

# SC22 Magnetic Field Cancelling System

## *User Manual*

*December 2008*

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This manual applies to SC22 Firmware version 1.06.xx

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# 1. Safety and Certifications

## 1.1 Environmental conditions.

The SC22 is designed to be safe (but not necessarily meet its performance specification) at least under the following environmental conditions:

- indoor use
- altitude up to 2000 metres
- temperature 5°C to 40°C
- maximum relative humidity 80% up to 31°C, decreasing linearly to 50% at 40°C
- supply voltage fluctuations not exceeding +10% -20% of the nominal voltage
- transient overvoltage, installation category II
- pollution degree 2 (IEC 664)

## 1.2 Other conditions of use.

- this User Manual must be read before operating the SC22
- the SC22 must only be used for its designed purpose as described in this manual
- if the SC22 is used in a manner not specified in this manual, the protection provided by the equipment may be impaired
- the SC22 must be grounded (earthed) using the power cable supplied
- dangerous voltages are present inside the SC22 control unit, it should only be opened by trained electrical engineers or technicians
- the SC22 must not be installed in a manner that prevents access to the power switch and power cable on the back panel, the heat sink on the back panel must not be covered.
- the connectors on the SC22 back panel labelled "X FIELD CABLE, Y FIELD CABLE, and Z FIELD CABLE" must be connected only to field cables of the type supplied by Spicer Consulting which have a minimum insulation rating of 250V RMS AC
- the field cancelling cables must not be damaged during installation enabling external power sources to connect to the cable screening or inner cores via such damage
- the connector on the back panel labelled "FIELD SENSOR" must only be connected to the correct sensor products supplied by Spicer Consulting
- the outside of the SC22 may be cleaned, if required, with a soft cloth dampened with water
- if the magnetic field sensor is mounted on any area which is heated for maintenance e.g. on an electron gun which is baked at 300°C, it must be removed before the heating operation is performed

## 1.3 Declaration of conformity

- This product is certified to comply with the European Low Voltage Directive according to BS EN 61010-1
- This product is certified to comply with BS EN 50081-1  
Electromagnetic Compatibility - Generic emission standard  
Part 1. Residential, commercial and light industrial.
- This product is certified to comply with BS EN 50082-1  
Electromagnetic Compatibility - Generic immunity standard  
Part 1. Residential, commercial and light industrial.

This declaration is made by Spicer Consulting Ltd. the manufacturer of the apparatus, at Eden Laboratory, Broadmead Road, Stewartby, Bedfordshire, England. MK43 9ND

## 2. Quick start instructions

For users who are familiar with other Spicer Consulting Field Cancelling products the following instructions should enable quick installation of an SC22 system.

- 2.1 Decide the location for the X, Y & Z field cancelling cables and install them in the room (Figs 2 or 3) or on the Helmholtz frame (appendix 2). Note the X, Y & Z cable loops must be orthogonal.
- 2.2 Position the magnetic field sensor on the EBeam tool (typically bottom of the column). Align the sensor with the field vectors on its label orthogonal to the cable loops.
- 2.3 Plug the sensor and the X, Y & Z cables into the back of the SC22 control unit.
- 2.4 Plug the power cable into the back of the SC22 control unit and into a suitable power outlet.
- 2.5 Turn the SC22 on with the power switch on the back panel adjacent to the power cord IEC inlet.
- 2.6 The front panel display will light and display within about 5 seconds
- 2.7 Follow the instructions on the front panel display to setup the system
- 2.8 After setup, check that the green FIELD OK indicator on the display is present
- 2.9 Look at the EBeam tool image to see that the field disturbance has been removed or reduced by the field cancelling.
- 3.0 If further image improvement is required, optimise the sensor position. After each time you move the sensor, press the "SETUP" button and follow the displayed instructions.

You can change the units of the magnetic field measurement by pressing the "UNITS" button on the front panel. (This button has no effect on cancelling and can be pressed at any time.) A pop up window will appear with a list of units. Each press of the units button moves the cursor to the next unit on the list. Stop pressing when you reach the chosen units.

You can turn the field cancelling on and off by pressing the "CANCEL-STANDBY" button on the front panel and following the instructions on the display panel.

**Note: Please do not use the power switch on the back panel for this purpose.**

### 3. Product Description

The SC22 is a fourth generation Magnetic Field Cancelling System, designed to improve the performance of electronic instruments that are sensitive to magnetic fields, such as electron microscopes and electron beam metrology tools. The SC22 is an enhanced replacement for the SC12 system, which has an installed base of over 1000 units world wide.

It is important to note that mechanical vibration, acoustic noise and ground loops in the electron beam tool installation can produce imaging defects similar to magnetic fields. The SC22 cannot remove or improve image defects that are not caused by magnetic fields.

Fig. 1. Control Unit



The SC22 system comprises a Magnetic Field Control Unit (Fig. 1) an AC Magnetic Field Sensor and three multicore cables, which are installed in the room where the field is to be cancelled. The Control Unit power amplifiers drive currents through the cables to create a field which is the opposite sign to the changes in the ambient field. The magnetic field sensor measures the resulting field and real time negative feedback reduces the changing magnetic field by the loop gain of the system. The system is dynamic, automatically responding to field changes within 100  $\mu$ s.

A typical SC22 system installation on an SEM is shown in Fig. 2. The control unit is not shown. The cables make one turn and are shown in red, green and blue. The actual cables are grey or black and usually installed in white plastic conduits. Where the room has a false ceiling, the Z cable is usually installed above it. The magnetic field sensor is located close to the bottom of the electron beam column. An optional mount enables it to be strapped to the column if required.

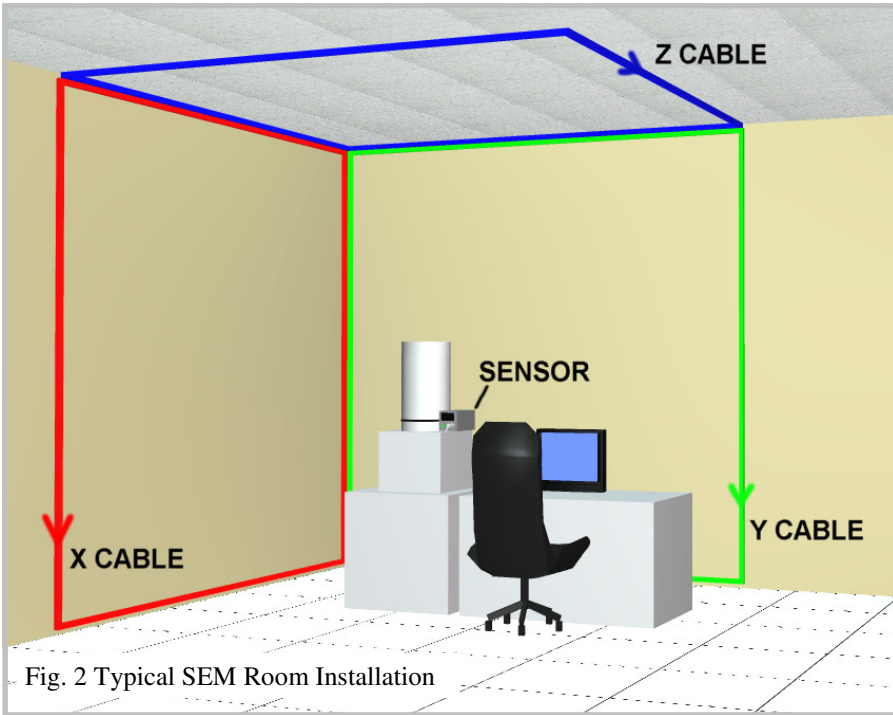


Fig. 2 Typical SEM Room Installation

The amount by which the field is reduced is determined by the loop gain of the system, which is automatically set by the SC22 to 50 times. The system does not cancel DC magnetic fields, including changes in the earth's field (the larger SC20 system does) nor does it cancel the field everywhere in the room. It creates a region around the magnetic field sensor where the AC field is much reduced. The volume of this region depends mostly on the gradient of the ambient field and the positioning of the field cables.

The maximum field that the SC22 can cancel is called the "Dynamic Range" and it depends on the details of the field cable installation. To specify the dynamic range and the other SC22 performance parameters rigorously, we use a reference room cable installation that is shown in Fig. 3. The electron beam column is centred in the 3m x 5m X and Y loops (which cross over above and below the column) and the 5m x 5m Z loop. The Fig. 3 installation is recommended if the field to be cancelled is bigger than 20 mG pk-pk. The dynamic range with this installation is 60 mG pk-pk on the X & Y axes and 35 mG pk-pk on the Z axis.

The SC22 control unit measures and displays the amplitudes of the X, Y & Z field components and the total vector field on its LCD panel. Tesla and Gauss units, RMS & pk-pk can be selected. The measuring system can resolve 1µG (100 pT) field changes. The real-time measured fields are available on front panel BNC's as analog voltage levels for oscilloscope display.



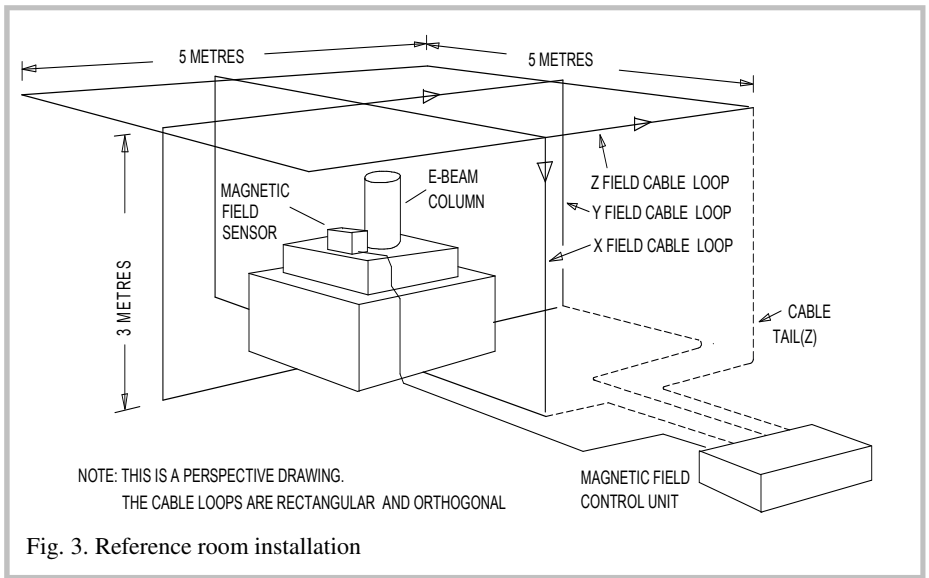


Fig. 3. Reference room installation

The magnetic field amplitude is continuously monitored and compared with preset “trip levels” to provide “GO/NOGO” indication of the field quality. The LCD panel and a small green LED on the sensor indicate that the field is “OK”.

The SC22 controls are much simpler than the older SC12 system and are supervised by an embedded microcomputer. The microcomputer user interface communicates through the 3.5 inch colour TFT display on the SC22 front panel in Fig. 1. Examples of the display images are in section 6 of this manual. There are just 3 control buttons on the front panel in Fig. 1. The “units” button enables choice of the displayed field units. It has no effect on field cancelling. The “setup” button starts a 4 second program that measures and sets the gain and phase of the feedback loop. The “cancel/standby” button turns cancelling on and off.

## 4. The microcomputer user interface

### 4.1 Operation following power loss.

The SC22 remembers all the details of its operating state. When power is restored it resumes operation in the remembered state, including whether it is cancelling or on standby. At power up, the SC22 checks the installation. If it was cancelling before power down and the setup has not changed, it resumes cancelling. If it finds the installation has changed, the SC22 displays “Setup req” in the top left corner of the screen and “System setup required” at the bottom of the screen. In this state, it requires operator intervention before it will start cancelling.

### 4.2 Sensor and Cable Detection

The SC22 detects the presence of the AC Sensor and X, Y and Z cables when they are plugged in. If no sensor is connected, a message “No AC sensor detected” appears at the bottom of the screen. If you plug in a DC sensor or a mixer with only one sensor connected, the SC22 displays “Incorrect Sensor Configuration”. If any cable is not detected, an indicator appears to the left of the relevant channel display, for example “No X cable”. If there is an AC sensor, but no cables, a message says “No cancelling cables detected”.

### 4.3 Setting up the SC22

The system will only run its setup program if the AC sensor and at least one field cable are plugged in. If it is run with only 1 or 2 field cables it will have to be run again later with all 3.

In the “Setup required” state, the SC22 measures fields and allows you to change the units of the display using the UNITS button, but it does not cancel fields and the CANCEL/STANDBY button is inactive. Before it can cancel, you must press the SETUP button to instruct the SC22 to configure its internal gain and phase controls.

To run setup, press and hold the SETUP button for 2.5 seconds. The delay on this button is to lessen the risk of accidental use. When you release the SETUP button, the system automatically tests the gain and phase of each channel. After about 4 seconds, you will see either the Setup Results or the Setup Errors screen. If you see the Setup Warnings screen, then press the SETUP button to view the Setup Results screen. Warnings are listed in Section 7.2.

The Setup Results screen looks like this.

Channel	Gain	XY Swap
X	+1.0	X
Y	+1.0	Y
Z	+1.0	

The Setup Results screen shows what internal phase and gain the SC22 microcomputer has set to achieve negative feedback with a cancelling factor of 50 times. The phase is indicated by a positive or negative value for the gain.

If you have installed all the cables with their arrows in the direction shown in Fig. 2 or Fig. 3, then the gains will all be positive. If you have installed any cable in the opposite direction, then the system automatically changes the phase and shows the gain as negative. The size of the gain would be 1.0 for the reference cable installation of Fig. 3. It will be set higher to allow for the reduced field generated by the Fig. 2 installation with the cables on the walls. The normal range is 0.25 to 4.0.

In addition, the SC22 can correct for a swap of the X and Y cables (or a 90 degree rotation of the sensor). The normal result is shown with X and Y in white. When they are swapped, Y and X are shown in red.

After you have viewed the Setup results, press the SETUP button again to start cancelling.

If the microcomputer detects a serious problem during setup the Setup Errors screen will be displayed. A listing of the errors it can detect is in Section 7.2.

#### **4.4 Cancel/Standby**

Once the SC22 is set up, the CANCEL/STANDBY button enables and disables cancelling. When the SC22 is cancelling, press the button momentarily to momentarily interrupt cancelling. The yellow “Standby” light appears in the top left corner of the screen. If you hold the button for more than 2.5 seconds, the “Standby” light turns red to indicate that it has latched permanently. You can now release the button and the system will remain in standby mode. To re-enable cancelling, press the CANCEL/STANDBY button again. A message at the bottom of the screen indicates whether the system is cancelling or in standby.

#### **4.5 Measurement Units**

The UNITS button allows you to set the magnetic field units for the X, Y, Z and Total Field displays. Press the button once to display the list of options. Press it again to move to the next item on the list. Release the button for 1.5 seconds to accept the current units. The current units are shown in the top right corner of the screen. This button affects the display only – it has no effect on cancelling. The available options are as follows:

mG RMS	MilliGauss Root Mean Square
mG Pk-Pk	MilliGauss Peak to Peak
nT RMS	NanoTesla Root Mean Square
nT Pk-Pk	NanoTesla Peak to Peak
uT RMS	MicroTesla Root Mean Square
uT Pk-Pk	MicroTesla Peak to Peak

#### **4.6 Field Ok and Trip Indication**

When the SC22 is set up and cancelling, the “Field Ok” light should come on in the top left corner of the screen. This indicates that the RMS field on all cancelling channels is below the factory preset trip level of 0.25 mG (25 nT) RMS. If the field exceeds this level on any channel, the “TRIP” light by that channel comes on. It stays on for 1 minute and then clears automatically if the field is then below the trip level. This is to enable transient bad fields to be detected. If any channel trips, the “Field Ok” light turns off, but it comes on again as soon as the field falls below the trip level on all channels, even though the “TRIP” lights stay on for longer. The “Field Ok” light on the magnetic field sensor comes on at the same time as the “Field Ok” light on the screen.

#### **4.7 Clipping and Oscillation**

A field on any channel greater than 40 mG pk-pk (4 uT pk-pk) is too large for the ADC in the SC22 to measure. If this happens when the system is not cancelling, the SC22 displays a “CLIP” light by the channel, to indicate that the field value on the display is incorrect (it’s typically smaller than the true value).

If a field on any channel greater than 10 mG pk-pk (1 uT pk-pk) occurs while cancelling, the SC22 concludes that the channel is oscillating. This is possible if the sensor has been moved or rotated after setup. In this case the SC22 displays “OSC” by the channel. If this condition occurs continuously for more than 1 minute, the SC22 automatically stops cancelling and goes into the “Setup Required” state.

If clipping is detected during setup (section 4.3) the loop gain set by the microcomputer will be less accurate but still within  $\pm 10\%$  for fields up to 60 mG pk-pk (6 uT pk-pk).

## 5. Installation

Usually, the SC22 system will be installed by Spicer Consulting staff or our agents who have been trained in installation. It is not a good idea to delegate the installation to electrical contractors because the SC22 system is not an electrical power installation. The field cables carry a maximum of  $\pm 20$  Volts and  $\pm 0.8$  Amps/core. Correct functioning of the system depends on correct placement of the field cables and the sensors, factors which are generally of no concern to electrical contractors.

Usually, the SC22 installation is best done after the electron microscope is installed and operational. Installation in an empty room is possible (and for sales demonstrations is sometimes done) but the purpose of using field cancelling is to improve the performance of the electron microscope. The best installations take account of the positioning of the microscope in the room and the fields which were measured in the pre-installation survey. Also, optimising the sensor position requires the electron microscope to be operating to observe the effect of the magnetic field on its image.

### 5.1 Control unit installation

There is considerable flexibility in siting the SC22 control unit. It can be located on part of the microscope console (preferred for TEM installations) or elsewhere in the room. A location close to the column or the sensor should be avoided. The power supply in the SC22 control unit uses a high quality toroidal transformer for minimum magnetic field radiation but there is no sense in making the fields worse by any amount. The installer should refer to section 5.3 to ensure that the field cable tails can reach the control unit.

*Do not install the control unit on top of heat sources.*

*Do not cover the top of the control unit or the rear heat sink.*

### 5.2 Power connection

The Magnetic Field Control Unit should be connected to a suitable source of AC power using the power cable supplied. The AC power source must provide a ground (earth) connection to the unit via the power cable.

*No responsibility is assumed by the manufacturer or the supplier of the unit for damage, injury or malfunction of any kind resulting from operation without a correct ground (earth) connection.*

The power input socket is on the back of the unit at the left with the power input switch beside it. The SC22 can be operated from two AC power voltage ranges:

120 V - for operation from 96 volts to 132 volts RMS at 50 Hz or 60 Hz

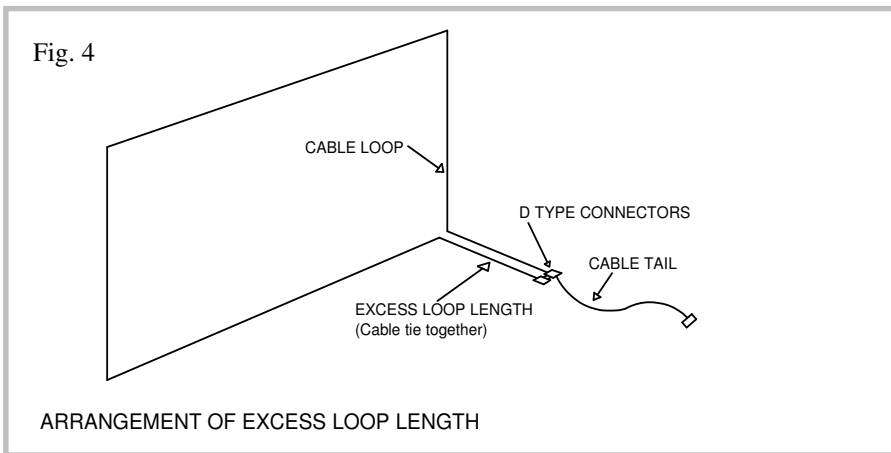
240 V - for operation from 192 volts to 264 volts RMS at 50 Hz or 60 Hz

The SC22 measures the AC power to determine the correct range to use. If the measurement is within the 120 Volt limits, it switches to 120 Volt operation two seconds after power up.

### 5.3 Field cable installation

Most installations are similar to Fig. 2. The field cancelling cables are manufactured with a loop and a tail. The loop parts are shown in Fig. 2 in red, green and blue. The loop creates the field and the tail (which makes no field) connects the loop to the control unit. The cables have 15 pin D type connectors which plug together to form the loop. The standard “room” cables have X and Y loops 16 metres long and a Z loop 20 metres long. The tails are 7 metres long. The cable loops should not be shortened. Excess loop length should be treated as in Fig 4. Longer cables are available to special order.

The X, Y and Z cables must be orthogonal (i.e. at right angles to each other). The X, Y and Z field vectors on the magnetic field sensor front label will be aligned to the cable axes. It is OK for the mechanical axes of the electron beam tool to be at any angle to the cables and the room walls.



The Fig. 2 installation is suitable for most SEM applications where the electron beam column is 1 to 2 metres from the room walls. The maximum field which can be cancelled (the dynamic range) depends on the size and position of the cable loops relative to the electron beam column. With 5m x 3m X and Y loops and the column 1.5 m from the walls the dynamic range is about 30 mG ( $3 \mu\text{T}$ ) pk-pk. The SC22 field cables are supplied with a pack of self adhesive fixing clips which can be used to fix the field cables to surfaces. These are suitable for temporary or experimental cable installations but are unsightly.

Permanent neat installations are best done with white plastic rectangular trunking (e.g. the “Coiled Mini-trunking” manufactured by Mita UK Ltd, available from RS on stock No. 202-9514, which comes in 12 metre coils and is easily cut to length on site.)

If the field to be cancelled is large ( $>20$  mG pk-pk), the Fig 3 installation should be used. There are many actual installations done this way using the earlier SC12 field cancelling system. The practical disadvantage of this installation is that parts of the cables run across the floor. This is particularly disliked by architects and health and safety officers. (Electron microscope users generally are not bothered because their microscope probably has many cables running across the floor anyway.) Cables on the floor can be protected with rubber cable protectors which can be glued down to minimise the tripping hazard. There are no dangerous voltages in the field cancelling cables. Fortunately, the alternative Fig. 2 installation, which mostly eliminates cables on the floor, has sufficient dynamic range for most fields encountered.

When the room is large or in clean rooms where there are no local walls, alternative cable installations are possible. One option is to install Helmholtz cables on a frame around the microscope. Most electron beam tools used in clean rooms are built inside their own enclosures that can be used to support the Helmholtz cables, so a separate frame is not necessary. The SC22 Helmholtz cables are thinner than the standard “room” cables and have less cores. OEM customers who wish to build the SC22 system into their electron beam tool should consult Spicer Consulting staff for applications support. Information about Helmholtz cables and frames is in appendix 2.

Recently, large TEM’s have been developed with astonishing performance employing electron monochromators, aberration correctors and electron energy loss spectrometers. The electron beam columns on these instruments can be over 2 metres long. However, their performance can only be achieved in a very low ambient magnetic field. To achieve field cancelling to a low enough level over the length of the column requires the use of large room sized Helmholtz coils. These are described in Appendix 3.

#### **5.4 Sensor installation**

The SC22 magnetic field sensor is shown in Fig. 5. and installed on an SEM in Fig. 6. At the start of the installation, an initial location for the sensor should be chosen. This location should be the best estimate of where the field needs to be cancelled. The sensor is typically located at the base of the column or strapped to it using the optional mount in Fig. 7.

The HX field vector arrow on the sensor label should be orthogonal (i.e. at right angles) to the plane of the X cable. However, if the sensor is rotated 90 degrees the SC22 system microcomputer will detect this during setup and swap the X and Y axes.



Fig. 5 SC22 AC Sensor

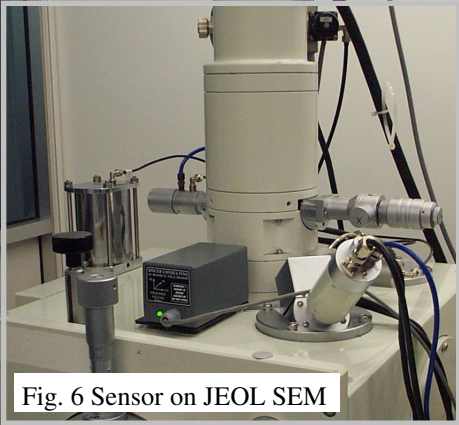


Fig. 6 Sensor on JEOL SEM

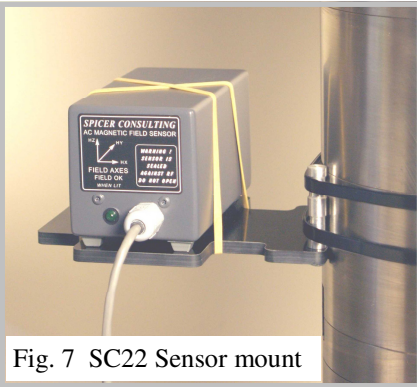


Fig. 7 SC22 Sensor mount

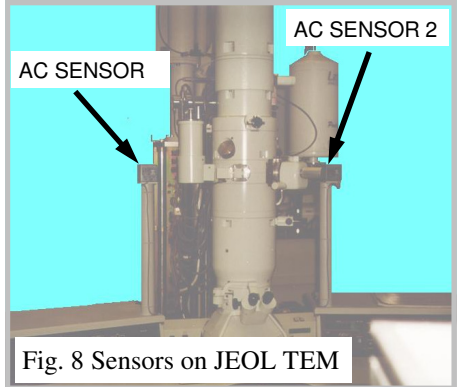


Fig. 8 Sensors on JEOL TEM

On TEMs the sensor is usually mounted to the side of the column at goniometer height. An installation with two sensors on a TEM is shown in Fig. 8. When two sensors are used, their outputs are combined with the mixer in Fig. 9 to create a “virtual sensor” that can appear to be located inside the column. If two sensors are used they must be parallel and facing the same direction. When the mixer is used, both sensors must be plugged in, otherwise the screen displays “Incorrect Sensor Configuration”.

The controls on the mixer are used to tune the field disturbance on the microscope image to a minimum. This is equivalent to adjusting the position of the virtual sensor. An extension cable is provided with the mixer so that it can be located near the microscope viewing screen so that the image can be viewed while the mixer controls are adjusted. After tuning, the extension cable should be removed and the mixer installed as in Fig. 9.



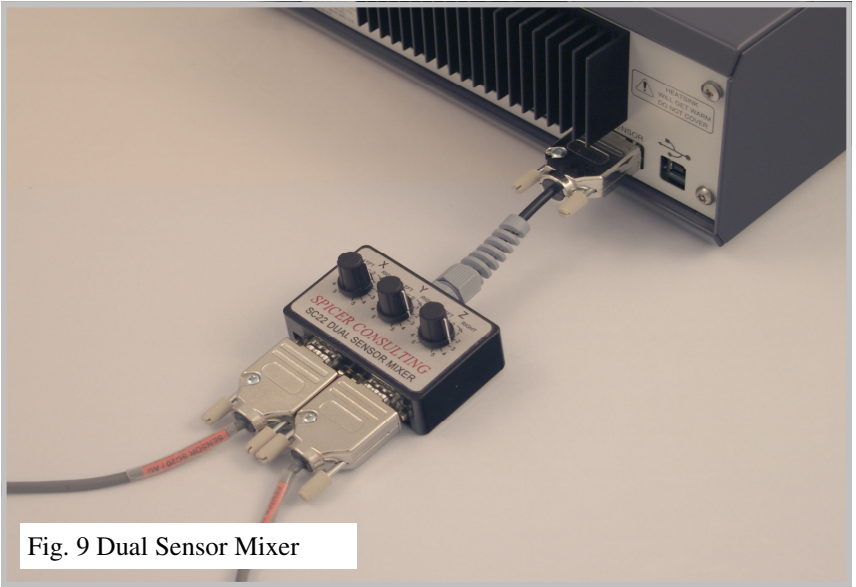


Fig. 9 Dual Sensor Mixer

## 6. Operation

### 6.1 Cancelling

The SC22 is designed to operate continuously with minimum attention. Routinely, the operator just has to check that the “FIELD OK” is displayed and that none of the sensors have been moved from the correct position.

The appearance of the display screen when the system is cancelling and the field is OK is shown in Fig. 10.

The appearance of the display screen when the system is in standby (so cancelling is off) is shown in Fig. 11.

Fig. 12 is a “composite” screen showing a large number of error indicators to illustrate where they appear on the screen. Section 4 of this manual describes the error indicators and the conditions when they occur.

Installations on transmission electron microscopes (TEMs) may require more attention by the operator, including putting the SC22 in STANDBY during TEM magnification changes. So it is recommended that the control unit is installed on the TEM console within easy reach of the TEM operator. During operation of a TEM, when the operator changes magnification or imaging mode, large changes to the currents in the lenses in the electron beam column result and large changes to the magnetic flux leaking from the column. The leaking flux can overload the cancelling system causing the “FIELD OK” display to go out for about 1-2 minutes and make large transient fields in the room that may affect other instruments. The SC22 will recover without operator intervention, but it is better to put the SC22 into STANDBY.

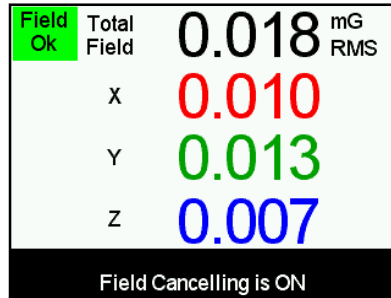


Fig. 10 Screen when Cancelling

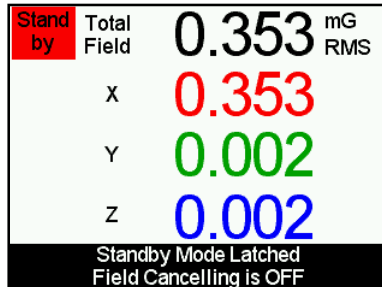


Fig. 11 Screen display in standby

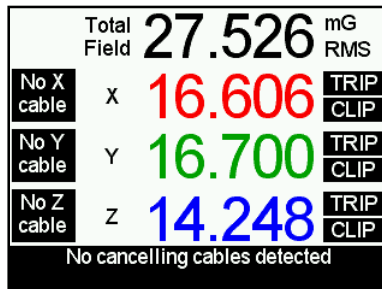


Fig. 12 Screen with error messages

If it is necessary to move the sensors for more than a few minutes e.g. during maintenance of the electron microscope, the SC22 should be put into STANDBY (section 4.4). Although the SC22 will not be damaged if the sensors are moved to an arbitrary location while cancelling, the system may oscillate and create a large magnetic field which may interfere with other instruments. If the SC22 detects long term oscillation it will stop cancelling and go into “Setup required” mode (section 4.7). After the maintenance, the sensors and any field cables which have been moved should be returned to the correct position before the setup program is run (section 4.3).

SC22 installations on CDSEMs and E-Beam Lithography Tools, may be affected by short transient magnetic fields generated by the wafer loading robot or solenoid valves in the vacuum system. These transient fields may overload the cancelling system and cause the “FIELD OK” display to go out during the transient. These transient bad fields can usually be ignored because the electron beam is not being actively used at these times.

## **6.2 Practical hints**

Do not place objects which create local AC fields close to the sensors. Soldering irons, portable lamps, portable transformers, small power supplies and laptop computers all make local AC fields. The SC22 system will cancel the field at the sensor whatever its source. If most of the field is coming from a soldering iron placed a few centimetres from the sensor, the system will create quite large fields in the rest of the room in order to cancel the field from the soldering iron. Watch out for flat screen monitors and tracker ball controls on TEM's. They usually make fields at several hundred Hz.

## **6.3 Field measurements**

The SC22 can make accurate magnetic field measurements of fields up to 40 mG pk-pk (4 uT pk-pk). The analog to digital converter in the SC22 has an input range of 40 mG pk-pk. Larger fields will activate the clip detector, see for example the Z axis in Fig. 12 and section 4.7. The SC22 field measurements are over the full bandwidth of the AC sensor, 5 Hz to 20 kHz. The units of the display can be selected by the “UNITS” push button (section 4.5). The RMS measurements are true root mean square values.

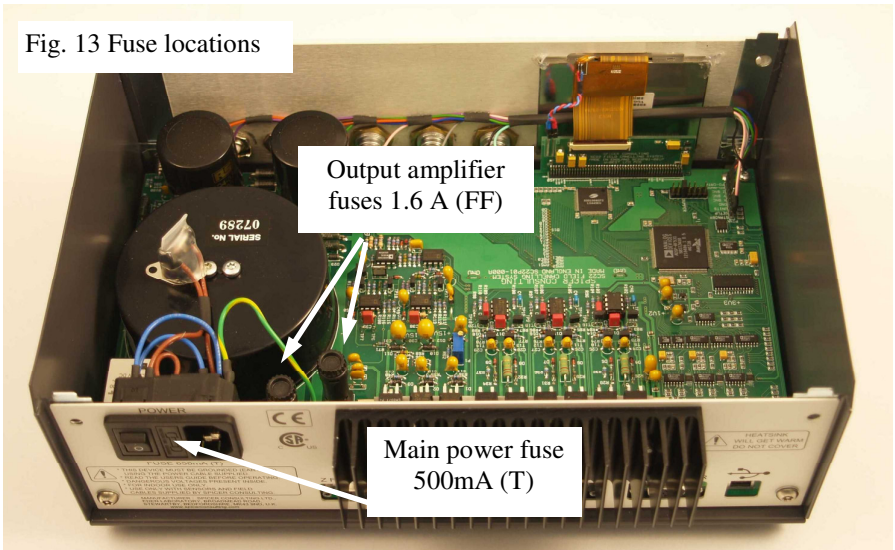
When interpreting the SC22 field measurements or comparing them against a specification from a microscope manufacturer, it is useful to remember the following. A sine wave field of just a single frequency e.g. 60 Hz, that measures 1 mG RMS, should measure 2.83 mG pk-pk. For complex field waveforms containing harmonics this 2.83 factor does not hold. This is particularly true if the field waveform contains short transient field spikes that will be measured by the pk-pk algorithm but be suppressed by the averaging inherent in the RMS algorithm. The effect is more noticeable for small fields e.g. 20  $\mu$ G pk-pk.

The real time field waveforms are available for oscilloscope display on the BNC connectors on the SC22 front panel. The BNC outputs have 10 k $\Omega$  series resistors for protection so should be connected only to 1 M $\Omega$  oscilloscope inputs using the coax cable supplied with the SC22. The scaling is 1V/mG.

## 7. Trouble shooting

### 7.1 Replacing fuses

This information on the SC22 fuses is provided for reference and to ensure that any replaced fuses have the correct ratings. The location, function, and rating of the fuses is shown in Fig. 13. Spare fuses are supplied with each SC22 shipped. However, in normal operation of the SC22, none of the fuses should ever blow. A blown fuse probably indicates a fault and the unit will need to be returned to the supplier or the factory for repair. The main power fuse is located in the IEC power inlet and the power cable must be unplugged for access to the fuse. Slide out the little fuse holder drawer with the fuse symbol. The fuse holder contains two fuses, the active fuse (furthest in) and a spare.



The SC22 Control Unit should only ever be opened by a qualified electrical engineer or technician. The power cable should be unplugged from the back panel before the unit is opened. To open the unit, remove the top two fixing screws in the front panel and the top two fixing screws in the rear panel then remove the lid by pulling upwards. No other screws in the unit should ever be removed.

## 7.2 Problems reported by the system during Setup

If the SC22 detects any problems during setup with the way the system is installed, it displays the Setup Warnings or Setup Errors screen. These screens may show one or more of the errors or warnings listed below. Each error or warning may have several possible causes, so it is worthwhile looking them up here to help with troubleshooting.

### **W01: Clipping during setup**

This warning occurs if the ambient field is more than about 36 mG pk-pk (3.6 uT pk-pk) . Under this condition, the SC22 loop gain is set less accurately, but it is still within  $\pm 10\%$  up to 60 mG pk-pk (6 uT pk-pk).

### **E01: Axes rotated XYZ -> ZXY**

### **E02: Axes rotated XYZ -> YZX**

These errors occur if the cables are plugged into the control unit in the wrong order. For example, E01 means the Z cable is plugged into the X output, the X cable is in the Y output and the Y cable is in the Z output. One of these errors also appears if the cables are correct, but the sensor is on its side and rotated by 90 degrees.

### **E03: X and Z axes swapped**

### **E04: Y and Z axes swapped**

These errors occur if the X and Z (or Y and Z) cables are swapped at the back of the control unit. If the cables are correct, E03 occurs if the sensor is on its side and E04 occurs if the sensor is mounted vertically.

### **W02: X and Y channels swapped**

### **E05: X or Y axis swapped**

The above warning occurs when both X and Y cables are plugged in, and the cables are swapped or the sensor is rotated 90 degrees. The system can correct for that situation. The error occurs if the X and Y axes are swapped, but only one of the X and Y cables are plugged in.

### **E06: X cable too weak**

### **E07: Y cable too weak**

### **E08: Z cable too weak**

The above errors occur if the cable is installed in too large a loop or it is too distant from the sensor. Another possible cause is the use of Helmholtz frame cables for a room-size installation. The consequence of weak cables is that the SC22 cannot achieve a cancelling factor of 50 even with the loop gain set to maximum. An error indicates that the cancelling factor would be less than 6. Weak cables also give rise to reduced dynamic range, so these errors indicate that the installation needs to be improved if there are large ambient fields to be cancelled. The errors also appear if you have plugged the tail into the control unit, but have not joined together the main loop connectors. If the cables are correct, these errors may occur if the sensor is not correctly placed near the column, but has been moved away for some reason.

**W03: X axis making too much Y field**

**W04: X axis making too much Z field**

**W05: Y axis making too much X field**

**W06: Y axis making too much Z field**

**W07: Z axis making too much X field**

**W08: Z axis making too much Y field**

These warnings occur if the SC22 measures more field in an unintended direction than in the intended direction on any given axis.

This can occur if the cables are not well centred about the sensor position. W03 or W05 occurs if the X or Y cable is off-centre sideways. W04 or W06 occurs if the X or Y cable is too high or too low. W07 or W08 occurs if the Z cable is off-centre sideways. This may happen if the Z cable is in the ceiling, running all around the outside edge of the room, but the sensor is in the corner or near the side of the room. A wall-mounted or ceiling-mounted cable loop does not have to go all the way across the room, in many situations it can be made smaller in order to be better centred on the microscope column.

The column or chamber of an electron microscope can also distort the field directions causing these warnings. Spacing the sensor a few centimetres away from them may help.

If these warnings occur, the SC22 reduces the gain so that the interaction between channels does not cause the system to oscillate. If possible, find a sensor location that does not report these warnings, because it allows the SC22 to provide a better cancelling factor.

When you have finished viewing the error messages, press the SETUP button to continue. If there were only warnings, the SC22 displays the Setup Results screen (Section 4.3) and starts cancelling when you press the SETUP button again. If there were any setup errors, the SC22 goes back to the normal field measurement display, but remains in the system disabled state. You must correct the errors and re-run setup before it will enable cancelling. The earlier errors in the list prevent reporting of the later ones, so it may take more than one pass to correct the installation.

### 7.3 Operational problems

The SC22 microcomputer controller takes care of most of the setup problems that used to be encountered by users of the older SC12 field cancelling system.

However there is at least one problem that it cannot comprehend or correct as follows.

*Problem*        Cancelling “works” but does not improve microscope image

*Causes*

- bad image caused by mechanical vibration
- bad image caused by ground loop in microscope installation
- bad image caused by internal fault in microscope
- uncanceled field too small to affect image
- sensor is in completely the wrong place
- sensor has been moved after setup
- sensor is mounted on a vibrating surface



## 8. Performance Specification

<b>CO-ORDINATE SYSTEM</b>	X, Y, Z rectangular Cartesian
<b>UNITS</b>	Gauss, Tesla (switchable)
<b>FIELD CANCELLING</b>	
Components cancelled	X, Y, Z field components
Dynamic range (X & Y) <sup>(note:1)</sup>	60 mG (6 $\mu$ T) pk-pk (installation Fig. 3)
Dynamic range (Z) <sup>(note:1)</sup>	35 mG (3.5 $\mu$ T) pk-pk (installation Fig. 3)
Field cancelling factor	50 X at 50/60 Hz (installation Fig. 3)
Bandwidth	0.5 Hz - 5000 Hz
System 1/f noise limit below 0.1Hz	< 100 $\mu$ G (10 nT) pk-pk
System wideband noise limit	1 $\mu$ G (100pT) RMS 5 Hz - 20 kHz
<b>FIELD MEASUREMENT and MONITORING</b>	
Display	3.5 inch LCD TFT colour panel
Measurements displayed (updated every 0.4 secs)	X axis field at sensor Y axis field at sensor Z axis field at sensor TOTAL vector field at sensor
Measurement bandwidth	5 Hz -20 kHz
Readout units selectable	mG RMS mG pk-pk $\mu$ T RMS $\mu$ T pk-pk nT RMS nT pk-pk
Display range (reading)	X, Y, Z pk-pk 0 - 40.000 mG (0 - 4.0000 $\mu$ T) (0 - 4000.0 nT) X, Y, Z RMS 0 - 20.000 mG (0 - 2.0000 $\mu$ T) (0 - 2000.0 nT) TOTAL pk-pk 0 - 69.282 mG (0 - 6.9282 $\mu$ T) (0 - 6928.2 nT) TOTAL RMS 0 - 34.641 mG (0 - 3.4641 $\mu$ T) (0 - 3464.1 nT) (clip detector displays if pk-pk exceeds 99% of range)
Accuracy	$\pm$ 1.0 % of reading $\pm$ 1 $\mu$ G (100 pT)
Sensor wideband noise limit	1 $\mu$ G (100pT) RMS
Field OK indicator	OK indicator appears when X & Y & Z fields are < 250 $\mu$ G RMS
Trip indicators X, Y, Z	Trip indicator appears if the field on that axis > 250 $\mu$ G RMS and disappears after 60 seconds if the field < 250 $\mu$ G RMS
<b>X, Y, Z REAL TIME FIELD OUTPUTS</b>	
Scaling	1.0 V/mG (10V/ $\mu$ T)
Range	$\pm$ 12 Volts
Source resistance	10 k $\Omega$
Connectors	3 x BNC
Bandwidth	5 Hz - 20 kHz
<b>POWER</b>	120/240 V (+10% -20%) 50/60 Hz , 50 VA

Note 1: Dynamic range is stated when operating at the nominal AC power input of 120 or 240 volts RMS.  
de-rate linearly for lower voltages.

## 9. Appendices

### Appendix 1. Magnetic field basics

This section provides background information on magnetic fields with reference to electron microscopes and similar instruments. If you have a good working knowledge of magnetic fields and electron microscopes please skip this section.

Magnetic fields are created by electric currents in the space around where the currents flow. Currents which do not change with time (called direct currents or DC) make constant magnetic fields which we call DC fields. A gradual change in a direct current creates a corresponding gradual change in the DC field. By convention we refer to unchanging fields and fields which change in this slow non-periodic manner as DC fields.

The planet earth is surrounded by a DC magnetic field which is created by a direct current flowing in the earth's molten core. The current flow and the magnetic field are sustained by the "dynamo" effect. The earth's field undergoes significant changes (including sign reversal) rather randomly on a time scale of thousands of years. There are also smaller changes, on a daily time scale, of 1 to 5 mG. For most electron microscope environments, the earth's field can be considered constant.

Currents which change sign in a regular periodic manner with time are called alternating currents or AC and give rise to corresponding AC magnetic fields. The most common AC fields are created by power lines and usually have fundamental frequencies of 50 or 60 Hz (referred to as "line" frequency) often with harmonics up to about 5 kHz. AC fields at other frequencies may be generated by rotating machines containing permanent magnets. Examples are magnetic stirrers and plasma etch machines which may make fields at about 0.3 Hz.

The units used to measure magnetic fields are as follows....

SI unit of magnetic field strength: Amp/metre (A/m)

SI unit of magnetic flux density: Tesla (T)

CGS unit of magnetic flux density: Gauss (G)

The SI units are the modern units but the old CGS unit, the Gauss, is still so widely used that it has been kept in the SC22. The old CGS unit of magnetic field strength, the Oersted, is now rarely used.

The Amp/metre unit is commonly used by the electricity supply industry as it relates directly to the currents that are generating the magnetic field. The Tesla and Gauss are units of the flux density created by the magnetic field and are the most common units used in measurement of fields.

The relationship between the units (in air or space) is as follows...

$$1 \text{ Amp/metre} = 1.257 \text{ microTesla} = 12.57 \text{ milliGauss}$$

The magnitude of the earth's field is about 0.5 Gauss (50 microTesla).

Magnetic field is a vector quantity, that is, it has a magnitude and a direction. In Fig. 2 the X, Y and Z cables each make one component of the magnetic field vector. The X axis component is perpendicular to the plane of the X cable. The Y axis component is perpendicular to the plane of the Y cable. The Z axis component is perpendicular to the plane of the Z cable.

Electron microscopes control the motion of their electrons using electric and magnetic fields inside the part of the instrument called the "column". Focussed ion beam systems are similar. The column usually comprises a stack of electron optical components, "lenses" to focus the electron beam and "deflectors" to position the beam. The column is mostly made of ferromagnetic iron which serves as the magnetic circuit for the lenses and the mechanical structure of the column. The magnetic fields inside some of the lenses can be as large as 10,000 Gauss (1.0 Tesla) i.e. 20,000 times the earth's field. The iron structure of the column serves as a partial barrier to magnetic fields entering the column from outside and the large internal lens fields leaking out.

The earth's field penetrates the electron beam column from outside (to some extent) and adds to the magnetic fields in the lenses and deflectors but this is not a problem because it changes very slowly. Its effect is adjusted out with the instrument controls during routine operation of the microscope and the operator is generally unaware of its presence. The fields which degrade the performance of the microscope are fields which change during operation, DC or AC fields. Usually, DC fields penetrate the column more than AC fields. This is because AC fields are also attenuated by the mechanism called "eddy current shielding".

Electron microscopes form their image either by projection (TEMs) or by scanning to form a TV like image (SEMs, STEMs). The effect of DC or AC fields on projected images is to move the whole image and the result is loss of resolution on the image screen. The effect of DC or AC fields on scanned images is to move parts of the image. AC line fields typically produce wiggly edges on the image often called "edge tearing" or "ragging" or "flags". DC fields may cause discontinuities in the image and cause straight lines to look like mountain ranges. Some microscope manufacturers design their scanning systems to operate synchronously with the 50 or 60 Hz line. This removes the edge tearing caused by the AC line but introduces distortion into the image (e.g. the image of a square grid is bent). However, distortion is generally less visible than edge tearing and may be acceptable for some applications.

## Appendix 2. Helmholtz coils and frames

For field cancelling on electron microscopes where it is not possible to use room cables e.g. in large open plan clean rooms, field cables can often be installed in the Helmholtz coil configuration. This may involve the use of a frame to support the cables around the electron beam tool or for tools that have their own enclosure, the cables can be installed inside it.

The standard Helmholtz coil (HH) cables we supply are thinner than the standard room cables and have 16m loops and 2m tails. Room cables should not be used because they are too thick to fit the frame and the loop gain would be too high.

Our normal custom frame is shown in Fig. 14 Typically the frame is made to order to the customer's dimensions to suit the particular electron beam tool. This frame is useful in sizes to about 2 x 1.5 x 1.5 metres. Larger frames can be made using thicker section frame material. Whatever frame is used it should have electrically insulating joints (Fig. 14) so that it does not make a "shorted turn" that stops field cancelling of the higher frequency field harmonics. The same "no shorted turns" requirement applies to installation in the enclosure of electron beam tools used in wafer fabs. OEM customers planning to install the SC22 in their tool enclosures should consult our support staff for help regarding shorted turns.

Fig. 15 shows how the HH cables should be installed on a frame or in an enclosure. The HH cables have arrows spaced along their length to indicate the correct installation direction. The direction of the arrows on the cables in Fig. 15 is very important. Both of the two X loops must have their arrows pointing in the same direction for their fields to be additive. (Also for Y and Z. ) Otherwise the fields will subtract and the system will not work.

The Fig. 14 frame has multiple grooves that can accommodate the cables with plastic cover strips to enable a neat installation to be made.

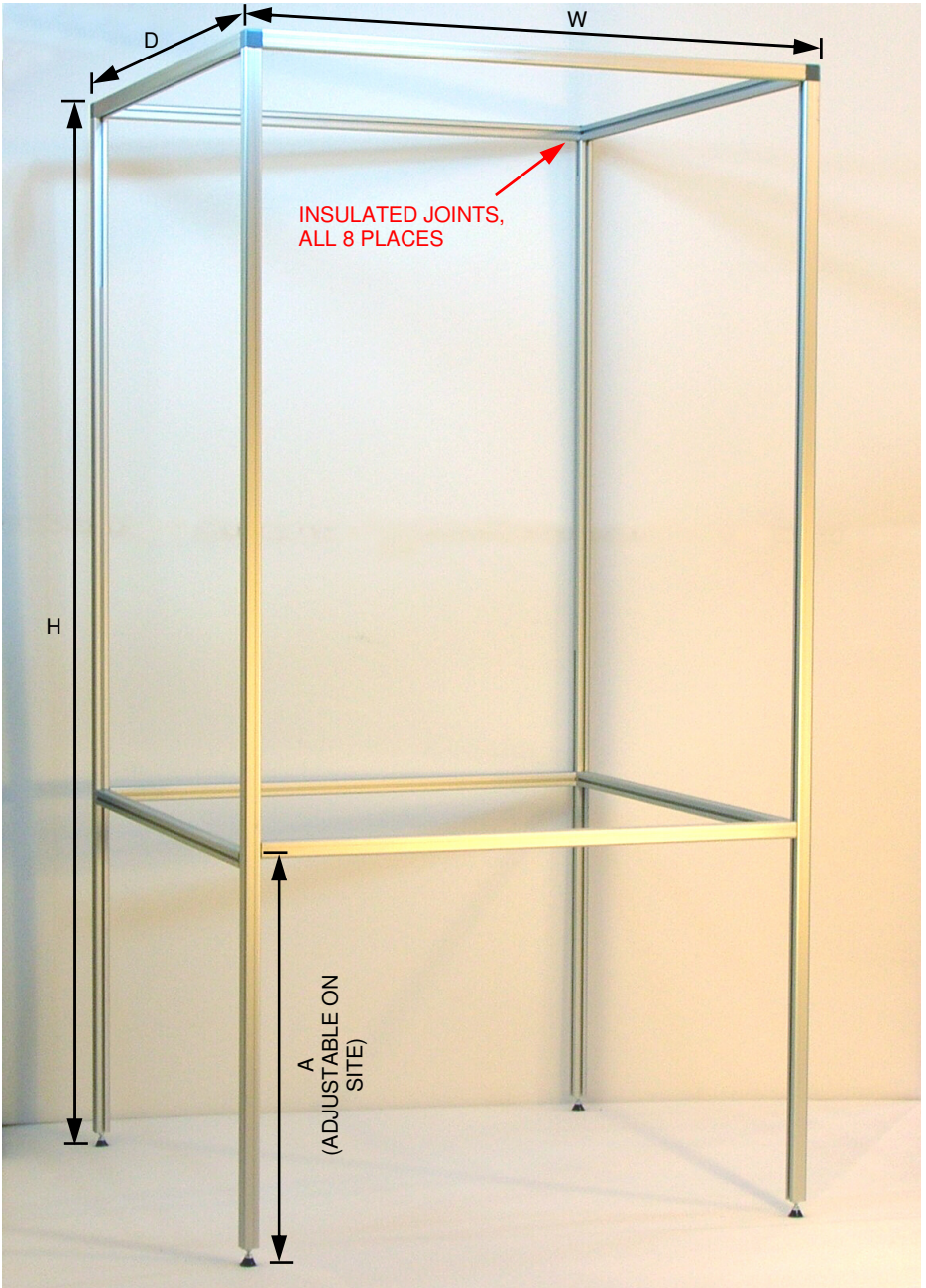
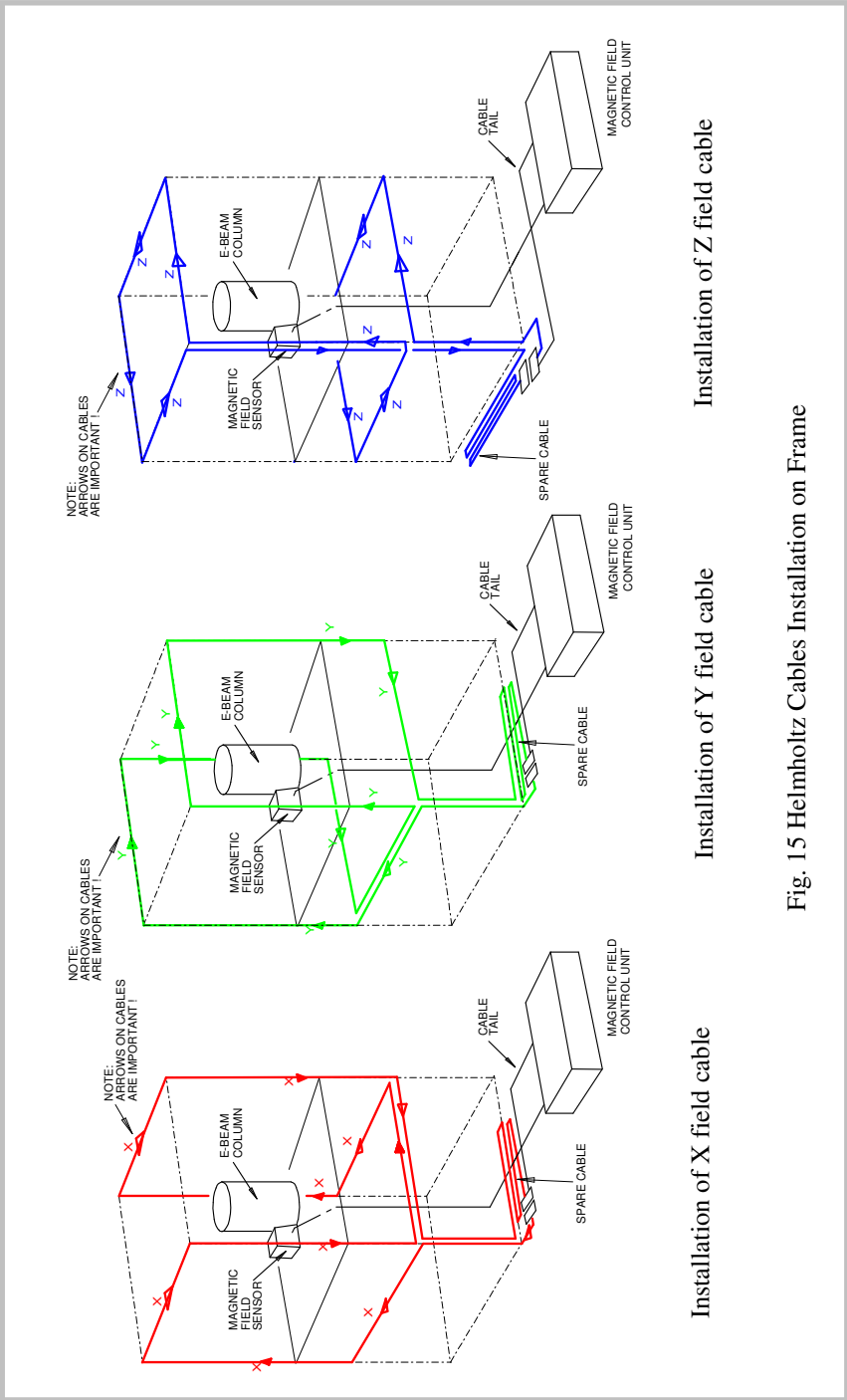


Fig. 14 Custom Cable Frame

Frame is made to order. Customer specifies dimensions H, W, D. Frame in photo has H=2060, W=1060, D=1060 mm. Frame is supplied dismantled, for on-site assembly.



Installation of Z field cable

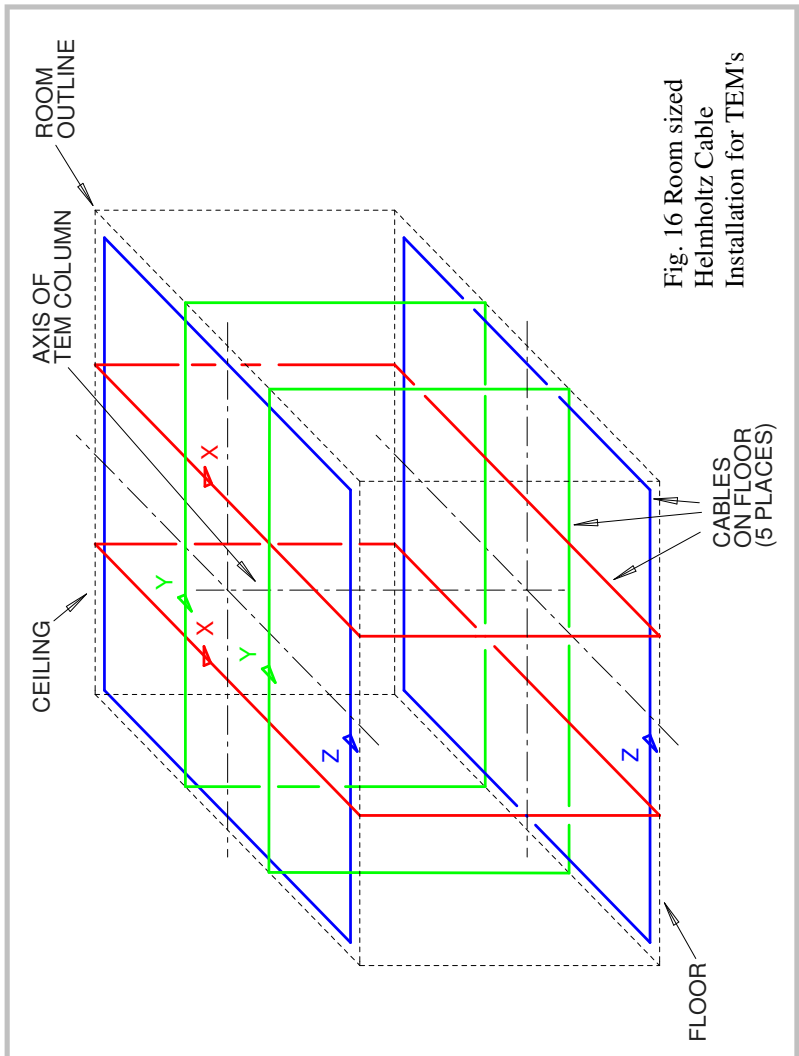
Installation of Y field cable

Installation of X field cable

Fig. 15 Helmholtz Cables Installation on Frame

### Appendix 3. Large TEM's room sized Helmholtz coils

Large Helmholtz coils can be used to achieve the demanding field cancelling performance required by the latest TEM's. Usually, special 2 loop cables are made to suit the room dimensions. The centring of the column in the cable loops is important as in Fig. 16 below. The separation between the 2 loops can be optimised to give very uniform field cancelling along the column. For these large installation the customer usually works with our support staff to optimise the cable design and accommodate the cables running across the floor.



## Appendix 4. Cancelling factor data

The cancelling factor is the ratio of the uncanceled field to the canceled field and it is a function of frequency. The SC22 cancelling factor is plotted in Fig. 17. These are measured results with the Fig. 3 reference installation after setup has been run (section 4.3). Similar cancelling factors are obtained with the Fig. 2 installation after setup has been run.

The setup program sets the SC22 internal amplifier gain and phase so that the cancelling factor is 50 at 50/60 Hz. If the sensor is moved after setup the cancelling factor will probably change because the loop gain will no longer be optimised for the new sensor location. Setup (section 4.3) should always be run after moving the sensor.

