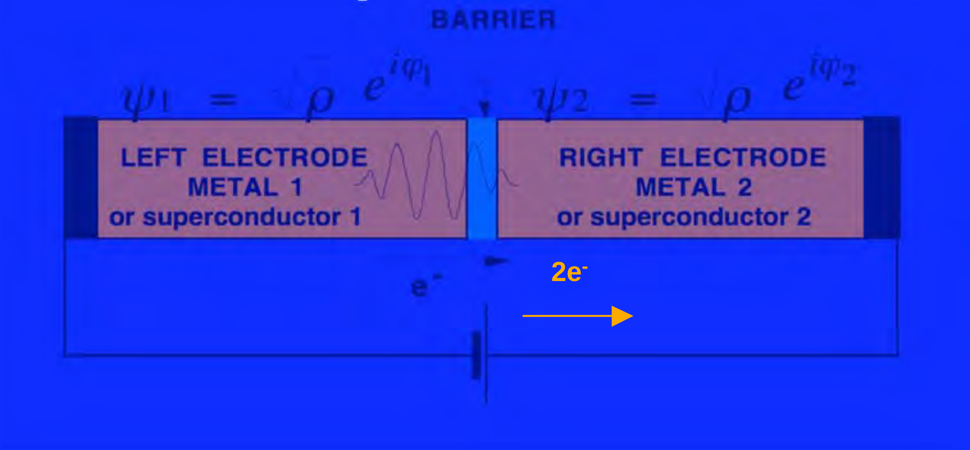
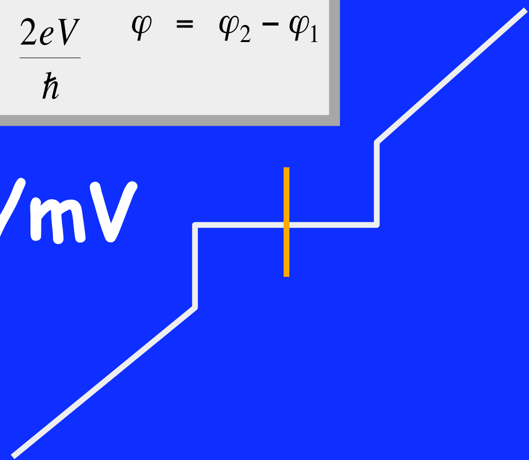
Why superconducting electronics?

- Extremely non-linear IV&RT characteristics
- The Josephson effects $I=I_c\sin\varphi$, $\dot{\varphi}=2eV/\hbar$
- Low noise
- Low loss
- Low dissipation
- Less weight
- High resolution
- High speed $f_c \sim (2e/h)I_cR_N$
- High frequency f_J = 483 GHz/mV
- Quantum limited sensitivity

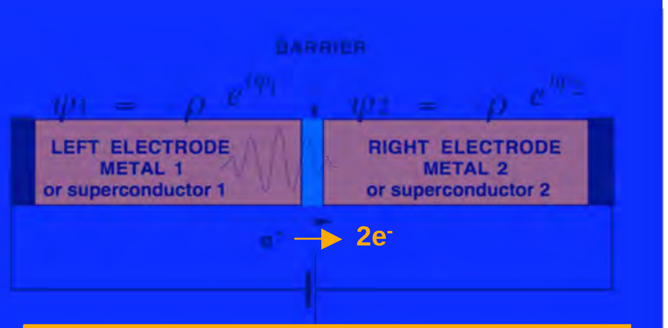


$$I = I_c \sin\varphi$$
$$\frac{d\varphi}{dt} = \frac{2eV}{\hbar} \qquad \varphi = \varphi_2 - \varphi_1$$



Devices & Applications

- Devices such as
  - SIS tunnel junctions
  - Josephson junctions
  - SQUIDs
  - Magnetometers/Gradiometers (fT)
  - Hot electron bolometer (HEB) devices
  - Transition edge bolometers
  - Digital electronics (e.g., RSFQ)
- For applications such as
  - Microwave
    - Radio astronomy, X-ray astronomy, THz Hilbert spectroscopy
    - Oscillators (GHz-THz) (JJs and FFOs)
    - Filters
  - Certification, Standards, Medicine, Geology, NDE
  - High resolution instrumentation (pV, pA,…)
- For fundamental research
  - Transport properties (tunneling, vortices, superconductivity,…)
  - Superconductivity (why?, order parameter, pairing state, etc…)



$$I = I_c \sin\varphi$$

$$\frac{d\varphi}{dt} = \frac{2eV}{\hbar} \qquad \varphi = \varphi_2 - \varphi_1$$

483 GHz / mV

Why *not* superconducting electronics?

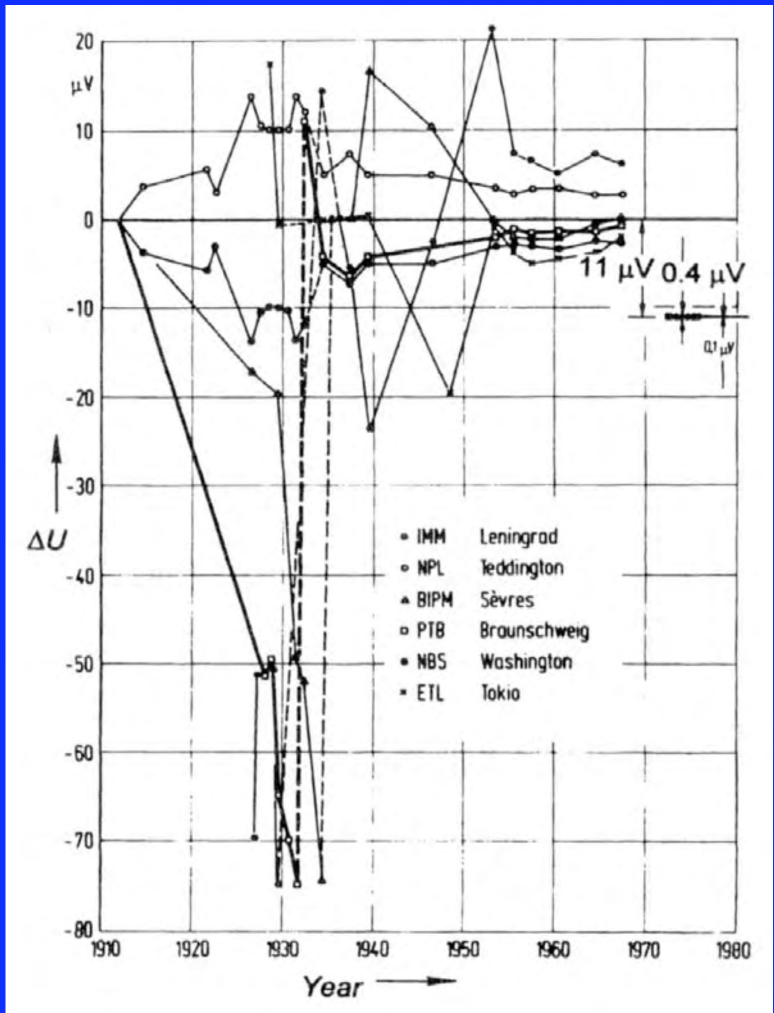
- Cooling and Cryogenics
  - Additional costs
  - Additional weight
  - Additional vibrations…?
  - Additional power requirements
- Sensitivity could mean saturation
  - From incoming signals
  - From EMI
- End user values
  - If price vs performance gives no advantage
  - If other technologies solves the problem

Applications

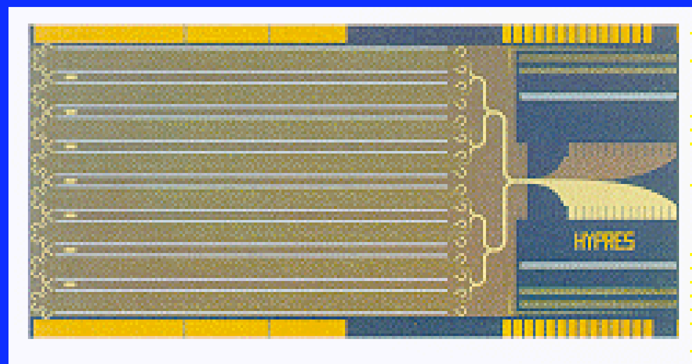
- Metrology, Volt standard
- High frequency applications
- Magnetommeters, SQUIDs
- Amplifiers, SQUIDs
- Imaging, MRI, SQUIDs
- Power applications

Metrology:

The volt standard development

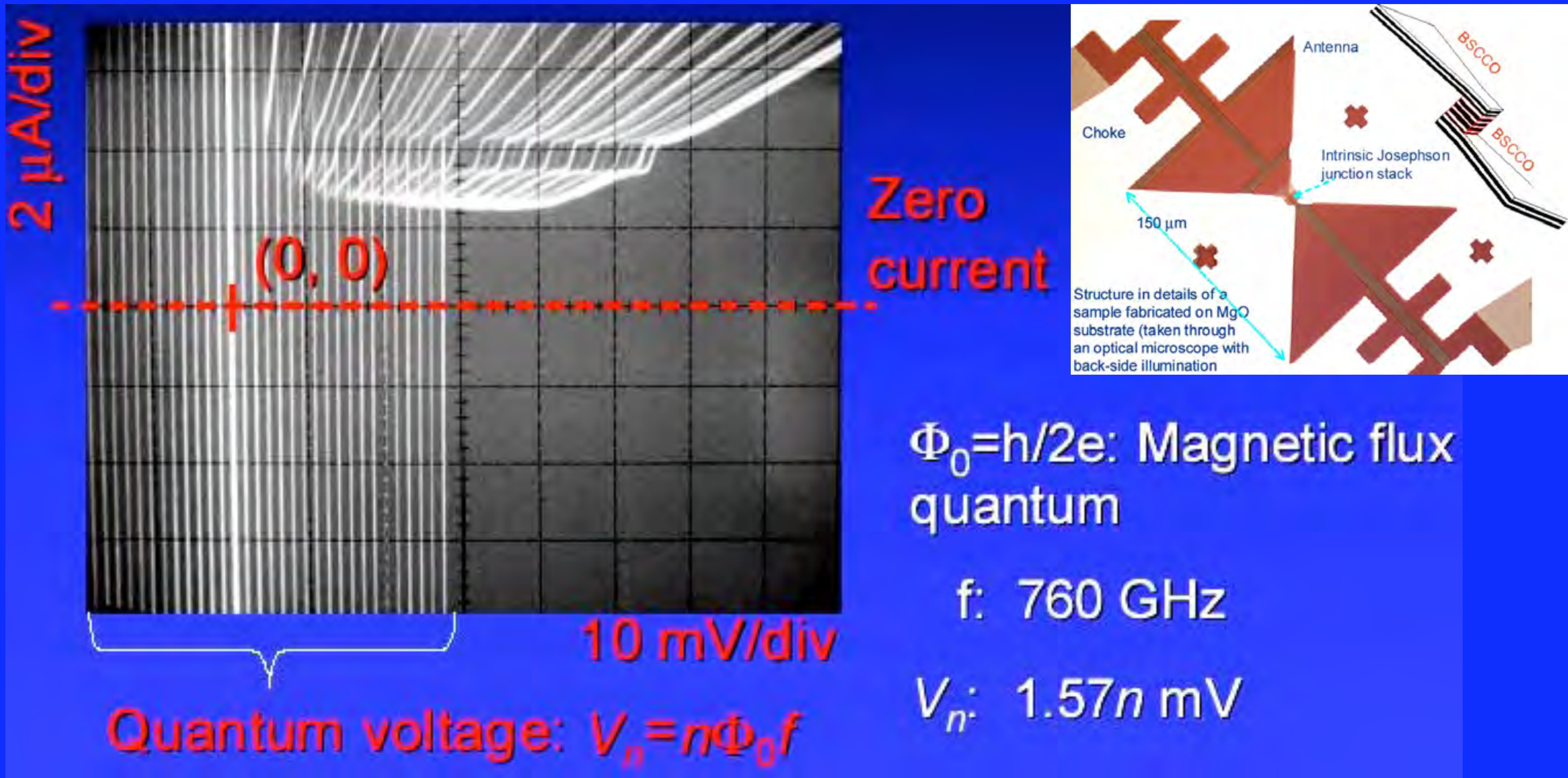


$\cdot V = n\Phi_o f$



HTS oscillators and Voltage standards…!?

Zero-crossing Shapiro steps observed in BSCCO intrinsic Josephson junctions with f_{LO} = 760 GHz



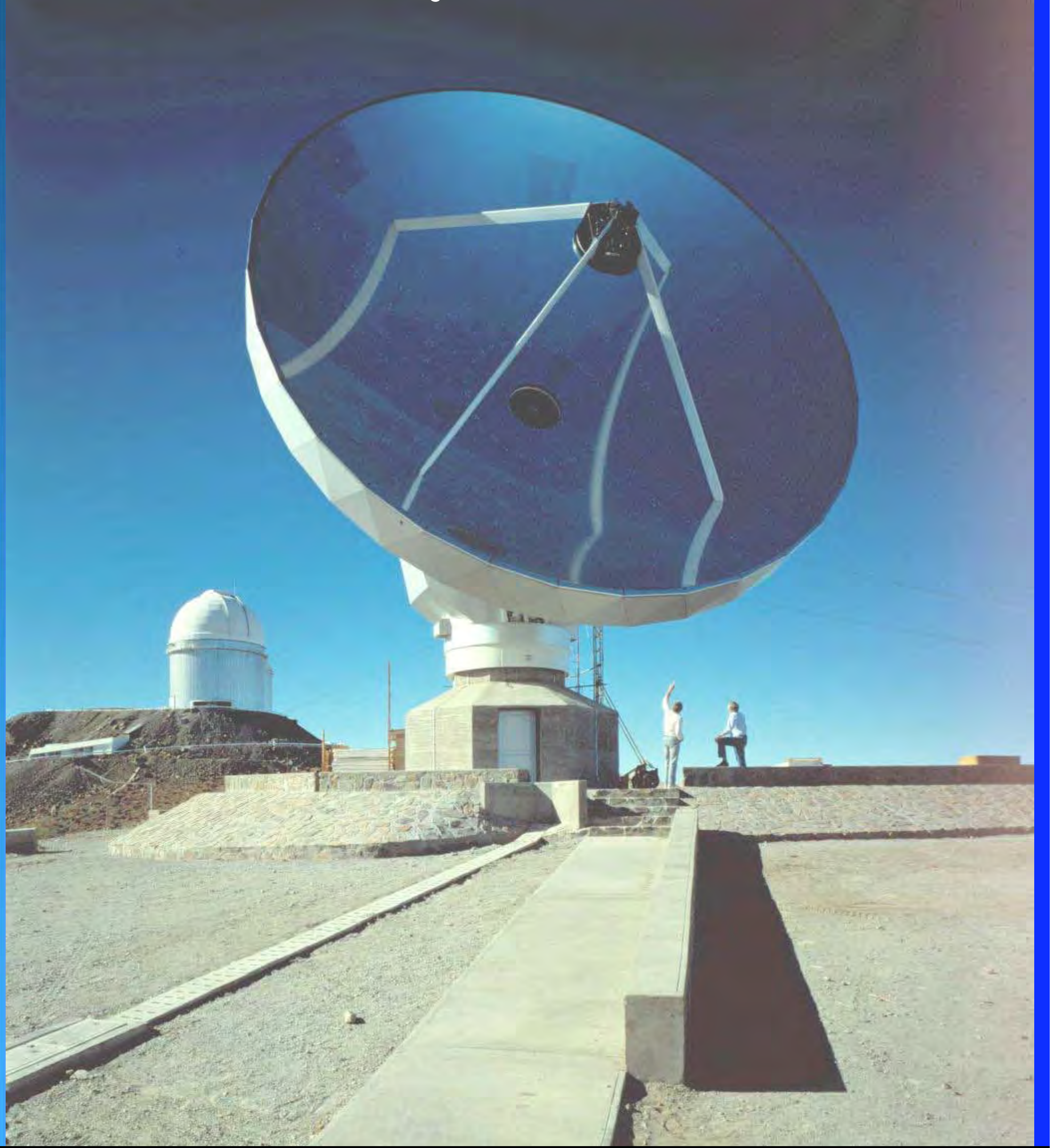
H. B. Wang (RIEC, Tohoku University, Japan: hbwang@riec.tohoku.ac.jp
Shapiro steps observed up to 2,5 THz and zero-crossing steps up to 2,5 V and 50 K

High frequency applications

- SIS mixers, for radio telescopes
- Hot electron bolometers
- Transition edge sensors, X-ray detectors
- Passive filters for cell phone stations

Radioastronomy

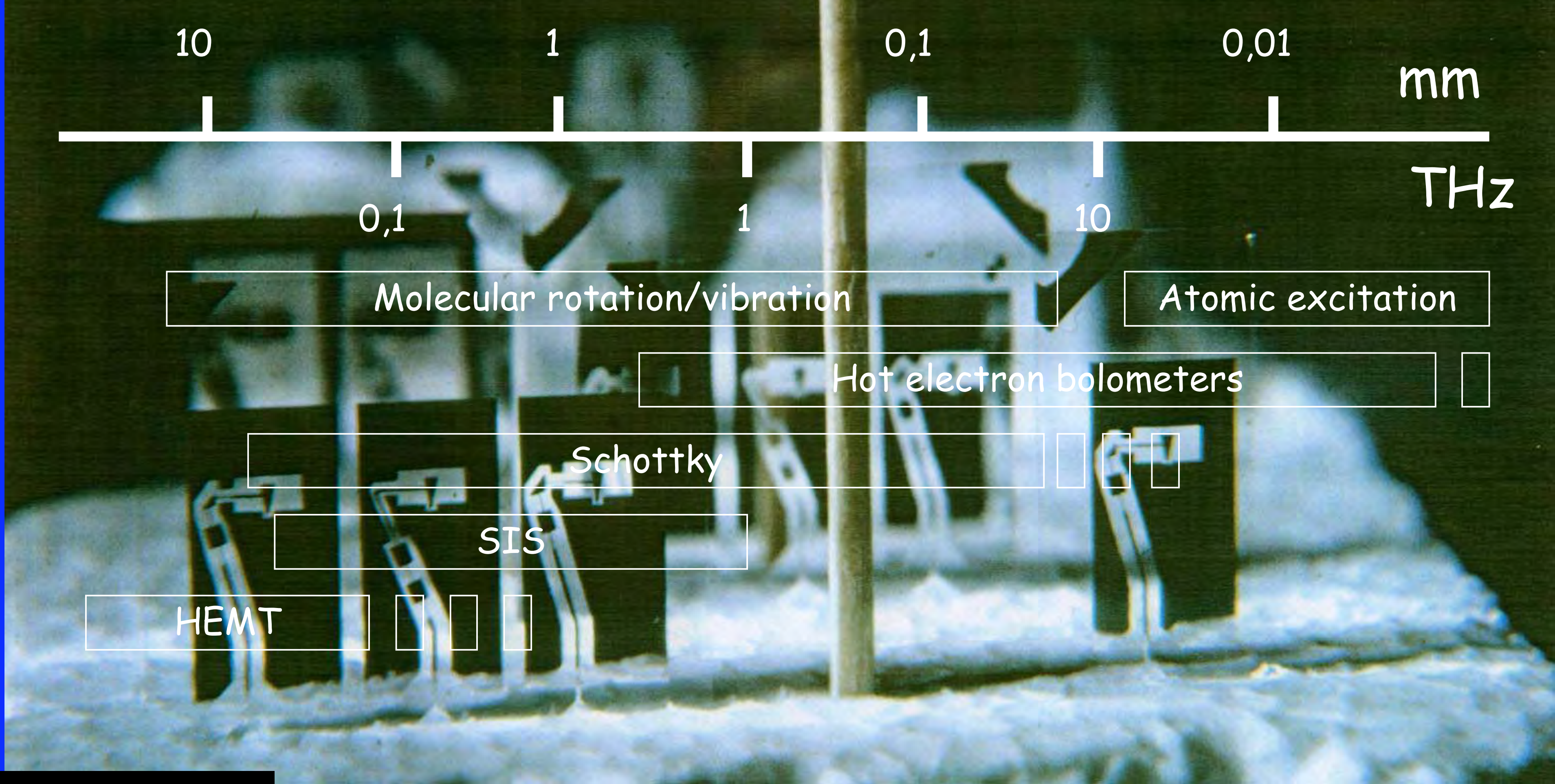
SEST - the Swedish-ESO Submillimetre Telescope in La Silla (Chile). This is a collaboration between the Swedish National Facility for Radio Astronomy (Onsala Space Observatory) and ESO (European South Observatory). The upper frequency limit of SEST is 350 GHz. Courtesy of European South Observatory



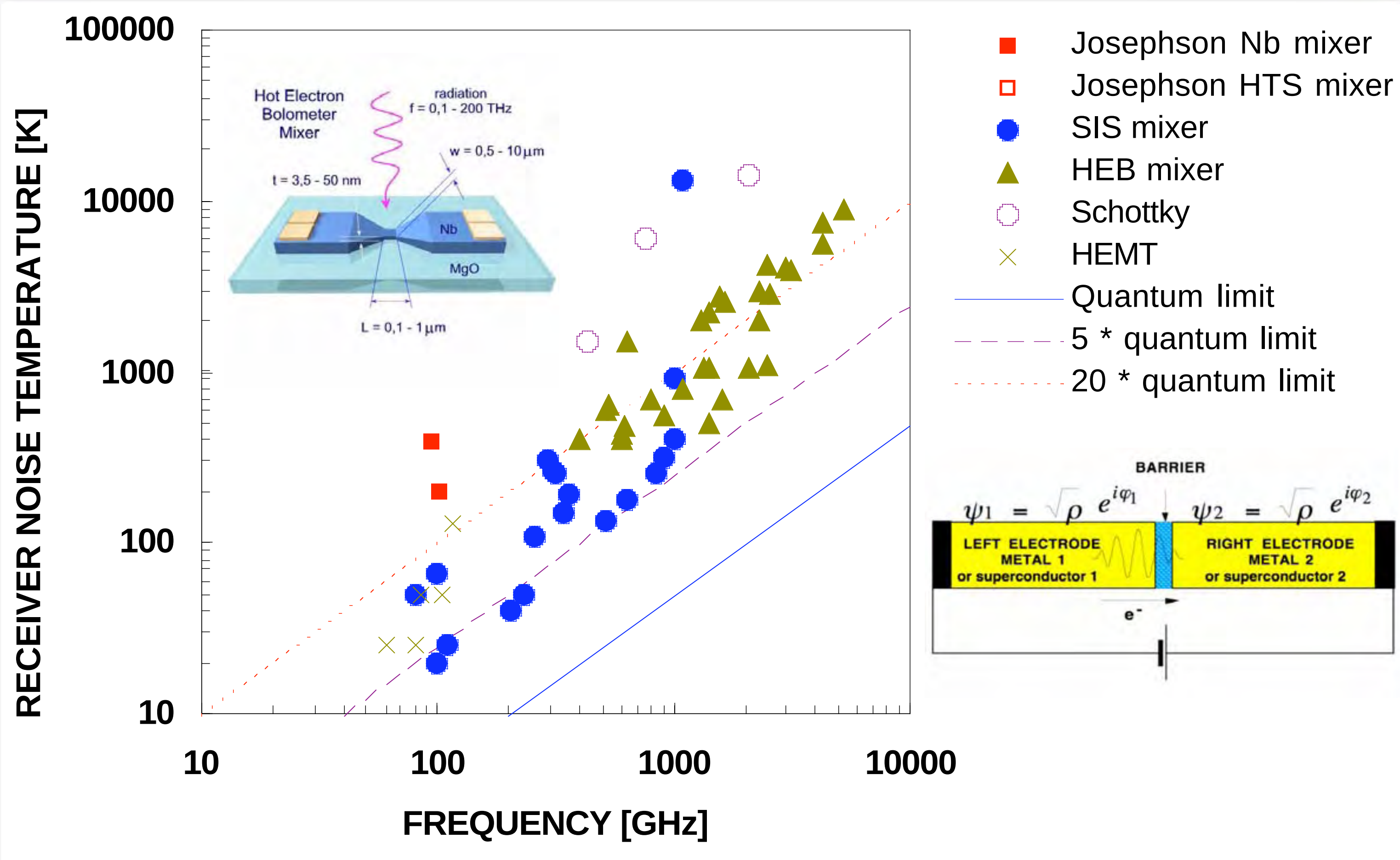
http://www.ls.eso.org/lasilla/Telescopes/SEST/SEST.html

High frequency applications

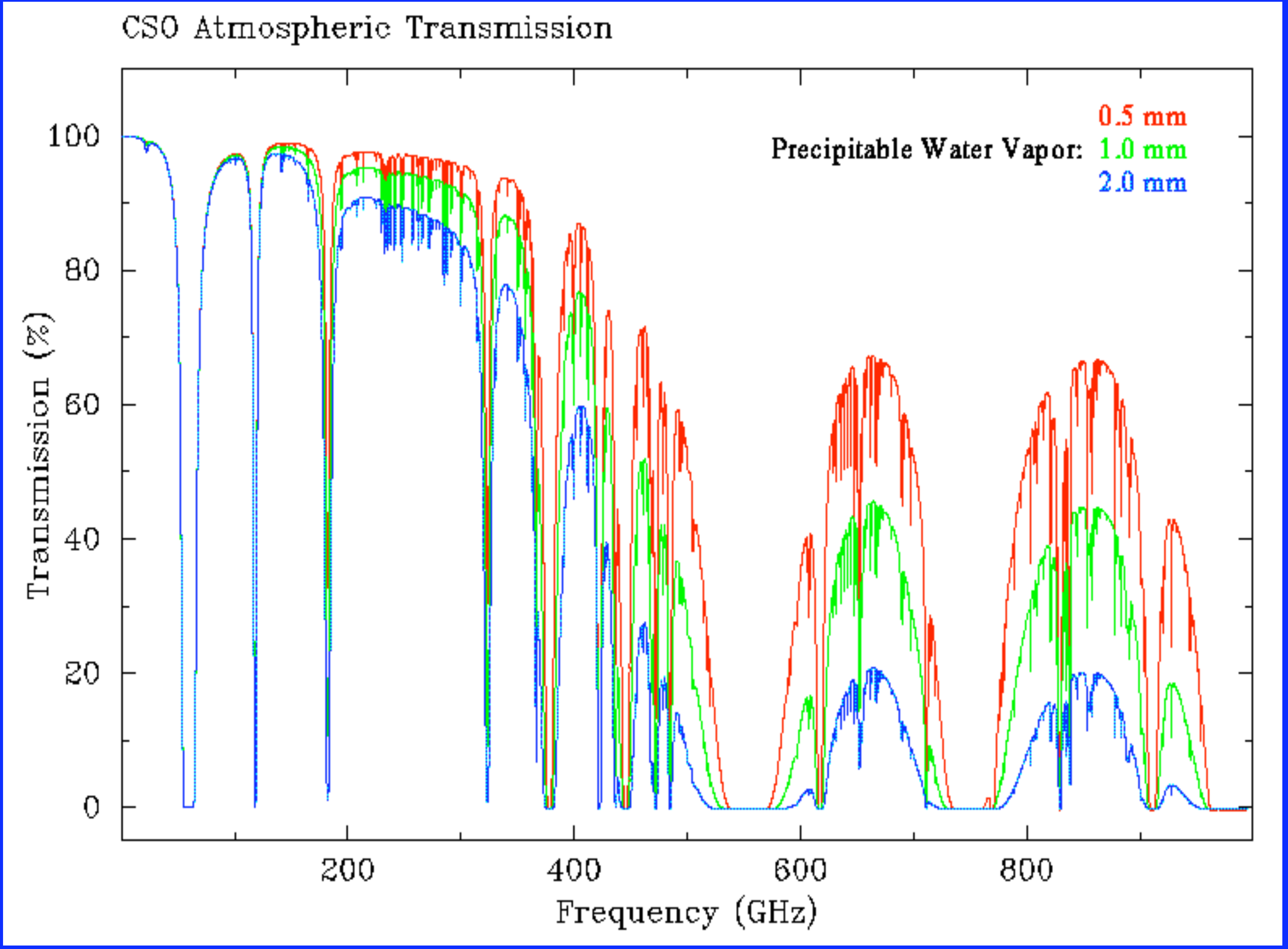
Frequency/wavelength regions for which different front-end technologies are used for low noise receivers



State-of-the-art double sideband (DSB) receiver noise temperatures for different technologies. The lowest noise temperature is given by the "quantum limit", $T = hf/k_B$.

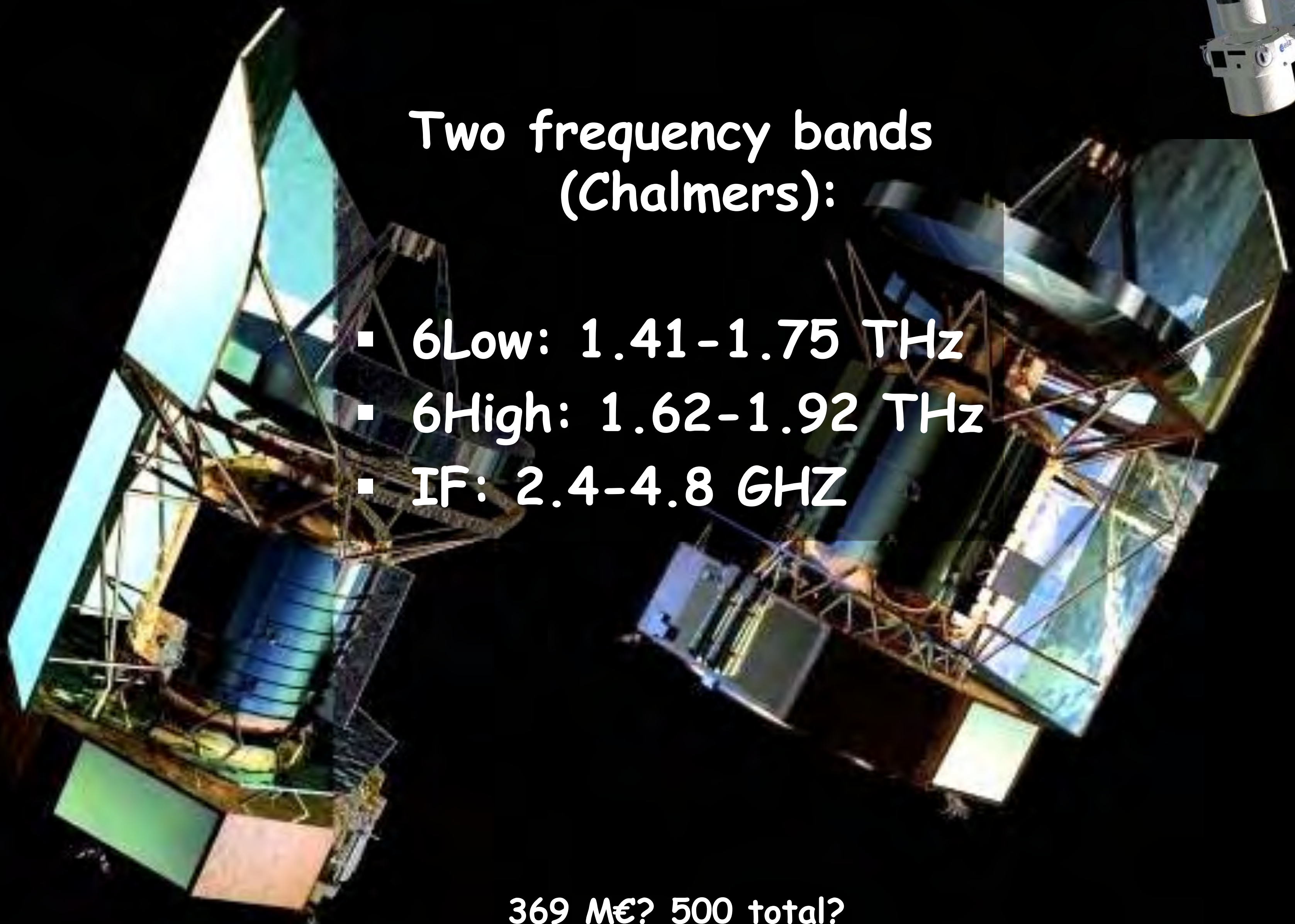


Atmospheric transmission
Low transmission through the atmosphere



Herschel Space Observatory

to be launched feb. 2007



Two frequency bands (Chalmers):

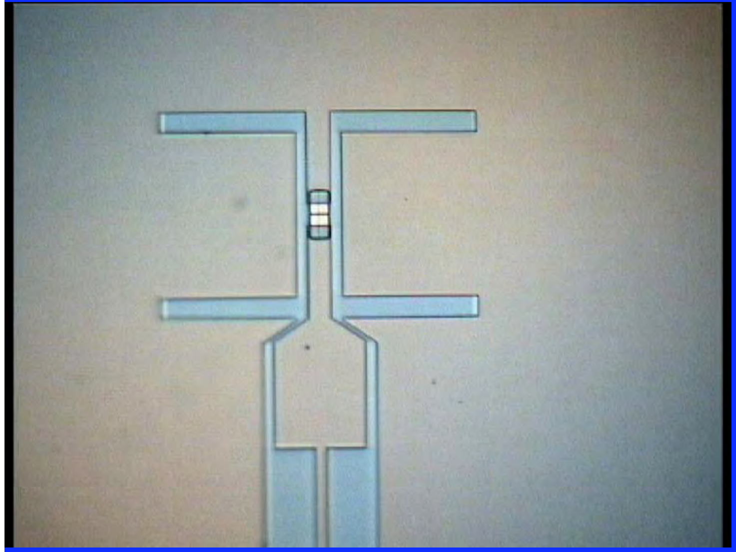
- 6Low: 1.41-1.75 THz
- 6High: 1.62-1.92 THz
- IF: 2.4-4.8 GHZ

369 M€? 500 total?

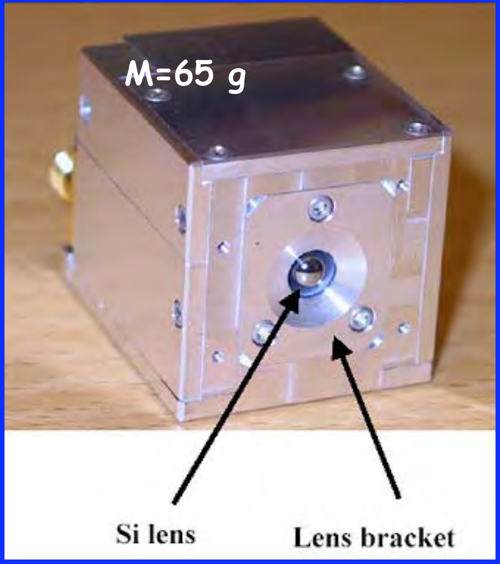
http://sci.esa.int/first

Integrated Planar Antennas

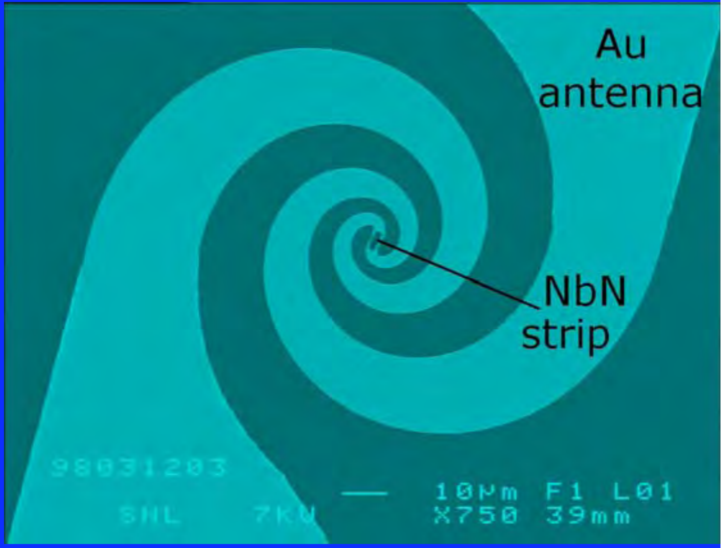
Double slot antenna



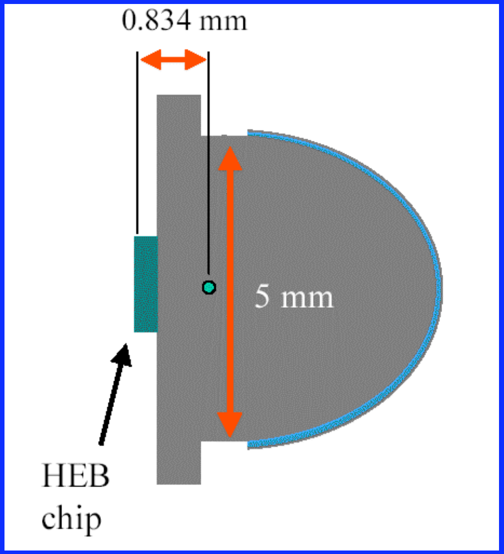
Mixer mount

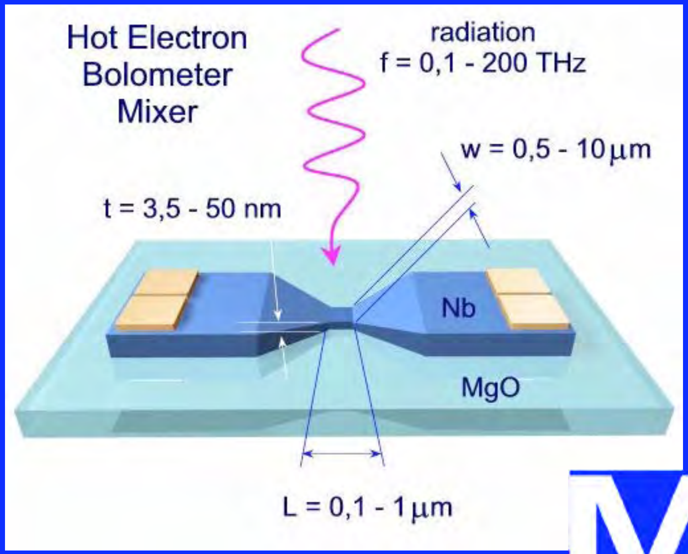


Spiral antenna



Quasi-optical coupling

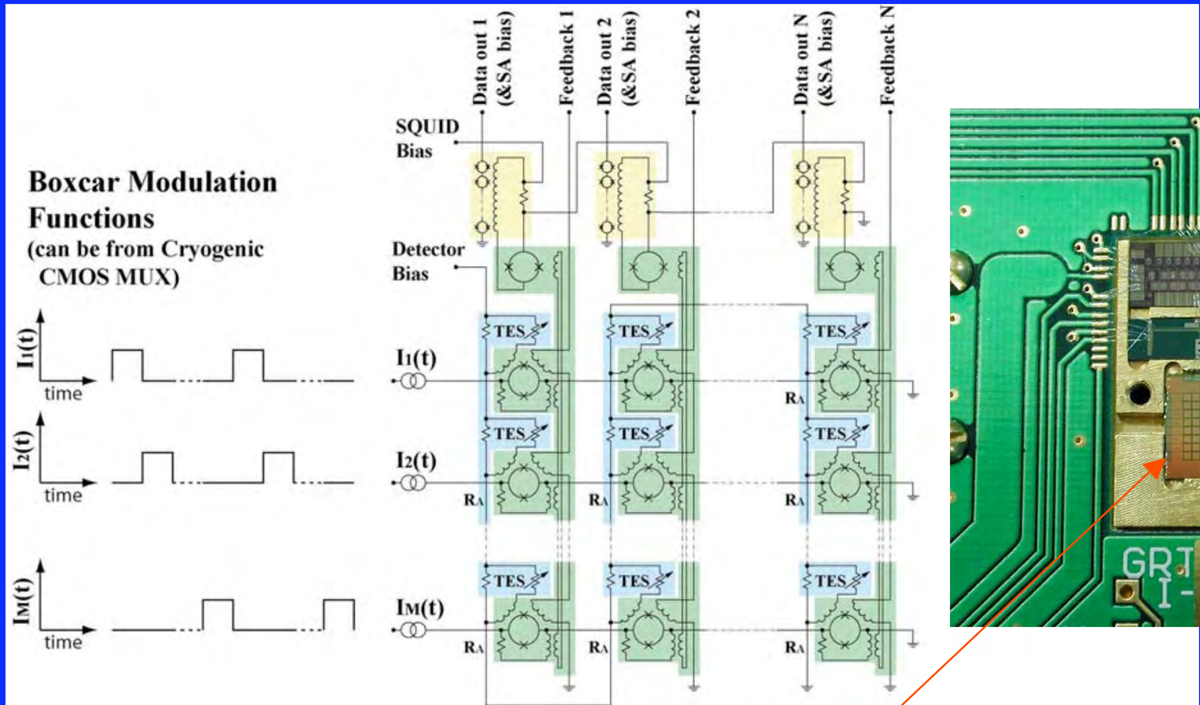


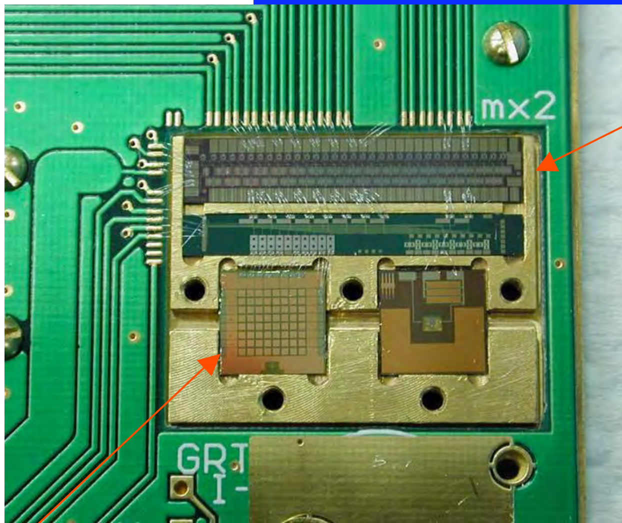


CHALMERS

MC2

TES with time-division SQUID multiplexer

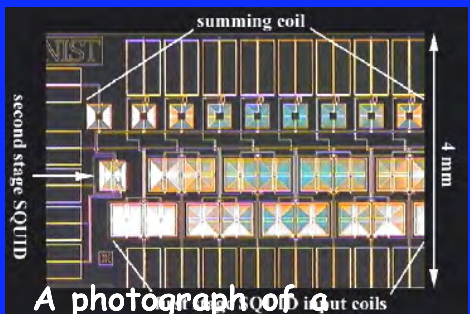




1 x 32 SQUID multiplexer

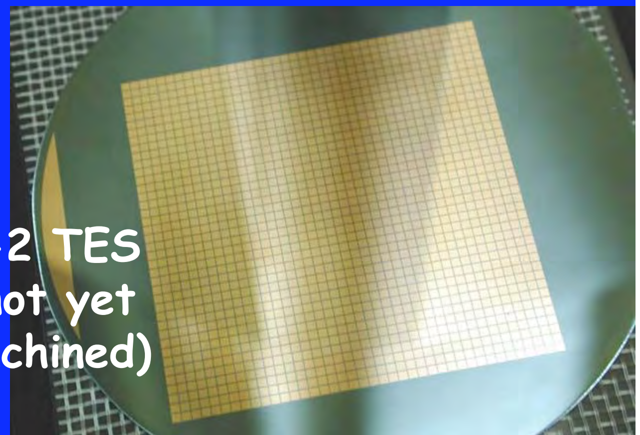
8 pixels of 8 x 8 x-ray array being read out in a 1 x 8 multiplexed column

8 x 8 x-ray array



A photograph of a portion of the 1 x 32 channel SQUID multipl...

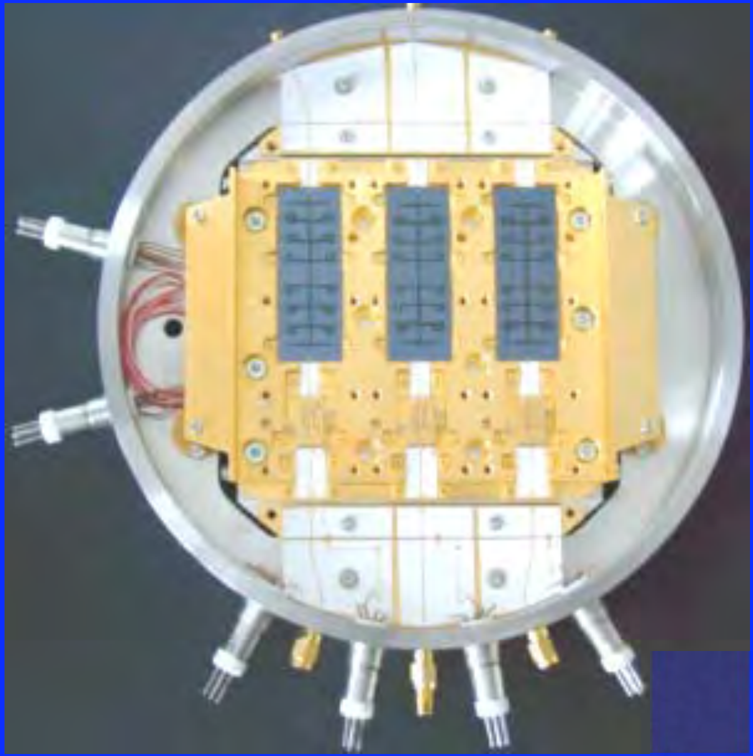
32 x 40 SCUBA-2 TES array (not yet micromachined)

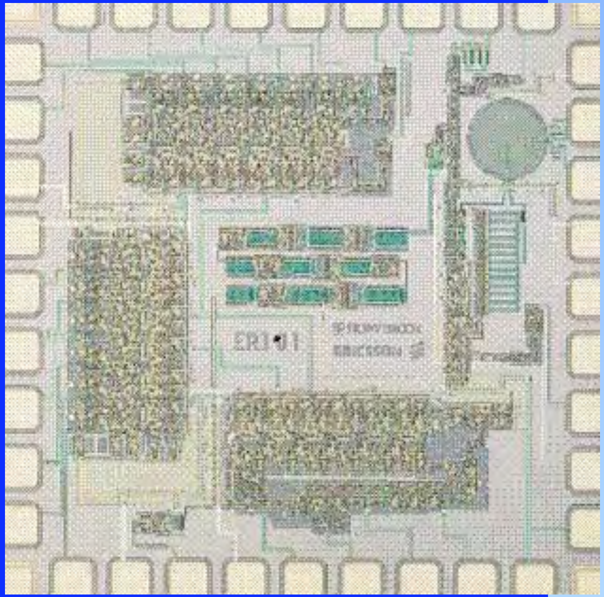


NIST
National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce

PTh30, 10:40-12:30, Poster Session IV, SQUIDs/Standards, Thursday, 10/7/03:Design & performance of a time-domain SQUID multiplexer system for read-out of superconducting transition-edge sensors arrays, C.D.Reintsema, et al.

Superconductor Technologies Inc & Conductus





"A KILLER APPLICATION"

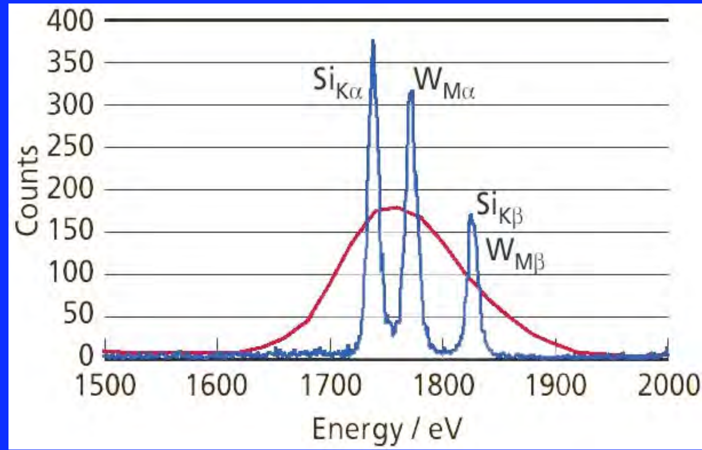
EDAX

VeriCold Technologies

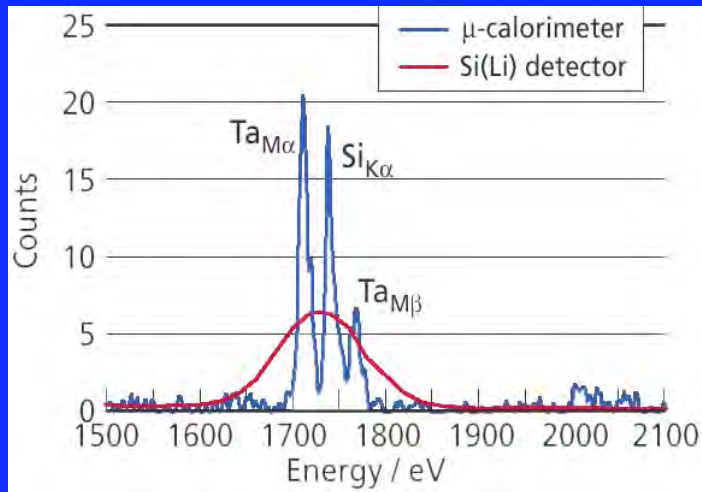
Joint project of
EDAX and Verioold

TES

- Mechanically cooled microcalorimeter EDS detector
- No Liquid Helium or other cryogens
- Resolutions of 15eV @ Al K
- X-ray energy is measured via temperature change on detector
- High energy resolution at low operating temperatures (100 mK)
- Increase in temperature results in change in resistance
- Resistance change measurement with superconducting electronics (SQUID)
- Increase in temp ≈ energy of absorbed photon
- Output is EDS spectra



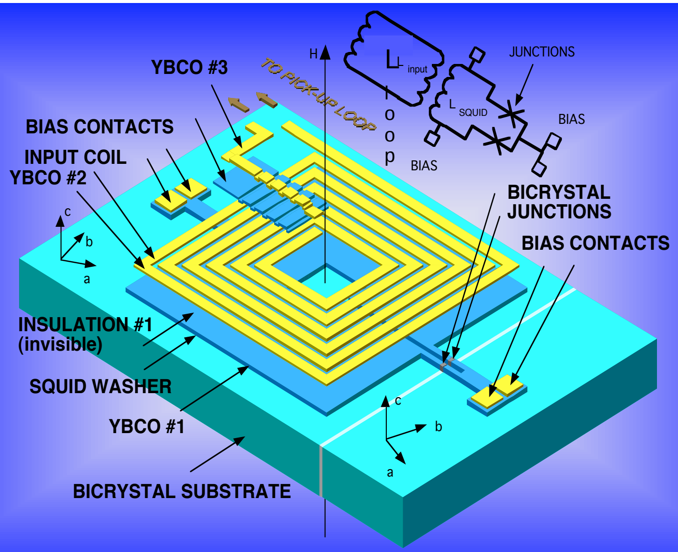
Spectral data of WSi_2 sample measured under the following conditions: 5KV, 203pA and 60s acquisition time. W and Si can be identified.



Spectral data of $TaSi_2$ measured under the same conditions as above: 5kV, 203pA and 60s acquisition time.

http://www.vericold.com/

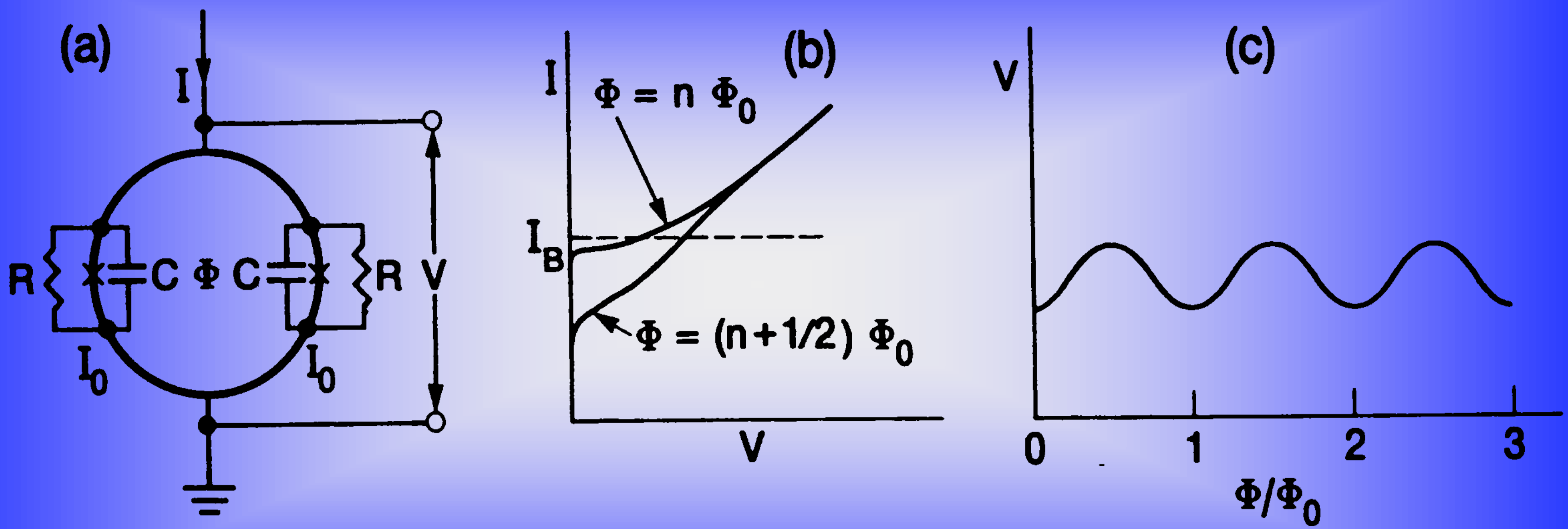
www.edax.com/products/Microanalysis/detectors/special_EDS/Polaris.html



The SQUID

SQUID: Superconductor Quantum Interference Device

The SQUID is a flux-to-voltage transducer



The dc SQUID; (b) I-V characteristics; (c) V vs. Φ/Φ_0 at constant bias current I.

ITh5, 18:20-19:10, Oral Session VII, Thursday, 10/7/03:
SQUIDs: The limit to measurement, J.Gallop.

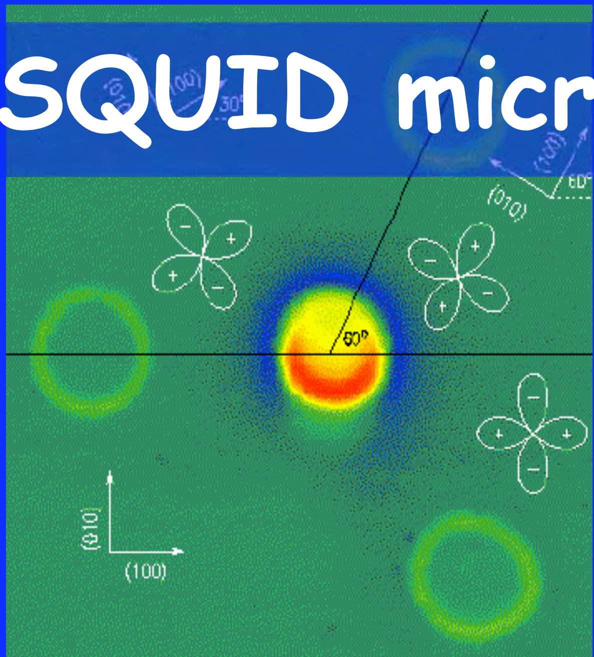
SQUID applications

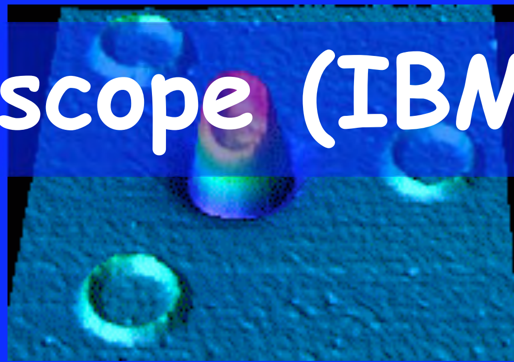
- Magnetometers
- Magnetic microscopes
- Non-destructive evaluation NDE
- Geology and prospecting
- pV- and pA-meters
- Biomagnetism, e.g., MEG, MCG, …
- Medicine and diagnostics
- Low frequency NMR and MRI

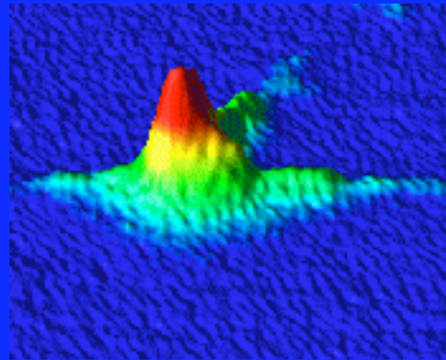
IBM Journal of Research & Development

http://www.research.ibm.com/sup/kirtley.htm

SQUID microscope (IBM)







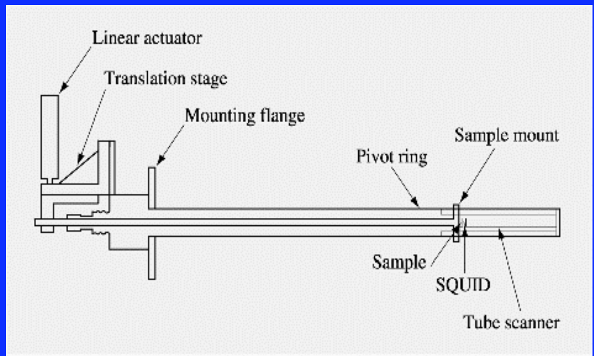


Figure 1

Schematic diagram of our scanning SQUID microscope [16].

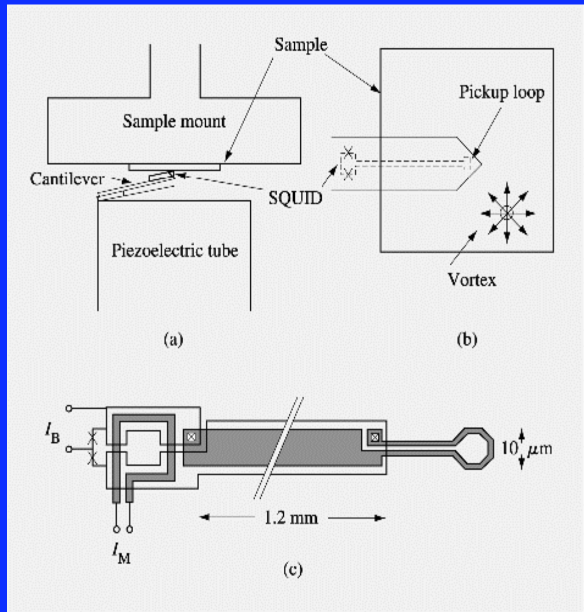


Figure 2

(a, b) Expanded views of the sample area; (c) schematic layout of the integrated magnetometer [16].

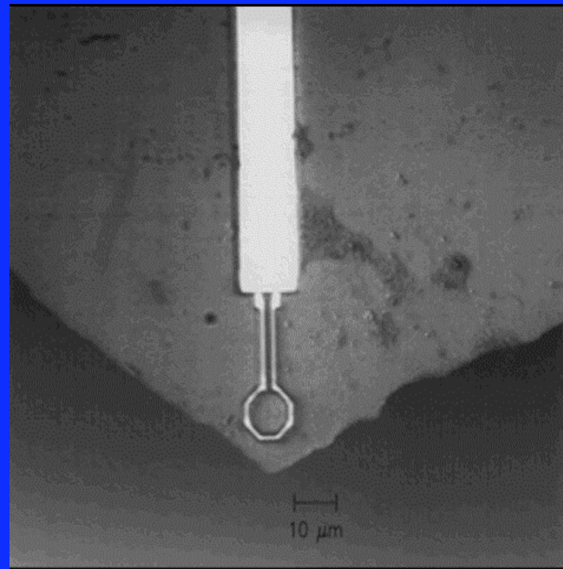
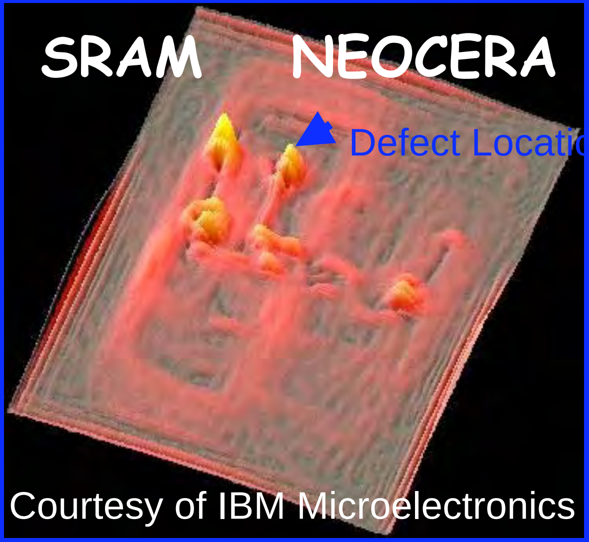


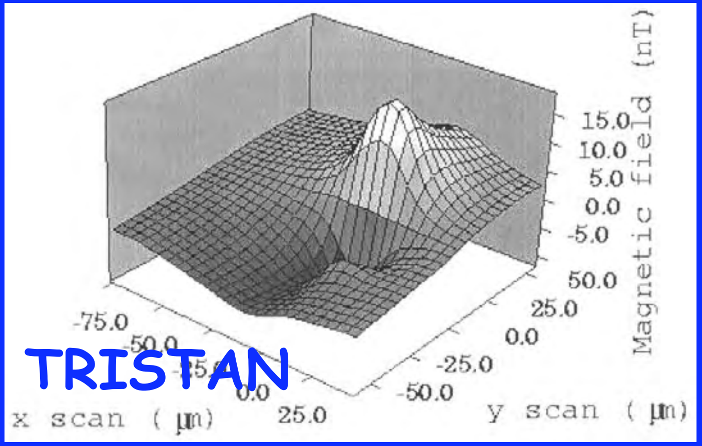
Figure 3

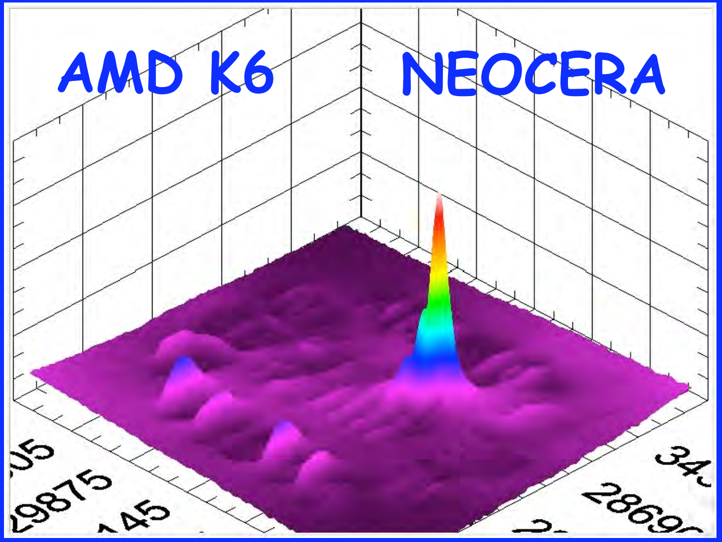
Optical image of the tip of a SQUID sensor after polishing.

SQUID microscopes for semiconductor industry

$Al_xGa_{1-x}As/GaAs$ heterostructure: Y. Tokura *et al*, "Noninvasive determination of the ballistic-electron current distribution",
Phys. Rev. B, 54,1947 - 1952, 1996.

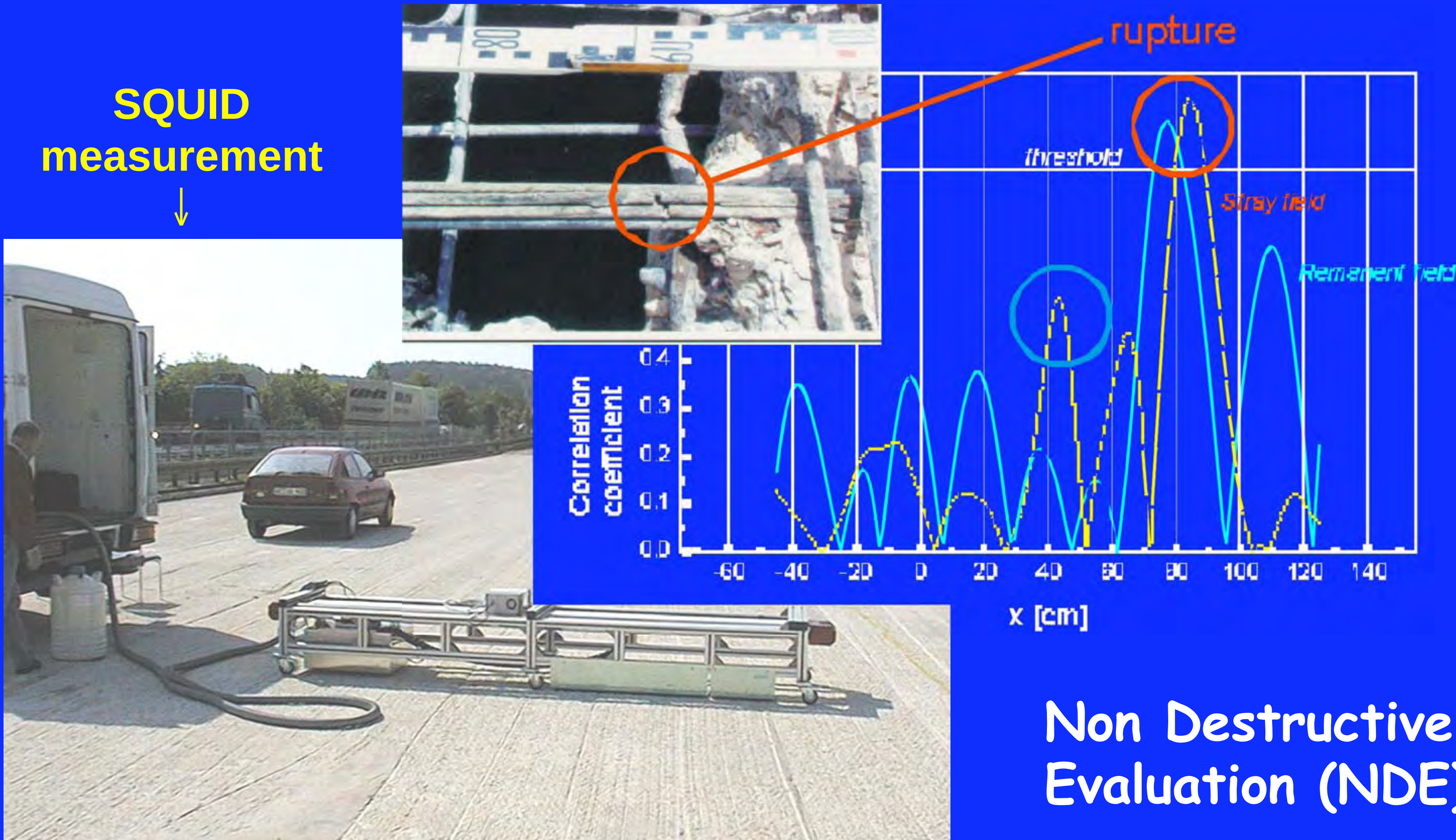






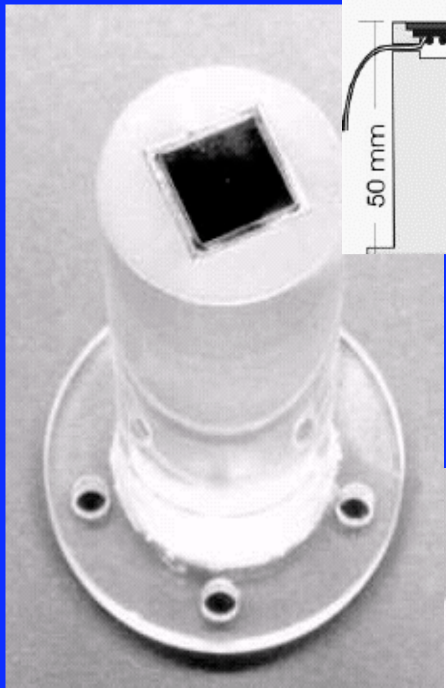
SQUID localization of cracks in rebars on a German highway bridge

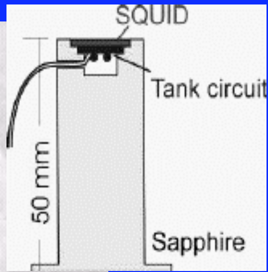
SQUID measurement ↓

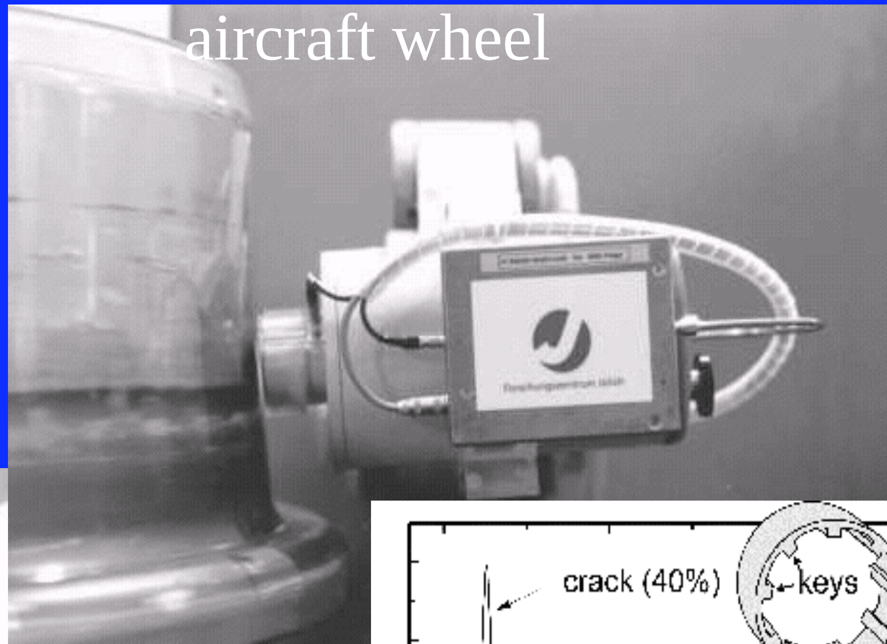


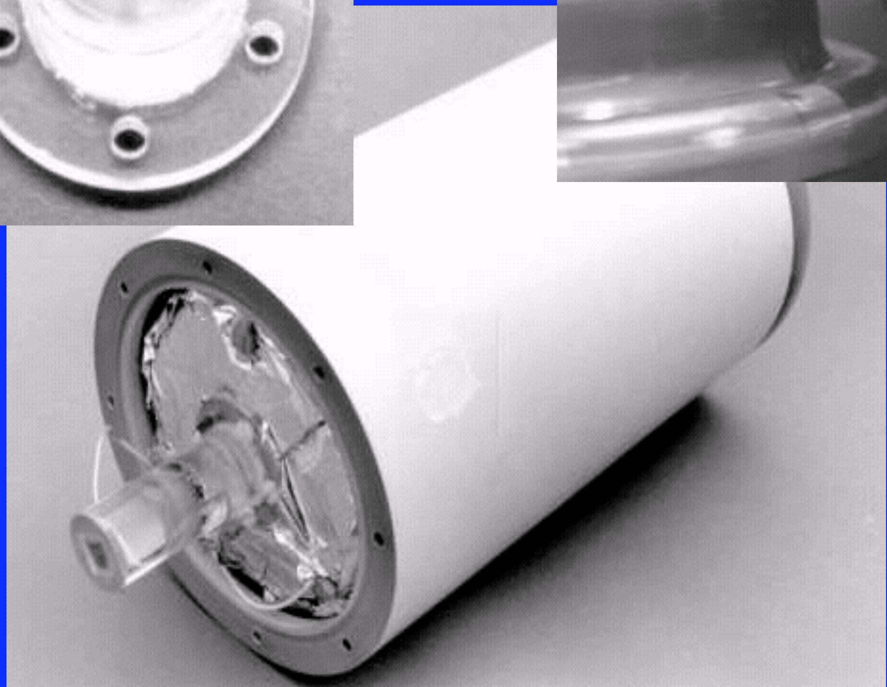
Non Destructive Evaluation (NDE)

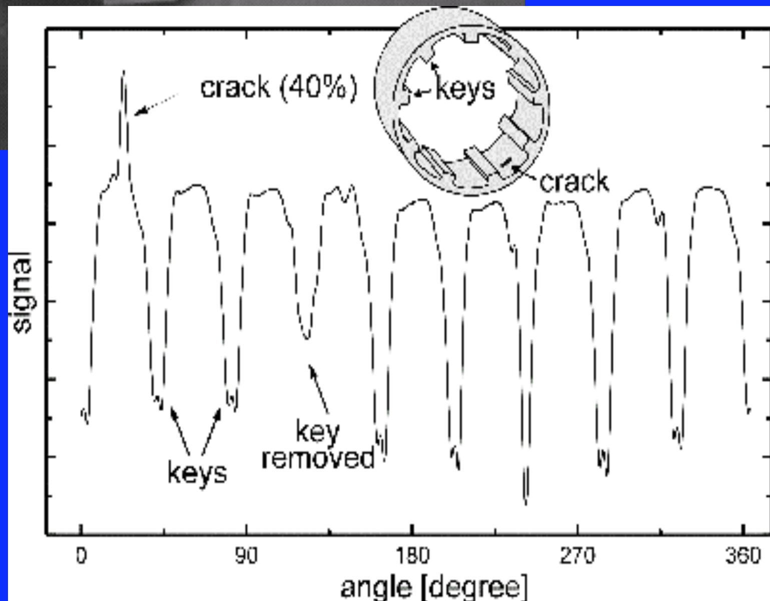
Non Destructive Evaluation (NDE)











Geology and prospecting

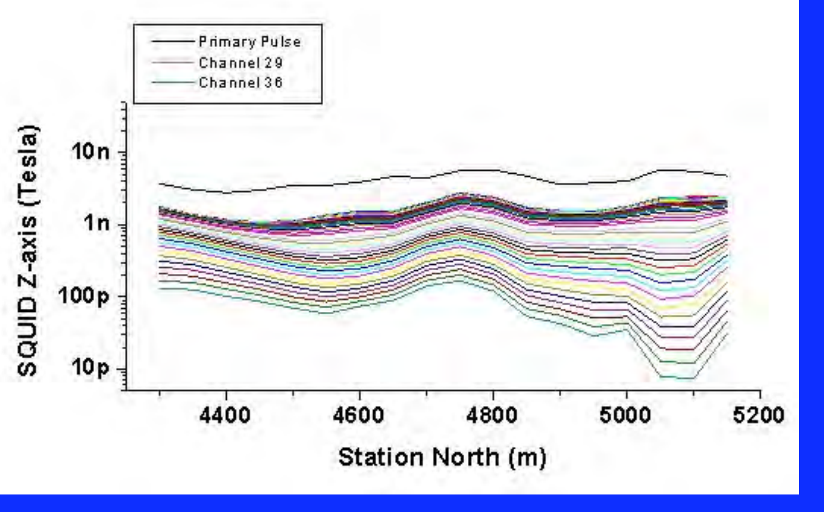
CSRIO

OUTER RIM
EXPLORATION SERVICE

CSRIO

OUTER RIM
EXPLORATION SERVICE

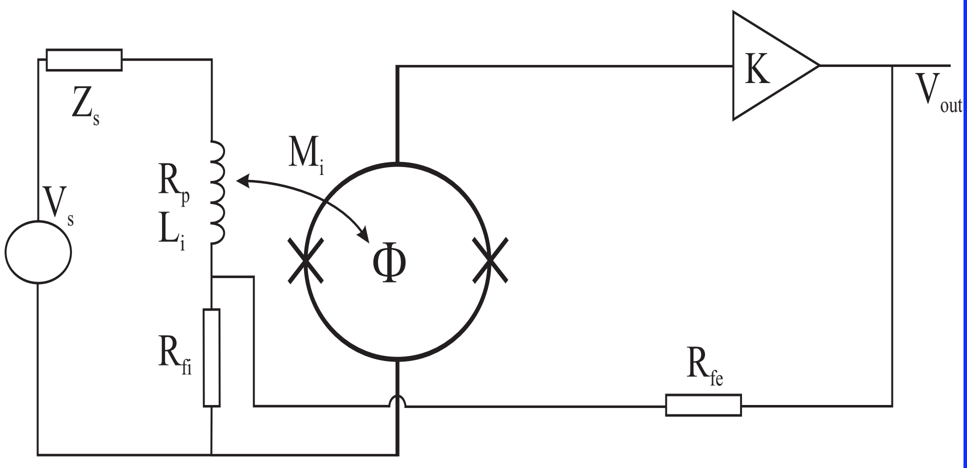
2G Enterprises



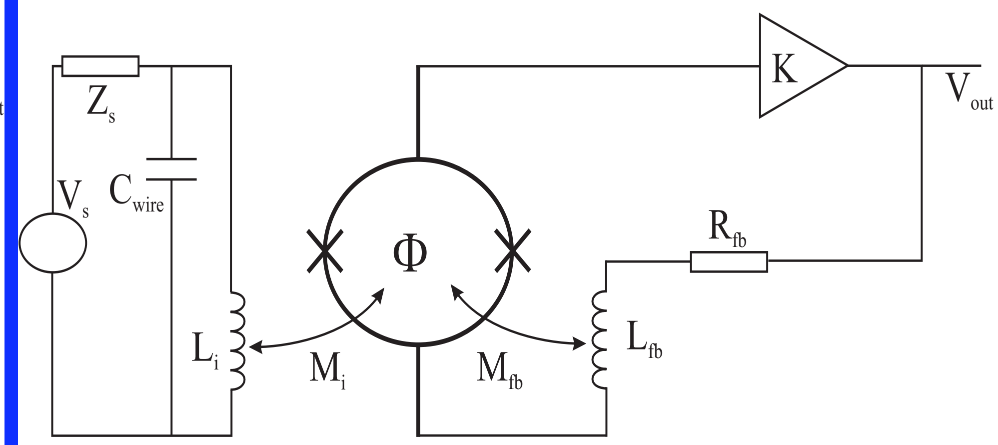
ITh4, 17:30-18:20, Oral Session VII, Thursday, 10/7/03:
The impact of SQUIDs on geophysics, C.P.Foley.

SQUID voltage, current amplifiers

Feedback schemes for the SQUID amplifiers



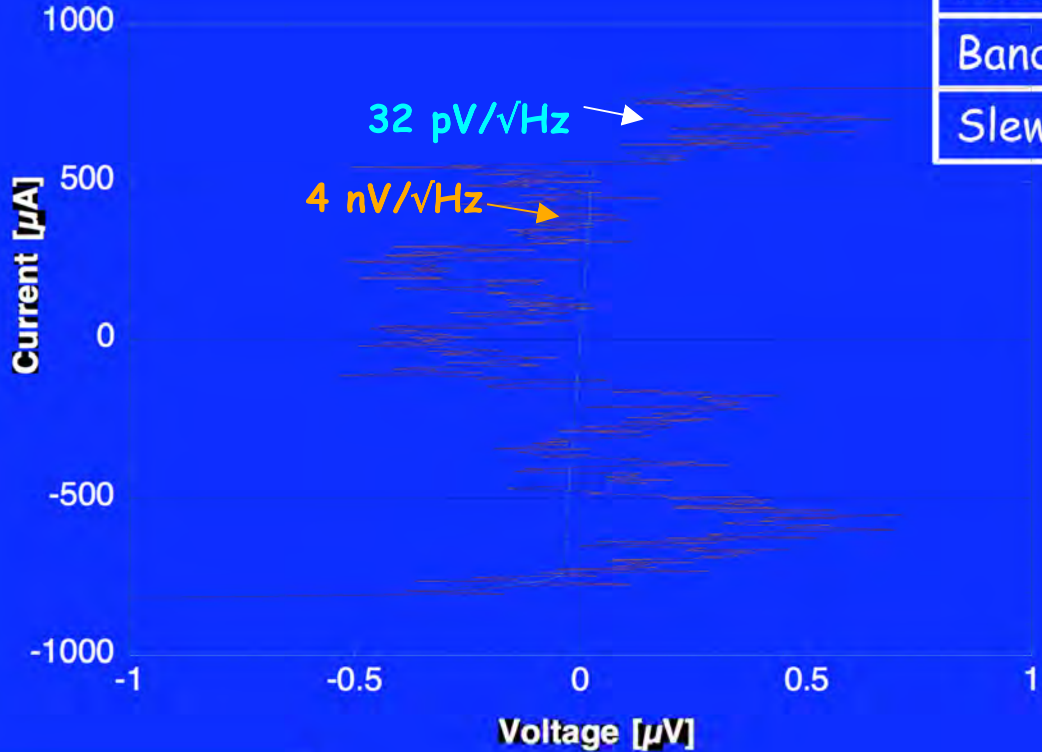
Voltage amplifier



Current amplifier

Low voltage IV-characteristics of another SQUID

Blue curve is data taken with picovoltmeter.
Orange curve is data taken with commercial low-noise amplifier (PAR5113).



Best performance of our voltage amplifiers in different configurations

Voltage noise	3.2	pV/√Hz
Current noise	0.28	pA/√Hz
Energy sensitivity	$1.7 * 10^{-22}$	J
Noise temperature	10	K
Bandwidth	300	kHz
Slew rate (R_s = 10 Ω)	91	mV/s

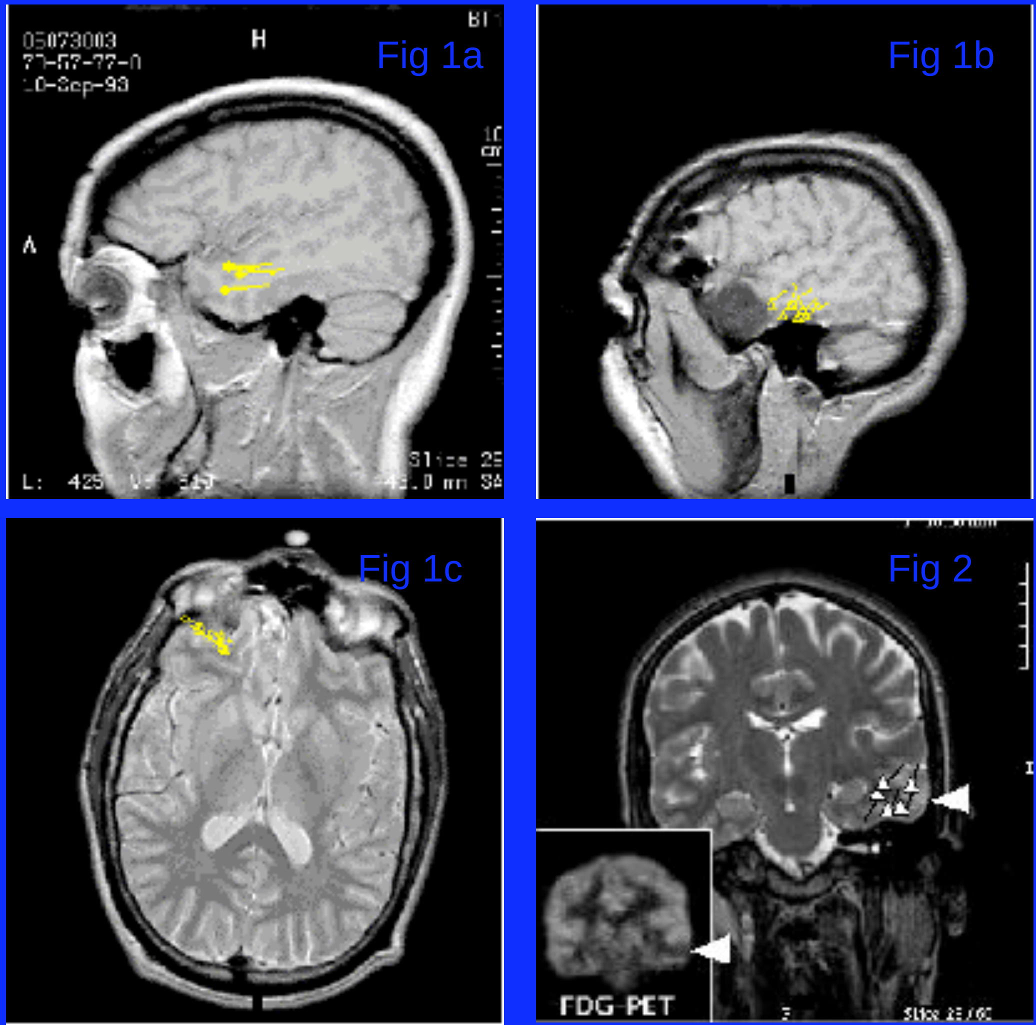
CHALMERS

MC2

Medicine, biophysics and chemistry

- Biomagnetism: MEG, MCG, ...
- Biophysics:
  - Diagnostics by magnetic tagging of antibodies
  - Special frequency characteristics, no rinsing
- MRI (Magetic Resonance Imaging)
  - Low frequency, low noise amplifiers, sc solenoids
- NMR (Nuclear Magnetic Resonance)
  - Low frequency, small fields, sc solenoids
- NQR (Nuclear Quadropole Resonance)
  - Low frequency, low noise amplifiers, sc solenoids

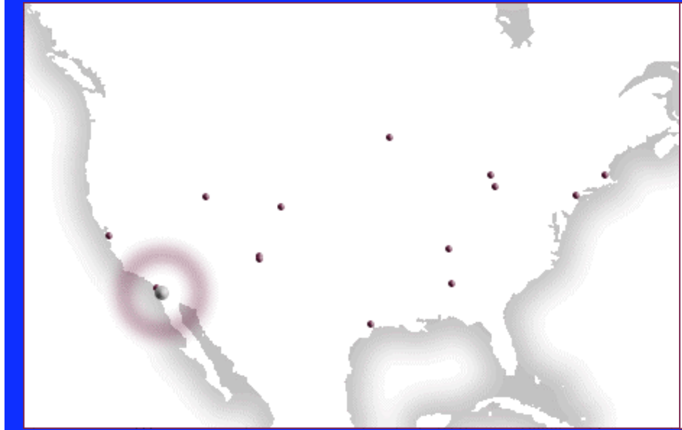
Magnetoencephalogram MEG

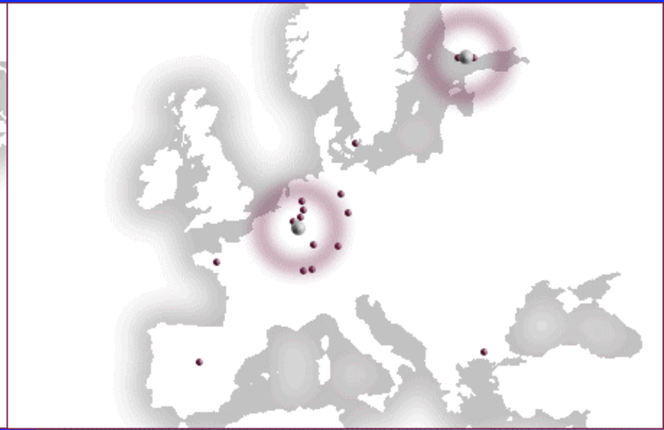


http://www.4dneuroimaging.com/external_english/html/appsepi.html

http://www.uth.tmc.edu/clinicalneuro/epilepsy.htm

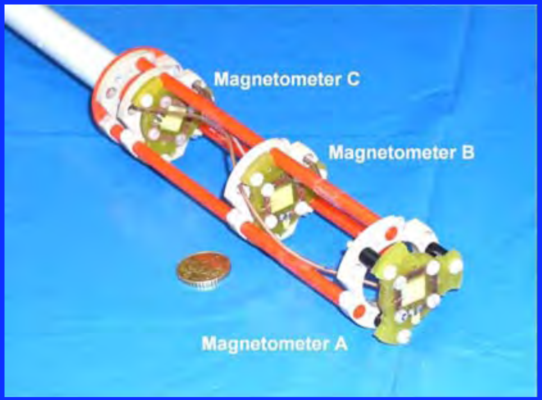
Installed systems

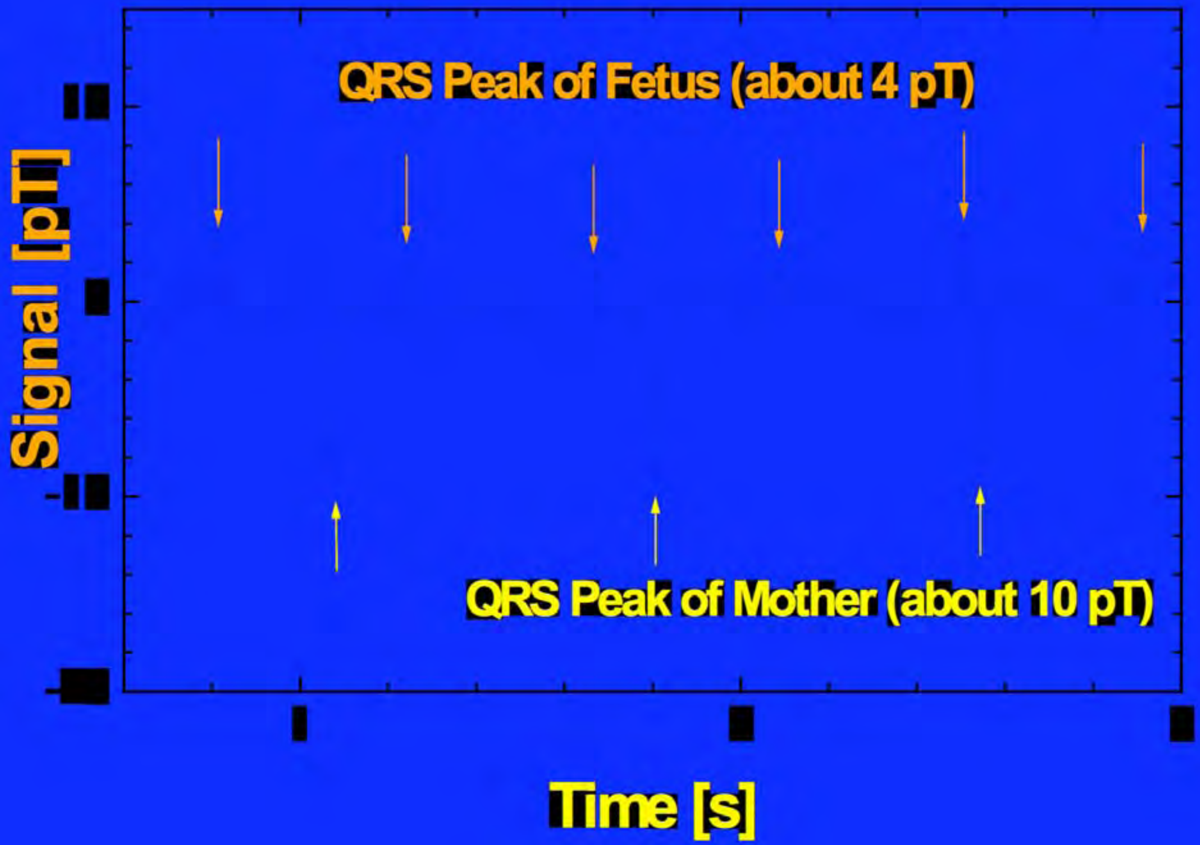




Real Time Fetal heart Signals at 37th week Measured Using 1th Order Gradiometer in MSR

Pick-up area: 1 cm^2
Baseline: 18 cm
Video bandwidth: 0.025 – 90 [Hz]
SNR: 2





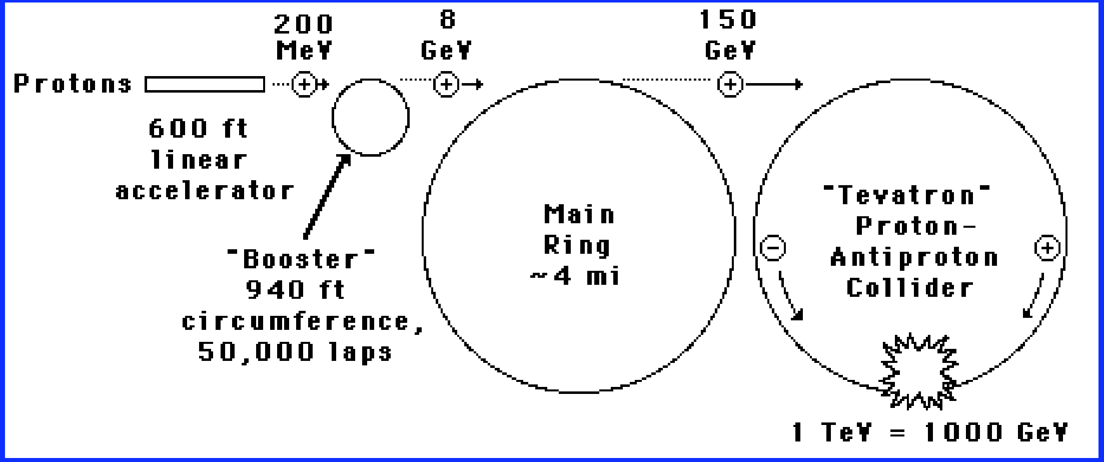
This is the first demonstration to record fetal heart signal in real time, using HTS SQUID gradiometer!

Power applications

- Strong magnets for
  - particle accelerators
  - NMR
  - Research
- Small compact generators and motors
  - Submarines, boats, trains
- Power transmission
- Levitating trains

Power applications

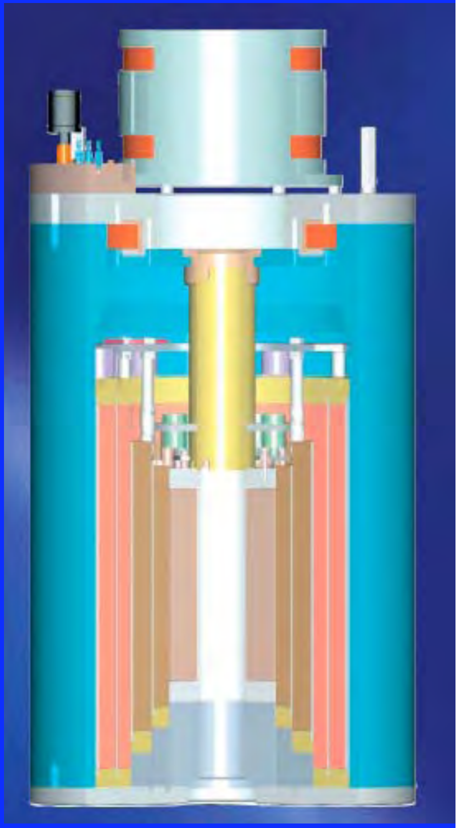
•Strong magnets for particle accelerators Fermilab Chicago



•Strong magnets for Magnetic resonance imaging

extremely uniform fields across the subject and extreme stability over time

•20T magnet



Power applications

Compact motors and generators

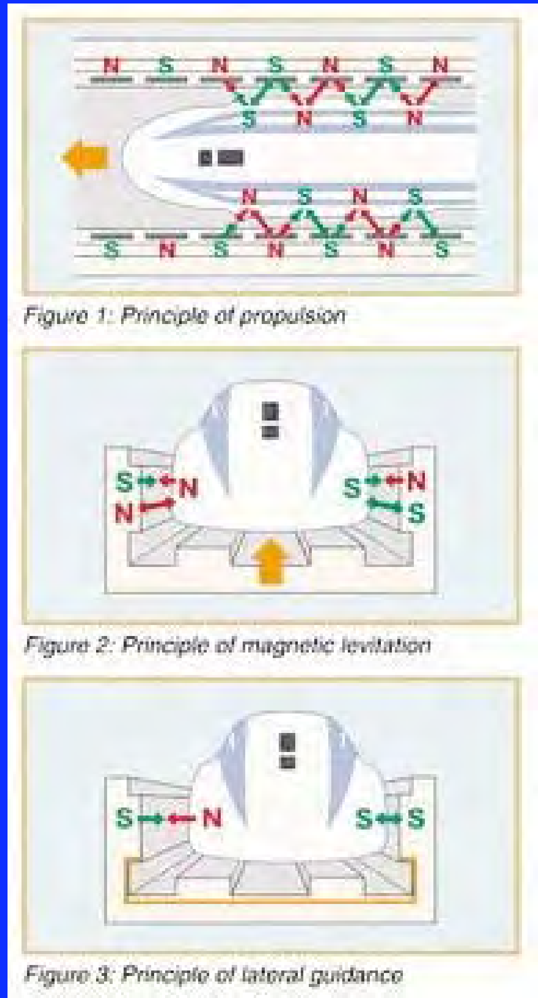
In 1995 the Naval Research Laboratory demonstrated a 167 hp motor with high-Tc superconducting coils made from Bi-2223. It was tested at 4.2K and at liquid neon temperature, 28K with 112 hp produced at the higher temperature.

In mid-July, 2001, American Superconductor unveiled a 5000-horsepower motor made with superconducting wire (below). And expects to deliver an even larger 36.5MW HTS ship propulsion motor to the U.S. Navy by September 2006

Power applications
Levitating trains

•Magnetic-levitation is an application where superconductors perform extremely well. Transport vehicles such as trains can be made to "float" on strong superconducting magnets, virtually eliminating friction between the train and its tracks.

•The Yamanashi Maglev Test Line opened on April 3, 1997. In December 2003, the MLX01 test vehicle attained an incredible speed of 581 kph.

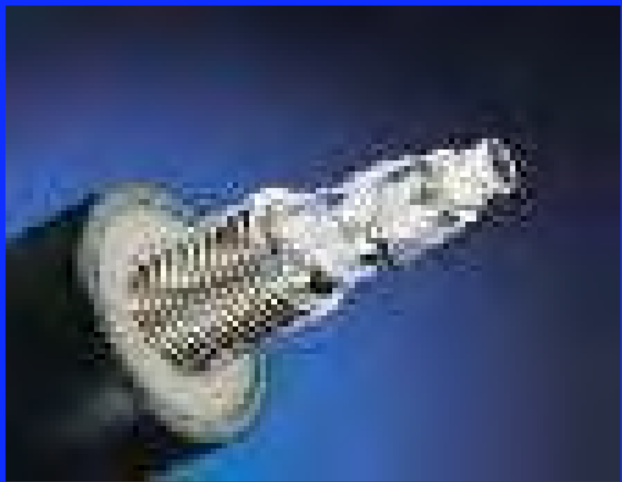


Power applications

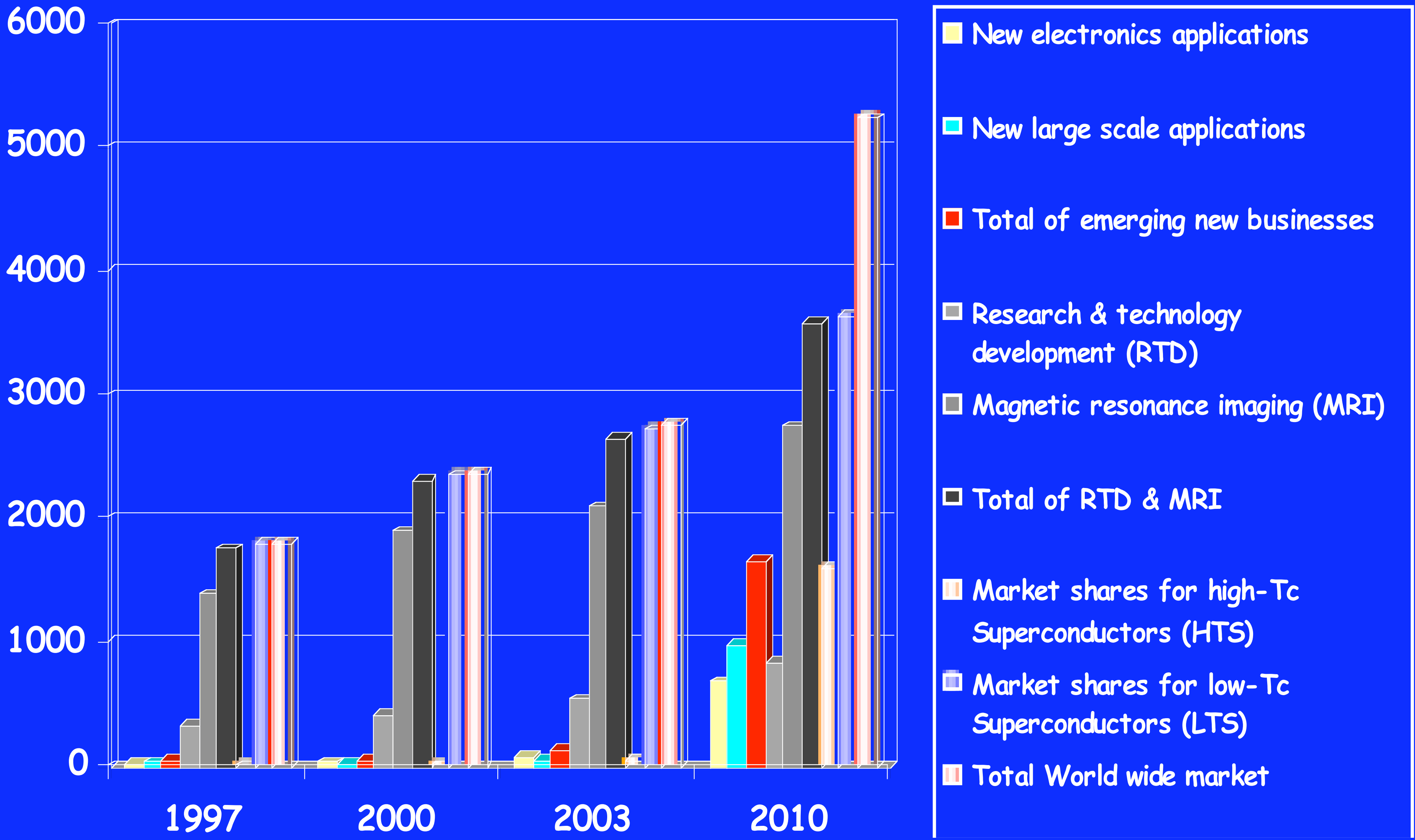
Power Transmission

10% to 15% of generated electricity is dissipated in resistive losses in transmission lines

- In the summer of 2001 Pirelli completed installation of three 400-foot HTS cables for Detroit Edison at the Frisbie Substation capable of delivering 100 million watts of power



Worldwide Market for Superconductivity and Market Shares for Low- and High-T_c Superconductors in M€



Cryo coolers

Wishes:

- Cheap
- Small
- Invisible
- Efficient
- Reliable
- No vibrations
- Non-magnetic