Returning Units for Repair

Before returning any product for repair and/or adjustment, call AE Customer Service and discuss the problem with a representative. Be prepared to give the serial number of the unit and the reason for the proposed return. This consultation call allows Customer Service to determine whether the problem can be corrected in the field or if the unit needs to be returned. Such technical consultation is always available at no charge.

If you return a unit without first getting authorization from Customer Service and that unit is found to be functional, you will be charged a re-test and calibration fee plus shipping charges.
CONGRATULATIONS ...

On your purchase of AE’s MDX 500 DC magnetron drive, which is designed for continuous hard use into a vacuum environment. Advanced circuit design and calibrated instrumentation make these units the most accurate, most efficient, and most versatile in the world today.

The Advanced Energy® MDX 500 magnetron drive provides exceptional efficiency from line to load, quick response to changes in the load, and extremely low stored energy in the output filter. In addition, it lets you regulate power, current, or voltage.

The standard ARC-OUT™ arc-suppression circuitry provides outstanding suppression and quenching of arcs, cutting off the energy that feeds hot spots.

Typical applications include dc sputtering with RF bias, basic magnetron sputtering, dc bias for cathodic-arc deposition (sputter etching), and dc-biased RF sputtering.
SAFETY

⚠️ YOU SHOULD KNOW...

DANGER! Capacitor discharge time of the 300 V bus is 4 minutes. Do not remove top cover. None of the unit's parts are user-serviceable.

DO NOT BE CARELESS AROUND THIS EQUIPMENT.
WARNING

SAFE OPERATING PROCEDURES AND PROPER USE OF THE EQUIPMENT ARE THE RESPONSIBILITY OF THE USER OF THIS SYSTEM.

⚠️ YOU SHOULD KNOW...

DANGER! Operating and maintenance personnel must have the correct training before setting up and maintaining high-energy electrical equipment. THIS EQUIPMENT MUST BE INSTALLED ACCORDING TO APPLICABLE REQUIREMENTS.

⚠️ YOU SHOULD KNOW...

This equipment must be operated in a pollution degree two environment.

Advanced Energy Industries, Inc., provides information on its products and associated hazards, but it assumes no responsibility for the after-sale operation of the equipment or the safety practices of the owner or operator.

This equipment produces potentially lethal high-voltage and high-current energy. You should read this manual and understand its contents before you attempt to hook up or operate the equipment it describes. Follow all safety precautions. **Never defeat interlocks or grounds.**

⚠️ YOU SHOULD KNOW...

This device is tested for and complies with safety standard prEN50178 and EMC standard EN55011 and must be installed and used only in compliance with these standards and applicable requirements.
To ensure years of dependable service, Advanced Energy® products are thoroughly tested and designed to be among the most reliable and highest quality systems available worldwide. All parts and labor carry our standard 1-year warranty.

For Customer Service or Support, call:

AE, Colorado (970) 221-0108
Fax: (970) 416-3334

AE, California (408) 263-8784
Fax: (408) 263-8992

AE, Texas (512) 719-3939
Fax: (512) 719-4319

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AE, Japan 81-3-3235-1511
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Fax: 44 (0)1869 325004

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Additional AE Sales Office:
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DIE
MDX 500
MAGNETRON-ANSTEUERUNG
VON ADVANCED ENERGY®

Benutzerhandbuch

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Artikelnr. 5700349-B
March 1997


Im Interesse der stetigen Verbesserung unserer Produkte behält sich Advanced Energy Industries, Inc. das Recht vor, Produktänderungen ohne Vorankündigung oder sonstige Verpflichtungen vorzunehmen. Die in diesem Handbuch enthaltenen Informationen waren an dem auf der Titelseite angegebenen Datum nach unserem Wissen korrekt.

Weitere Informationen sind von Advanced Energy Industries, Inc. unter folgender Anschrift erhältlich: 1625 Sharp Point Drive, Fort Collins, CO 80525, USA.

Rücksendung von Geräten zu Reparaturzwecken


Wenn Sie ein Gerät zurücksenden, ohne zunächst vom Kundendienst eine Genehmigung dazu erhalten zu haben, und sich das Gerät als betriebsbereit herausstellt, müssen Sie eine Test- und Kalibriergebühr entrichten und für alle Versandkosten aufkommen.

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ACHTUNG

DIE VERANTWORTUNG FÜR DEN SICHEREN BETRIEB UND DIE ORDNUNGSGEMÄSSE VERWENDUNG DES GERÄTS LIEGT BEIM BENUTZER DIESES SYSTEMS.

⚠️ BITTE BEACHTEN...

ACHTUNG LEBENSGEFAHR! Elektrische Hochenergie-Geräte dürfen nur von speziell dafür ausgebildetem Betriebs- und Wartungspersonal aufgestellt und gewartet werden. DIESES GERÄT MUSS ENTSPRECHEND DEN GELTENDEN VORSCHRIFTEN INSTALLIERT WERDEN.

⚠️ BITTE BEACHTEN...

Für den Betrieb dieses Geräts müssen die Voraussetzungen in bezug auf Verschmutzungsgrad Zwei erfüllt werden.

Advanced Energy Industries, Inc. stellt Informationen über seine Produkte und die damit verbundenen Risiken und Gefahren zu Verfügung, übernimmt jedoch keinerlei Verantwortung für den Betrieb dieses Geräts nach dessen Verkauf bzw. für die Sicherheitsvorkehrungen, die vom Besitzer oder Anwender getroffen werden.


⚠️ BITTE BEACHTEN...

SICHERHEIT

ACHTUNG LEBENSGEFÄHRL! Die Kondensator-Entladungszeit des 300-V-Bus beträgt vier Minuten. Niemals die obere Abdeckung abnehmen. Das Gerät enthält keine Bauteile, die vom Benutzer zu reparieren oder zu warten sind.

IM UMGANG MIT DIESEM GERÄT IMMER ÄUSSERSTE SORGFALT WALDEN LASSEN!
HERZLICHEN
GLÜCKWUNSCH ...


Die standardmäßige Lichtbogen-Unterdrückungsschaltung ARC-OUT™ ermöglicht eine hervorragende Unterdrückung und Lösung von Lichtbögen und verhindert so ein Abfließen von Energie in Hot Spots.

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- Electrical specifications  page 1-14
- (Elektrische Spezifikation) (page 1-28)
- Connectors  page 2-7
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- (Aufstellen des Geräts) (page 3-25)
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- Indicators  page 2-13 through 2-15
- Front and rear panel controls  page 2-17 and 2-18

We also think that you will find Overview of the Manual (page ix) and Interpreting the Manual (page xi) useful. They are very short sections and will guide you through the manual. Overview of the Manual explains the organization of the manual so that you can more quickly find what you need. Interpreting the Manual explains how the type conventions work (what it means when a word appears in capitalized italic type, for instance) and what the five icons (symbols) mean.
OVERVIEW OF THE MANUAL

The main table of contents is a general outline of major topics covered in the manual. It contains only the main headings within each chapter so that you can skim it and get a general idea of what is contained here, without having to look at a lot of headings. When you turn to one of the five chapters, you will find a detailed table of contents that lists every heading in that particular chapter. This will help you to quickly decide which page contains the information you are looking for. Throughout the manual, the chapter titles appear at the top right-hand corner of each odd-numbered page.

Part I contains two chapters: What It Is, and How It Works. What It Is gives a general overview of the MDX magnetron drive, its various features and configurations, and its typical applications. A detailed description of the functional specifications and a list of the electrical, physical and environmental specifications also appear.

How It Works contains a functional block diagram and important information on connections, including listings of all input, output, and reference pins. This section briefly discusses status indicators and describes functions that are available through the User port.

Part II consists of two chapters: Preparing for Use, and Choosing Modes/Settings. Preparing for Use provides information on connection and wiring options, spacing and cooling requirements, and start-up procedures.

Choosing Modes/Settings contains information on selecting one of the three methods of output regulation: power, current, or voltage. The section explains accessing functions through the analog/digital ("User") interface. It also includes an explanation of the contactor hold function and the impedance options.

Part III contains two technical operating notes: one on dc bias and one on grounding considerations.
INTERPRETING THE MANUAL

Type Conventions

To help you quickly pick out what is being discussed, the manual presents certain words and phrases in unique type styles.

Pin and line names appear in capitalized italics (*LEVEL IN.A*). Labels that are on the MDX (switches, indicators, etc.) generally appear in boldface capital letters (*LEVEL*). Exceptions are port names, which simply begin with a capital letter (User port).

Functions appear in boldface lowercase letters (*contactor hold*).

How to Use the Manual Symbols

⚠️ **YOU SHOULD KNOW…**

**Safety notes.** Important notes concerning potential harm to people.

⚠️ **YOU SHOULD KNOW…**

**Warning notes.** Important notes concerning possible harm to this unit or associated equipment.

✉️ **YOU SHOULD KNOW…**

**Operating notes.** More thoughts on how to use the extended features provided.
Hook-up and interfacing notes. General practices for connecting input and output power or for connecting communication and control interfaces.

Service notes. General practices for maintaining this equipment in top running condition.
PART I

GETTING TO KNOW YOUR MDX MAGNETRON DRIVE
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GENERAL DESCRIPTION

The dc magnetron drives in the MDX series prove just how convenient and efficient advanced high-frequency switchmode power supplies are. They...

- Are light and compact
- Are highly efficient (low heat emission)
- Provide excellent regulation and stability
- Have a highly reliable solid state design
- Are modular
- Store very little energy in the output filter.

These magnetron drives offer superior output response time, low output ripple voltage, and considerable space savings over lower frequency designs. The modular design fosters easy service and repair.

Output Regulation

You can use the MDX as a power, current, or voltage source, depending on the method of output regulation selected. Set the setpoint level with a locking potentiometer to ensure repeatability from run to run.

Displays

Internal circuitry takes and interprets instrumentation and status readings then displays the result on the digital front panel display and LED indicators. Power, voltage, current, and interlock status are examples of the parameters that are displayed.

Built-in Protection

The MDX has complete internal protection for all overload conditions. It provides three separate pins on the User port and a front-panel indicator for safety-related inputs, such as vacuum, water, and auxiliary (user-specified) interlocks.

Arc-suppression Circuitry

ARC-OUT™ provides multilevel suppression and quenching of different types of arcs. An added advantage is that ARC-OUT reduces target burn-in time and material loss. This feature also prevents energy from being dumped into hot spots by sensing a drop in impedance then immediately shutting the power off.
Start-up occurs after an arc is controlled so that the hot spots cool before power is re-applied, thus preventing repeated arcing.
TYPICAL APPLICATIONS

Basic Magnetron Sputtering

Four output configuration options are available for the MDX: negative output voltage or positive output voltage, and 500 V at 1 A or 1000 V at 0.5 A.

Danger! An understanding of grounding and the proper hookup of grounds is essential to personnel safety and is necessary for the proper operation of your system. In all cases, you must connect the chassis ground stud on the rear of the MDX to earth ground with the lowest possible impedance.

Factory Configuration

The MDX arrives with the polarity, voltage/current, and analog reference voltage you specified in the purchase order. A negative configuration is illustrated on the next page (Figure 1-1).

The output of the power supply is always referenced to the chassis. We provide a ground stud to make a low impedance connection to the load.
Figure 1-1. Factory configuration (negative output).
DC Sputtering with RF Bias

WARNING! You must place an ac blocking filter in series with the output of the dc power supply if your system uses a dc power supply in combination with an ac power supply that has an output frequency greater than 50 kHz.

In this application (see Figure 1-2 on the next page), proper installation of the RF generator and tuner is critical to proper operation of the system. Proper installation includes good, solid RF grounding and dc installation.

You must place an RF filter between the dc output and the chamber because 13.56 MHz is very disruptive to the typical dc magnetron power supply. There is no need to put a filter between the RF tuner output and the chamber because Advanced Energy® tuners provide a dc block.

The purpose of this type of installation is to elevate the potential on the biased substrate. With proper installation and programming, an Advanced Energy® RFX can control the developed dc bias on the substrate (see the operating note on dc bias, page DC-3).

This extra control parameter (RF bias) may provide higher deposition rates or better film structure. The results will vary with each application. Biasing alters the ion and acceleration potentials, and these altered potentials provide the desired results.
Figure 1-2. Typical configuration for dc sputtering with RF bias.
DC-biased RF Sputtering

WARNING! You must place an ac blocking filter in series with the output of the dc power supply if your system uses a dc power supply in combination with an ac power supply that has an output frequency greater than 50 kHz.

Figure 1-3 (on the next page) shows a typical RF sputtering application, where the target shield and chamber walls are referenced to ground, but the substrate is directly biased with a dc power supply. This could be a planar magnetron or an “S” gun installation.

Improper grounding of the tuner, chamber, and MDX will result in radio frequency interference (RFI), which often manifests in this application by valves chattering or your computer behaving erratically.

DANGER! Lethal high-voltage potentials will be present if the tuner, chamber, and MDX are not properly grounded.

Some RF sputtering applications require a length of cable between the tuner output and the vacuum feedthrough. Only use this type of connection—with extreme caution—if there is no way to mount the tuner directly to the vacuum feedthrough. The impedance transformation that takes place within the interconnect cable can create large circulating currents on this cable. The power dissipated is a function of $I^2R$ losses. This formula shows that any increase in circulating current greatly increases the losses in the cable.

In light of this fact, use a Teflon® dielectric cable because Teflon has a more favorable thermal characteristic than other cable materials. The Teflon will minimize migration of the center conductor due to overheating, thus reducing the probability of the center conductor shorting to the outer sheath.

A key consideration in any RF installation is the RF return path. Power supply/tuner connection: The power supply usually connects to the tuning network through a coaxial cable, and the braided shield on this cable acts as an adequate RF return for this section of the circuit.
**Tuner/chamber connection:** Pay special attention to the connection between the tuning network and chamber. On all Advanced Energy® tuners, the aluminum chassis provides the RF return path. Ideally, you should bolt this chassis directly onto the vacuum chamber, thus establishing good surface contact. If this is not possible, connect the tuner and chamber with a solid copper strap. Avoid using braid—the fine strands within the braid form a highly inductive path and may melt from overheating. Also avoid using stainless steel hardware—steel is a poor conductor at high frequencies because of its ferromagnetic properties. Brass hardware is a better choice because brass is a good conductor and is readily available.

![Diagram](image)

*Figure 1-3. Typical configuration for RF sputtering with dc bias.*
SPECIFICATIONS

Functional Specifications

Control Signal Sources
Either the front panel or the optional analog/digital interface let you control output.

Methods of Output Regulation
Choose power, current, or voltage as the value that remains constant when the MDX is producing output.

Methods of Control
Local or remote.

Programmable Setpoints
Program an output level (up to the unit's maximum rated output) for power, current, or voltage.

Arc Suppression
The MDX quickly detects arc conditions and modifies output to prevent damage to the target and substrate.

Digital Meter
The digital meter on the front panel display can show information in watts (W), volts (V), or amps (A)—regardless of whether the output is power, current, or voltage regulation; when you initially turn on output, the digital meter displays setpoint or program information in the regulation mode you have selected.

Ramp Switches
Select a ramp time—fast ramp or some combination of 0.1 s, 1 s, or 10 s (the ramp times are additive)—by configuring the ramp switches on the rear control panel.

Fault Conditions
The faults that will cause the MDX to shut off output are interlock, input power, and overtemperature.
Electrical Specifications

Input Voltage 115/230 V ac (50/60 Hz)

Input Current 10/5 A
Power factor = 0.52

Output Power 0 to 500 W

Output Voltage:
  Low Tap* 0 to 600 V; 900 V ignition voltage
  High Tap* 0 to 1200 V; 1200 V ignition voltage

Output Current:
  Low Tap* 0 to 1 A
  High Tap* 0 to 0.5 A
(*Factory configured)

Output Ripple
  Switching: 2% p-p (100 kHz)
  Line: 1% p-p (100/120 Hz)

Front Panel to Actual Output Accuracy
0.2% of full rated output or 2% of the setpoint, whichever value is greater.

Repeatability ± 0.25%

I/O to Actual Output Accuracy
0.2% of full rated output or 2% of the setpoint, whichever value is greater.

Physical Specifications

Size 89 mm (H) x 216 mm (W) x 381 mm (D)
      (3.5 in x 8.5 in x 16.0 in)

Weight 5.5 kg (12.25 lb)

Output Connector UHF style; Fischer style or SHV style (optional).
The shield is connected to the chassis ground. The center conductor will be positive or negative
reference to the shield, depending on what was specified when the unit was ordered.

**Output Cable**

RG-8U coaxial cable and/or discrete cables

**Environmental Specifications**

**Ambient Temperature:**
- **Operating:** Minimum 0°C, maximum 40°C (maximum value of average over 24 hr is 35°C)
- **Storage:** Class 1K4. Minimum -25°C, maximum 55°C
- **Transportation:** Class 2K3. Minimum -25°C, maximum 55°C (for short periods of up to 24 hr, the maximum is 70°C)

**Coolant Flow Requirements**

Cooling air should be free of corrosive vapors and particles, conductive particles, and particles that could become conductive after exposure to moisture.

**Humidity**

Class 3K3. 5 to 85% relative humidity

**Atmospheric Pressure:**
- **Operating:** 800 mbar minimum (approx. 2000 m above sea level)
- **Storage:** 800 mbar minimum (approx. 2000 m above sea level)
- **Transportation:** 660 mbar minimum (approx. 3265 m above sea level)

**Pollution Degree**

Two. Only non-conductive pollution occurs.

**EMC**

Tested for electromagnetic compatibility. See the "Safety" section in the front of the manual for specific standards.
Symbols

The following symbols appear on the unit:

- Short circuit protected
- Fuse
- AC power
- Discharge greater than 5 s
- Dangerous voltage
- Protective Earth Ground

DANGER! Capacitor discharge time of the 300 V bus is 4 minutes. Do not remove top cover. None of the unit’s parts are user-serviceable.
TRAIL 1
PRODUKTBESCHREIBUNG

ALLGEMEINE BESCHREIBUNG

Die Gleichstrom-Magnetron-Stromversorgungen der MDX-Serie stellen unter Beweis, wie benutzerfreundlich und effizient fortschrittliche HF-Schaltnetzteilesein können.

Sie...
- sind leicht und kompakt,
- sind höchst effizient (geringe Wärmeabgabe),
- bieten ausgezeichnete Regelung und Stabilität,
- weisen eine höchst zuverlässige Halbleiterkonstruktion auf,
- sind modular ausgelegt,
- speichern sehr wenig Energie im Ausgangsfilter.


Ausgangsregelung

Je nach der gewählten Ausgangsregelungsmethode kann die MDX-Ansteuerung als Leistungs-, Strom- oder Spannungsquelle eingesetzt werden. Um eine gute Reproduzierbarkeit von Durchlauf zu Durchlauf zu gewährleisten, wird der Sollwertpegel mit Hilfe eines Raster-Potentiometers eingestellt.

Anzeigen

Meßwerte und Statusberichte werden von den internen Schaltungen empfangen und über die Digitalanzeige und Leuchtdioden (LEDs) an der Frontplatte des Geräts angezeigt. Zu den angezeigten Parametern gehören zum Beispiel Leistung, Spannung, Stromstärke und der Status der Verriegelungen.

Eingebaute Schutzvorrichtungen

Lichtbogen-Unterdrückungsschaltungen

Die ARC-OUT™-Funktion gewährleistet eine umfassende Unterdrückung und Löschung von verschiedenen Lichtbogentypen. ARC-OUT verkürzt die Target-Einbrennzeiten und reduziert die Materialverluste. Findet ein Impedanzabfall statt, wird dies mit Hilfe der Funktion ARC-OUT sofort erfasst und das Gerät umgehend ausgeschaltet. Auf diese Weise wird ein Abließen von Energie in Hot Spots vermieden. Der Systemstart nach einem Lichtbogen wird kontrolliert durchgeführt, damit die Hot Spots vor der erneuten Stromzufuhr abkühlen können und eine erneute Lichtbogenbildung vermieden wird.
TYPISCHE ANWENDUNGEN

Einfache Magnetron-Kathodenzerstäubung

Die MDX-Stromversorgung hat vier Konfigurationsmöglichkeiten: negative Ausgangsspannung oder positive Ausgangsspannung und 500 V bei 1 A oder 1000 V bei 0,5 A.

Achtung Lebensgefahr! Um die Sicherheit des Personals und einen ordnungsgemäßen Betrieb dieses Systems zu gewährleisten, sind umfassende Kenntnisse über Erdung und korrekte Erdungsanschlüsse unerlässlich. Der Masseanschluß an der Rückseite des MDX-Geräts muß auf jeden Fall mit möglichst kleiner Impedanz geerdet werden.

Werksseitige Konfiguration

Wenn Sie die MDX-Stromversorgung erhalten, weist sie die von Ihnen in Ihrer Bestellung angegebene Polarität, Spannung/Stromstärke und analoge Referenzspannung auf. Auf der nächsten Seite finden Sie Abbildungen der negativen Konfiguration (Abbildung 1-4).

Der Ausgang der Stromversorgungseinheit ist immer auf das Chassis bezogen. Es steht ein Masseanschluß zur Verfügung, mit dem ein Erdverbindung niedriger Impedanz hergestellt werden kann.
Gleichstrom-Kathodenzerstäubung mit HF-Vorspannung

ACHTUNG! Wenn Ihr System sowohl eine Gleichstrom als auch eine Wechselstrom- versorgungseinheit verwendet, die eine Ausgangsfrequenz von über 50 kHz aufweist, muß ein Wechselstrom- Sperrfilter mit dem Ausgang der Gleichstromversorgungseinheit in Serie geschaltet werden.


Mit diesem zusätzlichen Steuerparameter (HF-Vorspannung) können höhere Abscheidungsgeschwindigkeiten oder eine bessere Schichtstruktur erzielt werden. Die Ergebnisse sind je nach Anwendung verschieden. Das Anlegen einer Vorspannung ändert die Ionen- und Beschleunigungsspannung, und mit diesen modifizierten Spannungen wiederum werden die gewünschten Ergebnisse erzielt.
Abbildung 1-5. Typische Konfiguration für Gleichstrom-Kathodenzerstäubung mit HF-Vorspannung.
PRODUKTBESCHREIBUNG

HF-Kathodenzerstäubung mit Gleichstrom-Vorspannung

ACHTUNG! Wenn Ihr System sowohl eine Gleichstrom- als auch eine Wechselstromversorgungseinheit verwendet, die eine Ausgangsfrequenz von über 50 kHz aufweist, muß ein Wechselstrom-Sperrfilter mit dem Ausgang der Gleichstromversorgungseinheit in Serie geschaltet werden.

Abbildung 1-6 (auf der nächsten Seite) zeigt eine typische HF-Kathodenzerstäubungsanwendung, bei der Target-Abschirmung und Kammerwände zwar geerdet sind, aber direkt an das Substrat mit einer Gleichstromversorgungseinheit eine Vorspannung angelegt wird. Dabei kann es sich um eine Planar-Magnetron- oder eine "S-Gun"-Installation handeln.

Eine nichtordnungsgemäße Erdung des Tuners, der Kammer und der MDX-Einheit führt zu Hochfrequenzstörungen, die sich bei dieser Anwendung häufig durch unkontrolliertes Verhalten Ihrer Systemsteuerung bemerkbar macht.

ACHTUNG LEBENSGEFahr! Wenn Tuner, Kammer und MDX nicht ordnungsgemäß geerdet sind, kommt es zu lebensgefährlichen Hochspannungspotentialen.


Einer der wichtigsten Punkte, die bei jeder HF-Installation in Betracht gezogen werden müssen, ist der HF-Rückleiter. **Stromversorgungseinheit/Tuner-Anschluß:** Die Stromversorgungseinheit wird normalerweise mit einem Koaxialkabel an den Tuner angeschlossen. Die Abschirmleitze dieses Kabels fungiert als ausreichender HF-Rückleiter für diesen Teil der Schaltung.


![Diagram](image-url)

**Abbildung 1-6. Typische Konfiguration für HF-Kathodenzerstäubung mit Gleichstrom-Vorspannung.**
TECHNISCHE DATEN

Funktionsspezifikationen

Schnittstellen
Der Ausgang kann entweder über das Bedienfeld an der Frontplatte oder die optionale analoge/digitale Schnittstelle gesteuert werden.

Methoden zur Ausgangsregulierung
Wählen Sie als Wert, der am eingeschalteten Ausgang der MDX-Stromversorgung konstant bleiben soll, Leistung, Stromstärke oder Spannung aus.

Programmierbare Sollwerte
Sie können für Leistung, Strom oder Spannung einen Sollwert programmieren (bis zum maximal zulässigen Ausgangswert für das Gerät).

Bogen-Unterdrückung
Die MDX-Stromversorgung erfaßt Bogen-Bedingungen schnell und modifiziert den Ausgang, um eine Beschädigung von Target und Substrat zu vermeiden.

Digitalmeßgerät
Die Digitalanzeige an der Frontplatte kann Informationen in Watt (W), Volt (V) oder Ampere (A) anzeigen, unabhängig davon, ob als Ausgang Leistung, Stromstärke oder Spannung gewählt wurde. Wenn der Ausgang eingeschaltet wird, zeigt das Digitalmeßgerät Sollwert- oder Programmdaten in dem von Ihnen ausgewählten Regelmodus an.

Ramp-Schalter
Mit Hilfe der Ramp-Schalter an der Rückseite des Geräts können Sie die Anstiegszeit des Sollwerts festlegen: Schnellanstieg (Fast Ramp) oder eine Kombination aus 0,1 s, 1 s oder 10 s (die Anstiegszeiten werden addiert).

Fehlerbedingungen
Die Fehlerbedingungen, die zum Abschalten des MDX-Ausgangs führen, sind Verriegelung, Eingangsleistung und Überhitzung.
Elektrische Spezifikationen

Eingangsspannung 115/230 V Wechselspannung (50/60 Hz)

Eingangsstrom 10/5 A
Leistungsfaktor = 0,52

Ausgangsleistung 0 bis 500 W

Ausgangsspannung:
- Untere Anzapfung* 0 to 600 V; 900 V Zündspannung
- Obere Anzapfung* 0 to 1200 V; 1200 V Zündspannung

Ausgangstrom:
- Untere Anzapfung* 0 bis 1 A oder
- Obere Anzapfung* 0 bis 0,5 A
(*Werkseinstellung)

Ausgangswelligkeit des Schaltnetzteiles: 2% Spitze-Spitze (100 kHz)
der Versorgungsspannung: 1% Spitze-Spitze (100/120 Hz)

Genauigkeit der Anzeige zum Ausgang
0,2% des maximalen Nennwertes am Ausgang
oder 2% des Sollwertes, je nach dem welcher ist größer.

Wiederkehrgenauigkeit ± 0,25%

Genauigkeit des Interfaces zum Ausgang
0,2% des maximalen Nennwertes am Ausgang
oder 2% des Sollwertes, je nach dem welcher ist größer.

Physische Spezifikationen

Abmessungen 89 mm (H) x 216 mm (B) x 381 mm (T)
(3,5 Zoll x 8,5 Zoll x 15,0 Zoll)

Gewicht 5,5 kg (12,25 am. Pfund)
PRODUKTBESCHREIBUNG

Ausgangsteckverbinder
Typ UHF; Typ Fischer oder Typ SHV (wahlweise). Die Abschirmung ist an die Gehäuseerdung angeschlossen. Der Zentralleiter ist positiv oder negativ bezüglich der Abschirmung, je nachdem, was bei der Bestellung des Geräts angegeben wurde.

Ausgangskabel
RG-8U-Koaxialkabel und/oder diskrete Kabel

Umgebungsspezifikationen

Umgebungs temperatur:

Bei Betrieb
Mindestens 0°C, höchstens 40°C (der zulässige Höchstwert im 24-Stunden-Durchschnitt beträgt 35°C)

Bei Lagerung
Klasse 1K4. Mindestens -25°C, höchstens 55°C

Bei Transport
Klasse 2K3. Mindestens -25°C, höchstens 55°C (für kurze Zeiträume bis zu 24 Stunden beträgt der Höchstwert 70°C)

Kühlwasserfluss
In der Kühlwasser dürfen sich keine korrosiven Dämpfe, Partikel, leitende Partikel bzw. Partikel, die bei Feuchtigkeitskontakt leitend werden könnten, befinden.

Luftfeuchtigkeit
Klasse 3K3. 5 bis 85% relative Luftfeuchtigkeit

Atmosphärischer Druck:

Bei Betrieb
Mindestens 800 mbar (ca. 2000 m über Meeresspiegel)

Bei Lagerung
Mindestens 800 mbar (ca. 2000 m über Meeresspiegel)

Bei Transport
Mindestens 660 mbar (ca. 3265 m über Meeresspiegel)
Verschmutzungsgrad
Zwei. Es kommt nur zu nichtleitender
Verschmutzung.

EMV
Das Gerät ist auf elektromagnetische
Verträglichkeit getestet.
Siehe Konformitätsbescheinigung für spezifische
Standards.

Symbole
Auf dem Gerät sind folgende Symbole abgebildet:

- Kurzschlußfester Ausgang

- Sicherung

- Wechselstrom

- Entladung über 5 s

- Gefährliche Spannung

- Schutzerde
CONTENTS

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THEORY OF OPERATION

The MDX magnetron drive is a sophisticated dc power supply designed exclusively for use into vacuum environments. The figure below and the following paragraphs outline the theory of operation.

![Diagram of MDX 500 functional block diagram.](image)

**Input**
In the input section, the MDX applies ac line voltage through fuses to a contactor. The contactor, when closed, delivers the line voltage to a rectifier bridge, where it is converted to dc. The MDX then applies the dc voltage to bus capacitors through soft-start circuitry. This bus provides dc voltage to the inverter section. The input section also contains a control transformer, which supplies 24 V ac to the housekeeping and inverter sections.

**Housekeeping Supply**
The housekeeping supply section provides $\pm 24$ V dc to power the logic circuitry and control panel.

**Inverter**
The inverter section converts dc to pulse-width-modulated, 50 kHz ac voltage by alternating the current through two sets of switching transistors (see Figures 2-2 and 2-3 on the next page).

**Output**
In the output section, an isolation transformer steps up the 50 kHz ac voltage from the inverter section and sends it to a full-wave rectifier bridge. The resulting dc then passes out through a filter network and through the output measurement section.
Figure 2-2. Illustration of switching theory.

Figure 2-3. Detail of Figure 2-2, illustrating current flow through switching transistors (dashed lines represent flow).
**Output Measurement**
The output measurement section measures current, voltage, and power. The MDX conditions these signals to 0 to 10 V dc (or 0 to 5 V dc) and sends them to both the logic control and remote interface sections.

**Control**
The control section uses operator-supplied parameters and setpoints to control the output. This section also provides status information to the operator through all interfaces and controls the input section.

**Control Panel Display**
The display on the control panel communicates operator-supplied inputs to the logic control section and provides the operator with status information.

**Remote Interface (optional)**
The remote interface communicates operator-supplied inputs to the control section from the User port (analog and digital) and provides the operator with status information.
CONNECTORS

Input Power Connector
The unit's IEC 320 receptacle provides the ac line input connection.

See page 3-11 for details on making this connection.

Output Connector
You must purchase the cable for the output connection from AE separately.

The standard output connector is a UHF style, but an SHV style or Fischer type connector is optional. See page 3-12 for details on making this connection.
Optional User Port

The analog/digital User port, located on the rear panel, is a 25-pin, female, D subminiature connector. Its associated male connector, connector shell, and jack post screws come in the hardware kit. The table below provides information about each pin. See page 3-12 for details on making this connection.

![Figure 2-4. Illustration of pin locations.](image)

**Pin-description Table**

The User port is primarily an “analog” interface that allows the use of a remote controller. Pin locations number from right to left on the connector’s face (see Figure 2-4). **Note:** An “.A” appended to a pin name indicates an analog signal; a “.D” indicates a digital signal. A bar over a signal name indicates that the signal is true when low. Also, depending on which factory configuration was chosen, full scale is either 5 V or 10 V.

<table>
<thead>
<tr>
<th>Pin No.</th>
<th>Pin Name</th>
<th>Description</th>
<th>Refer to</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>I OUT.A</td>
<td>output, 0 to 10 V (or 0 to 5 V)</td>
<td>p. 3-13</td>
</tr>
<tr>
<td>2</td>
<td>P OUT.A</td>
<td>output, 0 to 10 V (or 0 to 5 V)</td>
<td>p. 3-13</td>
</tr>
<tr>
<td>3</td>
<td>V OUT.A</td>
<td>output, 0 to 10 V (or 0 to 5 V)</td>
<td>p. 3-13</td>
</tr>
<tr>
<td>4</td>
<td>WATER ILK.D</td>
<td>input, 0 to 15 V</td>
<td>p. 3-13</td>
</tr>
<tr>
<td>5</td>
<td>VAC ILK.D</td>
<td>input, 0 to 15 V</td>
<td>p. 3-13</td>
</tr>
<tr>
<td>6</td>
<td>MAIN INTLK.D</td>
<td>input, 0 to 15 V</td>
<td>p. 3-13</td>
</tr>
<tr>
<td>7</td>
<td>RMT OFF.D</td>
<td>input, 0 to 15 V</td>
<td>p. 3-13</td>
</tr>
<tr>
<td>8</td>
<td>RMT ON.D</td>
<td>input, 0 to 15 V</td>
<td>p. 3-13</td>
</tr>
<tr>
<td>9</td>
<td>GND</td>
<td>chassis ground</td>
<td>p. 3-14</td>
</tr>
<tr>
<td>10</td>
<td>REF.A</td>
<td>10 V reference level (or 5 V reference level)</td>
<td>p. 3-14</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(5 mA max.)</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>unassigned</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pin No.</td>
<td>Pin Name</td>
<td>Description</td>
<td>Refer to</td>
</tr>
<tr>
<td>---------</td>
<td>--------------</td>
<td>----------------------------------</td>
<td>----------</td>
</tr>
<tr>
<td>12</td>
<td>LEVEL OUT.A</td>
<td>output, 0 to 10 V (or 0 to 5 V)</td>
<td>p. 3-14</td>
</tr>
<tr>
<td>13</td>
<td>STPT OK.D</td>
<td>output, 0 to 15 V</td>
<td>p. 3-14</td>
</tr>
<tr>
<td>14</td>
<td>V AUX.A</td>
<td>output, 15 V (100 mA max.)</td>
<td>p. 3-14</td>
</tr>
<tr>
<td>15</td>
<td>unassigned</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>P REG.D</td>
<td>input, 0 to 15 V</td>
<td>p. 3-14</td>
</tr>
<tr>
<td>17</td>
<td>T REG.D</td>
<td>input, 0 to 15 V</td>
<td>p. 3-14</td>
</tr>
<tr>
<td>18</td>
<td>unassigned</td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>unassigned</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>GND</td>
<td>chassis ground</td>
<td>p. 3-14</td>
</tr>
<tr>
<td>21</td>
<td>GND</td>
<td>chassis ground</td>
<td>p. 3-14</td>
</tr>
<tr>
<td>22</td>
<td>OUTPUT.D</td>
<td>output, 0 to 15 V</td>
<td>p. 3-15</td>
</tr>
<tr>
<td>23</td>
<td>LEVEL IN.A</td>
<td>input, 0 to 10 V (or 0 to 5 V)</td>
<td>p. 3-15</td>
</tr>
<tr>
<td>24</td>
<td>unassigned</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>GND</td>
<td>chassis ground</td>
<td>p. 3-15</td>
</tr>
</tbody>
</table>
STATUS INFORMATION

Output Status Signals

You can monitor the MDX externally by means of output lines on the User port. Digital signals are 0 to 15 V; analog signals are 0 to 10 V (or 0 to 5 V). The table below details the function of each output line.

<table>
<thead>
<tr>
<th>Pin</th>
<th>Name</th>
<th>Functional Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>I OUT. A</td>
<td>Varying 0 to 10 V (or 0 to 5 V) signal, representing output current.</td>
</tr>
<tr>
<td>2</td>
<td>P OUT. A</td>
<td>Varying 0 to 10 V (or 0 to 5 V) signal, representing output power.</td>
</tr>
<tr>
<td>3</td>
<td>V OUT. A</td>
<td>Varying 0 to 10 V (or 0 to 5 V) signal, representing output voltage.</td>
</tr>
<tr>
<td>12</td>
<td>LEVEL OUT. A</td>
<td>Varying 0 to 10 V (or 0 to 5 V) signal, representing the programmed setpoint.</td>
</tr>
<tr>
<td>13</td>
<td>STPT OK.D</td>
<td>Indicates that the output is equal to the requested setpoint when the signal goes low.</td>
</tr>
<tr>
<td>22</td>
<td>OUTPUT.D</td>
<td>Indicates that the output has been turned on when the signal goes low.</td>
</tr>
</tbody>
</table>
Indicators

You can monitor MDX functions by checking—
1) the six status indicator LEDs that appear below the digital meter,
2) the LEDs on the switches, and
3) the LEDs that appear to the right of the digital meter.

Status Indicator LEDs

Six status indicator LEDs that convey information about the status of the MDX appear below the digital meter. The table below details their exact meanings.

<table>
<thead>
<tr>
<th>Status Indicator LEDs</th>
<th>Functional Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARC</td>
<td>Lights to indicate that the impedance of the chamber dropped enough to cause the current produced by the MDX to reach the built-in overcurrent trip point.</td>
</tr>
<tr>
<td>SETPOINT</td>
<td>Lights when output is equal to the programmed setpoint; goes out when output is turned off.</td>
</tr>
<tr>
<td>OUTPUT</td>
<td>Lights to indicate that output has been turned on.</td>
</tr>
<tr>
<td>INTERLOCK</td>
<td>Lights when all interlock conditions have been satisfied; flashes if the interlock string is broken (see User pins 4, 5, and 6: WATER ILK.D, VAC ILK.D, MAIN INTLK.D). When an interlock fails, the MDX turns off the output and cannot turn it back on until the interlock condition is satisfied.</td>
</tr>
<tr>
<td>PLASMA</td>
<td>Lights to indicate that output is on and output current is greater than 10 mA.</td>
</tr>
<tr>
<td>REMOTE</td>
<td>Lights to indicate that the remote interface has been given either on/off control or setpoint control or both.</td>
</tr>
</tbody>
</table>
LEDs on Switches

LEDs on the front panel switches light and flash to convey a variety of information, as the table below explains.

<table>
<thead>
<tr>
<th>Switch LEDs</th>
<th>Functional Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>OUTPUT POWER, STOP</td>
<td>This LED lights when the MDX is not producing output.</td>
</tr>
<tr>
<td>OUTPUT POWER, START</td>
<td>This LED lights when output is on.</td>
</tr>
<tr>
<td>REGULATION, POWER and CURRENT</td>
<td>The POWER LED lights when power regulation has been selected; the CURRENT LED lights when current regulation has been selected; both the POWER and CURRENT LEDs light when voltage regulation has been selected. Both the POWER and CURRENT LEDs flash if no mode of regulation has been selected.</td>
</tr>
</tbody>
</table>

Note that the POWER and CURRENT switches latch when pressed; each switch must be deselected by pressing it again if you want to specify another mode of regulation.
Digital Meter LEDs

Four LEDs are located to the right of the digital meter. These LEDs indicate which parameter is being displayed on the digital meter. To toggle among the parameters, press the DISPLAY switch until the appropriate LED lights. (See the front panel foldout at the end of this chapter.) The table below explains the meaning of each LED.

<table>
<thead>
<tr>
<th>Digital Meter LED</th>
<th>Functional Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>WATTS</td>
<td>Lights when selected with the DISPLAY switch while the output is on; the actual output power will be displayed on the digital meter.</td>
</tr>
<tr>
<td>VOLTS</td>
<td>Lights when selected with the DISPLAY switch while the output is on; the actual output voltage will be displayed on the digital meter.</td>
</tr>
<tr>
<td>AMPS</td>
<td>Lights when selected with the DISPLAY switch while the output is on; the actual output current will be displayed on the digital meter.</td>
</tr>
<tr>
<td>SETPOINT</td>
<td>Lights when selected with the DISPLAY switch or when the unit is in STOP mode. When the SETPOINT LED lights, the digital meter is monitoring the setpoint level in the selected mode of regulation. The LEVEL knob may then be used to adjust the setpoint.</td>
</tr>
</tbody>
</table>
### INTERFACING

**Front Panel Controls**

<table>
<thead>
<tr>
<th>Control</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>OUTPUT POWER, STOP</td>
<td>Turns off output.</td>
</tr>
<tr>
<td>OUTPUT POWER, START</td>
<td>Turns on output if the front panel has control of the on/off function, all interlock conditions are satisfied, and a regulation mode has been selected. If a setpoint value has been specified, the MDX will go to that level.</td>
</tr>
<tr>
<td>REGULATION, POWER and CURRENT</td>
<td>Selects what method of output regulation the MDX will use (if the control panel has control of the LEVEL function). Pressing the POWER switch chooses the power method; pressing the CURRENT switch chooses the current method; and pressing both POWER and CURRENT together chooses the voltage method. See &quot;Output Regulation,&quot; page 4-3, for a detailed discussion.</td>
</tr>
<tr>
<td>LEVEL knob</td>
<td>Is used to set or adjust the output setpoint. The LEVEL knob can be used whether the output is turned on or off. The DISPLAY switch must be pressed until the SETPOINT LED to the right of the digital meter lights to view the setpoint. The setpoint is displayed on the digital meter in the selected mode of output regulation.</td>
</tr>
<tr>
<td>DISPLAY</td>
<td>Is used to select the parameter to be displayed on the digital meter.</td>
</tr>
</tbody>
</table>
# Rear Panel Controls

<table>
<thead>
<tr>
<th>Control</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ON/OFF</strong></td>
<td>Turns the input power on and off.</td>
</tr>
<tr>
<td><strong>RAMP, 0.1 S</strong></td>
<td>When down, this switch sets the ramp time to 0.1 s.</td>
</tr>
<tr>
<td><strong>RAMP, 1.0 S</strong></td>
<td>When down, this switch sets the ramp time to 1 s.</td>
</tr>
<tr>
<td><strong>RAMP, 10 S</strong></td>
<td>When down, this switch sets the ramp time to 10 s.</td>
</tr>
<tr>
<td><strong>LOCAL, ON</strong></td>
<td>This switch selects between the front panel and the User port for on control. When up, this switch gives control to the User port; when down, it gives control to the front panel. (Note: The off signal may be received from both the front panel and the User port.)</td>
</tr>
<tr>
<td><strong>LOCAL, SETPT</strong></td>
<td>This switch selects between the front panel and the User port for control of regulation method and setpoint level. When up, this switch gives control to the User port; when down, it gives control the front panel.</td>
</tr>
<tr>
<td><strong>C HOLD</strong></td>
<td>When down, this switch enables the <strong>contactor hold</strong> function, which causes the contactor to remain closed after the first ramp start. <strong>Contactor hold</strong> shortens the time needed for the output to reach setpoint on subsequent runs.</td>
</tr>
</tbody>
</table>
User Port Functions

Many of the functions that are available from the control panel are also available through the user interface.

The available functions include:
- Turning output on and off
- Specifying method of output regulation
- Completing the system interlock string
- Specifying output setpoint
- Monitoring output parameters and status

The table below lists parameters that can be monitored through the User port. The parameters tell you—

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Associated pins</th>
</tr>
</thead>
<tbody>
<tr>
<td>whether output is enabled</td>
<td>pin 22</td>
</tr>
<tr>
<td>whether setpoint level been reached</td>
<td>pin 13</td>
</tr>
<tr>
<td>what the output voltage is</td>
<td>pin 3</td>
</tr>
<tr>
<td>what the output power is</td>
<td>pin 2</td>
</tr>
<tr>
<td>what the output current is</td>
<td>pin 1</td>
</tr>
<tr>
<td>what the setpoint level is</td>
<td>pin 12</td>
</tr>
</tbody>
</table>
MDX 500 Front View
PART II

OPERATING YOUR MDX MAGNETRON DRIVE
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SETTING UP

⚠️ YOU SHOULD KNOW...

DANGER! Operating and maintenance personnel must have the correct training before setting up and maintaining high-energy electrical equipment. THIS EQUIPMENT MUST BE INSTALLED ACCORDING TO THE APPLICABLE REQUIREMENTS.

Unpacking

Unpack and inspect your MDX magnetron drive power supply carefully. Check for obvious physical damage. If no damage is apparent, proceed to make the connections. If you do see signs of shipping damage, contact Advanced Energy Industries, Inc., and the carrier immediately. Save the shipping container for submitting necessary claims to the carrier.

⚠️ YOU SHOULD KNOW...

DANGER! Capacitor discharge time of the 300 V bus is 4 minutes. Do not remove top cover. None of the unit's parts are user-serviceable.
Spacing Requirements

- The clearance between either side of the MDX and the enclosure must be 25 mm (1 in).
- No clearance is required between the top of the MDX and the top of the enclosure.
- No clearance is required between the units.
- The clearance between the rear of the MDX and the enclosure must be 76 mm (3 in), with adequate ventilation (see page 3-8).

Figure 3-1. Illustration of top, side, and inter-unit clearance requirements for MDX units stacked in an enclosure.
Figure 3-2. Illustration of rear clearance requirements for MDX units stacked in an enclosure.
Cooling Requirements

For the MDX to be sufficiently cooled, the enclosure must be configured to:

- Bring in ambient-temperature air (40°C maximum)
- Distribute input air to the power supplies
- Prevent exhaust air from circulating back and becoming input air
- Exhaust the hot air from the rack easily.

You may need to add air baffles to the rack to prevent exhaust air from recirculating.

Figure 3-3. Graphic representation of the view looking down on the top of an MDX in an enclosure. The arrows show the direction of air flow.
MAKING REAR PANEL CONNECTIONS

Grounding

An earth terminal stud is located on the rear panel (see the foldout of the rear panel at the end of Chapter 2).

For optimum performance, ground the chassis stud to the chamber ground.

Connecting Input Power

The standard line voltage is 115 or 230 V ac, 50/60 Hz. The input and output power voltages for this and any AE power supply appears on an enclosed checklist. The line input connection is provided by an IEC 320 receptacle.

WARNING! Line cord must be installed or terminated according to applicable requirements.

If your input power line cord does not end in a plug, you must attach the line cord to the input power source manually (see Figure 3-4). The colors of the wires inside the line cord represent the following:

- Brown or Black = Line
- Blue = Neutral
- Green/Yellow = Protective earth ground
Figure 3-4. Illustration of wires inside input power line cord.

Connecting the Output

Take off the output connector cover by removing the two M3 screws with a Phillips screwdriver. Use a mating connector to connect the power supply output to the load. If you use a coaxial cable, the shield can be the return. However, always use a separate ground braid between the system ground and the power supply stud for safety purposes. When you have finished, replace the connector cover.

The shield is connected to the chassis ground. The center conductor will be positive or negative reference to the shield, depending on what was specified when the unit was ordered.

Connecting for User-Remote Control

Control is given to the User port if one or both of the two LOCAL switches on the rear panel are closed. A detailed description of each signal begins on the next page. Following that are several wiring diagrams that illustrate three- and two-wire control, external output monitoring, external setpoint programming, the normal interlock connection, and the “cheater” plug.

A quick-reference pin-description table for this port is on pages 2-8 and 2-9.
Signal Descriptions: User I/O Pins

pin 1. I OUT.A. This output provides a fully buffered 0 to 10 V (or 0 to 5 V) signal representing output current. The supply can produce 10 V = 1 A or 5 V = 1 A (referenced to ground), depending on the factory configuration. Accuracy is within 0.2% of full scale or 2% of the setpoint, whichever is greater. The signal’s impedance is 100 Ω, and its current should be limited to 2 mA.

pin 2. P OUT.A. This output provides a fully buffered 0 to 10 V (or 0 to 5 V) signal representing output power. The supply can produce 10 V = 500 W or 5 V = 500 W (referenced to ground), depending on the factory configuration. Accuracy is within 0.2% of full scale or 2% of the setpoint, whichever is greater. The signal’s impedance is 100 Ω, and its current should be limited to 2 mA.

pin 3. V OUT.A. This output provides a fully buffered 0 to 10 V (or 0 to 5 V) signal representing output voltage. The supply can produce 10 V = 1200 V dc or 5 V = 1200 V dc (referenced to ground), depending on the factory configuration. Accuracy is within 0.2% of full scale or 2% of the setpoint, whichever is greater. The signal’s impedance is 100 Ω, its and current should be limited to 2 mA.

pin 4. WATER ILK.D. This input signal, in conjunction with VAC ILK.D (pin 5) and MAIN ILK.D (pin 6), monitors the system interlock string. If the interlock conditions are not all satisfied (water, vacuum, and auxiliary), the output cannot be turned on. If any of the interlocks are broken while the output is running, the output will turn off and the INTERLOCK status LED will flash. This pin should be referenced to ground.

pin 5. VAC ILK.D. See discussion of pin 4 (WATER ILK.D).

pin 6. MAIN ILK.D. This input signal is a general purpose current loop that allows the main contactor to close. If the main interlock is not satisfied, the circuit will not be completed to ground. This will prevent the main dc bus from becoming energized but will allow the logic circuits to function (i.e., the front panel indicators will still work).

pin 7. RMT OFF.D. This input signal is used to turn off output from the User port. An open circuit between RMT OFF.D and ground will turn off output power. It should be referenced to ground.

pin 8. RMT ON.D. This input signal is used to turn on output from the User port. Closure between RMT ON.D and ground will turn on output power when enabled through the LOCAL ON switch. It should be referenced to ground.
pin 9. GND.

pin 10. REF.A. This output signal provides an accurate 10 V reference (10 V ± 20 mV) or a 5 V reference (5 V ± 10 mV), depending on the factory configuration. This pin should be referenced to ground. Its impedance is 100 Ω, and current should be limited to 2 mA.

pin 11. unassigned.

pin 12. LEVEL OUT.A. This output provides a fully buffered 0 to 10 V (or 0 to 5 V) signal representing the MDX unit's programmed setpoint level: 10 V = maximum setpoint or 5 V = maximum setpoint (referenced to ground), depending on the factory configuration. Its impedance is 100 Ω, and the current should be limited to 2 mA.

pin 13. STPT OK.D. This 0 to 15 V output signal indicates that the output is equal to the requested setpoint by going low. (The SETPOINT status LED on the front panel will also light.) It will sink 35 mA and should be referenced to ground. It is internally pulled up to 15 V through a 10 kΩ resistor, and its impedance is 100 Ω.

pin 14. V AUX.A. This connection is a user-available 15 V power source referenced to ground. The user can draw as much as 100 mA from this source. Source impedance is less than 0.1 Ω and is fuse protected.

pin 15. unassigned.

pin 16. P REG.D. This 0 to 15 V input signal, in conjunction with pin 17 (I REG.D), indicates the method of output regulation. When P REG.D is low and I REG.D is high, the power method is selected. When both signals are low, the voltage method is selected. This pin should be referenced to ground.

pin 17. I REG.D. This 0 to 15 V input signal, in conjunction with pin 16 (P REG.D), indicates the method of output regulation. When I REG.D is low and P REG.D is high, the current method is selected. When both signals are low, the voltage method is selected. This pin should be referenced to ground.

pin 18. unassigned.

pin 19. unassigned.

pin 20. GND.

pin 21. GND.
pin 22. **OUTPUT.D.** When high, this 0 to 15 V output signal indicates that the output is off. When low, it indicates that output is on and will ramp up to whatever setpoint has been specified (the OUTPUT POWER, START LED on the front panel will also light). It will sink 35 mA and should be referenced to ground. It is internally pulled up to 15 V through a 10-kΩ resistor, and its impedance is 100 Ω.

pin 23. **LEVEL IN.A.** This 0 to 10 V (or 0 to 5 V) input signal is used to remotely program the output level (see Figure 3-7, page 3-17): 10 V = maximum output level or 5 V = maximum output level, depending on the factory configuration. This signal should be referenced to ground.

pin 24. unassigned.

pin 25. GND.
Wiring Options

Three-wire Control

If you want to use both an on switch and an off switch, select this wiring option (see Figure 3-5). Contact of \texttt{RMT ON.D} (pin 8) with \texttt{GND} (pin 9) will cause output to turn on. However, \texttt{RMT OFF.D} (pin 7) must be pulled low before output can be turned on. You can prevent output from coming on by letting \texttt{RMT OFF.D} (pin 7) float high.

![Wiring diagram for three-wire control.](image)

Two-wire Control

You might want to connect \texttt{pins 7 and 8} (\texttt{RMT OFF.D} and \texttt{RMT ON.D}) and control them as one input (see Figure 3-6). This two-wire control is useful if your system's on/off requirements are simple. That is, if you want to use one device (such as a relay) to control the MDX rather than using one device to control the on function and one device to control the off function, this method may be more convenient for you. When \texttt{pins 7 and 8} are connected to \texttt{User pin 9} (\texttt{GND}), the output will turn on immediately. If you let \texttt{User pins 7 and 8} float high while output is being produced, output will be turned off.

![Wiring diagram for two-wire control.](image)
External Monitoring of Output

In cases where there is no control panel, an external device can be hooked up to display what voltage, power, or current level the MDX is producing (see Figure 3-7). For each of the outputs, either 5 V or 10 V represents full scale, depending on the factory option selected.

![Wiring diagram](image)

*Figure 3-7. Wiring diagram for externally monitoring the output.*

External Programming of Setpoint

The next figure (Figure 3-8) shows how to wire the input lines so that you can specify output setpoint level from an external source. You will also need to specify method of output regulation—see page 4-3.

![Wiring diagram](image)

*Figure 3-8. Wiring diagram for externally programming the output setpoint.*
Digital Output and Input Signals

The following figure shows the wiring configuration for the digital output signals.

![Wiring diagram for the digital output signals.](image)

Figure 3-9. Wiring diagram for the digital output signals.

The following figure shows the wiring configuration for the digital input signals.

![Wiring diagram for the digital input signals.](image)

Figure 3-10. Wiring diagram for the digital input signals.

Normal Interlock Connection

The following figure (Figure 3-11) shows one way to connect sensors to the interlock lines. For example, MAIN INTLK.D (pin 6) can be used to warn if a door is open, VAC ILK D (pin 5) to indicate if the chamber contains a vacuum, and WATER ILK D (pin 4) to warn of problems with the cooling system for the magnetron. If any connection is open, the interlock string is broken and output will not come on. Similarly, if any connection opens during operation, the output will be turned off and the INTERLOCK LED will flash.
PREPARING FOR USE

The VAC ILK.D and WATER ILK.D lines are digital inputs are shown in Figure 3-10. MAIN ILK.D controls a relay that supplies 24 V to the main contactor (see Figure 3-12).

Cheater Plug

The “cheater plug” (see Figure 3-13) that came attached to the User connector makes it possible for you to run the MDX essentially right out of the box, without making any wiring adjustments. You can continue to use the cheater plug if you want to ignore (“cheat”) the interlock lines.
If the User port won’t be used, you must leave the cheater plug attached to the MDX.

WARNING! You are defeating the interlocks if you use the cheater plug.

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Pin</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAIN INLK.D</td>
<td>6</td>
</tr>
<tr>
<td>VAC ILK.D</td>
<td>5</td>
</tr>
<tr>
<td>WATER ILK.D</td>
<td>4</td>
</tr>
<tr>
<td>RMT OFF.D</td>
<td>7</td>
</tr>
<tr>
<td>GND</td>
<td>9</td>
</tr>
</tbody>
</table>

*Figure 3-13. Wiring diagram for the “cheater” plug.*

**Disconnecting**

Disconnect the MDX from all voltage sources before making any adjustments or replacements and before doing any maintenance or repair.

DANGER! Internal components may remain live for 4 min after the MDX has been disconnected.

Make sure replacement fuses are of the same rating and specific type as those being replaced.
FIRST-TIME OPERATION

Start-Up Procedure

1. Make sure that the necessary external inputs are supplied (refer to signal descriptions on pages 3-13 through 3-15) or that the “cheater plug” is installed on the User connector on the rear of the MDX (see page 3-19). In addition, ensure that protection earth ground is supplied.

2. Connect the output connector.

3. Turn on the on/off switch on the rear panel of the MDX. The digital meter will display the current setpoint, and the OUTPUT POWER, STOP LED will be lit. The INTERLOCK LED will also be lit.

4. Select the regulation mode that you want by pressing the appropriate switch(es). The relevant switch LED(s) will light. See page 4-3 for more information on output regulation.

5. Set the ramp rate by setting the rear panel RAMP switches (any combination of 0.1, 1.0, and 10) for the desired ramp time. See pages 2-18 and 4-6 for more information on ramp switches.

6. To preset the output level (in local mode), adjust the LEVEL knob while you watch the digital meter.

DANGER! The next step will result in high voltage levels at the output connector. Take appropriate steps to prevent electrical shock.

7. Press OUTPUT POWER, START. The main contactor will close, and the OUTPUT POWER, START LED will light. The SETPOINT, OUTPUT, and PLASMA status LEDs will also light.

8. Press the DISPLAY switch to cycle through each of the parameters available for display to verify system operation.
9. Turn the LEVEL knob to vary the output (in local mode) while you watch the digital meter.

10. Press the OUTPUT POWER, STOP switch any time to turn off output.
AUFTESSELN DES GERÄTS

ACHTUNG LEBENSGEFÅHR! Elektrische Hochenergie-Geräte dürfen nur von speziell dafür ausgebildetem Betriebs- und Wartungspersonal aufgestellt und gewartet werden. DIESES GERÄT MUSS ENTSPRECHEND DEN GELTENDEN VORSCHRIFTEN INSTALLIERT WERDEN.

Auspicken


ACHTUNG LEBENSGEFÅHR! Die Kondensator-Entladungszeit des 300-V-Bus beträgt vier Minuten. Niemals die obere Abdeckung abnehmen. Das Gerät enthält keine Bauteile, die vom Benutzer zu reparieren oder zu warten sind.
Platzerfordernisse

- Der seitliche Abstand zwischen der MDX-Einheit und der jeweiligen Schrankwand muß mindestens 25 mm (1 Zoll) betragen.
- Zwischen der Oberseite der MDX-Einheit und der Schrankdecke ist kein Abstand erforderlich.
- Zwischen den MDX-Einheiten ist kein Abstand erforderlich.
- Der Abstand zwischen der Rückseite der MDX-Einheit und der Schrankrückwand muß mindestens 76 mm (3 Zoll) betragen. Außerdem muß für angemessene Belüftung gesorgt werden (s. Seite 3-28).

Kühlungserfordernisse

Um eine ausreichende Kühlung der MDX-Einheit zu gewährleisten, muß der Schrank folgendermaßen ausgelegt sein:

- Es muß Luft mit Umgebungstemperatur einströmen (maximal 40°C).
- Die einströmende Luft muß auf die Netzteile gleichmäßig verteilt werden.
- Ein Zurückzirkulieren der Abluft als Einlaßluft muß verhindert werden.
- Die heiße Abluft muß problemlos vom Gestell abgeführt werden.

Es ist unter Umständen erforderlich, das Gestell mit Luftleitblechen auszustatten, um ein Zirkulieren der Abluft zu verhindern.

ANSCHLÜSSE AN DER RÜCKSEITE

Erdung

An der Rückwand des Geräts befindet sich ein Erdungsanschluß (s. Darstellung der Rückwand auf dem Faltplan am Ende von Kapitel 2).

![Bitte beachten...]

Beste Ergebnisse werden erzielt, wenn dieser Erdungsanschluß mit der Kammererdung verbunden wird.

Anschlüsse für den Stromversorgungseingang


![Bitte beachten...]

ACHTUNG! Die Netzzuleitung muß in Übereinstimmung mit den einschlägigen Vorschriften installiert bzw. angeschlossen werden.

Wenn die Netzzuleitung für die Eingangsstromversorgung nicht mit einem Stecker versehen ist, müssen Sie die Netzzuleitung manuell direkt mit der Netzeinspeisung verdrahten (s. Abbildung 3-17). Die Farben der Leiter im Netzkabel haben folgende Bedeutung:

- Braun oder schwarz = Spannungsführender Leiter - L
- Blau = Neutralleiter - N
- Grün/Gelb = Schutzerde - PE
Abbildung 3-17. Darstellung der Drähte innerhalb eines Netzkabels.

Ausgangsanschluß


Die Abschirmung wird über das Gehäuse geerdet. Die Polarität des Zentralleiter ist positiv oder negativ zur Abschirmung, je nachdem, was bei der Bestellung des Geräts angegeben wurde.

Anschluß der Fernbedienung

Signalbeschreibungen: Analog/Digital-Schnittstelle

Pin 1. I OUT.A. Dieser Ausgang liefert ein voll gepuffertes Signal von 0 bis 10 V (bzw. von 0 bis 5 V), das die Ausgangsstromstärke darstellt. Je nach werkseitiger Konfiguration kann die Versorgungseinheit 10 V = 1 A oder 5 V = 1 A (bezogen auf Masse) produzieren. Die Genauigkeit liegt im Bereich von 2% des tatsächlichen Ausgangspegels oder 0,2% des höchstzulässigen Ausgangspegels, je nachdem, welcher der beiden Werte größer ist. Die Impedanz beträgt 100 Ω. Der Ausgangsstrom ist auf 2 mA zu begrenzen.

Pin 2. P OUT.A. Dieser Ausgang liefert ein voll gepuffertes Signal von 0 bis 10 V (bzw. von 0 bis 5 V), das die Ausgangsleistung darstellt. Je nach werkseitiger Konfiguration kann die Versorgungseinheit 10 V = 500 W oder 5 V = 500 W (bezogen auf Masse) produzieren. Die Genauigkeit liegt im Bereich von 2% des tatsächlichen Ausgangspegels oder 0,2% des höchstzulässigen Ausgangspegels, je nachdem, welcher der beiden Werte größer ist. Die Impedanz beträgt 100 Ω. Der Ausgangsstrom ist auf 2 mA zu begrenzen.


Pin 5. VAC ILK.D. Siehe Beschreibung von Pin 4 (WATER ILK.D).
Pin 6. MAIN INTLKD. Bei diesem Eingangssignal handelt es sich um eine Mehrgeweck-Verriegelungsschleife, mit der der Hauptschutz geschlossen werden kann. Werden die Bedingungen für die Hauptverriegelung nicht erfüllt, wird der Stromkreis nicht geschlossen. Auf diese Weise kann der Haupt-Gleichstrombus nicht aktiviert werden, jedoch funktionieren die logischen Schaltungen noch (d.h. die Anzeigen an der Frontplatte arbeiten weiter).


Pin 9. GND. Massepin.

Pin 10. REF.A. Dieses Ausgangssignal liefert je nach werkseitiger Konfiguration eine präzise 10-V-Referenzspannung (10 V ± 20 mV) bzw. eine 5-V-Referenzspannung (5 V ± 10 mV). Dieser Pin ist auf Masse zu beziehen. Die Impedanz beträgt 100 Ω. Der Ausgangstrom ist auf 2 mA zu begrenzen.


Pin 12. LEVEL OUT.A. Dieser Ausgang stellt ein voll gepuffertes Signal von 0 bis 10 V (bzw. 0 bis 5 V) zur Verfügung, das den programmierten Sollwertpegel des MDX-Geräts darstellt. Je nach werkseitiger Konfiguration gilt: 10 V = Höchstpegel oder 5 V = Höchstpegel (bezogen auf Masse). Die Impedanz beträgt 100 Ω. Der Ausgangstrom ist auf 2 mA zu begrenzen.

Pin 13. STPT OK.D. Wenn dieses Ausgangssignal von 0-15 V gegen Null geht, bedeutet dies, daß der Ausgang den angeforderten Sollwert erreicht hat. (Außerdem leuchtet die Status-LED SETPOINT an der Frontplatte auf.) Dieses Signal liefert einen Strom von 35 mA und ist auf Masse zu beziehen. Es wird intern mit einem Pull-Up-Widerstand von 10 kΩ auf 15 V gebracht. Seine Impedanz beträgt 100 Ω.

Pin 14. V AUX.A. Dieser Anschluß ist eine auf Masse bezogene Spannungsquelle von 15 V, die dem Benutzer zur Verfügung steht. Der Benutzer kann bis zu 100 mA von dieser Quelle entnehmen. Die Quellimpedanz liegt unter 0,1 Ω und ist durch eine Sicherung geschützt.
INSTALLATION


Pin 20. GND. Massepin.

Pin 21. GND. Massepin.

Pin 22. OUTPUT D. Ist dieses Ausgangssignal von 0 bis 15 V hoch, ist der Ausgang ausgeschaltet. Ist es niedrig, ist der Ausgang eingeschaltet und führt den Anstieg auf den jeweils festgelegten Sollwert durch (außerdem leuchtet die LED OUTPUT POWER, START an der Frontplatte). Es liefert 35 mA und ist auf Masse zu beziehen. Es wird intern mit einem Pull-Up-Widerstand von 10 kΩ auf 15 V gebracht, und seine Impedanz beträgt 100 Ω.

Pin 23. LEVEL IN A. Mit diesem Eingangssignal von 0 bis 10 V (bzw. 0 bis 5 V) wird der Ausgangspiegel programmiert (s. Abbildung 3-19 auf Seite 3-37). Je nach werksseitiger Konfiguration gilt: 10 V = maximaler Ausgangspegel oder 5 V = maximaler Ausgangspegel. Dieses Signal ist auf Masse zu beziehen.


Pin 25. GND. Massepin.
Verdrahtungsoptionen

Dreileiter-Steuerung


Abbildung 3-18. Schaltplan für die Dreileiter-Steuerung.

Zweileiter-Steuerung

Pin 7 und 8 (RMT OFF.D und RMT ON.D) können miteinander verbunden und als ein Eingang gesteuert werden (s. Abbildung 3-19). Diese Zweidraht-Steuerung empfiehlt sich, wenn die Ein-/Aus-Erfordernisse des jeweiligen Systems einfach sind. Wenn Sie die MDX-Einheit also mit einem Kontakt steuern möchten (z.B. mit einem Relais), anstatt einen Kontakt für die Einschalt- und einen für die Ausschaltfunktion zu verwenden, so könnte diese Verdrahtungsoption für Sie die bevorzugte sein. Werden Pin 7 und 8 mit dem Pin 9 (GND) verbunden, wird der Ausgang sofort aktiviert. Wenn bei der Ausgangszerzeugung die Pins 7 und 8 hoch bleiben, wird der Ausgang ausgeschaltet.

Abbildung 3-19. Schaltplan für die Zweileiter-Steuerung.
**Externe Ausgangsüberwachung**


![Diagram](image)

*Abbildung 3-20. Schaltplan für die externe Ausgangsüberwachung.*

**Externe Sollwertprogrammierung**

Die nächste Abbildung (Abbildung 3-21) zeigt, wie die Eingangsleitungen zu verdrahten sind, wenn der Sollwert von einem externen Potentiometer erzeugt werden soll. Sie müssen bei dieser Option außerdem die Betriebsart des Netzteiles festlegen. Seite 4-3.

![Diagram](image)

*Abbildung 3-21. Schaltplan für die externe Sollwertprogrammierung.*
Digitale Ausgangssignale

Aus der folgenden Abbildung geht die interne Schaltung der digitalen Ausgangssignale hervor.

![DIagramm 1](image1)

*Abbildung 3-22. Schaltplan für die digitalen Ausgangssignale.*

Das folgende Bild zeigt die interne Schaltung der digitalen Eingänge.

![Diagramm 2](image2)

*Abbildung 3-23. Interne Schaltung der digitalen Eingänge.*

Normaler Verriegelungsanschluß

werden. Wenn während des Betriebs einer der Anschlüsse geöffnet wird, wird der Ausgang abgeschaltet, und die LED **INTERLOCK** beginnt zu blinken.

<table>
<thead>
<tr>
<th>MAIN INTLK.D</th>
<th>6</th>
<th>8</th>
<th>ole</th>
</tr>
</thead>
<tbody>
<tr>
<td>VAC ILK.D</td>
<td>5</td>
<td>8</td>
<td>ole</td>
</tr>
<tr>
<td>WATER ILK.D</td>
<td>4</td>
<td>8</td>
<td>ole</td>
</tr>
<tr>
<td>GND</td>
<td>9</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Abbildung 3-24. Üblicher Anschluß einer Verriegelungsschleife.*

Die Schaltung der digitalen Eingänge **VAC ILK.D** und **WATER ILK.D** ist in Bild 3-23 dargestellt. Der Eingang **MAIN INTLK.D** steuert ein Relais, das 24 V zur Erregerspule des Hauptschützes schaltet (Siehe Bild 3-25).

![Diagram 3-25](image)

*Abbildung 3-25. Anschluß des Einganges MAIN INTLK.D.*

**Blindstecker ("Cheater Plug")**

Der Blindstecker ("Cheater Plug"), der bei der Auslieferung des Geräts in den Benutzersteckverbinder eingesteckt war (s. Abbildung 3-26), gibt Ihnen die Möglichkeit, die MDX-Stromversorgung sofort ohne weitere Verdrahtungsmaßnahmen in Betrieb zu nehmen. Wenn Sie die Verriegelungsleitungen nicht benutzen möchten, können Sie den Blindstecker auch weiterhin verwenden.
BITTE BEACHTEN...

Wird die Analog/Digital-Schnittstelle nicht verwendet, muß der Blindstecker an die MDX-Stromversorgung angeschlossen werden.

ACHTUNG! Wenn Sie mit dem Blindstecker arbeiten, werden die Verriegelungsleitungen unwirksam gemacht.

| MAIN INLK.D | 6 |
| VAC IMK.D   | 5 |
| WATER ILK.D | 4 |
| RMT OFF.D   | 7 |
| GND         | 9 |

Abbildung 3-26. Schaltplan für den Blindstecker ("Cheater Plug").

Entfernen der Anschlüsse

Bevor an der MDX-Einheit Justier-, Austausch-, Wartungs- oder Reparaturmaßnahmen vorgenommen werden, muß die Netzzuleitung unterbrochen werden.

ACHTUNG LEBENSGEFÄHR! Interne Bauteile können noch bis zu vier Minuten nach dem Entfernen aller Zuleitungen Spannung führen!

BITTE BEACHTEN...

Nennleistung und Eigenschaften von Ersatzsicherungen müssen mit denen der Originalsicherungen übereinstimmen.
ERSTE INBETRIEBNAHME

Verfahren bei der Inbetriebnahme

1. Vergewissern Sie sich, daß die erforderlichen externen Eingangssignale und Erdverbindungen anliegen (s. Signalbeschreibungen auf den Seiten 3-33 bis 3-35) bzw. daß der Blindstecker ("Cheater Plug") an der Analog/Digital-Schnittstelle an der Rückseite des MDX-Geräts angeschlossen ist (s. Seite 3-39).

2. Schließen Sie den Ausgangssteckverbinder an.


4. Wählen Sie den von Ihnen gewünschten Ausgangsregulierungsmodus, indem Sie den (die) jeweiligen Schalter drücken. Die entsprechende(n) LED(s) leuchten auf. Auf Seite 4-3 finden Sie weitere Informationen über die Ausgangsregulierung.

5. Wählen Sie Anstiegs geschwindigkeit, indem Sie die RAMP-Schalter an der Rückseite der Einheit (eine beliebige Kombination aus 0.1, 1.0 und 10) auf den gewünschten Wert einstellen. Auf den Seiten 2-18 und 4-6 finden Sie weitere Informationen über die RAMP-Schalter.

6. Stellen Sie zur Vorprogrammierung des Ausgangspegels (im lokalen Modus) den Drehschalter LEVEL ein, und achten Sie dabei auf die Anzeige des Digitalmeßgeräts.

ACHTUNG LEBENSGEFAHR! Der nächste Schritt führt zu hohen Spannungswerten am Ausgangsanschluß. Führen Sie die zur Verhinderung von Elektroschocks erforderlichen Schutzmaßnahmen durch.

7. Drücken Sie auf OUTPUT POWER, START. Der Hauptschutz wird geschlossen, und die LED OUTPUT POWER, START leuchtet auf. Die Status-LEDs SETPOINT, OUTPUT und PLASMA leuchten nun ebenfalls.
8. Drücken Sie den Schalter **DISPLAY**, um sich nach und nach alle Parameter, die angezeigt werden können, anzuschauen und sich vom ordnungsgemäßen Systembetrieb zu überzeugen.


10. Durch Betätigung des Schalters **OUTPUT POWER, STOP** können Sie den Ausgang jederzeit ausschalten.
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OUTPUT REGULATION

Throughout this manual, we refer to the product of the MDX magnetron drive generically as “output” because it is possible to regulate power, current, or voltage. You can choose one of these three methods of output regulation.

Power

Power regulation is selected from the front panel by pressing the **POWER** switch under the **REGULATION** label. (The LED on the switch will light.)

From the User port, ensure that \textit{pin 16 (P REG.D)} is low and \textit{pin 17 (I REG.D)} is high.

Current

Select current regulation from the front panel by pressing the **CURRENT** switch under the **REGULATION** label. (The LED on the switch will light.)

From the User port, ensure that \textit{pin 16 (P REG.D)} is high and \textit{pin 17 (I REG.D)} is low.

Voltage

Select voltage regulation from the front panel by pressing both **POWER** and **CURRENT** switches under the **REGULATION** label. (Both LEDs on the switches will light.)

From the User port, ensure that both \textit{pin 16 (P REG.D)} and \textit{pin 17 (I REG.D)} are low.
Setpoints and Ramp Switches

Setpoint Level

You can program an output setpoint level whether or not output is being produced.

*Front Panel:*
1. Press the **DISPLAY** switch until the **SETPOINT** LED to the right of the digital meter lights.
2. Use the **LEVEL** knob to specify the desired setpoint level (displayed on the digital meter).

The **SETPOINT** status indicator LED (see page 2-13) lights when output is equal to the pre-selected setpoint; it goes out when the output has been turned off.

*User Interface:*
Use *pin 23 (LEVEL IN.A)* to program output setpoint level (see detailed signal description on page 3-15).

Parameters that can be monitored from the User port are:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>User pins</th>
</tr>
</thead>
<tbody>
<tr>
<td>Setpoint level</td>
<td><em>pin 23</em></td>
</tr>
<tr>
<td>Whether programmed output setpoint level has been attained</td>
<td><em>pin 13</em></td>
</tr>
</tbody>
</table>
Ramp Switches

There are three RAMP switches located on the rear panel.

**RAMP 0.1** sets the ramp time to setpoint to 0.1 s.

**RAMP 1.0** sets the ramp time to setpoint to 1.0 s.

**RAMP 10** sets the ramp time to setpoint to 10.0 s.

These switches can be used individually or in combination to specify the amount of time (0.1 to 11.1 s) the MDX will take to reach the specified output setpoint. If none of the switches is turned on, fast ramp occurs. The time of the fast ramp will depend on whether contactor hold is enabled and whether you are turning output on for the first time.
REMOTE OPERATION

With a control/display panel, you give on control to the User port when you close (place in the up position) the LOCAL, ON switch on the rear panel. Off control is always available from both the front panel and the User port. Give setpoint control to the User port by closing (placing in the up position) the LOCAL, SETPOINT switch on the rear panel.

Setpoint Level

- To select voltage regulation, make both pin 17 (I REG.D) and pin 16 (P REG.D) low.
- To select power regulation, make pin 17 (I REG.D) high, and make pin 16 (P REG.D) is low.
- To select current regulation, make pin 17 (I REG.D) low, and make pin 16 (P REG.D) high.

<table>
<thead>
<tr>
<th>Method of Output Regulation</th>
<th>Condition of Signal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage</td>
<td>pin 17</td>
</tr>
<tr>
<td>Power</td>
<td>low</td>
</tr>
<tr>
<td>Current</td>
<td>high</td>
</tr>
<tr>
<td></td>
<td>low</td>
</tr>
</tbody>
</table>

- Use pin 23 (LEVEL IN.A) to set the desired output level.
- Use pin 12 (LEVEL OUT.A) to monitor the output level.

On/Off

From the rear panel, place the LOCAL, ON switch in the up position to transfer control of output on (pin 8) to the User port. Output off is always available from both the front panel and the User port. (See detailed description of User pins beginning on page 3-13.)

- Use pin 8 (RMT ON.D) to turn output on.
- Use pin 7 (RMT OFF.D) to turn output off (see discussion of two-wire and three-wire control on page 3-16).

YOU SHOULD KNOW...

RMT OFF.D will override all commands and force the MDX to shut off output power.
CONTACTOR HOLD

To help prolong the life of the main and soft-start contactors, the MDX is equipped with a **contactor hold** feature. If your process run times are short, you may want to specify that the contactors stay energized after the first start cycle. With this feature, when the **C HOLD** switch on the rear panel is set to the down position, the contactors will remain closed after the first time the dc bus is energized, regardless of whether output is being produced or not. If the switch is set to the up position, the contactors will close and open as output is turned on and off. Interlock faults and bus voltage faults will open the contactors whether or not **C HOLD** is enabled.
IMPEDANCE OPTIONS

Each MDX is equipped with a built-in impedance-matching transformer. See Figures 4-1 and 4-2 on the following pages for voltage/current and impedance options.
Figure 4-1. Voltage/current and low impedance options.
Figure 4-2. Voltage/current and high impedance options.
PART III

LEARNING MORE ABOUT YOUR MAGNETRON DRIVE
DC BIAS

"Dc bias" refers to the dc component of the RF power that is developed between the cathode and the anode of a typical RF plasma vacuum system. This dc component is blocked from the RF generator by the capacitors that are used in the impedance-matching networks.

The dc potential is a controllable parameter. It is also a valuable indicator that itself changes in response to changes in other process parameters. Some of the parameters that affect dc bias are molecular densities and ratios of process gases, cathode/anode surface area ratios, pressure regimes and stability, and RF power densities. While some of these parameters are controllable, others are fixed and so must be worked around.

The amount of dc bias that is developed within a process system depends upon the system design or the process being run. Although a systems manufacturer can use modeling or empirical data to predict the dc bias that should be expected with a specific system or process, a power supply manufacturer cannot.

In any case, you can determine dc bias by measuring it yourself with a high-voltage probe.

DANGER! Lethal high-voltage and high-current potentials are present during the measurement of dc bias. Extreme caution is required to ensure the safety of yourself and of those working with you. Carelessness can cause severe burns, paralysis, or instant death.

Measure dc bias at the RF feedthrough. The farther the probe is from the feedthrough, the less accurate the measurement. This is because dc bias decreases with distance from the feedthrough due to electrical loss. A convenient point for taking this measurement, if you are using an Advanced Energy® impedance-matching network, is inside the impedance-matching network itself, at the output of the series capacitor.

Dc bias can be regulated in two ways, the choice of which depends upon the process or application. The mutually exclusive choices result in either maximum range or maximum resolution.
If you choose maximum range, run the RF generator at maximum power when you measure dc bias. In the more advanced, microprocessor-controlled RF generators, a normalization (calibration) function makes it possible to tailor the process to the dc bias regulation. With one of these generators, maximum power will also equate with maximum dc bias. By normalizing for the maximum dc bias, the process will have the widest range of available dc biases.

If resolution of the dc bias control is more important, set your system up for a "typical" process before you measure dc bias. The new microprocessor-controlled generators will calibrate the dc bias over a smaller power cross section, thus providing a higher resolution over a smaller area of operation.

Since what is best for one application will not necessarily be best for another application, you may calibrate for either resolution or range, and then later repeat the process for the other possibility.
GROUNDING

Current seeks the path of lowest resistance. If several paths are characterized by similar impedances, the current flow may randomly switch paths. This switching may appear as oscillations and cause interference ("noise") with electronic equipment. The goal in any system design is to provide a known, fixed, lowest impedance path. The way to do this is to provide good grounding.

Grounding is important for a variety of reasons:
- it ensures safety of personnel
- it protects equipment
- it is necessary for agency approvals
- it prevents electromagnetic radiation
- it prevents electromagnetic interference
- it provides a known reference for control signals

Grounding requirements and standards are set and promulgated by various commercial and governmental agencies. Information is available from UL, CSA, VDE, FCC, IEEE, SAE, CISPR, and many local government agencies. Always check whatever documents are mandated by your local authorities. This note is intended to provide a broad overview of grounding issues and considerations.

AC and DC Grounding

In the real world there is a significant difference between the techniques used to provide a good dc ground and those used to provide a good ac ground. Just because a system has a very low dc resistance to earth-ground does not at all imply that it has a good ac earth-ground, or vice versa. A dc ground connection requires conductors and connectors with adequate cross-sectional area for the current to be carried; these conductors and connectors must also be made of material with very little resistance.

An ac ground requires conductors and connectors with adequate surface area for the current to be carried; however, the conductors and connectors must also have very little inductive reactance or capacitive reactance to ensure the lowest possible impedance. This becomes more critical as the frequency increases into the RF range.
The major safety issue concerning improperly grounded equipment is that people can come in contact with dangerous voltages. Although this danger is usually viewed as being caused by dc or 50/60 Hz ac voltages, this is not necessarily the case. The multimeter is a typical measuring instrument used to determine whether or not a system or component is grounded. A multimeter is designed to measure dc voltage and current, ac voltage and current, and resistance. However, it is not sensitive to high-frequency energy and often will not even detect the presence of RF energy, much less give accurate readings. Since RF can be present without being detected by common means, there is a significant potential for harm to personnel from RF surface burns, arcs that penetrate the skin, and other such injuries.

Equipment designed to measure RF energy is expensive and bulky, and must be calibrated over narrow frequency ranges. Most facilities do not have this kind of equipment on hand. It is therefore very important that all appropriate personnel (those involved in design, installation, maintenance, and operations) are knowledgeable about all aspects of grounding for electrical energies, from dc through RF.

⚠️ YOU SHOULD KNOW…

DANGER! Operating and maintenance personnel must have the correct training before setting up and maintaining high-energy electrical equipment.

While significant numbers of RF problems are caused by improper grounding of RF power supplies used in a process, all plasma systems produce some RF energy that must be taken into account when the system is designed. As examples: Plasma arcs are like small lightening bolts that cause broad-band RF interference; a plasma chamber is a type of oscillator and radiates RF energy if not shielded; electric motors/relays/solenoids can produce RF energy when they are actuated; even microcomputers used in instruments and controllers can produce RF energy that can cause problems with other circuits. Each one of these sources may interfere with the proper operation of electronic instruments and controls within the system. In the worst cases, this energy can cause noise in equipment at some distance from the source, often hundreds of feet or more away.

Symptoms of Noise Problems

Some grounding problems are inevitable in complex and high-power systems. A good system developer understands grounding problems and, therefore, has a development lab with good earth grounds. This ensures that the new system works well during construction and testing. However, a common occurrence is that when it is installed at a customer’s site, nothing works. This is typically due to poor earth-grounding techniques.
Similarly, noise problems will not always surface during the development phase of the components that will be used in the system. This is because a manufacturer cannot simulate the exact environment in which the components (power supplies, for instance) will be used. Noise problems tend not to show up until the component is installed and operating in its intended environment. Then, after a few minutes or hours of normal operation, the system finds itself someplace out in left field. Inputs are ignored and outputs are gibberish. The system may respond to a reset, or it may have to be turned off and then back on again, at which point it commences operating as though nothing had happened. There may be an obvious cause, such as an electrostatic discharge from somebody's finger to a keyboard, or the upset occurs every time another machine is turned on or off. Or there may be no obvious cause, and nothing the operator can do will make the upset repeat itself. But a few minutes, or a few hours, or a few days later it happens again.

One symptom of electrical noise problems is randomness, both in the occurrence of the problem and in what the system does in its failure. All operational upsets that occur at seemingly random intervals are not necessarily caused by noise in the system. Marginal bus voltages, inadequate decoupling, rarely encountered software conditions, or timing coincidences can produce upsets that seem to occur randomly. On the other hand, some noise sources can produce upsets downright periodically. Nevertheless, the more difficult it is to characterize an upset as to cause and effect, the more likely it is to be a noise problem.

Types and Sources of Electrical Noise

The name given to electrical noises other than those that are inherent in the circuit components (such as thermal noise) is EMI: electromagnetic interference. Motors, power switches, fluorescent lights, electrostatic discharges, etc., are sources of EMI. There is a veritable alphabet soup of EMI types, and these are briefly described below.

Supply Line Transients

Anything that switches heavy current loads on to or off of ac or dc power lines will cause large transients in these power lines. Switching a vacuum pump on or off, for example, can put a large voltage spike onto the ac power lines.

The basic mechanism behind supply line transients is shown in Fig. 1. The battery represents any power source, ac or dc. The coils represent the line inductance between the power source and the switchable loads R1 and R2. If both loads are drawing current, the line current flowing through the line inductance establishes a magnetic field of some value. Then, when one of the loads is switched off, the field due to that component of the line current
collapses, generating transient voltages, \( v = L \frac{di}{dt} \), which try to maintain the current at its original level. That’s called an “inductive kick.” Because of contact bounce, transients are generated whether the switch is being opened or closed, but they’re worse when the switch is being opened.

![Diagram of circuit with inductor and resistors](image)

*Figure 1. Supply line transients.*

An inductive kick of one type or another is involved in most line transients. Other mechanisms for line transients exist, involving noise pickup on the lines. The noise voltages are then conducted to a susceptible circuit right along with the power.

**EMP and RFI**

Anything that produces arcs or sparks will radiate electromagnetic pulses (EMP) or radio-frequency interference (RFI). Spark discharges have probably caused more software upsets in digital equipment than any other single noise source. The upsetting mechanism is the EMP produced by the spark. The EMP induces transients in the circuit, which are what actually cause the upset.

Arcs and sparks occur in plasma chambers, electron-beam systems, and magnetron sputtering systems; in associated equipment such as electric motors and switches; and in static discharges. Electric motors that have commutator bars produce an arc as the brushes pass from one bar to the next. Dc motors and the “universal” (ac/dc) motors that are used to power hand tools are the kinds that have commutator bars. In switches, the same inductive kick that puts transients on the supply lines will cause an opening or closing switch to throw a spark. Vacuum systems contain vacuum pumps, solenoid valves, motors, power supplies, and many other noise producers.

**ESD**

Electrostatic discharge (ESD) is the spark that occurs when a person picks up a static charge from walking across a carpet, and then discharges it into a keyboard, or whatever else can be touched. Walking across a carpet in a dry climate, a person can accumulate a static voltage of 35 kV. The current pulse
from an electrostatic discharge has an extremely fast rise time — typically, 4 A/nsec. Figure 2 shows ESD waveforms that have been observed by some investigators of ESD phenomena.

![Waveforms of electrostatic discharge currents from a hand-held metallic object.](image)

It is enlightening to calculate the L(di/dt) voltage required to drive an ESD current pulse through a couple of inches of straight wire. Two inches of straight wire has about 50 nH of inductance. That’s not very much, but using 50 nH for L and 4 A/nsec for di/dt gives an L(di/dt) drop of about 200 V. Recent observations by W.M. King suggest even faster rise times (Fig. 2B) and the occurrence of multiple discharges during a single discharge event.

Obviously, ESD sensitivity needs to be considered in the design of equipment that is going to be used in difficult industrial environments. Although humidity is controlled in many IC clean rooms, this is not the case in many other clean rooms. Any time large volumes of air are moved, electrostatic energy will build
up. This can cause ESD problems for a system's control circuitry, whether in
the system computer, a power supply's microprocessor, an electronic vacuum
pump, or a critical endpoint detector such as an RGA computer.

**Ground Noise**

Currents in ground lines are another source of noise. These can be 60-Hz
currents from the power lines, or RF hash, or crosstalk from other signals that
are sharing this particular wire as a signal return line. Noise in the ground
lines is often referred to as a "ground loop" problem. The basic concept of the
ground loop is shown in Fig. 3. The problem is that true earth-ground is not
really at the same potential in all locations. If the two ends of a wire are
earth-grounded at different locations, the voltage difference between the two
"ground" points can drive significant currents (several amperes) through the
wire. Consider the wire to be part of a loop which contains, in addition to the
wire, a voltage source that represents the difference in potential between the
two ground points, and you have the classical "ground loop." By extension,
the term is used to refer to any unwanted (and often unexpected) currents in a
ground line.

![Diagram of a ground loop](image)

*Figure 3. Illustration of a ground loop.*

**“Radiated” and “Conducted” Noise**

Radiated noise is noise that arrives at the victim circuit in the form of
electromagnetic radiation, such as EMP and RFI. It causes trouble by
inducing extraneous voltages in the circuit. Conducted noise is noise that
arrives at the victim circuit already in the form of an extraneous voltage,
typically via the ac or dc power lines.

You can defend against radiated noise by carefully designing layouts and
using effective shielding techniques. You can defend against conducted noise
with filters and suppressors, although layouts and grounding techniques are
important here, too.
Types of Failures and Failure Mechanisms

A major problem that EMI can cause in digital systems is intermittent operational malfunction. These software upsets occur when the system is in operation at the time an EMI source is activated, and are usually characterized by a loss of information or a jump in the execution of the program to some random location in memory. The person who has to iron out such problems is tempted to say the program counter went crazy. There is usually no damage to the hardware, and normal operation can resume as soon as the EMI has passed or the source is de-activated. Resuming normal operation usually requires manual or automatic reset, and possibly re-entering of lost information.

Electrostatic discharges from operating personnel can cause not only software upsets, but also permanent ("hard") damage to the system. For this to happen the system doesn't even have to be in operation. Sometimes the permanent damage is latent, meaning the initial damage may be marginal and require further aggravation through operating stress and time before permanent failure takes place. Sometimes the damage is hidden.

Current Loops

The first thing most people learn about electricity is that current won't flow unless it can flow in a closed loop. This simple fact is sometimes temporarily forgotten by the overworked engineer who has spent the past several years mastering the intricacies of the DO loop, the timing loop, the feedback loop, and maybe even the ground loop.

![You Should Know](image)

The simple current loop probably owes its apparent demise to the invention of the ground symbol. By a stroke of the pen you avoid having to draw the return paths of most of the current loops in the circuit. Then "ground" turns into an infinite current sink, so that any current that flows into it is gone and forgotten. Forgotten it may be, but it's not gone. It must return to its source, so that its path will by all the laws of nature form a closed loop.

The physical geometry of a given current loop is the key to why it generates EMI, why it's susceptible to EMI, and how to shield it. Specifically, it's the area of the loop that matters.

Any flow of current generates a magnetic field with an intensity that varies inversely to the distance from the wire that carries the current. Two parallel wires conducting currents +I and -I (as in signal feed and return lines) would generate a nonzero magnetic field near the wires if the distance from a given point to one wire is noticeably different than the distance from the same point...
to the other wire, but farther away (relative to the wire spacing). Where the distances from a given point to either wire are about the same, the fields from both wires tend to cancel out.

Thus, maintaining proximity between feed and return paths is an important way to minimize their interference with other signals. The way to maintain their proximity is essentially to minimize their loop area. And, because the mutual inductance from current loop A to current loop B is the same as the mutual inductance from current loop B to current loop A, a circuit that doesn't radiate interference doesn't receive it either.

Thus, from the standpoint of reducing both generation of EMI and susceptibility to EMI, the hard rule is to keep loop areas small. To say that loop areas should be minimized is the same as saying the circuit inductance should be minimized. Inductance is by definition the constant of proportionality between current and the magnetic field it produces: $\phi = LI$. Holding the feed and return wires close together so as to promote field cancellation can be described either as minimizing the loop area or as minimizing $L$. It's the same thing.

Shielding

There are three basic kinds of shields: shielding against capacitive coupling, shielding against inductive coupling, and RF shielding. Capacitive coupling is electric field coupling, so shielding against it amounts to shielding against electric fields. As will be seen, this is relatively easy. Inductive coupling is magnetic field coupling, so shielding against it is shielding against magnetic fields. This is a little more difficult. Strangely enough, this type of shielding does not in general involve the use of magnetic materials. RF shielding, the classical "metallic barrier" against all sorts of electromagnetic fields, is what most people picture when they think about shielding. Its effectiveness depends partly on the selection of the shielding material, but mostly, as it turns out, on the treatment of its seams and the geometry of its openings.

**Shielding Against Capacitive Coupling**

Capacitive coupling involves the passage of interfering signals through mutual or stray capacitances that aren't shown on the circuit diagram, but which the experienced engineer knows are there. Capacitive coupling to your body is what would cause an unstable oscillator to change its frequency when you reach your hand over the circuit, for example. More importantly, in a digital system it causes crosstalk in multi-wire cables.

The way to block capacitive coupling is to enclose the circuit or conductor you want to protect in a metal shield. That's called an electrostatic or Faraday shield. If coverage is 100%, the shield does not have to be grounded, but it usually is, to ensure that circuit-to-shield capacitances go to signal reference.
ground rather than acting as feedback and crosstalk elements. Besides, from a mechanical point of view, grounding it is almost inevitable.

A grounded Faraday shield can be used to break capacitive coupling between a noisy circuit and a victim circuit, as shown in Fig. 4. Figure 4A shows two circuits capacitively coupled through the stray capacitance between them. In Figure 4B the stray capacitance is intercepted by a grounded Faraday shield, so that interference currents are shunted to ground. For example, a grounded plane can be inserted between PCBs (printed circuit boards) to eliminate most of the capacitive coupling among them.

![Capacitive Coupling](image)

(a) Capacitive Coupling

![Electrostatic Shielding](image)

(b) Electrostatic Shielding

*Figure 4. Use of Faraday shield.*

**Shielding Against Inductive Coupling**

With inductive coupling, the physical mechanism involved is a magnetic flux density B from some external interference source that links with a current loop in the victim circuit, and generates a voltage in the loop in accordance with Lenz's law: \( V = N A (dB/dt) \), where in this case \( N = 1 \) and \( A \) is the area of the current loop in the victim circuit.
There are two aspects to defending a circuit against inductive coupling. One aspect is to try to minimize the offensive fields at their source. This is done by minimizing the area of the current loop at the source so as to promote field cancellation, as described in the section on current loops. The other aspect is to minimize the inductive pickup in the victim circuit by minimizing the area of that current loop, since, from Lenz's law, the induced voltage is proportional to this area. So the two aspects really involve the same corrective action: Minimize the areas of the current loops. In other words, minimizing the offensiveness of a circuit inherently minimizes its susceptibility.

Shielding against inductive coupling means nothing more nor less than controlling the dimensions of the current loops in the circuit. We will look at two examples of this type of "shielding": the coaxial cable and the twisted pair.

The Coaxial Cable. Figure 5 shows a coaxial cable carrying a current I from a signal source to a receiving load. The shield carries the same current as the center conductor. Outside the shield, the magnetic field produced by +I flowing in the center conductor is cancelled by the field produced by -I flowing in the shield. To the extent that the cable is ideal in producing zero external magnetic field, it is immune to inductive pickup from external sources. The cable effectively adds zero area to the loop. This is true only if the shield carries the same current as does the center conductor.

In the real world, both the signal source and the receiving load are likely to have one end connected to a common signal ground. In that case, should the cable be grounded at one end, both ends, or neither end? The answer is that it should be grounded at both ends. Figure 6A shows the situation when the cable shield is grounded at only one end. In that case the current loop runs down the center conductor of the cable, then back through the common ground connection. The loop area is not well defined. The shield not only does not carry the same current as the center conductor, but it doesn't carry any current at all. There is no field cancellation at all. The shield has no effect whatsoever on either the generation of EMI or susceptibility to EMI. (It is, however, still effective as an electrostatic shield, or at least it would be if the shield coverage were 100%.)
Figure 6B shows the situation when the cable is grounded at both ends. Does the shield carry all of the return current, or only a portion of it on account of the shunting effect of the common ground connection? The answer to that question depends on the frequency content of the signal. In general, the current loop will follow the path of least impedance. At low frequencies, 0 Hz to several kilohertz, where the inductive reactance is insignificant, the current will follow the path of least resistance. Above a few kilohertz, where inductive reactance predominates, the current will follow the path of least inductance. The path of least inductance is the path of minimum loop area. Hence, for higher frequencies the shield carries virtually the same current as the center conductor, and is therefore effective against both generation and reception of EMI.

(a) Shield Has No Effect

(b) Two Return Paths

*Figure 6. Use of coaxial cable.*

Note that we have now introduced the infamous “ground loop” problem, as shown in Fig. 7A. Fortunately, a digital system has some built-in immunity to moderate ground loop noise. In a noisy environment, however, you can break the ground loop and still maintain the shielding effectiveness of the coaxial cable by inserting an optical coupler, as shown in Fig. 7B. What the optical coupler does, basically, is allow you to redefine the signal source as being ungrounded, so that the optically coupled end of the cable need not be grounded; this still lets the shield carry the same current as the center conductor. Obviously, if the signal source weren't grounded in the first place, the optical coupler wouldn't be needed.
Figure 7. Use of optical coupler.

The Twisted Pair. A cheaper way to minimize loop area is to run the feed and return wires right next to each other. This isn’t as effective as a coaxial cable in minimizing loop area. An ideal coaxial cable adds zero area to the loop, whereas merely keeping the feed and return wires next to each other is bound to add a finite area.

However, two things work to make this cheaper method almost as good as a coaxial cable. First, coaxial cables are not ideal. If the shield current isn’t evenly distributed around the center conductor at every cross-section of the cable (it isn’t), then field cancellation external to the shield is incomplete. Since field cancellation is incomplete, the effective area added to the loop by the cable isn’t zero. Second, in the cheaper method the feed and return wires can be twisted together. This not only maintains their proximity, but the noise picked up in one twist tends to cancel out the noise picked up in the next twist down the line. Thus the “twisted pair” turns out to be about as good a shield against inductive coupling as coaxial cable is.

The twisted pair does not, however, provide electrostatic shielding (i.e., shielding against capacitive coupling). Another operational difference is that the coaxial cable works better at higher frequencies. This is primarily because
the twisted pair adds more capacitive loading to the signal source than does the coaxial cable. The twisted pair is normally considered useful up to only about 1 MHz; the coaxial cable is considered useful up to 1 GHz.

**RF Shielding**

A time-varying electric field generates a time-varying magnetic field, and vice versa. Far from the source of a time-varying EM field, the ratio of the amplitudes of the electric and magnetic fields is always 377 Ω. Up close to the source of the fields, however, this ratio can be quite different, and dependent on the nature of the source. The field where the ratio is near 377 Ω is called the far field, and the field where the ratio is significantly different from 377 Ω is called the near field. The ratio itself is called the wave impedance, E/H.

The near field goes out about one-sixth of a wavelength from the source. At 1 MHz this is about 150 ft., and at 10 MHz it’s about 15 ft. That means that if an EMI source is in the same room with the victim circuit, it’s likely to be a near field problem. The reason this matters is that in the near field an RF interference problem could be almost entirely due to E-field coupling or H-field coupling, and that could influence the choice of an RF shield or whether an RF shield will help at all.

In the near field of a whip antenna, the E/H ratio is higher than 377 Ω, which means it’s mainly an E-field generator. A wire-wrap post can be a whip antenna. Interference from a whip antenna would be by electric field coupling, which is basically capacitive coupling. Methods to protect a circuit from capacitive coupling, such as a Faraday shield, would be effective against RF interference from a whip antenna. A gridded-ground structure would be less effective.

In the near field of a loop antenna, the E/H ratio is lower than 377 Ω, which means it’s mainly an H-field generator. Any current loop is a loop antenna. Interference from a loop antenna would be by magnetic field coupling, which is basically the same as inductive coupling. Methods to protect a circuit from inductive coupling, such as a gridded-ground structure, would be effective against RF interference from a loop antenna. A Faraday shield would be less effective.

A more difficult case of RF interference, near field or far field, may require a genuine metallic RF shield. The idea behind RF shielding is that time-varying EMI fields induce currents in the shielding material. The induced currents dissipate energy in two ways: $I^2R$ losses in the shielding material and radiation losses as they re-radiate their own EM fields. The energy for both of these mechanisms is drawn from the impinging EMI fields — thus the EMI is weakened as it penetrates the shield.
More formally, the $I^2R$ losses are referred to as absorption loss, and the re-radiation is called reflection loss. As it turns out, absorption loss is the primary shielding mechanism for H-fields, and reflection loss is the primary shielding mechanism for E-fields. Reflection loss, being a surface phenomenon, is pretty much independent of the thickness of the shielding material. Both loss mechanisms, however, are dependent on the frequency ($\omega$) of the impinging EMI field, and on the permeability ($\mu$) and conductivity ($\sigma$) of the shielding material. These loss mechanisms vary approximately as follows:

reflection loss to an E-field (in dB) \( \sim \log \frac{\sigma}{\omega \mu} \)

absorption loss to an H-field (in dB) \( \sim t \sqrt{\omega \sigma \mu} \)

Where:

$\tau$ = the thickness of the shielding material.

The first expression indicates that 1) E-field shielding is more effective if the shield material is highly conductive and less effective if the shield is ferromagnetic, and 2) that low-frequency fields are easier to block than high-frequency fields. This is shown in Fig. 8.

![Reflection Loss vs Frequency](image)

*Figure 8. E-field shielding.*

Copper and aluminum both have the same permeability, but copper is slightly more conductive, and so provides slightly greater reflection loss to an E-field. Steel is less effective for two reasons. First, it has a somewhat elevated permeability due to its iron content, and, second, as tends to be the case with magnetic materials, it is less conductive.

On the other hand, according to the expression for absorption loss to an H-field, H-field shielding is more effective at higher frequencies and with shield material that has both high conductivity and high permeability. In practice, however, selecting steel for its high permeability involves some compromise in conductivity. But the increase in permeability more than makes up for the
decrease in conductivity, as can be seen in Fig. 9. This figure also shows the effect of shield thickness.

![Graph showing absorption loss vs. frequency for different materials](image)

**Figure 9. H-field shielding.**

A composite of E-field and H-field shielding is shown in Fig. 10. However, this type of data is meaningful only in the far field. In the near field, the EMI could be 90% H-field, in which case the reflection loss is irrelevant. It would be advisable then to beef up the absorption loss, at the expense of reflection loss, by choosing steel. A better conductor than steel might be less expensive, but it would also be ineffective.

![Graph showing total shielding effectiveness vs. frequency](image)

**Figure 10. E- and H-field shielding.**
A characteristic that can be exploited for low-frequency magnetic fields is the ability of a high-permeability material such as mumetal to divert the field by presenting a very low reluctance path to the magnetic flux. Above a few kilohertz, however, the permeability of such materials is the same as steel.

In actual fact the selection of a shielding material turns out to be less important than the presence of seams, joints and holes in the physical structure of the enclosure. The shielding mechanisms are related to the induction of currents in the shield material, but the currents must be allowed to flow freely. If they have to detour around slots and holes, as shown in Fig. 11, the shield loses much of its effectiveness.

As can be seen in Fig. 11, the severity of the detour has less to do with the area of the hole than it does with the geometry of the hole. Comparing Fig. 11C with Fig. 11D shows that a long narrow discontinuity such as a seam can cause more RF leakage than a line of holes with larger total area. A person who is responsible for designing or selecting rack or chassis enclosures for an EMI environment needs to be familiar with the techniques that are available for maintaining electrical continuity across seams. Information on these techniques is available in the references at the end of this note.

![Diagram](a) Induced Shield Current

![Diagram](b) Rectangular Slot

![Diagram](c) Section of Shield

![Diagram](d)

*Figure 11. Effect of shield discontinuity on magnetically induced shield current.*
Grounds

There are two kinds of grounds: earth ground (safety ground) and signal ground. The earth is not an equipotential surface, so earth-ground potential varies. In addition, its other electrical properties are not conducive to its use as a return conductor in a circuit. However, circuits are often connected to earth ground for protection against shock hazards. The other kind of ground, signal ground, is an arbitrarily selected reference node in a circuit—the node with respect to which other node voltages in the circuit are measured.

Earth Ground

The standard U.S. three-wire, single-phase ac power distribution system is represented in Fig. 12. The white wire is earth-grounded at the service entrance. If a load circuit has a metal enclosure or chassis, and if the black wire develops a short to the enclosure, there will be a shock hazard to operating personnel, unless the enclosure itself is earth-grounded. If the enclosure is earth-grounded, a short results in a blown fuse rather than a “hot” enclosure. The earth-ground connection to the enclosure is called a safety ground. The advantage of the three-wire power system is that it distributes a safety ground along with the power.

Note that the safety-ground wire carries no current, except in case of a fault, so that at least for low frequencies it’s at earth-ground potential along its entire length. The voltage of the white wire, on the other hand, may be several volts different than the voltage of ground, due to the IR drop along its length.

![Diagram](image)

*Figure 12. Single-phase power distribution.*
In high-power systems and systems that radiate high levels of noise, it is common practice to provide each system with an individual earth-ground. This is done by driving a copper stake or stakes into the ground under or very close to the frame of the system, even to the extent of drilling holes through concrete floors.

In multistory buildings it is even more difficult to provide a low-impedance, secure connection to the earth. Many times this is done by using a copper pipe that provides water to the system. This practice is suspect because the water pipe may travel a considerable distance before making contact with the earth, and thus may have a relatively high impedance/resistance. In a multistory system, a heavy copper strap should connect the system frame to an earth-ground stake by the shortest possible path.

All earth-ground connections should be made with 1-1.5 in. copper strap whenever possible. This practice provides a low-impedance path for both dc and ac.

In many areas the soil is very dry and has high electrical resistance. This is cured by providing a grid of stakes or a mat of copper wires, and a means of continually wetting the earth around the stakes or grid.

In the past, the earth around the ground stake was saturated with copper sulfate. However, the toxicity of copper sulfate combined with its high solubility endangers groundwater supplies, and so this practice is now illegal. Other, nontoxic electrolytes are sometimes used, depending on local laws.

**Signal Ground**

Signal ground is a single point in a circuit that is designated to be the reference node for the circuit. Commonly, wires that connect to this single point are also referred to as “signal ground.” In some circles “power supply common” or PSC is the preferred terminology for these conductors. In any case, the manner in which these wires connect to the actual reference point is the basis of distinction among three kinds of signal-ground wiring methods: series, parallel, and multipoint (shown in Fig. 13).
Figure 13. Three ways to wire the grounds.

The series connection is pretty common because it's simple and economical. It's the noisiest of the three, however, due to common-ground impedance coupling between the circuits. When several circuits share a ground wire, currents from one circuit, flowing through the finite impedance of the common ground line, cause variations in the ground potential of the other circuits. Given that the currents in a digital system tend to be spiked, and that the common impedance is mainly inductive reactance, the variations could be bad enough to cause bit errors in high current or particularly noisy situations.

The parallel connection eliminates common-ground impedance problems, but uses a lot of wire. Other disadvantages are that the impedance of the individual ground lines can be very high, and the ground lines themselves can become sources of EMI.
In the multipoint system, ground impedance is minimized by using a ground plane with the various circuits connected to it by very short ground leads. This type of connection would be used mainly in RF circuits above 10 MHz.

**Practical Grounding**

A combination of series and parallel ground-wiring methods can be used to trade off economic and electrical considerations. The idea is to run series connections for circuits that have similar noise properties, and connect them at a single reference point, as in the parallel method (shown in Fig. 14).

In Fig. 14, the "noisy and high current signal ground" connects to things like motors and relays. The hardware ground is the safety-ground connection to chassis, racks, and cabinets. It's a mistake to use the hardware ground as a return path for signal currents because it's fairly noisy (for example, it's the hardware ground that receives an ESD spark) and tends to have high resistance due to joints and seams.

![Diagram of ground connections](image)

*Figure 14. Parallel connection of series grounds.*

Screws and bolts don't always make good electrical connections because of galvanic action, corrosion, and dirt. These kinds of connections may work well at first, and then cause mysterious maladies as the system ages.
Figure 15 illustrates a grounding system for a typical power supply setup in a vacuum-process system, showing an application of the series/parallel ground-wiring method. Ground lines 1 and 2 are normally required by code but cannot be relied upon in high-power systems. Ground lines 3, 4, and 5 illustrate series grounding.

Ground lines 6 and 7 illustrate parallel grounding. They ensure that power supply 1 (PS1) and power supply 2 (PS2) are integral parts of the system grounding scheme (the utility connection is usually not a quality ground). Ground line 8 provides the primary system earth-ground connection.

Current return 9 ensures a current return path for the power supply output and should not be confused with the ground lines (1 through 8). See the typical applications discussed on pages 1-9 through 1-16 for instructions on how to connect this line with the earth-ground terminal.
The separation of grounds shown in Fig. 16 is similar to what is shown in Fig. 15, but here it is shown at the PCB level. Currents in multiplexed LED displays tend to put a lot of noise on the ground and supply lines because of the constant switching and changing involved in the scanning process. The segment driver ground is relatively quiet, since it doesn't conduct the LED currents. The digit-driver ground is noisier, and should be provided with a separate path to the PCB ground terminal, even if the PCB ground layout is gridded. The LED feed and return current paths should be laid out on opposite sides of the board like parallel flat conductors.

Figure 16. Separate ground for multiplexed LED display.

Figure 17 shows right and wrong ways to make ground connections in racks. Note that the safety ground connections from panel to rack are made through ground straps, not panel screws. Rack 1 correctly connects signal ground to rack ground only at the single reference point. Rack 2 incorrectly connects signal ground to rack ground at two points, creating a ground loop around points 1, 2, 3, 4, 1.

Breaking the "electronics ground" connection to point 1 eliminates the ground loop, but leaves signal ground in rack 2 sharing a ground impedance with the relatively noisy hardware ground to the reference point; in fact, it may end up using hardware ground as a return path for signal and power supply currents. This will probably cause more problems than the ground loop.
Figure 17. Electronic circuits mounted in equipment racks should have separate ground connections. Rack 1 shows correct grounding; rack 2 shows incorrect grounding.

**Braided Cable**

Ground impedance problems can sometimes be eliminated by using braided cable. The reduction in impedance is due to skin effect: At higher frequencies the current tends to flow along the surface of a conductor rather than uniformly through its bulk. While this effect tends to increase the impedance of a given conductor, it also indicates the way to minimize impedance—to manipulate the shape of the cross-section so as to provide more surface area. For its bulk, braided cable is almost pure surface.

Depending on the length of the cable and the actual frequencies involved, there may be situations where braided cable is not desirable. The individual strands of wire in the braided cable may present a high inductance to RF and actually impede current flow. For high-power RF applications, it is usually best to use a wide copper strap.
### Glossary

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<td>Digital ground</td>
<td>Ground-line connections for nondifferential-input, paired signal wires. These wires are paired for noise-rejection purposes. The ground wire of the pair may be connected to an individual ground connection or to a common ground connection.</td>
</tr>
<tr>
<td>Data signal ground</td>
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<td>Analog signal ground</td>
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<tr>
<td>Signal common</td>
<td>A return conductor (usually low current) common to several circuits.</td>
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<tr>
<td>Power common</td>
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<tr>
<td>Common return</td>
<td></td>
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<tr>
<td>RF return</td>
<td>The path or paths that RF energy uses to return to its source (such as an RF generator). RF energy is a surface phenomenon and may travel over the surface of insulated wires, chassis, frames, floors, or equipment faces. Special methods must be used to ensure that there is a solid earth-ground in systems that produce or use RF energy.</td>
</tr>
<tr>
<td>Ground</td>
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<tr>
<td>Earth ground</td>
<td>A terminal intended to ensure, by means of a special connection, the grounding (earthing) of part of an apparatus when properly connected to an earth electrode.</td>
</tr>
<tr>
<td>Grounding conductor</td>
<td>The conductor that is used to establish ground and that connects a piece of equipment or device to the ground electrode.</td>
</tr>
<tr>
<td>Ground electrode</td>
<td>A conductor, group of conductors, mat, or grid, in intimate contact with the earth for the purpose of providing a connection with ground. This electrode determines the lowest ground potential for an electrical system.</td>
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<td>Ground loop</td>
<td>A potentially detrimental loop formed when two or more points in an electrical system that are normally at ground potential are connected by an additional conducting path.</td>
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<tr>
<td>Earth resistivity</td>
<td>A measurement of the electrical resistance of a unit volume of soil. The common unit of measure is the ohm-meter, which is the resistance measured between faces of a cubic meter of soil by driving ground electrodes into the earth 1 m apart to a depth of 1 m.</td>
</tr>
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<td>Conducted interference</td>
<td>Interference resulting from conducted radio-frequency noise, switching spikes, lightening strikes, or conducted electrical noise (produced by the operation of other equipment) that enters equipment by direct coupling.</td>
</tr>
<tr>
<td>Radiated interference</td>
<td>Interference resulting from radiated electromagnetic energy that enters equipment.</td>
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<td>Impedance</td>
<td>Symbol, Z. Unit, ohm (Ω). The total opposition offered by a circuit to the flow of ac current. It may be expressed as a vector sum of resistance (the &quot;real&quot; part) and reactance (the &quot;imaginary&quot; part), or as a magnitude and phase angle. Capacitive reactance increases as frequency decreases; inductive reactance increases as frequency increases.</td>
</tr>
<tr>
<td>Resistance</td>
<td>Symbol, R. Unit, ohm (Ω). The simple opposition to current flow. The &quot;real&quot; part of impedance. Defined as that factor by which the mean-square conduction current must be multiplied to determine the corresponding power lost by dissipation as heat or other permanent radiation loss of electromagnetic energy from the circuit.</td>
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Parting Thoughts

The references by Ott and by White were the main sources of information for the original article from which most of the material in this note was taken. According to that article, reference 4 "is probably the finest treatment currently available on the subject."

Courses and seminars on the subject of electromagnetic interference are given regularly throughout the year. Information on these can be obtained from:

IEEE Electromagnetic Compatibility Society

- EMC Education Committee
  345 East 47th Street
  New York, NY 10017
  Phone: (212) 752-6800

- Don White Consultants, Inc.
  International Training Centre
  P. O. Box D
  Gainesville, VA 22055
  Phone: (703) 347-0030

The EMC Education committee has available a videotape: "Introduction to EMC — A Video Training Tape," by Henry Ott. Don White Consultants offers a series of training courses on many different aspects of electromagnetic compatibility. Most organizations that sponsor EMC courses also offer in-plant presentations.

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References


7. TranZorb Quick Reference Guide. General Semi-conductor Industries, P.O. Box 3078, Tempe, AZ 85281.


Warranty Claims

Advanced Energy® products are warranted to be free from failures due to defects in material and workmanship for 12 months after they are shipped from the factory (please see warranty statement, below, for details).

In order to claim shipping or handling damage, you must inspect the delivered goods and report such damage to AE within 30 days of your receipt of the goods. Please note that failing to report any damage within this period is the same as acknowledging that the goods were received undamaged.

For a warranty claim to be valid, it must:
- be made within the applicable warranty period
- include the product serial number and a full description of the circumstances giving rise to the claim
- have been assigned a return authorization number (see below) by AE Customer Service

All warranty work will be performed at an authorized AE service center (see list of contacts at the front of the manual). You are responsible for obtaining authorization (see details below) to return any defective units, prepaying the freight costs, and ensuring that the units are returned to an authorized AE service center. AE will return the repaired unit (freight prepaid) to you by second-day air shipment (or ground carrier for local returns); repair parts and labor will be provided free of charge. Whoever ships the unit (either you or AE) is responsible for properly packaging and adequately insuring the unit.

Authorized Returns

Before returning any product for repair and/or adjustment, call AE Customer Service and discuss the problem with them. Be prepared to give them the serial number of the unit and the reason for the proposed return. This consultation call will allow Customer Service to determine if the unit must actually be returned for the problem to be corrected. Such technical consultation is always available at no charge.

Units that are returned without authorization from AE Customer Service and that are found to be functional will not be covered under the warranty (see warranty statement, below). That is, you will have to pay a retest and calibration fee, and all shipping charges.

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AE’s products are continually changing as ways to improve them are discovered. AE is happy to upgrade older units so that they reflect recent improvements. The fee for upgrading a unit will be a percentage of the current list price, based on the age of the unit. Such an upgraded unit will carry a 6-month warranty (which will be added to any time remaining on the original warranty). Contact Customer Service for specifics on getting an older unit upgraded to the current revision level.

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The seller makes no express or implied warranty that the goods are merchantable or fit for any particular purpose except as specifically stated in printed AE specifications. The sole responsibility of the Seller shall be that it will manufacture the goods in accordance with its published specifications and that the goods will be free from defects in material and workmanship. The seller’s liability for breach of an expressed warranty shall exist only if the goods are installed, started in operation, and tested in conformity with the seller’s published instructions. The seller expressly excludes any warranty whatsoever concerning goods that have been subject to misuse, negligence, or accident, or that have been altered or repaired by anyone other than the seller or the seller's duly authorized agent. This warranty is expressly made in lieu of any and all other warranties, express or implied, unless otherwise agreed to in writing. The warranty period is 12 months after the date the goods are shipped from AE. In all cases, the seller has sole responsibility for determining the cause and nature of the failure, and the seller’s determination with regard thereto shall be final.
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