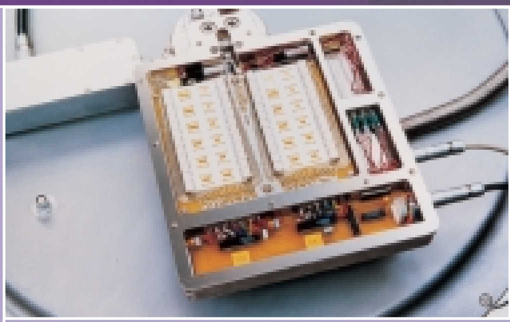
PRIMARY RESISTANCE STANDARD

QHR2000 A NEW STANDARD IN MEASUREMENT



- Comparison of the 100 Ohm standard with RK to 1 part in 10^8.
- Cryogenic Current Comparator (CCC) in separate low loss cryostat.
- Wide range of ratios for comparing resistances over the range 1 to 10k Ohm.
- CCC fully shielded with turns ratio accuracy of 10^{-10}.
- 14 Tesla magnet for ease of use.
- LabVIEW® software for automated operation, measurement and analysis.
- Integrated system with low He consumption.
- Full environmental shielding, a screened room is not necessary.

CRYOGENIC
CRYOGENIC LIMITED

INTRODUCTION

The Cryogenic Current Comparator (CCC) bridge is a breakthrough in the science of electrical measurement. It provides the ability to resolve and measure currents and resistance values to an accuracy of 10^{-9}.

The QHR2000 series of instruments was developed to meet the needs of standards laboratories around the world for a new level of accuracy in the calibration and maintenance of primary resistance standards.

The technology used in the QHR also opens up new possibilities for studying small signal effects in the presence of large backgrounds. The QHR2000 consists of two parts. The first is a Quantum Hall Resistance reference system which provides an absolute value of resistance related to the von Klitzing constant of 25812.807 Ohms. To provide this reference, a Quantum Hall semiconducting device is maintained at 0.3K with a He-3 refrigerator in a magnetic field of up to 14 Tesla, generated by a superconducting magnet. Under these conditions the Quantum Hall plateaux of resistance are easily obtained.

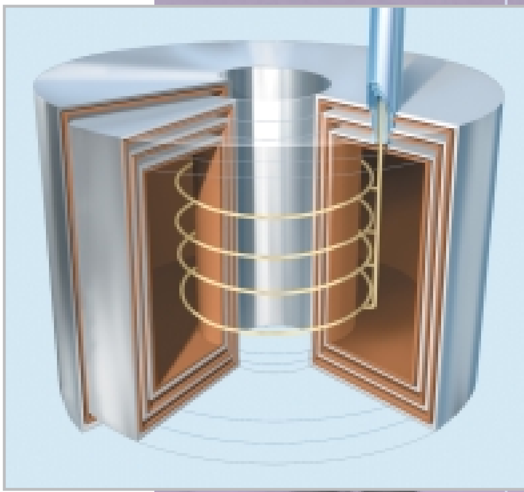
The second part is the CCC Bridge, which allows two independent and isolated currents of different values to be compared and controlled with an accuracy of better than 10^{-9}. The CCC forms part of a bridge circuit driving current into the two resistors which are to be compared. The differential voltage is detected with a sensitive nanovoltmeter.

The QHR2000 can be supplied as a full turn-key system for metrology purposes. For all applications, components such as the CCC bridge can be supplied as an independent instrument.

CCC

THE CRYOGENIC CURRENT COMPARATOR (CCC)

The CCC is a remarkable device which uses the shielding properties of a superconductor to make it possible to balance and control DC currents to very high precision.



The Cryogenic Current Comparator showing the single toroidal screen which encloses the coils by wrapping round itself 3 times without any electrical contact between the layers.

There are two geometries used in the CCC. As shown in this diagram the drive coils are internal to the shield. There is an alternative design in which the detector coil is internal to the shield. For the internal drive coil the currents are fed to two coils enclosed in the toroidal superconducting shield. The shield is not a closed loop but is designed in such a way that the magnetic field escaping from the shield depends only on the ampere turns of the coil inside the shield and not on the coil's position or size.

Thus, two coils with equal and opposite ampere turns generate no external field. A Superconducting Quantum Interference Device (SQUID) is used to detect the presence of external field and feedback is used to control the currents to ensure their accurate balance.

With up to 24 coils enclosed in a single shield, it is possible to produce many different current ratios and to hold all of them to high precision. In the CCC, current ratios of up to 200:1 can easily be produced. The ratios must of course be made up from a series of integer turn coils.

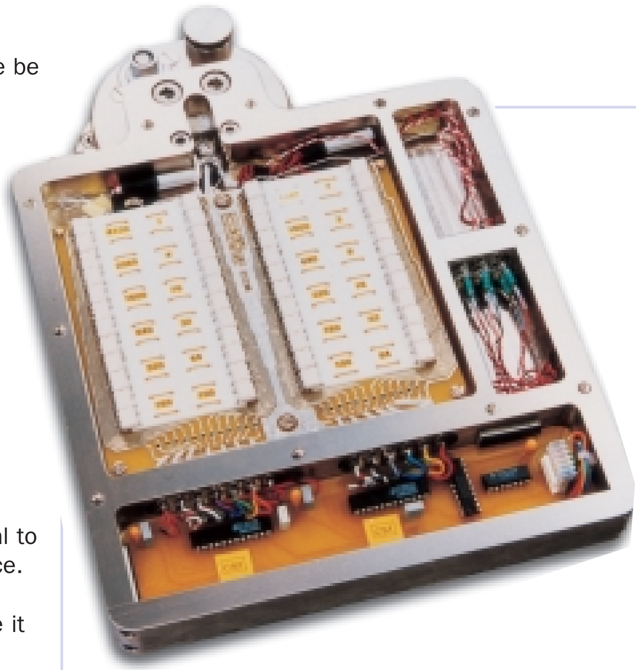
The standard instrument controls and compares currents within the range of 50 milliamps to 10 microamps, all with similar accuracy. Other current ranges are possible. Tests on the CCC have shown that the turns ratio errors are maintained to better than 10^{-10} absolute accuracy. This level of absolute accuracy is unprecedented in any analogue device with DC currents.

As with any SQUID system it is essential to avoid magnetic noise and RF interference. Great care is taken in the design of the CCC and its associated circuits to make it proof against externally or internally generated interference. As a result the QHR2000 can operate independently of a screened room.

The CCC is supplied complete with its own current sources and the SQUID electronics. The probe itself is well shielded from magnetic and RF interference. The isolation of all the windings and their connections are maintained to the very high level required for metrology.

The whole Cryogenic Current Comparator is engineered to be flexible in use, easy to understand and simple to operate, while at the same time maintaining the highest level of measurement precision. The device including the SQUID null detector is mounted into a single probe is installed in a special low loss cryostat.

To make coil selection easy the system uses reed relays to select the coils but they can also be replaced by links for test purposes. The selector relays are mounted at the cryostat head as shown in the illustration of the prototype unit.



Coil Selector

CCC

circuit

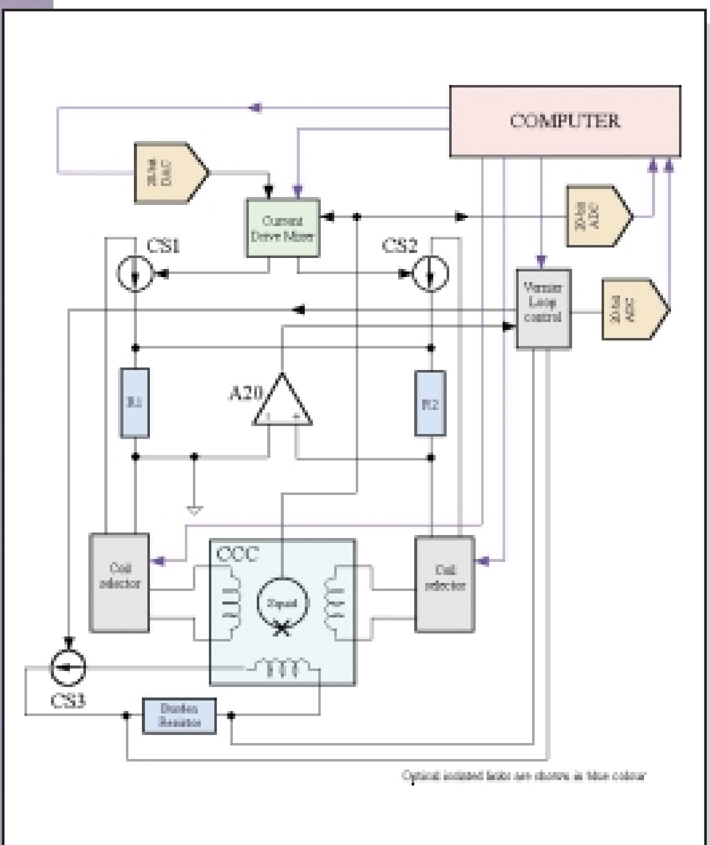
THE BRIDGE CIRCUIT

The DC bridge circuit is shown in the illustration. It consists of two fully isolated power supplies, CS1 and CS2 providing currents to the two resistors under test. The currents in CS1 and CS2 are set to first order from the computer in the appropriate ratio for the resistive elements of the bridge. Precise control within the limits of the CCC to 10^{-9} or better is provided by feedback from the SQUID output. The resistors can be just two resistors of the same or different values, a resistor and a QHE device or even two QHE devices for comparison of their performance.

Measurements are carried out under computer control with the currents ramped to a pre-set value, both positive and negative, where they are held constant with sufficiently low noise and drift to allow very precise measurements to be made. The currents are normally chosen to provide a voltage drop of 0.3 volts across the 100 ohms test resistors. The nanovolt amplifier is capable of very low level measurements so as to provide the resolution required. The voltage measured across the bridge by the nanovolt meter represents the difference in the value of the two resistors after allowing for the current ratios of the CCC.

To obtain accurate results for metrological purposes an alternative arrangement is preferred. A third current is added to a single turn in the CCC which gives a null voltage across the bridge. The third current then represents the difference of the resistance values. Its value can be accurately determined.

Repeating the measurement by reversing the current to positive and negative values for several cycles allows the elimination of thermo-electric offsets and gives a statistical estimate of the random error.



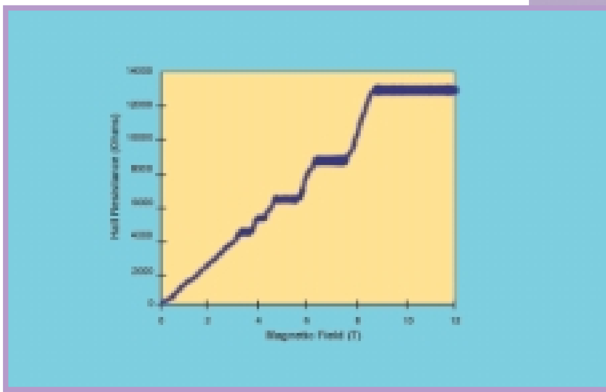
The nanovoltmeter and all current sources are given isolated power sources. Fibre optic cables are used between the computer and the current sources to ensure that the bridge is both isolated and free from RFI and other noise sources. The nanovolt detection circuit is similarly isolated.

It is particularly important that, where the bridge is used for metrology applications, it should be possible for the user to carry out independent checks on all aspects of the system, to guard against unexpected systematic errors. For routine measurements, calibrating a batch of resistors, it is appropriate to use a form of scanner circuit. Scanners allow collection of data from several resistors automatically under computer control.

standard

THE QUANTUM HALL STANDARD

The QHR2000 uses the Quantum Hall Effect (QHE) to provide an absolute value of resistance which is dependent only on the value of Planck's constant and that of the electron charge. This value is known as the von Klitzing constant and is taken as 25812.807 Ohms.



The quantised Hall resistance as a function of magnetic field, with an excitation current of 10 μA.

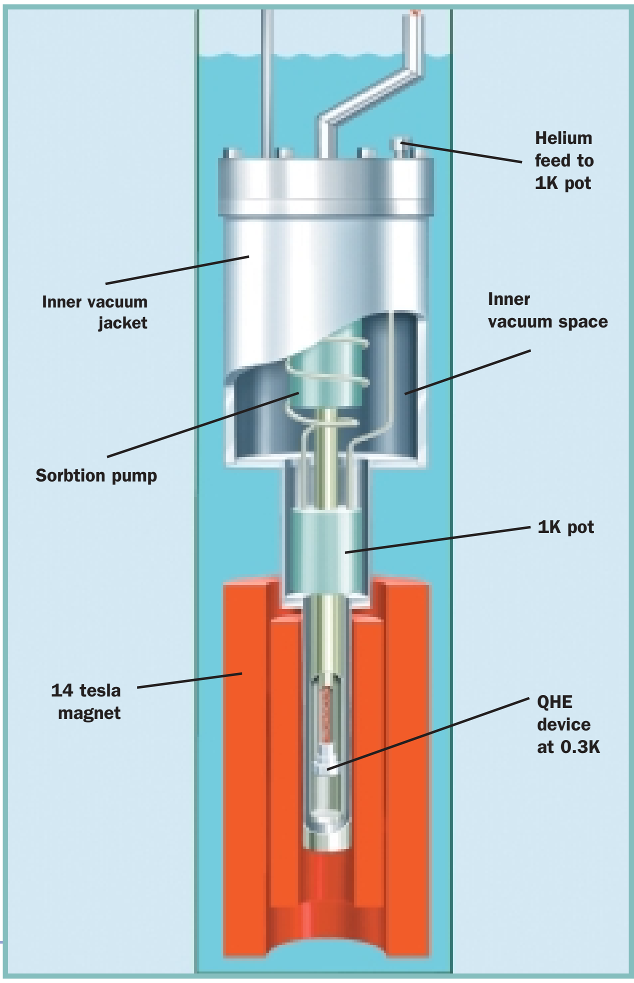
Measurements are made to characterise the QHE devices using the standard software of the QHR 2000. A typical set of plateaux is shown. The linearity of the 2 and 4 plateaux can readily be seen. For resistance characterisation the n=2 and n=4 plateaux are used giving resistance values of 12906.4035 Ohms and 6453.2017 Ohms.

A low contact and forward resistance is also important, as it means that the geometry of the Hall probe leads will not affect the Quantum Hall Resistance. The QHR2000 allows measurement of the forward voltage along the device. At the centre of the plateaux it should be zero.

The use of the two plateaux gives added security to the reliability of the measurement as it provides a further independent check for systematic errors.

The QHR2000 can use any suitable QHE device mounted on a standard connector. Cryogenic Ltd will normally provide a GaAs high mobility device from a well established source.

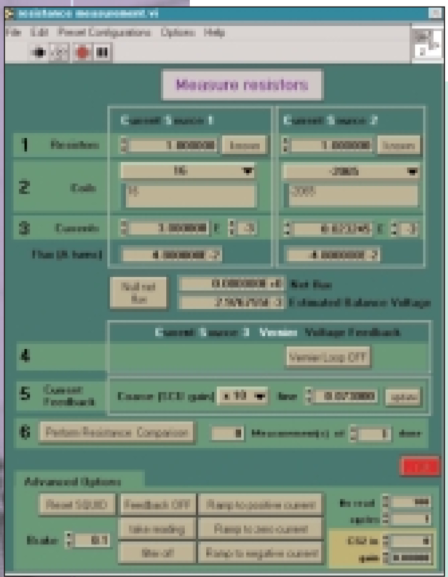
To provide the best and most versatile performance, the QHR2000 is equipped with a closed cycle He-3 refrigerator to produce an operating temperature of 0.3K for the QHE device. The steps are present at 1K and for some samples this may be sufficient.



QHR2000 He-3 refrigerator and superconducting magnet assembly

automation

AUTOMATION AND SOFTWARE



The control system for the QHR2000 and the CCC uses the well established and flexible LabVIEW® software running in a fast Pentium based computer. National Instrument IEEE and data acquisition cards are fitted to ensure a high level of reliability.

The LabVIEW® software allows an open measurement structure to be developed. The software is graphical and is composed using icons for functions. Virtual Instruments are called up on the screen which graphically display the logical structure of the program. Program development is by drawing new logical structures on the screen rather than by writing line by line code. This process is far faster and more secure, as well as more user friendly than older programming systems. It makes the QHR2000 that much easier to use.

The open software structure allows the metrologist to oversee the program and to control the instrument's operation, reducing the possibility of undetected systematic errors.

All functions of the system, including operation of the He-3 refrigerator can be controlled from the computer. Individual VI windows allow the magnetic field to be set to a fixed value or swept to display the plateaux in the Quantum Hall voltage. Other VI's such as those shown allow set-up of the system and analysis of the data collected.

specification

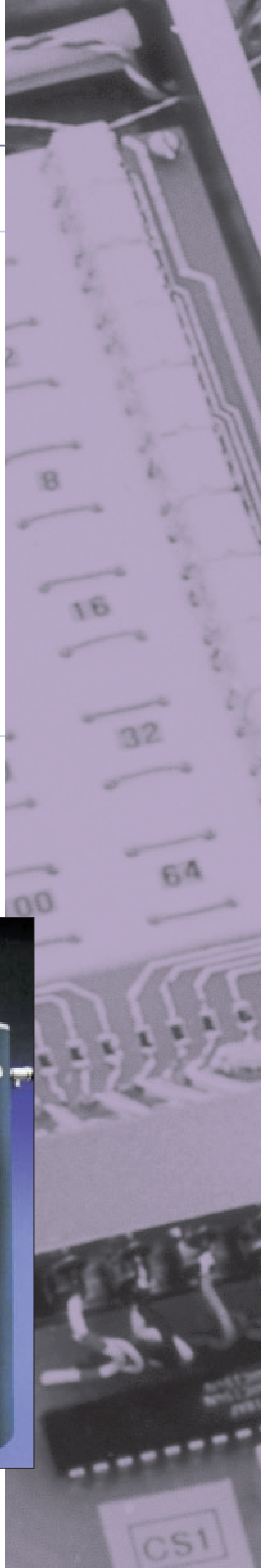
TECHNICAL SPECIFICATION

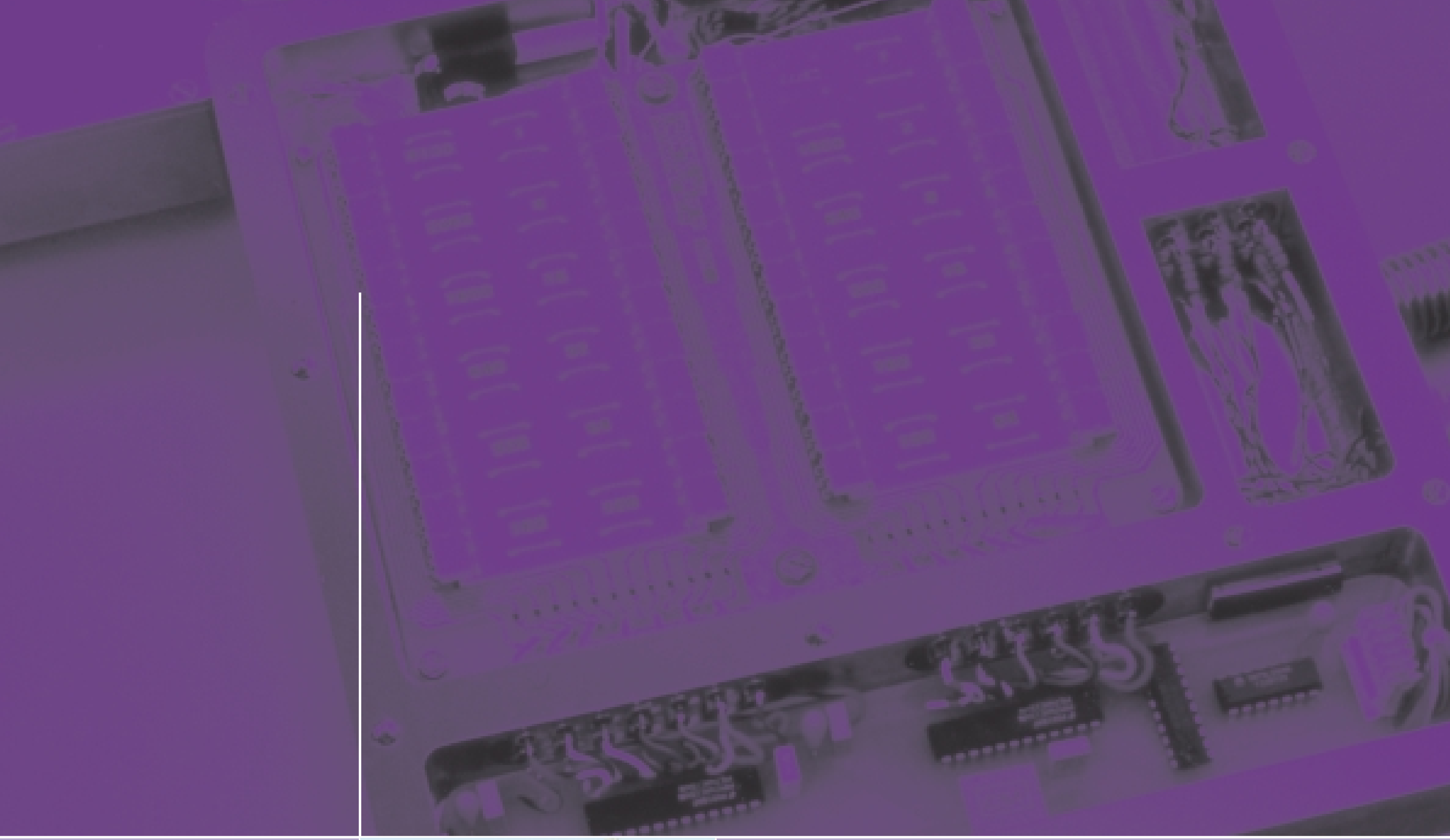
Typical System Specifications	
Primary resistance standard:	100 Ohm
Accuracy of determination to the von Klitzing constant:	10^{-8}
Systematic error determination by reference to NPL standard:	+/- $3x10^{-8}$
or by special option:	+/- $1x10^{-8}$
System isolation better than (dry conditions 20°C ambient temperature):	1000 Gigaohm
Helium consumption:	3 litres per day
Helium hold time:	30 days
Typical measurement sequence time:	25 minutes
Cryogenic Current Comparator Bridge	
Typical Coil sets included:	1,1,1,2,4,8,16,16,32, 32,64,64,100,100,160, 160,320,320,640,640, 1600,1600,2065,4130
Ratio self calibration accuracy:	10^{-10}
Gain factor to SQUID:	5000 Volts/Ampere-turns
Noise level:	1.5 x 10^{-9} Ampere-turns
Normal operating ampere turns:	96 milliamp turns
Maximum operating ampere turns (coil set):	10,000 milliamp turns
Maximum available current:	50 milliamp
Sweep ramp rate (typical coil set):	50 milliamp turns / second

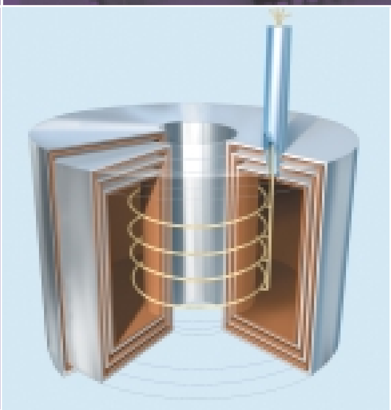
For confirmation of the latest specification, please contact our sales department.

Rigorous test procedures are applied during all stages of manufacture with particular care given to the key electronic and cryogenic components. An error budget is produced and evaluated for each system. As the units are produced in series, Cryogenic applies a policy of continuing product improvement and development, in collaboration with research institutes such as the UK National Physical Laboratory.

Formal tests are carried out in our works followed by a full evaluation at the National Physical Laboratory (NPL) in London.
The systematic and random errors are assessed. Comparisons are also made to the NPL calibrated values. Clients are welcome to attend these tests to have the best understanding of the system and to receive initial training in its operation.
All systems are installed at the customers facility by our own engineers who provide training for local personnel and ensure that the system is fully operational on-site to the standards required for metrological applications.







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