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THE ADVANCED ENERGY® PDW 2200 GENERATOR

User Manual

PN: 5706007-B
October 1991

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THE ADVANCED ENERGY® PDW 2200 GENERATOR

User Manual

ADVANCED ENERGY INDUSTRIES, INC

1600 Prospect Parkway
Fort Collins, Colorado 80525
(303) 221-4670
Telex #45-0938

PN: 5706007-B
October 1991

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all others	contact your local service center—see the list on the next page

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AE Service Centers

Company Name	Phone/Fax Numbers
Vacutec AB Sweden	46 (0) 40-437270 ***Fax:*** 46 (0) 40-435538
Gambetti Kenologia snc Italy	39 (02) 9055660 ***Fax:*** 39 (02) 9052778
Segen Technologies, Ltd. Israel	972 (03) 9363106 ***Fax:*** 972 (03) 9362030
Zeus Co., Ltd. Korea	82 (02) 577-3181 ***Fax:*** 82 (02) 576-3199
Schmidt Scientific Taiwan	886 (02) 5013468 ***Fax:*** 886 (02) 25029692

Returning Units for Repair

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.

If you return a unit without first getting authorization from Customer Service, and that unit is found to be functional, you will have to pay a retest and calibration fee, and all shipping charges.

Upgrading Units

AE will upgrade older units for a fee (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).

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WARNING

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

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 user.

This equipment produces potentially lethal high-voltage, high-current, radio frequency (RF) 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**.



DANGER! All personnel who work with or who are exposed to this equipment must take precautions to protect themselves against serious or possibly fatal bodily injury.

DO NOT BE CARELESS AROUND THIS EQUIPMENT.

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CONGRATULATIONS ...

On your purchase of AE's PDW pulsed generator, designed for hard use in a vacuum environment. Advanced circuit design and calibrated instrumentation make these units the most accurate, most efficient, and most versatile in the world today.

Since 1981, AE's power supplies and controllers have been contributing to a broad range of advanced technological processes such as semiconductor fabrication, optical coating, printed circuit manufacturing, glass coating, and data storage media plating. In the United States, Europe, and Asia, Advanced Energy Industries, Inc., is known for its quality products and strong customer support.

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READ THIS PAGE!

We know that some of you want to start the PDW now and that you don't feel you have the time to read the entire manual. Below is a list of the subsections you will need to read in order to get started. We also think that you will find Overview of the Manual (page iii) and Interpreting the Manual (page v) useful. They are very short sections, and are intended to 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 the type conventions (what it means when a word appears in capitalized italic type, for instance), and what the three icons (symbols) mean.

- Physical specifications 1-15
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OVERVIEW OF THE MANUAL

The main table of contents is an outline of the major topics covered in the manual. It contains only the chapter titles and the major sections 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. Throughout the manual, the chapter titles are printed at the top right-hand corner of each odd-numbered page.

When you turn to a chapter, you will find a detailed table of contents that lists each subheading in the chapter. This will show you which page contains the information you are looking for.

Part 1, Getting to Know Your PDW Generator, contains two chapters: What It Is and How It Works. What It Is describes the PDW's basic features and specifications, and discusses four typical applications.

How It Works contains a functional block diagram, a description of the front panel control and status indicators, and important information on connectors and signal descriptions.

Part II, Operating Your PDW Generator, also contains one chapter: Preparing for Use. This chapter provides information on unpacking, cooling, making connections, and testing.

Part III, Learning More About Your PDW Generator, contains a detailed description of grounding techniques.

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INTERPRETING THE MANUAL

Type Conventions

To help you quickly pick out what is being discussed, the manual presents certain words and phrases in type that is different from the rest of the text.
Pin and line names appear in capitalized italics (*X OTMP.D).* Labels that are on the PDW (switches, indicators, etc.) appear in boldface capital letters (**POWER**). Connector names begin with a capital letter (User connector). Functions are printed in boldface lowercase letters (**on/off**).

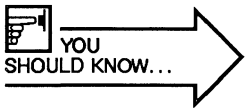
How to Use the Symbols



Safety notes. Important safety information concerning potential harm to people.



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



Operating notes. More thoughts on how to use the extended features provided.

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Hook-up and interfacing notes. General practices concerning input and output power connections, or used in connecting communication and control interfaces.



Service notes. General practices to be used in maintaining this equipment in top running condition.

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PART I

GETTING TO KNOW YOUR PDW GENERATOR

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PART I

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GENERAL DESCRIPTION

The PDW 2200 plasma generator supplies from 0-2200 W of power at a fixed frequency of 400 kHz. The RF output is sinusoidal, and at full rated power, all harmonics are 50 dB below the power level of the fundamental. The PDW is well suited to chemical vapor deposition (CVD), etching, dielectric sputtering, plasma polymer systems, and other applications where a pure high-power waveform is desired at this frequency. The PDW's precise control of power optimizes electrical moding, specific specie production, control of stress, and gas transport interactions.

The PDW's power-conversion technique stores virtually no energy at the output, and, with proper system shielding techniques, produces little EMI/RFI. The PDW is equipped with a standard internal power line filter.

The PDW arc-suppression circuit turns off RF power in less than 1 μs. This fast response, combined with the very low stored energy at the output, eliminates direct damage and particulate contamination. The PDW operates continuously into a load mismatch range without harm; in such cases load power is reduced.

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TYPICAL APPLICATIONS

The next pages contain illustrations and discussions of special considerations for four typical applications of the PDW generator.

The PDW should be properly grounded through its input power ac ground. Additionally, you must take care that the cable shielding is connected properly. This is the best way to minimize, if not eliminate, EMI (electromagnetic interference) problems. In some cases, EMI will cause chattering valves or other erratic behavior.

The PDW is designed to exceed U.S. and European standards for radiated and conducted emissions. Radiated emissions are generally caused by improper equipment installation. That is, a well designed plasma chamber, with good shielding and grounding, will not radiate emissions. Refer to Part III and page 3-7 of this manual for further details related to grounding and shielding.

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Plasma Etching/Deposition

This figure shows a typical chamber configuration for plasma etching and plasma deposition systems. This system could be either single wafer or batch.

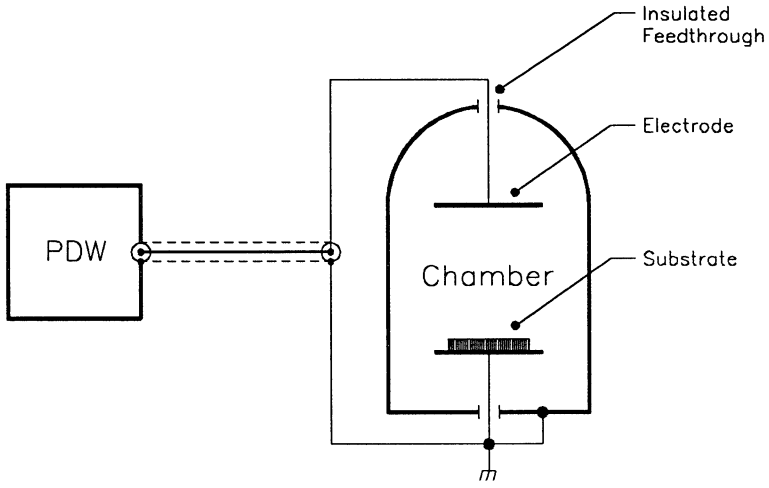


Figure 1-1. Typical configuration for plasma etching/deposition.

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Reactive Ion Etching

This illustration shows a typical configuration for reactive ion etching. Having a powered lower electrode instead of a powered upper electrode presents no unique electrical hook-up problems. The same care regarding good RF grounding and good mechanical connections is required in this application as is required in any application.

This application typically involves lower pressures than are used for plasma etching, and hence it has a different impedance. With lower pressure also comes the potential for a more difficult "strike voltage."

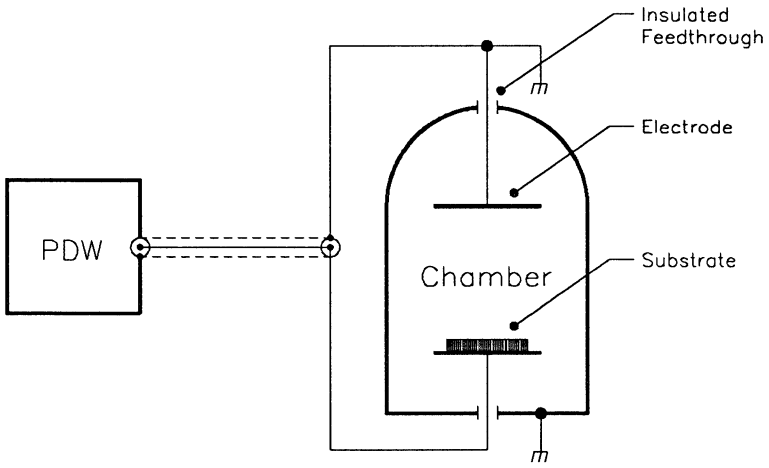


Figure 1-2. Typical configuration for reactive ion etching.

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RF Sputtering

This illustration shows a typical sputtering application, where the target shield, substrate, and chamber walls are referenced to ground. This could be a planar magnetron or an "S" gun installation.

Improper grounding of the PDW will result in EMI, which is often evidenced in this application by chattering valves or by computers and process instrumentation behaving erratically. Refer to page 3-7 and Part III for more information on making connections and grounding.

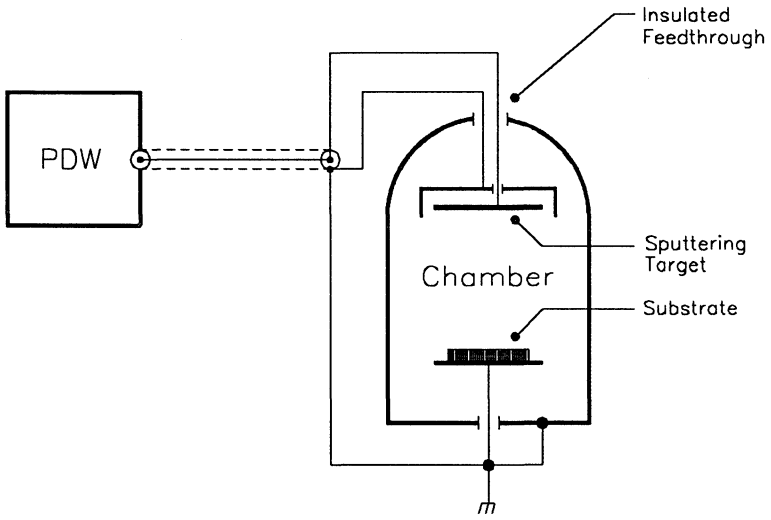


Figure 1-3. Typical configuration for RF sputtering.

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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 such as the PDW.

In this application, proper installation of the RF generator is critical to proper operation of the system. Proper installation includes good, solid RF grounding and dc installation. Refer to Part III for more information on grounding.

A blocking filter should be used to isolate the dc supply from the RF energy supplied by the PDW. The PDW should also be protected from external dc bias sources. See figures 1-4 and 1-5 for further details. Contact Advanced Energy Industries, Inc., or your representative for specific application assistance.

The purpose of this type of installation is to elevate the potential on the biased substrate or target. With proper installation and programming, the PDW will be able to control the developed dc bias on the substrate.

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.

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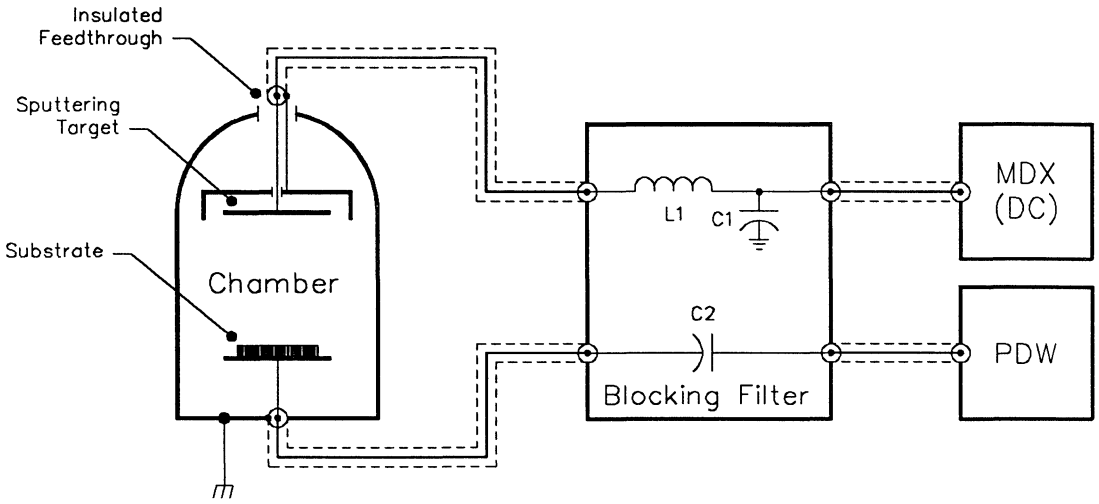


Figure 1-4. Typical configuration for dc sputtering with RF bias on the substrate.

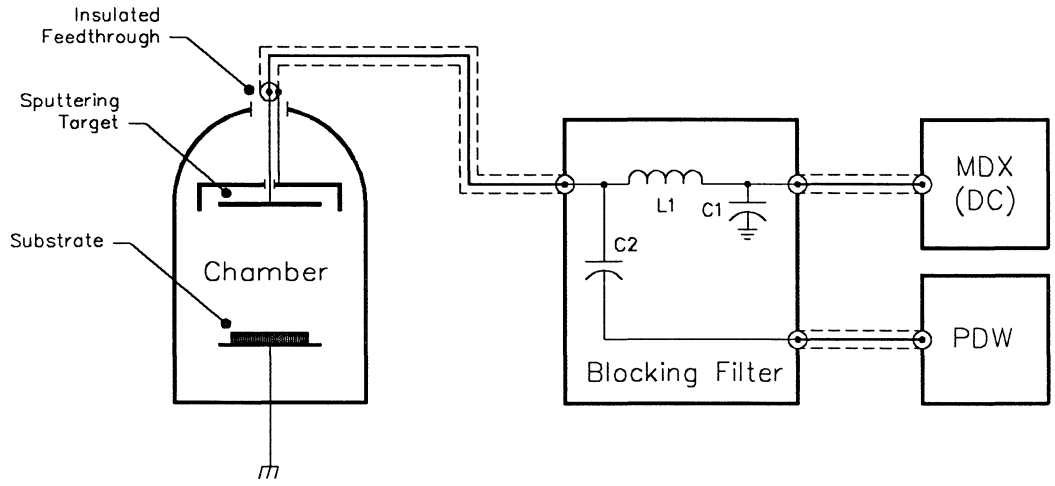


Figure 1-5. Typical configuration for combined dc and RF on the same electrode.

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SPECIFICATIONS

Functional Specifications

Methods of Output Regulation	The PDW regulates output based on either forward power or load power. In forward power regulation, the forward power measured at the output connector remains constant. In load power regulation, the forward power measured at the output connector can vary to keep the power dissipated in the load constant.
Power Measurements	The PDW measures and displays reflected power, and depending on the regulation mode, either forward or load power.
Fault Conditions	Three conditions cause the PDW to shut off output power: overtemperature, line fault, and arc (if **arc latch** is active). See page 2-17 for information on the arc-latch switch.
Limit Conditions	Limit conditions require attention, but do not shut off output power. They serve as diagnostic tools to let you know why the unit cannot reach setpoint. They are indicated by LEDs on the front panel. The four conditions are voltage limit, current limit, reflected power limit, and load limit.

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Physical Specifications

Frequency	400 kHz; accuracy is ±0.005%.
Output Power	2200 W maximum (50-Ω load).
Output Impedance	50 Ω.
Power Control Range	1% to 100%.
Power Regulation (Load or Forward)	Less than 1% of the setpoint or 3 W, whichever is greater, for loads not exceeding 2:1 VSWR.
Power Accuracy (Load or Forward)	User port signal will be within 1% or 3 W, whichever is greater. Scale factor is 10 V for 2200 W.
Reflected Power	440 W maximum.
Reflected Power Accuracy	User port signal will be within ±2% or 3 W, whichever is greater. Scale factor is 10 V for 440 W.
Ac Line Regulation	7.5% change in line voltage produces less than 0.25% change in output power.
Output Voltage	400 V ac rms maximum.
Harmonics	At full rated output, all harmonics are greater than 50 dB below the fundamental output frequency when operated into a 50-Ω load.
Load Mismatch Tolerance	Continuous operation into any load mismatch without failure or oscillation.

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Load Mismatch Limits	The following limits (measured at the output connector) protect the generator from damage due to load mismatch: Peak RF current: 8 ± 0.4 A Peak RF voltage: 400 ± 20 V Reflected power: 440 ± 20 W.
Input Requirements	208 V ac +10% or -15%, 50/60 Hz, three phase, 8.9 A per phase.
Internal Power Dissipation	550 W maximum.
Weight	53 lb. (24 kg).
Size	8.72" (H) x 16.75" (W) x 21" (D) (22.2 cm x 42.6 cm x 53.3 cm).
Ambient Temperature:	
Operating	Minimum 0°C, maximum 40°C (maximum value of average over 24 hr.: 35°C). If the units are enclosed in cabinets, the operator will ascertain the temperature at the place of installation and ensure that the maximum ambient temperature is not exceeded.
Storage	Minimum -25°C, maximum 55°C.
Transportation	Minimum -25°C, maximum 55°C (for short periods of up to 24 hrs., the maximum is 70°C).
Coolant (Water) Temperature	Minimum 5°C, maximum 35°C.

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Coolant Flow Parameters:

Volume	30 gph minimum
Pressure	100 psi maximum; minimum pressure is that differential pressure, from input to output, needed to provide minimum flow volume.
Contamination	Water used as a coolant medium should meet the following specifications:

pH between 7 and 9
total chlorine <20 ppm
total nitrate <10 ppm
total sulfate <100 ppm
total dissolved solids <250 ppm
total hardness expressed as calcium carbonate equivalent <250 ppm
specific resistivity of 2500 Ω per centimeter or higher at 25°C
as a rule of thumb, total dissolved solids (TDS) can be estimated from:

$$TDS = \frac{640{,}000}{specific\ resistivity\ (\ in\ ohms\ per\ centimeter\ )}$$

Humidity 15-85% relative humidity; no condensation or icing.

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).

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THEORY OF OPERATION

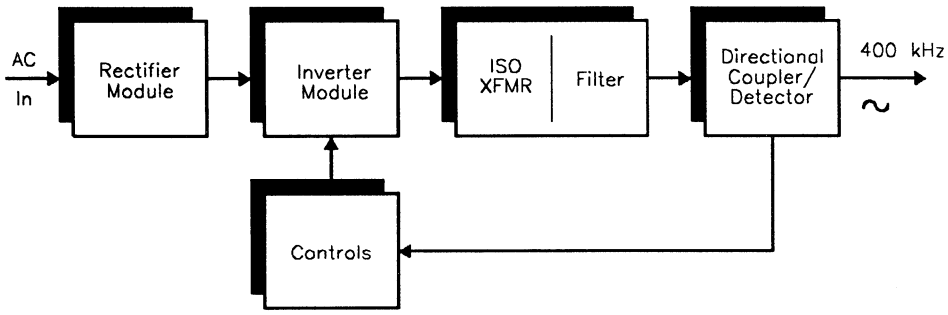


Figure 2-1. PDW block diagram.

The PDW efficiently creates sinusoidal voltage waveforms by switching rectified dc power through a filter and an isolation transformer. A directional coupler/detector samples the RF power signal and uses the signal to control the switch waveforms and therefore the output power. Depending upon the method of regulation, either the detected forward power or the computed load power can be used as a control signal.

Rectifier Module

The full wave bridge rectifier converts the ac input voltage into a steady dc signal. This power is provided directly to the inverter module.

Inverter Module

The inverter module is composed of a set of switches which are either fully on or fully off. When the switches are on, very little voltage drop occurs across them. When they are off, virtually no current flows through them. Since the power dissipated in a switch is the product of the voltage across and the current through the device, neither case represents a large power loss. This makes the power supply very efficient.

Isolation Transformer

The inverter module produces a waveform with substantial energy at the fundamental switching frequency, which is set to be the desired output frequency. This waveform goes to the isolation transformer.

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The isolation transformer isolates both the output of the inverter module and the low-voltage control signal from the output power line. It also transforms the impedance to a standard 50-Ω level.

Filter

The filter is a combination of inductors and capacitors especially designed to pass only the frequency of interest and reject other frequencies (i.e., a bandpass filter). The output of the filter therefore is a nearly perfect sine wave. This wave is then delivered to the directional coupler/detector.

Directional Coupler/Detector

The directional coupler/detector samples the voltages and currents in the RF power line and determines the forward and reflected power. These quantities can be thought of as the power flowing toward the load and the power reflected back from the load, respectively. Forward power minus reflected power is the power dissipated in the load and is called the load power. (See page 2-15 for more information on forward, reflected, and load power.) The directional coupler/detector produces analog signals proportional to all three quantities and uses them, through a feedback control loop, to control the power supply output.

The PDW uses sophisticated circuitry to compensate for, or eliminate, offsets and non-linearities inherent in the power sampling and detection process. As a result, the control signals (and hence the output power) generated in this section are accurate and linear. Forward, reflected, and load power levels are displayed on the front panel and are provided at the User connector.

Controls

The control section controls the switches that regulate the output power. It has limit and trip circuits that prevent switch failure. It also supervises communications with the front panel and the User connector.

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CONNECTORS

Input Power Connector

The ac line input connection is provided by means of a three-wire (plus ground), 10-A, Hirschmann connector.

Output Power Connector

The type N female output connector on the PDW rear panel mates with a standard type N male plug and RG-8 coaxial cable. The protective cover over the output connector is interlocked so that the PDW will not operate if you remove the cover.

User Connector

The 25-pin, D subminiature, User connector is located on the PDW rear panel. The pin-description table on the next page gives a brief description of each pin; for a more detailed discussion, see page 3-9. ***Note:*** An ".A" appended to a pin name indicates an analog signal; a ".D" indicates a digital signal.

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Pin-description Table

Pin	Name	Description	Refer to
1	*X MPWR RET.D*	maximum power return, negative output, used with *pin 14*	p. 3-9
2	*X RPWR.A*	reverse power sense, positive output, used with *pin 15*, 0-10 V	p. 3-9
3	*X LFPWR.A*	load and forward power sense, positive output, used with *pin 16,* 0-10 V	p. 3-9
4	*X RFONC.D*	RF power on command, positive input, used with *pin 17*	p. 3-9
5	*X STPT.A*	setpoint control, positive input, used with *pin 18*, 0-10 V	p. 3-9
6	*X 24 PRO*	24 V dc unregulated supply	p. 3-9
7	*X RFON RET.D*	RF on indicator return, positive output, used with *pin 20*	p. 3-10
8	unassigned		
9	*X OTMP RET.D*	overtemperature return, negative output, used with *pin 22*	p. 3-10
10	*X INTLK.D*	interlock loop, positive input, used with *pin 23*	p. 3-10
11	*X LEVSEL.D*	load and forward power level select, negative input	p. 3-10

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Pin	Name	Description	Refer to
12	unassigned		
13	unassigned		
14	*X MPWR.D*	maximum power limit, positive output, used with *pin 1*	p. 3-10
15	*X RPWR REF.A*	reverse power sense reference, negative output, used with *pin 2*	p. 3-11
16	*X LFPWR REF.A*	load and forward power sense reference, negative output, used with *pin 3*	p. 3-11
17	*X RFONC RET.D*	RF **power on** command return, negative input, used with *pin 4*	p. 3-11
18	*X STPT REF.A*	setpoint control reference, negative input, used with *pin 5*	p. 3-11
19	*X PS RET.D*	chassis ground, power supply return	p. 3-11
20	*X RFON.D*	RF on indicator, positive output, used with *pin 7*	p. 3-11
21	*X PS RET.D*	chassis ground, power supply return	p. 3-11
22	*X OTMP.D*	overtemperature indicator, positive output, used with *pin 9*	p. 3-11
23	*X INTLK.D*	interlock loop, negative input, used with *pin 10*	p. 3-12
24	*X 5V PRO*	5 V dc supply	p. 3-12
25	unassigned		

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FRONT PANEL DESCRIPTION

Status LEDs

PDW functions can be monitored by checking the five green status LEDs on the front panel.

Status LED	Function
POWER	Lights to indicate that line power is on and that the auxiliary supply is working properly.
INTERLOCK	Lights to indicate that all system interlock conditions are satisfied. RF power cannot be turned on unless the **INTERLOCK** LED is on. To satisfy the interlock string the following conditions must be met: 1. The safety cover over the RF output connector on the rear panel must be in place. 2. The 34-pin flat ribbon cable between the logic PCB and the directional coupler PCB must be connected. 3. The impedance between the two interlock pins (*10* and *23*) on the User connector must be less than 880 Ω. See the signal descriptions for *pins 10* (page 3-10) and *23* (page 3-12) for additional interlock information.
OUTPUT	Lights to indicate the RF output is enabled. In the event of an overtemperature or line fault the **OUTPUT** LED turns off (and RF is disabled) until the fault is reset. Reset by taking *pin 4 (RFONC.D)* to the inactive state for at least 10 ms before returning it to the active state. For more information on *pin 4*, see the signal descriptions on page 3-9.
PLASMA	Lights to indicate that over 2% (44 W) of the maximum rated output power is being delivered to the load (normally indicates plasma ignition).

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Status LED	Function
AT SETPOINT	Lights to indicate that actual output power is within 1% of power setpoint. The desired power level is set through the User connector. The PDW measures the actual output power at the output connector. If the desired level and the actual level are within 1% of each other, the unit is operating within setpoint and the **AT SETPOINT** LED lights. If the desired output level exceeds 44 W and the **OUTPUT** status indicator is lit, but the **AT SETPOINT** and **PLASMA** status indicators fail to light, a high-impedance load condition exists. Make sure the output cable is connected and the chamber's gas mixture, pressure, and temperature are correct.

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Limit LEDs

The limit indicators are yellow LEDs used for troubleshooting.

Limit LED	Function
VOLTAGE	Lights to indicate that the impedance of the load is too high for the PDW to deliver power at the programmed setpoint. Tuner range must be expanded.
CURRENT	Lights to indicate that the impedance of the load is too low for the PDW to deliver power at the programmed setpoint. Tuner range must be expanded.
REFL POWER	Lights to indicate that the load is too reactive for the PDW to deliver power at the programmed setpoint. Tuner range must be expanded.
LOAD	Lights to indicate that the load is too reactive for the PDW to deliver power at the programmed setpoint. Tuner range must be expanded.

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Fault LEDs

The fault indicators are yellow LEDs used for troubleshooting.

Fault LED	Function
ARC	Lights to indicate a very low load impedance. This is usually caused by a chamber arc. The PDW arc fault circuitry can be programmed in two ways using the arc-latch switch (**SW1**). 1) When the switch is in the latching position (**C1**), an arc condition turns off output power in less than 1 µs. The **ARC** LED lights to indicate the arc. Output remains off and the LED remains on until reset. Reset by taking *pin 4 (RFONC.D)* to the inactive state for at least 10 ms before returning it to the active state. For more information on *pin 4*, see the signal descriptions on page 3-9. ***Note:*** The PDW is shipped from the factory with the switch in the latching position (**C1**). 2) When the switch is in the non-latching (**C2**) position, an arc condition turns the output power off for 100 ms. After 100 ms, power turns back on. The **ARC** LED lights to indicate the arc and remains lit until reset. Reset by taking *pin 4 (RFONC.D)* to the inactive state for at least 10 ms before returning it to the active state. For more information on *pin 4*, see the signal descriptions on page 3-9. See page 2-17 for more information on the arc-latch switch.

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Fault LED	Function
OVERTEMP	Lights to indicate that the PDW has reached an excessive temperature (above 45°C). The output power will turn off and remain off until the overtemperature condition clears and *pin 4 (RFONC.D)* is reset. Reset by taking *pin 4* to the inactive state for at least 10 ms and then returning it to the active state. For more information on *pin 4*, see the signal descriptions on page 3-9.
LINE	Lights to indicate that the input line voltage is outside the specified range (more than 10% higher than 208 V ac or 15% lower than 208 V ac). If output power is on, it will turn off and will remain off until the input line voltage returns to the specified range and *pin 4 (RFONC.D)* is reset. Reset by taking *pin 4* to the inactive state for at least 10 ms and then returning it to the active state. For more information on *pin 4*, see the signal descriptions on page 3-9. If RF is off, the three-phase input contactor will open and output power will be inhibited until the line voltage returns to the specified range. With output RF at maximum power, check the input line to make sure voltage is within the specified range.

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Bar Graph Indicators

Bar Graph	Function
FORWARD/LOAD POWER	Indicates either forward or load power depending on the state of *pin 11 (X LEVSEL.D)*. The green 10-segment logarithmic graph displays values from 69.57 W to 2200 W (0 dB to -15 dB). For more information on *pin 11*, see page 3-10.
REFLECTED POWER	Indicates reflected power. The yellow 10-segment logarithmic graph displays values from 13.91 W to 440 W (0 dB to -15 dB).

Control Switch

Switch	Function
POWER	**OFF** turns the auxiliary power supply off. However, power is still supplied to the internal cooling fan and the line filter. Placing the circuit breaker in the off position removes all power from the unit. **ON** turns the auxiliary supply on. The **POWER** status LED turns on. The **INTERLOCK** LED will also light if the interlock loop is satisfied.

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REGULATION

The PDW can regulate power based on either forward or load power measurements. The method used by the PDW is determined by the User *pin 11 (X LEVSEL.D)*. This digital input signal is connected to a 4.7-kΩ pulldown resistor. An open or ground signal programs the generator to regulate output based on forward power; the forward power measured at the output connector will remain constant. The inactive (open or ground) level must be less than 0.5 V dc. A voltage of 5.2 V dc to 4.5 V dc on this pin with respect to chassis ground programs the generator to regulate output based on load power; the forward power will vary to keep the power dissipated in the load constant. This signal should be referenced against *X PS RET.D (pins 19, 21)*.

The front panel meter displays forward power if the method of output regulation is forward power, and load power if the method of output regulation is load power.

The following discussion defines forward, reflected, and load power.

Forward and Reflected Power

In a mismatched system (the load impedance does not match the connecting cable impedance), there will always be a standing wave on the connecting cable. You can imagine this standing wave as being created by the interference of two travelling waves, one moving toward the load and one returning to the generator. The power in the imagined wave moving toward the load is the "forward" power, and the power in the imagined return wave is the reverse or "reflected" power.

Mathematically, in a system with a reference (cable) impedance Z_0, forward and reflected voltages ($V_{f/r}$) and current ($I_{f/r}$) can be defined as:

$$V_{f/r} = \frac{V \pm (Z_0 I)}{2}$$

$$I_{f/r} = \frac{\left(\frac{V}{Z_0}\right) \pm I}{2}$$

The plus sign is used for forward voltage and current and the minus sign for reflected voltage and current.

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The forward and reflected powers are the product of the voltages and currents:

$P_f = V_f \times I_f$ and $P_r = V_r \times I_r$

Neither the forward nor the reflected power directly determine the process results. See the paragraph on load power below.

Load Power

The load power is the power actually dissipated in the load. If the load is not reactive, the load power is simply the voltage times the current. If the load is reactive, there will be a phase angle (θ) between the voltage and current, and the load power will be equal to $V \times I \times \cos\theta$. In terms of forward and reflected power, the load power is the forward power minus the reflected power. Generally, the important factor in a process is the load power, because by definition that is the actual power delivered to the load.

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ARC-LATCH SWITCH

The arc-latch switch (**SW1**) is a toggle switch located on the logic board that can be set in either the latching (**C1**) or non-latching position (**C2**). It is shipped from the factory in the latching position. To access the logic board, you must first remove the top cover; **SW1** is located under the ribbon cable. Figure 2-2 on page 2-18 shows the location of the switch.



WARNING! The non-latching arc shutdown feature is only recommended for applications where chamber arcs occur frequently and do not detrimentally affect the process.

Control	Description
Arc latch	**C2** (non-latching). Turns the output off for 100 ms after an arc occurs and then turns it back on. RF power will continuously turn on and off until the arc condition is removed. To indicate an arc has occurred, the **ARC FAULT** LED remains on until the unit is reset. Reset by taking *pin 4 (X RFONC.D)* to the inactive state for at least 10 ms and then returning it to the active state. For more information on *pin 4*, see the signal descriptions on page 3-9. **C1** (latching). Turns the output off if an arc occurs; the **ARC** LED lights to indicate the arc. The output remains off and the LED remains on until the unit is reset. Reset by taking *pin 4 (X RFONC.D)* to the inactive state for at least 10 ms and then returning it to the active state. For more information on *pin 4*, see the signal descriptions on page 3-9.

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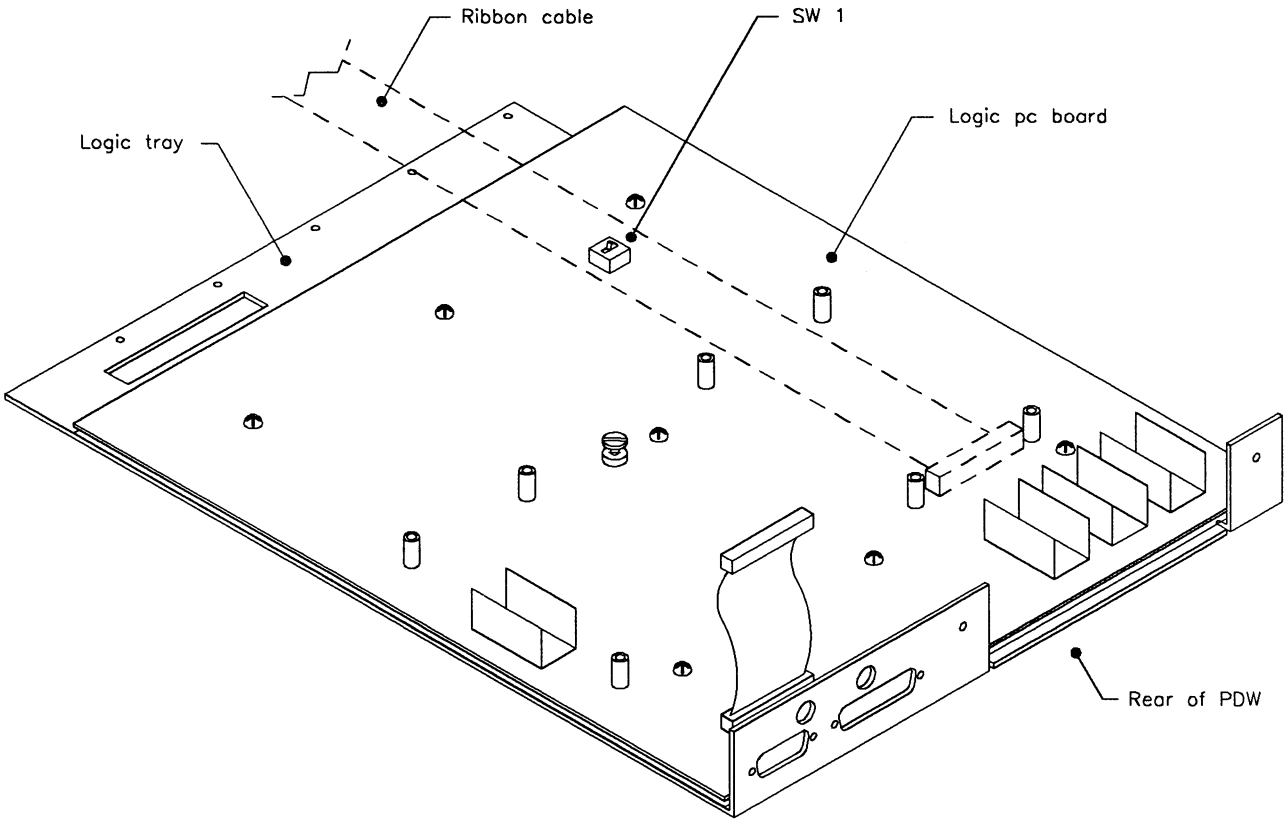
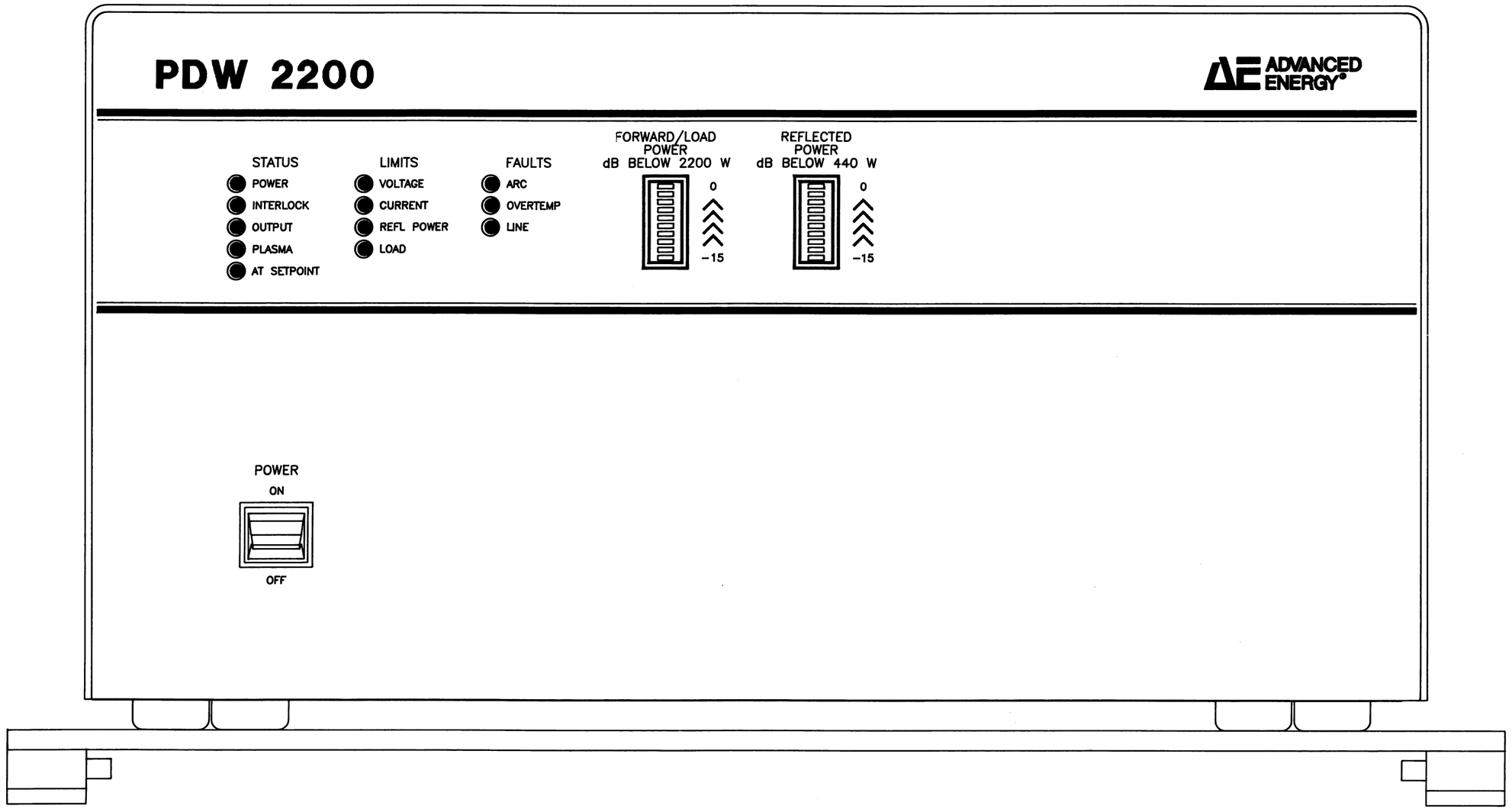


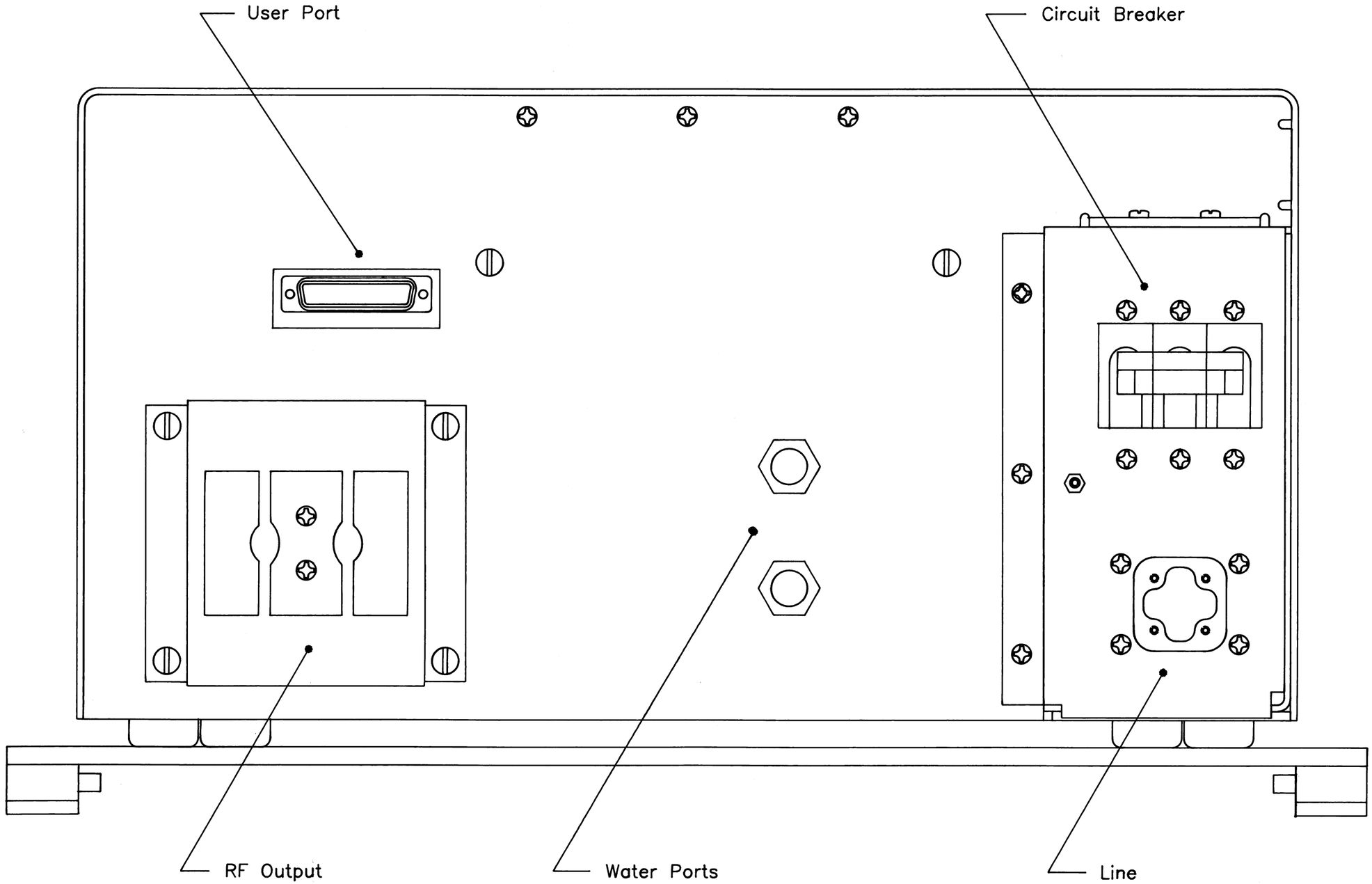
Figure 2-2. Location of SW1 on PDW logic board.

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PDW Front View

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PDW Rear View

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PART II

OPERATING YOUR PDW GENERATOR

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PART II

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SETTING UP

Unpacking

Unpack and inspect your power supply carefully. Check for obvious physical damage. 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.

Cooling Requirements

For the PDW to be sufficiently cooled, it must have adequate coolant circulation at a coolant temperature between 5°C and 35°C. Refer to the specifications on pages 1-16 and 1-17 for more details.

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MAKING REAR PANEL CONNECTIONS

Grounding

A protective earth terminal stud is located to the right of the User connector (see the foldout of the rear panel at the end of Chapter 2). Attach the ground stud to the chamber chassis ground with at least 12-gauge, stranded wire. To minimize EMI, grounding wire should be less than 6 in. long. For more information on grounding, see Part III.



DANGER! Connect the protective earth terminal on the PDW rear panel to protective earth-ground before making any other connection.



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

Connecting Input Power



WARNING! Before making any input line power connections, turn off building circuit breakers supplying 208 V ac, three-phase power to the PDW.

The PDW requires 8.9 A, 208 V ac, three-phase service. To connect the input, place the 10-A circuit breaker on the rear panel (see the foldout at the end of Chapter 2) in the off position and attach the line cord to the 208-V, three-phase source with ground.

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Connecting Output Power



WARNING! Once input connections are complete, lethal voltages are potentially present at the output connector. Be sure this connector is terminated and follow normal safety precautions when the system is operating.

The female output connector on the PDW uses a standard male type N plug (Amphenol part #82-530) and standard RG-8U coaxial cable. To reduce radiated electromagnetic interference (EMI), shield the RF cable and connect the shield to the chamber ground.

Before making any RF output connections, make sure that the PDW rear panel circuit breaker is off.

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Configuring the User Connector

A 25-pin male, D subminiature, insulated connector provides the User interface for the PDW. A detailed description of each signal begins below. ***Note:*** An ".A" appended to a pin name indicates an analog signal; a ".D" indicates a digital signal.

Signal Descriptions

Pin 1. X MPWR RET.D. This digital output signal is the emitter terminal of an opto-coupler. The collector of the opto-coupler is connected to *pin 14 (X MPWR.D)*. See *pin 14* for the signal description.

Pin 2. X RPWR.A. This 0-10 V dc analog output signal, in conjunction with *pin 15 (X RPWR REF.A)*, monitors the reverse (reflected) power. It is scaled to represent 0-440 W. Accuracy is ±2% of level between 440 W and 150 W. Below 150 W accuracy is ±3 W. See Fig. 3-6 on page 3-15.

Pin 3. X LFPWR.A. This 0-10 V dc analog output signal, in conjunction with *pin 16 (X LFPWR REF.A)*, monitors the level of either the load or forward power. (*Pin 11 (X LEVSEL.D*) selects load or forward power.) It is scaled to represent 0-2200 W. Accuracy is ±1% of level between 2200 W and 300 W. Below 300 W the accuracy is ±3 W. See Fig. 3-6 on page 3-15.

Pin 4. X RFONC.D. This digital input signal is connected to the anode of an opto-coupler through a 1-kΩ resistor. The cathode is connected through a 1-kΩ resistor to *pin 17 (X RFONC RET.D)*. RF power will be enabled when a minimum of 5 mA current flow is provided from *pin 4* to *pin 17*. The maximum allowed current is 15.8 mA. RF power will be disabled when the current flow is reduced below 200 μA. See Fig. 3-2 on page 3-13.

Pin 5. X STPT.A. This 0-10 V dc analog input signal, in conjunction with *pin 18 (X STPT REF.A*), controls the level of the output power. It is scaled to represent 0-2200 W. Accuracy is ±1% of level between 2200 W and 300 W. Below 300 W the accuracy is ±3 W. A signal of less than 50 mV ± 20 mV (11 ± 4.4 W) will produce 0 W of RF output. See Fig. 3-5 on page 3-15.

Pin 6. X 24 V PRO. This supply voltage output is a source of unregulated voltage between 22 V dc and 30 V dc. Source impedance

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is 510 Ω. Average output current is limited to 20 mA. This output is referenced to chassis ground, *X PS RET.D (pin 12 or pin 19*). See Fig. 3-7 on page 3-16.

Pin 7. X RFON RET.D. This digital output signal is the emitter terminal of an opto-coupler. The collector of the opto-coupler is connected to *pin 20 (X RFON.D*). See *pin 20* for the signal description.

Pin 8. Unassigned.

Pin 9. X OTMP RET.D. This digital output signal is the emitter terminal of an opto-coupler. The collector of the opto-coupler is connected to *pin 22 (X OTMP.D)*. See *pin 22* for the signal description.

Pin 10. X INTLK.D. This digital input signal is connected to 15 V dc through a 1-kΩ resistor. This signal must be connected to the other interlock signal, *pin 23 (X INTLK.D*), with less than 880 Ω to satisfy the interlock requirements. A resistance greater than 1.32 kΩ will not satisfy the interlock requirements. A broken interlock string prevents RF from being turned on. If the interlock is opened when *X RFONC.D* is active, RF turns off and the front panel **INTERLOCK** LED goes out. To restore RF power, first, satisfy the interlock requirements. Second, reset the power on command by taking *pin 4 (X RFONC.D*) to the inactive state for at least 10 ms and then returning it to the active state. See Fig. 3-3 on page 3-14.

Pin 11. X LEVSEL.D. This digital input signal is connected to a 4.7-kΩ pulldown resistor. A voltage of 5.2 V dc to 4.5 V dc on this pin with respect to chassis ground programs the generator to regulate output based on the load power. An open or ground signal programs the generator to regulate output based on forward power. The inactive (open or ground) level must be less than 0.5 V dc. This signal should be referenced against *X PS RET.D (pins 19, 21*) See Fig. 3-4 on page 3-14. For more information on load and forward power regulation, see page 2-15.

Pin 12. Unassigned.

Pin 13. Unassigned.

Pin 14. X MPWR.D. This digital output signal is the collector terminal of an opto-coupler. The emitter terminal is connected to *pin 1 (X MPWR RET.D*). A low impedance between *pin 1* and *pin 14* indicates that the generator cannot produce the power requested by the *X STPT.A* control voltage (between *pins 5* and *18*). The front panel

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display **AT SETPOINT** LED turns off whenever this signal is active (low impedance). The maximum sink current is limited to 12 mA. The maximum differential voltage between *pin 14* and *pin 1* is 45 V dc. The minimum differential voltage is -0.5 V dc. The maximum common mode voltage between *pin 14* and *pin 1* to chassis ground is ±50 V. See Fig. 3-1 on page 3-13.

Pin 15. X RPWR REF.A. Reference for *pin 2 (X RPWR.A).*

Pin 16. X LFPWR REF.A. Reference for *pin 3 (X LFPWR.A*).

Pin 17. X RFONC RET.D. This digital input signal is connected to the cathode of an opto-coupler through a 1-kΩ resistor. The anode is connected through a 1-kΩ resistor to *pin 4 (X RFONC.D*). See *pin 4* for the signal description.

Pin 18. X STPT REF.A. Reference for *pin 5 (X STPT.A).*

Pin 19. X PS RET.D. This reference signal is a dedicated ground that returns to the internal system ground, then to chassis ground, and finally to protective earth ground. *Pin 6 (X +24 V PRO), pin 24 (X +5 V PRO), and pin 11 (X LEVSEL.D*) should be referenced to this pin. Same as *pin 21.*

Pin 20. X RFON.D. This digital output signal is the collector terminal of an opto-coupler. The emitter terminal is connected to *pin 7 (X RFON RET.D)*. A low impedance between *pin 7* and *pin 20* indicates that the RF output is enabled. The front panel display **OUTPUT** LED will be lit whenever *X RFON.D* is active (low impedance). The maximum sink current is limited to 12 mA. The maximum differential voltage between *pin 14* and *pin 1* is 45 V dc. The minimum differential voltage is -0.5 V dc. The maximum common mode voltage between *pin 20* and *pin 7* to chassis ground is ±50 V. See Fig. 3-1 on page 3-13.

Pin 21. X PS RET.D. This reference signal is a dedicated ground that returns to the internal system ground, then to chassis ground, and finally to protective earth ground. *Pin 6 (X +24 V PRO), pin 24 (X +5 V PRO), and pin 11 (X LEVSEL.D*) should be referenced to this pin. Same as *pin 19.*

Pin 22. X OTMP.D. This digital output signal is the collector terminal of an opto-coupler. The emitter terminal is connected to *pin 9 (X OTMP RET.D)*. A low impedance between *pin 9* and *pin 22* indicates that the generator has turned off RF power because of excessive

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internal temperatures (greater than 45°C). The front panel display **OVERTEMP** LED will be lit whenever, *X OTMP.D* is active (low impedance). An overtemperature fault will prevent RF from being turned on. If the overtemperature fault occurs after the *X RFONC.D* signal is active, RF will be turned off, the three-phase contactor will open, and the front panel **OVERTEMP** LED will light. To restore RF power, first, lower the internal generator temperature to below 40°C. Second, reset the power on command by taking *pin 4 (X RFONC.D)* to the inactive state for at least 10 ms and then returning it to the active state.

The maximum sink current is limited to 12 mA. The maximum differential voltage between *pin 22* and *pin 9* is 45 V dc. The minimum differential voltage is -0.5 V dc. The maximum common mode voltage between *pin 14* and *pin 1* to chassis ground is ±50 V. See Fig. 3-1 on page 3-13.

Pin 23. X INTLK.D. This digital input signal is connected to the anode of an opto-coupler through a 1-kΩ resistor. The cathode of the opto-coupler is connected to chassis ground. 15 V dc is connected through a 1-kΩ resistor to the other interlock signal, *pin 10 (X INTLK.D)*. See *pin 10* for the signal description.

Pin 24. X 5 V PRO. This supply voltage output is a source of regulated voltage between 4.8 V dc and 5.2 V dc with respect to chassis ground. Source impedance is 220 Ω. Average output current is limited to 2 mA. This output is referenced to chassis ground (*pin 12 or pin 19*). See Fig. 3-7 on page 3-16.

Pin 25. Unassigned.

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Wiring Options

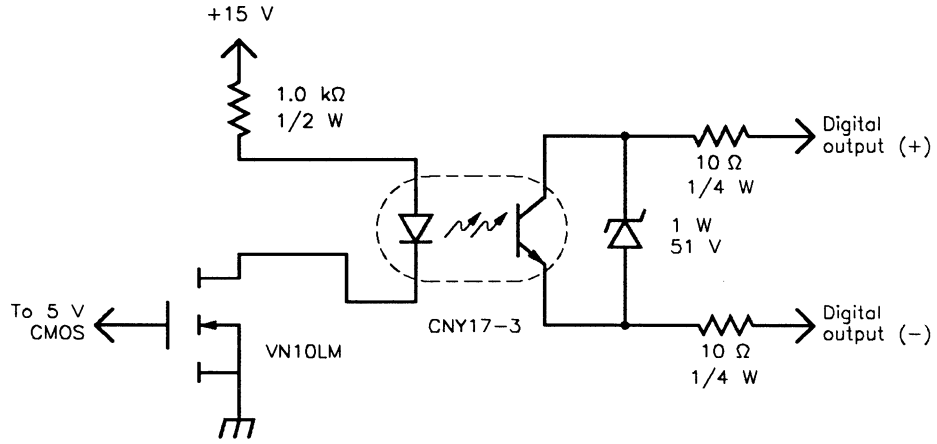


Figure 3-1. Digital output interface for pin 14 (X MPWR.D), pin 20 (RFON.D), and pin 22 (X OTMP.D).

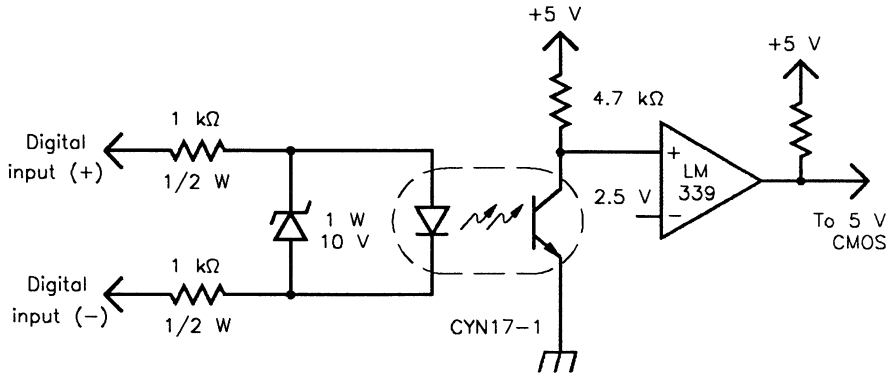


Figure 3-2. Digital input interface for pin 4 (X RFONC.D).

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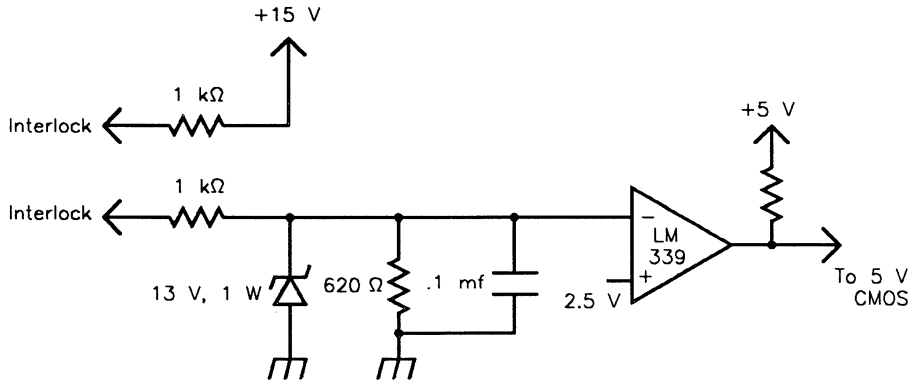


Figure 3-3. Digital input interface for pin 10 and 23 (X INTLK.D).

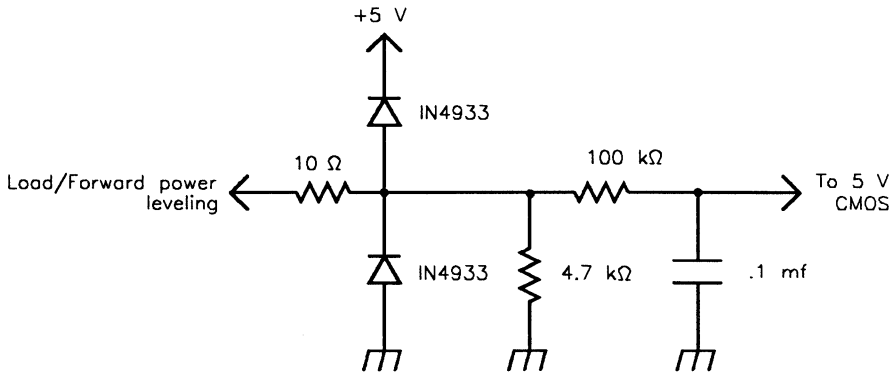


Figure 3-4. Digital input interface for pin 11 (X LEVSEL.D).

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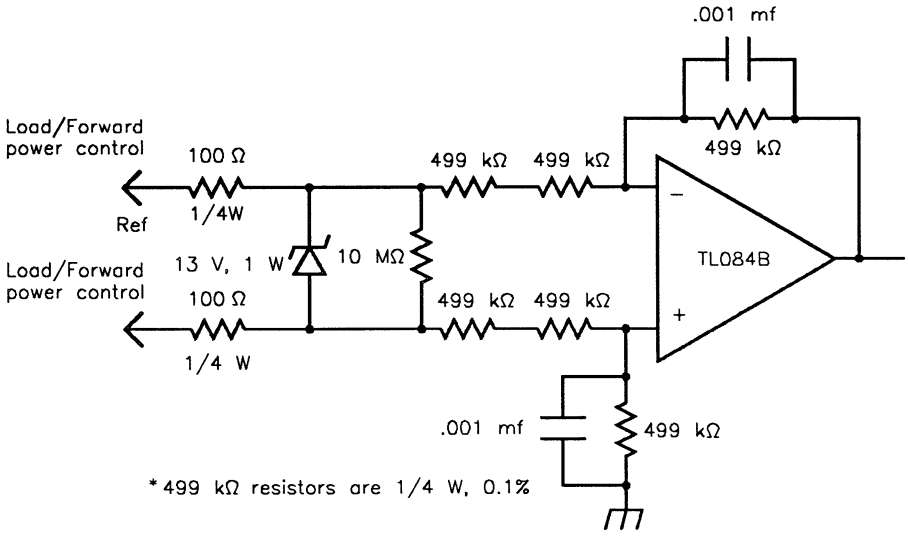


Figure 3-5. Digital input interface for pin 5 (X STPT.A).

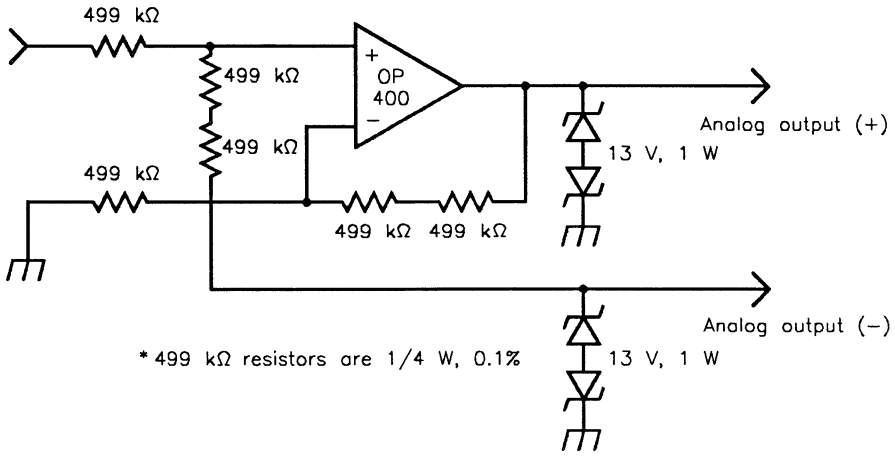


Figure 3-6. Analog output interface for pin 2 (X RPWR.A), pin 15 (X RPWR REF.A), pin 3 (X LFPWR.A), and pin 16 (X LFPWR REF.A).

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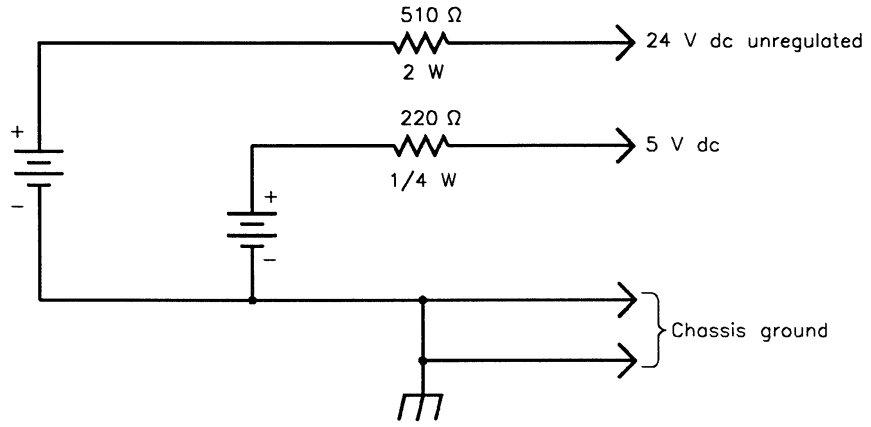


Figure 3-7. Supply voltage interface for pin 6 (X 24 PRO), pin 24 (X 5V PRO), and pin 21 (X PS RET.D).

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TESTING THE PDW

Use the following procedure during the initial inspection to verify basic operation of the PDW.

1. Connect an appropriate load to the output of the PDW. For testing the PDW you will need a 50-Ω load rated for 2200 W of RF power. An acceptable load is manufactured by Bird Corporation, Bird p/n 8329-300.



DANGER! Contact with the RF output of the PDW can cause serious injury or even death. Take care to ensure that all connections are tight before turning on RF power from the PDW.

2. Connect a suitable test box to the User connector:
a. Connect a jumper wire between *pin 10 and pin 23 (X INTLK.D* pins) to satisfy the interlock requirements.
b. Provide a setpoint voltage between *pin 5 (X STPT.A*) and *pin 18 (X STPT REF.A).* For rough testing, this voltage can be derived from *pin 6 (X 24 V PRO)* unregulated power supply with a dropping resistor, potentiometer, and zener diode. Alternatively, a precision millivolt standard may be used for accurate testing of the power supply.
c. Finally, you will need a means of turning on the PDW by providing a signal to the *pin 4 (X RFONC.D)* and *pin 17 (X RFONC RET.D).* This signal can be provided by connecting *pin 17* to chassis ground and *pin 4* through a switch to *pin 24 (X +5V PRO).* The switch will then act as an on/off switch for the PDW. Set the switch to the off (non-conducting) position.

3. Connect a suitable source of cooling water at a temperature between 5°C and 35°C.

4. Connect three-phase 208 V ac input power to the PDW input power connector.

5. Turn on the rear circuit breaker. You should hear the internal fan come on.

6. Turn on the front panel **POWER** switch. The **POWER** and **INTERLOCK** LEDs should light.

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7. Adjust the potentiometer on the test box fully counterclockwise (or set the millivolt standard, if used, to zero output).

8. Turn the switch on the test box to the **ON** (conducting) position. The **OUTPUT** LED should come on.

9. Turn the potentiometer on the test box clockwise (or advance the millivolt standard, if used) until you see the first segment light on the **FORWARD/LOAD POWER** bar graph. At this point the **PLASMA** and **SETPOINT** status LEDs should light.

10. Adjust the potentiometer on the test box (or advance the millivolt standard, if used) to any power up to 2200 W.

11. You should now be able to turn the RF on and off with the switch on the test box, and the PDW should return the requested power level automatically. A precision voltmeter connected between User connector *pin 3* and *pin 16* will read the output power accurately with a scale factor of 10 V dc equals 2200 W.

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PART III

LEARNING MORE ABOUT YOUR PDW GENERATOR

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PART III

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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.

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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.



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 acount 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 occurence is that when it is installed at a customer's site, nothing works. This is typically due to poor earth-grounding techniques.

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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

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collapses, generating transient voltages, v=L(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.

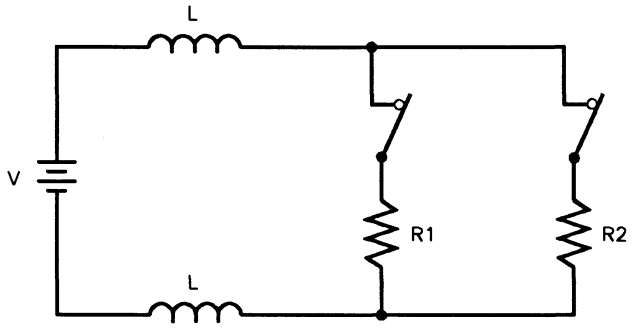


Figure 1. Supply line transients.

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.

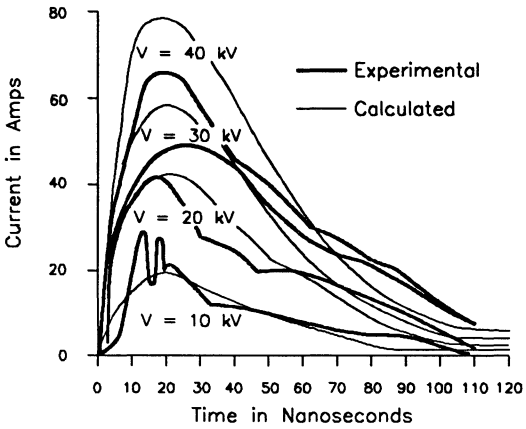
Arcs and sparks occur in plasma chambers, electron-beam systems, and magnetron sputtering systems; in associated equipment such as electric motors and switches; and in static discharges. Electric motors that have commutator bars produce an arc as the brushes pass from one bar to the next. Dc motors and 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

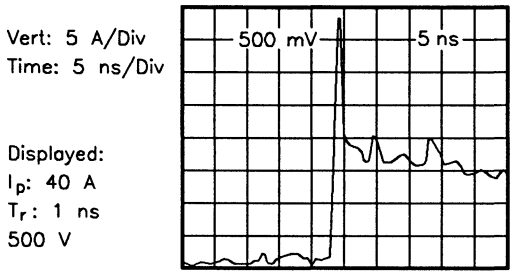
Electrostatic discharge (ESD) is the spark that occurs when a person picks up a static charge from walking across a carpet, and then discharges it into a keyboard, or whatever else can be touched. Walking across a carpet in a dry climate, a person can accumulate a static voltage of 35 kV. The current pulse

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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.



(a)



(b)

Figure 2. Waveforms of electrostatic discharge currents from a hand-held metallic object.

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

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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.

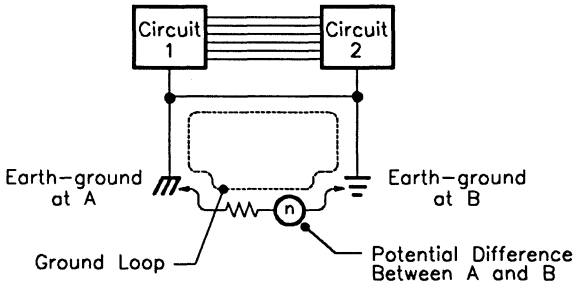


Figure 3. Illustration of a ground loop.

"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.

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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.



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

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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

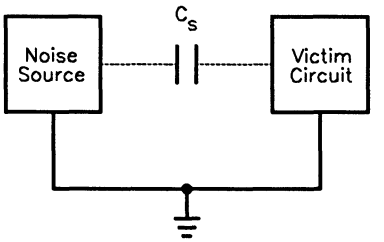
Capacitive coupling involves the passage of interfering signals through mutual or stray capacitances that aren't shown on the circuit diagram, but which the experienced engineer knows are there. Capacitive coupling to your body is what would cause an unstable oscillator to change its frequency when you 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

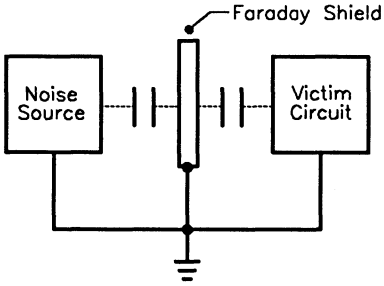
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ground rather than acting as feedback and crosstalk elements. Besides, from a mechanical point of view, grounding it is almost inevitable.

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.



(a) Capacitive Coupling



(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: $v = NA(dB/dt)$, where in this case $N = 1$ and A is the area of the current loop in the victim circuit.

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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.

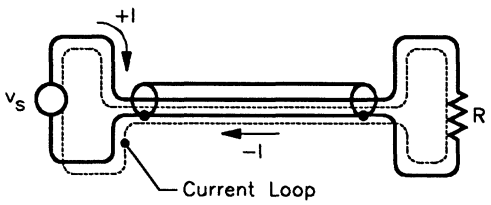
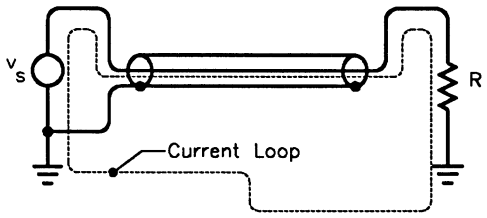


Figure 5. External to the shield, $\phi = 0$

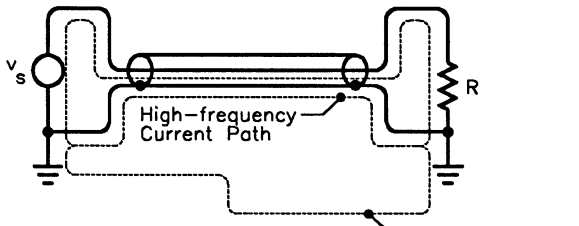
In the real world, both the signal source and the receiving load are likely to have one end connected to a common signal ground. In that case, should the cable be grounded at one end, both ends, or neither end? The answer is that it should be grounded at both ends. Figure 6A shows the situation when 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%.)

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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.

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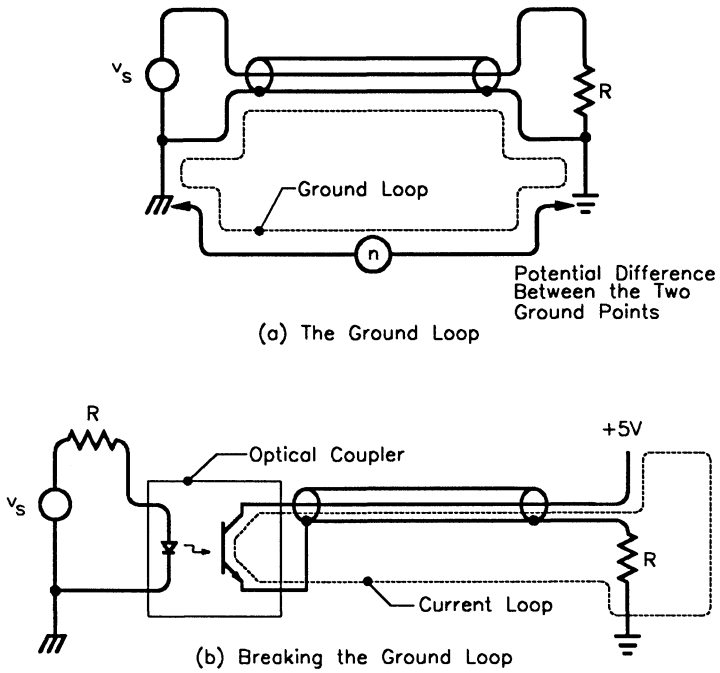


Figure 7. Use of optical coupler.

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

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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 1MHz 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.

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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 (ω) of the impinging EMI field, and on the permeability (μ) and conductivity (σ) of the shielding material. These loss mechanisms vary approximately as follows:

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

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

Where:

t = 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.

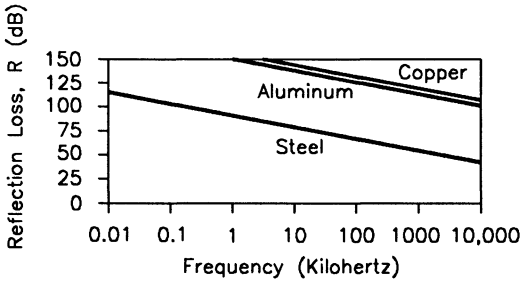


Figure 8. E-field shielding.

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

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decrease in conductivity, as can be seen in Fig. 9. This figure also shows the effect of shield thickness.

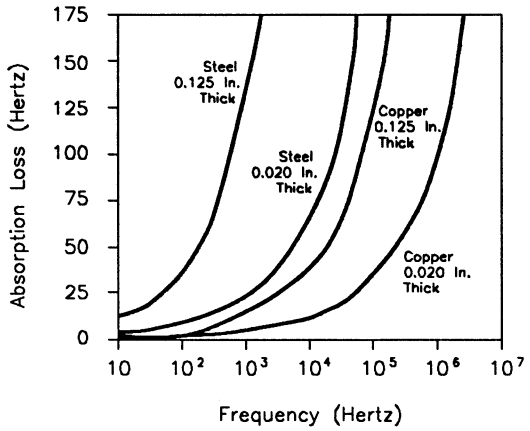


Figure 9. H-field shielding.

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.

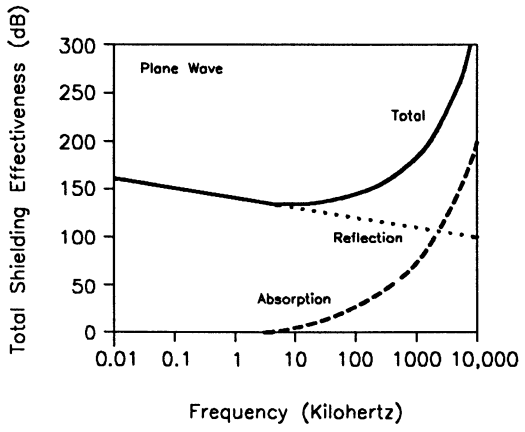


Figure 10. E- and H-field shielding.

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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.

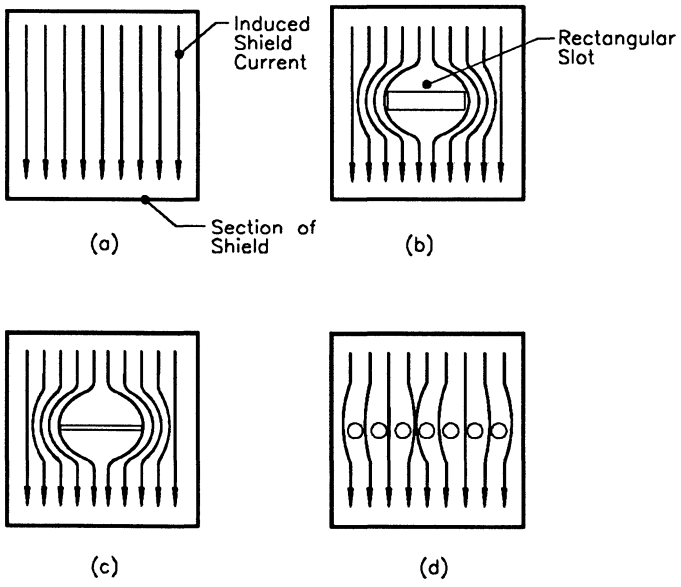


Figure 11. Effect of shield discontinuity on magnetically induced shield current.

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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.

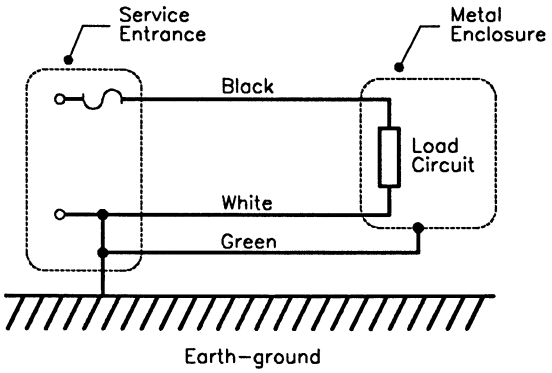


Figure 12. Single-phase power distribution.

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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).

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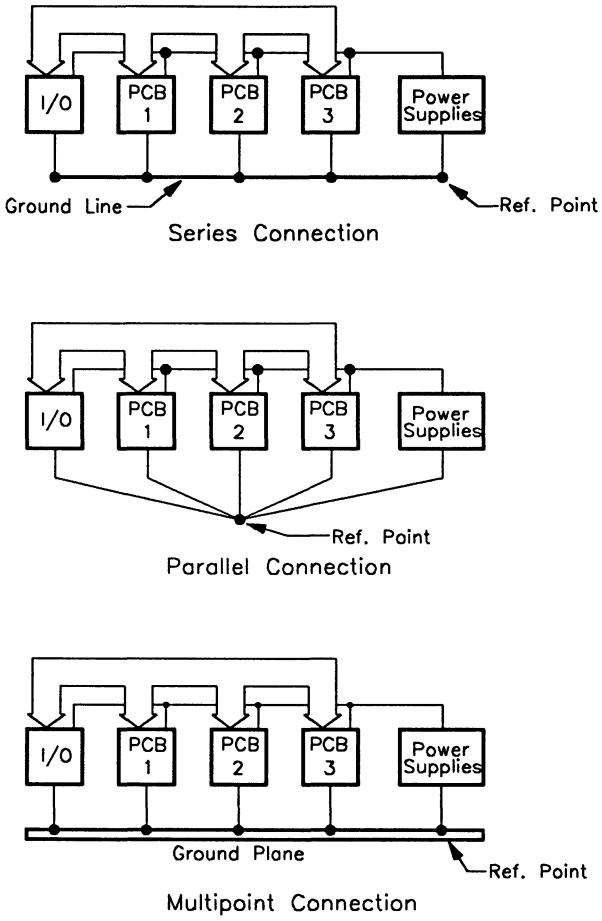


Figure 13. Three ways to wire the grounds.

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.

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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.

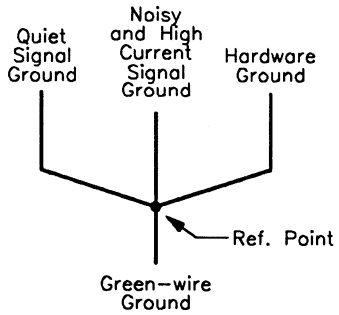


Figure 14. Parallel connection of series grounds.

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.

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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.

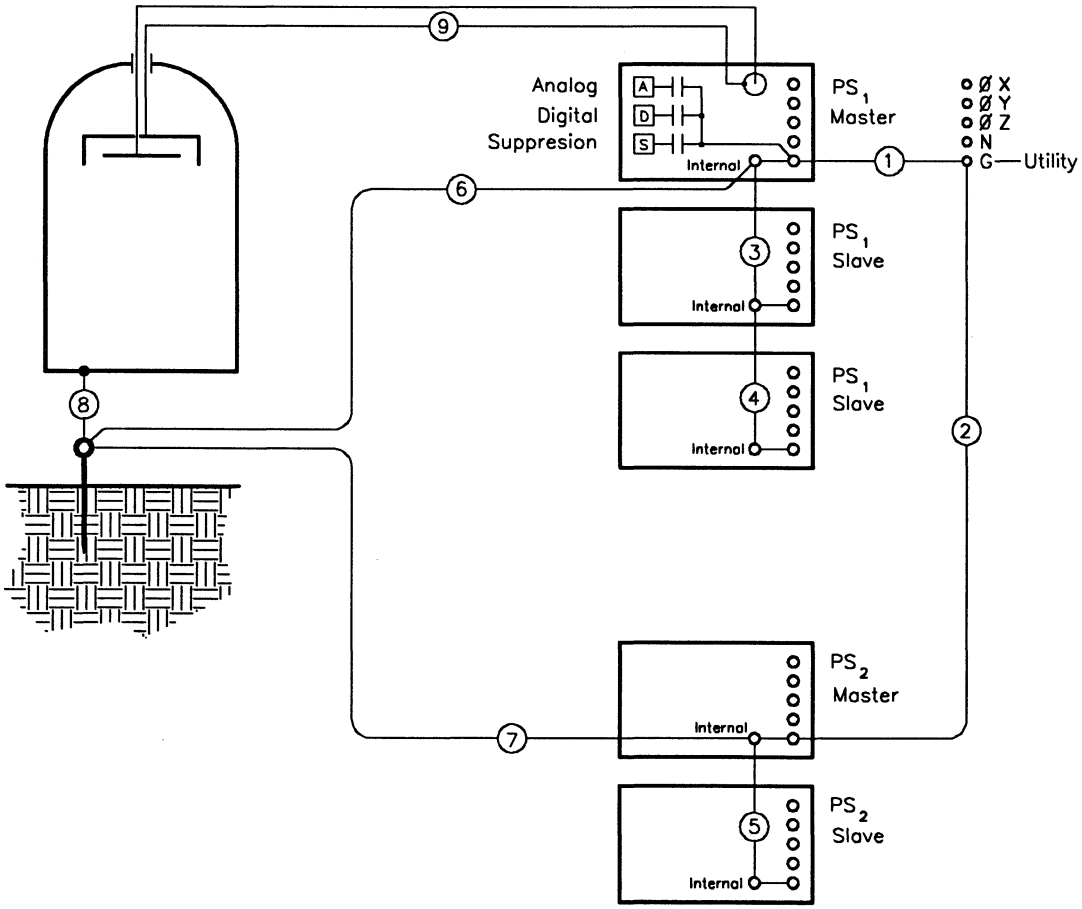


Figure 15. Grounding connections for power supplies in a process system.

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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.

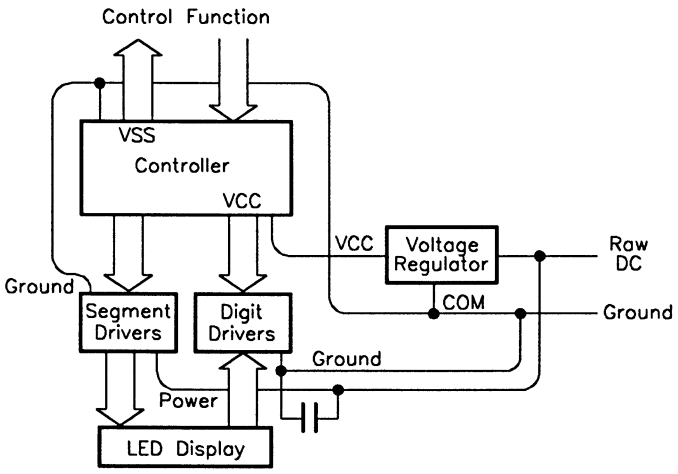


Figure 16. Separate ground for multiplexed LED display.

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.

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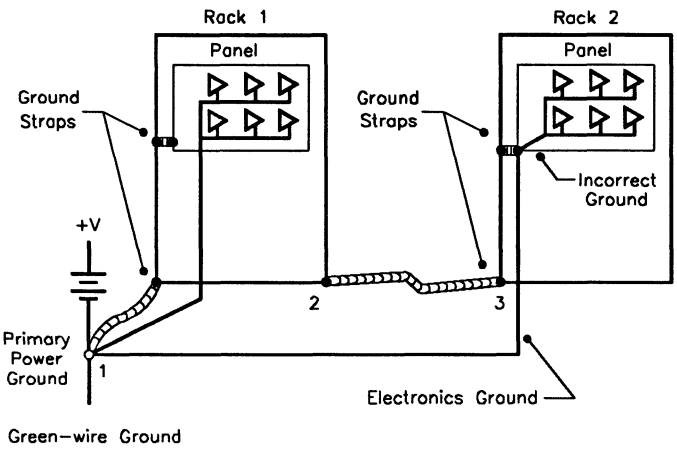


Figure 17. Electronic circuits mounted in equipment racks should have separate ground connections. Rack 1 shows correct grounding; rack 2 shows incorrect grounding.

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.

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Glossary

Digital ground Data signal ground Analog signal ground	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.
Signal common Power common Common return	A return conductor (usually low current) common to several circuits.
RF return	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.
Ground Earth ground	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.
Grounding conductor	The conductor that is used to establish ground and that connects a piece of equipment or device to the ground electrode.
Ground electrode	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.
Ground loop	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.

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Earth resistivity	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.
Conducted interference	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.
Radiated interference	Interference resulting from radiated electromagnetic energy that enters equipment.
Impedance	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 "real" part) and reactance (the "imaginary" part), or as a magnitude and phase angle. Capacitive reactance increases as frequency decreases; inductive reactance increases as frequency increases.
Resistance	Symbol, R. Unit, ohm (Ω). The simple opposition to current flow. The “real” 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.

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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 22065
  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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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.

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- 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.

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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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REV	RFC	DESCRIPTION OF CHANGE	ORIG/DATE	CHK/DATE	APP/DATE
A	-	ORIGINAL ISSUE		JD	
B	-	RES. ADD. CHANGE VALUES	RL		
C	-	U22 DG411 WAS DG211, C213-219,221,228-236 WERE DSS310. C237,230,243 WERE .1, C239-242 WERE DSS310.	DILLON	LAWLESS	CCC
D	PDP 23	C7 OPEN WAS 53PF 500V, R12 10K WAS 510. R11 240 WAS 510.	DILLON	LAWLESS	MWT
E	PDP 38	C92 OPEN WAS .001PF ON SHEET 3.	LAWLESS	ANDERS	CCC
F	PDP 52	ADDED: NOTE 3 ON SHEET 1, DESIGNATOR FOR NOTES 3 ON SHEETS 1 & 3. ADDED: TO DISPLAY NOTE ON SHEET 4.	LAWLESS	DILLON	MWT
G	PDP 79	CHANGED U6 FROM 74HC04 TO 74HC14, ADDED .001UF CAP ACROSS R9.	6/19/92	PP	MR	MR
H	PDP 98	U15A, U14B & U15B, TSC426 WAS TSC246.	8/10/92	EM	GWP	MWT
J	PDP 94	R121, 33.2K WAS 10K; R102, 1K WAS 10; C124, .015 WAS .01 R42, 142, 143, 144, 147, 148 AND 161, 33.2K WAS 33K SH12 - R133 AND 134 33.2K WAS 33K.	10/29/92	EM	PP	MT
K		CONVERTED TO TANGO, ADDED CIRCUITRY ON SHEET 2.	11/30/92	PP	MT	MT
L	RFC 7721	C5 WAS 20PF AND C6 WAS .01 ON PAGE 4	5/8/95	LRM	PP	CC

NOTES: UNLESS OTHERWISE SPECIFIED
1) ALL RESISTANCE VALUES ARE IN OHMS, 1/4W , MF, 1%.
2) ALL CAPACITANCE VALUES ARE IN MICROFARADS, .100V
3) USED WITH 2306058B.
4) PARENT SCHEMATIC SCH6058
5) ALL REF DES WITH 'B' AS A PREFIX ARE INSTALLED ON SOLDER SIDE.

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Fri Jul 07 1995 09:22:01 5036023L.S02

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REV	RFC	DESCRIPTION OF CHANGE	ORIG/DATE	CHK/DATE	APP/DATE
		SEE SHEET 1.			

SH1 REF PWR 5V=440W

SH1 FWD PWR 5V = 3

SH4 VF- R13 499K 1% MF, R30 1.00K, R29 499K 1% MF

SH4 VF+ R14 499K 1% MF, C25 15PF 1KV, R31 1.00K, R32 MF 1% 499K

C26 15PF 1KV

U10:A TL084BCN

R28 10.0K

U10:B TL084BCN

C57 1000PF 50V 1N4148 CR10

U10:D TL084BCN

C56 1000PF 50V CR11 1N4148

U10:C TL084BCN

+5VREF

R53 523, R54 49.9K, R59 523

C58 0.1, C59 0.1

U22:C DG411DJ

SH4 VR- R15 499K 1% MF, R35 1.00K, R34 499K 1% MF

SH4 VR+ R16 499K 1% MF, C27 15PF 1KV, R36 1.00K, R37 MF 1% 499K

C28 15PF 1KV

U11:A TL084BCN

R33 10.0K

U11:B TL084BCN

C61 1000PF 50V CR12 1N4148

U11:D TL084BCN

C60 1000PF 50V CR13 1N4148

U11:C TL084BCN

U22:D DG411DJ

C92 OPEN

Y2 6.00MHZ

C108 .01 50V

C145 0.1, Z5 47K (D0 D1 D3 D5 D6)

Z4 47K (D7 D8 D9 D10 D12) C144 0.1

Z3 10K (D2 D4 D11) C110 0.1

Z6 10K (DB0 DB1 DB2 DB3 DB4 DB5 DB6 DB7) C157 0.1

P1, R137 4.75K CAL/

C113 0.1, C116 10 50V, C143 35V 2.2, C130 0.1, C112 0.1

C156 0.1

U29 ML2233

C115 2.2 35V, C114 2.2 35V, C111 0.1

U35 27C256-150

C183 0.1, C182 10 50V, C179 10 50V, C178 0.1

WJ20 WJ19 WJ18 WJ21

U40 AD7237

R159 200K, R160 200K, R2 10.0K, R1 10.0K, C1 0.1

U1:A OP200GP

C142 0.1

U34 GAL22V10

R108 4.75K

U26:B 74HC04, U26:C 74HC04

WATCHDOG SH2

DC RESET* SH4

SH2 RESET*

Fri Jul 07 1995 09:22:31 5036023L.S03

DO NOT SCALE	SIGNATURE	DATE
UNLESS OTHERWISE SPECIFIED ALL DIMENSIONS ARE IN INCHES INTERPRET PER ANSI Y14.5M-1982 PERFECT ORIENTATION AT MMC REQUIRED FOR RELATED FEATURES	ORIGINATOR C. CAMUS	
	CHECKED DEANGELIS	3/28/91
	APPROVED C.CAMUS	5/26/91
	PARTS TO BE FREE OF BURRS BREAK ALL EDGES	
TOLERANCES: .XX = ±.020 .XXX = ±.010 > = ±.05 X/X = ±1/32 ∠ = ±1°	MANAGIT #	
	TITLE BLOCK REVISION G	

TITLE: PDW LOGIC SCHEMATIC

DRAWING NUMBER D 5036023 REV L

SCALE NTS SHEET 3 OF 4

ADVANCED ENERGY (R)

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REV	RFC	DESCRIPTION OF CHANGE	ORIG/DATE	CHK/DATE	APP/DATE
		SEE SHEET 1.			

J5 — TO V-PHASE SWITCHCARD: N.C., G DR PWR, G DR COM, VOADR, VOARTN, VOBDR, BOVRTN, VOCT-, VOCT+, N.C.

J6 — TO F-PHASE SWITCHCARD: N.C., G DR PWR, G DR COM, FOADR, FOARTN, FOBDR, FOBRTN, FOCT-, FOCT+, N.C.

J2 — TO LEFT CHASSIS: NC, CNKTR, BUS OK, N.C., +24V, GND, GND, GND, -24V, +5VREF, G DR PWR, G DR COM

J4 — TO RF FILTER: +5V, 0RFF, 1RFF, 2RFF, 3RFF, 4RFF, 5RFF, 6RFF, 7RFF, GND, FLT V FB, NC, NC, NC

J3 — TO DIRECTIONAL COUPLER: +15V, IFB, VF+, VF-, VR+, VR-, VFB, +5V, DC RESET*, +5VREF, NC, -5V, GND, -15V; R17 1.00K, R18 1.00K

J7 — TO DISPLAY: +15D, +15D, POWER GND, POWER GND, REF PWR, LN FLT*, FWD PWR, O TEMP*, LD LMT*, ARC*, RPWR LMT*, I LMT*, V LMT*, SETPNT*, PLASMA*, OUTPUT*, INTLK*, 3.57 VDREF, POWER GND, POWER GND, POWER GND, POWER GND, POWER GND, POWER GND, POWER GND, POWER GND; REF PWR DIS, LN FLT*, FWD PWR DIS, O TEMP*, LD LMT*, ARC*, RPWR LMT*, I LMT*, V LMT*, SETPNT*, PLASMA*, OUTPUT*, INTLK*, +3.57 VDREF; C195 0.1

J1 — OPEN COVER GND, OPEN COVER SIG, OT SIG, OT GND; MNT3 OPEN COVER GND, OPEN COVER SIG, OT SIG

POWER PINS

+15V — R6 4.02K, CR1 LM329CZ, R5 17.4K, 10K R4, R3 57.6K, C18 0.1, R21 100, U1:B OP200GP, R20 100, Q1 2N3904, R23 100 2W 5% CC, C33 0.1, C34 16V 10, +5VREF

+5VREF — R72 10.0K, R71 24.9K, U19:C TL084BCN, R73 100, +3.57 VDREF

+5V — C10 0.1, R19 100

+15V — C76 0.1, U22:E DG411DJ, C91 0.1, C90 0.1, -15V

+15V — C181 0.1, C180 0.1, C129 0.1, C109 0.1

+5V — C66 0.1, U17:B LT1016CN, C67 0.1, -5V

SPARES

U12:E 74HC86N; U41:F 4049BP; U26:F 74HC04; U4:F 74HC04; U2:B 74AC74; U13:B 4078; SW1:A; U5:D 74HC00; U42:D 4011BP; U42:C 4011BP; U42:B 4011BP

U10:E, U11:E, U19:E, U27:E, U47:C OP200GP; U28:E, U36:E, U30:E, U38:E LM339N, U37:E LM339N, U21:C OP200GP; U30:B, U19:B, U28:B TL084BCN; U41:G 4049BP, U23:E 74HC86N, U3:G 74HC04, U15:C TSC426, U14:C TSC426, U16:E 74HC00; U9:C 74HCT393; U7:E 74HC00, U4:G 74HC04, U26:G 74HC04, U2:C 74AC74, U5:C 74HC00, U42:E 4011BP, U6:G 74HC14; U1:C OP200GP, U18:B LM311N, U20:C TL288CP, U25:C TL288CP

XI RF PWR ON+ — R163 1K 1/2W 5% CF, CR58 10V, C229 22000PF
XI RF PWR ON- — R162 1K 1/2W 5% CF, C214 22000PF
XI RF ON+ — R176 10.0, CR69 1N4757 51V, C232 22000PF
XI RF ON- — R175 10.0, C217 22000PF
XI OTEMP+ — R165 10.0, CR63 1N4757 51V, C233 22000PF
XI OTEMP- — R177 10.0, C218 22000PF
XI RPWR — R187 499K 1% MF, R188 499K 1% MF, R189 499K 1% MF, OP200GP U47:B, R186 499K 1% MF, R185 499K 1% MF, R184 499K 1% MF
XI INTLK- — CR78 1N4744 15V, CR84 1N4743 13V, C244 1000PF 50V, C242, CR77 1N4744 15V, CR83 1N4744 15V, C243 1000PF 50V, C241, CR82 1N4744 15V, R178 1.00K, C219 22000PF, R182 1.00K, C234 22000PF, CR64 1N4743 13V
XI STPT*+ — C196 0.1, CR67 1N4757 51V, C197 0.1, R164 510 2W 5% CC, C230 22000PF, C215 22000PF
XI STPT*- — R172 10.0, CR76 1N4757 51V, C213 22000PF, R183 10.0, C228 22000PF
XI LOAD REG — C199 0.1, CR66 1N4933, C236 22000PF, R181 210, R180 10.0, C221 22000PF, R179 4.75K, CR65 1N4933
XI PWR — R169 499K 1% MF, R170 499K 1% MF, R171 499K 1% MF, OP200GP U47:A, R168 499K 1% MF, R167 499K 1% MF, R166 499K 1% MF, C198 0.1
XI SIG+ — CR85 1N4744 15V, CR86 1N4743 13V, C237 1000PF 50V, C239, C240, C238 1000PF 50V, R174 100, C231 22000PF, CR59 1N4744 15V, CR60 1N4743 13V, CR79 1N4744 15V, CR80 1N4744 15V, CR81 1N4744 15V
XI SIG- — CR68 1N4744 15V, CR61 1N4744 15V, CR62 1N4744 15V, R173 100, C216 22000PF, C220 0.1, C235 22000PF, MNT7

CR72 1N4001, HS3, VR4, LM7815 — +24V, C205 0.1, C204 10 50V, 5.0W, C207 10 50V, C206 0.1, +15D, CR73 1N4745A 16V

CR74 1N4001, HS4, VR5, LM7815 — +24V, C209 0.1, C208 10 50V, 7.0W, C211 10 50V, C210 0.1, +15V, CR75 1N4745A 16V

CR70 1N4001, HS2, VR3, 78T05 — +24V, R192 25 5W 5% WW, C202 0.1, C201 10 50V, 8.0W, C223 10 16V, C203 0.1, +5V, CR71 1N4734 5.6V

CR26 1N4001, HS1:A, VR1, LM7915 — C117 0.1, C118 10 50V, 3.0W, C119 10 50V, C120 0.1, CR27 1N4745A 16V, -24V, -15V

CR57 1N4001, HS1, VR2, LM7905 — C184 0.1, C187 10 50V, 1.0W, C186 10 16V, C185 0.1, CR56 5.6V 1N4734, -24V, -5V

C9 0.1, C96 0.1, C94 0.1, C107 0.1, C127 0.1, C189 0.1, C225 0.1, C224 0.1, C222 0.1, C200 0.1

CONNECTOR MOUNTED ON CHASSIS

J8 — I/O

7	RF POWER ON	4	
8	RF POWER ON RETURN	17	
14	RF ON	20	
13	RF ON RETURN	7	
18	OVERTEMP	22	
17	OVERTEMP RETURN	9	
3	REVERSE POWER SENSE	2	
4	REVERSE POWER SENSE REF	15	
19	+ INTERLOCK LOOP	10	
20	- INTERLOCK LOOP	23	
11	24 VDC UNREGULATED	6	
12	CHASSIS GROUND	19	
2	MAXIMUM POWER	14	
1	MAXIMUM POWER RETURN	1	
22	5VDC	24	
21	LOAD/FORWARD POWER LEVELING	11	
NC 23	NOT USED	NC 12	
NC 25	NOT USED	NC 13	
NC 24	NOT USED	NC 25	
5	LOAD/FORWARD POWER SENSE	3	
6	LOAD/FORWARD POWER SENSE REF	16	
9	SETPOINT CONTROL	5	
10	SETPOINT CONTROL REF	18	
NC 15	EXTERNAL CONTROL SELECT	NC 8	
16	CHASSIS GROUND	21	
NC 26			

DO NOT SCALE	SIGNATURE	DATE
UNLESS OTHERWISE SPECIFIED ALL DIMENSIONS ARE IN INCHES INTERPRET PER ANSI Y14.5M-1982 PERFECT ORIENTATION AT MMC REQUIRED FOR RELATED FEATURES	ORIGINATOR C.CAMUS	
	CHECKED DEANGELIS	3/28/91
	APPROVED C.CAMUS	5/26/91
TOLERANCES: .XX = ±.020 .XXX = ±.010 > = ±.005 X/X = ±.02 ∠ = ±2°	PARTS TO BE FREE OF BURRS BREAK ALL EDGES	
	MANAGIT #	
	TITLE BLOCK REVISION G	

TITLE: PDW LOGIC SCHEMATIC

D | DRAWING NUMBER 5036023 | REV L

SCALE NONE | SHEET 4 OF 4

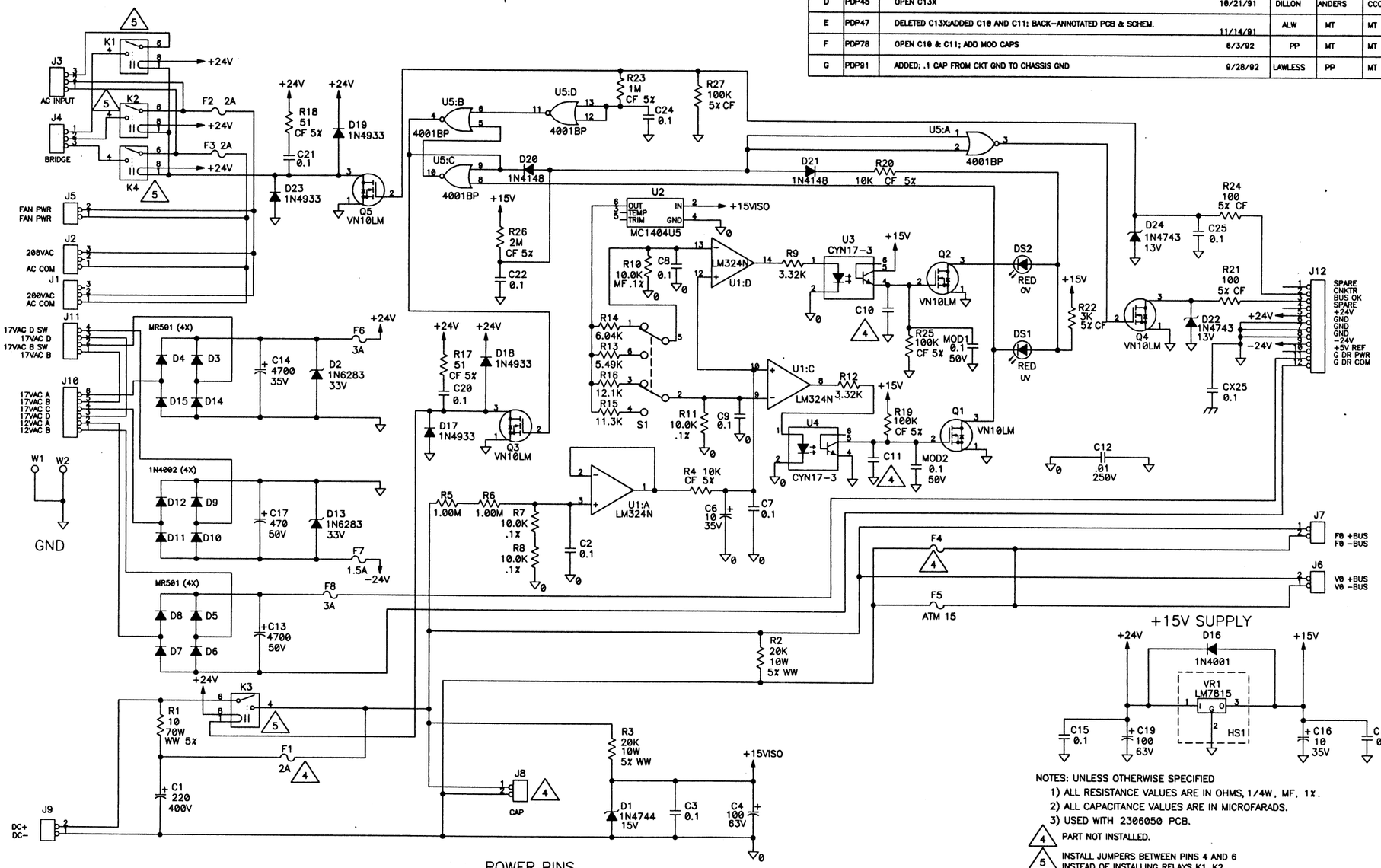
ADVANCED ENERGY

Tue Oct 17 1995 11:48:53 5036023L.S04

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H	PDP 94	OPEN F4; F5 WAS 10A	10/27/92	EM	
J	3750	CHANGED R9 & R12 TO 3.32K	6/4/93	BP	
K	3677	CHANGED F6 & F8 TO 1711047, F7 TO 1711025. CONVERTED TO TANGO.	6/4/93	BP	MT

REV	ECO	DESCRIPTION OF CHANGE		DRAWN	CHECKED	APPROVED
A	–	ORIGINAL ISSUE	3/29/91	GKC	MT	CCC
B	–	ADD OPTO ISO. AND OTHER CURCUITS, DELETE F7 & F10	7/2/91	RSL	MT	MT
C	–	REMOVED; RX3, RX5, VALUE CHANGES		LAWLESS	DILLON	CCC
D	PDP45	OPEN C13X	10/21/91	DILLON	ANDERS	CCC
E	PDP47	DELETED C13X;ADDED C10 AND C11; BACK-ANNOTATED PCB & SCHEM.	11/14/91	ALW	MT	MT
F	PDP78	OPEN C10 & C11; ADD MOD CAPS	6/3/92	PP	MT	MT
G	PDP81	ADDED; .1 CAP FROM CKT GND TO CHASSIS GND	9/28/92	LAWLESS	PP	MT



WARNING: ⏚0 IS AT –BUS POTENTIAL. CONTACT WITH THIS GROUND MAY CAUSE SERIOUS INJURY OR DEATH.

NOTES: UNLESS OTHERWISE SPECIFIED
1) ALL RESISTANCE VALUES ARE IN OHMS, 1/4W, MF, 1%.
2) ALL CAPACITANCE VALUES ARE IN MICROFARADS.
3) USED WITH 2306050 PCB.
4 PART NOT INSTALLED.
5 INSTALL JUMPERS BETWEEN PINS 4 AND 6 INSTEAD OF INSTALLING RELAYS K1, K2, K3 AND K4.

	SIGNATURE	DATE
DESIGNED	C.CAMUS	3/29/91
DRAWN	G.CHOCK	3/29/91
CHECKED	M.THOMPSON	3/29/91
PROJ. ENG.	C.CAMUS	3/29/91
PROD. ENG.		

TITLE: PDW LEFT CHASSIS SCHEMATIC

DRAWING NUMBER: C 5036052 REV. K

SCALE: NTS SHEET 1 OF 1

ADVANCED ENERGY®

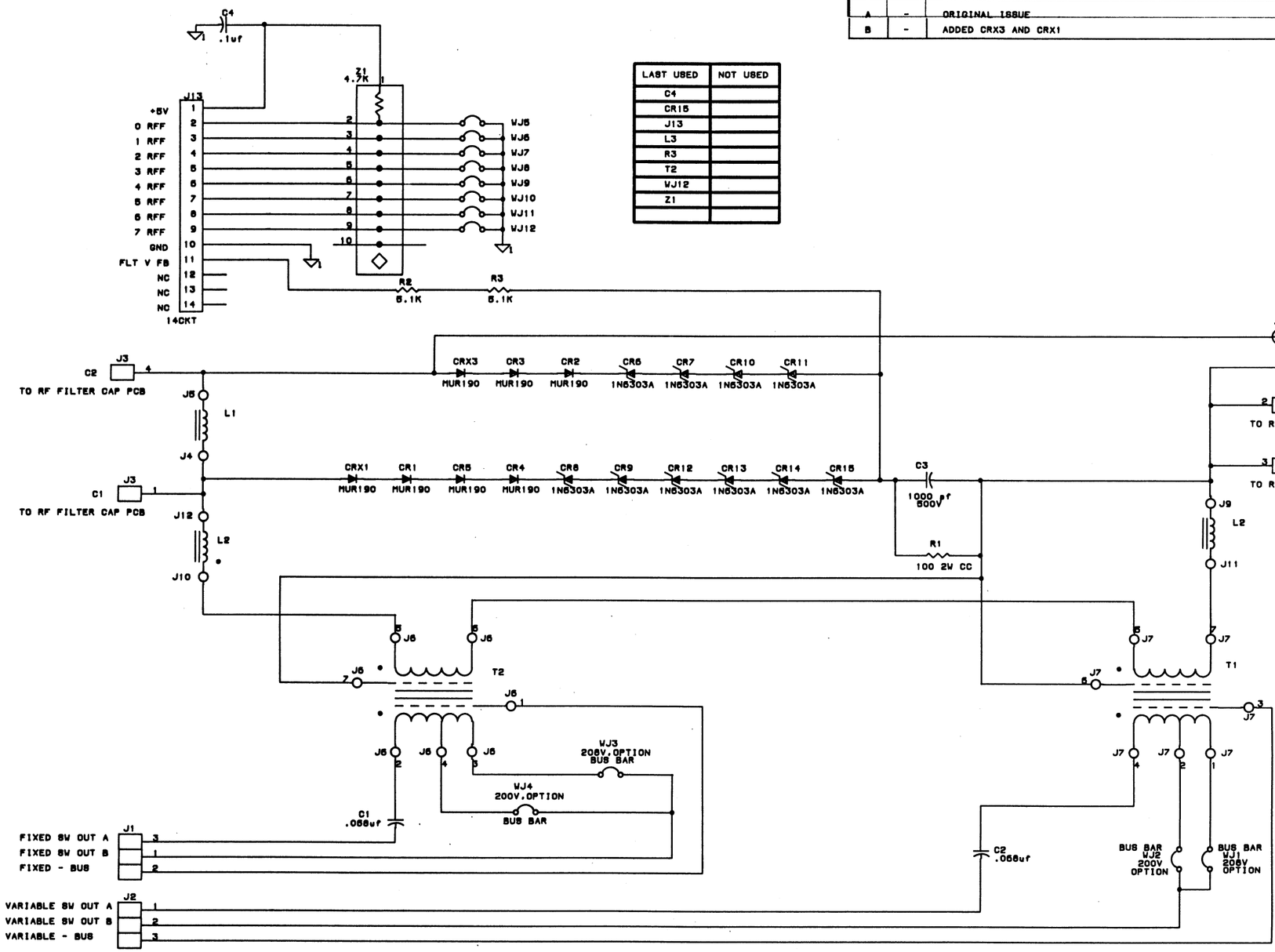
5036052K

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144919

REV	ECO	DESCRIPTION OF CHANGE	DRAWN	CHECKED	APPROVED
A	-	ORIGINAL ISSUE			
B	-	ADDED CRX3 AND CRX1	Lawless	Dillon	2cc

LAST USED	NOT USED
C4	
CR15	
J13	
L3	
R3	
T2	
WJ12	
Z1	



NOTES (UNLESS OTHERWISE SPECIFIED):
1. ALL RESISTANCE VALUES ARE IN OHMS, 1/4W, CF.
2. USES SAME PCB AS VDE PDP3500.

DO NOT SCALE	SIGNATURE	DATE
UNLESS OTHERWISE SPECIFIED ALL DIMENSIONS ARE IN INCHES INTERPRET PER ANSI Y14.5M — 1982	DESIGNED C CAMUS	4/3/91
	DRAWN B.PERRY	4/3/91
TOLERANCES XX = ± .020 XXX = ± .010 Ø = ± .005 X/X = ± 1/32 ∠ = ± 2°	CHECKED	
	PROJ ENG C CAMUS	4/5/91
	PROD ENG	
PARTS TO BE FREE OF BURRS BREAK ALL EDGES	THIRD ANGLE PROJECTION	
	TITLE BLOCK REVISION E	

TITLE: PDW 400KHZ RF FILTER SCHEMATIC

C | DRAWING NUMBER 5036058 | REV B

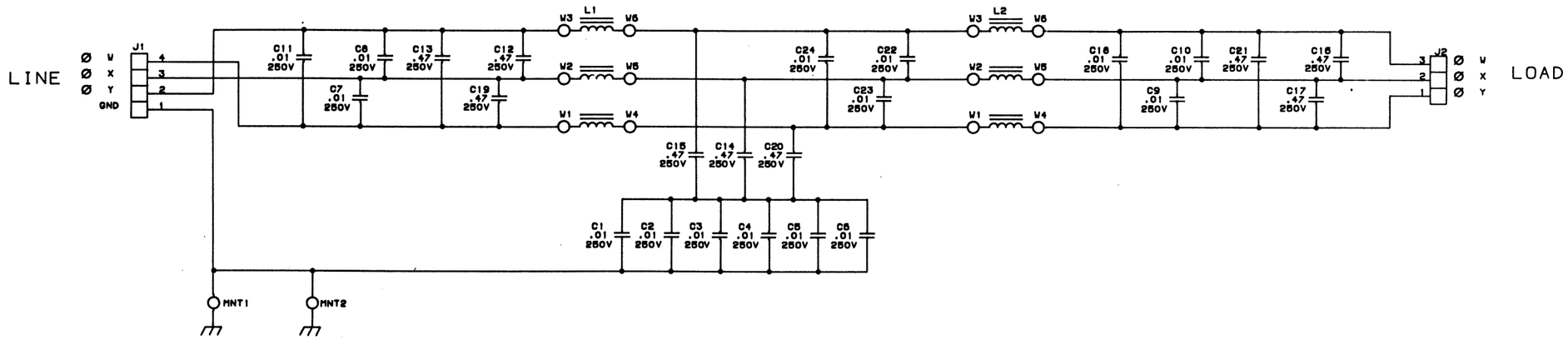
SCALE NTS | SHEET 1 OF 1

ADVANCED ENERGY

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144919

REV	ECO	DESCRIPTION OF CHANGE	DRAWN	CHECKED	APPROVED
A	-	ORIGINAL ISSUE 3/29/91	GKC	MT	CCC
B	-	CHANGED C12-17,C19 & C20 TO .47 AND W1-W2 TO MNT1-MNT2. 6/10/91	BP	.	CCC
C	-	CHANGED WIRE PADS AT L2. ADDED NOTE 3	[illegible]	Dillon	CC C



NOTES: UNLESS OTHERWISE SPECIFIED
1. ALL RESISTANCE VALUES ARE IN OHMS, 1/4W, CF.
2. ALL CAPACITANCE VALUES ARE IN MICROFARADS.
3. L2 WIRE PADS HAVE COSMETIC REFERENCE DESIGNATOR WHICH DIFFER FROM ACTUAL DESIGNATOR.

DO NOT SCALE

UNLESS OTHERWISE SPECIFIED ALL DIMENSIONS ARE IN INCHES INTERPRET PER ANSI Y14.5M — 1982

TOLERANCES
XX = ± .020
XXX = ± .010
Ø = ± .005
X/X = ± 1/32
∠ = ± 2°

PARTS TO BE FREE OF BURRS. BREAK ALL EDGES

	SIGNATURE	DATE
DESIGNED	C.CAMUS	3/22/91
DRAWN	G.CHOCK	3/22/91
CHECKED	M.THOMPSON	3/29/91
PROD ENG	C.CAMUS	3/29/91
PROD ENG	.	.

THIRD ANGLE PROJECTION

TITLE BLOCK REVISION E

PDX/PDW
LINE FILTER
SCHEMATIC

C | DRAWING NUMBER 5036065 | C

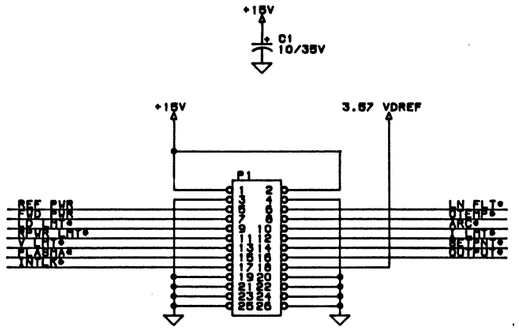
SCALE NTS | SHEET 1 1

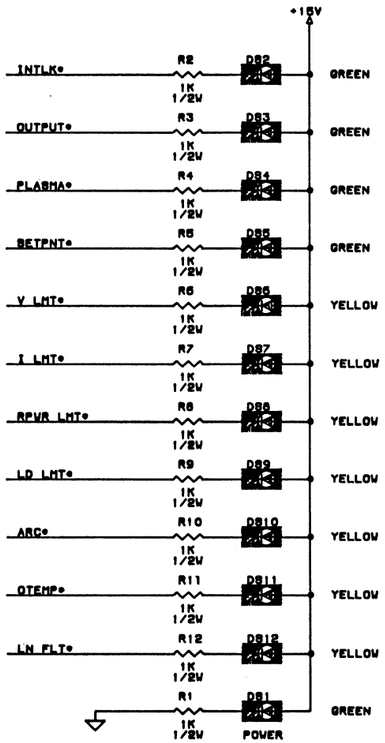
ADVANCED ENERGY

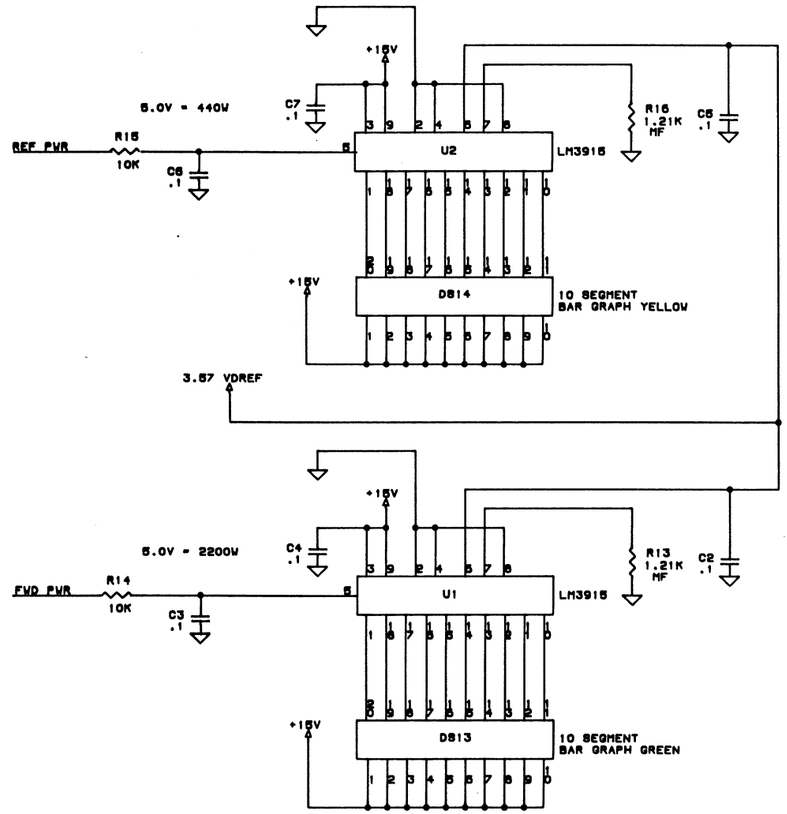
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144919

REV	ECO	DESCRIPTION OF CHANGE		DRAWN	CHECKED	APPROVED
A	-	ORIGINAL ISSUE	3/27/91	GKC	MT	CCC
B	-	ADDED R14 AND R15	6/26/91	PAP	.	CCC
C	-	REMOVED SOFTWARE DESIGNATION		Lawless	DILLON	CCC







NOTES: UNLESS OTHERWISE SPECIFIED
1. ALL RESISTANCE VALUES ARE IN OHMS, 1/4W, CF.
2. ALL CAPACITANCE VALUES ARE IN MICROFARADS.

DO NOT SCALE	SIGNATURE	DATE
UNLESS OTHERWISE SPECIFIED ALL DIMENSIONS ARE IN INCHES INTERPRET PER ANSI Y14.5M – 1982	DESIGNED C.CAMUS	3/22/91
	DRAWN G.CHOCK	3/22/91
TOLERANCES XX = ± .020 XXX = ± .010 Ø = ± .005 X/X = ± 1/32 ∠ = ± 2°	CHECKED M.T.	3/27/91
	PROJ ENG C.CAMUS	3/27/91
	PROD ENG .	.
PARTS TO BE FREE OF BURRS BREAK ALL EDGES	THIRD ANGLE PROJECTION	
	TITLE BLOCK REVISION	E

TITLE: PDW DISPLAY SCHEMATIC

SIZE	DRAWING NUMBER	REV
C	5036066	C
SCALE NTS	SHEET 1	OF 1

ADVANCED ENERGY

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REV	ECO	DESCRIPTION OF CHANGE	DR'N	CHK'D	APPROVED
A	-	ORIGINAL ISSUE	.	.	.
B	-	VALUE CHANGES	LAWLESS	PD	CCC
C	PDP69	R2 AND R5 20K WERE 10K.	DONITA	EM	CCC
D	PDP94	C2; 100pf WAS .01pf 10/27/92	EM		

RF FILTER OUT
W2
W3
RF FILTER GND
DIR C OUT
M=40
M=40
M=40
W1
W4
W5
W6
W7
W8
W9
W10
W11
W12
W13
W14
W15
C17 100PF 500V
C18 100PF 500V
C19 30PF 500V
C20 1-10PF
C32 30PF 500V
C34 2200PF 500V
WJ1
R25 100K 1%
R26 1% 15 20W
C29 100PF 500V
C30 100PF 500V
C31 30PF 500V
C37 1-10PF
C33 30PF 500V
C38 1000PF 500V
WJ2
R28 100K 1%
R29 30 20W 1%
CR1 MUR105
CR5 MUR105
CR2 MUR105
CR6 MUR105
C3 100PF
R19 7.50K 1%
R4 1K 25T
5.000V = 8.00 ARF
R30 4.42K 1%
R36 15 20W 1%
U1C TL084
R32 510
CR7 1N4740
C40 .001
+15VIN
-15VIN
J2
IFB
VF+
VF-
VR+
VR-
VFB
NC
RF GND
+15V
R3 100K 25T
R11 1.5M
C1 .001
R10 100K 1%
R2 20K 25T
100mv = 0W
R13 140K 1%
R21 10.0K 1%
Z1E TND921
Z1F TND921
Z1H TND921
Z1G TND921
U3 LM6321
C16 0.1
C15 .01
C14 .01
C13 0.1
-15V
C26 .01
C27 0.1
R24 51
C28 100PF 500V
R22 OPEN
R23 100 20W
C5 .01
C7 .47
U18 TL084
CR8 1N4740
R34 1K 1%
R33 1K 1%
R14 100K 25T
R17 1.5M
C9 .001
R18 100K 1%
R5 20K 25T
100mv = 0W
R15 127K 1%
R20 10.0K 1%
Z1A TND921
Z1B TND921
Z1D TND921
Z1C TND921
U2 LM6321
C24 0.1
C23 .01
C12 .01
C11 0.1
C22 .01
C21 0.1
R27 51
C25 100PF 500V
R6 OPEN
R7 100 20W
C4 .47
U1D TL084
CR9 1N4740
R35 1K 1%
C35 10 35V
C36 0.1
C49 10 35V
C48 0.1
C2 100pf
R1 2K 25T
R9 7.15K 1%
5.000V = 400 VRF
C6 0.1
C10 0.1
U1A TL084
CR12 1N4740
CR10 1N4148
CR11 1N4148
R37 510
C41 .001
U4 LM6321
C47 .01
C42 0.1
C45 .01
C45 0.1
C44 0.1
C43 .01
CR4 1N4148
CR3 1N4148
R31 5.1K
C39 470PF 500V
R8 7.15K 1%

C49	WJ2	R12
CR12	W16	R16
J2		J1
R38		
Z1		
U4		
LAST USED		NOT USED

NOTES: UNLESS OTHERWISE SPECIFIED
1. ALL RESISTANCE VALUES ARE IN OHMS, 1/4W, CF.
2. ALL CAPACITANCE VALUES ARE IN MICROFARADS.
3. USES SAME PCB AS VDE PDP 3500.

DO NOT SCALE
UNLESS OTHERWISE SPECIFIED ALL DIMENSIONS ARE IN INCHES INTERPRET PER ANSI Y14.5M - 1982
TOLERANCES
XX = ± .020
XXX = ± .010
ANGLES = ± 1°
FINISH = 63
BREAK ALL EDGES

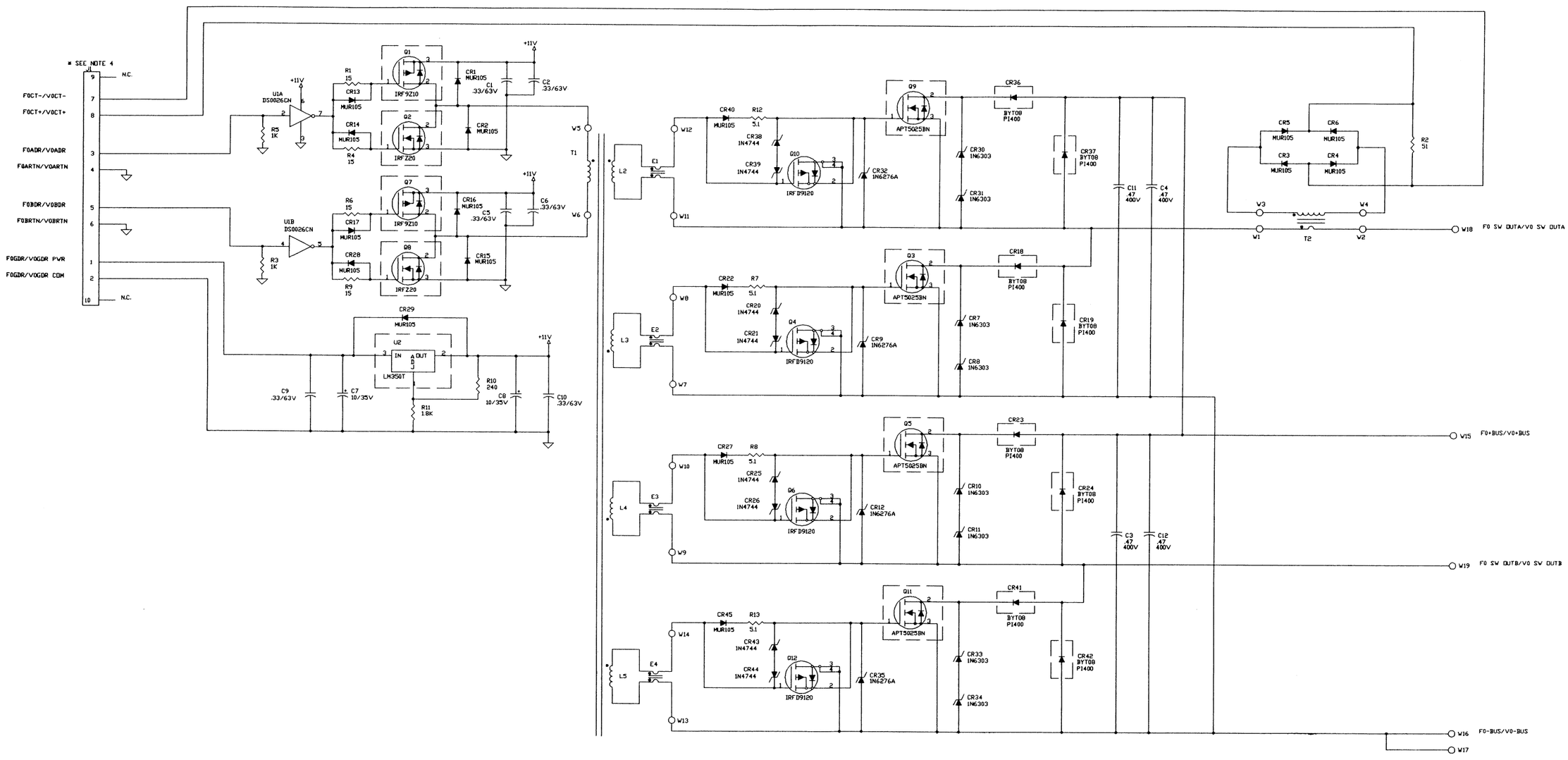
DRAWN	B.PERRY	4/10/91
TRACED	B.PERRY	4/15/91
DESIGN	CHECK	
PROJ ENG	C.CAMUS	4/22/91
QUALITY		
MFG		

PDW
DIRECTIONAL
COUPLER

5036068 D
NTS 1 1

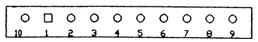
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A	-	ORIGINAL ISSUE	TAA	MT	CCC
B	-	REMOVED SOFTWARE DESIGNATION	LAWLESS	DILLON	CCC
C	PDP86	ADD NOTE 4. CORRECTION TO CR9	.	.	.



NOTES (UNLESS OTHERWISE SPECIFIED):

1. ALL RESISTORS ARE 1/4W CF; RESISTANCE VALUES ARE IN OHMS.
2. ALL CAPACITANCE VALUES ARE IN MICROFARADS.
3. ALL SYMBOLS WITH DASHED OUTLINE ARE MOUNTED TO HEATSINK.
4. PIN LAYOUT FOR J1 GOES AS FOLLOWS:



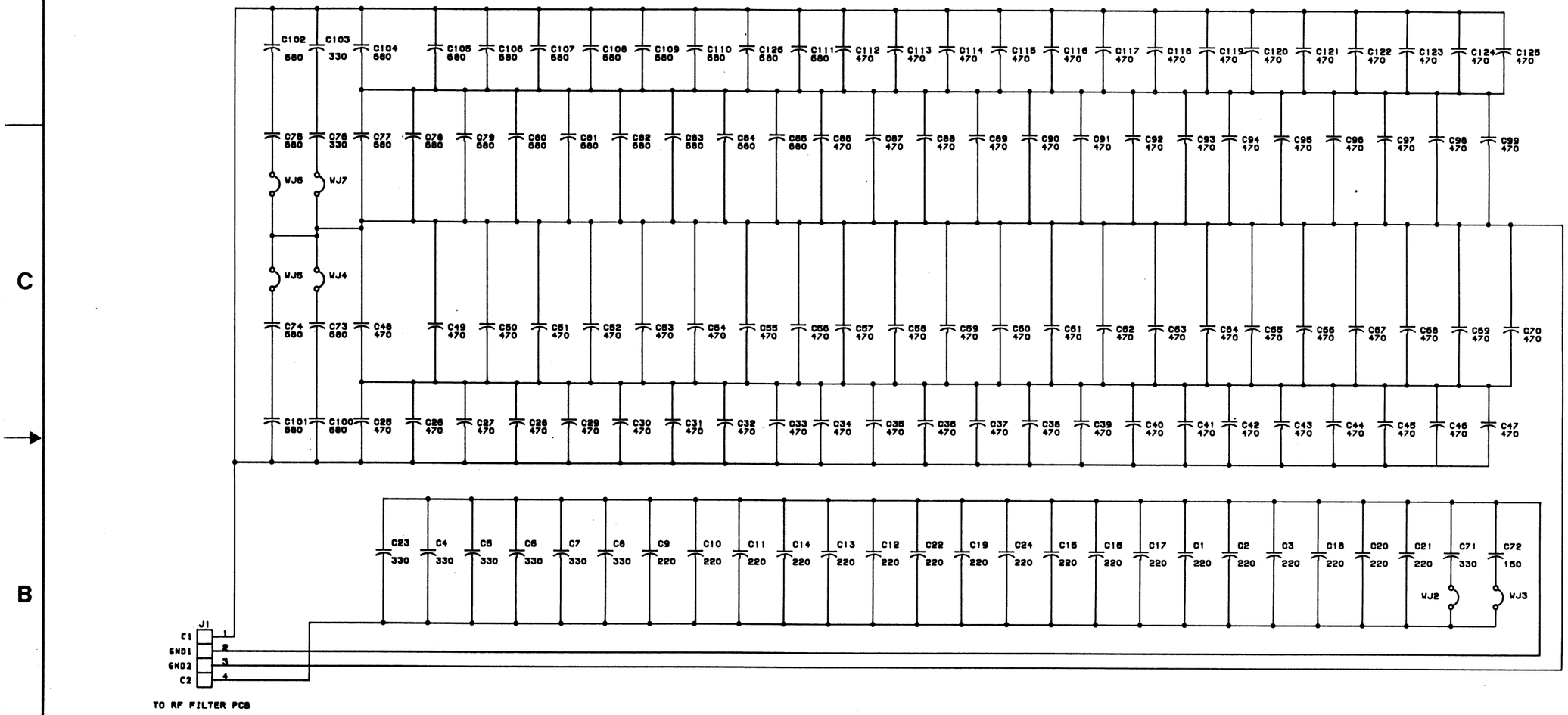
LAST USED	NOT USED
C13	
CR45	
L4	
J1	
R15	
R13	
U2	
Q12	
W19	

ANDERS	4/12/91	PDW SWITCH SCHEMATIC	
ANDERS	4/12/91		
MIKE T.	4/12/91		
C CAMUS	4/12/91	5036070	C
.	.	NTS	1 1

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144918

REV	ECO	DESCRIPTION OF CHANGE	DRAWN	CHECKED	APPROVED
A	-	ORIGINAL ISSUE 3/29/91	GKC	MT	CCC
B	-	REMOVED SOFTWARE DESIGNATION	Fawkes	Dillon	CCC



NOTES: UNLESS OTHERWISE SPECIFIED
1. ALL CAPACITANCE VALUES ARE IN PICOFARADS.

DO NOT SCALE	SIGNATURE	DATE
UNLESS OTHERWISE SPECIFIED ALL DIMENSIONS ARE IN INCHES INTERPRET PER ANSI Y14.5M — 1982	DESIGNED C.CAMUS	3/18/91
	DRAWN G.CHOCK	3/18/91
TOLERANCES .XX = ± .020 .XXX = ± .010 Ø = ± .005 X/X = ± 1/32 ∠ = ± 2°	CHECKED M.THOMPSON	3/29/91
	PROJ ENG C.CAMUS	3/29/91
	PROD ENG	
PARTS TO BE FREE OF BURRS BREAK ALL EDGES	THIRD ANGLE PROJECTION	
	TITLE BLOCK REVISION	E

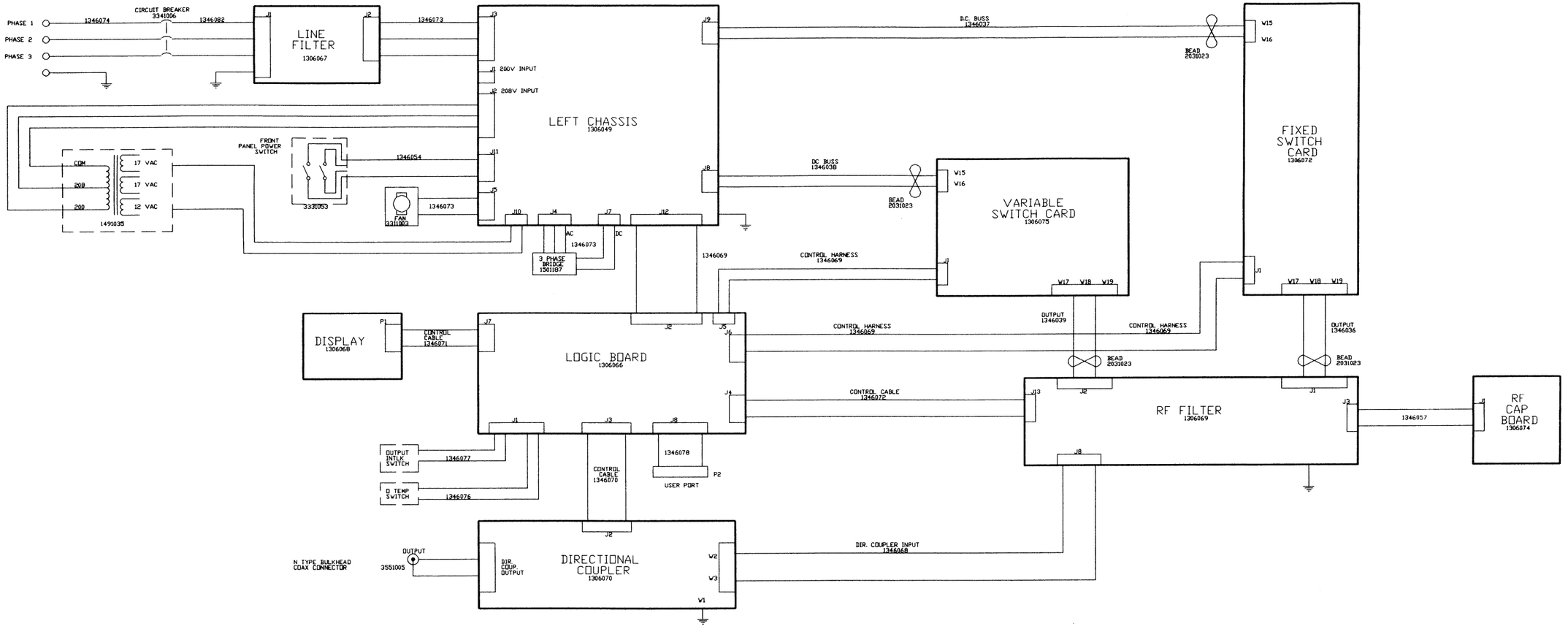
PDW 400KHz RF FILTER CAP SCHEMATIC

SIZE	DRAWING NUMBER	REV
C	5036072	B
SCALE NTS	SHEET 1 OF 1	

ADVANCED ENERGY

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A	-	ORIGINAL ISSUE	DONITA	X	X



NOTES: UNLESS OTHERWISE SPECIFIED
1. ALL RESISTANCE VALUES ARE IN OHMS, 1/4W, CF.
2. ALL CAPACITANCE VALUES ARE IN MICROFARADS.

COMPUTER GENERATED DWG. ORCAD STD III, VER 3.21

C.CAMUS	9-27-91	PDW INTERCONNECT SCHEMATIC
P.ARANTO	10-2-91	
C.CAMUS	.	
C.CAMUS	.	5036076 A
.	.	NTS 1 1

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REV	RFC	DESCRIPTION OF CHANGE	ORIG/DATE	CHK/DATE	APP/DATE
A	*	ORIGINAL ISSUE - BASED ON 5036023L. 5/10/95	LRM	PP	CC

NOTES: UNLESS OTHERWISE SPECIFIED
1) ALL RESISTANCE VALUES ARE IN OHMS, 1/4W . MF. 1%.
2) ALL CAPACITANCE VALUES ARE IN MICROFARADS, .100V
3) USED WITH 2306058B.
4) PARENT SCHEMATIC SCH6058
5) ALL REF DES WITH 'B' AS A PREFIX ARE INSTALLED ON SOLDER SIDE.

Fri Jul 07 1995 09:16:48 5036133A.S01

DO NOT SCALE	SIGNATURE	DATE
UNLESS OTHERWISE SPECIFIED ALL DIMENSIONS ARE IN INCHES INTERPRET PER ANSI Y14.5M-1982 PERFECT ORIENTATION AT MMC REQUIRED FOR RELATED FEATURES	ORIGINATOR L.MILLER	5/10/95
	CHECKED P.PERRY	5/10/95
	APPROVED C.CAMUS	5/10/95
	PARTS TO BE FREE OF BURRS BREAK ALL EDGES	
TOLERANCES: .XX = ±.020 .XXX = ±.010 > = ±.005 X/X = ±1/32 ∠ = ±1°	MANAGIT #	
	TITLE BLOCK REVISION G	

TITLE: PDW LOGIC SCHEMATIC

DRAWING NUMBER	REV
5036133	A

SCALE NTS | SHEET 1 OF 4

ADVANCED ENERGY (R)

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REV	RFC	DESCRIPTION OF CHANGE	ORIG/DATE	CHK/DATE	APP/DATE
		SEE SHEET 1.			

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	CHECKED P.PERRY	5/10/95
	APPROVED C.CAMUS	5/10/95
	PARTS TO BE FREE OF BURRS BREAK ALL EDGES	
TOLERANCES: .XX = ±.20 .XXX = ±.10 > = ±.05 X/X = ±1/32 ∠ = ±1°	MANAGIT #	
	TITLE BLOCK REVISION	G

TITLE: PDW LOGIC SCHEMTAIC

DRAWING NUMBER	REV.
5036133	A

SCALE: NTS | SHEET 2 OF 4

ADVANCED ENERGY

Fri Jul 07 1995 09:17:28 5036133A.S02

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REV	RFC	DESCRIPTION OF CHANGE	ORIG/DATE	CHK/DATE	APP/DATE
		SEE SHEET 1.			

SH1 REF PWR 5V=440W

SH1 FWD PWR 5V = 3

SH4 VF- R13 499K 1% MF; R30 1.00K; R29 499K 1% MF; C26 15PF 1KV; U10:A TL084BCN

SH4 VF+ R14 499K 1% MF; C25 15PF 1KV; R31 1.00K; R32 MF 1% 499K

R28 10.0K; U10:B TL084BCN

C57 1000PF 50V; CR10 1N4148; U10:D TL084BCN

C56 1000PF 50V; CR11 1N4148; U10:C TL084BCN

+5VREF; R53 523; C58 0.1; R54 49.9K; C59 0.1; R59 523

U22:C DG411DJ

SH4 VR- R15 499K 1% MF; R35 1.00K; C28 15PF 1KV; R34 499K 1% MF; U11:A TL084BCN

SH4 VR+ R16 499K 1% MF; C27 15PF 1KV; R36 1.00K; R37 MF 1% 499K

R33 10.0K; U11:B TL084BCN

C61 1000PF 50V; CR12 1N4148; U11:D TL084BCN

C60 1000PF 50V; CR13 1N4148; U11:C TL084BCN

U22:D DG411DJ; C92 OPEN

C145 OPEN; Z5 OPEN; D0 D1 D3 D5 D6

P1 OPEN; R137 OPEN; +5V; CAL/

C113 OPEN; C116 OPEN 50V; C143 OPEN 35V; C130 OPEN; C112 OPEN

U29 OPEN; VIN+ VIN- VREF DAV SYNC CS CLK RD WR A0; D12 D11 D10 D9 D8 D7 D6 D5 D4 D3 D2 D1 D0

C115 OPEN 35V; C114 OPEN 35V; C111 OPEN; -5V

C142 OPEN; U34 OPEN; I/O/Q; UCLK

Y2 OPEN; C108 OPEN 50V

R108 OPEN; GAL22V10

Z4 OPEN; D7 D8 D9 D10 D12; C144 OPEN

Z3 OPEN; D2 D4 D11; C110 OPEN

C156 OPEN; U35 OPEN; A0 A1 A2 A3 A4 A5 A6 A7 A8 A9 A10 A11 A12 A13 A14 F/R CE OE VPP; O0 O1 O2 O3 O4 O5 O6 O7

U26:B 74HC04; U26:C 74HC04

Z6 OPEN; DB0 DB1 DB2 DB3 DB4 DB5 DB6 DB7; C157 OPEN

C183 OPEN; C182 OPEN 50V; C179 OPEN 50V; C178 OPEN

U40 OPEN; VOUTA VOUTB ROFSA ROFSB REFINA REFINB REFOUT LDAC WR A0 A1 CS; R159 OPEN; R160 OPEN; R2 OPEN; R1 10.0K; C1 0.1; U1:A OP200GP

WJ20 WJ19 WJ18 WJ21

LDAC WRDAC A0 F/R

WATCHDOG SH2

DC RESET* SH4

SH2 RESET*

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	CHECKED P.PERRY	5/10/95
	APPROVED C.CAMUS	5/10/95
TOLERANCES: .XX = ±.20 .XXX = ±.10 > = ±.05 X/X = ±2° ∠ = ±2°	PARTS TO BE FREE OF BURRS BREAK ALL EDGES	
	MANAGIT #	
	TITLE BLOCK REVISION	G

TITLE: PDW LOGIC SCHEMATIC

D | DRAWING NUMBER 5036133 | REV A

SCALE NTS | SHEET 3 OF 4

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REV	RFC	DESCRIPTION OF CHANGE	ORIG/DATE	CHK/DATE	APP/DATE
		SEE SHEET 1.			

J5
G DR PWR
G DR COM
VOADR
VOARTN
VOBDR
BOVRTN
VOCT-
VOCT+
N.C.
TO V-PHASE SWITCHCARD

J6
G DR PWR
G DR COM
FOADR
FOARTN
FOBDR
FOBRTN
FOCT-
FOCT+
N.C.
TO F-PHASE SWITCHCARD

J2
NC
CNKTR
BUS OK
N.C.
+24V
GND
GND
GND
-24V
+5VREF
G DR PWR
G DR COM
-24V
+5VREF
TO LEFT CHASIS

J4
+5V
0RFF
1RFF
2RFF
3RFF
4RFF
5RFF
6RFF
7RFF
GND
FLT V FB
NC
NC
NC
FLT V FB
TO RF FILTER

J3
+15V
IFB
VF+
VF-
VR+
VR-
VFB
+5V
-5V
DC RESET*
+5VREF
+5VREF
GND
-15V
TO DIRECTIONAL COUPLER

J7
+15D
+15D
POWER GND
POWER GND
REF PWR
LN FLT*
FWD PWR
O.TEMP*
LD LMT*
ARC*
RPWR LMT*
I LMT*
V LMT*
SETPNT*
PLASMA*
OUTPUT*
INTLK*
3.57 VDREF
POWER GND
POWER GND
POWER GND
POWER GND
POWER GND
POWER GND
POWER GND
REF PWR DIS
LN FLT*
FWD PWR DIS
O.TEMP*
LD LMT*
ARC*
RPWR LMT*
I LMT*
V LMT*
SETPNT*
PLASMA*
OUTPUT*
INTLK*
+3.57 VDREF
C195 0.1
TO DISPLAY

J1
OPEN COVER GND
OPEN COVER SIG
OT SIG
OT GND
MNT3

POWER PINS

SPARES

XI RF PWR ON+
XI RF PWR ON-
XI RF ON+
XI RF ON-
XI OTEMP+
XI OTEMP-
XI RPWR
XI INTLK-
XI STPT*+
XI STPT*-
XI LOAD REG
XI PWR
XI SIG+
XI SIG-

J8
CONNECTOR MOUNTED ON CHASSIS
RF POWER ON
RF POWER ON RETURN
RF ON
RF ON RETURN
OVERTEMP
OVERTEMP RETURN
REVERSE POWER SENSE
REVERSE POWER SENSE REF
+ INTERLOCK LOOP
- INTERLOCK LOOP
24 VDC UNREGULATED
CHASSIS GROUND
MAXIMUM POWER
MAXIMUM POWER RETURN
5VDC
LOAD/FORWARD POWER LEVELING
NOT USED
NOT USED
NOT USED
LOAD/FORWARD POWER SENSE
LOAD/FORWARD POWER SENSE REF
SETPOINT CONTROL
SETPOINT CONTROL REF
EXTERNAL CONTROL SELECT
CHASSIS GROUND
I/O

DO NOT SCALE	SIGNATURE	DATE
UNLESS OTHERWISE SPECIFIED ALL DIMENSIONS ARE IN INCHES INTERPRET PER ANSI Y14.5M-1982 PERFECT ORIENTATION AT MMC REQUIRED FOR RELATED FEATURES	ORIGINATOR L.MILLER	5/10/95
	CHECKED P.PERRY	5/10/95
	APPROVED C.CAMUS	5/10/95
	PARTS TO BE FREE OF BURRS BREAK ALL EDGES	
TOLERANCES: .XX = ±.020 .XXX = ±.010 >= ±.005 X/X = 1/32 ∠ = ±1°	MANAGIT #	
	TITLE BLOCK REVISION G	

TITLE: PDW LOGIC SCHEMATIC
SIZE D | DRAWING NUMBER 5036133 | REV A
SCALE NONE | SHEET 4 OF 4
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