

# SC24 Magnetic Field Cancelling System

## *User Manual*

*June 2015*

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This manual applies to SC24 Firmware version 1.01.01

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# 1. Safety and Certifications

## 1.1 Environmental conditions.

The SC24 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 120/240 V AC
- supply voltage fluctuations not exceeding +10% -20% of the nominal voltage
- transient overvoltage, installation category II
- pollution degree 2 (IEC 664)
- IP rating: none

## 1.2 Other conditions of use.

- this User Manual must be read before operating the SC24
- the SC24 must only be used for its designed purpose as described in this manual
- if the SC24 is used in a manner not specified in this manual, the protection provided by the equipment may be impaired
- the SC24 must be grounded (earthed) using the power cable supplied
- dangerous voltages are present inside the SC24 control unit. It should only be opened by trained electrical engineers or technicians
- the SC24 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 SC24 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 SC24 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 61010-1:2010
- 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

Options for installation of the field cancelling cables are shown on page 7.

Complex dual-loop installations as Fig. 1 are usually done by our trained agents from custom drawings supplied by Spicer Consulting to fit the customer's room.

For users who are familiar with other Spicer Consulting Field Cancelling products who wish to install the SC24 themselves, the following instructions are a guide.

- Decide the location for the X, Y & Z field cancelling cables and install them in the room (Figs 1, 2 or 3) or on a Helmholtz frame (appendix 2). Note the X, Y & Z cable loops must be orthogonal. For dual-loops (Fig.1) the current direction labels attached to the cables must point in the same direction.
- Position the magnetic field sensor (or sensors) adjacent to the electron microscope column using the sensor mounts (page 12) as necessary. Align the sensors with the field vectors on their labels orthogonal to the cable loops.
- Plug the sensors and the X, Y & Z cables into the back of the SC24 control unit.
- Plug the power cable into the back of the SC24 control unit and into a suitable power outlet.
- Turn the SC24 on with the power switch on the back panel adjacent to the power cord IEC inlet
- The front panel touch screen display will light up within about 5 seconds.
- Follow the instructions on the display to setup the system.  
The SC24 will test the installation and report any installation errors.
- After successful setup the SC24 will enable cancelling, and the green FIELD OK indicator on the display should be present.
- Look at the microscope image to see that the field disturbance has been removed or reduced by the field cancelling.
- 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.
- For installations with 2 sensors use the adjust menu to tune the mixer for minimum image disturbance

You can change the displayed magnetic field units by touching the "UNITS" button on the display. A pop up window will appear with the selection of units.

You can turn the field cancelling on and off by touching the "CANCEL-STANDBY" button.

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

## Room Installation options

Fig. 1. Installation for TEMs and new Lab Builds

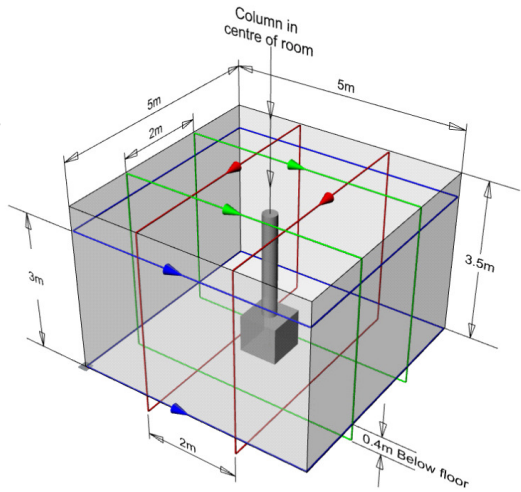


Fig. 2. Basic Installation for TEMs and SEMs

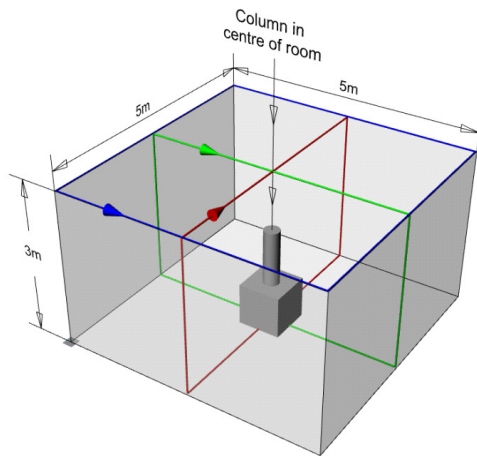
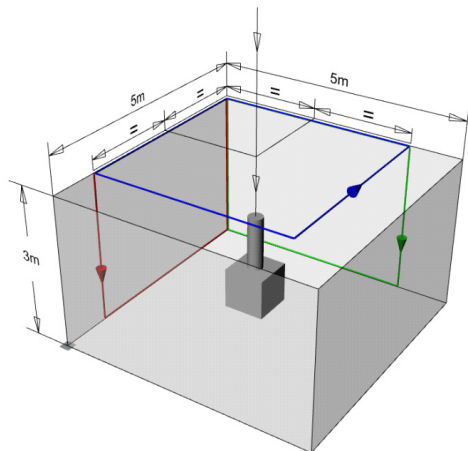


Fig. 3. Minimal Installation for SEMs



Notes:

X cable loops: RED

Y cable loops: GREEN

Z cable loops: BLUE

### 3. Product Description

The SC24 is a fourth generation Magnetic Field Cancelling System, designed to improve the performance of electronic instruments which are sensitive to magnetic fields, such as electron microscopes and electron beam metrology tools. The SC24 is an enhanced replacement for the SC20 system, which has an installed base of over 400 units world wide.



Fig. 4 SC24 Control Unit

The SC24 system comprises a magnetic field control unit, one or two magnetic field sensors and three orthogonal axis multicore cables, that are installed in the room where the field is to be cancelled, (or on a frame around the microscope). Best field cancelling performance is usually achieved with room cables. Options for installation of the SC24 cables in the microscope room are shown on page 7.

The field cancelling method is wide band analog negative feedback. When the ambient magnetic field changes, the SC24 system stabilises the field by dynamically creating nearly equal and opposite field changes using its power amplifiers to drive currents through the cables.

The magnetic field sensor measures the resulting field and real time negative feedback reduces the ambient field by the loop gain of the system. The system is dynamic, automatically responding to field changes within 100  $\mu$ s.

An embedded microcomputer controls the system and digitises the fields for measurement but is not within the feedback loop.



Fig. 5  
Sensor SC24/AC



Fig. 6  
Sensor SC24/DC+AC



The SC24 can use one or two AC sensors or one or two wideband DC sensors. Wideband DC sensors are only necessary when the ambient has bad DC fields, typically from DC powered trams or trains. The AC sensors are lower cost and slightly easier to use.

Typically for SEMs one magnetic field sensor is used, located near the bottom of the electron beam column. Typically for TEMs two sensors are used spaced about 300mm from either side of the electron beam column at the sample stage height.

The SC24 system does not cancel the field everywhere in the room. It creates a region around the magnetic field sensors where the field is much reduced. The volume of this region depends on the uniformity of the ambient field and the design of the field cables.

The SC24 user interface is a touch screen LCD display panel shown below. This is a typical display for an SC24 with one or two wideband DC sensors when the system is cancelling and the field is OK.

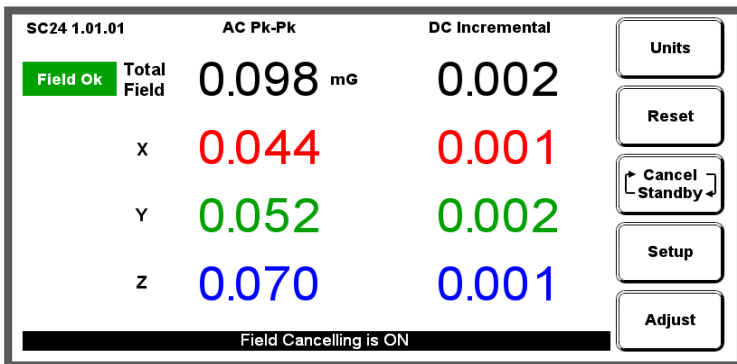


Fig. 7 Field OK screen

The five buttons control operation of the system. The “Units” button calls up the units sub menu to select RMS or pk-pk, Tesla or Gauss units. The choice of units has no effect on cancelling. The “Reset” button clears the “TRIP” indicators and resets the “zero field” operating point of the DC sensors. The “Cancel/Standby” button turns cancelling on and off. The “Adjust” button enables entry to the adjustment menu (for expert users) described in the user interface section.

The SC24 has “one button” automatic setup. On setup it analyses the installation, reports installation problems and sets up the feedback loop gain and phase. All setup parameters are stored in non-volatile memory. On subsequent power up it re-tests the installation. If it find no changes it resumes operation in the pre-power loss state, otherwise it requests setup.

Magnetic field amplitudes are displayed with 100pT (1.0 µGauss) resolution. The DC field amplitudes are not displayed for AC sensors.

The magnetic field amplitudes are continuously monitored and compared with preset trip levels to provide “Field OK” indication.

## 4. Installation

Page 7 has drawings of the room cable installation options.

Usually, the SC24 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 SC24 system is not an electrical power installation. The field cables carry a maximum of  $\pm 20$  Volts and  $\pm 1.0$  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.

The SC24 installation may be done before or after the electron microscope is installed and operational. Increasingly, for new microscope lab builds it is done before, and Spicer Consulting engineers will coordinate with the building architects and contractors.

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. Spicer Consulting usually models the fields in the room and provides detailed cable dimensions to fit the installation room.

Optimising the sensor position requires the electron microscope to be operating to observe the effect of the magnetic field on its image.

### 4.1 Control unit installation

There is considerable flexibility in siting the SC24 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 SC24 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.***

### 4.2 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 SC24 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 SC24 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.

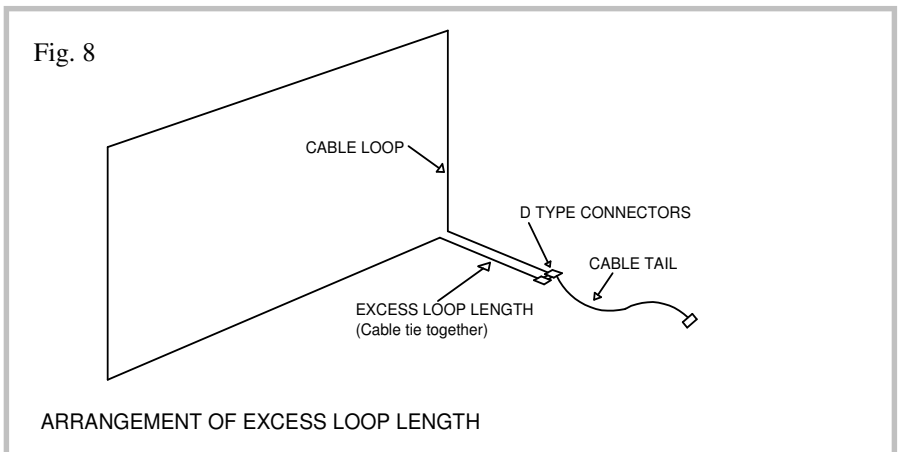
### 4.3 Field cable installation

The field cancelling cables are manufactured with a loop and a tail. The cables have 15 pin D type connectors which plug together to form the loop. The loop parts are shown in Figs. 1, 2 & 3 (page 7) in red, green and blue. The loop creates the field and the tail (which makes no field) connects the loop to the control unit.

Fig. 1 installations have dual loops. All cables have arrow labels on their loops indicating the current direction. The arrows on dual loops must point in the same direction as in Fig. 1.

Standard “room” cables (typical for Figs. 2 & 3 installations) 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. 8. 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.



#### 4.4 Sensor installation

SC24 magnetic field sensors are in Figs. 5 & 6 on page 8.

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.

For an SEM the sensor is typically located near the base of the column or strapped to it using one of the standard mounts shown below.



TEM installations usually use two sensors mounted at specimen stage height, spaced 300mm from each side of the column. The sensor should be oriented with the HX field vector arrow on the sensor label orthogonal (i.e. at right angles) to

the plane of the X cable. However, if the sensor is rotated 90 degrees the SC24 system microcomputer will detect this during setup and swap the X and Y axes.

With “Sensor SC24/AC” the SC24 provides useful cancelling from 2.5Hz to 5kHz. The ratio of the ambient field to the cancelled field is called the cancelling factor. It is a function of frequency and is greater than 50 at 60Hz. (Page 37)

With “Sensor SC24/DC+AC” the SC24 provides useful cancelling from DC to 5kHz. The cancelling factor is greater than 400 at DC and 100 at 60Hz.

“Sensor SC24/DC+AC” contains small Helmholtz coils that surround its field sensing elements. They are used to offset the DC component of the ambient field including the earth’s field. At reset, the microcomputer in the sensor adjusts and remembers the currents in the coils to set the X, Y, Z sensor outputs to zero. The reset process takes 1 second. The sensor must be reset if it is moved.

The SC24 has two sensor inputs. It can work with one or two sensors. They must be the same type, AC or DC and they must be oriented in parallel in the same direction. The SC24 detects the sensor type to choose the correct filters in the cancelling feedback loop. If different types are plugged in, the SC24 reports a sensor error.

When there are two sensors the SC24 enables the mixer function. The “mixed field” is a weighted combination of the sensor outputs, creating an adjustable “virtual sensor” between the two sensors. The mixer is adjusted by observing the microscope image and tuning for best image improvement. Operation of the mixer is described in the user interface section.

## 5. Operation

### 5.1 Cancelling

The SC24 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. 9. The appearance of the display screen when the system is in standby (so cancelling is off) is shown in Fig. 10.

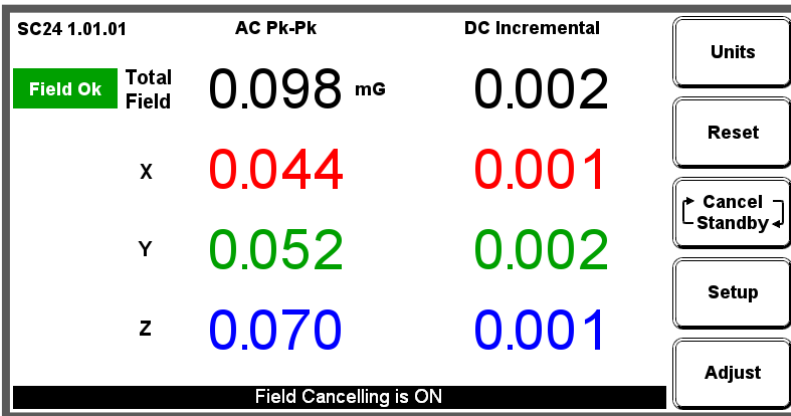


Fig. 9 Field OK screen

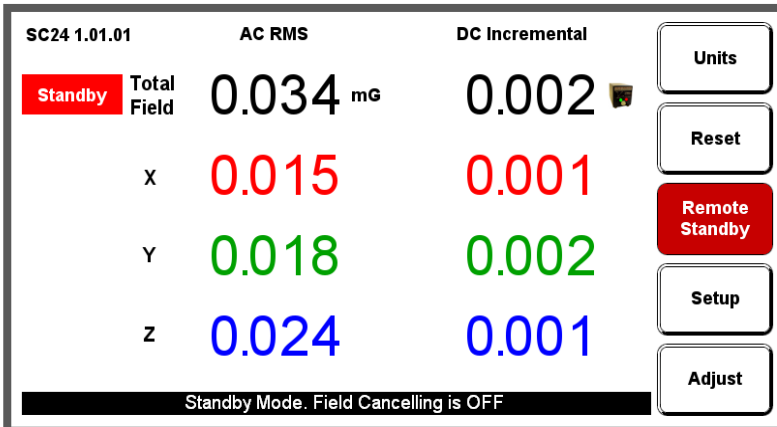


Fig. 10 Standby screen

Fig. 11 is a “composite” screen showing a large number of error indicators to show where they appear on the screen.

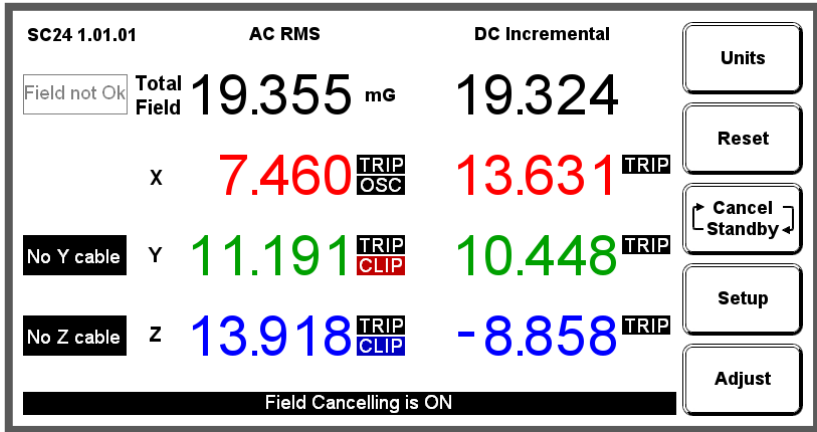


Fig. 11 Composite error screen

Sections 6 & 7 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. If using AC sensors or not using auto reset, the operator may wish to put the SC24 into Standby during TEM magnification changes. Therefore it is recommended that either a remote standby/cancel control is used or the control unit is installed on the TEM console within easy reach of the TEM operator.

If it is necessary to move the sensors for more than a few minutes e.g. during maintenance of the electron microscope, the SC24 should be put into Standby (section 6.5). Although the SC24 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 SC24 detects long term oscillation it will stop cancelling and go into “Setup required” mode (section 6.8). 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 6.4).

## 5.2 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 SC24 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.

## 5.3 Field measurements

The SC24 can make accurate magnetic field measurements of fields up to 40 mG ( $4 \mu\text{T}$ ) pk-pk. The analog to digital converter in the SC24 has an input range of 40 mG pk-pk. Larger fields will exceed the range of the analog to digital converter and activate the clip detector, see for example the Z axis in Fig. 11 and section 6.8. The SC24 field measurements are over a bandwidth of the 25 Hz to 20 kHz for AC sensors and DC to 10 kHz for DC sensors. The units of the display can be selected by the "Units" button (section 6.6). The RMS measurements are true root mean square values. DC Incremental readings appear when DC sensors are connected.

When interpreting the SC24 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  $\mu\text{G}$  pk-pk.



## **6. The microcomputer user interface**

### **6.1 Operation following power loss.**

The SC24 remembers all the details of its operating state. When power is restored it resumes operation in the remembered state, including whether it was cancelling or on standby. At power up, the SC24 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 SC24 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.

### **6.2 Sensor and Cable Detection**

The SC24 detects the presence of the sensors and X, Y and Z cables when they are plugged in.

You may plug in up to two AC sensors or up to two DC sensors. If you plug in one sensor, it may be in either the SENSOR 1 (LEFT) or the SENSOR 2 (RIGHT) input. If you plug in two sensors, they must be of the same type. If no sensors are connected, a message “No sensors detected. Setup disabled” appears at the bottom of the screen. If two sensors of different types are connected, the message says “Incorrect sensor configuration. Setup disabled”. If DC sensors are connected, then the “DC Incremental” field is displayed.

If any cable is not detected, an indicator appears to the left of the relevant channel display, for example “No X cable”. If the sensors are ok, but no cables are connected, a message says “No cancelling cables detected. Setup disabled”. If any SC26 cables are connected, a message says “Incorrect cancelling cables detected. Setup disabled”

### **6.3 Resetting the DC sensors**

If there are one or two DC sensors, they must be reset whenever they are moved. This is because field cancelling sensors are very sensitive, which means that they are overloaded by the earth’s magnetic field. Unlike AC sensors, DC Sensors do not recover automatically after being moved. The reset operation sets the output of the sensor to zero at the current place and time.

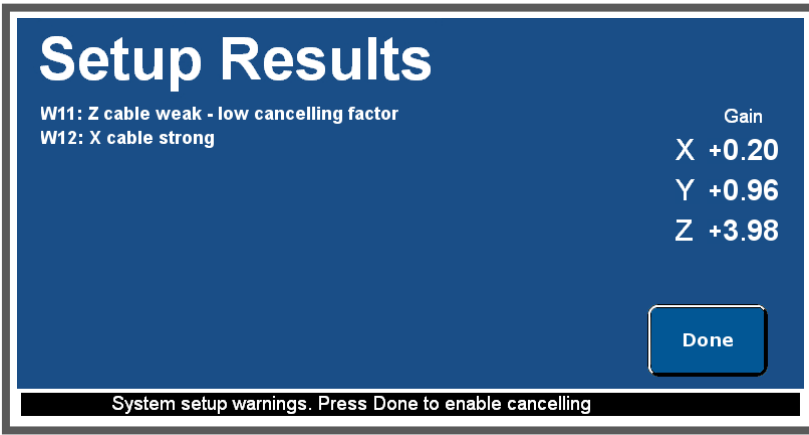
To reset the DC sensors, press the “Reset” button. This also clears all the “TRIP” lights. If a DC sensor is too near an ion pump (or other strong magnet), it flashes its red LED to indicate that it cannot reset. The maximum absolute field for the DC sensor to reset is  $\pm 2000$  mG ( $\pm 200$   $\mu$ T).

### **6.4 Setting up the SC24**

The system enables the “Setup” button if the sensors are ok and at least one field cable is plugged in. If it is set up with only 1 or 2 field cables it will have to be set up again later with all 3. If the Setup button is disabled, the message at the bottom of the screen gives the reason.

In the “Setup required” state, the SC24 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 disabled. Before it can cancel, you must press the Setup button to instruct the SC24 to configure its internal gain and phase controls.

To run setup, press the Setup button. A screen tells you that the setup process interrupts cancelling and generates test fields. Press the “Ok” button to proceed. The system automatically tests the gain and phase of each channel while displaying a progress bar, then displays the Setup Results screen.



Errors and warnings may be shown on the left hand side of the screen. They are listed in Section 7.2. Errors indicate a serious condition that prevents cancelling. Warnings alert you to parameters that are not optimal, but do not prevent cancelling. The right hand side of the Setup Results screen shows the internal phase and gain that the SC24 microcomputer has set to achieve negative feedback with the optimum cancelling factor. 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 Figs. 1-3, 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. 1. It will be higher for the Fig. 3 installation with the cables on the walls. The normal range is 0.25 to 4.0.

In addition, the SC24 can correct for a swap of the X and Y cables (or a 90 degree rotation of the sensor). The normal result is shown in order: X, Y, Z. When they are swapped, they are shown in order: Y, X, Z and a warning appears.

After you have viewed the Setup results, press the Done button. If there were no errors, cancelling starts immediately.

## 6.5 Cancel/Standby

Once the SC24 is set up, the “Cancel/Standby” button is enabled. This button simply enables and disables cancelling. (The SC24 does not have temporary and latched standby modes like the SC22). When cancelling is disabled, the red “Standby” light appears at the top left of the screen, and a message at the bottom of the screen says “Standby Mode. Field Cancelling is OFF”. When cancelling is enabled the message says “Field Cancelling is ON”.

You can connect an SC24 remote standby control to the “EXT STBY” input on the back panel of the control unit. This enables the microscope operator to put the SC24 into standby without having to put the control unit on the operator’s desk. When DC sensors are in use, they are automatically reset when the remote standby is released. When the remote standby is operated, a red light shows at the position of the “Cancel/Standby” control.

## 6.6 Measurement Units

The “Units” button opens a window that allows you to set the magnetic field units and AC mode for the displays. Press the button to display the available options. The options for units are:

mG	MilliGauss
nT	NanoTesla
$\mu$ T	MicroTesla

The options for the AC field display are

RMS	Root Mean Square
Pk-Pk	Peak to Peak

Pressing a button changes the unit or mode immediately. Press “Done” to close the “Units” window.

## 6.7 Field Ok and Trip Indication

When the SC24 is set up and cancelling, the green “Field Ok” light should come on in the top left corner of the screen. This indicates that the field on all cancelling channels is below both the adjustable AC and DC trip levels. The default AC trip level is 0.25 mG (25 nT) RMS and the default DC trip level is 1 mG (100 nT). To adjust the trip levels, see section 6.13.

If the RMS AC field exceeds the AC trip level on any channel, the “TRIP” light by the AC reading for that channel comes on (ref. Fig. 11 Page 15). Similarly, if the positive or negative DC field exceeds the DC trip level on any channel, the “TRIP” light by the DC reading for that channel comes on. The DC trips are only active when DC sensors are plugged in. The “TRIP” lights stay on for 1 minute and then clear 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 (Showing “Field not Ok” in grey), but it comes on again as soon as the field falls below the trip levels 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.

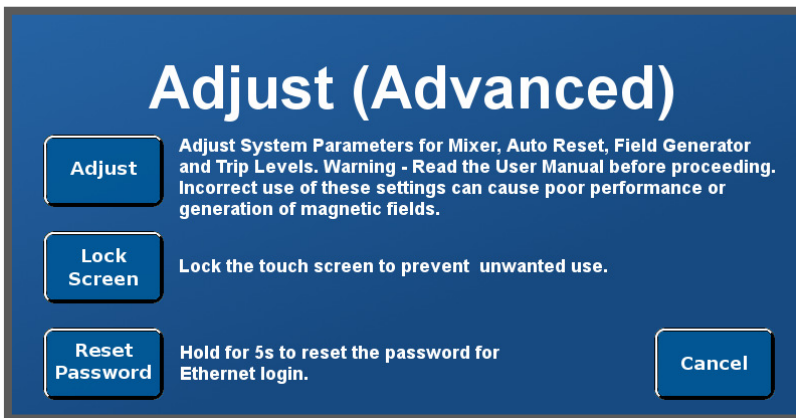
## 6.8 Clipping and Oscillation

A field on any channel greater than  $\pm 20$  mG ( $\pm 2$   $\mu$ T) is too large for the ADC in the SC24 to measure. If this happens when the system is not cancelling, the SC24 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). A blue “CLIP” light indicates clipping at the negative limit, a red light indicates clipping at the positive limit and a black light indicates a large AC signal that is clipping at both. If clipping is detected during setup (section 6.4) the loop gain set by the microcomputer will be less accurate.

If a field on any channel greater than 10 mG (1  $\mu$ T) pk-pk occurs while cancelling, the SC24 concludes that the channel is oscillating. This is possible if the sensor has been moved or rotated after setup. In this case the SC24 displays “OSC” by the channel. If this condition occurs continuously for more than 1 minute, the SC24 automatically stops cancelling and goes into the “Setup Required” state.

## 6.9 Adjustments

The “Adjust” button gives access to advanced features of the SC24.

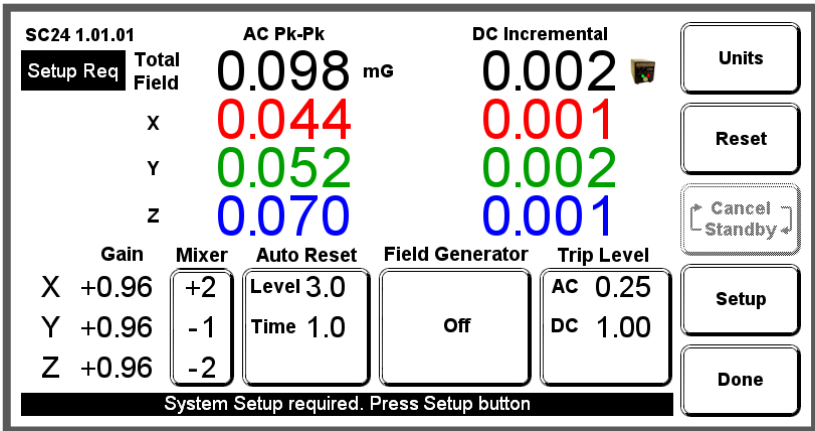


“Lock Screen” returns to the normal field display but replaces the main buttons with the lock panel. To unlock the screen, press and hold the “Unlock” button for 5 seconds. In some environments, it is useful to lock the screen to prevent the controls from being inadvertently operated by cleaners.

“Reset Password” clears the password for Ethernet login when held for 5s. This feature is provided in case the Ethernet password is set and then forgotten. For full details of the USB and Ethernet Monitor features, please refer to their own documentation.

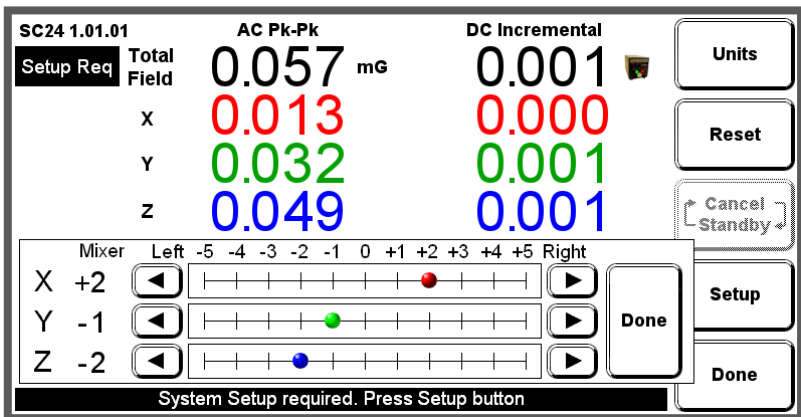
“Cancel” simply returns to the main field screen.

Adjust” moves the field display up to make room for controls that adjust the SC24 mixer, auto reset, field generator and trip levels. These are described in the following sections. The SC24 should not be left in this mode. When you have finished making adjustments, press the “Done” button to go back to the normal field display.



## 6.10 Mixer

The SC24’s internal mixer is provided so that two sensors may be connected to the control unit. The mixer combines the signals to create a single virtual sensor somewhere on a line between the two physical sensors. This is useful for cases where a physical sensor cannot be placed in the optimum location. Press the mixer button to open a window that adjusts the settings.

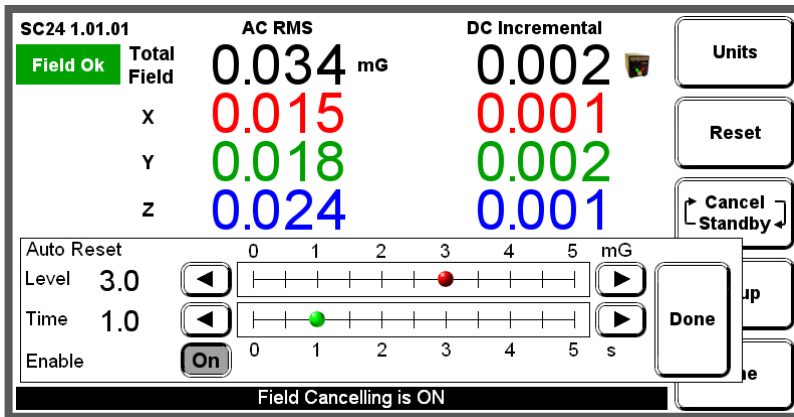


The mixer is disabled if only one sensor is connected. When two sensors are connected, the mixer is enabled and the “Mixer” panel shows the mixer settings.

The range of the mixer is from -5 (fully over to the SENSOR 1- left) through 0 (Mid way between the sensors) to +5 (fully over to SENSOR 2 - right). Each of the X, Y and Z channels has its own independent mixer. To adjust the mixer, touch the scale to position or drag the knob, or press the up and down arrows to move it one click at a time. The mixer responds immediately to your changes. Press the “Done” button to exit the mixer window.

### 6.11 Auto Reset

The SC24 has an auto reset feature for use with microscopes that generate DC magnetic fields that overload the cancelling system when they change mode. When AC sensors are in use, the SC24 recovers after a few seconds, but with DC sensors it cannot recover. Auto reset is enabled only for DC sensors. When enabled, a sensor icon appears to the right of the DC incremental total field value.



Press the “Auto Reset” button to open the above window to adjust the settings.

The auto reset function resets the DC sensors when the Total DC field remains above the level set for the time set. It should be adjusted so that it always captures a change in microscope mode, but does not respond to other field changes. The level has a range from 0.5 to 5 mG (50 to 500 nT). The time has a range from 1 to 5 seconds. Smaller values of both settings make the auto reset more sensitive. To adjust the settings, touch the scale or press the up and down arrows. Press the “Done” button to exit the window.

Each time the auto reset “resets” the reset button momentarily turns red.

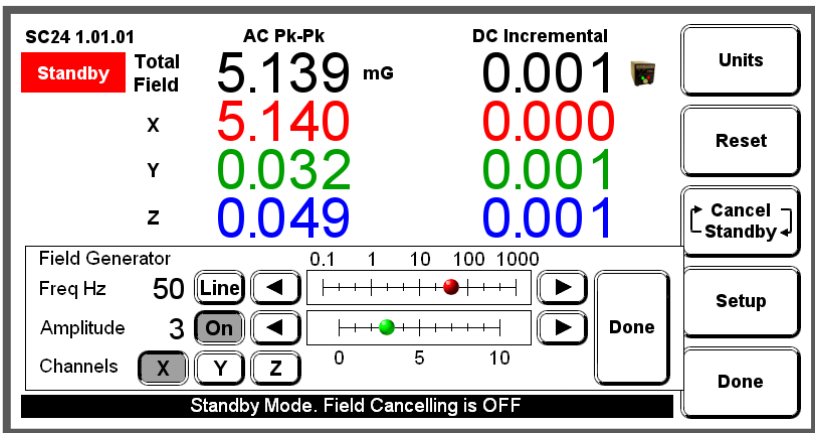
When the DC sensors reset, a new level of DC field is established and this change may shift the microscope image. This one-time shift is unlikely to be a problem, because the microscope’s operating mode has just been changed.

(Note: Auto reset cannot be used to extend the dynamic range of the cancelling system to cancel larger ambient fields from the environment, because it would cause image shifts at arbitrary times depending on the ambient field.)

## 6.12 Field Generator

The field generator function enables advanced users to make test fields that aid the diagnosis and troubleshooting of magnetic field problems. The SC24 field generator does not drive a separate cable like the SC20 field generator. Instead, it drives the main field cancelling cables so that you do not have to set up another cable to use it. You can run the field generator in cancel or standby mode. In standby mode, it simply generates a field using the installed cancelling cables. In cancel mode, it generates a field and also cancels it.

From the “Adjust” screen, press the “Field Generator” button to open the “Field Generator” window shown below, which summarises and enables adjustment of the field generator settings.



The frequency slider sets a square wave field at one of the following frequencies: 0.1, 0.2, 0.5, 1, 2, 5, 10, 20, 50, 100, 200, 500, 1000 Hz. You can override the frequency slider by pressing the “Line” button, which generates a sine wave at the local power line frequency (50 or 60 Hz). The SC24 then shows the power line frequency. (To do this it needs to have cancelling cables plugged in when it is powered up).

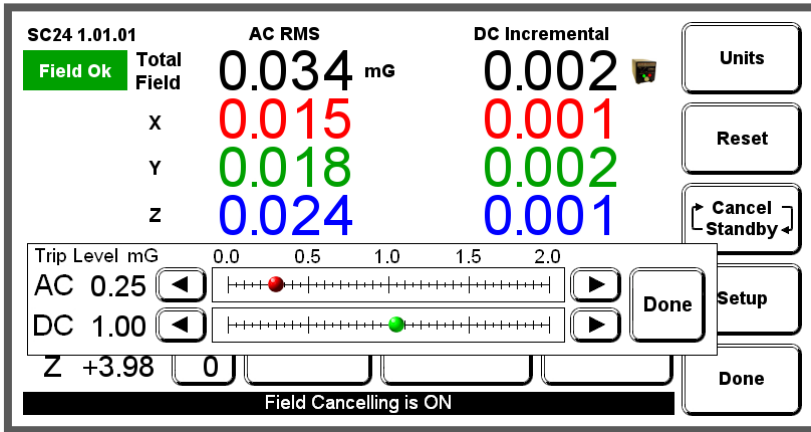
The “Amplitude” slider sets the amplitude from 0 to 10 in arbitrary units. The “on” button next to the “Amplitude” slider turns the whole field generator on or off. The “Channels” buttons independently send the field generator signal to the “X”, “Y” and “Z” channels. The field generator responds immediately to your changes. Press the “Done” button to exit the window.

The field generator stays on when you exit the “Field Generator” window, but it automatically turns off when you exit the “Adjust” screen.

### 6.13 Trip Levels

The “Trip Level” panel shows the current AC RMS and DC trip levels. The trip levels have no effect on cancelling, but smaller values make the “TRIP” lights and “Field Not Ok” more sensitive. In some circumstances, increasing the trip levels may cause the “Field Ok” light to stay on, but this does not mean the actual fields are any better. For this reason, it is recommended that only advanced users change the trip levels from the factory set default values.

From the “Adjust” screen, press the “Trip Level” button to open the “Trip Level” window shown below.



The range of settings for both levels is 0.05 to 2.00 mG (5 to 200 nT). To adjust the settings, touch the scale or press the up and down arrows. Press the “Done” button to exit the window.



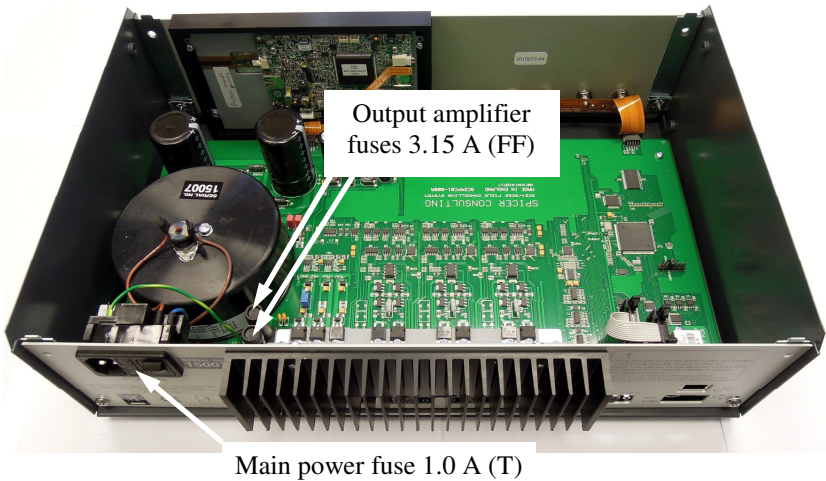
## 7. Trouble shooting

### 7.1 Replacing fuses

This information on the SC24 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. 12. Spare fuses are supplied with each SC24 shipped. However, in normal operation of the SC24, 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.

Fig. 12 Fuse locations



The SC24 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 during setup, the SC24 detects any problems with the way the system is installed, it displays warnings or errors on the Setup Results screen. The errors or warnings are 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 36 mG (3.6  $\mu$ T) pk-pk. Under this condition, the SC24 loop gain is set less accurately.

### **E01: X cable open circuit**

### **E02: Y cable open circuit**

### **E03: Z cable open circuit**

These errors occur if a cable is plugged in, but is open circuit (or very high resistance). This could happen if you have plugged the tail into the control unit, but have not joined together the main loop connectors.

### **E04: Sensors in different orientations**

This error occurs if there are multiple sensors and they are not all pointing in the same direction.

### **E05: X reversed between sensors**

### **E06: Y reversed between sensors**

### **E07: Z reversed between sensors**

These errors occur if there are two sensors and one sensor detects a setup field of the opposite sign to the other in one axis. This could happen if you have double loop cables installed with the loops in opposite directions.

### **E08: Axes rotated XYZ -> ZXY**

### **E09: Axes rotated XYZ -> YZX**

These errors occur if the cables are plugged into the control unit in the wrong order. For example, E08 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.

### **E10: X and Z axes swapped**

### **E11: 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, E10 occurs if the sensor is on its side and E11 occurs if the sensor is mounted vertically.

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

### **E12: 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.

**W09: X cable weak – low cancelling factor**

**W10: Y cable weak – low cancelling factor**

**W11: Z cable weak – low cancelling factor**

**E13: X cable too weak**

**E14: Y cable too weak**

**E15: Z cable too weak**

The above warnings 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 SC24 cannot achieve the optimum cancelling factor even with the loop gain set to maximum. An error indicates that the cable is more than 8 times weaker than the reference installation and the cancelling factor would be down by more than a factor of 2 from optimum. Weak cables also give rise to reduced dynamic range, so these warnings indicate that the installation needs to be improved if there are large ambient fields to be cancelled. 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.

**W12: X cable strong**

**W13: Y cable strong**

**W14: Z cable strong**

**E16: X cable too strong**

**E17: Y cable too strong**

**E18: Z cable too strong**

The above warnings occur if the cable is installed in too small a loop or it is too close to the sensor. Another possible cause is the use of room-size cables for a frame-size installation. The consequence of strong cables is that the SC24 cannot set the loop gain as accurately. An error indicates that the cables are more than 8 times stronger than the reference installation. Strong cables also give rise to increased dynamic range, so these warnings indicate that the installation can cancel larger fields than in the specifications. If the cables are correct, these errors may occur if the sensor is not correctly placed near the column, but has been moved next to a cable.

**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 SC24 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 SC24 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 SC24 to provide a better cancelling factor.

When you have finished viewing the error messages, press the “Done” button to continue. If there were only warnings, the SC24 starts cancelling immediately. If there were any setup errors, the SC24 goes back to the normal field measurement display, but remains in the “Setup Required” 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 SC24 microcomputer controller takes care of most of the setup problems that used to be encountered by users of the older Spicer Consulting field cancelling systems.

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

<i>Problem</i>	Cancelling “works” but does not improve microscope image
<i>Causes</i>	<ul style="list-style-type: none"><li>- bad image caused by mechanical vibration</li><li>- bad image caused by ground loop in microscope installation</li><li>- bad image caused by internal fault in microscope</li><li>- uncanceled field too small to affect image</li><li>- sensor is in completely the wrong place</li><li>- sensor has been moved after setup</li><li>- sensor is mounted on a vibrating surface</li></ul>

## 8. Performance Specification

### UNITS

Gauss, Tesla, selectable

### FIELD CANCELLING

Co-ordinates

X, Y, Z rectangular Cartesian

Components cancelled

X, Y, Z fields

Dynamic range (X & Y)<sup>NOTE 1</sup>

4.8  $\mu$ T pk-pk (installation Fig. 1)

Dynamic range (Z)<sup>NOTE 1</sup>

3.3 $\mu$ T pk-pk (installation Fig. 1)

#### 1. With Sensor SC24/AC

Field cancelling factor

> 50 X at 50/60 Hz

Bandwidth

2.5 Hz - 5000 Hz

Cancelling noise limit (0.5 to 5000Hz)

0.6 nT RMS total

#### 2. With Sensor SC24/DC+AC

Ambient DC field limit  $\pm$  200  $\mu$ T max

Field cancelling factor

> 100 X at 50/60 Hz

> 400 X at DC (incremental)

Bandwidth

DC - 5000 Hz

Cancelling noise limit (DC to 5000Hz)

0.7 nT RMS total

DC drift<sup>NOTE 3</sup>

< 2 nT/ 24 hours

### FIELD MEASUREMENT

#### Types

Real time field

AC RMS and pk-pk

DC incremental (Sensor SC24/DC+AC)

#### Display

LCD touch screen

See product description

Sensor dynamic range

4.2  $\mu$ T pk-pk

Accuracy<sup>NOTE 2</sup>

$\pm$  1.0 % of reading  $\pm$  0.1 nT

#### X, Y, Z real time field outputs

Scaling

10 V/ $\mu$ T (1.0V/mG)

Range

$\pm$  12 Volts

Source resistance

10 k $\Omega$

Connectors

3 x BNC

Bandwidth

25 Hz - 10 kHz (Sensor SC24/AC )

DC - 10 kHz (Sensor SC24/DC+AC )

### TEST FIELD GENERATOR

Sine wave

AC line frequency (50/60Hz) - line locked

Square wave

0.1, 0.2, 0.5, 1, 2, 5, 10, 20, 50, 100, 200, 500, 1000 Hz

### POWER

120 / 240 V 50/60 Hz, 100 VA

### DIMENSIONS

420 x 300 x 135 mm

### MASS

6.6 Kg

Note 1: Dynamic range is stated with standard cancelling cables.  
Larger range is available for extreme fields with custom cables.  
Dynamic range is stated at the nominal AC power input of 120 or 240 volts RMS  
De-rate linearly for lower voltages

Note 2: Sensors are calibrated with 50 Hz, 1 $\mu$ T RMS square wave field.

Note 3: Drift (@23°C  $\pm$ 2°C, after 2 hour warm-up)

## 9. Appendices

Appendix 1. Magnetic field basics

Appendix 2. Helmholtz coils and frames

Appendix 3. Cancelling factor data

## 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 SC24. 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 Figs. 1, 2 & 3 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 rectangular frame is shown in Fig. 13 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. 13) 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 SC24 in their tool enclosures should consult our support staff for help regarding shorted turns.

Fig. 14 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. 14 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. 13 frame has multiple grooves that can accommodate the cables with plastic cover strips to enable a neat installation to be made.

The field cancelling performance with rectangular frames like Fig. 13 is not as good as with room cable installations like Fig. 1 (page 7) because the uniformity of the field made by the small cable loops is much worse. Much of the problem is because the spacing between the cable loops is bigger than the ideal Helmholtz spacing, resulting in a dip in the field in the centre of the frame.

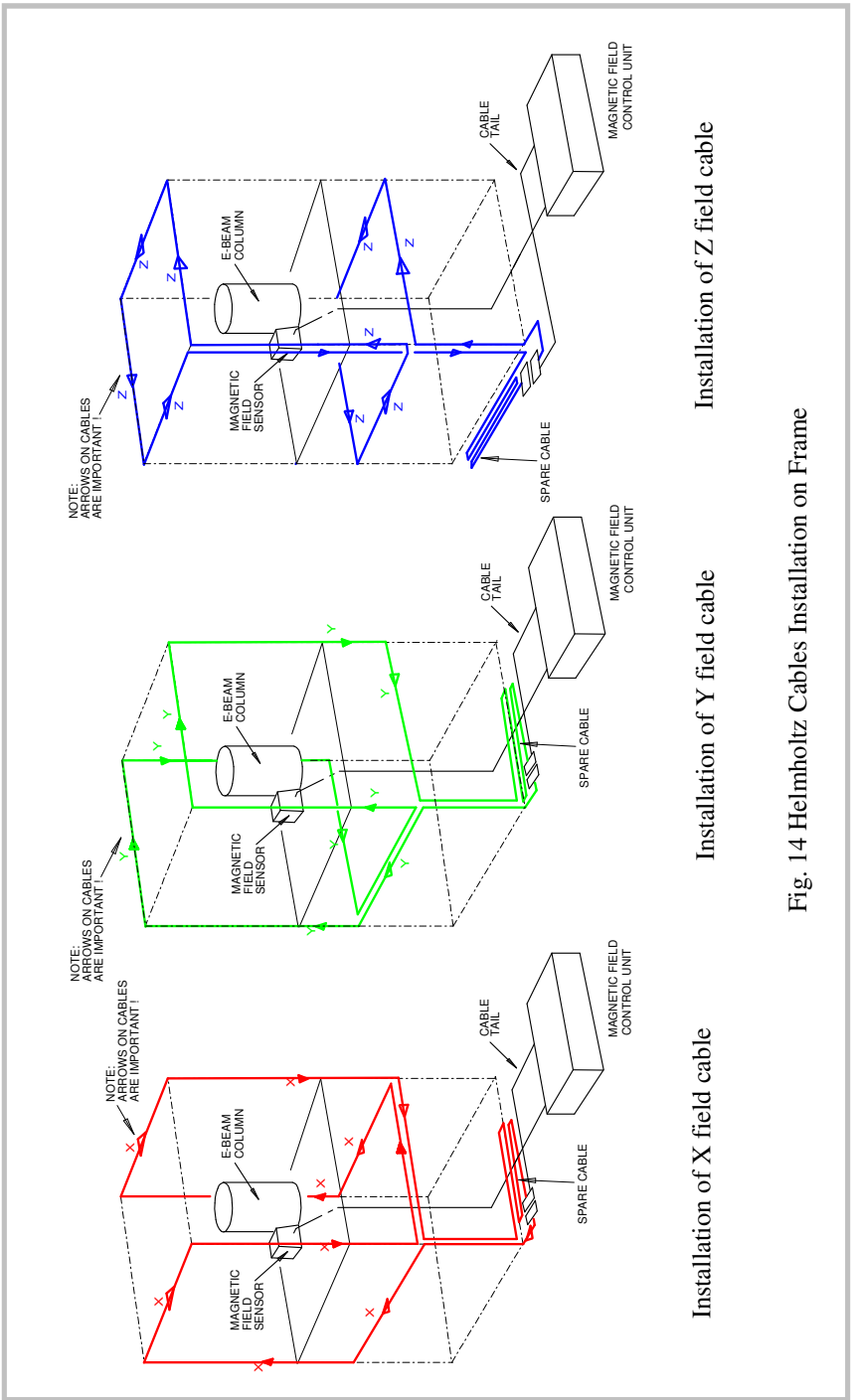
A much better frame shape is the octagonal frame (example in Fig. 15 page 36). With an octagon frame the spacing between the cable loops can be optimum for a uniform field. The example in Fig. 15 is a tall frame for a big TEM. It has four Z cable loops which are un-pluggable for access to the microscope.

Octagon frames can be made with different widths and heights to solve the particular customers field problem. They are very good if the microscope site has very big DC field from trams



Fig. 13 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. 14 Helmholtz Cables Installation on Frame

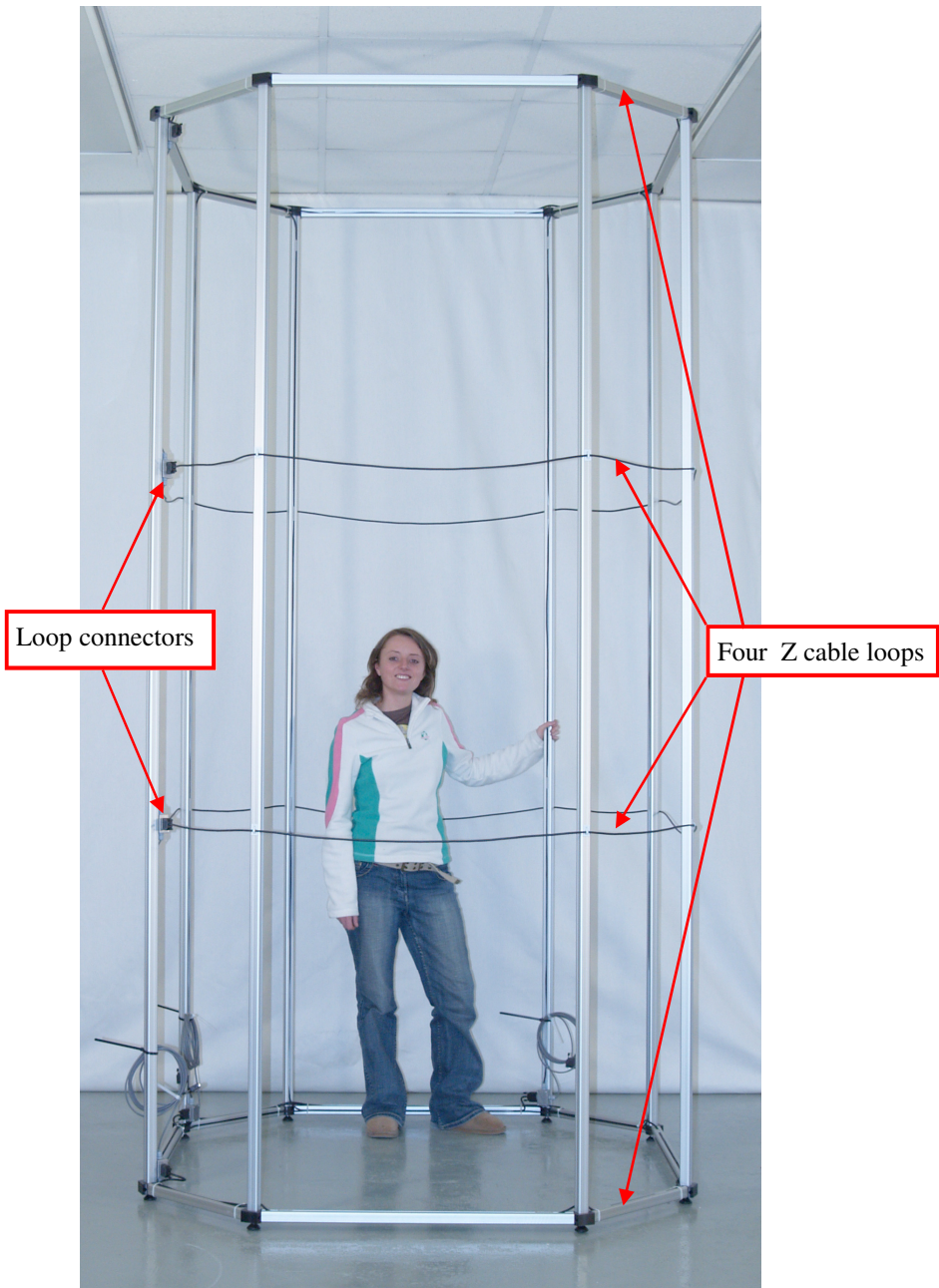


Fig. 15 Octagonal frame for large “stand alone” TEM – height 3 metres

### Appendix 3. Cancelling factor data

The “cancelling factor” is the ratio of the ambient field to the cancelled field. A Graph of the SC24 cancelling factor vs. frequency is below.

