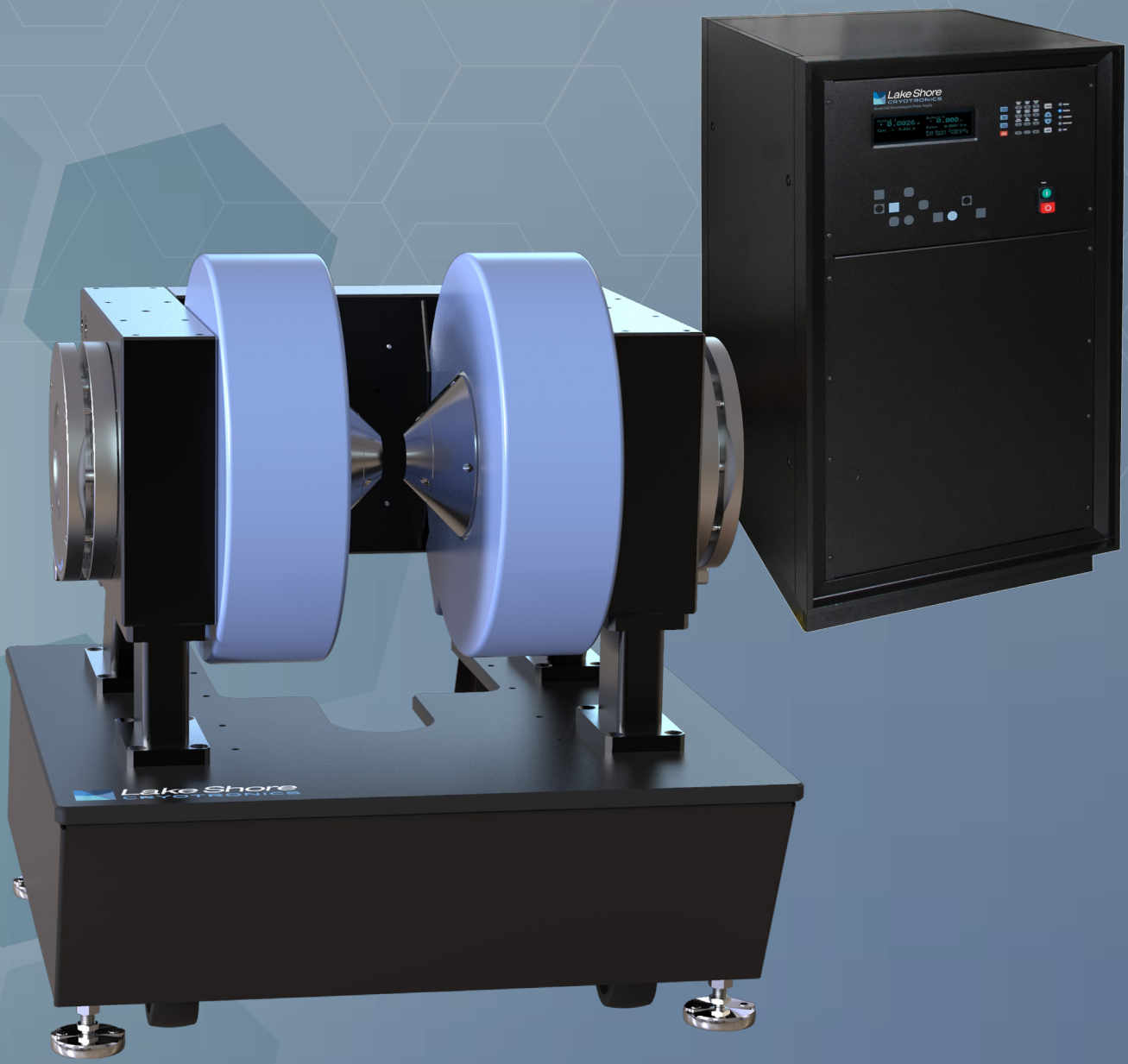
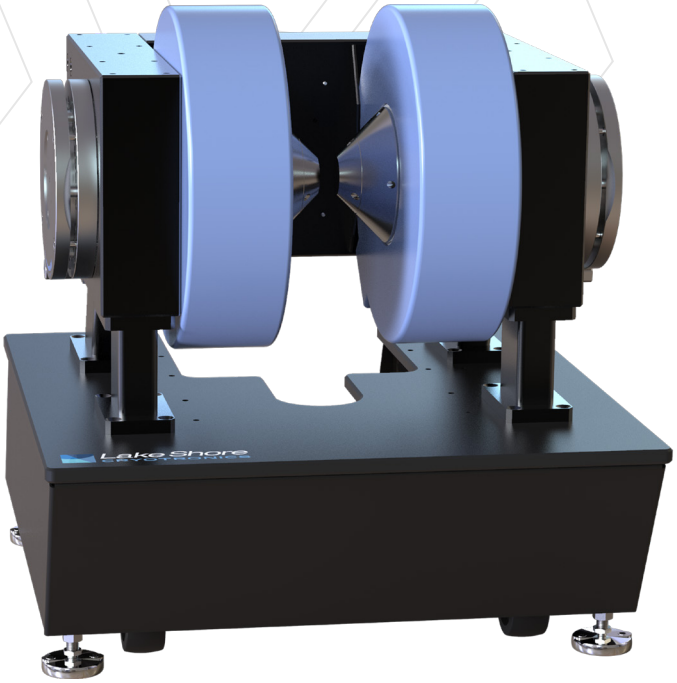
# **EM-V Series** Electromagnets and Electromagnet Power Supplies




Lake Shore
CRYOTRONICS
a **DwyerOmega** brand



## Introduction

The Lake Shore EM-4V and EM-7V electromagnets (EM-V Series) produce magnetic fields with a variety of indexed air gap and pole cap configurations. The EM-V Series are ideally suited for integration into customer-designed magnetic test platforms for applications including magneto-optical studies, magnetic hysteresis studies, in-line annealing, Hall effect studies, susceptibility measurements, spin magnetic resonance demonstrations, and biological studies.

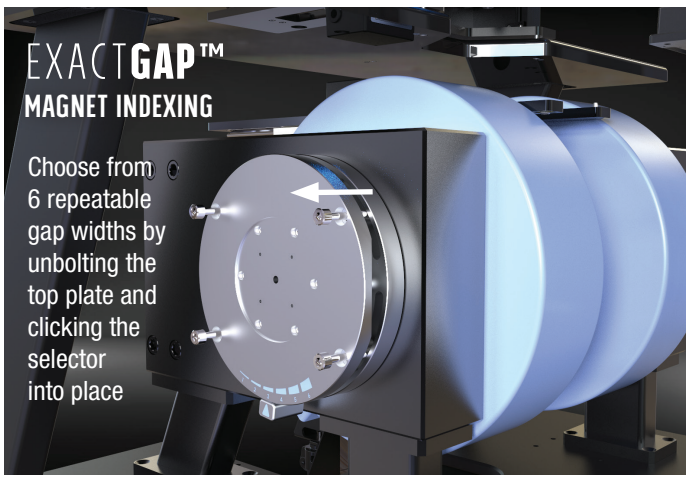
The EM-V Series magnet coupled with a Lake Shore magnet power supply (MPS) and teslameter form a versatile laboratory electromagnet capable of producing magnetic fields up to 3.22 T and supporting very fast ramp rates of up to 1 T/s. This system, with true bipolar MPS power output, provides rapid uniform magnetic field ramping and field reversal to avoid discontinuities that occur during zero crossover when using unipolar power supplies.

## EM-4V, EM-7V features

- Indexed pole gap settings (ExactGAP™) allow repeatable air gap changes without having to re-calibrate between changes
- Exceptional field intensities achieved with cylindrical or tapered pole caps
- Water-cooled coils provide excellent field stability and uniformity
- Removable pole caps facilitate variable pole face configurations and easy pole cap exchange
- Accurate pole alignment by precise construction of the air gap adjustment mechanism
- The EM-4V/EM-7V yoke designed for optimum air gap accessibility for both top and bottom of the magnet
- Compact size of the EM-4V permits convenient bench-top mounting
- Optional optical access pole caps available
- Optional shim kit is available

## ExactGAP™ indexed gap settings

The EM-V Series electromagnets feature ExactGAP™ indexed pole settings. The ExactGAP™ pole gap indexing makes it fast and easy to reconfigure the magnet gap for the required sample or option size without having to re-calibrate the magnet after changing the gap. Choose from 6 repeatable gap widths by unbolting the top plate and clicking the selector into place. The EM-V Series incorporate water-cooled coils and precision yokes made of magnetically soft, ultra-pure steel, assuring precise pole cap alignment as well as excellent field homogeneity and stability.



# Transform your electromagnet into a modular characterization system

The EM-V Series can be upgraded to a modular characterization system (MeasureReady™ MCS-EMP). This transforms the electromagnet into a complete measurement solution using options to enable sample inserts (for both magnet and electrical experiments), sample temperature control options, preconfigured measurement module options, and MeasureLINK™-MCS software to control data collection and analysis.

**MCS-EMP modular characterization system**

*Shown with optional sample holder in GlideLOCK™ mount*

*Electromagnet (power supply not shown)*

*Electromagnet system controller (ESC)*

## MCS-EMP modules and options

**Electronic measurement modules**
**FastHall™ Hall effect**
*(Others to come)*

**Temperature options**
**GlideLOCK™ oven**
**CCR/CCR-O**

**Temperature control**

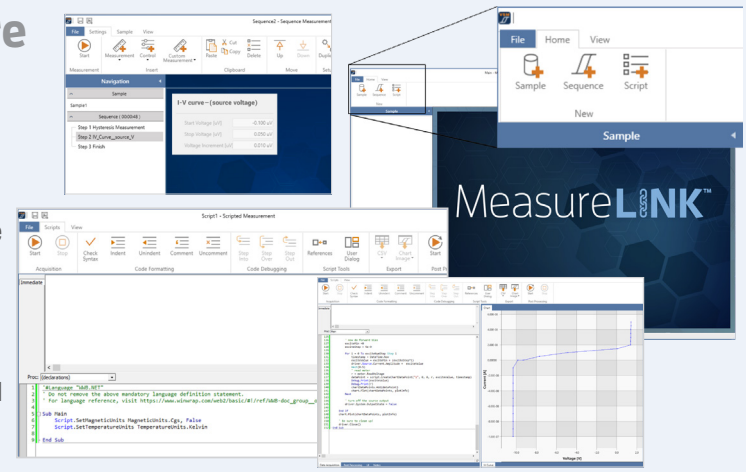
**Sample options**
**High performance sample holder/insert & cards**
**Room temperature top-side optical access**
**Manual rotation**

**Compatible measurement instruments**
**I55 precision current/voltage source**
**372/3708 AC resistance bridge**
**Add your own third-party instruments**

## MeasureLINK™-MCS software

MeasureLINK™-MCS software is the key component of each MeasureReady™ MCS system. It facilitates field control, temperature control, measurement sequencing, and integration functions.

This flexible software allows the user to monitor the real-time performance of the MCS-EMP and to construct measurement sequences from a set of predefined controls. The menu-driven graphical user interface (GUI) provides the ability to control field and temperature to a specific setpoint or to loop these parameters through a range of settings with a specified step value. The sequences can be saved and recalled for use in repeated measurements.




**Please see the MCS-EMP catalog for more details**

# EM-V Series electromagnet specifications

The EM-V Series electromagnets produce variable magnetic fields with a variety of air gap and pole cap configurations. They are ideal for applications including magneto-optical studies, magnetic hysteresis studies, in-line annealing, Hall effect studies, susceptibility measurements, spin magnetic resonance demonstrations, and biological studies.

### Applied field strength with optional high-field 2 in pole face—EMP-HF (±I%)

| ExactGAP™ setting | Air gap | EM-4V maximum field | EM-7V maximum field |
|---|---|---|---|
| **Index 1** | 7.5 mm (0.30 in) | 27.6 kOe (2.76 T) | 32.2 kOe (3.22 T) |
| **Index 2** | 12 mm (0.47 in) | 25.2 kOe (2.52 T) | 29.8 kOe (2.98 T) |
| **Index 3** | 20 mm (0.79 in) | 20.3 kOe (2.03 T) | 26.0 kOe (2.60 T) |
| **Index 4** | 25 mm (0.98 in) | 17.2 kOe (1.72 T) | 23.8 kOe (2.38 T) |
| **Index 5** | 28 mm (1.10 in) | 15.5 kOe (1.55 T) | 22.7 kOe (2.27 T) |
| **Index 6** | 50 mm (1.97 in) | 9.1 kOe (0.91 T) | 16.0 kOe (1.60 T) |

### Applied field strength with standard 2 in pole face (±I%)

| ExactGAP™ setting | Air gap | EM-4V maximum field | EM-7V maximum field |
|---|---|---|---|
| **Index 1** | 7.5 mm (0.30 in) | 26.1 kOe (2.61 T) | 30.5 kOe (3.05 T) |
| **Index 2** | 12 mm (0.47 in) | 23.7 kOe (2.37 T) | 28.3 kOe (2.83 T) |
| **Index 3** | 20 mm (0.79 in) | 19.6 kOe (1.96 T) | 24.7 kOe (2.47 T) |
| **Index 4** | 25 mm (0.98 in) | 16.9 kOe (1.69 T) | 22.8 kOe (2.28 T) |
| **Index 5** | 28 mm (1.10 in) | 15.4 kOe (1.54 T) | 21.7 kOe (2.17 T) |
| **Index 6** | 50 mm (1.97 in) | 9.1 kOe (0.91 T) | 15.4 kOe (1.54 T) |

### Applied field strength with standard 4 in pole face[1] (±I%)

| ExactGAP™ setting | Air gap | EM-4V maximum field | EM-7V maximum field |
|---|---|---|---|
| **Index 1** | 57.5 mm (2.26 in) | 7.9 kOe (0.79 T) | 13.5 kOe (1.35 T) |
| **Index 2** | 62 mm (2.44 in) | 7.3 kOe (0.73 T) | 12.8 kOe (1.28 T) |
| **Index 3** | 70 mm (2.76 in) | 6.5 kOe (0.65 T) | 11.7 kOe (1.17 T) |
| **Index 4** | 75 mm (2.95 in) | 6.1 kOe (0.61 T) | 11.0 kOe (1.10 T) |
| **Index 5** | 78 mm (3.07 in) | 5.9 kOe (0.59 T) | 10.7 kOe (1.07 T) |
| **Index 6** | 100 mm (3.94 in) | 4.6 kOe (0.46 T) | 8.6 kOe (0.86 T) |

### Applied field strength with standard 7 in pole face[2] (±I%)

| ExactGAP™ setting | Air gap | EM-7V maximum field |
|---|---|---|
| **Index 1** | 146.5 mm (5.77 in) | 6.0 kOe (0.60 T) |
| **Index 2** | 151 mm (5.94 in) | 5.9 kOe (0.59 T) |
| **Index 3** | 159 mm (6.26 in) | 5.6 kOe (0.56 T) |
| **Index 4** | 164 mm (6.46 in) | 5.4 kOe (0.54 T) |
| **Index 5** | Not recommended for this pole cap configuration | |
| **Index 6** | Not recommended for this pole cap configuration | |

*[1]Achieved by removing high or standard 4 in to 2 in pole caps*
*[2]Achieved by removing standard 7 in to 4 in pole caps; only valid for EM-7V magnet*

## EM-4V typical field uniformity

| Magnet configuration | | Uniformity over 1 $cm^3$ | 1% cylindrical volume | |
|---|---|---|---|---|
| Pole cap mm (in) | Air gap mm (in) | | Diameter mm (in) | Length mm (in) |
| 51 (2.0) | 13 (0.5) | ±0.16% | 36 (1.4) | 13 (0.5) |
| 51 (2.0) | 25 (1.0) | ±0.35% | 18 (0.7) | 25 (1.0) |
| 102 (4.0) | 25 (1.0) | ±0.05% | 64 (2.5) | 25 (1.0) |
| 102 (4.0) | 51 (2.0) | ±0.15% | 18 (0.7) | 51 (2.0) |

## EM-7V typical field uniformity

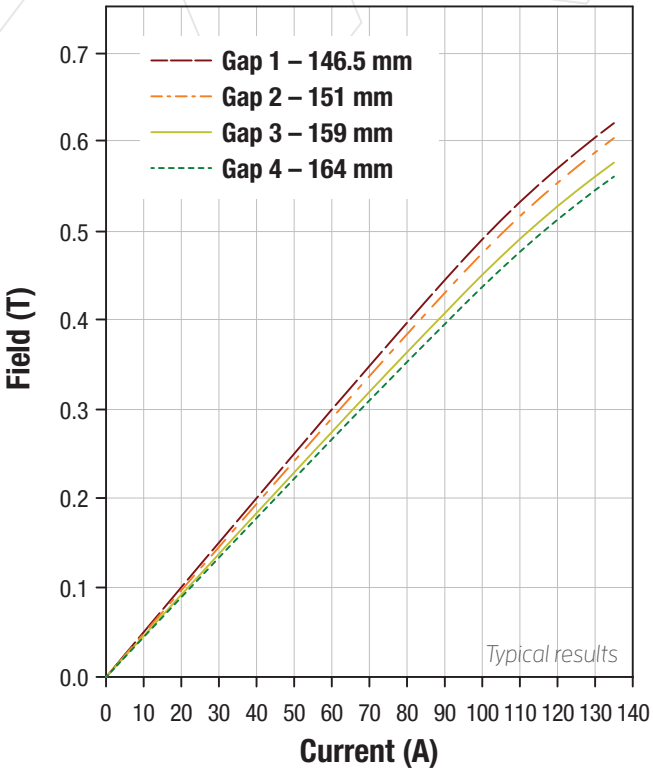
| Magnet configuration | | Uniformity over 1 $cm^3$ | 1% cylindrical volume | |
|---|---|---|---|---|
| Pole cap mm (in) | Air gap mm (in) | | Diameter mm (in) | Length mm (in) |
| 51 (2.0) | 13 (0.5) | ±0.11% | 36 (1.4) | 13 (0.5) |
| 51 (2.0) | 25 (1.0) | ±0.33% | 10 (0.4) | 25 (1.0) |
| 102 (4.0) | 25 (1.0) | ±0.03% | 66 (2.6) | 25 (1.0) |
| 102 (4.0) | 51 (2.0) | ±0.08% | 23 (0.9) | 51 (2.0) |

*NOTE: The third column gives uniformity over one cubic centimeter volume centered in the magnet gap. The last two columns give the cylindrical volume within which the magnetic field deviates by less than 1% from the central field. The cylindrical volume is coaxial with the magnet poles and centered in the gap.*

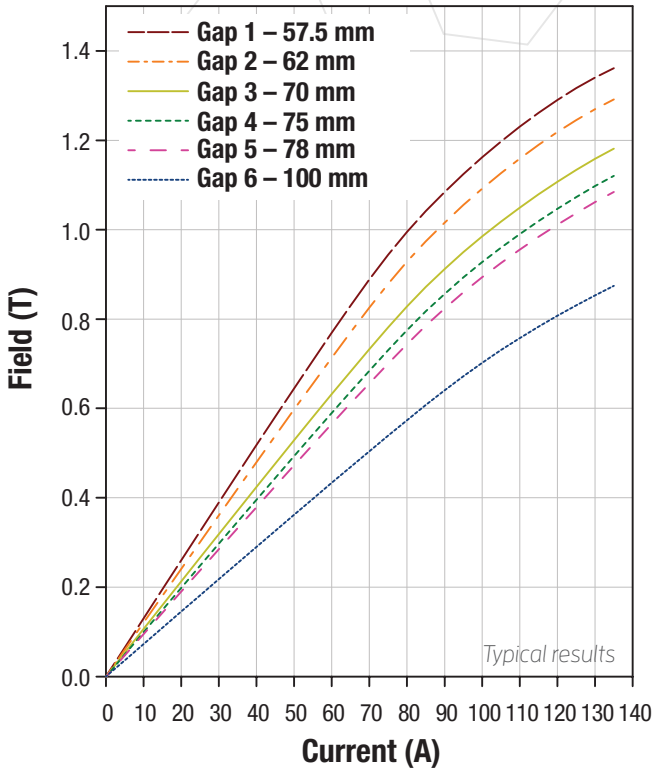
| | EM-4V | EM-7V |
|---|---|---|
| Air gaps With no pole caps | 57.5, 62, 70, 75, 78, and 100 mm | |
| With 2 in pole caps | 7.5, 12, 20, 25, 28, and 50 mm | |
| Coil resistance, nominal | 0.25 Ω per coil (0.5 Ω total wired in series) | 1.00 Ω per coil (0.5 Ω total wired in parallel) |
| Coil resistance, cold | 0.23 Ω per coil (0.46 Ω total wired in series) | 0.92 Ω per coil (0.46 Ω total wired in parallel) |
| Coil resistance, maximum | 0.27 Ω per coil (0.54 Ω total wired in series) | 1.08 Ω per coil (0.54 Ω total wired in parallel) |
| Integrated pole diameter | 100 mm (4 in) | 178 mm (7 in) |
| Available pole cap diameters | 50 mm (2 in) | 100 mm (4 in) and 50 mm (2 in) |
| Cooling water | Tap water or closed cooling system | |
| Water flow rate | 7.6 L/min (2 gal/min) | 11.4 L/min (3 gal/min) |
| Pressure drop | 200 kPa (30 psi) | 220 kPa (32 psi) |
| Water chiller cooling capacity | 2.5 kW (8,530 BTU/h) | 5.0 kW (17,060 BTU/h) |
| Water inlet temperature | 15 °C to 25 °C (59 °F to 77 °F) | |
| Coil over temperature limit | 45 °C (113 °F) | |
| Coil spacing, nominal | 121 mm (4.75 in) | 178 mm (7 in) |
| Coil size-width, nominal | 121 mm (4.75 in) | 132 mm (5.2 in) |
| Coil size-diameter, nominal | 311 mm (12.25 in) | 445 mm (17.5 in) |
| Current (maximum continuous operating) | ±70 A | ±135 A |
| Voltage, nominal | ±35 V (approximately 38 V at maximum coil temperature) | ±70 V (approximately 38 V at maximum coil temperature) |
| Continuous input power, nominal | 2.5 kVA (2.65 kVA at max temperature) | 9.45 kVA (10.125 kVA at max temperature) |
| Suggested power supply | Lake Shore Model 643 | Lake Shore Model 648 |
| **Size** | | |
| Height | 77 cm (30.3 in) | 52.7 cm (20.8 in) |
| Width | 78.7 cm (31 in) | 78.7 cm (31 in) |
| Depth | 88.9 cm (35 in) | 88.9 cm (35 in) |
| Weight | 201.9 kg (445 lb) | 635 kg (1400 lb) |
| Shipping weight | 215.5 kg (475 lb) | 660 kg (1500 lb) |
| Shipping dimensions | 0.97 m × 0.58 m × 0.56 m (38 in × 23 in × 22 in) | 0.86 m × 1.22 m × 1.19 m (34 in × 48 in × 47 in) |

# EM-V Series field plots (nominal)

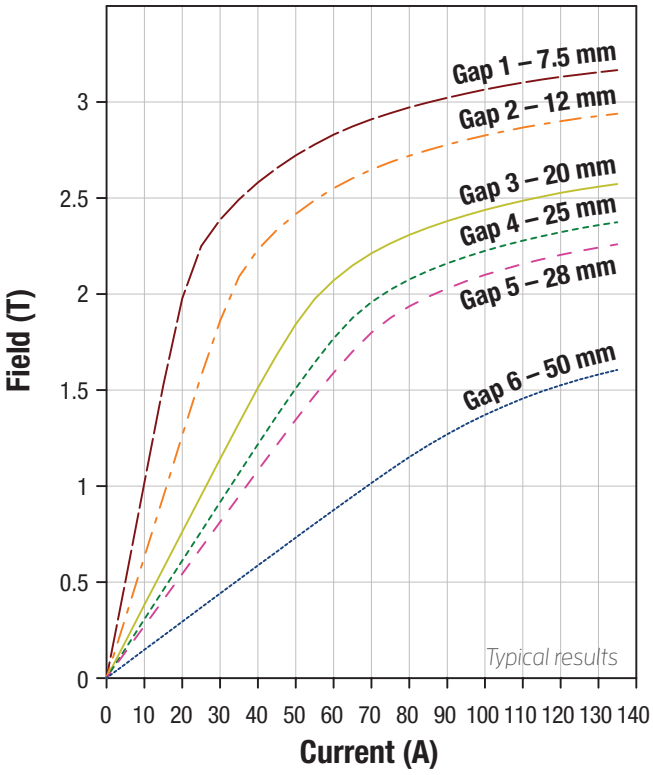
## EM-7V no pole caps field plot



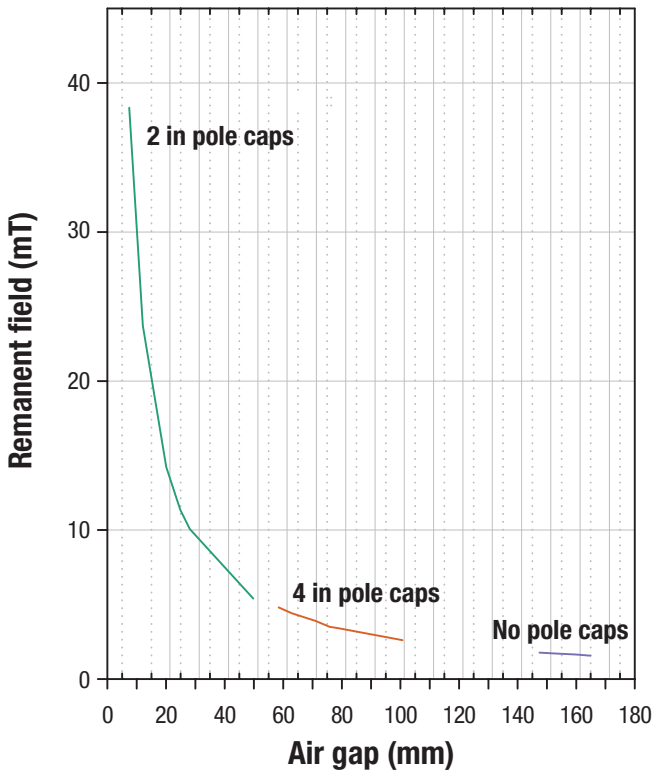

## EM-7V 100 mm (4 in) pole caps field plot



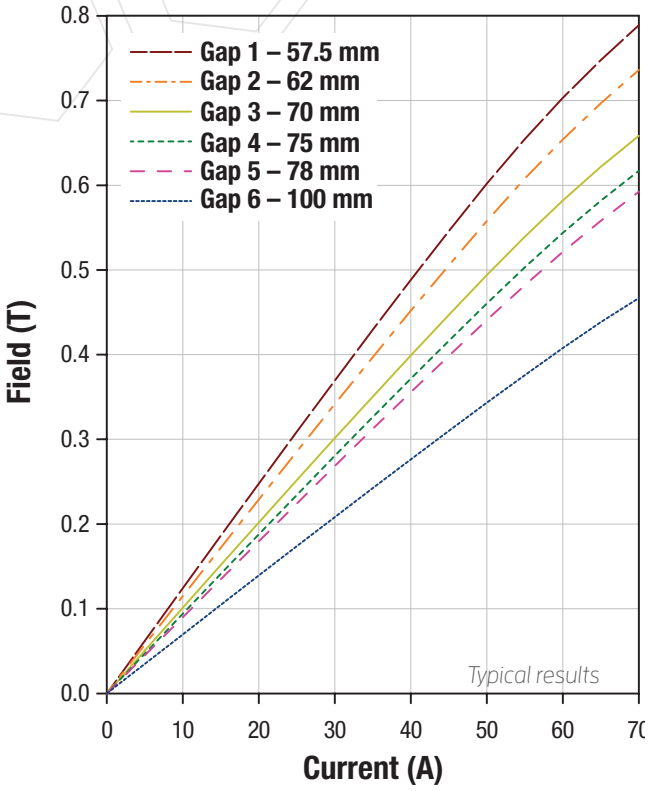

## EM-7V 50 mm (2 in) pole caps field plot



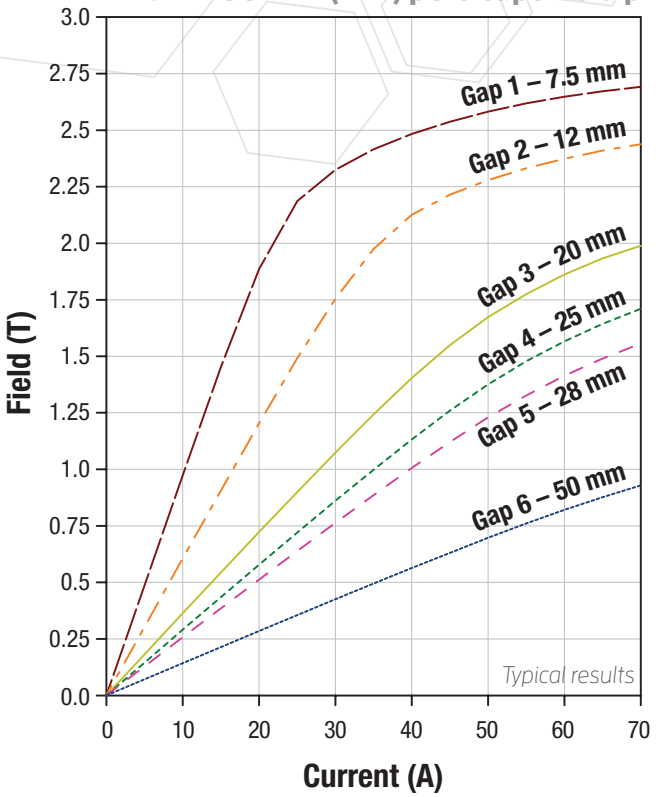

## EM-7V remanent field



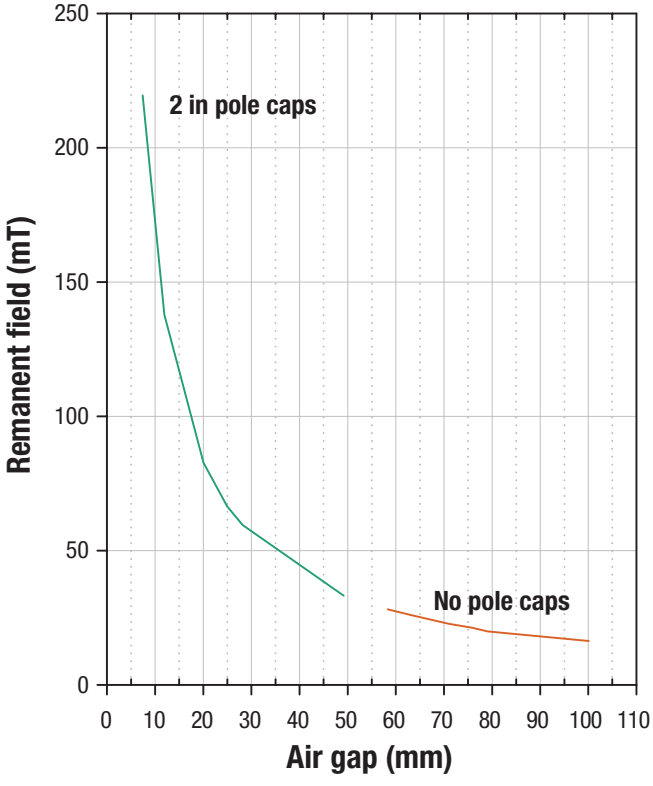
## EM-4V no pole caps field plot

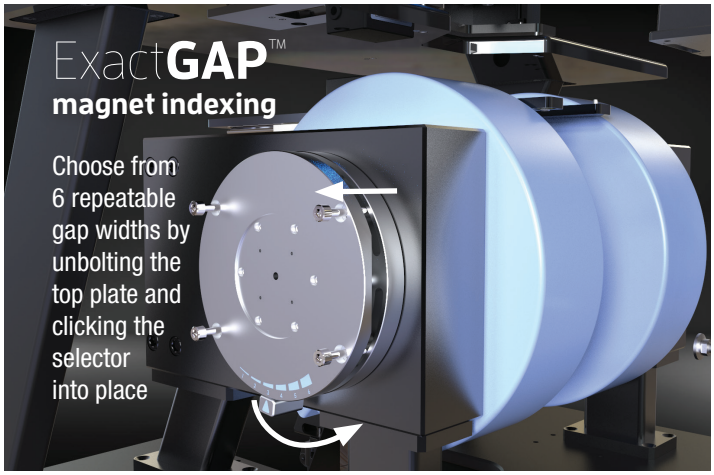



## EM-4V 50 mm (2 in) pole caps field plot




## EM-4V remanent field



# Electromagnet Power Supplies

# Model 643 electromagnet power supply

## Model 643 features

- Low noise
- Compact design
- CE mark certification
- ±70 A/±35 V, 2450 W
- Built-in fault protection
- Analog programming and IEEE-488 and USB interfaces
- Bipolar, linear, true 4-quadrant output
- 0.1 mA of programmed current resolution
- Can be modulated to frequencies up to 0.17 Hz at ±70 A

## Introduction

The Model 643 electromagnet power supply is a linear, bipolar current source providing true 4-quadrant output, eliminating the need for external switching or operator intervention to reverse current polarity. The Model 643 is capable of supplying ±70 A/±35 V to a nominal 0.5 Ω, 0.5 H load, and the output can be modulated from an external source to frequencies up to 0.17 Hz at ±70 A. Internally programmed output provides 20-bit resolution, while externally programmed output provides unlimited resolution.

The compact, low noise design of the Model 643 makes it the ideal supply for use in laboratory settings. When combined with a Lake Shore EM-4V electromagnet and Model 475 DSP gaussmeter, the 643 provides a versatile field control system ideal for a wide range of applications. These include magneto-optical, magnetic hysteresis and susceptibility, Hall effect measurements, and in-line annealing.

## Output architecture

The 643 output architecture relies on low noise linear input and output stages. Its linear circuitry permits operation with less electrical noise than switch-mode electromagnet power supplies. The clean field background allows greater resolution and finer detail in results drawn from data taken during high sensitivity experiments. One key benefit of this architecture is CE compliance to the electromagnetic compatibility (EMC) directive, including the radiated emissions requirement.

The true 4-quadrant output capability of the 643 is ideal for sweeping through both positive and negative fields. Tightly integrated analog control of the 4-quadrant output provides smooth current change with very low overshoot. This eliminates the need for external switching or operator intervention to reverse the polarity, significantly simplifying system design. The transition through zero current is smooth and continuous, allowing the user to readily control the magnetic field as polarity changes. This is achieved without reversal contactors or relays, which would produce unintended field spikes and other discontinuities. As a result, field hysteresis and other biases are avoided in the experimental data.

## Output programming

The 643 output current is programmed internally via the keypad or the computer interface, externally by analog programming input, or by the sum of the external and internal settings. For internal programming, the 643 incorporates a proprietary 20-bit digital-to-analog converter (DAC) that is monotonic over the entire output range and provides resolution of 0.1 mA. External programming provides unlimited resolution.

The 643 generates extremely smooth and continuous ramps with virtually no overshoot. The digitally generated constant current ramp rate is variable between 0.1 and 50 A/s. To ensure smooth ramp rate, the 643 updates the high-resolution DAC 23.7 times/s. A low-pass filter on the output DAC smooths the transitions at step changes during ramping.

## Output reading

The Model 643 provides high-resolution output readings. The output current reading reflects the actual current in the magnet, and has a resolution of 0.1 mA. The output voltage reading reports the voltage at the output terminals with a resolution of 0.1 mV. All output readings can be prominently displayed on the front panel and read over the computer interface.

## Protection

The Model 643 provides built-in protection against short circuit, open circuit, line loss, low line voltage, high line voltage, output over voltage, output over current, over temperature, and abrupt change of the external programming input. In the event of water flow failure, flow sensors provide feedback to the Model 643 and output current is set to 0 A. Internal heat sink, cold plate, and transformer temperatures are also monitored. Warnings are displayed before temperature limits are exceeded and current is set to 0 A. If temperatures continue to increase over safety limits, the Model 643 turns off.

A proprietary circuit limits the power dissipated in the water-cooled cold plate should low resistance and high line conditions exist. The Model 643 protects itself if operated into resistances outside of nominal limits. By limiting current output, the power supply will safely operate into a shorted load, and it operates safely into high resistance loads by limiting voltage output. The Model 643 is also protected against power loss under full operation and nominal magnet load. Both low and high power line conditions are reported on the front panel display.

## Interfaces

The Model 643 includes both parallel IEEE-488 and USB computer interfaces that provide access to operating data, stored parameters, and remote control of all front panel operating functions. The USB interface emulates an RS-232C serial port at a fixed 57,600 baud rate, but with the physical connections of a USB. This allows you to download firmware upgrades, ensuring your power supply is using the most current firmware version with no need for any physical changes. The Model 643 also provides two analog monitors for output current and voltage. Each monitor is a buffered, differential, analog voltage representation of the signal being monitored. The current monitor has a sensitivity of 7 V/70 A output, while the voltage monitor has a sensitivity of 3.5 V/35 V output.

## Display and keypad

The Model 643 incorporates a large 8-line by 40-character vacuum fluorescent display. Output current and output voltage readings are displayed simultaneously. Five front panel LEDs provide quick verification of instrument status, including ramping, compliance, fault, power limit, and computer interface mode. Error conditions are indicated on the main display along with an audible beeper. Extended error descriptions are available under the status key.

The keypad is arranged logically to separate the different functions of the power supply. The most common functions of the power supply are accessed using a single button press. The keypad can be locked in order to secure either all changes or just the instrument setup parameters allowing the supply output to be changed.

# Model 643 specifications

## Output

**Type:** Bipolar, 4-quadrant, DC current source
**Current generation:** Fully linear regulation with digital setting and analog control
**Current range:** ±70 A
**Compliance voltage (DC):** ±35 V nominal
**Power:** 2450 W nominal
**Nominal load:** 0.5 Ω, 0.5 H
**Maximum load resistance:** 0.6 Ω for ±70 A DC operation at +10% to -5% line voltage
**Minimum load resistance:** 0.4 Ω for ±70 A DC operation at +5% to -10% line voltage
**Load inductance range:** 0 H to 1 H
**Current ripple:** 5 mA RMS (0.007%) at 70 A into nominal load
**Current ripple frequency:** Dominated by the line frequency and its harmonics
**Temperature coefficient:** ±15 ppm of full scale/°C
**Line regulation:** ±60 ppm of full scale/10% line change
**Stability (1 h):** 1 mA/h (after warm-up)
**Stability (24 h):** 5 mA/24 h (typical, dominated by temperature coefficient and line regulation)
**Isolation:** Differential output is optically isolated from chassis to prevent ground loops
**Slew rate:** 50 A/s into nominal load, 100 A/s maximum into a resistive load
**Compliance voltage (AC):** ±43 V at +10% to -5% line
**Settling time:** <1 s for 10% step to within 1 mA of output into nominal load
**Modulation response:** ≤0.17 Hz at ±70 A sine wave into nominal load, <0.02% THD; ≤1 Hz at ±10 A sine wave into nominal load, <0.05% THD; ≤10 Hz at ±1 A sine wave into nominal load, <0.10% THD
**Attenuation:** -0.5 dB at 10 Hz
**Protection:** Short circuit, line loss, low line voltage, high line voltage, output over voltage, output over current, and over temperature
**Connector:** Two lugs with 6.4 mm (0.25 in) holes for M6 or 0.25 in bolts

## Output programming

### Internal current setting

**Resolution:** 0.1 mA (20-bit)
**Settling time:** 600 ms for 1% step to within 1 mA (of internal setting)
**Accuracy:** ±10 mA ±0.05% of setting
**Operation:** Keypad, computer interface
**Protection:** Programmable current setting limit

### Internal current ramp

**Ramp rate:** 0.0001 A/s to 50.0000 A/s (compliance limited)
**Update rate:** 23.7 increments/s
**Ramp segments:** 5
**Operation:** Keypad, computer interface
**Protection:** Programmable ramp rate limit

### External current programming

**Sensitivity:** 10 V/70 A
**Resolution:** Analog
**Accuracy:** ±10 mA ±1% of setting
**Input resistance:** 20 kΩ
**Operation:** Voltage program through rear panel, can be summed with internal current setting
**Limits:** Internally clamped at ±10.1 V and bandwidth limited at 40 Hz to protect output
**Connector:** Shared 15-pin D-sub

## Readings

### Output current

**Resolution:** 0.1 mA
**Accuracy:** ±10 mA ±0.05% of rdg
**Update rate:** 2.5 rdg/s display, 10 rdg/s interface

### Output voltage (at supply terminals)

**Resolution:** 1 mV
**Accuracy:** ±5 mV ±0.05% of rdg
**Update rate:** 2.5 rdg/s display, 5 rdg/s interface

## Front panel

**Display type:** 8-line by 40-character graphic vacuum fluorescent display module
**Display readings:** Output current, output voltage, and internal water temperature
**Display settings:** Output current and ramp rate
**Display annunciators:** Status and errors
**LED annunciators:** Fault, Compliance, Power Limit, Ramping, Remote
**Audible annunciator:** Errors and faults
**Keypad type:** 26 full-travel keys
**Keypad functions:** Direct access to common operations, menu-driven setup
**Power:** Green flush ON and red extended OFF push buttons

## Interface

### IEEE-488.2 interface

**Features:** SH1, AH1, T5, L4, SR1, RL1, PP0, DC1, DT0, C0, E1
**Reading rate:** To 10 rdg/s
**Software support:** National Instruments LabVIEW™ driver (consult Lake Shore for availability)

### USB interface

**Function:** Emulates a standard RS-232 serial port
**Baud rate:** 57,600
**Reading rate:** To 10 rdg/s
**Connector:** B-type USB connector
**Software support:** National Instruments LabVIEW™ driver (consult Lake Shore for availability)

### Output current monitor

**Sensitivity:** 7 V/70 A
**Accuracy:** ±1% of full scale
**Noise:** 1 mV RMS
**Source impedance:** 20 Ω
**Connector:** Shared 15-pin D-sub

### Output voltage monitor

**Sensitivity:** 3.5 V/35 V
**Accuracy:** 1% of full scale
**Noise:** 1 mV RMS
**Source impedance:** 20 Ω
**Connector:** Shared 15-pin D-sub

### Power supply cooling water

**Remote enable input:** TTL low or contact closure to enable output; jumper required if unused
**Valve power output:** 24 VAC at 1 A maximum, automatic or manual control
**Connector:** Shared 4-pin detachable terminal block; Flow switch and water valve optional

### Magnet cooling water

**Remote enable input:** TTL low or contact closure to enable output; jumper required if unused
**Valve power output:** 24 VAC at 1 A maximum, automatic or manual control
**Connector:** Shared 4-pin detachable terminal block
Flow, temperature switch, and water valve not included

### Auxiliary

**Emergency stop:** Requires 1 A, 24 VAC normally closed (NC) contact to enable power-up; jumper required if unused
**Fault output:** Relay with normally open (NO) or normally closed (NC) contact, 30 VDC at 1 A
**Remote enable input:** TTL low or contact closure to enable output; jumper required if unused
**Connector:** Shared 8-pin detachable terminal block
Emergency stop and inhibit switches not included

## General

### Line power

**Power:** 5500 VA max
**Voltage and current:** 200/208 VAC ±10%, 13 A/phase; 220/230 VAC ±10%, 12 A/phase; 380 VAC ±10%, 7 A/phase; 400/415 VAC ±10%, 6.5 A/phase
**Protection:** 3-phase thermal relay with adjustable current setting; two class CC 0.25 A fuses; over-voltage lockout circuit
**Frequency:** 50 Hz or 60 Hz
**Configuration:** 3-phase delta
**Connector:** 4-pin terminal block
**Features:** Soft start circuit, rear panel voltage selection indicator
Line voltage must be specified at time of order but is field reconfigurable; cable from power supply to facility power not included

### Cooling water

**Flow rate:** 5.7 L (1.5 gal)/min minimum
**Pressure range:** 34 kPa (5 psi) to 552 kPa (80 psi)
**Pressure drop:** 10 kPa (1.5 psi) at 5.7 L (1.5 gal)/min minimum for power supply only
**Temperature:** 15 °C to 30 °C (non-condensing)
**Connection:** Two 10 mm (0.38 in) hose barbs
**CAUTION:** Internal condensation can cause damage to the power supply
**Enclosure type:** 7 U high, 19 in rack mount with integral rack mount ears (25 mm (1 in) air space required on each side for ventilation)
**Size:** 483 mm W × 310 mm H × 572 mm D (19 in × 12.2 in × 22.5 in) with handles removed
**Weight:** 74 kg (163 lb)
**Shipping size:** 635 mm W × 559 mm H × 736 mm D (25 in × 22 in × 29 in)
**Shipping weight:** 103.4 kg (228 lb)
**Ambient temperature:** 15 °C to 35 °C at rated accuracy, 5 °C to 40 °C at reduced accuracy
**Humidity:** Non-condensing
**Warm-up:** 30 min at output current setting
**Approvals:** CE mark—low voltage compliance to EN61010-3, EMC compliance to EN55022-1

# Model 648 bipolar magnet power supply

## Model 648 features

- Low noise
- CE mark certification
- ±135 A/±75 V, 9.1 kW
- Built-in fault protection
- Bipolar, linear, 4-quadrant output
- 1 mA of programmed current resolution
- Analog programming and IEEE-488 and USB interfaces

## Introduction

The Model 648 electromagnet power supply is a robust, fault-tolerant 9 kW supply optimized for powering large 7 or 10 in research electromagnets. It is specifically designed for high precision laboratory use requiring extremely low electrical noise. The linear design removes undesirable higher frequency noise typical of switch mode power supplies. Eliminating the need for external switching or operator intervention to reverse current polarity, the Model 648 uses convenient bipolar, 4-quadrant operation. It is capable of supplying ±135 A/±75 V to a nominal 0.5 Ω, 0.5 H load. The Model 648 is built to last with a rugged design, integrated fault protection, and a simple, clean interior electronic design.

This robust power supply is developed to minimize downtime. It uses worry-free water cooling for quiet efficient operation compared to air-cooled power supplies. The seamless water lines only have external junctions, eliminating internal water leaks. In addition, safety interlocks ensure that cooling water is always flowing to the supply while operating. Magnet water can also be interlocked into the power supply if desired. Internal software controls manage water usage intelligently.

## Output architecture

The low electrical noise design of the Model 648 makes it the ideal power supply for use with large electromagnets in high precision laboratory settings, ensuring greater resolution and finer detail in data taken during highly sensitive measurements. Because low noise is critical to measurement systems, the Model 648 implements both a linear design and bipolar architecture. Linear magnet power supplies have several advantages over switch mode power supplies, primarily smooth field generation that is nearly free from offending electromagnetic signatures. The bipolar, 4-quadrant operation required to safely operate an inductive load provides clean transitions through zero without discontinuities.

## Output programming

The Model 648 output current is programmed internally via the keypad or the computer interface, externally by analog programming input, or by the sum of the external and internal settings. External programming via analog input signal provides analog resolution. The Model 648 generates extremely smooth and continuous ramps — the digitally generated constant current ramp rate is variable between 0.1 mA/s and 50.000 A/s. To ensure a smooth ramp rate, the power supply updates the high-resolution DAC 12.3 times per second.

## Output reading

The Model 648 provides high-resolution output current readings that reflect the actual current in the magnet, and have a resolution of 1 mA. The output voltage reading reports the voltage at the output terminals with a resolution of 1 mV. All output readings can be prominently displayed on the front panel and read over the computer interface.

## Protection

The Model 648 provides built-in protection against short circuit, open circuit, line loss, low line voltage, high line voltage, output over voltage, output over current, over temperature, and abrupt change of the external programming input. A proprietary circuit limits the power dissipated in the water-cooled cold plate should low resistance and high line conditions exist. The Model 648 protects itself if operated into resistances outside of nominal limits. By limiting current output, it will safely operate into a shorted load, and operate safely into high resistance loads by limiting voltage output. The Model 648 is also protected against power loss under full operation and nominal magnet load. Both low and high power line conditions are reported on the front panel display.

## Output

**Type:** Bipolar, 4-quadrant, DC voltage/current source
**Current generation:** Fully linear regulation with digital setting and analog control
**Current range:** ±135 A nominal
**Compliance voltage (DC):** ±75 V
**Power:** 9.1 kW nominal
**Nominal load:** 0.5 Ω, 0.5 H
**Maximum load resistance:** 0.55 Ω for ±135 A DC operation at +10% to -5% line voltage
**Minimum load resistance:** 0.41 Ω for ±135 A DC operation at +5% to -10% line voltage
**Load inductance range:** 0 H to 1 H
**Current ripple:** 10 mA RMS (0.007%) at 135 A into nominal load
**Current ripple frequency:** Dominated by the line frequency and its harmonics
**Temperature coefficient:** ±50 ppm of full scale/°C
**Line regulation:** ±75 ppm of full scale/10% line change
**Stability (1 h):** 2 mA/h (after warm-up, internal setting)
**Stability (24 h):** 10 mA/24 h (typical, internal setting, dominated by temperature coefficient and line regulation)
**Isolation:** Differential output is optically isolated from chassis to prevent ground loops
**Slew rate:** 50 A/s into nominal load (dominated by magnet characteristics), 100 A/s maximum into a resistive load
**Settling time:** <1 s for 10% step to within 1 mA of output into nominal load
**Harmonic distortion:** ≤0.1 Hz at ±135 A sine wave into resistive load, <0.02% THD; ≤10 Hz at ±10 A sine wave into resistive load, <0.30% THD
**Attenuation:** -0.5 dB at 10 Hz (external programming input)
**Protection:** Short circuit, line loss, low line voltage, high line voltage, output over voltage, output over current, and over temperature
**Connector:** Two lugs with 8.64 mm (0.34 in) holes for M8 or 5/16 in bolts

## Output programming

### Internal current setting

**Resolution:** 1.0 mA (20-bit)
**Settling time:** 600 ms for 1% step to within 1 mA (of internal setting)
**Accuracy:** ±20 mA ±0.05% of setting
**Operation:** Keypad, computer interface
**Protection:** Programmable current setting limit

### Internal current ramp

**Ramp rate:** 0.1 mA/s to 50.000 A/s (compliance limited)
**Update rate:** 12.3 increments/s
**Ramp segments:** 5
**Operation:** Keypad, computer interface
**Protection:** Programmable ramp rate limit

### External current programming

**Sensitivity:** 10 V/135 A
**Resolution:** Analog
**Accuracy:** ±20 mA ±1% of setting
**Input resistance:** 20 kΩ differential, 50 kΩ common-mode
**Operation:** Voltage program through rear panel, can be summed with internal current setting
**Limits:** Internally clamped at ±10.1 V and bandwidth limited -3 dB at 40 Hz (2 pole, low pass filter)
**Connector:** Shared 15-pin D-sub

## Readings

### Output current

**Resolution:** 1.0 mA
**Accuracy:** ±20 mA ±0.05% of rdg
**Update rate:** 2.5 rdg/s display, 10 rdg/s interface

### Output voltage (at supply terminals)

**Resolution:** 1.0 mV
**Accuracy:** ±10 mV ±0.05% of rdg
**Update rate:** 2.5 rdg/s display, 5 rdg/s interface

## Front panel

**Display type:** 8-line by 40-character graphic vacuum fluorescent display module
**Display readings:** Output current, output voltage, and internal water temperature
**Display settings:** Output current and ramp rate
**Display annunciators:** Status and errors
**LED annunciators:** Fault, Compliance, Power Limit, Ramping, Remote
**Audible annunciator:** Errors and faults
**Keypad type:** 20 full-travel keys
**Keypad functions:** Direct access to common operations, menu-driven setup
**Power:** Green flush ON and red extended OFF push buttons

## Interface

### IEEE-488.2 interface

**Features:** SH1, AH1, T5, L4, SR1, RL1, PP0, DC1, DT0, C0, E1
**Reading rate:** To 10 rdg/s
**Software support:** National Instruments LabVIEW™ driver (consult Lake Shore for availability)

### USB interface

**Function:** Emulates a standard RS-232 serial port
**Baud rate:** 57,600
**Reading rate:** To 10 rdg/s
**Connector:** Type B USB connector
**Software support:** National Instruments LabVIEW™ driver (consult Lake Shore for availability)

### Output current monitor

**Sensitivity:** 7 V/135 A
**Accuracy:** ±1% of full scale
**Noise:** 5 mV RMS
**Source impedance:** 20 Ω
**Connector:** Shared 15-pin D-sub

### Output voltage monitor

**Sensitivity:** 7 V/70 V
**Accuracy:** 1% of full scale
**Noise:** 2 mV RMS
**Source impedance:** 20 Ω
**Connector:** Shared 15-pin D-sub

### Power supply cooling water

**Remote enable input:** TTL low or contact closure to enable output; used for mandatory 1 gal/min flow switch (included)
**Connector:** 2-pin detachable terminal block connector
**Valve power output:** 24 VAC at 1.5 A maximum, automatic or manual control
**Connector:** 2-pin detachable terminal block connector
Water valve optional

### Magnet cooling water

**Remote enable input:** TTL low or contact closure to enable output; jumper required if unused
**Valve power output:** 24 VAC at 1.5 A maximum, automatic or manual control
**Connector:** Shared 4-pin detachable terminal block
Flow, temperature switch, and water valve not included

### Auxiliary

**Emergency stop:** Requires 1 A, 24 VAC normally closed (NC) contact to enable power-up; jumper required if unused
**Fault output:** Relay with normally open (NO) or normally closed (NC) contact, 30 VDC at 1 A
**Remote enable input:** TTL low or contact closure to enable output; jumper required if unused
**Connector:** Shared 8-pin detachable terminal block; Emergency stop and inhibit switches not included

## General

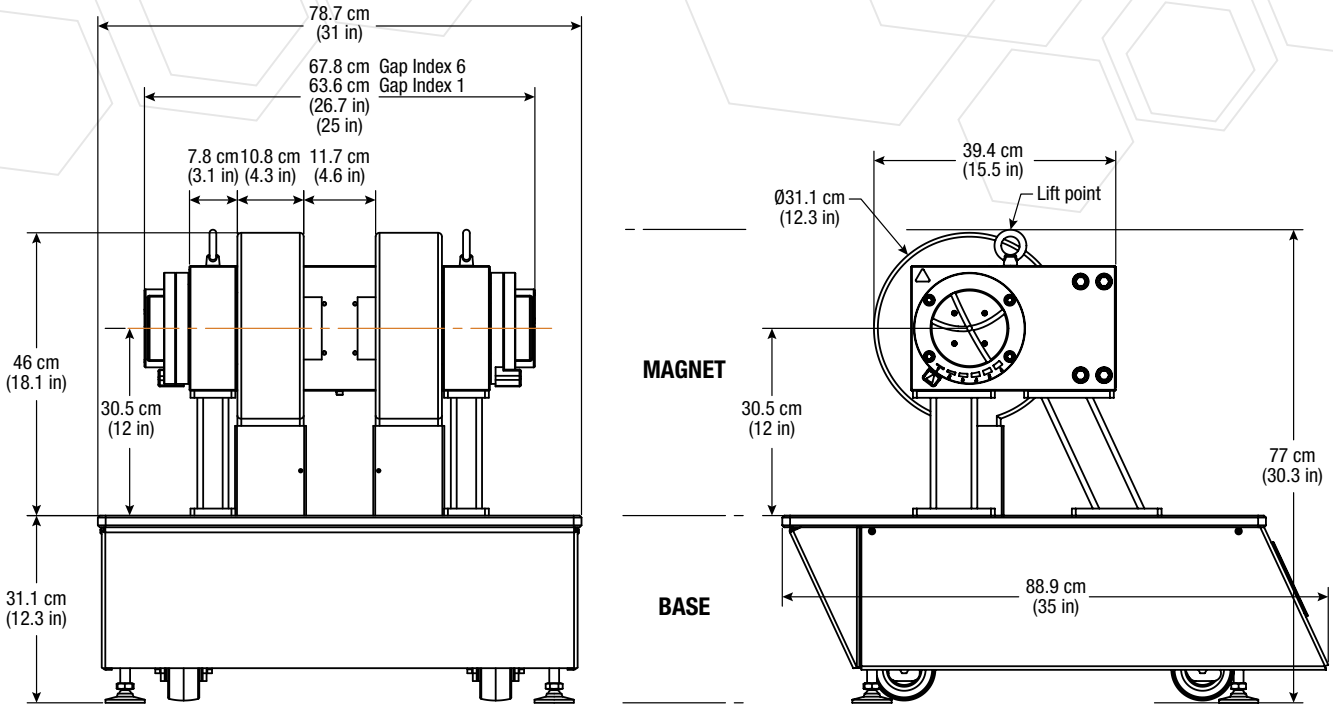
### Line power

**Power:** 15.5 kVA max
**Voltage and current:** 200 VAC ±5%, 41 A/phase; 208 VAC ±5%, 40 A/phase; 220 VAC ±5%, 38 A/phase; 230 VAC ±5%, 37 A/phase; 380 VAC ±5%, 23 A/phase; 400 VAC ±5%, 21 A/phase; 415 VAC ±5%, 21 A/phase
**Protection:** 3-phase thermal relay with adjustable current setting; two class CC 2 A fuses; over-voltage lockout circuit
**Frequency:** 50 Hz or 60 Hz
**Configuration:** 3-phase delta
**Connector:** 4-pin terminal block;
Line voltage must be specified at time of order but is field reconfigurable; cable from power supply to facility power not included

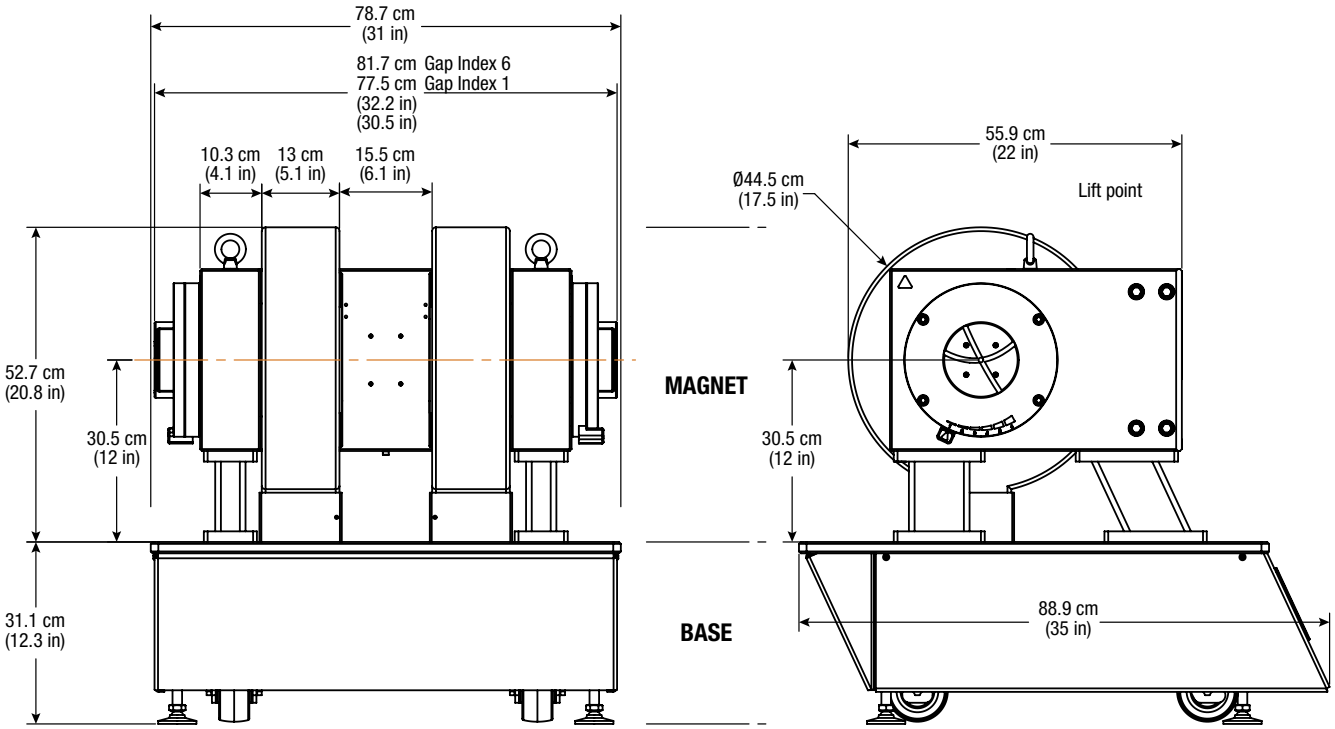
### Cooling water

**Flow rate:** 7.6 L (2.0 gal)/min minimum
**Maximum pressure:** 552 kPa (80 psi)
**Pressure drop:** 159 kPa (23 psi) at 7.6 L (2.0 gal)/min minimum for power supply and mandatory flow switch
**Temperature:** 15 °C to 30 °C (non-condensing)
**Connection:** Two 12.7 mm (0.5 in) hose barbs
**CAUTION:** Internal condensation can cause damage to the power supply
**Enclosure type:** Custom 19 in rack cabinet
**Size:** 559 mm W × 673 mm D × 1054 mm H (22 in × 26 in × 42 in)
**Weight:** 225 kg (495 lb)
**Shipping size:** 914 mm W × 1168 mm D × 1219 mm H (36 in × 46 in × 48 in)
**Shipping weight:** 281 kg (620 lb)
**Ambient temperature:** 15 °C to 35 °C at rated accuracy, 5 °C to 40 °C at reduced accuracy
**Humidity:** Non-condensing
**Warm-up:** 30 min at output current setting
**Approvals:** CE mark—low voltage compliance to EN61010-1, EMC compliance to EN61326-1

## EM-4V


78.7 cm
(31 in)
67.8 cm Gap Index 6
63.6 cm Gap Index 1
(26.7 in)
(25 in)
7.8 cm
(3.1 in)
10.8 cm
(4.3 in)
11.7 cm
(4.6 in)
46 cm
(18.1 in)
30.5 cm
(12 in)
31.1 cm
(12.3 in)
MAGNET
BASE
39.4 cm
(15.5 in)
Ø31.1 cm
(12.3 in)
Lift point
30.5 cm
(12 in)
77 cm
(30.3 in)
88.9 cm
(35 in)

## EM-7V


78.7 cm
(31 in)
81.7 cm Gap Index 6
77.5 cm Gap Index 1
(32.2 in)
(30.5 in)
10.3 cm
(4.1 in)
13 cm
(5.1 in)
15.5 cm
(6.1 in)
52.7 cm
(20.8 in)
30.5 cm
(12 in)
31.1 cm
(12.3 in)
MAGNET
BASE
55.9 cm
(22 in)
Ø44.5 cm
(17.5 in)
Lift point
30.5 cm
(12 in)
88.9 cm
(35 in)

# Ordering information

## Electromagnets

| | |
|---|---|
| **EM-4V** | 4 in electromagnet with base and standard 4 in to 2 in pole caps; includes water manifold and cables |
| **EM-4V-O** | 4 in electromagnet with base and optical access 4 in to 2 in pole caps; includes water manifold and cables |
| **EM-7V** | 7 in electromagnet with base and standard 4 in to 2 in pole caps; includes water manifold and cables |
| **EM-7V-O** | 7 in electromagnet with base and optical access 4 in to 2 in pole caps; includes water manifold and cables |

## Power supplies

| | |
|---|---|
| **648** | 7 in electromagnet power supply; specify AC power in configurator |
| **643** | 4 in electromagnet power supply; specify AC power in configurator |

## Accessories

| | |
|---|---|
| **MCS-EMP-HF** | High field non-optical pole caps |
| **MCS-EMP-HF-O** | High field optical access pole caps |

***For additional or custom pole caps, please contact Lake Shore***

| | |
|---|---|
| **TPS-FRG-100/120V** | Compact turbo pumping system; includes V-84 turbo pump (NW 40) with oil free dry scroll backing pump, FRG-700 full range gauge, controller, and interface cable to USB port; includes Agilent 24 month warranty NOTE: requires SYS-TP-KIT |
| **TPS-FRG-220/240V-CE** | Compact turbo pumping system; includes V-84 turbo pump (NW 40) with oil free dry scroll backing pump, FRG-700 full range gauge, controller, and interface cable to USB port; includes Agilent 24 month warranty NOTE: requires SYS-TP-KIT |
| **SYS-TP-KIT** | Includes all components necessary to connect NW 40 turbo pumping system to the vacuum port of any Lake Shore system (except probe stations) |
| **1220-50** | 50 L $LN_2$ Dewar with ½ in top withdraw port and 10 psi pressure relief valve |
| **E2M-110/120V** | Two-stage rotary vacuum pump with mist filter; 110 to 120 VAC NOTE: requires SYS-RP-KIT |
| **E2M-220/240V** | Two-stage rotary vacuum pump with mist filter; 220 to 240 VAC NOTE: requires SYS-RP-KIT |
| **EMP-SHIMS-4** | Shim kit for 4 in electromagnet (not compatible with the 8600 Series) |
| **EMP-SHIMS-7** | Shim kit for 7 in electromagnet (not compatible with the 8600 Series) |

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