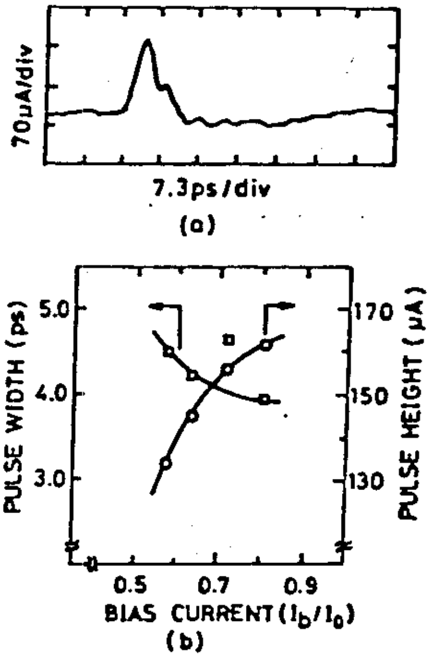


FIG. 2. (a) Current wave form of a traveling fluxon observed under the line bias current $I_b = 8.37$ mA. (b) Bias-current dependence of the width and the height of the traveling pulse. Bias current is normalized by the critical current of the JTL, 13 mA. A fluxon behaves as a relativistic particle because the product of the width and the height is nearly constant independent of the bias current.

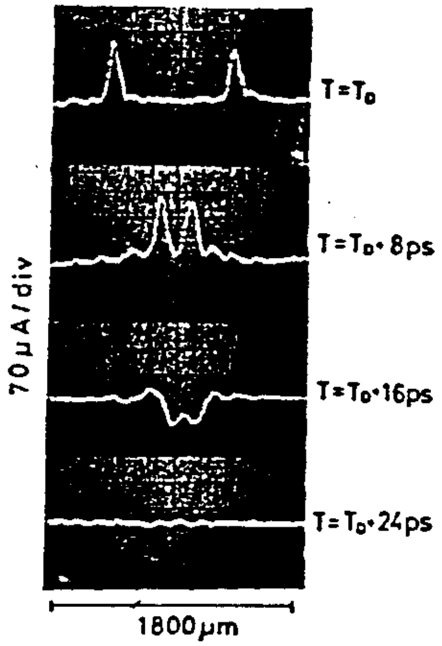


FIG. 3. A fluxon-antifluxon annihilation process observed by a new measuring system in space and time. After the collision, the two fluxons fade off by the breather decay mode.

JOSEPHSON SAMPLING CIRCUITS ARE NOW „STANDARD". TIME RESOLUTION : ~ 2-5pS.

High Tc applications (possibly)

1) EMF shielding
2) Resonators, transmission lines
3) Switches
4) Bolometers

} no josephson junctions required.

5) SQUIDS
6) Flux flow amplifier

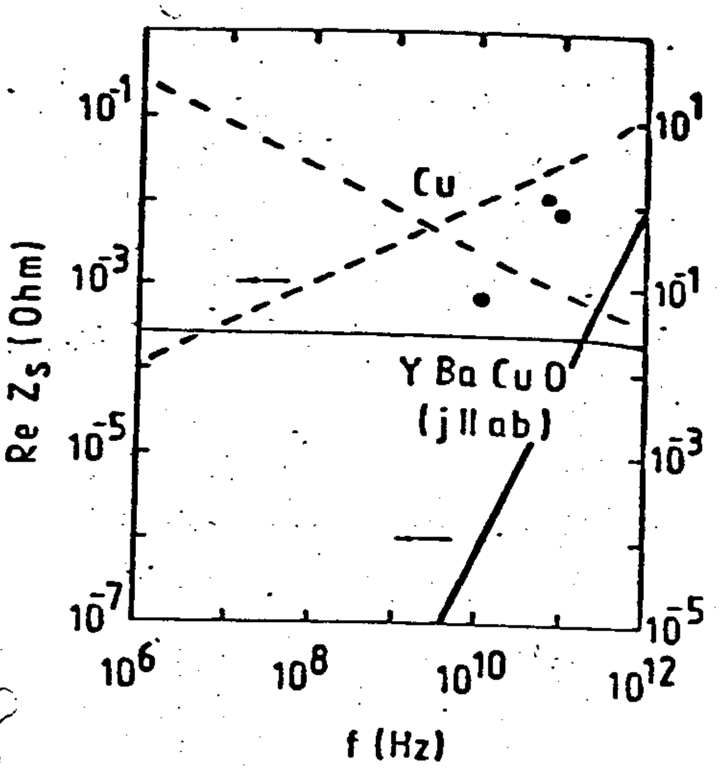
} low grade josephson junctions required.

7) mixers
8) rf amplifiers
9) samplers
⋮

} high quality josephson junctions required (as in low T_c)

⋮ new (never thought of) applications

surface resistance and penetration depth

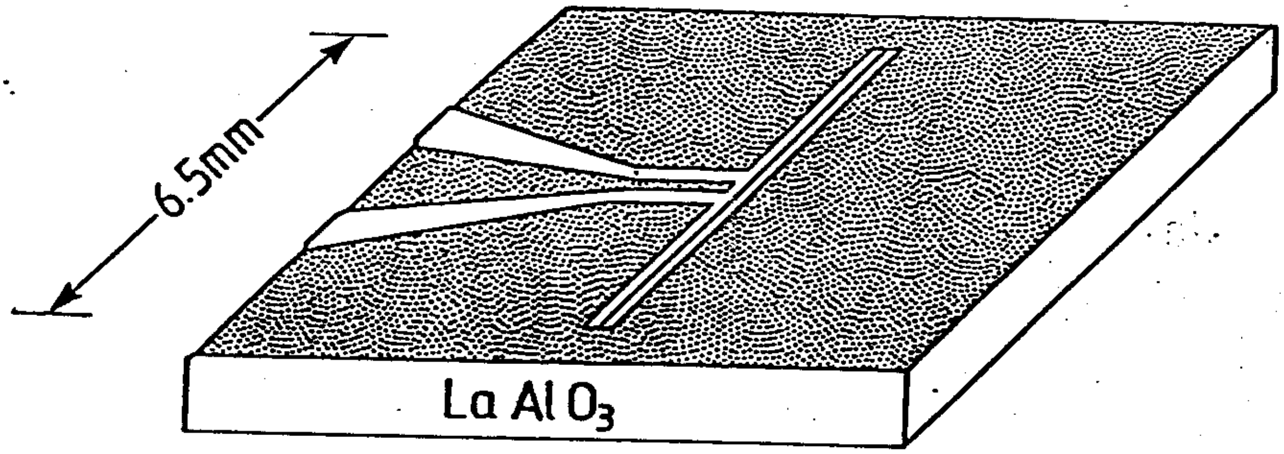


RF • CAVITY.

Braginsky 1990

EXAMPLE OF A SLOT LINE CAVITY

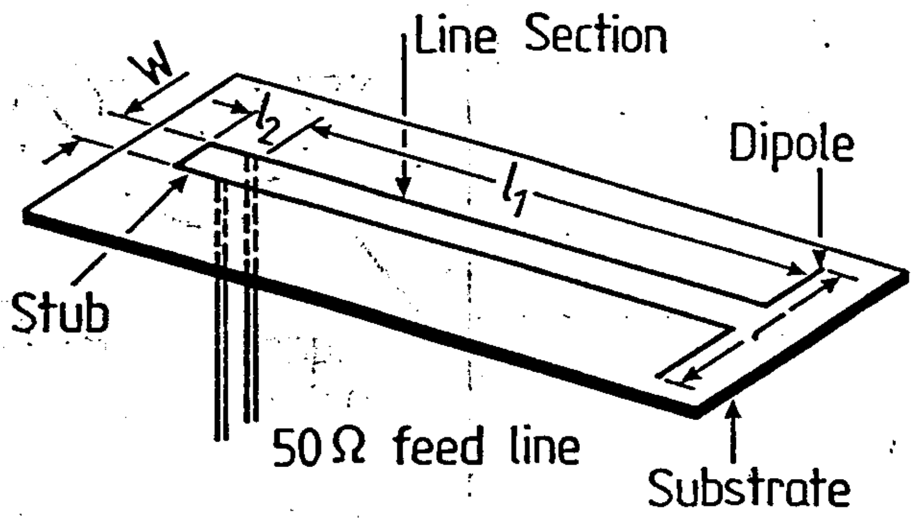
VALENZUELA et al.

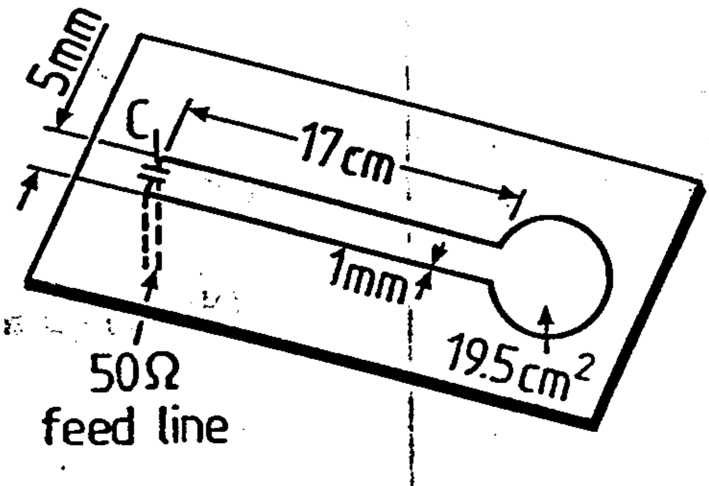


Comparison of Data at 77K:

Material	d µm	f GHz	R_S m Ohm	$Q_{Calc.}$	$Q_{Meas.}$
Au/Sapph	3	9.1	13.0	122	77
$Cu/LaAlO_3$	>>1	6.5	?	?	89
YBCO/MgO	0.35	8.8	0.6	1420	1300
$YBCO/LaAlO_3$	0.28	6.5	0.14	?	3850

Antenna's



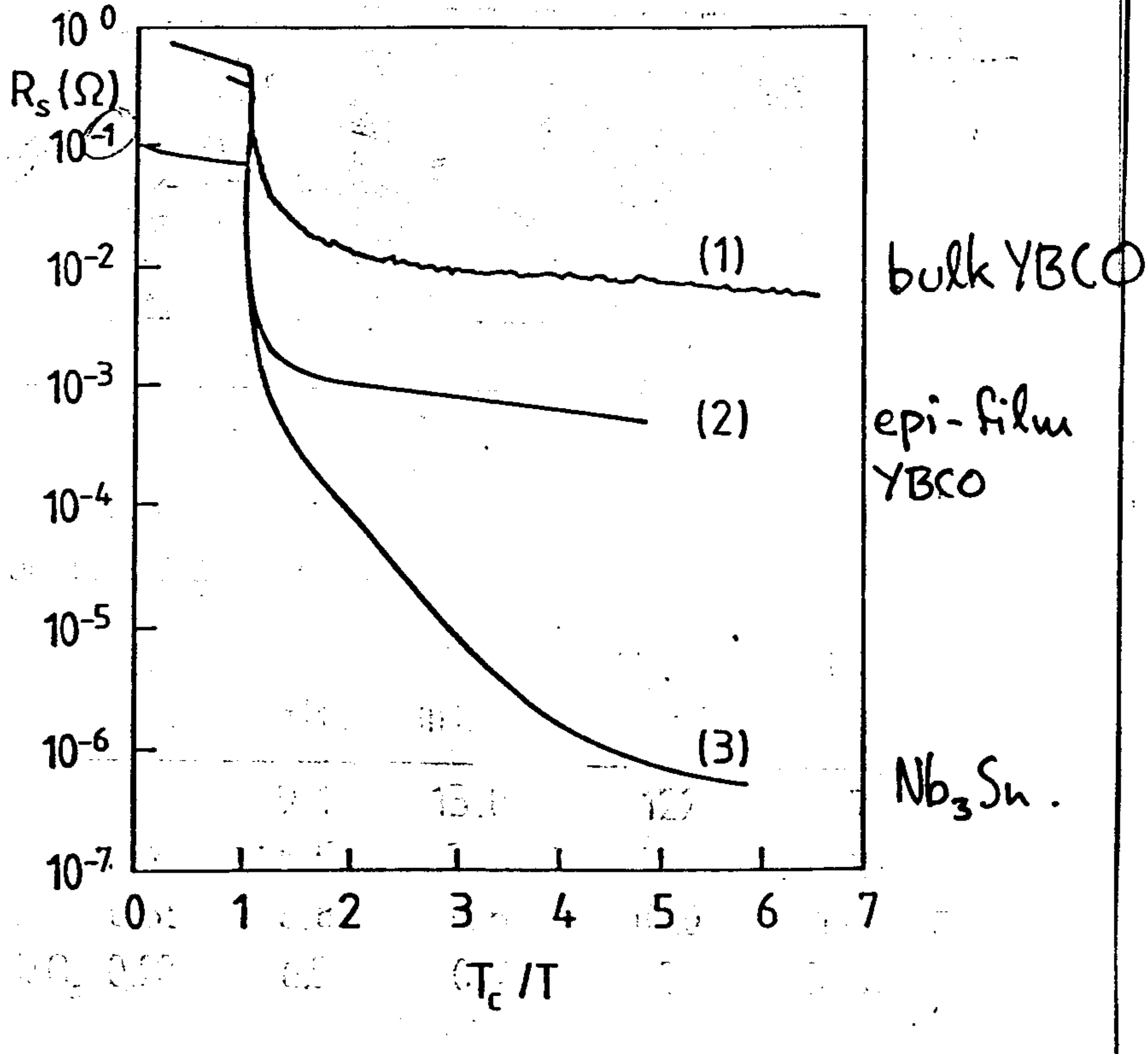


A Braginsky 1990

Fr 4a

Residual surface loss.

$$R_s(T) = R_{res} + A \cdot \exp(-\Delta/kT)$$



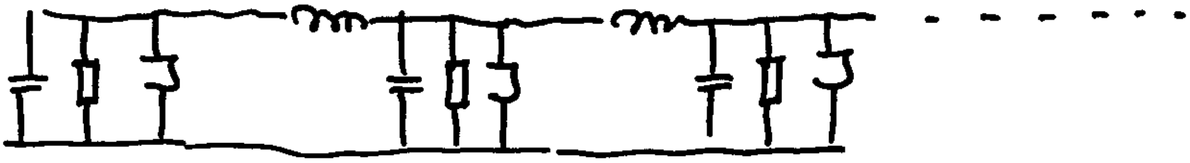
ref. A. Braginsky 1990

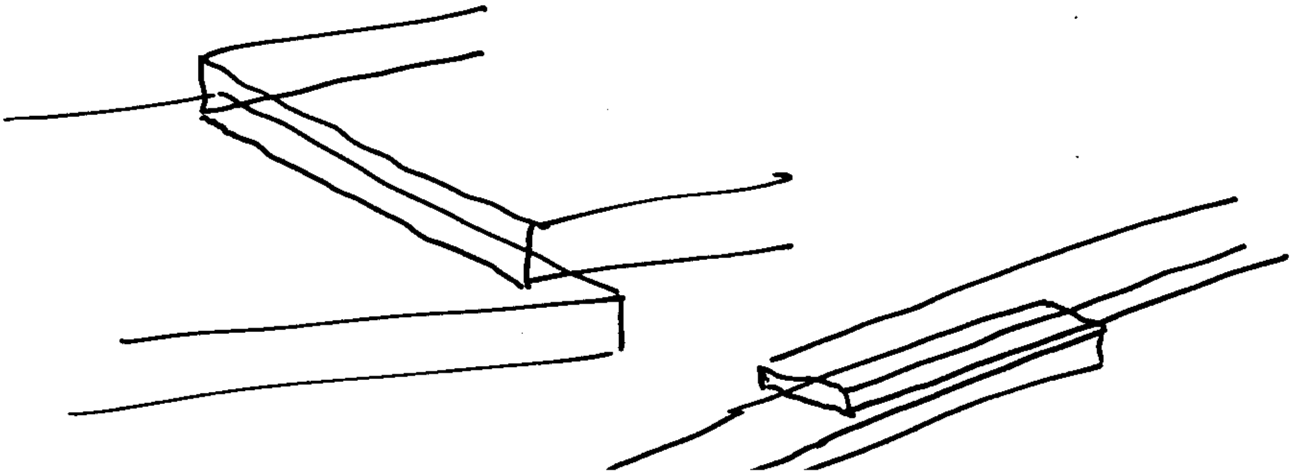
ONE APPLICATION

FLUX FLOW DEVICES

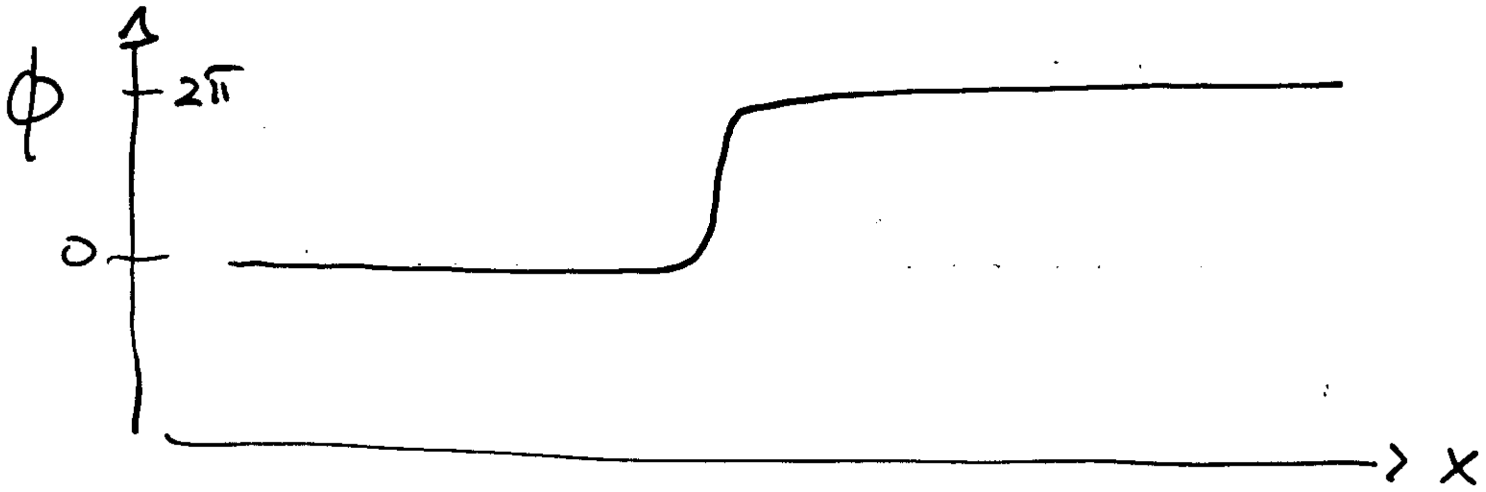
LONG JOSEPHSON JUNCTION

FLUXONS.

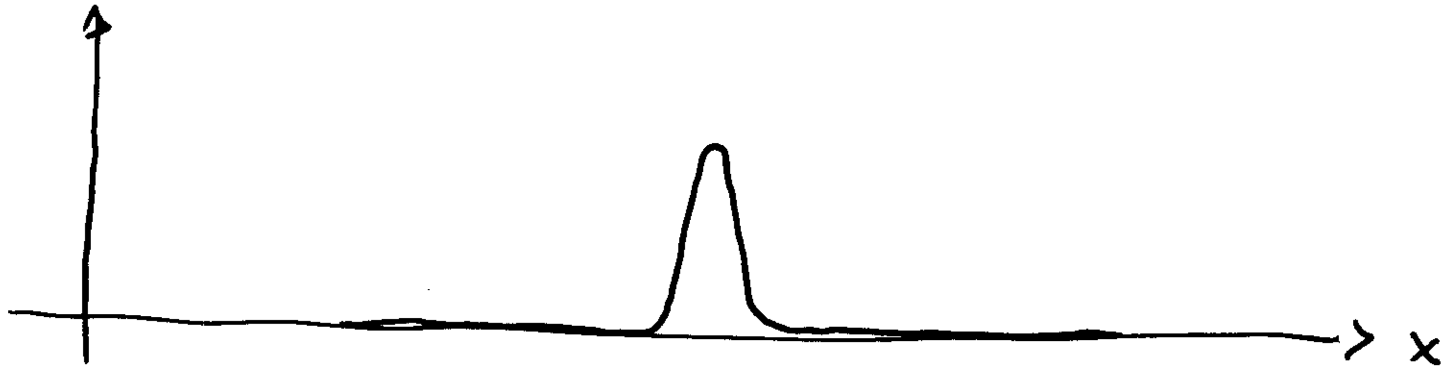




A FLUXON IS A LOCALIZED 2π PHASESHIFT



ϕ_t = Voltage



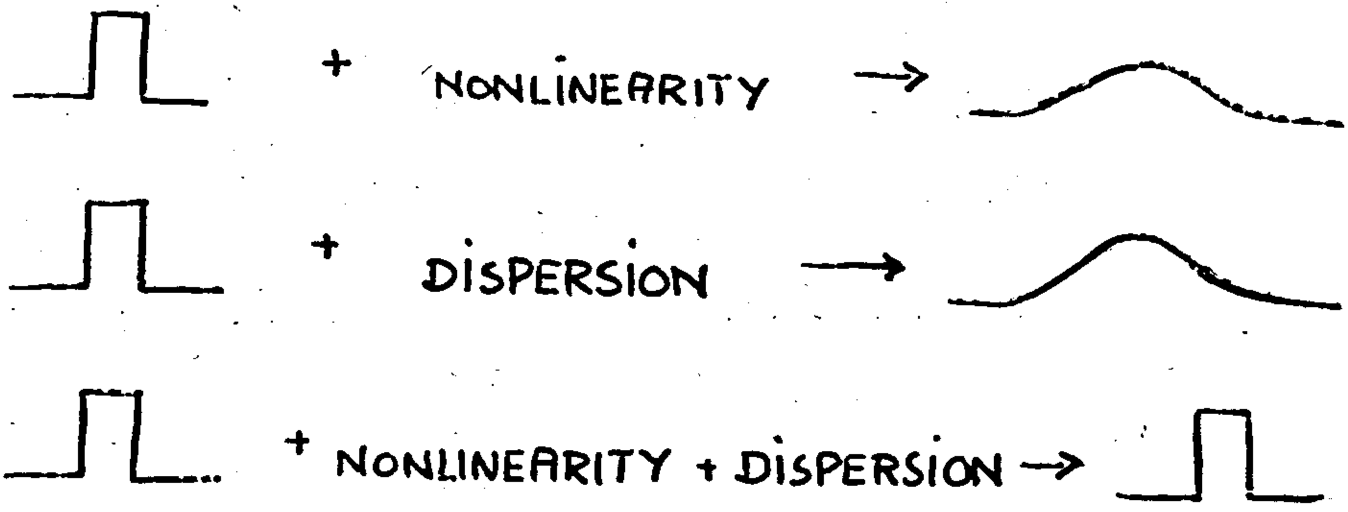
behaves as a soliton

(sine-Gordon soliton)

$$-\phi_{xx} + \phi_{tt} + \alpha\phi_t + \sin\phi = \eta$$

SOLITONS (FLUXONS)

(simple working definition)

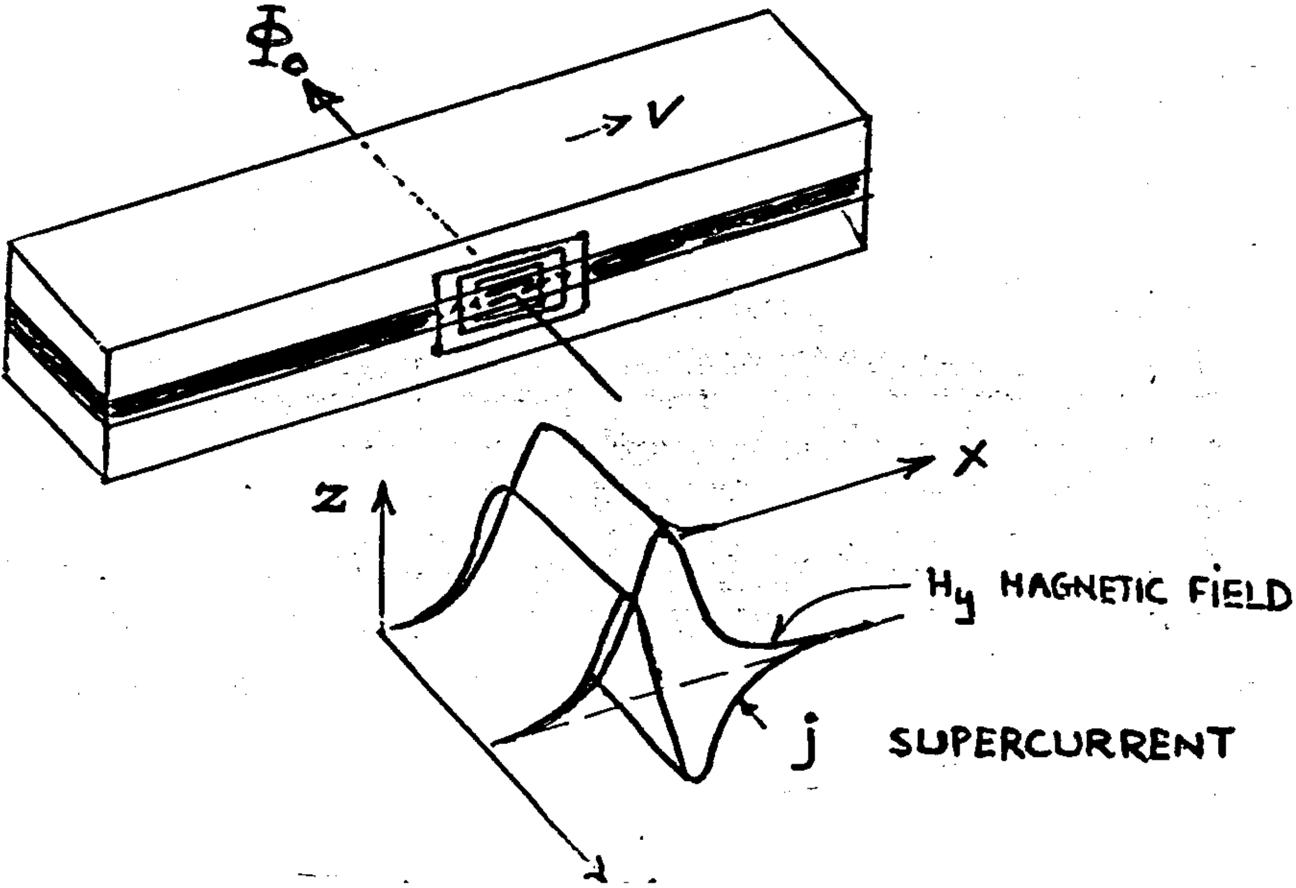


+ NONLINEARITY →

+ DISPERSION →

+ NONLINEARITY + DISPERSION →

- THEY HAVE PARTICLE LIKE PROPERTIES (RELATIVISTIC)
- SOLITONS AND ANTISOLITONS
- COLLISIONS : PASS THROUGH ($i > i_{th}$) or ANNIHILATE ($i < i_{th}$)



VORTEX FLOW TRANSISTORS

TYPICAL RESULTS : Current gain ~ 5 $\left(\frac{500}{W_S}(\mu\right.$

speed ~ 10pS

impedance level ~ 10mΩ

Van Zeghbroeck et al.

Nagatsuma et al.

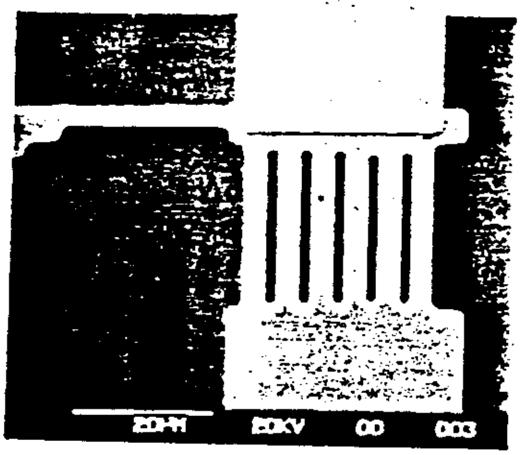


Figure 3. Photograph of the edge-junction Super-CIT.

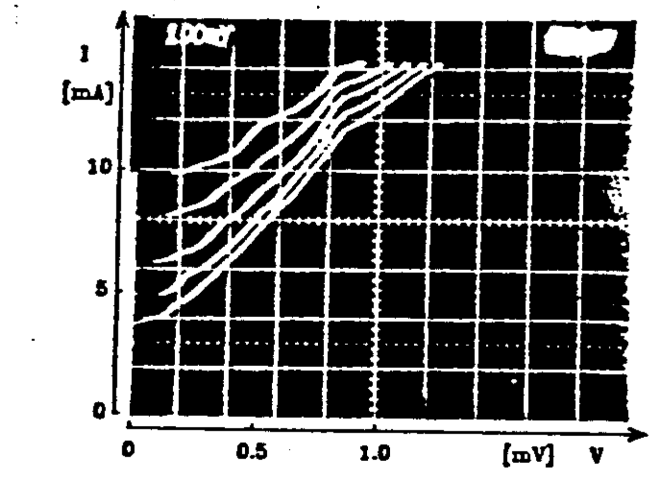


Figure 4. I-V curves of the edge-junction Super-CIT. J_{cr}=190KA/cm^2, L=30μm, λ_J=5μm. I_c=0(top trace), -1, -2, -3, -4mA(bottom trace). Vertical: 2mA/div, horizontal: 0.2mV/div.

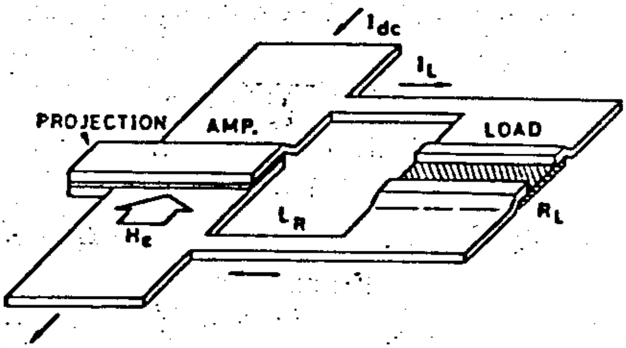


Fig. 2. Experimental circuit of the amplifier connected to a load resistor.

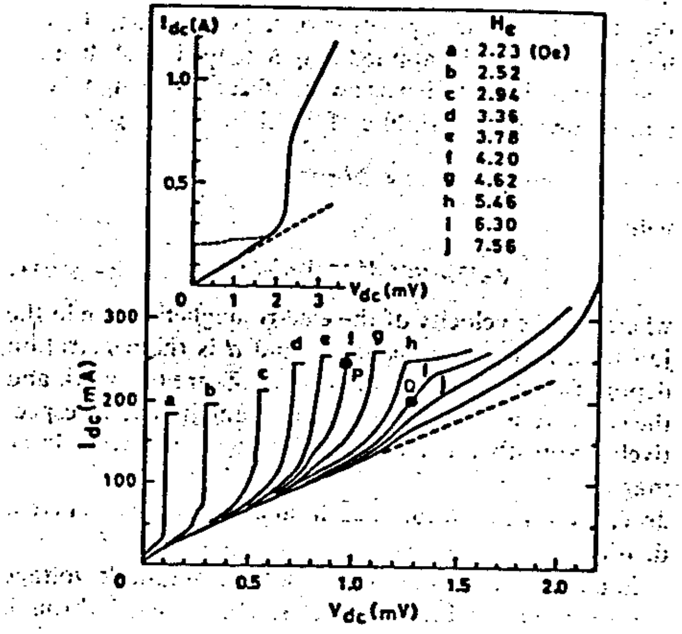
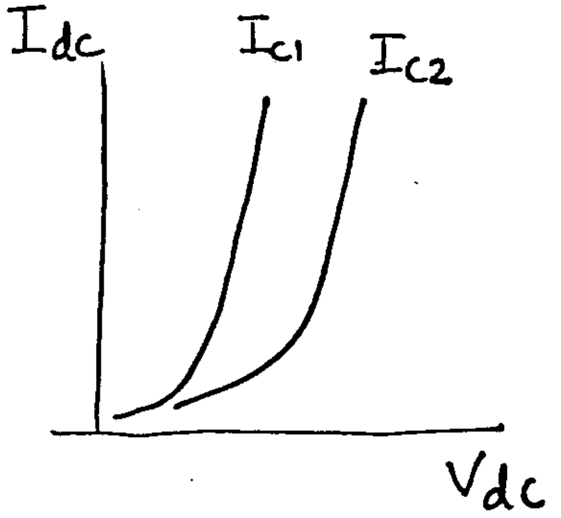


Fig. 3. DC I-V characteristic of the amplifier connected to a load resistor.

VFT (Vortex flow transistor)
CiT (current injection transistor)

A FLUX FLOW STATE IS CREATED IN A LONG JOSEPHSON JUNCTION.
IT IS CONTROLLED BY AN INJECTED CURRENT OR A CONTROL LINE.
FLUXONS PLAY THE ROLE OF ELECTRIC CHARGE CARRIERS IN A TRANSISTOR.



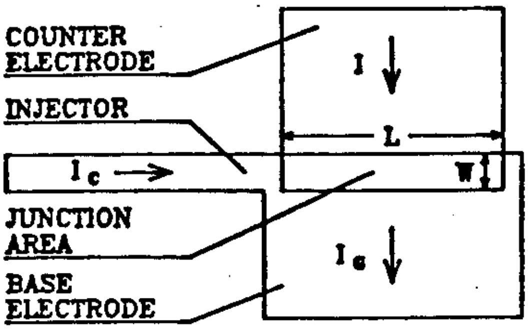
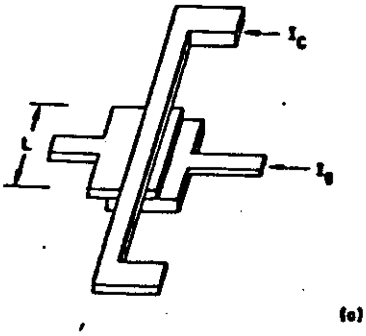


Figure 1. Geometry of the Super-CiT.

Current injection.
Van Zeghbroeck et al.

Magnetic field from control line



(a)

SINGLE L.J.

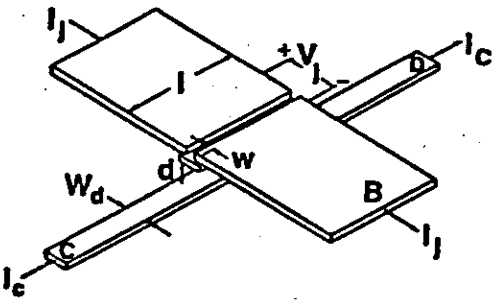
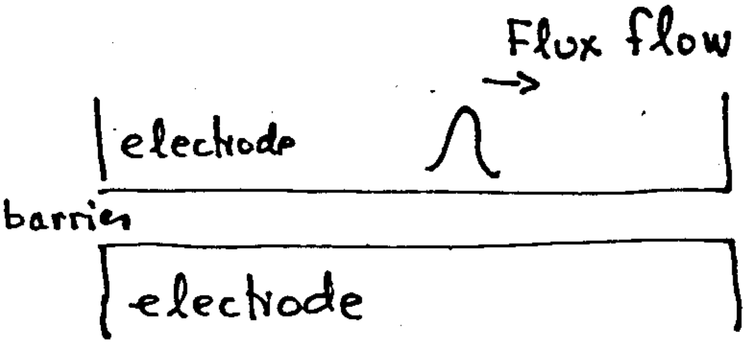


FIG. 1. Schematic representation of the VFT. I_c is the control current. V_j is the voltage developed across the VFT. Thickness of the films are not to scale.

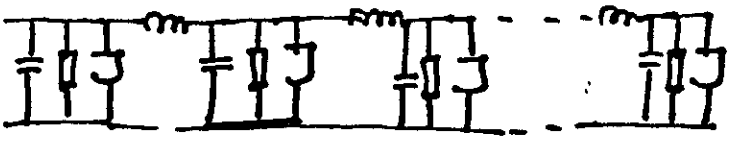
DOUBLE L.J.

FLUX FLOW TRANSISTOR IN High T_c

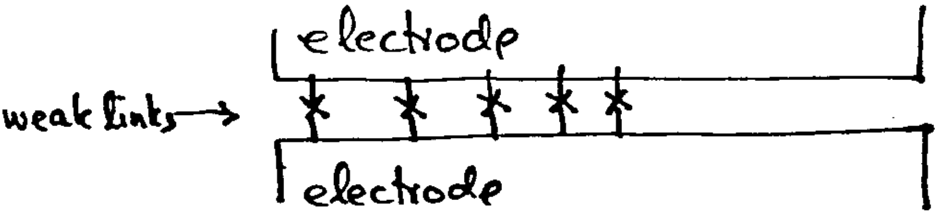
Long junction

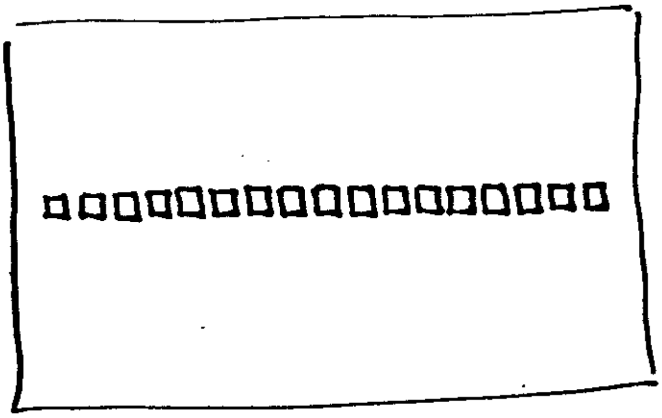


Normal model
parallel small junctions



New device





Advantage :
Weak links may be used
not barrier tunnel junctions.

VORTEX FLOW TRANSISTORS.

Work going on in IBM (Yorktown/Zurich

Kyushu
Madison
Moscow
Sandia.

VFT: Dual to a FET.

VFT	FET
low impedance	high impedance
current amplifier	voltage amplifier
fluxons	electrons
⋮	⋮

High Tc Flux-flow transistor (Martens et al)
1990

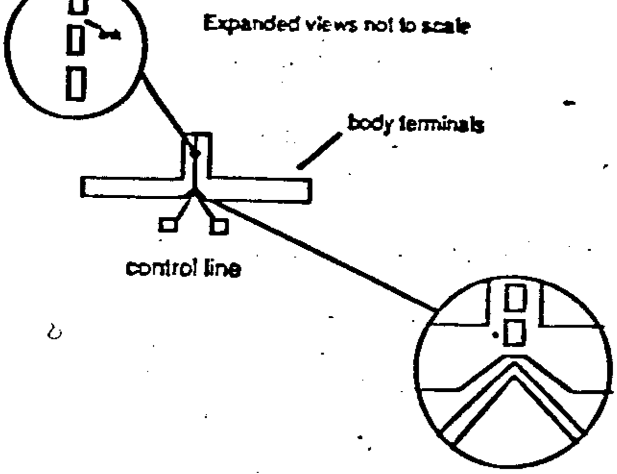


Figure 1. Structure of the SFFT. The 5 parallel weak links are operated in a flux flow state. The field from the external control line modulates the flux density in the link system. The links are about 2 µm by 10 µm and are separated from each other by 20 µm.

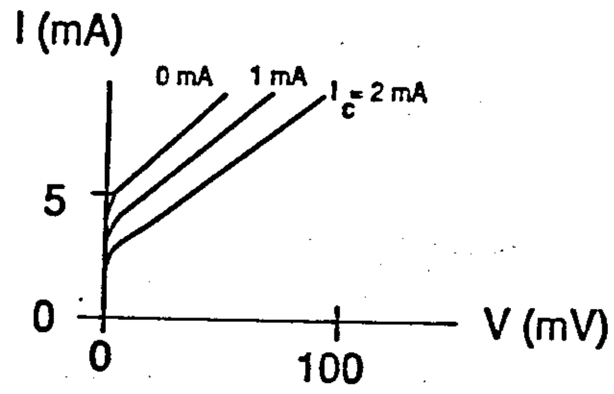


Figure 2. IV curve of the device in Fig. 1 (made of Tl, tested at 77K) showing the flux flow branch and the effect of control current. At higher current drives, the device switches into a normal state and this state is to be avoided because of its long thermal time constant.

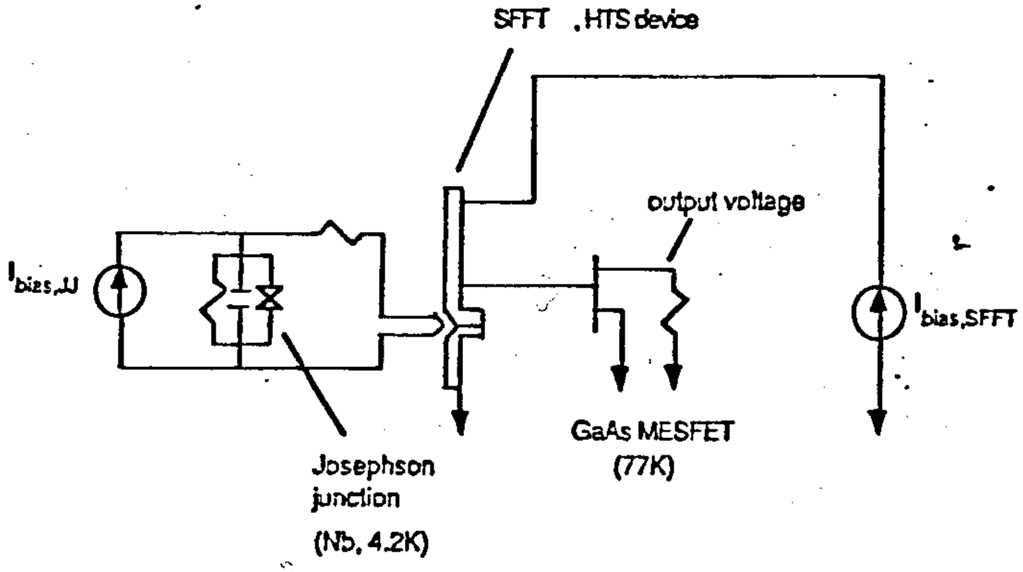
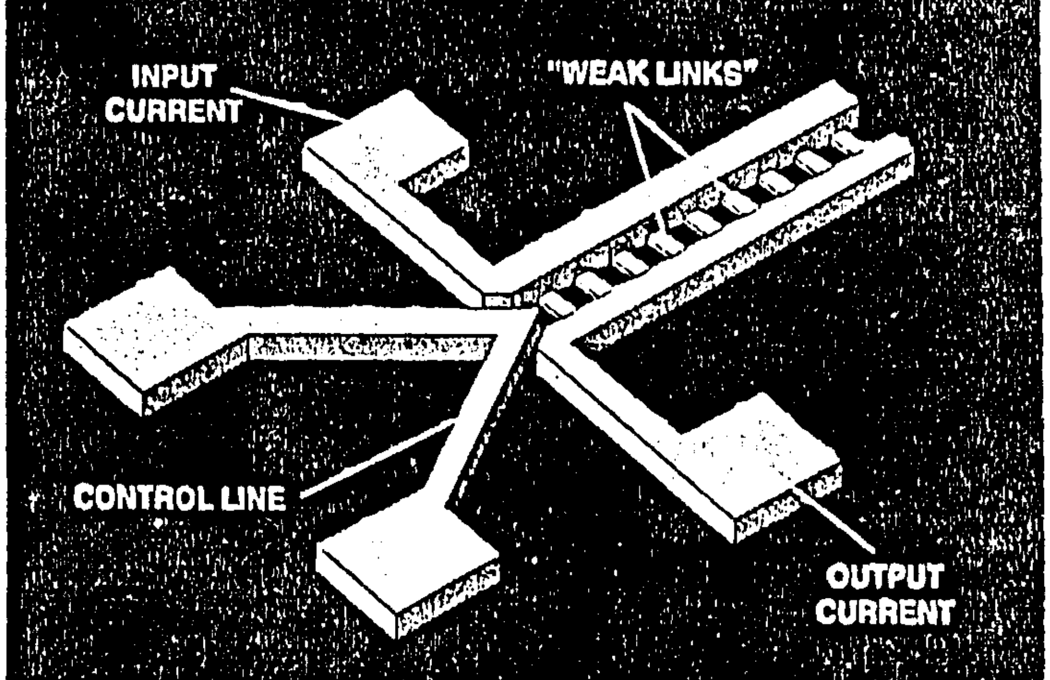


Figure 5. Experimental set-up of the line driver. The junction is driven to the point where it switches and the resulting current surge causes a voltage step at the SFFT output. The load is either a 50 Ω termination or a GaAs MESFET biased (NEC 24483, V_{gs}=3 V, I_d= 10 mA) and operating at 77K with a 50 Ω load across its drain and source terminals.

Martens et al 1990 Scientific American

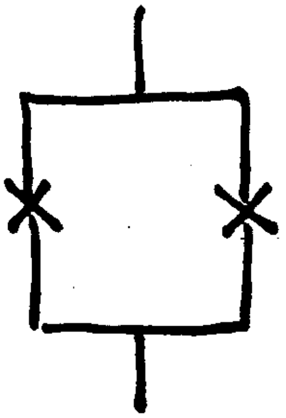
A SUPERCONDUCTING TRANSISTOR



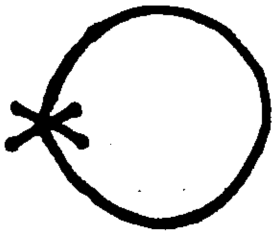
Current passing through the control line creates a magnetic field. This causes the weak links to lose their superconductivity, blocking the flow of current and "switching" the device.

SQUIDS

DC



rf



Junctions not so critical as in other applicatio

Laibowitz etal. YBCO

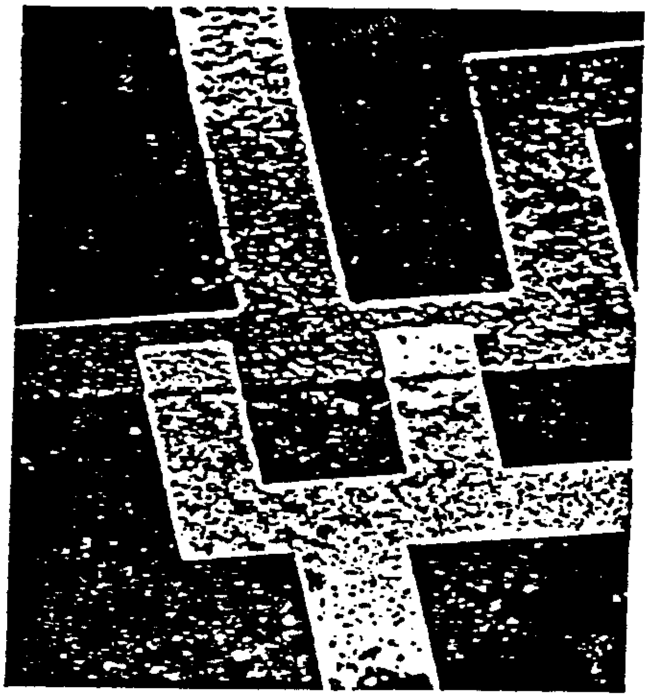


Fig 6: An YBCO edge junction highT_c SQUID.

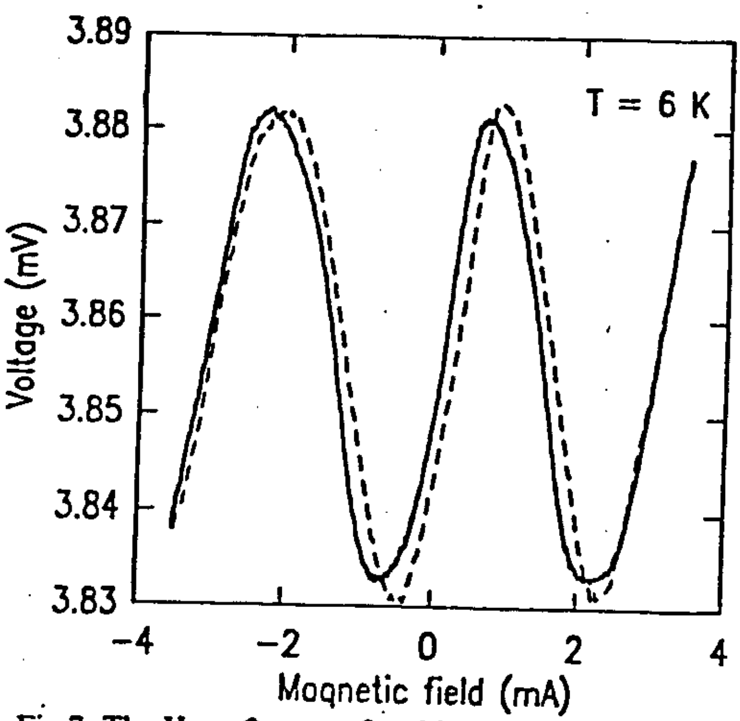


Fig 7: The V vs. Φ curve for this SQUID.

Germany

Heiden et al. 1990

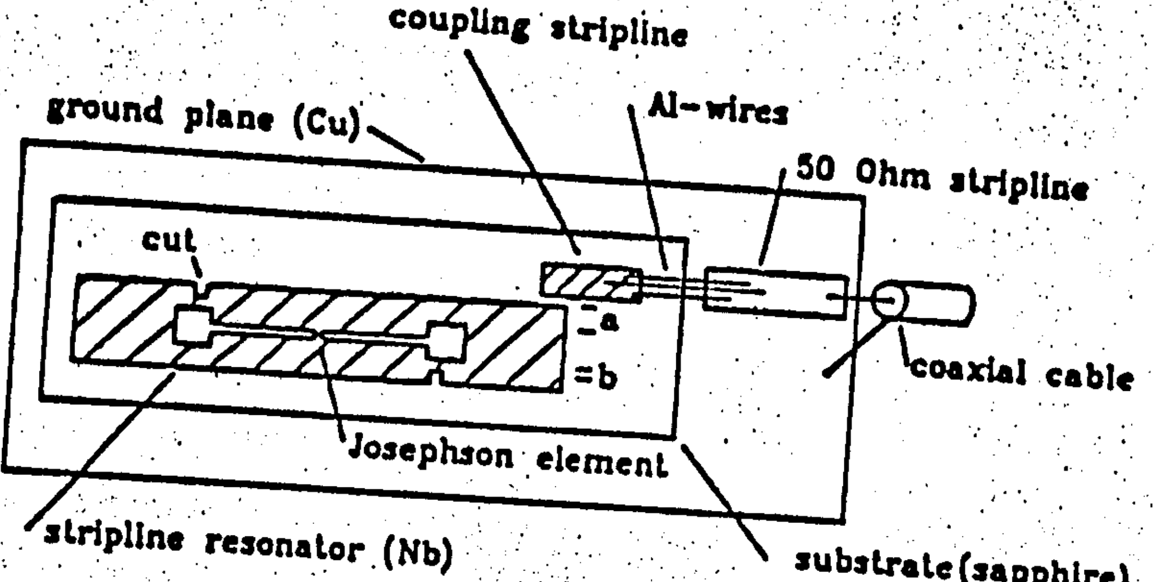


Fig. 1 Lay-out of a planar microwave rf-SQUID gradiometer

R. Koch et al 1990

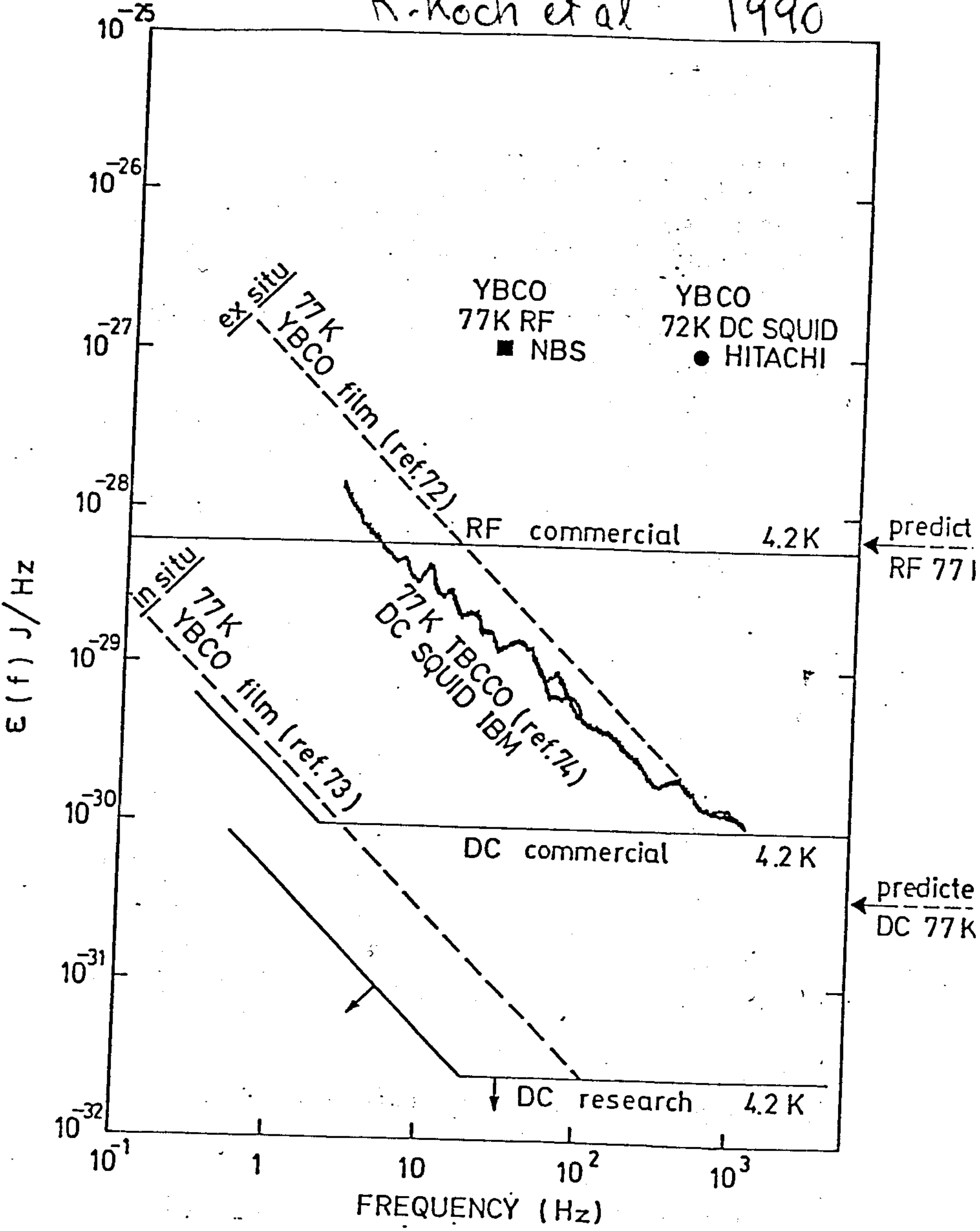


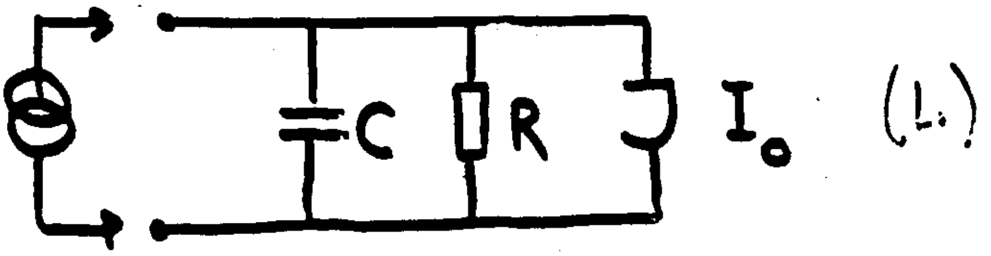
Fig. 3.11 Noise energy ε (f)/Hz versus frequency for several SQUID's (both low-T_c and high-T_c) and for YBCO thin films 73,74,75.

rf applications ?

depends on junction development.

Assume BCS scaling.

SHUNTED JUNCTION MODEL (as always)



THREE IMPORTANT FREQUENCES

① The plasma frequency $\boxed{\omega_0 = \sqrt{\frac{2eI_0}{\hbar C}}}$ $\frac{1}{\sqrt{LC}}$

② The characteristic frequency $\boxed{\omega_c = \frac{2eRI_0}{\hbar}}$ $\frac{R}{L}$

~ gap frequency

③ The RC cutoff frequency $\boxed{\omega_{RC} = \frac{1}{RC}}$ $\frac{1}{CR}$

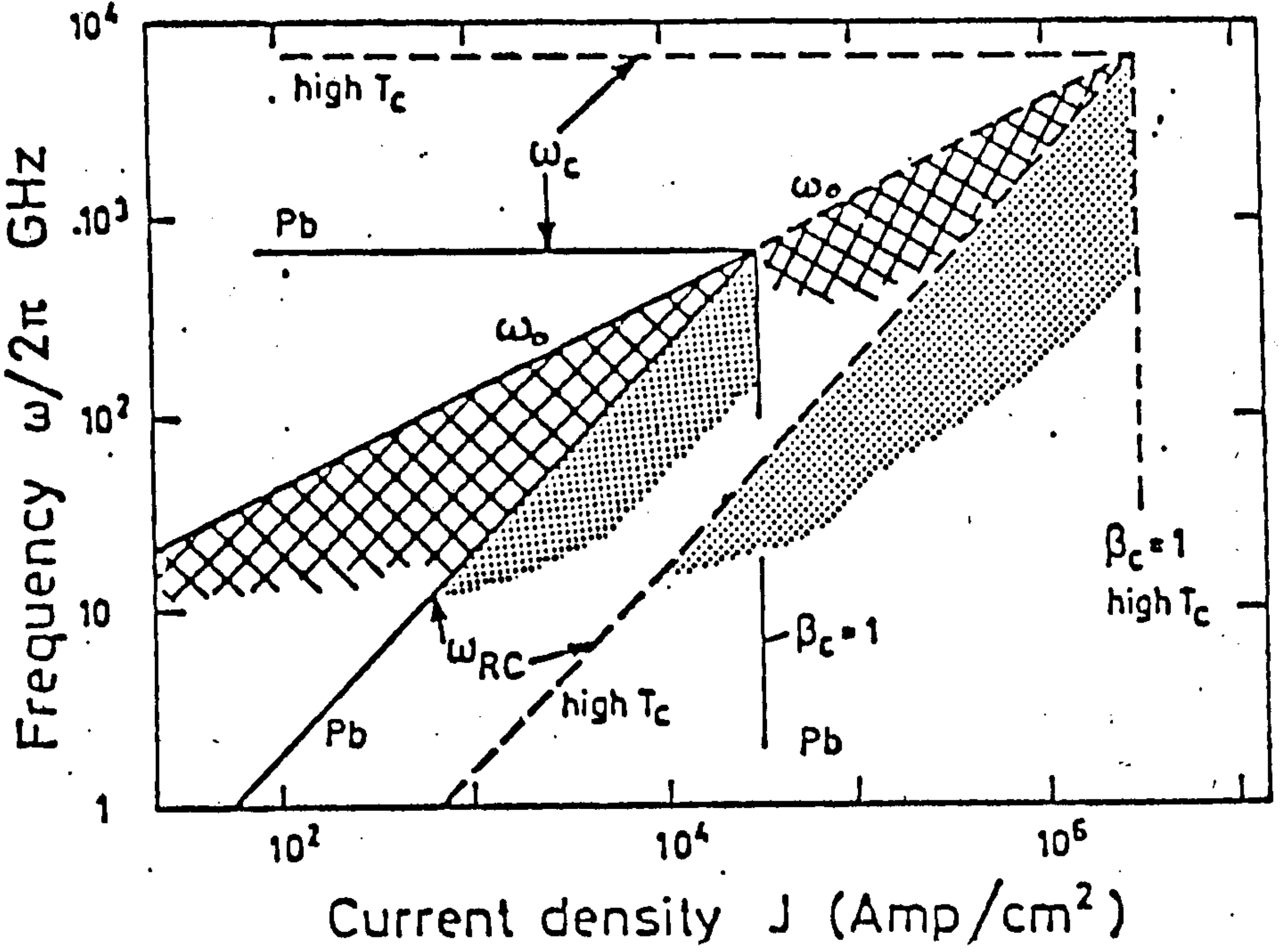
and the McCumber β : $\boxed{\beta_c = \frac{2eI_0}{\hbar} R^2 C}$

$\beta_c = \left(\frac{\omega_0}{\omega_{RC}}\right)^2$

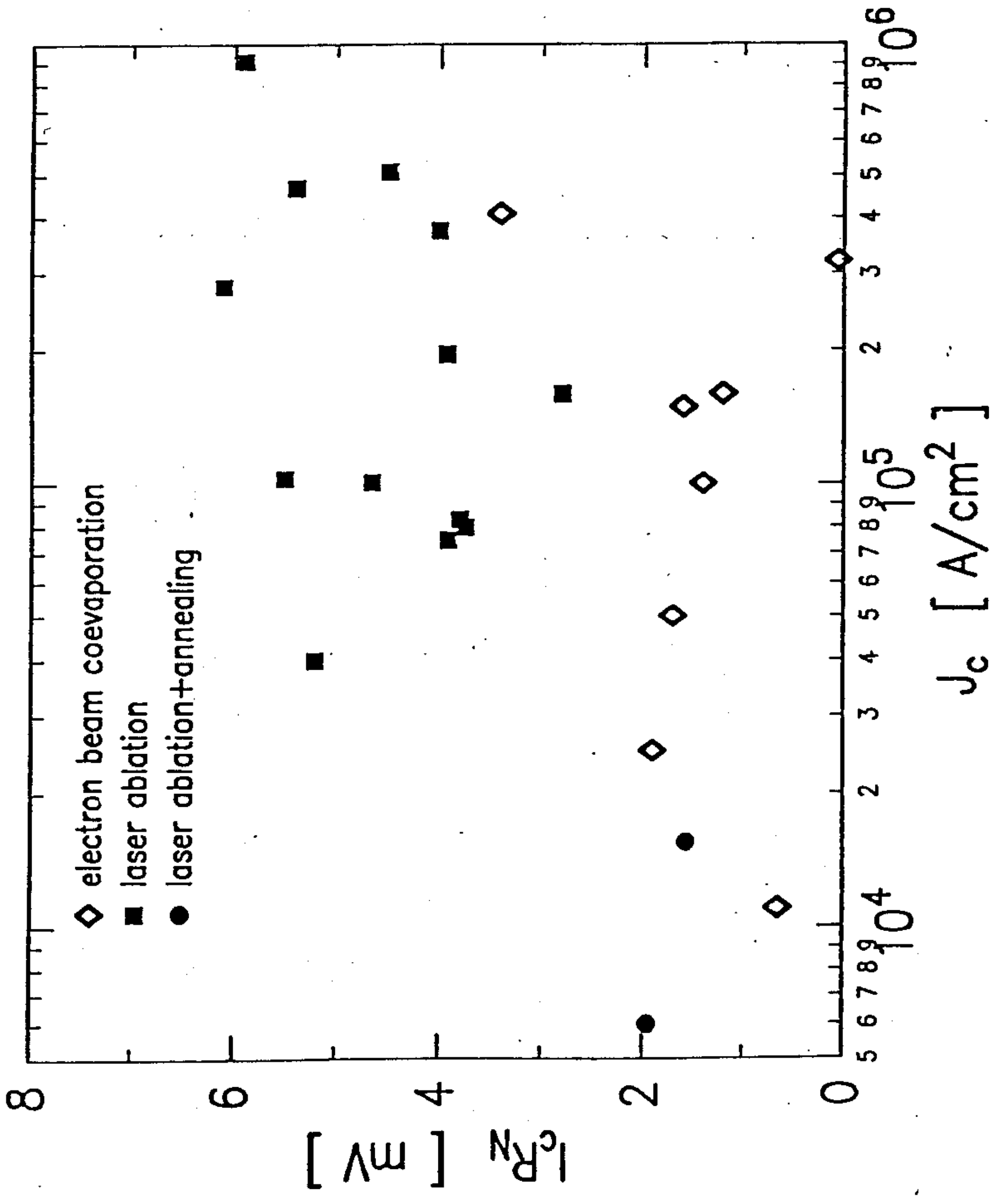
$, I_0 \propto A$

$R \propto A^{-1}$

Dependent on	Area	Current Density	Material
ω_0	No	Yes $J^{1/2}$	Yes
ω_c	No	No	Yes
ω_{RC}	No	Yes J^1	Yes
β_c	No	Yes J^{-1}	Yes


high T_c
ω_c
Pb
ω_o
ω_o
ω_{RC}
high T_c
Pb
$\beta_c = 1$
Pb
$\beta_c = 1$
high T_c
10^4
10^3
10^2
10
1
Frequency $\omega/2\pi$ GHz
10^2
10^4
10^6
Current density J (Amp/cm^2)

R Gross (IBM)

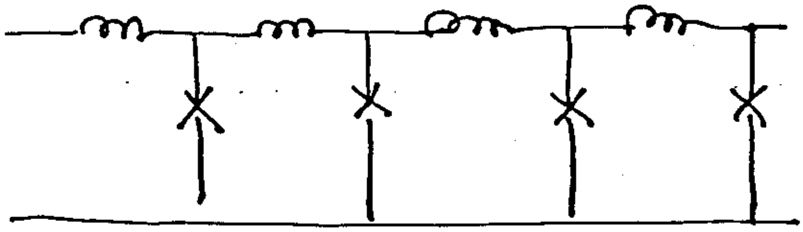


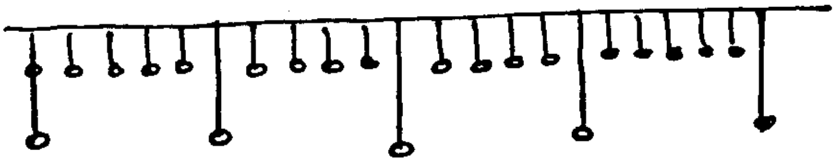
UGH3800: VOSSPLOT UGHBIN from RUDOLF at YKTVMV : BEST

11/16/89 12 15.17 on LAZEE

DIGITAL APPLICATIONS.

FLUX SHUTTLE





pendulum model.

LOGIC CIRCUIT

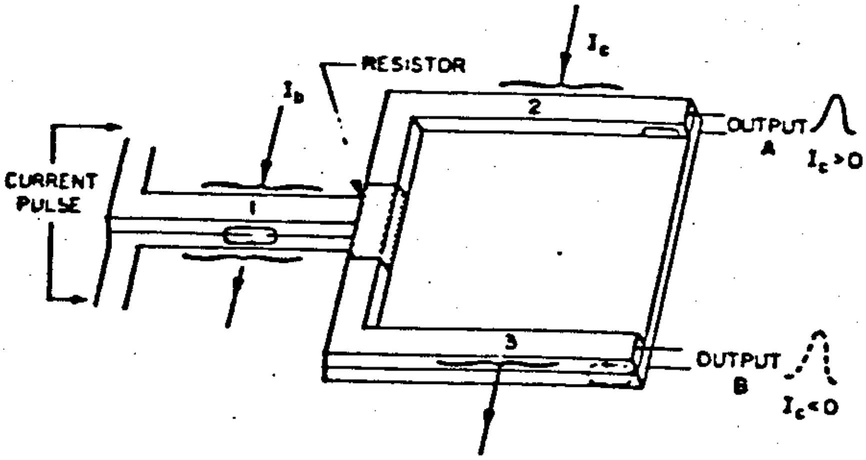


Figure 2 - The basic soliton device.

HTS Non-hysteretic junctions

pulse mode
- RFSQ
- phasemode logic

current latching