Low Voltage Power Supplies and Rack Protection for the DFE, Sequencer and Mixer Crates

Jamieson Olsen
Fermi National Accelerator Laboratory
Batavia, Illinois, USA 60510

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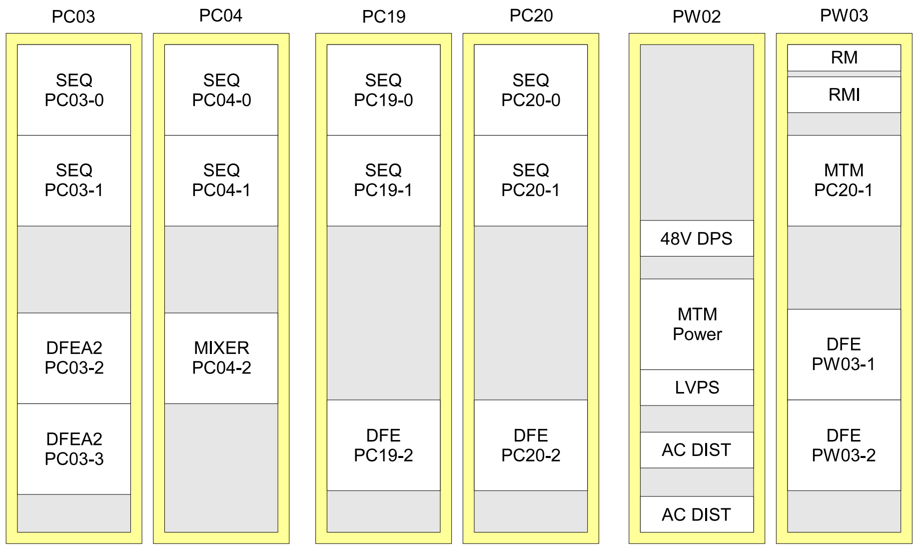

Figure 1: Rack and crate locations for DFE and Sequencer crates.

1 System Overview

There are four Digital Front End (DFE) and eight Sequencer crates located on the central and west platforms under the DZERO detector[1]. Each DFE and Sequencer crate requires two low voltage high current DC supplies for operation. A Vicor PFC Mini [2] unit is used to supply these two voltages for each crate. The power supply output voltage is monitored remotely using the DZERO Rack Monitor (RM) modules [3]. AC power to the DFE and Sequencer supplies is controlled by a relay in the AC Distribution box; this relay is driven by the Rack Monitor Interface (RMI) modules [4]. The power supplies may also be controlled remotely through the RM unit.

The Mixer crate is located in PC04 and is also powered by a Vicor PFC Mini supply. The Mixer power supply is bolted directly to the crate and is connected into the north AC distribution box. AC power to the Mixer supply is controlled exclusively by the rack protection system however the DC outputs of the supply may be controlled remotely through the RM.

Note that this document does not cover the two DFEA2 crates located in PC03. The DFEA2 crates are powered by a 48VDC distributed power system described on the DFEA2 Hardware webpage [5].

2 Location of Equipment

The DFE and Sequencer equipment is located in six racks shown in Figure 1.

2.1 Central Platform North

Four Sequencer crates, the Mixer crate, and two DFEA2 crates are located in racks PC03 and PC04. The DFEA2 crates are powered by 48VDC power supplies located on the west platform. The AC distribution box is located behind PC03 and PC04 between the aisle way and the back wall. A schematic of the north side hardware is shown in Figure 2.

Each rack has an RMI which checks for smoke, water drips, insufficient airflow and monitors the VESDA system. The RMI units in PC03 and PC04 are daisy chained so that a fault

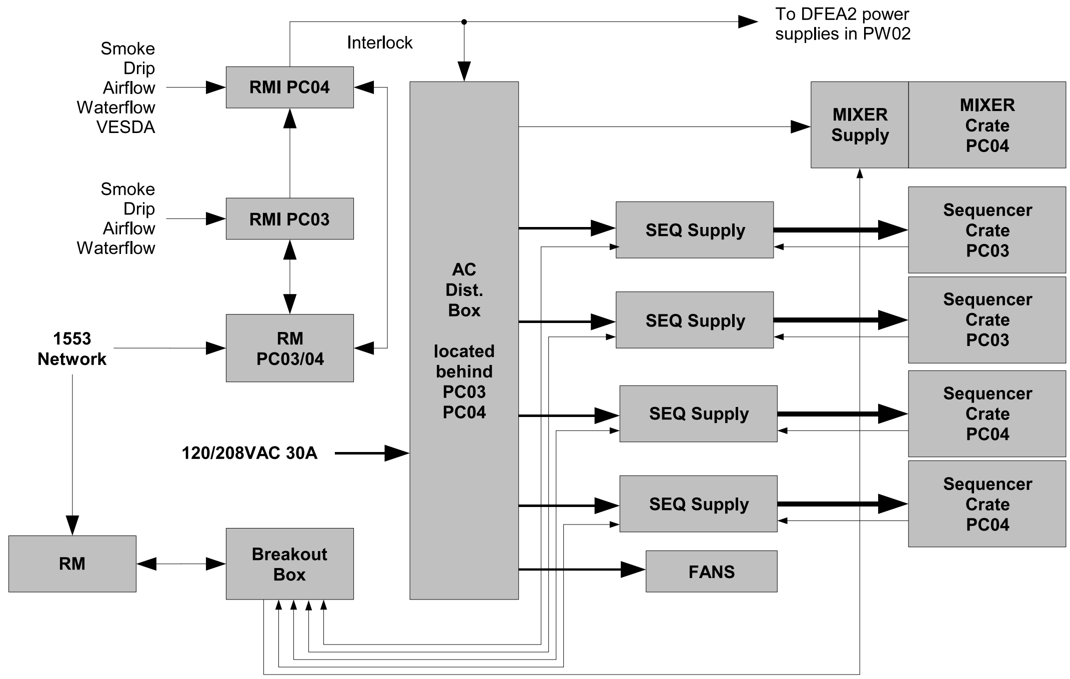

Figure 2: Central platform north.

in either rack will drop the interlock and de-energize the AC distribution box. The interlock signal from PC04 is also sent to the DFEA2 power supplies on the west platform. The RMI units in PC03 and PC04 connect to a RM located between racks PC03 and PC04. An additional RM is used for monitoring the power supplies and providing remote on/off control. A small "breakout box" is used to connect the power supply monitor/control harnesses to the RM connectors; the schematic for this box is located in Appendix A.3.

2.2 Central Platform South

Four Sequencer crates and two DFE crates are located on the south side of the central platform in racks PC19 and 20. The AC distribution box is located behind PC19 and PC20 between the aisle way and the back wall as shown in Figure 4. A schematic of the south side hardware is shown in Figure 3.

Each rack has an RMI which checks for smoke, water drips, insufficient airflow and monitors the VESDA system. The RMI units in PC19 and PC20 are daisy chained so that a fault in either rack will drop the interlock and de-energize the AC distribution box. The RMI units connect to a RM located between racks PC19 and PC20. An additional RM is used for monitoring the power supplies and providing remote on/off control. The breakout box used on this RM is identical to the one used on the north side.

2.3 West Platform

The power supplies on the west platform are bit more complicated due to the fact that the 48VDC DFEA2 power supplies are located in PW02 but the DFEA2 crates are located in PC03. The system is shown in Figure 5. In this system there are two AC distribution boxes: a large unit in the bottom of PW02 that feeds the BiRa distribution AC box above it. The rack

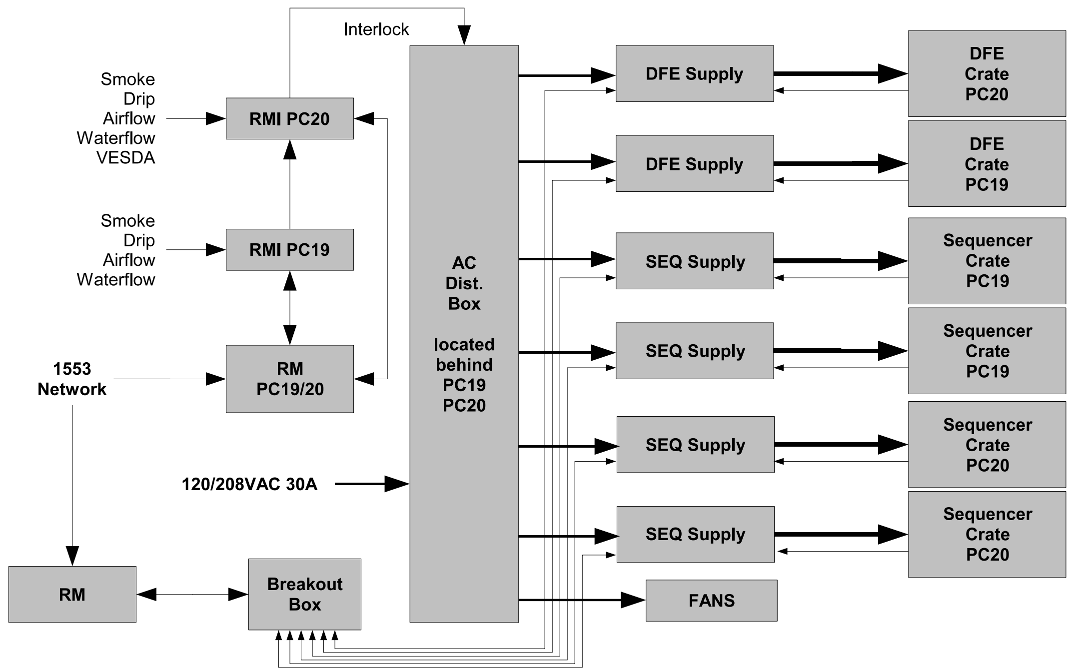

Figure 3: Central platform south.

Figure 4: This power supply chassis located behind PC19 and PC20 on the center platform. This picture of out of date – the AC distribution box is now located above the gold chassis box.

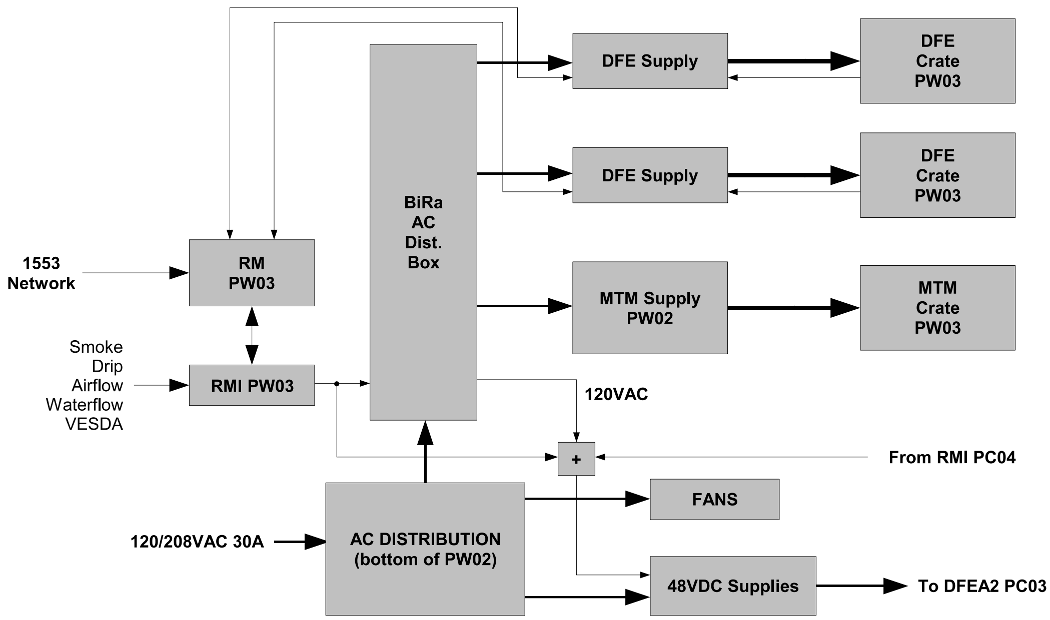

Figure 5: West platform.

protection system in PW02 and PW03 checks for water leaks, smoke, airflow and monitors the VESDA system. If the RMI detects a fault it drops the interlock, de-energizing the BiRa distribution box, DFE power supplies, the Muon MTM supply and the DFEA2 48VDC power supplies. The DFEA2 power supplies are unique in that the interlock signal from PW03 is logically ORed with the interlock signal from PC03/04: a fault condition in either of these locations will shut down the DFEA2 supplies. For more information on the DFEA2 system refer to the DFEA2 website [5].

3 AC Distribution

The AC distribution box used in this system is a custom unit manufactured by BiRA systems Inc. is model 8886 and the schematic is shown in Figure 6.

The circuit breakers used in the AC distribution box carry an interrupt rating of only 2500A and were judged insufficient for operation in the DZERO detector. In order to satisfy the 10,000A interrupt requirement three 30A slow blow fuses were wired in series with the main breaker in the AC distribution box. The fuse modification was made at DZERO not at BiRa.

When the interlocks are "made up" the RMI units supply a TTL level signal (5VDC @ 10mA) to the AC distribution boxes. This TTL level signal energizes a small solid state relay (SSR) and this relay in turn energizes a larger AC contactor. Nine 208VAC outputs are across the 3 phases for balanced loading and individually controlled with 15A breakers. An extra 120VAC output also used to power fans, etc.

3.1 Local AC Control

Under some circumstances it's necessary to remotely power down a supply without affecting operation of the other crates. Independent AC control is accomplished by adding a solid state

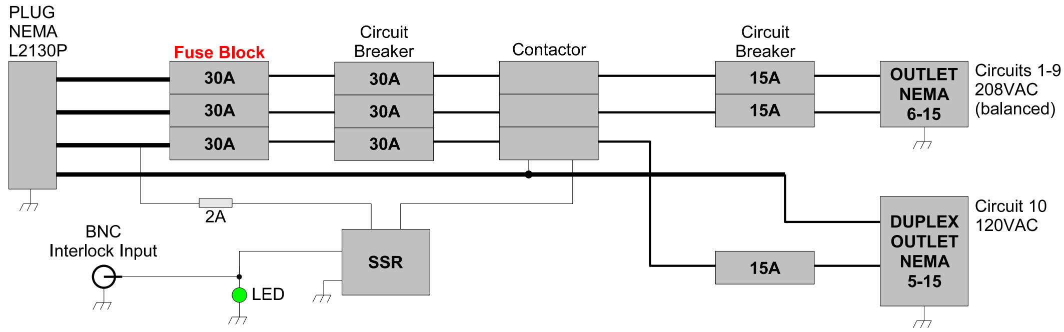

Figure 6: BiRa AC distribution box model 8886 with fuse modification.

relay in series with the AC input connector on each DFE and Sequencer power supply. The solid state relay is controlled by a digital output on a rack monitor. The Mixer power supply does not have this relay and is directly connected to the AC distribution box.

4 AC/DC Power Supplies

The Vicor PFC Mini power supply is the base unit used for the DFE, Sequencer and Mixer crates. The PFC Mini is obsolete – however Vicor still manufactures the "second generation" DC-DC converter modules. Each PFC mini unit features three bays which contain high power DC-DC converters.

4.1 DFE Power Supplies

The DFE power supply is a PFC mini configured for 3.3V @ 160A and 5VDC @ 40A. Some DFE power supplies use a pair of 5V 80A modules trimmed down to the desired voltage. All DFE supplies should be trimmed up to 3.45VDC and 5.25VDC. Use Vicor's online calculator for fixed output module trimming to determine the resistor values [7].

One ohm resistors should be used in place of the remote sense jumpers on the master 80A converter and also on the 5V 40A converter. Leave the factory jumpers on the slave converter (in the middle bay).

The AC power to the DFE power supplies is controlled by the rack protection system. The user may remotely control the AC power to the supply by enabling or disabling a solid state relay driven by the rack monitor. Another control line enables or disables the outputs of the PFC mini supply; this control bit is driven by a rack monitor. Both the 3.3V and 5V output voltages are monitored by the rack monitor.

4.2 Sequencer Power Supplies

The Sequencer power supply is a PFC mini configured for 5V @ 160A and 5.2VDC @ 80A. Three 5V 80A second generation modules are used and trimmed appropriately. Some of the eight Sequencer crates use resistors to protect the remote sense lines and some crates use fuses to protect the lines. In theory there should be no current flowing on the sense lines and the difference between fuses and resistors should be negligible; however this is not the case in our and the Sequencers are sensitive to the backplane. Hence each Sequencer crate requires specific trim up resistors for proper operation. Mike Utes maintains this document [6]. One ohm resistors should be used in place of the remote sense jumpers on the master

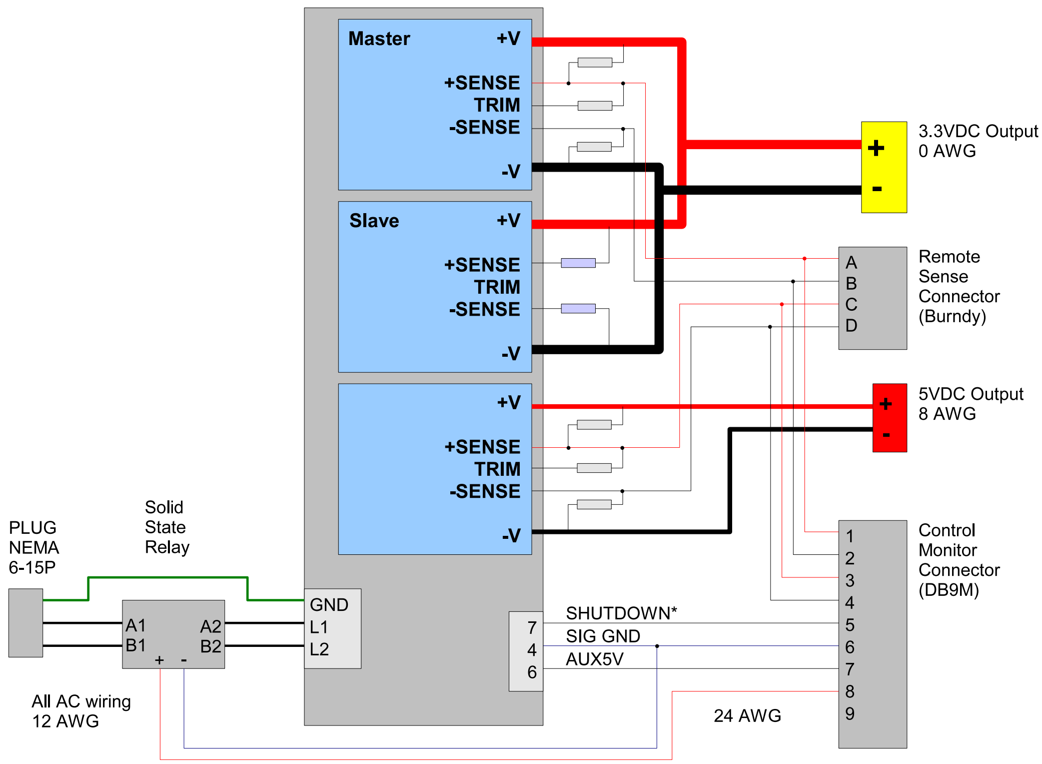

Figure 7: PFC mini supply configured for DFE crates.

80A converter and also on the 5.2V 80A converter. Leave the factory jumpers on the slave converter (in the middle bay).

The AC power to the Sequencer power supplies is controlled by the rack protection system. The user may remotely control the AC power to the supply by enabling or disabling a solid state relay driven by the rack monitor. Another control line enables or disables the outputs of the PFC mini supply; this control bit is driven by a rack monitor. Both the -5.2V and 5V output voltages are monitored by the rack monitor.

4.3 MIXER Power Supply

The Mixer power supply is a Vicor PFC Mini configured with three 80A 3.3V second generation modules. The three modules are wired in parallel and configured for 240A operation. Custom copper bus bars connect the power supply outputs to the Mixer backplane and the whole assembly is covered with a Plexiglas shield. This supply is configured for "local sense" operation. Spare Mixer supplies may be obtained through Neal Wilcer (CD/ESE group).

The AC power to the Mixer power is controlled only by the rack protection system as there is no solid state relay on this unit. The outputs of the Mixer power supply may be controlled remotely through the rack monitor.

4.4 PFC Mini Idiosyncrasies and Failure Modes

The distance between the supply and the load is about 12 feet for DFE and Sequencer crates. Remote sense configuration can compensate for voltage drops on the cables and the PFC Mini supplies do support remote sense operation. The problem is that remote sense doesn't

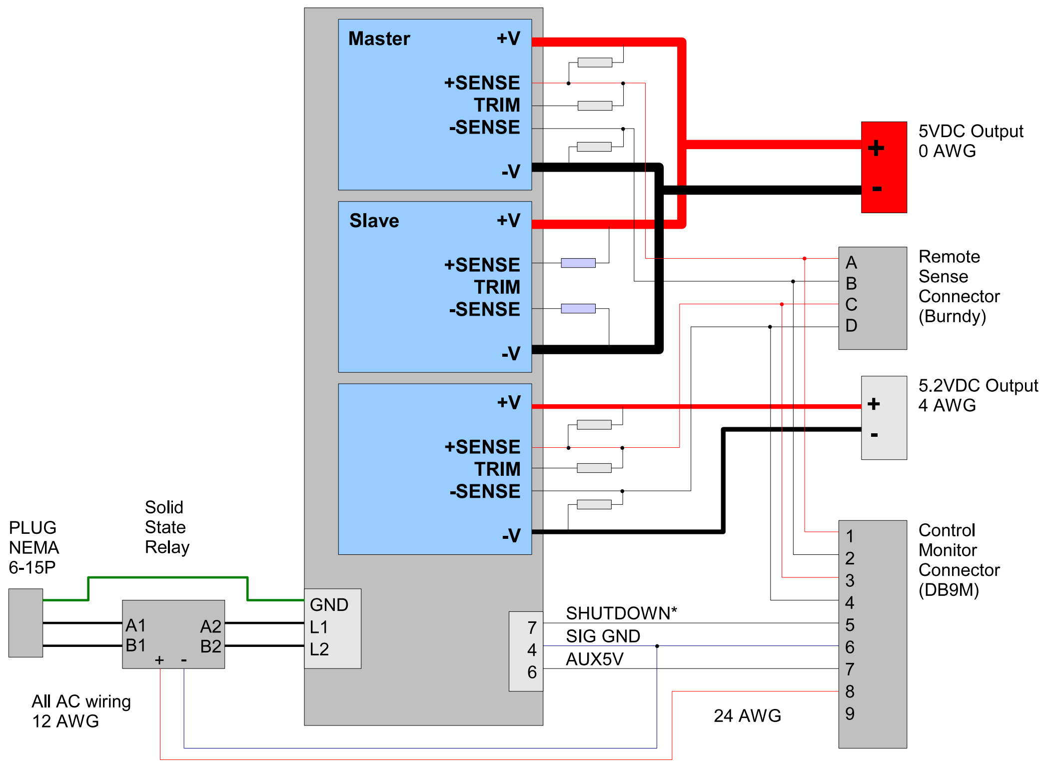

Figure 8: PFC mini supply configured for Sequencer crates.

work on these supplies. When configured for remote sense operation we observe undamped oscillation which leads to over-voltage shutdown. Filtering and shielding the sense lines does not appear to help.

In the end we ended up pulling the local sense jumpers and installing a one ohm resistor in its place and leaving the remote sense lines connected. This configuration is mostly local sense and requires careful output trimming to maintain a fairly constant voltage at the backplane. Unlike the Sequencer crates the DFE crate power consumption is highly dynamic and this translates into poor voltage regulation at the load. We simply set the voltage high enough to prevent the boards from going into reset and live with it. We're not proud of this.

From time to time we observe failures in the PFC mini DC-DC converter modules. The damage is often permanent. We suspect this is due to overheating but Vicor is performing post-mortem analysis on these now. Occasionally we observe that one of the supply outputs drops to around one volt and stays there. Turning the AC power off for a few minutes sometimes brings it back. This behavior is not well understood.

5 DC Distribution

Anderson "Power Pole" connectors are used to attach cables to the DFE and Sequencer power supplies. The DFE and Sequencer high current (160A) outputs use 0AWG cables; the Sequencer -5.2V outputs (80A) use 4AWG, and the 5V DFE output (40A) uses 6AWG. The thick cables drop down into the floor, under the aisle way, and back up through the racks to the crates. The average length is 12 feet and remote sense lines are used (sort of, see section 4.4). Large tin-plated copper crimped lugs are used for all high current cable connections.

	R/W	R/W	R
	P2	**P3**	**P7**
15			
14			
13			
12			
11		SEQ-PC04-1-OE	
10		SEQ-PC04-0-OE	
9		SEQ-PC03-1-OE	
8	MIXER-PC04-OE	SEQ-PC03-0-OE	
7			
6			
5			SEQ-PC04-1-AC-OK
4			SEQ-PC04-0-AC-OK
3		SEQ-PC04-0-PE	SEQ-PC03-1-AC-OK
2		SEQ-PC04-0-PE	SEQ-PC03-0-AC-OK
1		SEQ-PC03-1-PE	
0		SEQ-PC03-0-PE	

	R
	P5
ch15	
ch14	
ch13	
ch12	
ch11	
ch10	
ch9	
ch8	
ch7	SEQ-PC04-1-5.2V
ch6	SEQ-PC04-1-5V
ch5	SEQ-PC04-0-5.2V
ch4	SEQ-PC04-0-5V
ch3	SEQ-PC03-1-5.2V
ch2	SEQ-PC03-1-5V
ch1	SEQ-PC03-0-5.2V
ch1	SEQ-PC03-0-5V

Figure 9: The Central platform north rack monitor connections.

The current density through all conductors meets Fermilab design guidelines [8] and a detailed analysis of the DFE current path is in Appendix B.

The Mixer power supply (3.3V @ 240A) is directly connected to the backplane using massive copper bars. Since there is no significant voltage drop on the copper bus bars the power supply is configured for local sense operation.

6 Remote Control and Monitoring

DFE and Sequencer supplies are connected to a rack monitor which allows the user to remotely monitor the output voltages and the PFC Mini "AC OK" signal. Each DFE and Sequencer power supply has two control bits: PE (controls the AC input voltage) and OE (controls the power supply DC outputs). Both the PE and OE control bits are active high – both bits must be set to enable the power supply. The following sections describes the connections between the power supplies and Rack Monitor. Refer to the Rack Monitor documentation [3] to determine which registers to access through the 1553 network interface.

Note that the Mixer power supply has only one control bit (OE) and no status bits to monitor.

6.1 Central Platform North

The RM that controls the central platform north power supplies is located behind PC03 on a shelf attached to the detector support structure. Confirm that the I/O switches are set so that P2 and P3 are R/W and P6 and P7 are read-only. The Mixer power supply control cable (Figure 12)should be plugged into the 9-pin connector number 5 on the breakout box. The rack monitor connections are shown in Figure 9 where the control signals are shown in red and the status signals are shown in green.

6.2 Central Platform South

The RM that controls the central platform south power supplies is located behind PC19 on a shelf attached to the detector support structure. Confirm that the I/O switches are set

	R/W	R/W	R
	P2	P3	P7
15			
14			
13			
12			
11		SEQ-PC20-1-OE	
10		SEQ-PC20-0-OE	
9	DFE-PC20-2-OE	SEQ-PC19-1-OE	
8	DFE-PC19-2-OE	SEQ-PC19-0-OE	
7			
6			
5			SEQ-PC20-1-AC-OK
4			SEQ-PC20-0-AC-OK
3		SEQ-PC20-0-PE	SEQ-PC19-1-AC-OK
2		SEQ-PC20-0-PE	SEQ-PC19-0-AC-OK
1	DFE-PC20-2-PE	SEQ-PC19-1-PE	DFE-PC20-2-AC-OK
0	DFE-PC19-2-PE	SEQ-PC19-0-PE	DFE-PC19-2-AC-OK

	R
	P5
ch15	
ch14	
ch13	
ch12	
ch11	DFE-PC20-2-5V
ch10	DFE-PC20-2-3.3V
ch9	DFE-PC19-2-5V
ch8	DFE-PC19-2-3.3V
ch7	SEQ-PC20-1-5.2V
ch6	SEQ-PC20-1-5V
ch5	SEQ-PC20-0-5.2V
ch4	SEQ-PC20-0-5V
ch3	SEQ-PC19-1-5.2V
ch2	SEQ-PC19-1-5V
ch1	SEQ-PC19-0-5.2V
ch1	SEQ-PC19-0-5V

Figure 10: The central platform south rack monitor connections.

	R/W	R
	P2	P3
15		
14		
13		
12		
11		
10		
9	DFE-PW03-2-OE	
8	DFE-PW03-1-OE	
7		
6		
5		
4		
3		
2		
1	DFE-PW03-2-PE	DFE-PW03-2-AC-OK
0	DFE-PW03-1-PE	DFE-PW03-1-AC-OK

	R
	P5
ch15	
ch14	
ch13	
ch12	
ch11	
ch10	
ch9	
ch8	
ch7	
ch6	
ch5	
ch4	
ch3	DFE-PW03-2-5V
ch2	DFE-PW03-2-3.3V
ch1	DFE-PW03-1-5V
ch1	DFE-PW03-1-3.3V

Figure 11: The west platform rack monitor connections.

so that P2 and P3 are R/W and P6 and P7 are read-only. The rack monitor connections are shown in Figure 10 where the control signals are shown in red and the status signals are shown in green.

6.3 West Platform

The two DFE power supplies on the west platform are controlled by the rack monitor located in PW03. Confirm that the I/O switches are set so that P2 is R/W and P3 and P5 are read-only. The rack monitor connections are shown in Figure 11 where the control signals are shown in red and the status signals are shown in green.

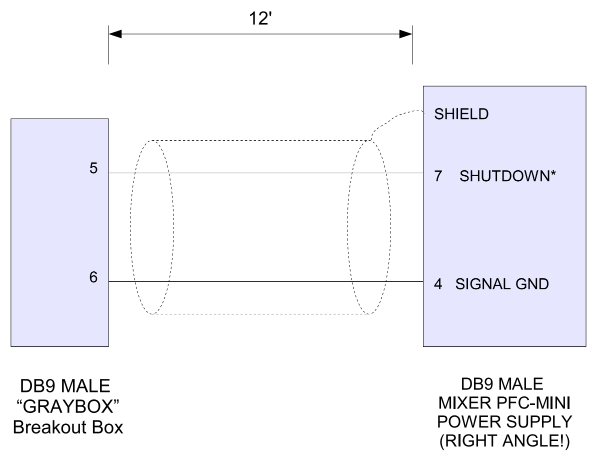

Figure 12: The control cable for the Mixer power supply.

Appendix A Control Cables

A.1 Mixer Control Cable

The control cable for the Mixer power supplies is shown in Figure 12. This cable allows for remote control of the power supply outputs. Voltage monitoring and user control of the AC is not supported on this power supply. This cable is to be installed in early 2008.

The DFE and Sequencer supplies use a standard (straight-through) DB9-DB9 cable for the connection back to the breakout box. Standard (straight-through) DB37-DB37 cables are used for the connection from the breakout box to the RM.

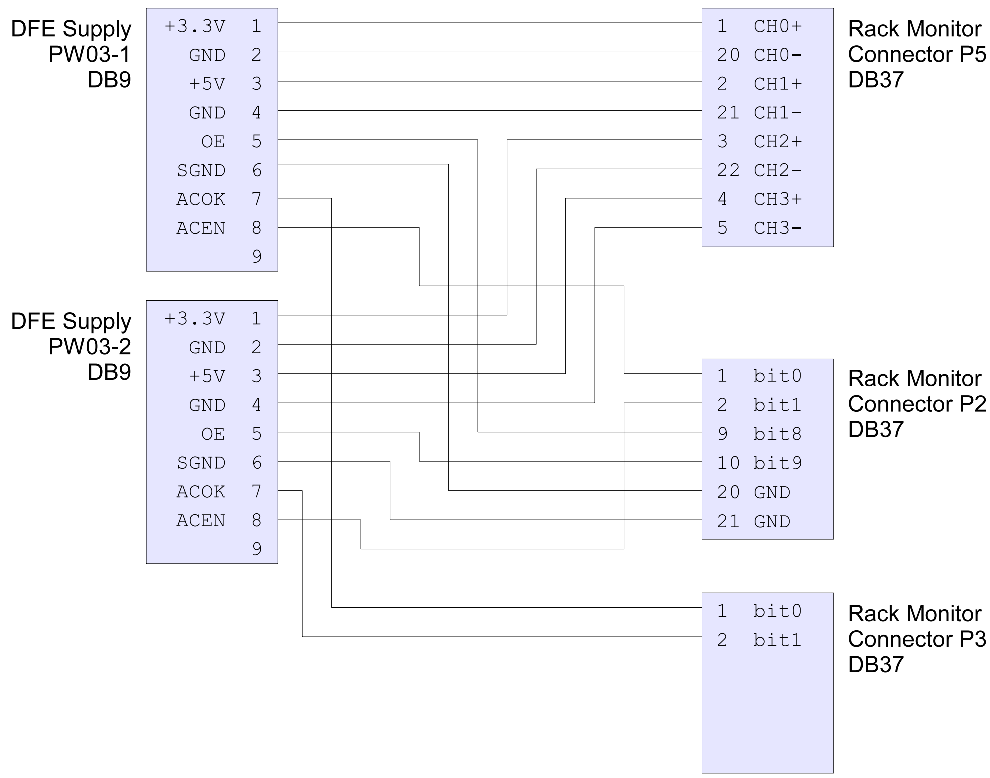

Figure 13: The DFE west platform cable harness.

A.2 West Platform DFE Cable

A custom cable harness is used to connect the two DFE power supplies to the rack monitor in PW03. The schematic for this cable is shown in Figure 13.

A.3 Breakout Box Schematic

An unreadable breakout box schematic is shown in Figure 14. A netlist format is also available if you're really interested!

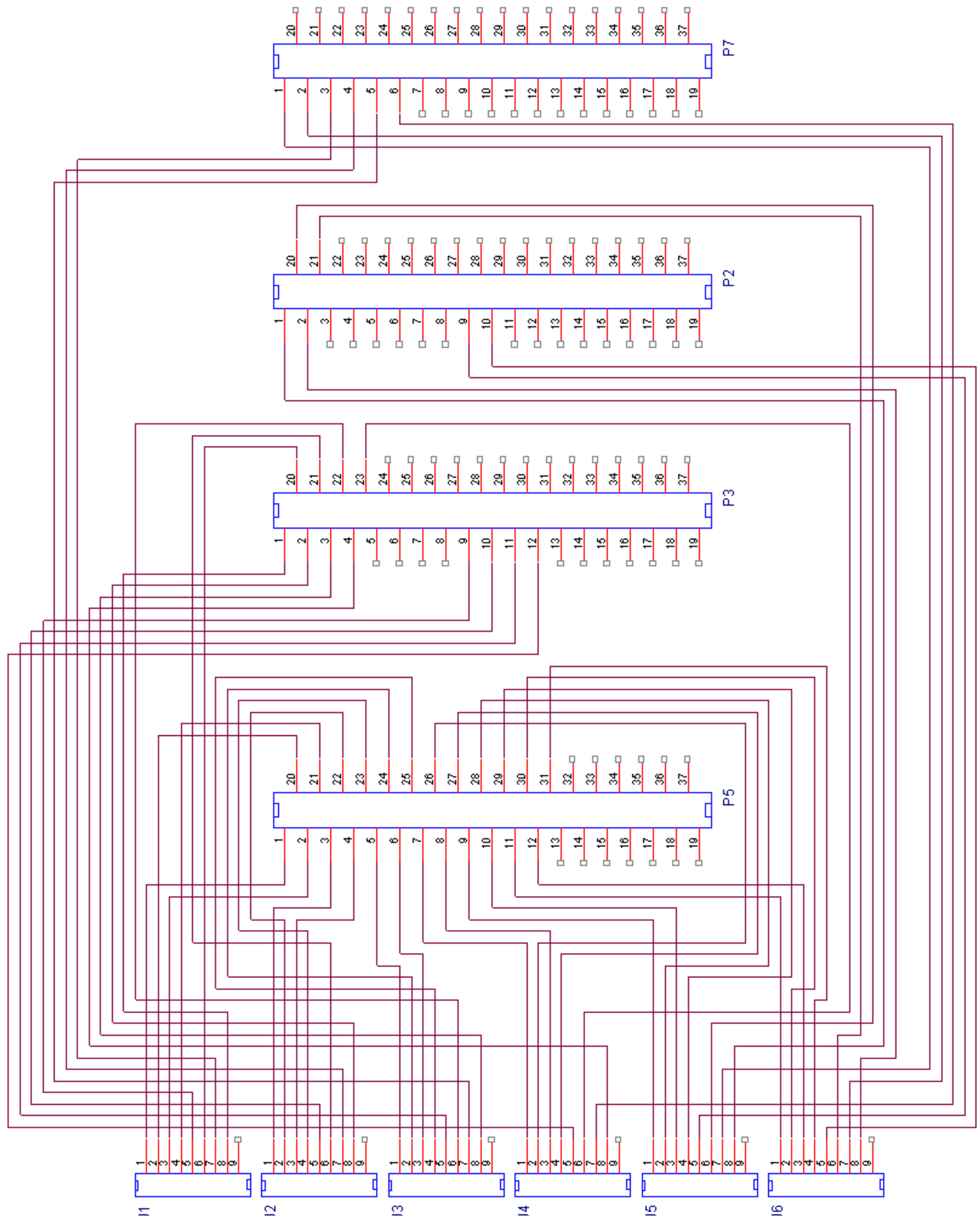

Figure 14: The breakout box schematic.

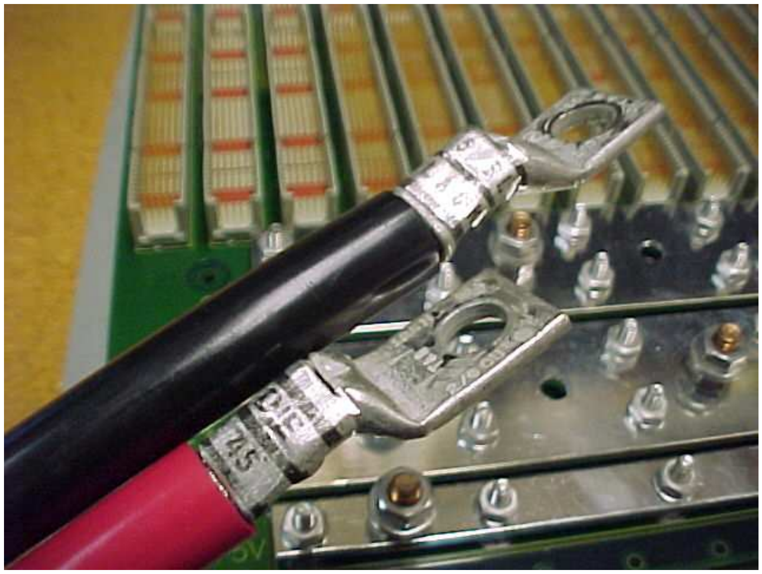

Figure 15: DFE backplane, busbars and lugs.

Appendix B DFE Backplane Current Density Calculations

Three large bus bars are used to distribute power on the DFE backplane. The high current 3.3V bus bar has maximum current density of $160A/((1.5in)(0.125in)) = 850A/in^2$ while the 5V bar the maximum current density is $40A/((0.75in)(0.125in)) = 425A/in^2$. The "ground return" bus bar handles the return current for both supplies so the current density here is $200A/((0.75in)(0.125in)) = 1050A/in^2$. While the return bus bar exceeds the $1000A/in^2$ design guideline [8] this is acceptable due to heat dissipation from the large metal area.

Worst case current density at the lug-busbar interface is determined by the surface area of standard 1/4 inch washer: $200A/(\pi(0.282in)^2 - \pi(0.125in)^2) = 996A/in^2$.

Current flows from the bus bar to the backplane pads through 18 8-32 hex nuts (ID = 0.375 in and OD = 0.550 in). Worst case current density here is calculated as $200A/((18)(\pi(0.550in)^2 - \pi(0.375in)^2)) = 87A/in^2$. Note that this calculation does not assume that any current is flowing through the stud.

Vias transfer the current from the bottom pads on the backplane to the internal power layers on the backplane. If the current density is calculated for each of the 12 vias per stud the $1000A/in^2$ design guideline is exceeded – however this is acceptable as the large copper power planes wick the heat away from the vias.

Each slot in the DFE backplane features 31 3.3V power pins, 6 5V power pins and 106 ground return pins (including shield pins). Thus the current density in these pins is calculated as: $160A/((20slots)(31pins/slot)) = 0.260A/pin$ (3.3V); $40A/((20slots)(6pins/slot)) = 0.330A/pin$ (5V); $200A/((20slots)(106pins/slot)) = 0.094A/pin$ (GND). The hard metric press fit pins are rated for 1A each.

References

[1] DZERO at Work Webpage
`http://www-d0.fnal.gov/atwork/index.html`

[2] Vicor PFC Mini Supply
`http://vicr.com/products/configurable/lopac`

[3] Al Frank, Rich Mahler and Mike Shea
The DZERO Rack Monitor Module
`http://www-linac.fnal.gov/linac_controls/hardware/DZero`

[4] DZERO Rack Monitor Interface Chassis (BiRa model 8300)
`http://www.bira.com/preview/content/products.php?do=product&prodid=21`

[5] Olsen, Jamieson
DFE Hardware and Firmware Webpage
`http://www-d0.fnal.gov/hardware/dfe/`

[6] Utes, Mike
Engineering Note U020131A revision B.
`http://d0server1.fnal.gov/users/utes/webpage/svxfiles/vicortrimresistors2.pdf`

[7] Trim Values for Fixed Output Vicor Modules
`http://www.vicorpower.com/technical_library/calculators/calc_vtrim-fixed.htm`

[8] Hance, Rick
Electrical Design Standards for Electronics to be used in
Experiment Apparatus at Fermilab
`http://www-d0.fnal.gov/~hance/guidelines.pdf`

[9] BiRA Systems Inc.
`http://www.bira.com`