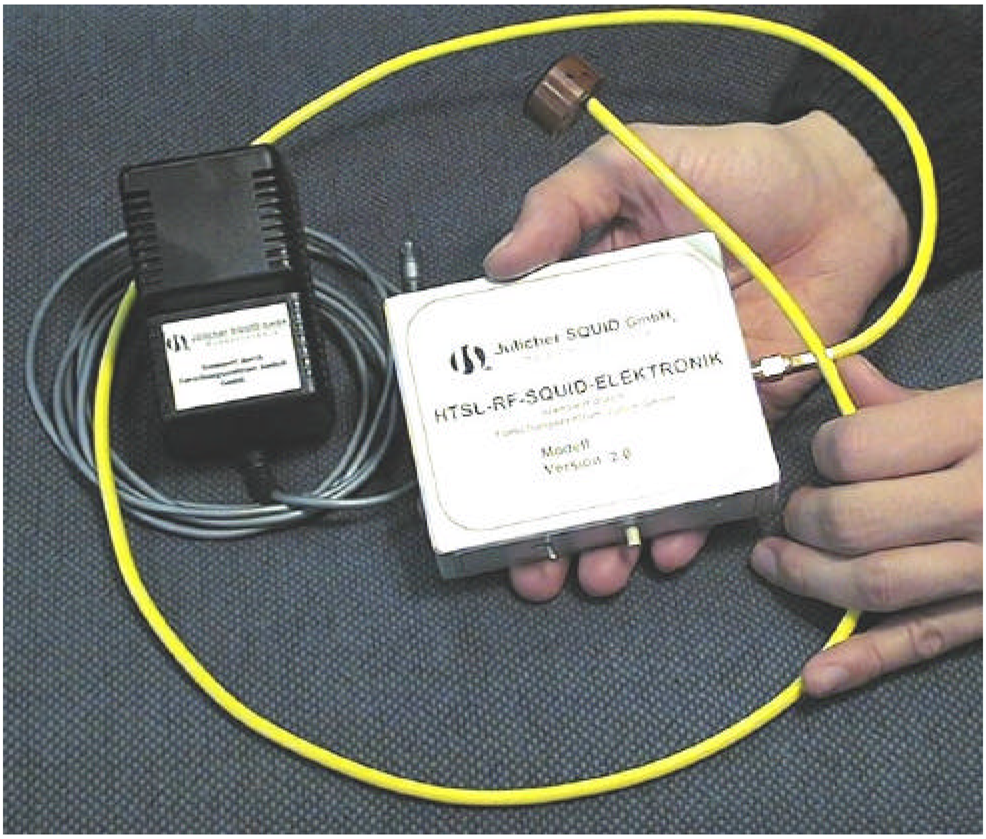
Jülicher SQUID GmbH
Sensortechnik



The Jülich SQUID Company (JSQ)

„Manufacturer of

the world´s finest

HTS-rf-SQUIDs“

Licensed by

Research Center Jülich

(Forschungszentrum Jülich GmbH)

What is a SQUID ?

SQUIDs (**S**uperconducting **QU**antum-**I**nterference-**D**evices) are the most sensitive sensors for magnetic fields. They make clever use of the properties, which are specific for superconductors: zero electrical resistance, expulsion of magnetic fields and quantization of magnetic flux. Using a superconducting ring with a weak link (a Josephson contact) and a coupled rf-resonance circuit allows to detect changes of the magnetic flux which are smaller than $10^{-6}\ \Phi_0$ (Φ_0 denotes the magnetic flux quantum of $2 \cdot 10^{-15}$ Tm^2 or $2 \cdot 10^{-7}$ Gauss cm^2). To get an idea of these changes are: The flux of the earth's magnetic field through an area of 1 mm^2 sums up to approx. $10^4\ \Phi_0$.
In order to operate a SQUID, the material has to be cooled below its critical temperature. Until 1986, the critical temperature of all known materials was pretty low and liquid helium had to be used for cooling. Unfortunately, liquid helium is expensive and difficult to handle. In 1986 so-called "High-Temperature Superconducting" (HTS) materials were discovered by Müller and Bednorz. These materials can be cooled with cheap and easy-to-handle liquid nitrogen. Now SQUIDs may be used outside of research labs.
JSQ is offering "thin-film-rf-SQUIDs" made from HTS materials. The design was developed at the Institute of Thin Film Technology at Research Center Jülich. The thin films made from $YBa_2Cu_3O_7$ are only 200 nm thick and are patterned onto ceramic substrates by photolithographic methods which are standard silicon processing technologies.

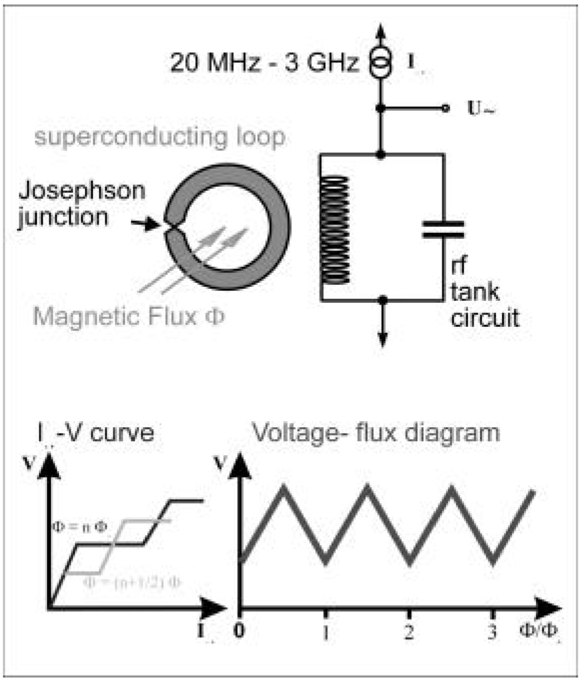


Fig. 1: A rf-SQUID with its rf-resonance circuit converts changes of the magnetic flux into a voltage pattern.

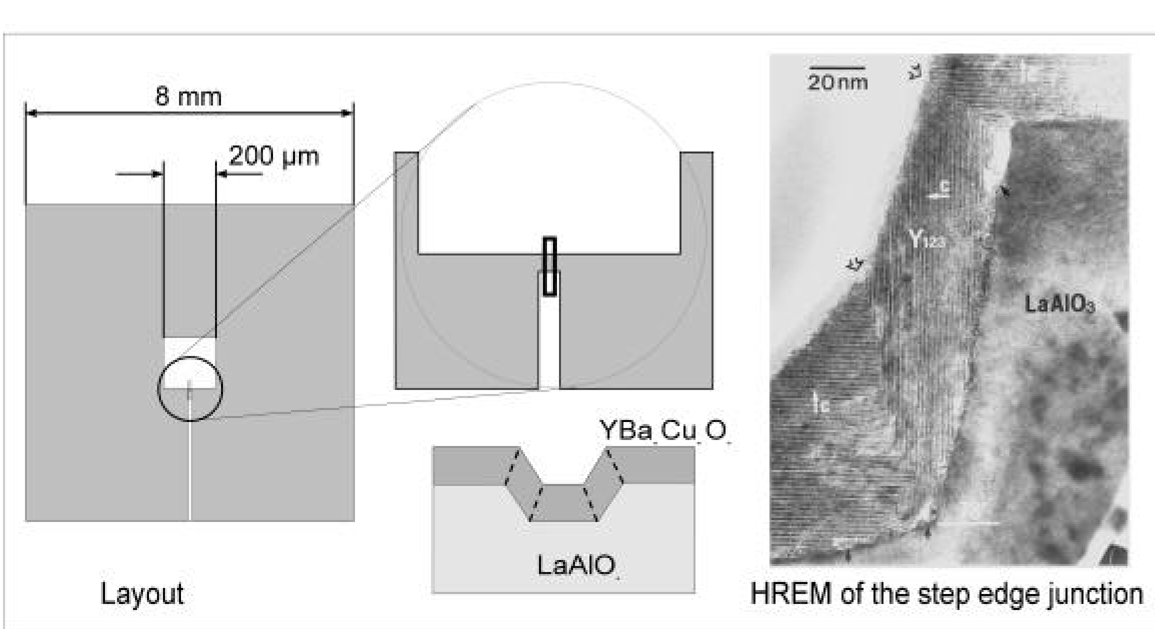


Fig. 2: Schematic picture of the rf-SQUID. The dark area denotes the super-conducting film (200 nm thick). This film encloses a rectangular hole which is accessible to the magnetic flux. The weak link is fabricated in the form of a step edge junction. Whenever flux passes through the weak link, a detectable electrical signal is generated.

Applications for HTS rf-SQUIDs by JSQ

With our HTS-rf-SQUIDs, it is possible to measure rapidly changing fields with extremely high sensitivity.
The different requirements for sensitivity, frequency and dynamic range vary greatly for different applications. Therefore, JSQ offers a line of new SQUIDs.

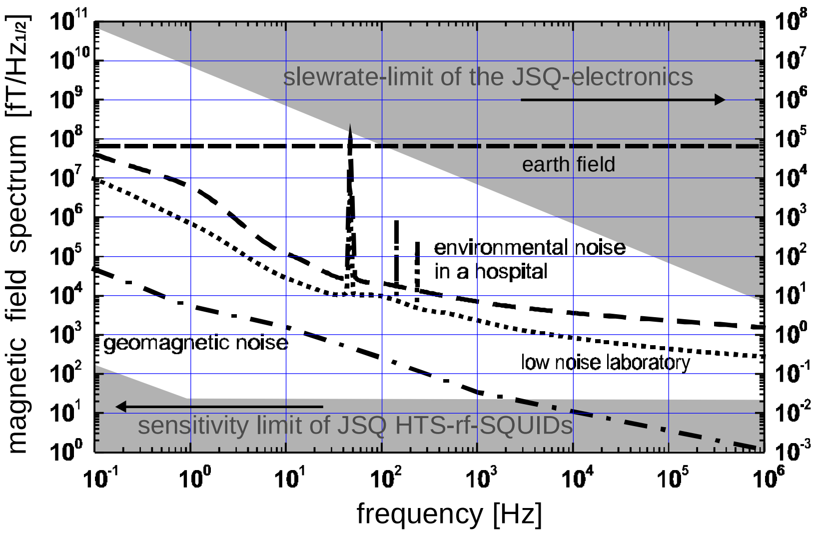


Fig. 3: The figure demonstrates the wide regime of operation of our sensors.

- white area: main regime of operation
- upper gray area: no stable operation possible. The magnetic fields are too large or change to rapidly.
- lower gray area: intrinsic noise dominates the sensor signal.

One sees that for our new sensors even a moving operation directly exposed to the magnetic field of the earth becomes possible. This is a true breakthrough. The new HTS-rf-SQUIDs by JSQ are especially qualified for the following tasks:

- **Biomagnetic diagnostics**, especially of the heart functions need the highest sensitivity, but use a small frequency range (0.01 Hz up to 300 Hz). With a sensitivity limit below 30 fT/√Hz, our new HTS-rf-SQUIDs are exceptionally well suited for cardiac measurements.

- **Geological surveying** needs a very high bandwidth from 0.001 Hz up to 10^5 Hz and a high sensitivity, while directly exposed to the full earth magnetic field. The problem of moving within the earth field is less important, because normally the sensors are not moving during operation.

- **Non-Destructive Evaluation (NDE)** of materials (i.e. detection of flaws and cracks in airplane parts, checking steel reinforcement buried inside concrete structures, monitoring material fatigue etc.). These applications use frequencies between 1 Hz and a few kHz. Mobile operation in the earth magnetic field is essential and therefore gradiometry is the best choice for stable operation.

Geological Applications

Magnetic field sensors can be used for geophysical electromagnetic exploration methods on the ground, in bore holes, and from airborne platforms. Especially, the TEM (transient electromagnetic) method is widely used for exploration of ore deposits and geological structures, at depths of several hundred meters. High-temperature superconductor (HTS) SQUID technology offers the possibility to construct robust sensors which have a high sensitivity and a wide dynamic and frequency range. Exploration with such sensors can provide a number of potential advantages over traditional induction coil systems. The HTS SQUID can offer compactness, low weight, inherently broad bandwidth and high low-frequency sensitivity at acceptable cost.

Fig. 4: HTS rf SQUID system set-up during TEM field trial. Liquid-nitrogen-cooled (LN_2) dewar with SQUID sensor is buried in the ground to reduce wind noises.

PRINCIPLE OF GEOPHYSICAL EXPLORATION METHODS: EXAMPLE TEM

The electromagnetic (EM) prospecting technique is the one most commonly used in mineral exploration. In TEM measurements, a strong square wave current is passed through a transmitter loop usually situated on or above the surface of the earth as shown in fig. 5.

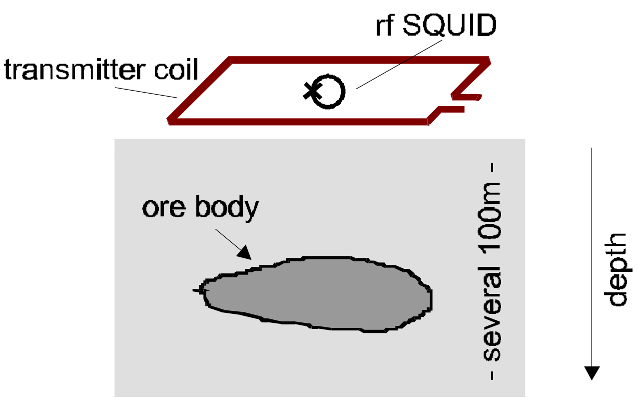
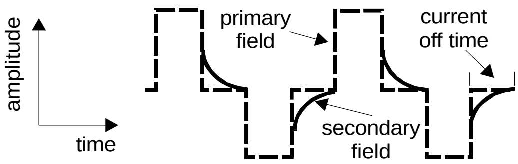
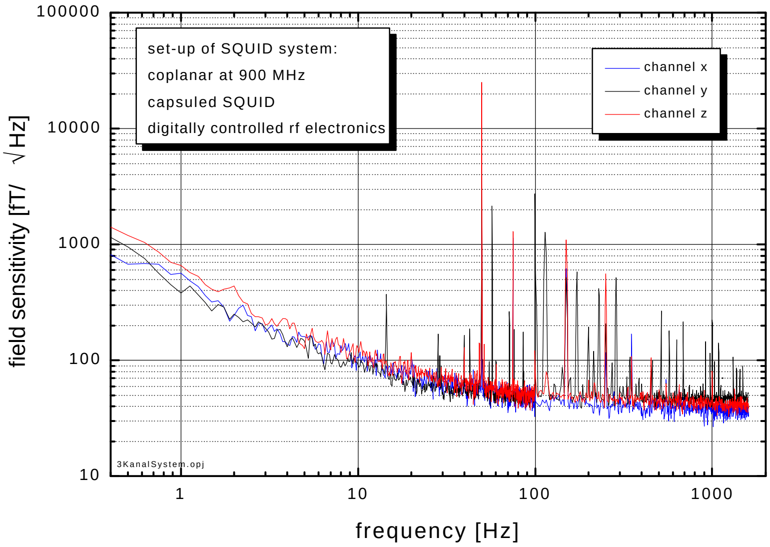


Fig. 5: Principle of TEM exploration method with transmitting coil and receiving SQUID sensor (left) and TEM bipolar transmitter pulse (primary field) including earth response (secondary field) (below).



The variation of the strong primary field (~100nT) will induce eddy currents in conductors present in the earth. The weak secondary fields (~pT) due to eddy currents induced in the ground can be measured with a suitable receiver, coil or SQUID in current-off periods between primary field pulses, as shown in fig. 5 (for a three axis field measurement see fig. 6). Averaging of the data is used to improve the signal-to-noise ratio (SNR). Early time secondary signals give information about upper geological layers, while late time signals (e.g.,>1ms) are due to the response of deeper structures. Therefore, to detect ore deposits in greater depths it is necessary to measure very weak signals at long delay times.

Fig. 6: Field Sensitivity of HTS rf-SQUID vectormagnetometer



GEO SQUID systems
The field sensitivity of a 3-axis, vector HTS rf SQUID magnetometer with coplanar resonators operating at 900MHz for geophysical exploration methods, especially for TEM and magnetotellurics (MT) is shown in figure 6. During field trials outside magnetic shielding a typical field sensitivity of about 40 fT/√Hz is achieved in the white noise region. The 1/f onset measured outside shielding starts at about 2kHz. The analog feedback electronics (version 2.0, manually controlled and version 3.0, digitally controlled) provide a stable operation with a slew rate of more than 2mT/s and dynamics of more than 110dB which meets the high requirements of TEM measurements. During TEM field trials, a good reproducibility of SQUID signals and a wide depth sensing range is achieved as shown in fig. 7.

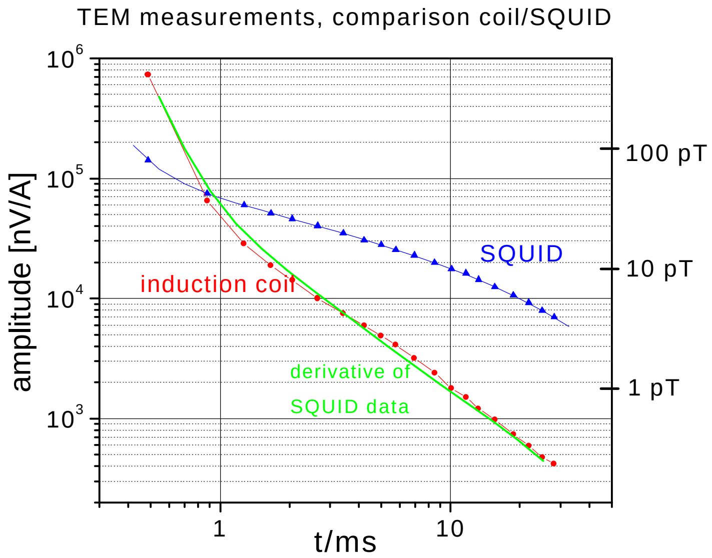


Fig. 7: TEM measurements with one channel HTS rf SQUID system; The figure shows the standard induction coil measurement with SQUID data. Since the SQUID measures fields, but the coil the time derivative of a field, the SQUID data are processed for exact comparison.
Loop of transmitter coil:
100m x 100m.

For geomagnetic applications we recommend the type M900 magnetometer with the 0.8 Gauss option.

Non-Destructive Evaluation Applications

Critical airplane parts need a periodic evaluation of their mechanical integrity. Standard testing procedures use ultrasonic, x-rays or eddy current testing. The use of SQUIDs is related to the eddy current method, but SQUID sensors have great advantages: better sensitivity and high dynamic at low frequencies enabling the detection of flaws in a depth of exceeding 1 cm.

One example: Aircraft wheel
The wheels of airliners require regular inspections, because they are highly stressed during landing and damage is critical. In addition, they experience tremendous heatloads during forceful breaking.

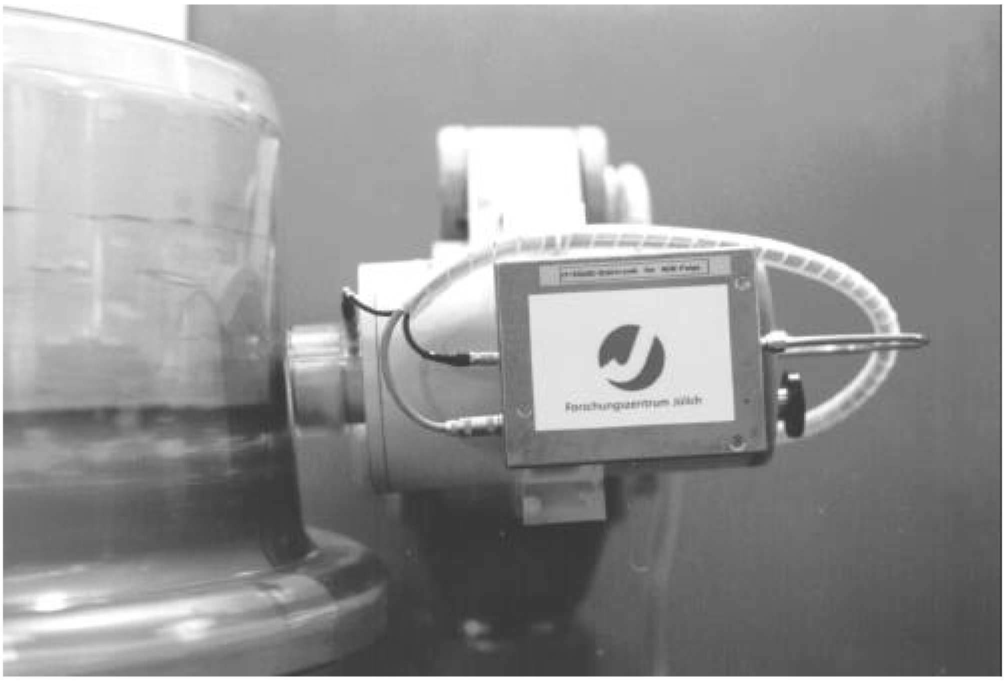


Fig. 8: Rim testing system including cryostat – working independent from orientation – with SQUID mounted inside on sapphire cold finger, SQUID electronics and eddy current excitation coil.

Fig. 8 shows an automatic rim scanning and testing system, equipped with an rf-SQUID sensor. This SQUID system is more sensitive than any conventional eddy current tester. Fig. 9 shows a linescan, which is dominated by the signature from ferromagnetic ridges (“keys”), which are fastened to the brake discs. An artificial partial crack inside the rim (less than 40% of the wall depth, 20 mm long) is clearly detected from the outside by the SQUID.

SQUIDs are also highly successful in detecting flaws in the reinforcement steel parts buried within concrete.

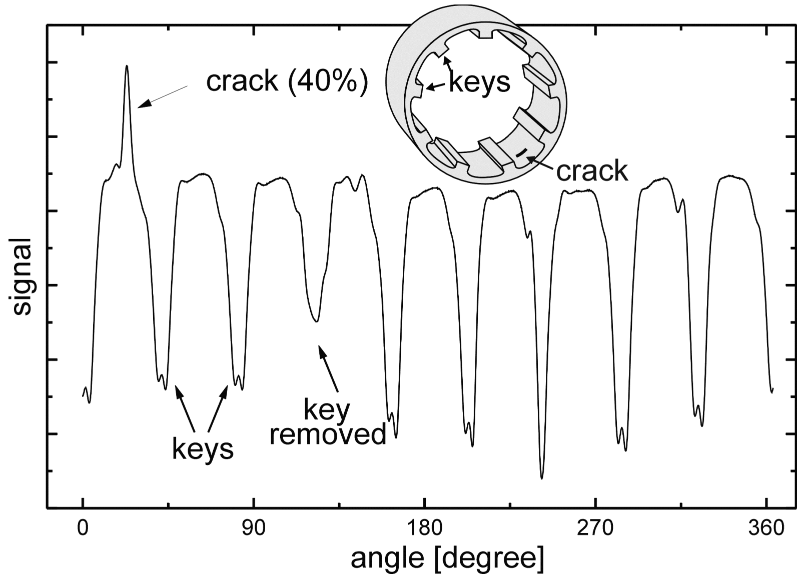
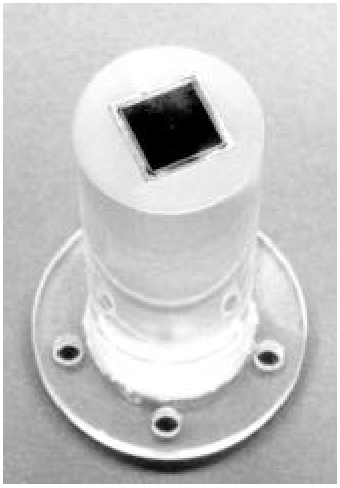


Fig. 9: One-dimensional scan of airplane rim with a crack at the inside, detected by a SQUID gradiometer from the outside.

For NDE applications it is necessary to move the SQUID around the specimen. For cooling a cryocooler or a cryostat for all positions (“upside-down”) is used. JSQ is offering a cryostat specially designed for this purpose.



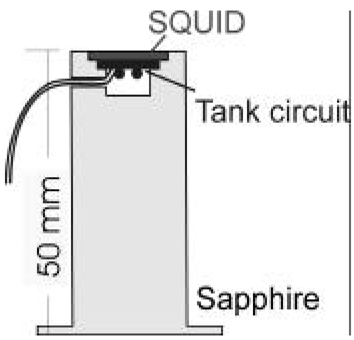


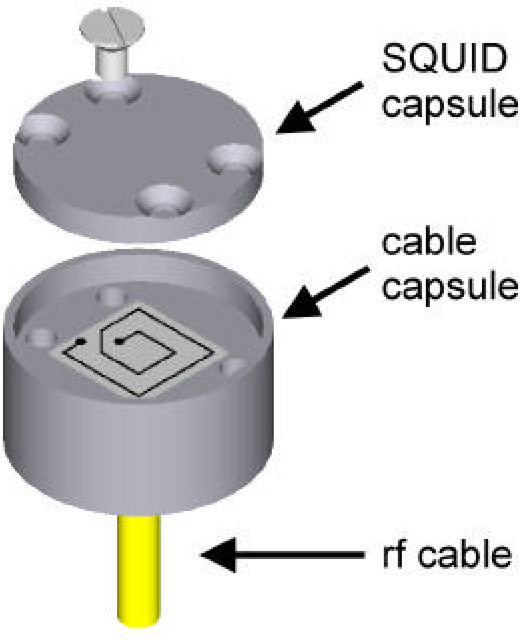
Fig. 10: left: complete cryostat
top right: sapphire finger with SQUID
bottom right: scheme of SQUID mounting

All NDE-setups use JSQ G900 SQUID gradiometers.

PRODUCTS

- SQUIDs by JSQ are very easy to handle, radiofrequency (rf) driven sensors for extremely low magnetic fields (present limit on selected sensors: 20 fT/√ Hz) and magnetic field gradients (< 1 pT/cm√Hz). These sensors are very fast. Therefore, a realtime measurement of rapidly changing magnetic fields (up to 1 MHz) becomes possible.
- The sensor material is superconducting YBaCuO, grown in thin films by a patented process. During operation, the sensors have to be cooled by liquid nitrogen (or cryocoolers). Due to the relatively high operation temperature (-198°C) compared to Low Temperature Superconductors (LTS), this material is called a High Temperature Superconductor (HTS).
- The sensors are fabricated by a modern lithographical process. Their unique design is protected by patents.
- JSQ offers these sensors complete with room temperature drive and read out electronics. The JSQ electronic control units run between 650 and 900 MHz. A completely computer controlled option (no manual adjustments needed) is available.
- The HTS rf-SQUIDs by JSQ are reliable, with fully guaranteed sensitivity and have demonstrated very stable performance.

We offer different magnetometer and gradiometer sensor packages. All sensor packages are sold together with a tuned and optimized dedicated electronic drive/readout unit, which we consider as the world's best rf–SQUID electronics:



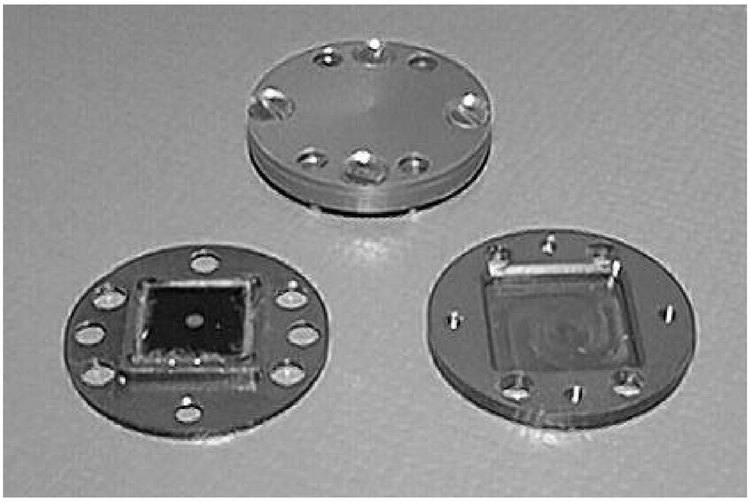


Fig. 11: JSQ SQUID capsule: left: complete capsule with rf cable
right: above: closed SQUID capsule
right below: opened SQUID capsule with resonator visible

Using SQUIDs in external fields

- In a magnetically shielded environment, all SQUIDs operate well.
- In the earth magnetic field, SQUIDs always work well, if they are mounted stable and free of vibrations.
- If SQUIDs move within the earth field or if SQUIDs sense rapidly changing fields, they may reach limits of operation.

Please take a look at figure 12.

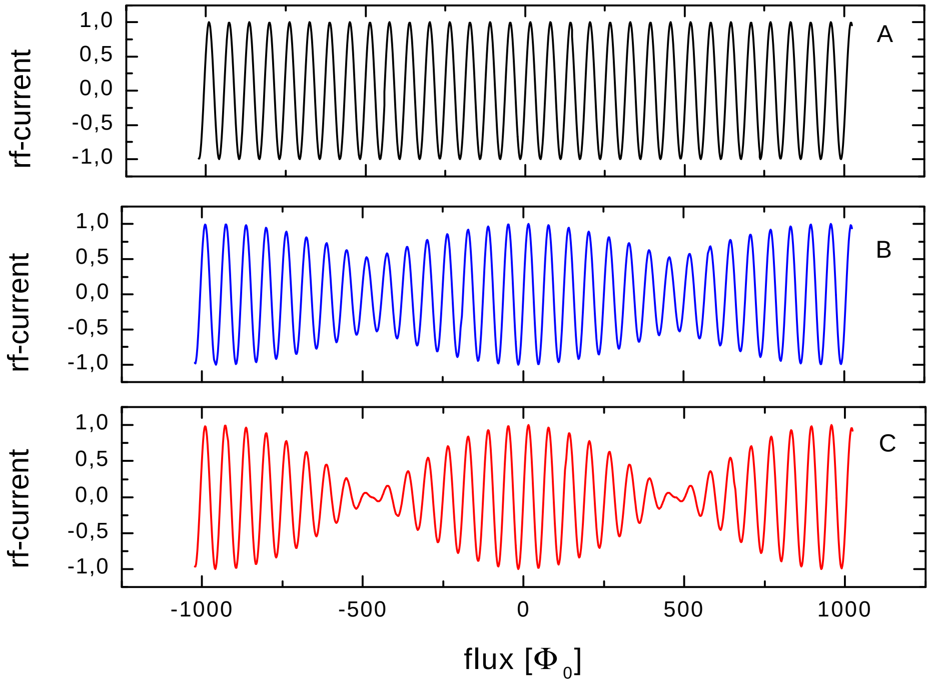


Fig. 12: rf-current patterns as a function of applied magnetic field for different SQUIDs

Sensor A is ideal - full stability maintained at all fields
Sensor B is still OK - it will work well at all shown fields
Sensor C has a problem at fields corresponding to fluxes of ±500 Φ_0 for example. It will not lock to the rf anymore. Nevertheless sensor C will work very well and with full sensitivity, if the external field changes are limited.

Standard Features

- All sensors are packaged and sealed
- All sensors are for operation immersed in liquid nitrogen
- Interconnecting cable to electronics unit provided
- M650 magnetometer with large circular flux concentrator
- M900 magnetometer with rectangular flux concentrator on chip 10 x 10 mm
- G900 planar gradiometer especially for NDE (material testing)
- G900 is designed for moving operation within the earth field
- D900 contains in one housing
  - one G900 gradiometer
  - one M900 magnetometer (without flux concentrator)
- D900 includes the cable to the electronics unit. Switching between G900 and M900 is accomplished by simply changing the pumping frequency at the electronics unit
- Standard electronics uses manual adjustments
  - Includes powersupply

Options

- Option: Sensor mounted in vaccum
  Needed for operation with cyrocoolers or position-independent operation (overhead, e.g.) in specialized cryostats
  We offer a complete NDE gradiometer system including
  - cryostat independent from orientation
  - sapphire cold finger for thermal anchoring of gradiometer G900
  - sensor mounted, wired and tested
  - test report

- Option: 0.8 Gauss operation
  Needed for magnetometers moving within the earth field
  - Note: G900 gradiometer is always specified for this mode of operation, no surcharge
    All M650 and M900 may be operated within the earth field, if stationary (not moving and not vibrating)

- Electronics: Option PC-remote control

- Electronics: Option Hand-panel remote control

- Electronics: Option Stand-alone microcontroller (automatically adjusts and controls 3 units and provides 3 analog outputs simultaneously)

The JSQ rf-SQUID Sensor Line

	Magnetometer		**Gradiometer planar type**	**Duo-Pack the magnetometer/gradiometer combination**	
	M650	**M900**	**G900**	**D900**	
	best sensitivity	best stability	for gradient detection	for system evaluation and education	
Field resolution @ 100 Hz	< 40 fT/√Hz	< 50 fT/√Hz	< 1 pT/cm√Hz	< 1 pT/√Hz	< 1 pT/cm√Hz
Field slew rate	> 2 mT/s	> 4 mT/s	> 7 mT/cm · s	> 10 mT/s	> 7 mT/cm · s
Flux concentrator	13.4 mm dia	8.5 x 8.5 mm^2	----	----	----
Field to flux transfer	1.8 - 3.1 nT/ϕ_0	2.6 - 3.9 nT/ϕ_0	7 nT/cm · ϕ_0	10 nT/ϕ_0	7 nT/ cm · ϕ_0
Balance	----	----	> 1000	----	> 200

Electronics	Model 650	Model 900
Tuning range (MHz)	410 - 750	tuning range 680 - 1050 MHz
Bandwidth	> 1 MHz	> 1 MHz
Dynamical Range	> ± 200 ϕ_0	> ± 200 ϕ_0
Output	> ± 10 V	> ± 10 V

SQUID Electronics

The model number of the electronics denotes to the highest adjustable frequency in MHz.

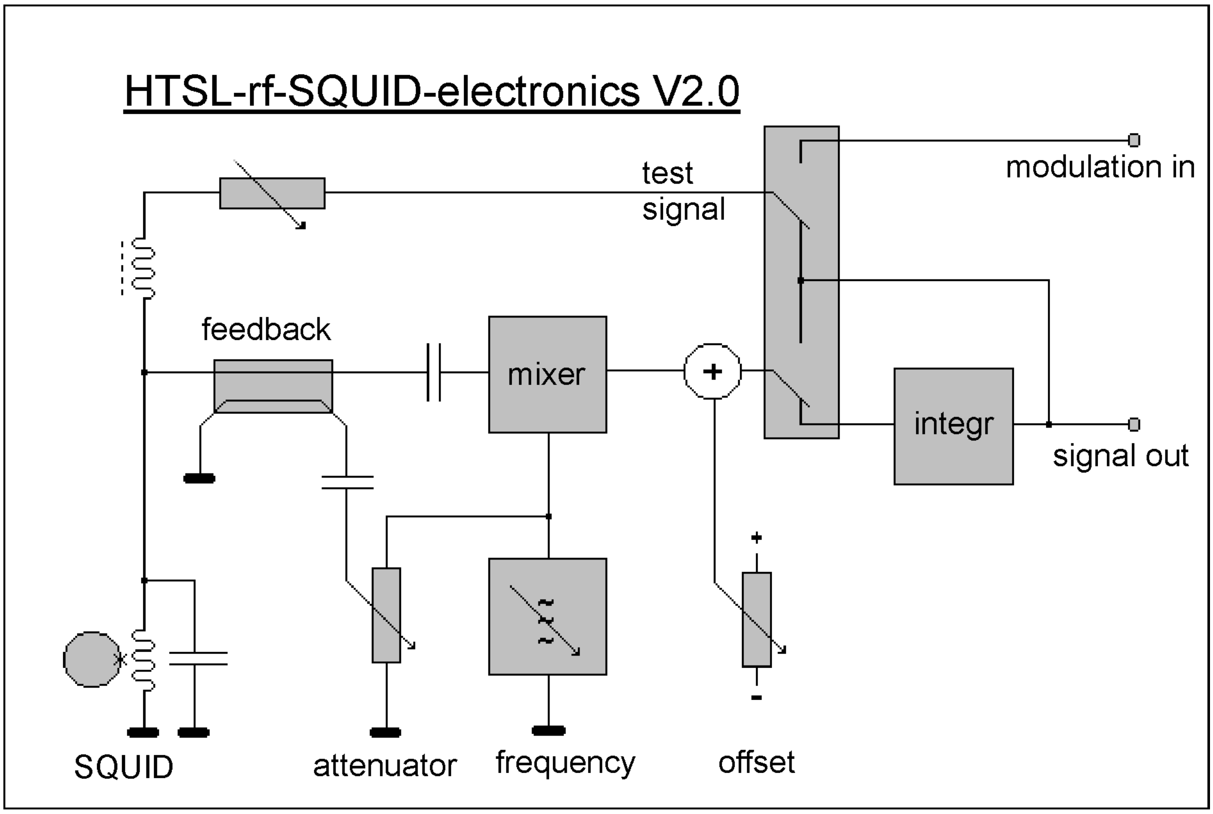


Fig. 13. Schematic of the JSQ HTS-rf-SQUID Electronics

Technical data: Model 900

case:	Aluminium (totally sealed)
size:	27x88x108 mm^3
weight:	520g
dc-power input:	+15V(70mA)/-15V(17mA)
RF-power output:	-75dBm to -115dBm (adjustable)
frequency:	650MHz to 1020MHz (adjustable)
signal output ampl.:	+/-10V
test output ampl.:	< 1Vpp
modulation input ampl.:	< 5Vpp

Jülicher SQUID GmbH (JSQ)

The Company

JSQ GmbH was founded by 28 employees of Research Center Jülich in May 1997. This team is responsible for the success of SQUID-projects realized at the research center under support of BMBF (German Ministry of Research). The worldwide unsurpassed experience of this team, including the SQUID-expert Prof. Dr. Yi Zhang and the direct connection with the research center are key factors for JSQ.
JSQ is located at Jülich and is operated according to German law. The company is managed by Dr. Ch. Buchal.

Newest Products

JSQ GmbH is producing and delivering HTS-SQUIDs and SQUID-Electronics according to the design developed and approved at Research Center Jülich. The products are low priced and of excellent, guaranteed quality. They are carefully tested and provide reliable performance.
JSQ GmbH offers an ensured basis of commercial supply of HTS-SQUIDs to its customers and partners. The production of HTS-SQUID-systems and components for products of other industrial partners are a long-term aim of JSQ GmbH.
All products are licensed developments of Research Center Jülich (Institute of Thin Film and Ion Technology). At present, JSQ is manufacturing exclusively in rented labs at Research Center Jülich. The production is performed by employees, who have also successfully developed the HTS-SQUID-systems at the research center. This close connection between development and production guarantees that the latest developments are available to our customers.

The JSQ team

Management:	Chris Buchal
Design:	Yi Zhang
Thin Film Technologies:	Jürgen Schubert, Willi Zander
Fabrication:	Marko Banzet
Electronics & Computing:	Ralf Otto, Norbert Wolters,
Systems:	Herbert Bousack, Rainer Hohmann, Jochen Krause
Machine Shop:	Jürgen Müller, Hans Wingens
Communication:	Inge Klaus, Susanne Muckel
Shipping:	Manfred Plum

How to contact JSQ

telephone:	(+ 49) 171 7 06 77 09
fax:	(+ 49) 24 61 61 46 73
e-mail:	*JSQ@jsquid.com*
mail:	JSQ GmbH, Lankenstr. 29, D-52428 Jülich, Germany

Please visit our website at: ***http://www.jsquid.com***