ETS-LINDGREN™
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DESCRIPTION, INSTALLATION and OPERATING GUIDE

for

EMFC-MKIV

E.L.F. MAGNETIC FIELD COMPENSATION SYSTEMS

EMFC-MKIV REV 1. 12/08 Item #206927

Serial # ___________________________

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1. OPERATORS SAFETY SUMMARY

The general safety information in this part of the summary is for both operating and servicing personnel. Specific warnings and cautions will be found throughout the manual where they apply.

1.1 CONFORMANCE TO INDUSTRY STANDARDS

This instrument complies with the following industry safety standards and regulatory requirements.

1.1.1 Safety

CSA: Electrical Bulletin

FM: Electrical Utilization Standard Class 3820

ANSI C39.5 — Safety Requirements for Electrical and Electronic Measuring and Controlling Instrumentation

1.1.2 Regulatory Requirements

VDE 0871 Class B — Regulations for RFI Suppression of High Frequency Apparatus and Installations.

1.2 TERMS

1.2.1 In This Manual

CAUTION statements identify conditions or practices that could result in damage to the equipment or other property.

WARNING statements identify conditions or practices that could result in personal injury or loss of life.

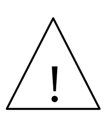
1.2.2 As Marked on Equipment

CAUTION indicates a personal injury hazard not immediately accessible as one reads the markings, or a hazard to property, including the equipment itself.

DANGER indicates a personal injury hazard immediately accessible as one reads the marking.

1.3 SYMBOLS

1.3.1 In This Manual



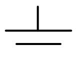
This symbol indicates where applicable cautionary or other information is found.

The CAUTION sign denotes a hazard. It calls attention to an operating procedure, practice, or the like, which, if not correctly performed or adhered to, could result in damage or destruction of part or all of the equipment. Do not proceed beyond a CAUTION sign until the indicated conditions are fully understood and met.

1.3.2 Symbols as Marked on Equipment

ATTENTION — Refer to manual for specific instruction in order to protect the instrument against damage.

Indicates dangerous voltages.



Earth terminal, ground.

1.4 POWER

1.4.1 Power Source

This product is intended to operate from a power source that does not apply more than 130 volts RMS between the supply conductors, or between either supply conductor and ground. A protective ground connection by way of the grounding conductor in the power cord is essential for safe operation.

1.4.2 Grounding the Product

This product is grounded through the grounding conductor of the power cord. To avoid electrical shock, plug the power cord into a properly wired receptacle before connecting to the product input or output terminals. A protective ground connection by way of the grounding conductor in the power cord is essential for safe operation.

1.4.3 Danger Arising From Loss of Ground

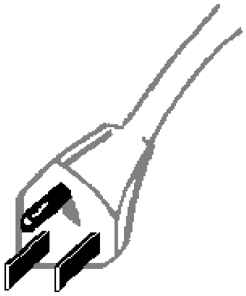
Upon loss of the protective-ground connection, all accessible conductive parts (including knobs and controls that may appear to be insulating) can render an electrical shock.

1.4.4 Use the Proper Power Cord

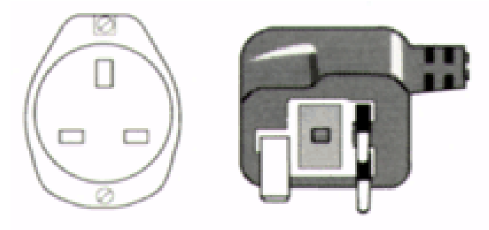
Use only the power cord and connector specified for your product.

Use only a power cord that is in good condition.

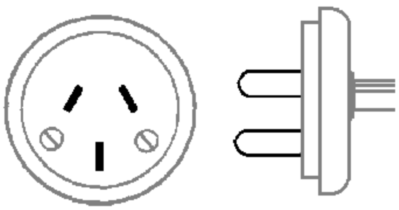
For detailed information on power cords and connectors see Table 1-1.



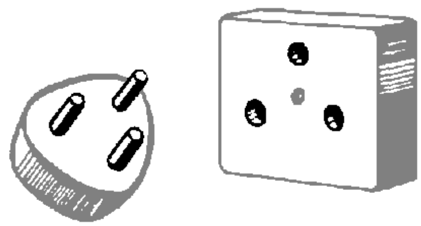
North/South America/Japan
2 blade w/ground pin
120V



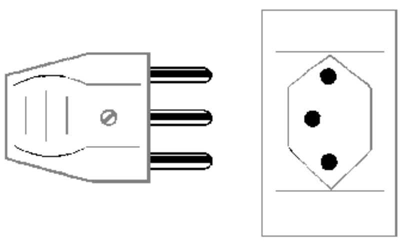
Britain/Ireland/Africa/Asia/India/
2 blades rectangular ground blade
230V



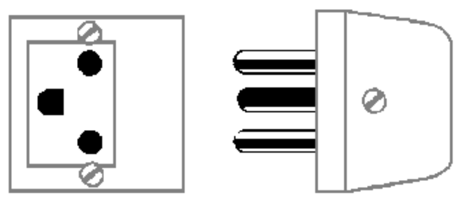
Australia/China/New Zealand/
Argentina 3 blade
240V



Israeli 3-pin/blade
220V



Swiss 3-pin
220V



Danish 3-pin
220V

Table 1-1 International power connector/voltage identification

1.4.5 Use the Proper Fuse

To avoid fire hazard, use only a fuse of the correct type, voltage rating and current rating as specified (normal blow, time delay etc.) on the product panels or in the product parts list. The use of repaired fuses and the short-circuiting of fuseholders must be avoided.

1.4.6 Do Not Operate in Explosive Atmospheres

This product is not certified for operation in an explosive atmosphere.

1.4.7 Do Not Remove Covers or Panels

To avoid personal injury, do not remove the product covers or panels unless qualified to do so. Do not operate the product, except for installation setup calibration by qualified personnel, or place this product in permanent operation without the covers and panels properly installed.

2. SERVICING SAFETY SUMMARY

SERVICING INFORMATION FOR QUALIFIED SERVICE PERSONNEL ONLY
Refer also to the preceding Operators Safety Summary.

2.1 Do Not Service Alone

Any internal adjustment, maintenance, and repair of the opened instrument under voltage should be should be carried out only by a skilled person who is aware of the hazard involved.

It is recommended that internal service or adjustment of this product only be performed when another person capable of rendering first aid and resuscitation is present.

Do not install substitute parts or perform any unauthorized modification to the instrument.

2.2 Use Care When Servicing With Power On

Dangerous voltages exist at several points in this product. To avoid personal injury, do not touch exposed primary circuit connections or components while power is on.

Disconnect power before removing protective panels, soldering, or replacing components.

2.3 Power Source

This product is intended to operate from a power source that does not apply more that 120 (optional 240 volts foreign) RMS between the supply conductors, or between either supply conductor and ground.

Prior to calibration or service requiring powered operation, verify that a protective electrical ground connection exists by way of the grounding conductor in the power cord. Grounding of this product is essential for safe calibration, operation, and power-on servicing.

3. INTRODUCTION

ETS•Lindgren EMFC-MKIV (EMF-Compensating) magnetic field active compensation shielding (MACS) systems are designed to significantly attenuate externally-induced time-varying magnetic fields in a protected volume (PV). Installed system PV's are normally set up to surround instrumentation such as an electron microscope or a production instrument; for example, an e-beam lithographic unit. To accommodate a range of possible applications, the EMFC-MKIV system is offered in two versions: the EMFC-QDC for sites requiring interfering magnetic signal attenuation over the broadest possible spectral range of interfering signals; and the specialized EMFC-AC version for electron microscopy (EM) applications requiring enhanced cancellation in the presence of a.c. mains induced magnetic interference. Designed for general site interference situations, the EMFC-MKIV system is extremely effective in attenuating interfering magnetic field spectra in the range of 800 μHz to 200 Hz (-AC version, 10 Hz to 200 Hz), with substantial reduction to 800 Hz. Environmental magnetic fields of peak-to-peak magnitudes exceeding 10 μT (100 mG) are typically reduced to values less than 50 nT (0.5 mG) peak-to-peak. The EMFC-AC system is designed to be highly effective in attenuating interfering a.c. mains induced magnetic fields within the instrument column for EM sites where a.c. field gradients are severe and extended low-frequency response is not required. EMFC-MKIV systems cancel power line induced "-AC" and "-QDC" external field modulations by direct, broadband processing of axial compensating signals derived from the interfering magnetic field's orthonormal components. With the active shielding system properly set up and operating, a.c.-line-related and environmental field variations are dramatically reduced in the protected volume. Active-feedback magnetic field shielding for instrumentation and production sites is a proven, cost-effective shielding technique that, for a majority of sites, provides significantly greater isocenter field attenuation than moderate levels of expensive passive shielding.

Wideband active magnetic shielding technology developed by ETS•Lindgren is based on the classic engineering principle of phase-compensated negative feedback. In the EMFC-MKIV system, magnetic field sensor feedback signals are appropriately applied as compensating fields to result in significant interfering magnetic field reduction over the entire frequency range affecting electron-beam instruments. Performance of ETS•Lindgren EMFC-MKIV magnetic field compensation systems has been maximized by simulation optimization of the individual sub-systems to achieve the best wideband active-compensation system performance presently available.

EMFC-MKIV systems include a tri-axial probe comprised of orthogonal sensors, a signal processor/amplifier rack cabinet, and a tri-axial arrangement of Helmholtz-configured uniaxial driven coil pairs. Fields detected by the probe axial sensors are phase corrected, inverted and, following power amplification, applied to the corresponding axial coil pair surrounding the PV. When the EMFC-MKIV system closed-loop amplification and offset coefficients have been adjusted at the installation site as specified in this document, interfering magnetic fields within the PV are suppressed by a minimum factor of 30; typically by a factor of 35 or above. Actual field reduction for a given interfering source depends on the source field gradient which is related to the proximity of the object causing the interference. The EMFC-MKIV system can be adjusted for optimal compensation of a specific interference source or for a best compromise between two or more sources.

Because the active-compensation principle employed is strictly that of real-time negative feedback, two significant operational benefits are realized. First, the EMFC-MKIV system is instantaneously adaptive to any time-varying magnetic interference with spectral components lying within its broad passband of approximately 1 millihertz through 1 kilohertz. Spectral and magnitude changes occurring within this range are “automatically” compensated with no significant effect on overall system interference-canceling performance at other frequencies. Second, the depth of field attenuation is essentially constant—once the EMFC-MKIV system has been installed and calibrated to match the PV's intrinsic axial excitation transfer coefficients (ETC's), the system’s interfering field attenuation coefficient remains essentially unchanged. All interfering signals less than the EMFC-MKIV system’s maximum compensation limit (approximately 10uT/100mG, peak) are consistently attenuated below the threshold acceptance value for the protected site.

Installation of the ETS•Lindgren EMFC-MKIV system (described in Section 5 page 23) is straightforward, and the installed active-shielding system compensation coils and system controller will, in most cases, have a negligible impact on room volume or aesthetics. Typically, the driven coils which generate the compensating magnetic field are routed along wall vertices and are non-intrusive; the coils may be installed either during RF-shielded room construction or afterward, for example in surface-mounted PVC conduit. Following placement of the driven coils, the sensor probe is installed in an appropriate location within the compensated volume as defined by (in, *e.g.*, scanning EM use) ion pump magnet fringe field contours and the driven coil pair geometry. The driven coils and probe are then interconnected with the system electronics package.

A proprietary setup algorithm and other selectable test modes incorporated in the EMFC-MKIV controller simplify post-installation operational checks and calibration adjustment of the EMFC-MKIV system. During setup, an internal DIP switch is accessed to invoke a test routine which is used for on-site internal offset zeroing (Note that the other DIP-selectable test routines, such as "Hold" and "Zero" are employed during production test, and are not generally used for installation setup and evaluation). An additional system evaluation mode that facilitates correct axial alignment of EMFC-AC system inductive sensors, is selected by means of a rear panel toggle switch (section 4.2.2 page 17).

Total system components installation time for coils, probe, controller and including setup adjustments is usually less than 1 day. Once setup adjustments have been made for a specific site, the EMFC-MKIV broadband magnetic field compensating system requires no further “fine-tuning” adjustments over the life of the system, even if the spectral and temporal properties of the interfering magnetic fields change significantly. Subsequent major changes in the room layout, however, may require repositioning of the EMFC-QDC field sensing probe, in which case recalibration of the system would be necessary.

ETS•Lindgren EMFC-MKIV system components are fully warranted for one year. Customer support and field service may be obtained through ETS•Lindgren Corporate Headquarters, Glendale Heights, Illinois 60139, USA (+1 630-307-7200) or foreign representatives (see A.6, page **Error! Bookmark not defined.** Worldwide Contact Information).

4. SYSTEM DESCRIPTION

4. SYSTEM DESCRIPTION

4.1 System Components

ETS•Lindgren magnetic field active-compensation-shielding (MACS) EMFC-MKIV feedback systems consist of four major subsections forming a high gain negative-feedback magnetic-field compensation system that senses and suppresses ambient interfering magnetic fields occurring within a wide frequency range. These subsections are the sensor, controller/ processor, power driver and compensating coil sets. Installation details regarding these elements may vary considerably from site to site, so it is important to understand the basic function and operational specifics of each item. This advice particularly applies to performance evaluation and analysis in cases of non-ideal sensor and compensating coils placement, where it is essential to recognize and correct any operational degradation attributable to deviation from the idealized installed geometry.

MACS™ systems are comprised of a high dynamic range compensated tri-axial fluxgate magnetic field sensing probe (or optional inductive sensors for specialized EM applications), multichannel signal processor and controller unit, DC-responding wideband power amplifier and, typically, a Helmholtz-configured magnetic induction coil pair aligned with each of the three orthogonal axes. System frequency response is nominally 0.8 mHz to 800 hertz, with maximum compensation occurring over a central passband of approximately .001 to 200 hertz. The EMFC-QDC system’s extended low-frequency response corresponds to a baseline recovery time of around 15 minutes for small offsets in the site static magnetic environment, and up to several hours for larger field shifts. By compensating “d.c."-like field changes in this manner, the system continuously adapts to the quiescent magnetic environment, over time factoring out non-periodic magnetic environment changes caused by repositioning of moderate-to-large ferromagnetic objects such as cabinets, desks, shelves, etc.

MAGNETIC FIELD SENSOR: EMFC-QDC extended-low-frequency reduction of time-varying ambient fields within the protected volume (PV) is accomplished by sensing the site orthogonal field components at a point inside the PV with a sensitive, low-noise tri-axial magnetometer probe. For the majority of sites, an electrostatically-shielded Bartington Mag-03MC1000 (full-scale range of ±1mT/±10G) is employed (See **Error! Reference source not found.** page **Error! Bookmark not defined.** for specifications); in special circumstances where the protected instrument or equipment requires the lowest possible ambient magnetic field environment with increased compensation resolution, the more sensitive Bartington Mag-03MC100 (f.s. of ±100uT/±1G) may be utilized to attain a significantly reduced digital offset stepsize (requires controller internal modifications, contact ETS-Lindgren for this option). The Bartington 03MC-series tri-axial magnetometers are comprised of three fluxgate sensing elements mounted orthogonally at one end of an electrostatically-shielded cylindrical enclosure that also contains the front-end switching and signal processing circuitry. A 10 pin male Hirose connector is mounted in the opposing end of the probe housing. The position and direction of each sensing element is printed on the sensor body, together with the product code, measurement range and serial number. Each of the sensing elements is precisely aligned along the central axis of the cylinder. Bipolar power for the sensors (±15V) is supplied via a signal cable shielded pair; three wires of two additional shielded pairs are used for the discrete X, Y and Z sensor output signals. For a unit with a full-scale range of ±1mT/±10G, the output voltage of each axis corresponds to a scale factor of 10.0mV/μT (1.0mV/mG) and compliance limit of ±10V. For test purposes, the probe sensor's direct axial output voltages are available at the three I/O BNC rear panel connectors on the system controller unit.

See Section 5.2 page 23 for probe installation details.

SYSTEM CONTROLLER: As the signal "control center" of the EMFC MACS system, the EMFC-MKIV series controller/processor unit (See Appendix A.2.2 for specifications page 36) provides real-time, broadband sensor signal magnitude and phase processing, and exercises the firmware-defined system operational control and recovery protocols.

Magnitude and phase processing of the tri-axial sensor input signals is required to maximize the closed-loop system gain which, in turn, determines the "at-probe" interfering magnetic field compensation (suppression) coefficient. In the EMFC-MKIV system, the three axial channels, X, Y, and Z, are identical and independent. All EMFC-MKIV MACS systems are built for and generally installed as a tri-axial configuration because, even in cases where site interfering fields may have little or no component in one axis, there is a beneficial cross-coupling factor due to the individual coil magnetic field geometries. This cross-coupling factor significantly increases the PV compensation volume for a tri-axial compensation approach compared with a 2-axis system.

Initial adjustment and operation of the EMFC-MKIV system has been simplified by inclusion of a setup algorithm and comprehensive fault monitoring in the controller. Once correctly adjusted for normal operating conditions (i.e., all controller subsystems functioning properly and incident field suppressed to specification), the controller does not normally require further adjustment. Should the ambient field component in any of the three orthogonal axes subsequently exceed the "warn" trip point due to a large increase in the ambient magnetic field or a "soft" equipment failure, indication is given at the EMFC-MKIV front panel and an audible annunciator chimes twice every minute. When in this "warning" state, the system continues to operate. If the apparent ambient magnetic field continues to exceed the affected channel(s) "trip" setpoint(s), the EMFC-MKIV power amplifier is disabled after a delay of approximately 17 seconds and three chimes sound in rapid succession, repeating at approximately thirty-second intervals as long as the ambient level variation exceeds the trip threshold.

To accommodate large step changes in local magnetic fields due to switching the protected instrument or equipment "on" or "off", or abnormal conditions such as a transient power interruption, an auto-recovery sequence has been incorporated into the EMFC-MKIV firmware. Should the system be tripped off by a large-scale magnetic field step, magnetic cycling or repeated power line disturbances lasting longer than approximately 17 seconds, after 18 minutes' delay, the system will twice attempt resetting itself at 1-minute intervals. During the 18 minutes' delay, the controller front panel LEVEL LED will be red (indicating an over-level tripoff), with a 100ms green flash every 1.5 seconds to indicate a delayed reset sequence in progress. This sequence normally permits automatic recovery without operator intervention. A relatively long initial delay has been specified to accommodate EM magnification-change routines which might otherwise induce nuisance EMFC-MKIV trip-offs.

Latched fault indication is provided on the front panel for any transient or steady-state fault affecting one or more of the processor's internal power supplies ["POWER"] or a trip due to overdrive of the power amplifier ["AMPLIFIER"]. Either of these faults, or a persistent magnetic field amplitude trip ["LEVEL"], will, as a safety measure, cause the amplifier to be shut off until it is reset (via front panel RESET pushbutton) by the system operator.

Controller front, rear and internal interconnects, adjustments and indicator functions are described in Sections 4.2.1 through 4.2.3 (pages 13 through 20).

DRIVER AMPLIFIER: High-current drive for the X, Y and Z-axis Helmholtz coil pairs is produced in response to the controller output signal by a three-channel power amplifier (See Appendix A.2.3 for specifications, page 37) co-located with the Controller in the Controller/Power Driver rack cabinet. The amplifier is wideband and d.c.-responding, and provides up to 150 watts peak output per axial channel as configured in the EMFC-MKIV active compensation system. RMS and d.c. current drive limits into the coil load are approximately ±2 amperes, corresponding to a minimum compensation limit of approximately 7 µT/70mG, peak-to-peak, for a standard installation consisting of coils comprised of 15 turns of 18 gauge wire and room size of approximately 15' by 12'.

Setup and operational notes for the Power Driver Amplifier are given in Section 4.2.4 (page 21).

COMPENSATION COILS: Generation of appropriate tri-axial compensating magnetic fields in response to the MACS™ system's compensating drive signals requires, for EMFC-MKIV system installations, two coils per axis of a suitable geometry situated around the protected volume. The planes of the two coils must be parallel and form an adequate approximation of the ideal Helmholtz geometry. Typically, the coils are installed around the vertices of the room, with the plane of each coil including one of two facing room boundary surfaces. In general, the coil pair sizes and spacing are dictated by the room dimensions and define a somewhat extended Helmholtz coil geometry where the separation between the two coils is somewhat greater than the ideal value, which is the average of the two orthogonal coil dimensions. However, this is not problematic since the effectiveness of the installed active-compensation system is approximately constant over a wide range of geometric variation; in practice, EMFC-MKIV system performance is not significantly degraded for coil spacings up to 2x the above-referenced ideal separation distance.

Specification and installation of system magnetic field compensating coils is presented in Section 5.4 (page 24).

4.2 System Controls, Connectors and Indicators

The following descriptions are intended to familiarize the operator with the location and function of the EMFC-MKIV system controls, connectors and indicators. These are also intended to provide a concise reference for the installer and maintenance technician. In all cases, X, Y and Z refer to the individual active-compensation orthogonal axes.

4.2.1 Controller Front Panel

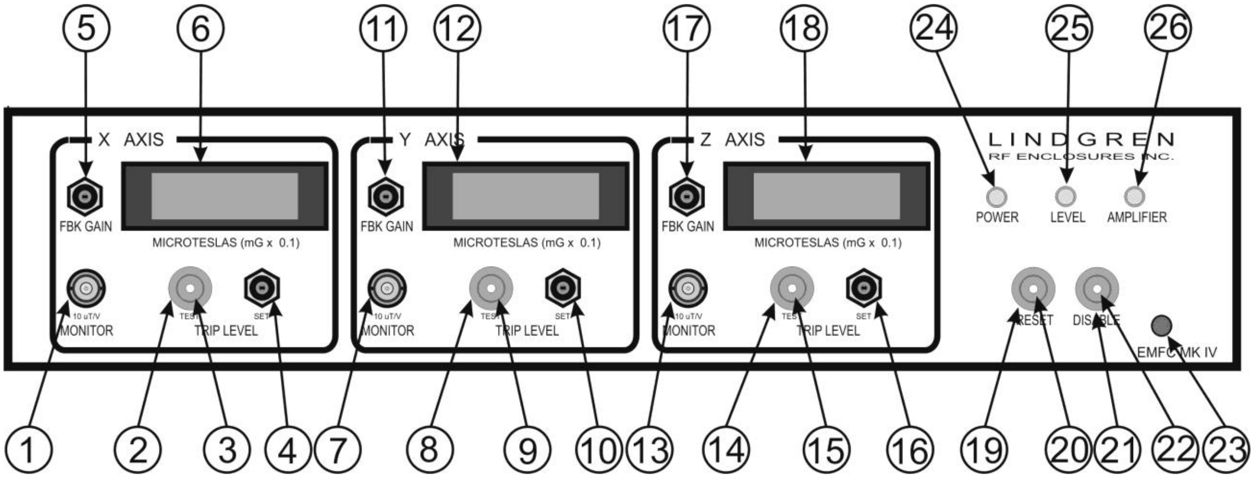


Figure 1, EMFC-MKIV Front Panel

Notes: Small trimpot tool or screwdriver required for recessed adjustments (designations 4, 10 and 16); in late production units, LED's (designations 3, 9, 15, 20 and 22) are located above the pushbutton switches.

(1) X MONITOR Output Connector (BNC F) - A 1V/µT signal corresponding to the post-processed magnetometer X-axis input is available at this testpoint. This monitor signal may be observed at the stated scale factor with high-impedance (> 1 MΩ) loading or with a reduction factor of 10 (-20 dB) into a 50-Ω termination impedance.

(2) X TRIP LEVEL Test Switch - Momentary pushbutton switch which, when depressed, displays the X-axis trip level threshold on the X-AXIS FIELD MAGNITUDE DISPLAY (6) so that it may be adjusted with the X TRIP LEVEL adjustment trimpot (4).

(3) X WARNING Indicator (alternatively located above switch)- A bi-color LED which glows green under normal operating conditions, but changes to red when the magnetic field strength exceeds the warning setpoint level, which is **fixed at 50% of the TRIP LEVEL adjustment value**.

(4) X TRIP LEVEL Adjustment Trimpot - Recessed 15-turn adjustment used to set the X-axis trip level threshold. Readout of the trip level value occurs on the X AXIS DISPLAY (6) when the X TRIP LEVEL TEST SWITCH (2) is depressed. A X-axis magnetic field reading exceeding the trip level setting for longer than approximately 17 seconds will trip off the system on a "LEVEL" fault, with the corresponding "LEVEL" LED (25) switching color from green to red.

(5) X FBK (Feedback) GAIN Adjustment Trimpot - A recessed 15-turn trimpot for adjusting the X-axis feedback loop gain coefficient. This control determines the system maximum "free-space" or ambient field reduction, and is an initial setup adjustment. Its correct final setting is approximately 10% CCW from the point where closed-loop oscillations occur [section 6.8 page 30].

(6) X Display - Nominally displays the X-axis field “absolute peak” value, corresponding to the maximum peak positive or negative X-axis magnitude of the interfering waveform with respect to the static X-axis site magnetic field component. It also displays the X-axis TRIP LEVEL adjustment trimpot (4) setting when the X TRIP LEVEL Test Switch (2) is depressed. Averaged X-axis field values may be displayed by internal jumper selection (jumper is located beneath Z-axis Panel Meter, see Figure 3 page 17).

(7) Y MONITOR Output Connector (BNC F) - A 1V/µT signal corresponding to the post-processed magnetometer Y-axis input is available at this testpoint. This monitor signal may be observed at the stated scale factor with high-impedance (> 1 MΩ) loading or with a reduction factor of 10 (-20 dB) into a 50-Ω termination impedance.

(8) Y TRIP LEVEL Test Switch - Momentary pushbutton switch which, when depressed, displays the Y-axis trip level threshold on the Y-AXIS FIELD MAGNITUDE DISPLAY (6) so that it may be adjusted with the Y TRIP LEVEL adjustment trimpot (8).

(9) Y WARNING Indicator (alternatively located above switch) - A bi-color LED which glows green under normal operating conditions, but changes to red when the magnetic field strength exceeds the warning setpoint level, which is **fixed at 50% of the TRIP LEVEL adjustment value**.

(10) Y TRIP LEVEL Adjustment Trimpot - Recessed 15-turn adjustment used to set the Y-axis trip level threshold. Readout of the trip level value occurs on the Y AXIS DISPLAY (12) when the Y TRIP LEVEL TEST SWITCH (8) is depressed. A Y-axis magnetic field reading exceeding the trip level setting for longer than approximately 17 seconds will trip off the system on a "LEVEL" fault, with the corresponding "LEVEL" LED (25) switching color from green to red.

(11) Y FBK (Feedback) GAIN Adjustment Trimpot - A recessed 15-turn trimpot for adjusting the Y-axis feedback loop gain coefficient. This control determines the system maximum “free-space” or ambient field reduction, and is an initial setup adjustment. Its correct final setting is approximately 10% CCW from the point where closed-loop oscillations occur [section 6.8 page 30].

(12) Y Display - Nominally displays the Y-axis field “absolute peak” value, corresponding to the maximum peak positive or negative Y-axis magnitude of the interfering waveform with respect to the static Y-axis site magnetic field component. It also displays the Y-axis TRIP LEVEL adjustment trimpot (10) setting when the Y TRIP LEVEL Test Switch (8) is depressed. Averaged Y-axis field values may be displayed by internal jumper selection (jumper is located beneath Z-axis Panel Meter, see Figure 3, page 20).

(13) Z MONITOR Output Connector (BNC F) - A 1V/µT signal corresponding to the post-processed magnetometer Z-axis input is available at this testpoint. This monitor signal may be observed at the stated scale factor with high-impedance (> 1 MΩ) loading or with a reduction factor of 10 (-20 dB) into a 50-Ω termination impedance.

(14) Z TRIP LEVEL Test Switch - Momentary pushbutton switch which, when depressed, displays the Z-axis trip level threshold on the Z-AXIS FIELD MAGNITUDE DISPLAY (18) so that it may be adjusted with the Z TRIP LEVEL adjustment trimpot (16).

(15) Z WARNING Indicator (alternatively located above switch) - A bi-color LED which glows green under normal operating conditions, but changes to red when the magnetic field strength exceeds the warning setpoint level, which is **fixed at 50% of the TRIP LEVEL adjustment value**.

(16) Z TRIP LEVEL Adjustment Trimpot - Recessed 15-turn adjustment used to set the Z-axis trip level threshold. Readout of the trip level value occurs on the Z AXIS DISPLAY (18) when the Z TRIP LEVEL TEST SWITCH (14) is depressed. A Z-axis magnetic field reading exceeding the trip level setting for longer than approximately 17 seconds will trip off the system on a "LEVEL" fault, with the corresponding "LEVEL" LED (25) switching color from green to red.

(17) Z FBK (Feedback) GAIN Adjustment Trimpot - A recessed 15-turn trimpot for adjusting the Z-axis feedback loop gain coefficient. This control determines the system maximum "free-space" or ambient field reduction, and is an initial setup adjustment. Its correct final setting is approximately 10% CCW from the point where closed-loop oscillations occur [section 6.8 page 30].

(18) Z Display - Nominally displays the Z-axis field "absolute peak" value, corresponding to the maximum peak positive or negative Z-axis magnitude of the interfering waveform with respect to the static Z-axis site magnetic field component. It also displays the Z-axis TRIP LEVEL adjustment trimpot (16) setting when the X TRIP LEVEL Test Switch (14) is depressed. Averaged Z-axis field values may be displayed by internal jumper selection (jumper is located beneath Z-axis Panel Meter, see Figure 3, page 20).

(19) RESET Switch - Resets the unit from any state to the initial ***Acquire*** state. Refer to section 7.3.1, "EMFC-MKIV Controller Operational States" (page 33).

(20) RESET Indicator (alternatively located above switch) - A bi-color LED which indicates the current state and the operating conditions of the unit. It will normally be green (solid or flashing) unless the unit is in the ***Disabled*** state, when it will be red flashing (to indicate that depressing the associated switch will re-enable the system). [Table 1, EMFC-MKIV Controller Operational States, page 32]

(21) DISABLE Switch - Disables the EMFC-MKIV by putting it in the ***Disabled*** state. Refer to section7.3.4, "EMFC-MKIV Controller Operational States".

(22) DISABLE Indicator (alternatively located above switch) - A bi-color LED that indicates the current state and the operating conditions of the unit. It will normally be green (solid or flashing) unless the unit is in the ***Disabled*** state, when it will be red solid. [Table 1, EMFC-MKIV Controller Operational States, page 32]

(23) Display Intensity Sensor - A photosensor which measures the ambient lighting conditions and adjusts the intensity of the front panel displays, if the system is set up for display dimming in low-light conditions (see section 6.5.10, page 28). Adjustment is via rear panel 15-turn recessed trimpot INTEN (42) .

(24) POWER Indicator - A bi-color LED which shows the detection of any fault conditions in the internal power supplies. This LED will normally be green. If any transient or steady-state faults are detected in the power supplies, it will be red. Actuating the **RESET Switch (16)** is required to clear this condition. This indicator will flash at 2 Hz if the system is in any calibration or test mode via rear panel X, Y NULL switch (40) or internal DIP switch (52).

(25) LEVEL Indicator - A bi-color LED which shows the detection of a magnetic field amplitude trip. This LED will normally be green. If any transient or steady-state magnetic field trips are detected, it will be red. Actuating the **RESET Switch (16)** is required to clear this condition. This indicator will flash at 2 Hz if the system is in any calibration or test mode via rear panel X, Y NULL switch (40) or internal DIP switch (52).

(26) AMPLIFIER Indicator - A bi-color LED which shows the detection of a trip due to overdrive of the power amplifier. This LED will normally be green. If any transient or steady-state overdrive trips are detected, it will be red. Actuating the **RESET Switch (16)** is required to clear this condition. This indicator will flash at 2 Hz if the system is in any calibration or test mode via rear panel X, Y NULL switch (40) or internal DIP switch (52).

4.2.2 Controller Rear Panel

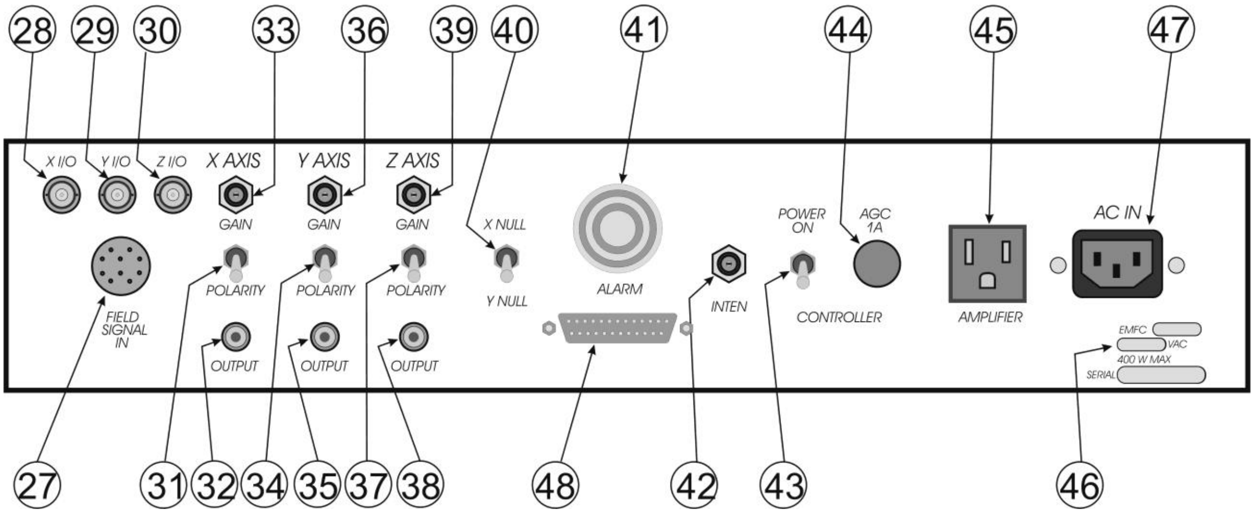


Figure 2, EMFC-MKIV RMC Rear Panel

Note: Rear panels of the standard EMFC and –RMC versions are identical except for addition of I/O connector (48) for –RMC version.

(27) FIELD SIGNAL IN - The MAG-03 tri-axial fluxgate magnetic field sensing probe is plugged into this connector.

(28) X I/O Input/Output Connector (BNC F) – When the MAG-03 fluxgate probe is connected, this BNC connector can be used to monitor the probe's X AXIS signal ($R_{Load} \geq 10K\ \Omega$). If the MAG-03 probe is not connected, this connector can be used to connect an input signal from a different type of probe, or to inject a test signal ($V_{INmax} \leq 10Vpp$).

(29) Y I/O Input/Output Connector (BNC F) - When the MAG-03 fluxgate probe is connected, this BNC connector can be used to monitor the probe's Y AXIS signal ($R_{Load} \geq 10K\ \Omega$). If the MAG-03 probe is not connected, this connector can be used to connect an input signal from a different type of probe, or to inject a test signal ($V_{INmax} \leq 10Vpp$).

(30) Z I/O Input/Output Connector (BNC F) - When the MAG-03 fluxgate probe is connected, this BNC connector can be used to monitor the probe's Z AXIS signal ($R_{Load} \geq 10K\ \Omega$). If the MAG-03 probe is not connected, this connector can be used to connect an input signal from a different type of probe, or to inject a test signal ($V_{INmax} \leq 10Vpp$).

(31) X POLARITY Switch - This switch changes the polarity of the X AXIS signal being fed into the controller. The polarity depends on the installation direction of the probe and coil pair, and the correct position of this switch will be determined during the setup procedure [section 6.9, page 30]. This switch has no effect on the signal seen on the **X I/O Input/Output Connector (28).**

(32) X OUTPUT (RCA F) - The X-axis cable that connects to the separate **DRIVER AMPLIFIER Channel 1 Input Connector is** plugged into this connector.

(33) X AXIS GAIN Adjustment Trimpot - A rear panel trimpot is provided for additional channel gain adjustment range. It may be used, if desired, to position the optimal front panel GAIN trimpot setpoint at a desired percentage of full-scale value. For large protected volume installations (greater than ca 100m^3), where the nominal full-scale value of the front panel GAIN trimpot adjustment may not provide adequate range to achieve an oscillation condition, CW adjustment of the rear panel trimpot provides the additional system gain required for this setup step. This trimpot is preset during manufacturing calibration/QC to its midpoint (8 turns CW from fully CCW), and is normally left at that setting for a majority of installation situations.

(34) Y POLARITY Switch - This switch changes the polarity of the Y AXIS signal being fed into the controller. The polarity depends on the installation direction of the probe and coil pair, and the correct position of this switch will be determined during the setup procedure [section 6.9 page 30]. This switch has no effect on the signal seen on the **Y I/O Input/Output Connector (29).**

(35) Y OUTPUT - The Y-axis cable that connects to the separate **DRIVER AMPLIFIER Channel 2 Input Connector is** plugged into this connector.

(36) Y AXIS GAIN Adjustment Trimpot - A rear panel trimpot is provided for additional channel gain adjustment range. It may be used, if desired, to position the optimal front panel GAIN trimpot setpoint at a desired percentage of full-scale value. For large protected volume installations (greater than ca 100m^3), where the nominal full-scale value of the front panel GAIN trimpot adjustment may not provide adequate range to achieve an oscillation condition, CW adjustment of the rear panel trimpot provides the additional 30system gain required for this setup step. This trimpot is preset during manufacturing calibration/QC to its midpoint (8 turns CW from fully CCW), and is normally left at that setting for a majority of installation situations.

(37) Z POLARITY Switch - This switch changes the polarity of the Z AXIS signal being fed into the controller. The polarity depends on the installation direction of the probe and coil pair, and the correct position of this switch will be determined during the setup procedure [section 6.9, page 30]. This switch has no effect on the signal seen on the **Z I/O Input/Output Connector (30).**

(38) Z OUTPUT - The X-axis cable that connects to the separate **DRIVER AMPLIFIER Channel 3 Input Connector is** plugged into this connector.

(39) Z AXIS GAIN Adjustment Trimpot - A rear panel trimpot is provided for additional channel gain adjustment range. It may be used, if desired, to position the optimal front panel GAIN trimpot setpoint at a desired percentage of full-scale value. For large protected volume installations (greater than ca 100m^3), where the nominal full-scale value of the front panel GAIN trimpot adjustment may not provide adequate range to achieve an oscillation condition, CW adjustment of the rear panel trimpot provides the additional system gain required for this setup step. This trimpot is preset during manufacturing calibration/QC to its midpoint (8 turns CW from fully CCW), and is normally left at that setting for a majority of installation situations.

(40) X NULL/(NORM)/Y NULL Test Switch – This switch selects either normal operation (center position) or one of two test mode positions ("X NULL" or "Y NULL). The purpose of this test mode is to facilitate orthogonality adjustment in the case where the optional EMFC-AC separate X and Y EM column-mounted inductive sensors are employed (see section 6.9, page 30). When this switch is in either "NULL" test mode position, the Controller front panel status indicator LED's (24, 25, 26) flash at a 2Hz rate.

(41) ALARM Annunciator – This component provides an audible signal to alert the operator of the following conditions:

- **Acquire –** The EMFC-QDC is in a baseline acquisition mode. The alarm pattern is two tone bursts separated by a 0.7 second interval, then a 1.5 second interval and then 2 tone bursts separated by a 1 second interval.

- **Warning –** The magnetic field level has reached 50% of the level set by the **X, Y or Z TRIP LEVEL Adjustment Trimpot (4, 10, 16)**. The alarm pattern is two 1.6 second tone bursts followed by a quiet period of 108 seconds.

- **Trip –** The magnetic field has reached the level set by the **X, Y or Z TRIP LEVEL Adjustment Trimpot (4, 10, 16)**. The alarm pattern is 3 quick tones, followed by a quiet period of 50 seconds.

(42) INTEN Control - Sets the brightness of the front panel displays under current ambient lighting conditions as detected by the **Display Intensity Sensor (23)**. Adjustment of this trimpot to its fully CW position will cause the displays to remain at full intensity (note: if displays blank under a high illumination condition, turn the INTEN CONTROL trimpot adjustment CCW until the displays unblank and remain at full intensity).

(43) POWER Switch – Turns controller power on and off. UP position is ON; DOWN position is OFF. This switch also controls power to the amplifier module. (The amplifier also has its own power switch.) When power is initially applied, the EMFC-MKIV will go through its power-up and baseline acquisition sequence (approximately 5 seconds).

(44) FUSE – Contains the AC power fuse (1Ampere for 100/120V systems; ½ Ampere for 220/240V systems). Caution: unplug controller from a.c. line before replacing the fuse.

(45) AMPLIFIER AC Power Output Connector – Provides AC power to the amplifier module.

The amplifier must be plugged into this Controller unit socket and NOT directly to the power line. Proper functioning and safety of the MACS system installation requires that the EMFC-MKIV controller switch AC power to the amplifier.

(46) AC Voltage Rating Nameplate – Specifies the nominal AC operating voltage for which the controller has been internally wired at the factory. Do not attempt to rewire the unit on-site to change the operating voltage as this may create an unsafe condition and will void the safety certification.

(47) AC Input Connector (IEC M) – Provides the connection point for the AC power source to the controller. Verify the unit input voltage and fuse ratings before connecting to a.c. supply mains.

(48) Serial Port (D-Sub 25S)– (Option) provides galvanically-isolated control connection for remote operation of RESET, DISABLE functions and remote monitoring of X, Y, Z, PWR, LVL, AMP TRIP and XYZ WRN (warn) status. Pinouts and I/O electrical specifications appear in Appendix A.5, page 43)

4.2.3 Controller, Internal

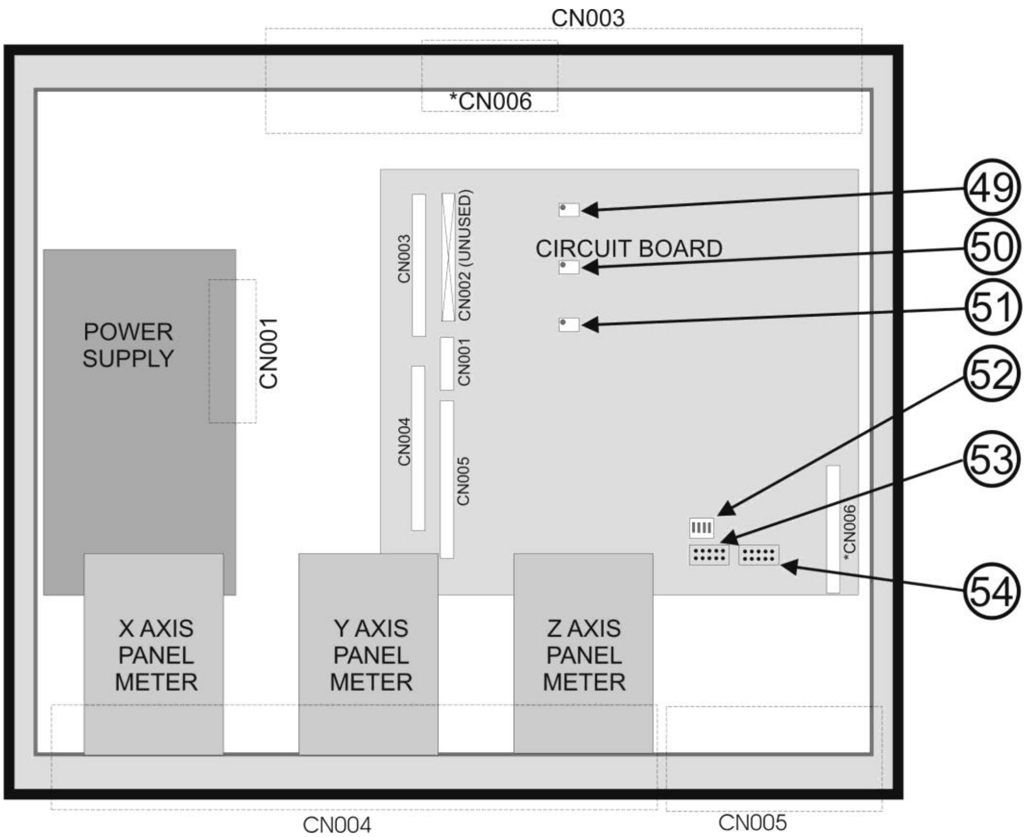


Figure 3, EMFC-MKIV Internal

(49) X-AXIS DC OFFSET Control - This 25 turn trimpot is used to null the DC offset voltage appearing on the X-axis (Channel 1) output of the Driver Amplifier. See section 6.9 (page 30) for adjustment procedure.

(50) Y-AXIS DC OFFSET Control - This 25 turn trimpot is used to null the DC offset voltage appearing on the Y-axis (Channel 2) output of the Driver Amplifier. See section 6.9 (page 30) for adjustment procedure.

(51) Z-AXIS DC OFFSET Control - This 25 turn trimpot is used to null the DC offset voltage appearing on the Z-axis (Channel 3) output of the Driver Amplifier. See section 6.9 (page 30) for adjustment procedure.

(52) TEST MODE Switches - This 4-position DIP switch is used to enable various test modes of the EMFC-MKIV. In normal operation, all 4 switches should be in the OPEN position. The 4 positions (as labeled on the circuit board) are:

OPT – This switch position is not used on the EMFC-MKIV.

TEST – This switch increases the clock rate of the digital integrator from the normal rate of 0.019 Hz to 305 Hz. It is used when the **DC OFFSET Trimpots (49, 50, 51)** are being adjusted, so that the system will respond and settle to a new adjustment value within 5 seconds.

ZERO – This switch forces the output voltage of the DAC's (Digital-to-Analog Converters, on main p.c.b.) to their nominal "zero" value. This mode is mainly used for production debug and calibration.

HOLD – This switch disables the digital integrator clock, causing the DAC's to maintain the voltage output at the time the switch is activated. This mode is mainly used for production debug and calibration.

If any of the switches are in their TEST MODE position (not OPEN), the front panel **POWER Indicator (24), LEVEL Indicator (25),** and **AMPLIFIER Indicator (26)** status LED's will flash at a 2 Hz rate. When flashing to indicate a TEST mode, the LEDs are illuminated for 400 msec and dark for 100 msec.

(54) DIGITAL CONTROLLER Programming Connector - This 10-pin connector is used to reprogram the Altera PLD that is used for the Digital Controller. The connector attaches to an Altera Bit-Blaster or Byte-Blaster.

(55) DIGITAL INTEGRATOR Programming Connector - This 10-pin connector is used to reprogram the Altera PLD that is used for the Digital Integrator. The connector attaches to an Altera Bit-Blaster or Byte-Blaster.

4.2.4 Power Driver

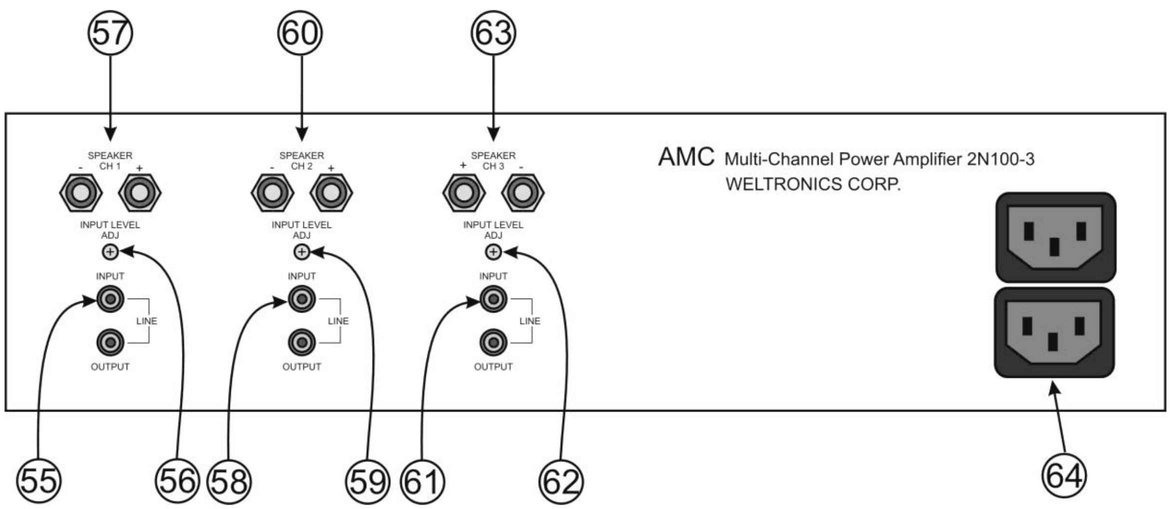


Figure 4, Power Driver Rear Panel

(55) CHANNEL 1 (X-AXIS) AMPLIFIER Input Connector (RCA F) – Signal input to the power amplifier. This RCA jack connects to the **X Output Connector (32)** on the controller.

(56) CHANNEL 1 (X-AXIS) AMPLIFIER Gain Control – This single-turn potentiometer should be set to maximum (fully clockwise). Normally, the Driver Amplifier is supplied with this control factory-sealed to its fully CW position.

(57) CHANNEL 1 (X-AXIS) AMPLIFIER Output Connectors (Binding Post Pair) – Signal output from Channel 1 of the Power Driver Amplifier. The two endpoints of the X-axis Helmholtz compensation coil pair are connected here.

(58) CHANNEL 2 (Y-AXIS) AMPLIFIER Input Connector (RCA F) – Signal input to the power amplifier. This RCA jack connects to the **Y Output Connector (35)** on the controller.

(59) CHANNEL 2 (Y-AXIS) AMPLIFIER Gain Control – This single-turn potentiometer should be set to maximum (fully clockwise). Normally, the Driver Amplifier is supplied with this control factory-sealed to its fully CW position.

(60) CHANNEL 2 (Y-AXIS) AMPLIFIER Output Connectors (Binding Post Pair) – Signal output from Channel 2 of the Power Driver Amplifier. The two endpoints of the Y-axis Helmholtz compensation coil pair are connected here.

(61) CHANNEL 3 (Z-AXIS) AMPLIFIER Input Connector (RCA F) – Signal input to the power amplifier. This RCA jack connects to the **Z Output Connector (38)** on the controller.

(62) CHANNEL 3 (Z-AXIS) AMPLIFIER Gain Control – This single-turn potentiometer should be set to maximum (fully clockwise). Normally, the Driver Amplifier is supplied with this control factory-sealed to its fully CW position.

(63) CHANNEL 3 (Z-AXIS) AMPLIFIER Output Connectors (Binding Post Pair) – Signal output from Channel 3 of the Power Driver Amplifier. The two endpoints of the X-axis Helmholtz compensation coil pair are connected here.

(64) AMPLIFIER Power Connection (IEC M) – The power cord from the **EMFC-MKIV Controller AC Power Output Connector (45)** is attached to this socket to provide AC power to the amplifier.

CAUTION: The power **must** come from the **AMPLIFIER AC Power Output Connector (45).** Do not connect directly to the site a.c. power mains. Proper functioning and safety of the MACS system installation requires that the EMFC-MKIV controller switch AC power to the amplifier.

5. INSTALLATION

5. INSTALLATION

5.1 System Layout

An EMFC-MKIV active-shielded site installation consists of a tri-axial fluxgate probe, a rack cabinet with an EMFC-MKIV controller and power amplifier module installed, and three orthogonal sets of Helmholtz coil pairs, usually positioned along the room vertices. For sites with closely spaced MACS protected volumes (PV's), non-conducting coil support frameworks may be employed.

5.2 Magnetic Field Sensor

A shielded version of the Bartington MAG03 tri-axial magnetometer probe is normally used. Optionally, for specialized EM applications, an EMFC-AC system is available which employs an inductive sensor set (contact factory for specification and installation details, see A.6 page **Error! Bookmark not defined.**).

Fluxgate probe installation for EMFC-MKIV systems is straightforward since the three axial sensors are pre-aligned with respect to each other and the epoxy probe casing, and the probe is supplied pre-aligned in its compensation coil assembly. Typically, the probe is mounted from the floor or ceiling but may also be mounted on the protected instrument or equipment if space permits. Best overall field cancellation occurs when the probe is located close to the center of the PV, as defined by the coil planes; note, however, that in any site installation the probe should be located at least 0.5 into the PV from the nearest Helmholtz coil cabling to avoid excessive axial cross- coupling.

It is also important to note that system performance is enhanced when the probe assembly is maximally distant from conductive sheets (i.e., walls of the r.f.-shielded enclosure or large metal cabinets). Maximizing this spacing reduces potentially destabilizing eddy-current effects. Location of the probe should also be maximized with respect to large ferromagnetic objects which may distort magnetic fields in the PV and introduce unwanted axial cross-coupling terms. Although these considerations are not critical for a majority of installations, in no event should the probe be mounted within 0.5 m of ferromagnetic objects or conductive surfaces, and the probe should be located no closer than 1 meter to the Controller/Driver rack chassis or any power transformer located within a.c. mains powered equipment.

5.3 Controller/Power Driver

Location of the EMFC-MKIV Controller/Power Driver rack chassis is permissible either within the PV or external to it and, generally, placement of this chassis is non-critical. However, because the Controller/Driver rack chassis assembly contains substantial ferromagnetic material, it should not be placed in close proximity to objects producing a strong local magnetic field.

At the rear of the EMFC-MKIV controller, connect the Bartington MAG-03 1000 probe cable plug [10 pin "Hirose"] to the **MAG-03 IN Connector (27)**. Connect the power input cord, power amplifier a.c. plug, and controller rear panel signal output cable to appropriate mating sockets. (Note: these interconnecting cables are normally provided as installed items on factory-supplied systems.) With the Controller rear panel **POWER Switch (43)** in the "OFF" (down) position, connect the a.c. line cord to an appropriate power outlet.

5.4 Helmholtz Coils

Compensation coils are normally installed along the vertices of the r.f.-shielded room containing the instrument to be protected from stray fields, although in special situations where a smaller, isolated local PV is required a frame constructed of non-conducting materials may be employed. Two similar-sized coils comprising a Helmholtz pair are required for each axis. Since the MACS compensation coils operate at non-hazardous voltages, they may be built-in directly with or without non-conducting conduit during room construction or plastic surface conduit may be added after the fact. Note: **any conduit containing coil cabling must be non-conducting or include a non-conducting isolation section** to avoid creating a "shorted turn" that would cause severe closed-loop instability and thus prevent field cancellation.

Electrical arrangement of the coils is preferably series-connected; in a typical site installation, a lead pair from each of the 6 individual coils is routed back to the controller location.

Recommended standard cabling for construction of the EMFC-MKIV coils is PVC-clad multiconductor control cable, consisting of 15 conductors of 18 gauge stranded wire. The conductors are cross-connected by means of 15-pin Molex or equivalent male/female plug sets to obtain a 15-turn coil assembly, as illustrated below:

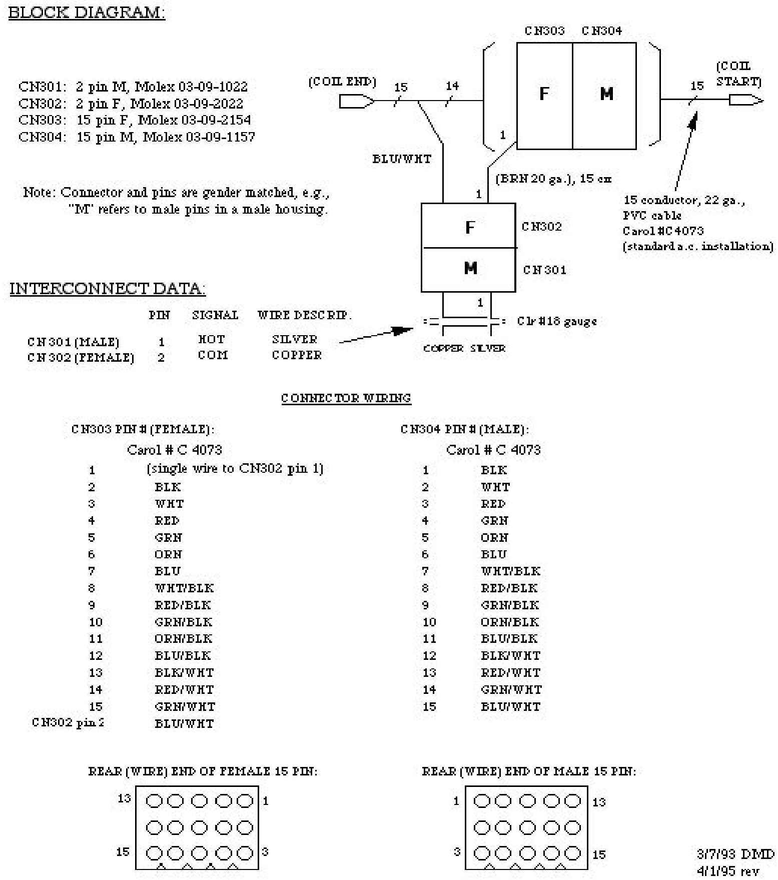


Figure 5 Helmholtz Coils Interconnections

Correct phasing of the individual coils in each axial pair is essential for proper operation of the system. Once connected as a Helmholtz pair, each coil's field vector, as seen at the coil center, must point in the same direction. After determining the correct wire phasing for same-sense current flow in each coil (current flow of both coils in same circular direction when observed from any imaginary point external to the PV on the coil pair axial centerline), the Helmholtz centerpoint splices are then made with wirenuts or similar non-permanent splicing devices, and red/black banana plugs are attached to the coil endpoint wires.

For installations requiring peak compensation fields in excess of 10 µT/100mG, cable comprised of 16 gauge or heavier wire should be substituted in place of the lighter 18 gauge cable normally specified, or, less ideally from the standpoint of driver amplifier dissipation and compensating field uniformity, two parallel-connected cable-turns per coil of standard 15-conductor 18 gauge cable may be used.

All wiring between the coils and amplifier should be 18 gauge "zip" cord, and the multiconductor cables of the Helmholtz coils must be placed in non-conductive plastic raceways or conduit. Carefully note all wire polarities to insure proper phasing of the individual coils (the "hot" wire of the zip cord is marked with a ridge or ridges, or if clear "audio speaker" zip cord is employed, identify the silver conductor as "hot"), and install red ("hot") and black (common) banana plugs on the zip cord conductors. Coils may be series- or parallel-connected, depending on actual coil impedances, to achieve a combined impedance in the range of 4 to 35 ohms. Series connection is preferred from a diagnostic and power dissipation perspective, while parallel connection can be resorted to in larger rooms where higher effective open loop gain and greater maximum compensating fields are required.

With the EMFC-MKIV controller power OFF or with the controller in "DISABLED" mode, plug wires from the Helmholtz coils into the Driver Amplifier output rear panel red/black (+/-) binding post pairs **(57, 60, 63)**, paying careful attention to the coil channel i.d.'s.

6. FINAL INSTALLATION and SETUP

6.1 Safety Considerations

6.2 Required Test Equipment and Tools

Required Test Equipment and Tools

The following equipment is necessary to install and adjust the EMFC-MKIV Controller and Amplifier:

1. Oscilloscope
2. DVM (4½ digit)
3. Adjustment Tool (or small flat-blade screwdriver)

For initial setup, a dual-channel oscilloscope should be connected to the front panel "monitor" BNC receptacle corresponding to the axis being adjusted. Note that the EMFC-MKIV controller monitor output [front panel BNC] scale factor is 1 µT (10 mG) per volt.

6.3 Initial Physical Setup

During the initial setup, access to controls on the internal printed circuit board is required. This requires removing the controller from the cabinet.

Disconnect all cables from the rear of the controller. Remove the mounting screws from the front panel of the controller and slide the controller out of the cabinet. Put a cloth or cardboard on top of the cabinet to protect the surface; then place the controller on top of the cabinet. Take the top cover off of the controller by removing the screws around the perimeter of the panel.

6.4 Initial Cabling

With the controller on top of the cabinet, make the following connections:

1) Connect the controller **X, Y and Z OUTPUTS (32, 35, 38)** to the **AMPLIFIER CHANNEL 1, 2 and 3 INPUTS (55, 58, 61)**.

2) Connect the ends of the Helmholtz compensating coils to the **AMPLIFIER CHANNEL 1, 2 and 3 OUTPUTS (57, 60, 63).**

3) Connect the amplifier power cord from the **AMPLIFIER AC Connector (47)** to the **Controller AC Power Output Connector (45) .**

CAUTION: The amplifier power MUST come from the controller; DO NOT connect the amplifier directly to wall power.

4) Connect the Bartington probe cable to the **MAG-03 IN Connector (27).**

5) Connect AC power to the **AC INPUT Connector (47).**

CAUTION: Be sure that the controller **POWER switch (36)** is in the OFF position before connecting the controller to AC power.

6.5 Initial Control Settings

Before starting the calibration process, verify the setpoints of the following controls:

1) **X FBK (Feedback) GAIN Control (5), Y FBK (Feedback) GAIN Control (11), Z FBK (Feedback) GAIN Control (17)** – Preset these 15-turn trimpots to their minimum setting positions by adjusting at least 16 turns CCW.
2) **X TRIP LEVEL Adjustment Trimpot (4), Y TRIP LEVEL Adjustment Trimpot (10), Z TRIP LEVEL Adjustment Trimpot (16)** – These trimpots are factory preset to 1.5 microtesla. Verify setpoints by depressing the associated **TRIP LEVEL** pushbutton switches **(2, 8, 14)** and adjust for display readings of 1.5µT (15mG) if necessary. Do not adjust to a lower value at this time; the appropriate tripoff threshold adjustment will be made later.
3) **X AXIS GAIN Adjustment Trimpot (33), Y AXIS GAIN Adjustment Trimpot (36), Z AXIS GAIN Adjustment Trimpot (39)** – Verify that these 15-turn rear panel trimpots are all preset at 8 turns CW from fully CCW.
4) **X, Y, Z POLARITY Switches (31, 34, 37)** – Preset all of these in the "UP" position. The appropriate final positions will be determined during the setup procedure.
5) **X NULL / Y NULL Switch (40)** – This should be set to NORM, its center position.
6) **INTEN Control (42)** – Preset the intensity control is factory preset fully clockwise and later readjust following installation for ambient light conditions found on site.
7) **POWER Switch (43)** – This should be in the OFF (down) position until the installer is instructed to turn the power on for setup adjustments, below.
8) **AMPLIFIER GAIN Controls (56, 59, 62)** – These controls should be fully CW (maximum gain position). Verify that the controls are turned fully CW and have been fixed in that position by application of silicone rubber adhesive.

6.6 Survey Probe Setup

A magnetic field survey system consisting of two survey probes with logging capability is helpful although not essential for system setup. Its primary utility is for evaluating and monitoring final installed system attenuation of interfering signals. If used, the location of the survey probes must meet the following criteria:

1) Location of each probe must be outside of the critical fringe field of any large magnets. Satisfactory locations are anywhere that observed fringe fields are at or below 50% of the saturation level of the probe (± 0.5mT/5.0G).
2) The probes must not be in close proximity (less than 0.5m) to large ferromagnetic objects, conducting objects, nor to the compensating coils themselves, nor within 1m of any power transformer.
3) One of the survey probes must be located within the space affected by the compensating coils.

6.7 Power-up Checks and Initial X, Y, Z Setup Adjustments

Apply power to the system by turning on the **POWER Switch (43).** The system should emit 4 chimes as it proceeds through its ***Acquire*** state.

The **POWER Indicator (24), LEVEL Indicator (25),** and **AMPLIFIER Indicator (26)** should all be solid green.

The **RESET Indicator (20)** and the **DISABLE Indicator (22)** should indicate either solid green or flashing green.

The **X, Y, and Z TRIP Indicators (3, 9, 15)** should all indicate solid green.

Connect the **X Monitor Output Connector (1)** to the oscilloscope. Set the horizontal sweep rate to 5 msec/division and the vertical gain to 10 millivolts/division. Any interfering field should be visible on the display. If the interfering field is predominantly line-related, the oscilloscope trigger source may be set to LINE input and the trigger level then adjusted for a stable display.

Gradually increase the X-axis feedback gain by turning the **X FBK (Feedback) GAIN Adjustment Trimpot (5)** clockwise. If the interfering magnetic field signal begins to slowly decrease with increasing trimpot rotation, the system polarity is correct and the following paragraph may be skipped.

IF the signal observed at the **X MONITOR Output Connector (1)** immediately jumps to a full-scale value (either positive or negative > 10V) after only a small CW rotation of the front panel **X FBK (Feedback) GAIN Adjustment Trimpot (5)**, then the overall system polarity is incorrect (feedback positive, rather than negative). To correct this condition, change the **X POLARITY Switch (31)** to its opposite position (pull handle sleeve out slightly to disengage lock) and then depress the **RESET Pushbutton Switch (16)** to reacquire the d.c. baseline.

Keep track of how many times the front panel **X FBK (Feedback) GAIN Adjustment Trimpot (5)** is rotated. The amplitude of the interfering signal on the oscilloscope should continue to decrease. At some point within the control's adjustment range (15 turns, total), the system should go into oscillation. IF the system is operating correctly, the resulting oscillation waveform on the oscilloscope will be about 80 millivolts pk-pk, with a frequency of about 1.5 KHz. Back off the gain by turning the **X FBK (Feedback) GAIN Adjustment Trimpot (5)** approximately 10% CCW. For example, if the oscillations started after the control has been rotated 5 turns, it should be backed off by approximately 10% of 5 turns, or about ½ turn. This is the optimum system gain setting, and will not normally require readjustment for the life of the MACS system unless the probe or coils are disturbed, or the magnetic coupling from coils to sensor is otherwise radically changed.

IF oscillations outside the frequency range of 1.0 – 2.0 KHz and/or greater than 150 millivolts pk-pk are observed, the system is operating out of specification and the problem must be identified and corrected. Probable causes are coil or coils mis-wired, probe in extremely poor location (too close to conductive materials or edge of coil) or coils too close to conductive surfaces (maintain 5 cm minimum separation when possible).

IF oscillations are NOT observed over the adjustment range, leave the front panel **X FBK (Feedback) GAIN Adjustment Trimpot (5)** at its maximum setting (fully CW) and adjust the rear panel **X AXIS GAIN Adjustment Trimpot (33)** until oscillations are observed, then advance the trimpot an additional 2 turns. Return to the above adjustment procedure and continue with adjustment of the front panel **X FBK (Feedback) GAIN Adjustment Trimpot (5)** as described.

Repeat the above procedure for the Y and Z channels, substituting **Y FBK (Feedback) GAIN Adjustment Trimpot (11), Z FBK (Feedback) GAIN Adjustment Trimpot (17), Y AXIS GAIN Adjustment Trimpot (36), and Z AXIS GAIN Adjustment Trimpot (39)** as necessary.

Reiterate the above X, Y and Z Channel gain adjustment procedure one additional time to minimize any gain offset due to cross-channel interaction.

On completion of the above feedback gain adjustment procedure, the system normally provides approximately 30-33 db of attenuation of the interfering magnetic fields.

6.8 D.C. Offset Adjustment

After the Feedback Gain Adjustments have been completed, the DC offset needs to be adjusted to minimize the DC current through the compensation coils. The procedure is:

1) Connect the DVM to the AMPLIFIER OUTPUT Connectors (45).
2) Change the “TEST” switch of the internal **TEST MODE Switches (42)** to the ON position. The “TEST” switch is position 2.
3) Adjust the internal **DC OFFSET Control (41)** to get a minimum value. This should typically be less than 100 mvolts.
4) Change the “TEST” switch of the internal **TEST MODE Switches (42)** back to the OFF position.

6.9 X NULL / Y NULL Setup

The **X NULL/(NORM)/Y NULL Test Switch (40)** is used primarily with specialized EMFC-AC system installations as an aid for adjusting individual electron microscope (EM) column-mounted inductive sensors for best "real world" orthogonality in the presence of column magnetic shielding. However, this test mode is also useful in some installations for probe X, Y orientation adjustment if the protected volume (PV) magnetic fields are slightly distorted due to ferromagnetic objects, such as steel cabinets, within the PV.

To align individual X- and Y-axis inductive sensors once installed on an EM, first put the **X NULL/(NORM)/Y NULL Test Switch (40)** in its "X NULL" (UP) position. The EMFC-MKIV system will then output a 55Hz sine wave excitation signal to the Y-axis and, while observing the X-axis display **(6)**, rotate the X-axis inductive sensor for deepest null. Repeat this procedure with the **X NULL/(NORM)/Y NULL Test Switch (40)** in its "Y NULL" (DOWN) position, observing the Y-axis display **(12)** while slowly rotating the Y-axis inductive sensor about the EM column central axis for a position giving an optimum null.

In the case of an EMFC-QDC system, the MAG03 probe is supplied as a precisely-aligned tri-axial sensor array. Visual probe alignment using the probe axial markings is usually satisfactory but in some cases readjustment to accommodate the site magnetic environment can improve performance. To verify magnetically-correct orientation of the X-Y plane with respect to the Z-axis centerline, turn the **X NULL/(NORM)/Y NULL Test Switch (40)** to its "X NULL" (UP) position. Observing the signal induced in the X-axis from the Y-axis excitation, adjust the sensor probe by rotating slightly about the Z-axis for best **X Display (6)** signal null.

6.10 Final Physical Setup and Cabling

Reinstall the Controller into the rack cabinet, following the checklist below.

Disconnect all cables from the rear of the controller. Replace and attach the top cover to the controller. Slide the controller into the cabinet and insert the rackmounting screws in the front panel of the controller. Reattach the rear panel cables in the same configuration as was done for the previous calibration exercises (see the section on “Initial Cabling” page 27).

Power up the system and let it run for at least 20 minutes to stabilize the system temperature. After this time has elapsed, check the DC offset for each channel at the Driver Amplifier output binding posts **(57, 60, 63)**, using a standard DVM. Each channel's d.c. value, averaged over a 15-second interval of low interfering magnetic field activity, should be less than ± 1 volt.

7. OPERATION

7.1 General Comments

The EMFC-MKIV is controlled by the firmware contained in a Programmable Logic Device (PLD). The PLD monitors various system conditions, responds to user controls, displays status information, and controls electrical outputs. A state machine in the PLD combines all of the input information with the current operating state. It determines what, if any, changes are to be made in the outputs and whether the operating state should change.

7.2 Power-up Sequence

When power is applied to the system or when the RESET pushbutton is pressed, the Controller firmware enters a baseline acquisition sequence which rapidly determines the environmental "d.c." magnetic field level and subsequently enters that level as the "zero interfering field" condition. This procedure is followed to minimize system response to constant-field (primarily geomagnetic) conditions. If a RESET acquisition operation is invoked during a magnetic offset due to external interference, the offset difference will be gradually factored out by the system channel digital integrator until the correct average environmental "d.c." field level is ultimately attained. The time scale required for this equilibration process is dependent on the offset value, and is determined by the system offset recovery rate of approximately 31 nT (310 µG) per minute.

7.3 EMFC-MKIV Controller Operational States

When the EMFC-MKIV is powered, it is always in one of the following states: ***Acquire, Setup, Operate, Disabled,*** or ***PowerTrip.*** The ***Acquire*** and ***PowerTrip*** states are divided into sub-states. The Controller State Flowchart graphically illustrates the states and the conditions that can cause changes.

The unit can be reset to the initial ***Acquire*** state from any other state by pressing and releasing the **RESET Switch (16).** The unit can be disabled from any state by pressing the **DISABLE Switch (18).**

The following table shows how the colors and patterns of the **RESET Indicator (17)** and the **DISABLE Indicator (19)** indicate the state of the EMFC-MKIV and the input conditions. For instance, if the **RESET Indicator (17)** is green and not flashing while the **DISABLE Indicator (19)** is green and flashing, then the controller is in either the ***Acquire***, ***Setup***, ***Operate***, or ***PowerTrip*** state and there is a Z WARNING condition.

Table 7-1, EMFC-MKIV Controller Operational States

RESET LED	DISABLE LED		STATE	Z WARNING
Green Flash	Green Solid		Acquire, Setup or PowerTrip	None
Green Solid	Green Flash		Acquire, Setup, Operate, or PowerTrip	Yes
Green Solid	Green Solid		Operate	None
Red Flash	Red Solid		Disabled	Don’t Care

7.3.1 Acquire

The ***Acquire*** state is divided into the two sub-states of ***FastAcquire*** and ***SlowAcquire***. The unit enters the ***FastAcquire*** state when power is initially applied, when it has recovered from a power trip, when it has automatically recovered from a level trip, or anytime the **RESET Switch (16)** is pressed and released**.**

During normal reacquisition sequencing, the controller stays in the ***FastAcquire*** state for 3.5 seconds and then in the ***SlowAcquire*** state for 0.5 seconds, after which it goes to the ***Setup*** state. However, if the **DISABLE Switch (18)** is pressed, the unit will immediately go to the ***Disabled*** state.

7.3.2 Setup

The unit enters the ***Setup*** state when it leaves the ***Acquire*** state.

If there are no faults and the X, Y and Z levels are below the trip setting, the unit will go to the ***Operate*** state. If there is a power trip, the unit will go to the ***PowerTrip*** state. A power trip is the loss of or out of spec operation of any of the three internal power supplies or a line transient connection.

If there is no power trip, but there is an amplifier trip or the **DISABLE Switch (18)** is pressed, the unit will go to the ***Disabled*** state. If there are no faults but the X, Y or Z levels are above the trip setting, the unit will stay in the ***Setup*** state. An amplifier trip occurs with excessive amplifier current due to either an external or internal fault, excessive amplifier output level due to controller failure or excessive input signal due to one or more extremely large ambient field changes.

7.3.3 Operate

The unit enters the ***Operate*** state when it successfully leaves the Setup state.

If there is a power trip, the unit will go to the ***PowerTrip*** state. If there is no power trip, but there is an amplifier trip, a failure of the reset timer to reactivate the system, or the **DISABLE Switch (21)** is pressed, the unit will go to the ***Disabled*** state. If there is a X, Y or Z trip condition that lasts for at least 18 seconds, the unit will go to the ***Disabled*** state. Otherwise, the unit will stay in the ***Operate*** state.

7.3.4 Disabled

The unit enters the ***Disabled*** state when there is an abnormal condition in the ***Setup***, ***Operate***, or ***PowerTrip*** state, or the **DISABLE Switch (21)** is pressed.

The unit will stay in this state until it is reset, either by pressing and releasing the **RESET Switch (19)**.

7.3.5 PowerTrip

The unit enters the ***PowerTrip*** state when it is in either the ***Setup*** state or the ***Operate*** state and a power supply fault is detected.

If the **DISABLE Switch (21)** is pressed, the unit will go to the ***Disabled*** state. Otherwise, it will wait 6 seconds for the power supply fault to clear. If the fault is gone after 6 seconds, the unit will restart in the

Acquire state. It will try this recovery cycle up to 3 times. If the fault is still present after the third retry, the system will go to the ***Disabled*** state.

8. General Comments

8.1 Scheduled Inspections

There are no normally scheduled inspections required.

8.2 Indications for Re-calibration

A check of the Z Monitor output connector signal will indicate the Z axis probe magnetic field. With the system operational this may be compared to values recorded during the initial system set up.

8.3 Re-calibration

Recalibration is normally not required unless some physical changes have been made to the room that potentially could affect the magnetic field measurements. For example repositioning of the probe.

8.4 Probe reposition

The probe should remain in its installed position and orientation. Movement of the probe may require recalibration.

8.5 Coil(s) reposition

The coils should remain in or near their installed position and orientation. Significant movement of the coils may require recalibration.

8.6 Subsystem repair or replacement

Contact Lindgren R.F. Enclosures, Inc.

8.7 Probe

The probe is the heart of the feedback system and the most sensitive to placement and surrounding environment. All effort must be taken to insure the isolation of the probe from changes.

8.8 W/Compensation Unit

8.9 Controller

The physical placement of the Controller should not affect the performance, it should be located where it is not likely to be disturbed unnecessarily.

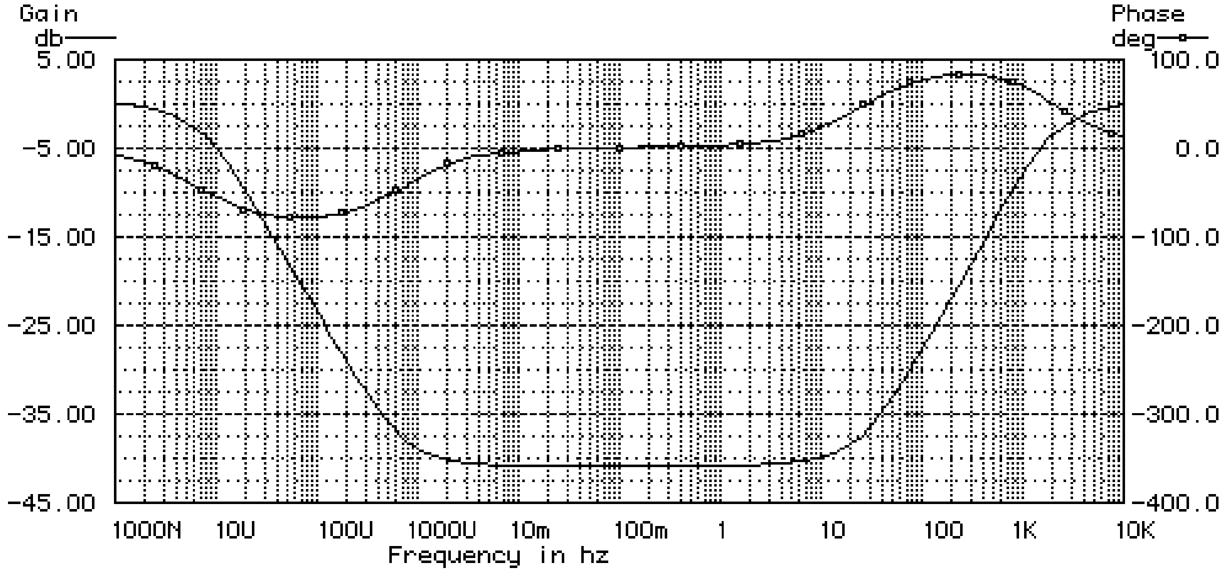
8.10 Power Driver

The physical placement of the Power Driver should not affect the performance, it should be located where it is not likely to be disturbed unnecessarily. Users are reminded that it must be plugged into the Controller.

. APPENDICES

A.1 System Specifications

System
Response




```
Frequency   =  100.00000E+02   hz          Gain        =   -0.218 db
Phase angle =  129.46856E-01   degrees     Group delay =  000.00000E-02 sec
Gain slope  =  365.25229E-03   db/octave   Peak gain   =   -0.109 db/F =  1.000E-06
Frequency delta =  137.43895E+02           Analysis point number 58
```

A.2 Subsystems

A.2.1 Probe

Supply voltage .... +/- 12V to +/-17V
Analog output .... +/-10V (+/-12V supply) swings to within 1V of supply voltage
Power supply rejection ratio 5µV/V
Output impedance.. <1Ω
Linearity error... < 0…15%
Output ripple... 0 to 1kHz maximally flat, +/-5% maximum above 1 kHz
Bandwidth... 0 to 3 kHz
Orthogonality error
    Between sensing axes .... <0.5°
    Z axis to reference face... <0.1°
Internal noise
    Standard version .... 7-12pTrms/√Hz at 1 Hz
    Low noise version... 4-6 Trms/√Hz at 1 Hz
Supply current .... +27mA, -8mA (+1.4mA per 100µT for each axis

A.2.2 Controller

Protected axis... 3, orthogonal

Suppression bandwidth...continuous .001 Hz to > 500 Hz
Field suppression, each axis, at sensor:
.001 to 10 Hz ....40 dB minimum (factor of 100)
>10 to 60 Hz ....32 dB minimum (factor of 40)
> 60 to 100 Hz ....28 dB minimum (factor of 25)
> 100 to 200 Hz ....20 dB minimum (factor of 10)
>200 to 500 Hz ....10 dB minimum (factor of 3.2)

Maximum field variation at MRI isocenter ....0.1 µT for 6 µT external field variation

Maximum number of interfering frequencies:...........................Unlimited
Maximum compensable field ....+/- 10.0 µT (+/-100mG) peak (driven coil and room geometry dependent)
Display, each axis..Digital, 0-19.99 µT (199.9 mG F.s.)
Display accuracy..+/-0.5%
Display/setpoint comparator mode ....x, y axis: peak; z axis: average
Calibrator (x, y) 20Hz, 5%
Sensor (x, y, z) type ....3-axis fluxgate, dimensions approximately 2.50 cm diameter x 20.2 cm length
Sensor noise floor..1.0 nT (10 microgauss), avg.
System power ....120 or 220 VAC, 60 or 50 Hz, 50 watts quiescent, 400 watts peak
Fault sense: ....a) z axis magnitude over trip limit
....b) internal power source(s) out of limits
....c) amplifier input power above limit
Fault indication..front panel LED(s), periodic chime
Controller/power driver enclosure ....rack case, overall dimensions (h x w x d) 19.4 cm x 48.3 cm x 44.5 cm (7.62 in x 19 in x 17.5 in)
System controller weight...26Kg (57lbs)

A.2.3 Amplifier

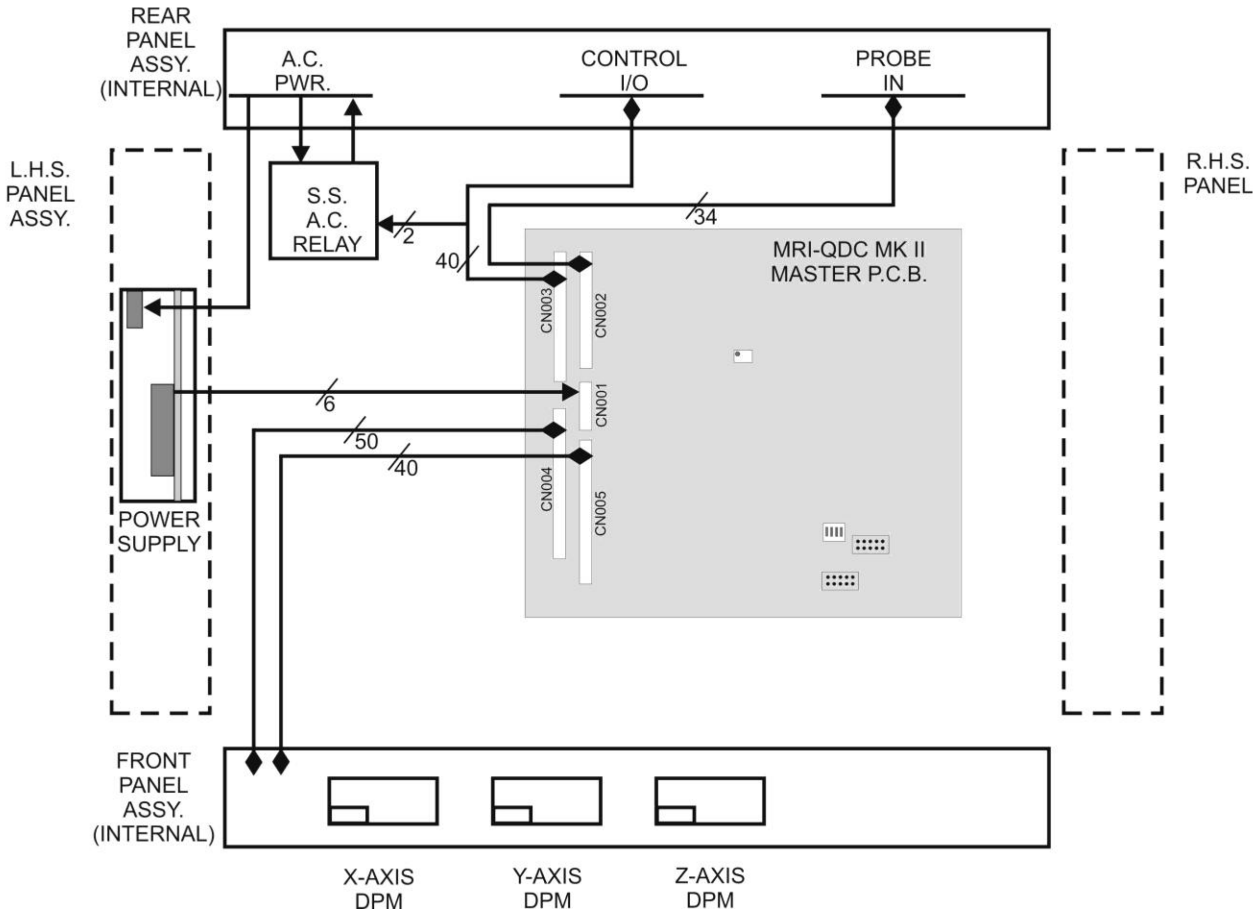
BRIDGING MODE
Rated power into 8 ohm (IHF)..250 W
Rated T.H.D. 20Hz-20KHz ....0.03 %
Clipping power into 8 ohm...> 300 W
Dynamic power into 8 ohm (IHF) ....500 W

2CH MODE
Rated power into 8 ohm (IHF)..100 W
Rated T.H.D. 20Hz-20KHz 0.03%
Clipping power into 8 ohm...115 W
Dynamic power into 8 ohm ....150 W
Current limit into 0.1 ohm and 1 ohm ....32 amps
Damping factor..> 200
Input sensitivity for 1W/ Rated power into 8 ohm 100mV/1Vrms
Input impedance 22K ohm//150pF
Frequency response 20Hz-20KHz...+/- 0.2 dB
Frequency response -3dB 5Hz-110KHz
Signal to noise radio “A” WTD (ref. 1W/8 ohm)......................................100 dB
Separation 20Hz-20KHz..>80 dB

OTHERS
Dimensions (W x H x D)...430 x 112 x 288 mm

Net Weight..9.4 Kg
Shipping Weight ....20.5 Kg

A.3 Replaceable Electrical Parts



A.4 Controller Flowchart

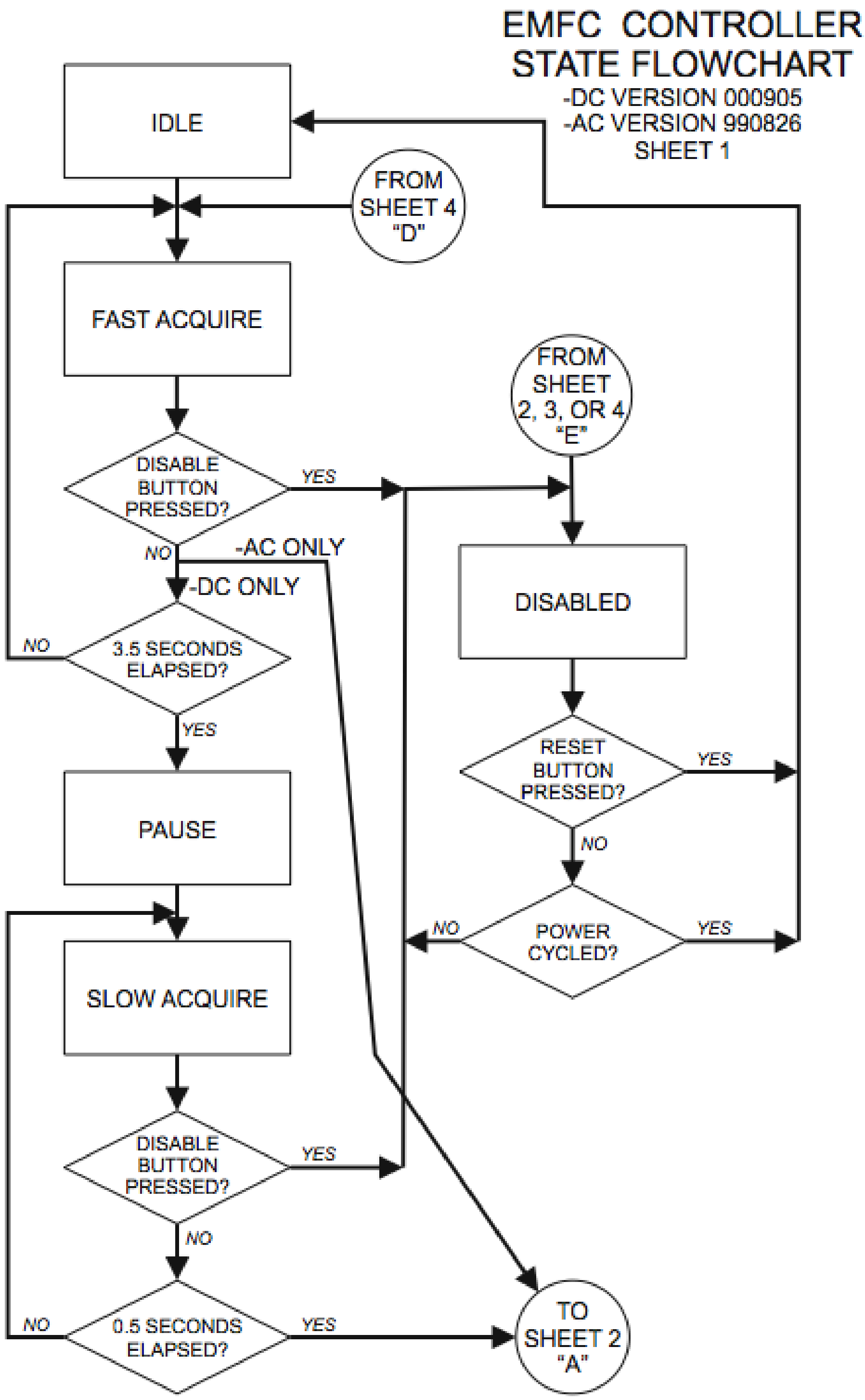


Figure 6 - Controller State Flowchart, Sheet 1

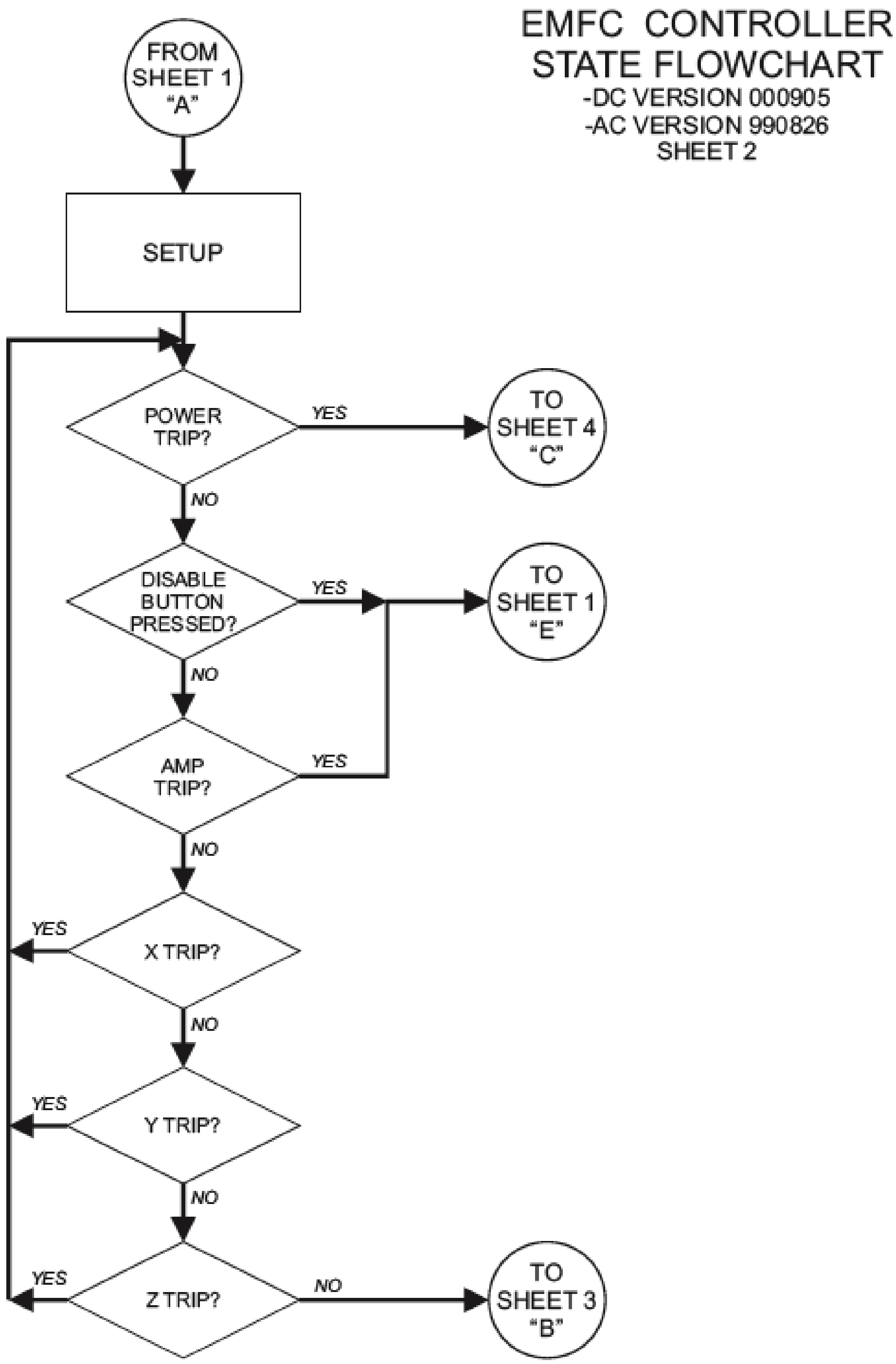


Figure 7 - Controller State Flowchart, Sheet 2

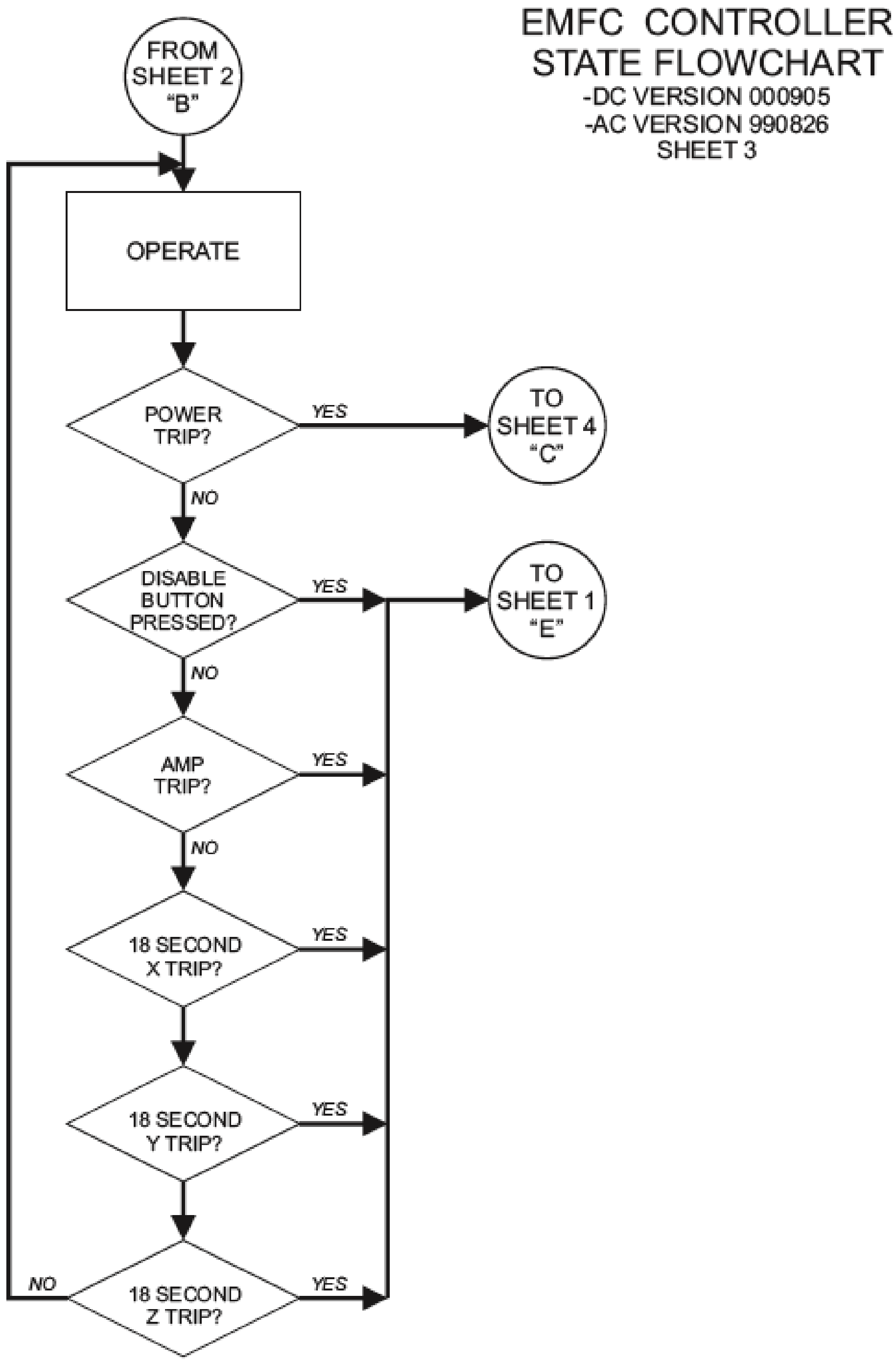


Figure 8 - Controller State Flowchart, Sheet 3

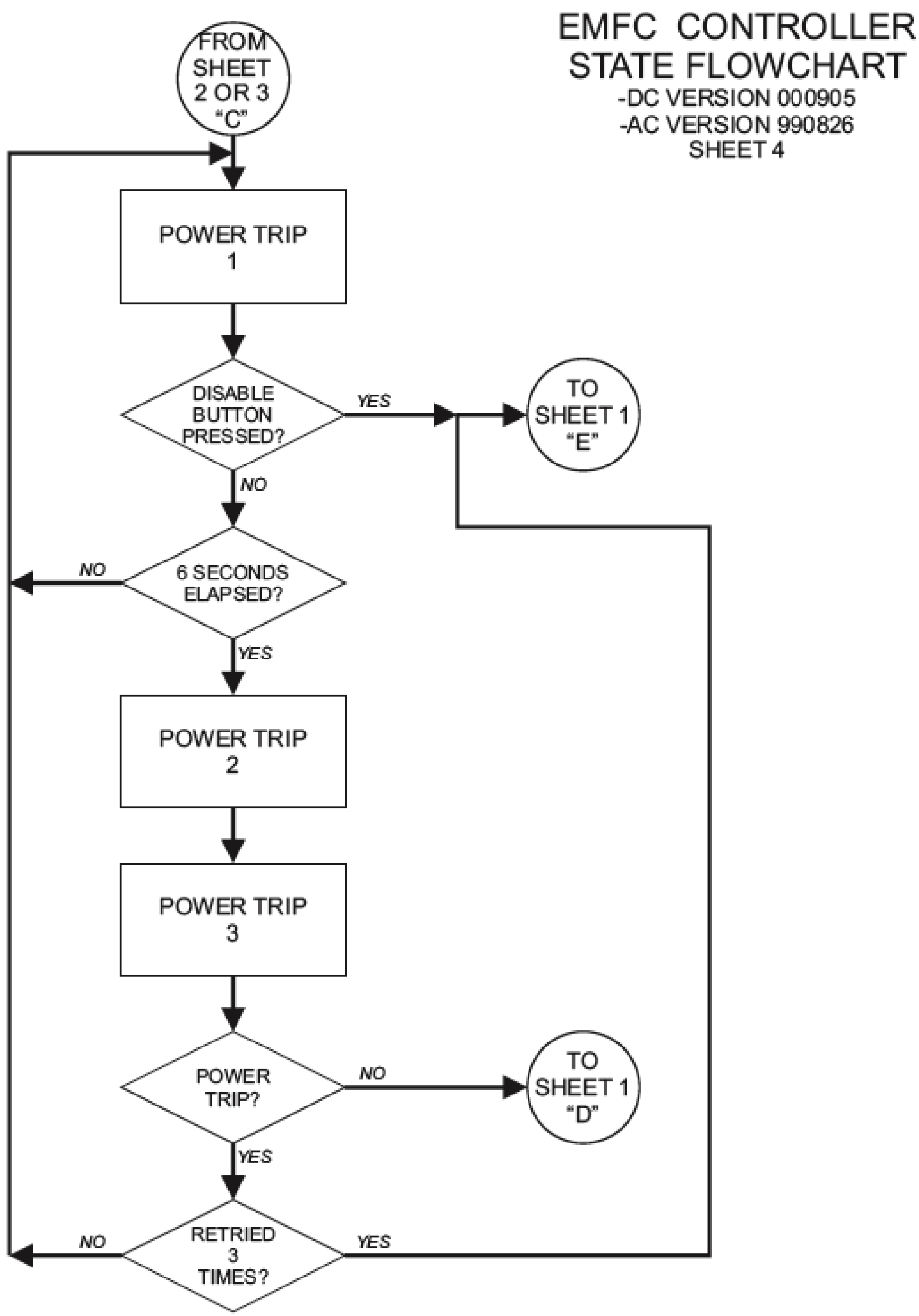


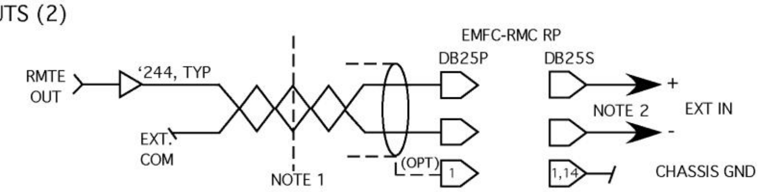
Figure 9 - Controller State Flowchart, Sheet 4

A.5 –RMC Remote Monitor/Control Option

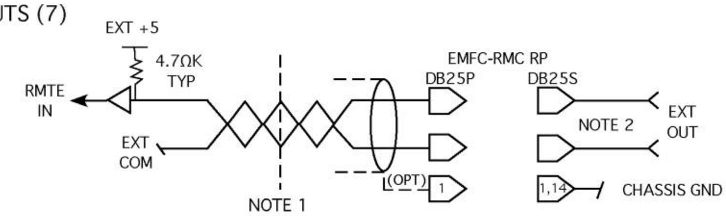
EMFC-RMC I/O INTERCONNECT NOTES:

1. TTL, EXTERNAL POWER:

1.1 INPUTS (2)



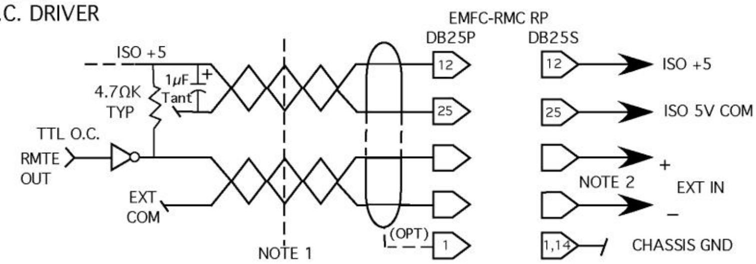
1.2 OUTPUTS (7)



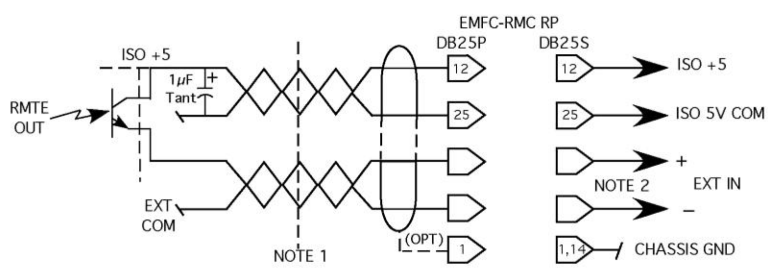
2. TTL, ISO POWER

2.1 INPUTS (2)

2.1.1 O.C. DRIVER



2.1.2 OPTO DRIVER

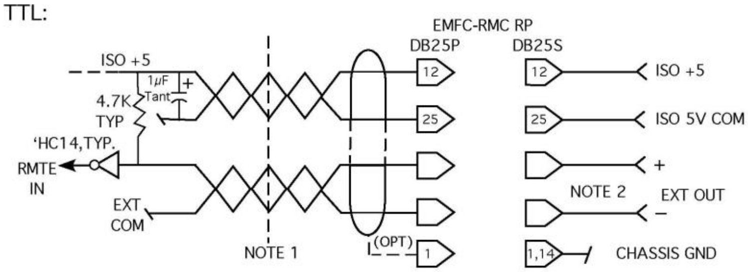


NOTES: 1. Interconnect cable up to 300m (Rs < 100Ω), twisted pairs and/or shielded
2. Pin Assignments per EMFC-RMC Spec

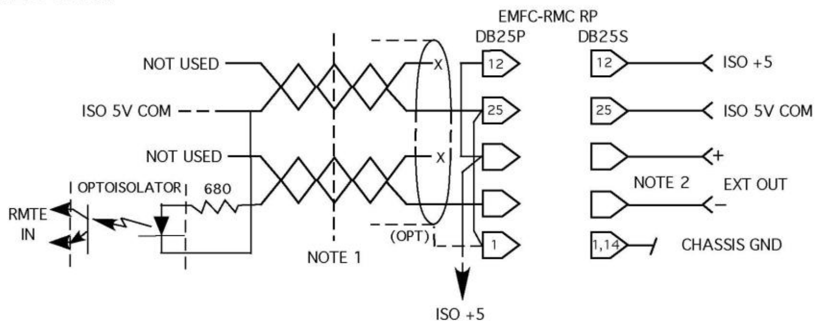
EMFC-RMC I/O INTERCONNECT NOTES, Cont'd:

2.2 OUTPUTS (7)

2.2.1 TTL:

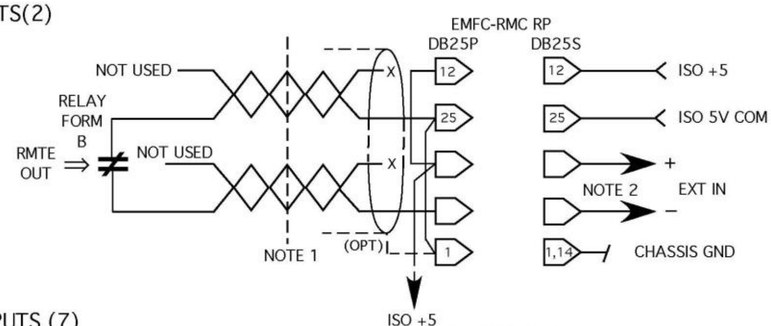


2.2.2 OPTO:

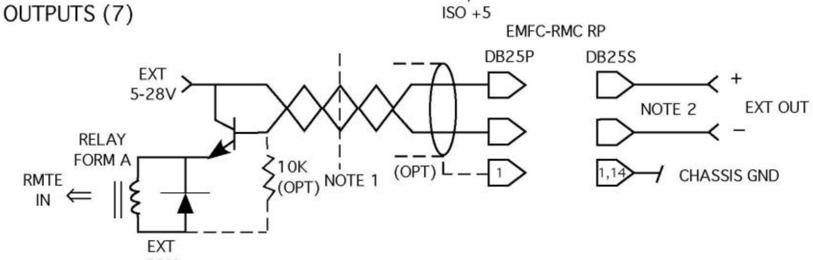


3. RELAY

3.1 INPUTS(2)



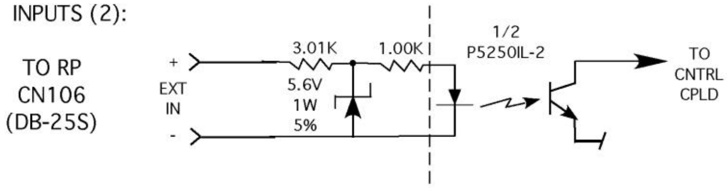
3.2 OUTPUTS (7)



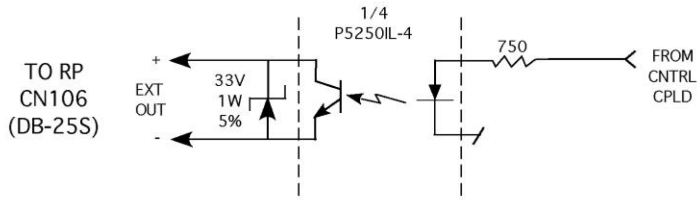
NOTES: 1. Interconnect cable up to 300m (Rs < 100Ω), twisted pairs and/or shielded
2. Pin Assignments per EMFC-RMC Spec

EMFC-RMC I/O INTERCONNECT NOTES, Cont'd:

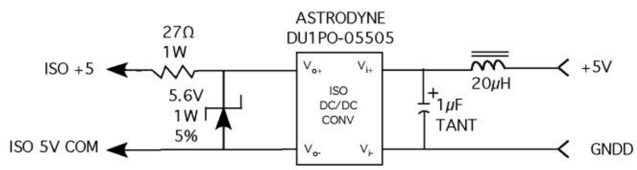
1. INPUTS (2):



2. OUTPUTS (7):



3. ISO PWR SOURCE:



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