TABLE OF CONTENTS

GRADIENT DRIVER THEORY - SGD BASE

1- INTRODUCTION

The SGD Base (AN8280G-TK) Cabinet is a system consisting of three switch-mode amplifiers, a switch-mode power supply and a system-control assembly mounted in a rack assembly..

The purpose of the gradient amplifiers is to produce highly stable three-axis waveforms to drive the gradient coils of a magnetic resonance imaging (MRI) system. The amplifier system accepts digital waveform data, converts the data to analog signals, and amplifies them to a high power level.

The rack assembly provides support and cooling air to the electronic modules. The front rack panel has a removable air filter. Air flow for the system is from front to back. Fans are located on a swing out panel in the rear. All modules mount onto the rack support rails. The line filter is located at the bottom of the rack.

The power supply unit (PSU) transforms and regulates the AC input to produce a high voltage output. The high voltage output is converted to the output signal by the axis amplifiers.

The System Control Assembly (SCA) includes the operator interface, and the auxiliary voltage supplies. The auxiliary voltages power the logic, analog circuitry, and fans. Local switching and an alpha-numeric display are located within the SCA unit. Control information from the SCA to the amplifiers, and status information from all three amplifiers to the SCA, are transferred on a common 34 conductor ribbon cable “Amplifier Bus”.

The amplifiers provide the high current drive to the gradient coils, and include all control interfaces and the input and output filters. The axis amplifier is a field replaceable unit. Connectors are provided on the rear of the amplifier for DC power from the PSU, and terminals for connection to the gradient load cables.

At the front of the amplifier are connectors for low voltage and oscilloscope monitoring. BNC connectors enable monitoring of the output current and voltage. A 34 circuit ribbon cable connector for the amplifier bus completes the complement of front panel connectors.

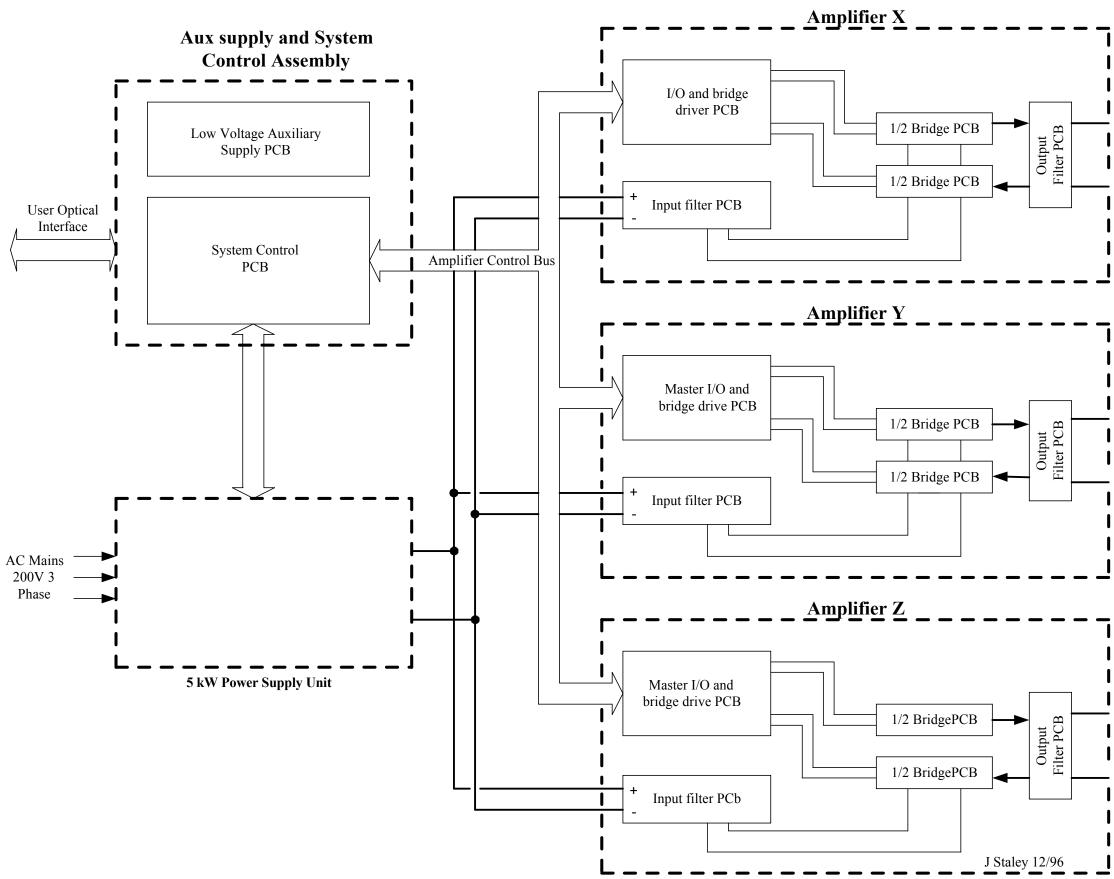
External connections to the system are:

The AC input (with safety ground)
The amplifier outputs to the three gradient coils (with shield ground)
The MDS , data and clock optical links.
The coil temperature data
The alternative electrical connections for user external data and clock

1- INTRODUCTION (continued)

Illustration 1-1 shows the relationship of the major assemblies within the AN8280G-TK system. This theory of operation begins with an overview of the (power supply and three amplifiers,) followed by a more detailed description of each of the sub-assemblies and their circuit functions. The power supply assembly includes the high voltage power supply. The SCA includes the SCA PCB and auxiliary PSU.

All communication and control to and from the system enters or exits from the SCA subassembly, located in the topmost location of the sleeve. Communication and control for the amplifiers is transmitted via a 34 line “amplifier bus,” common to the four major assemblies. System operating functions are controlled from the SCA. Amplifier local control and status functions (alarms and configuration modes,) are controlled by a micro-processor in each of the amplifiers.

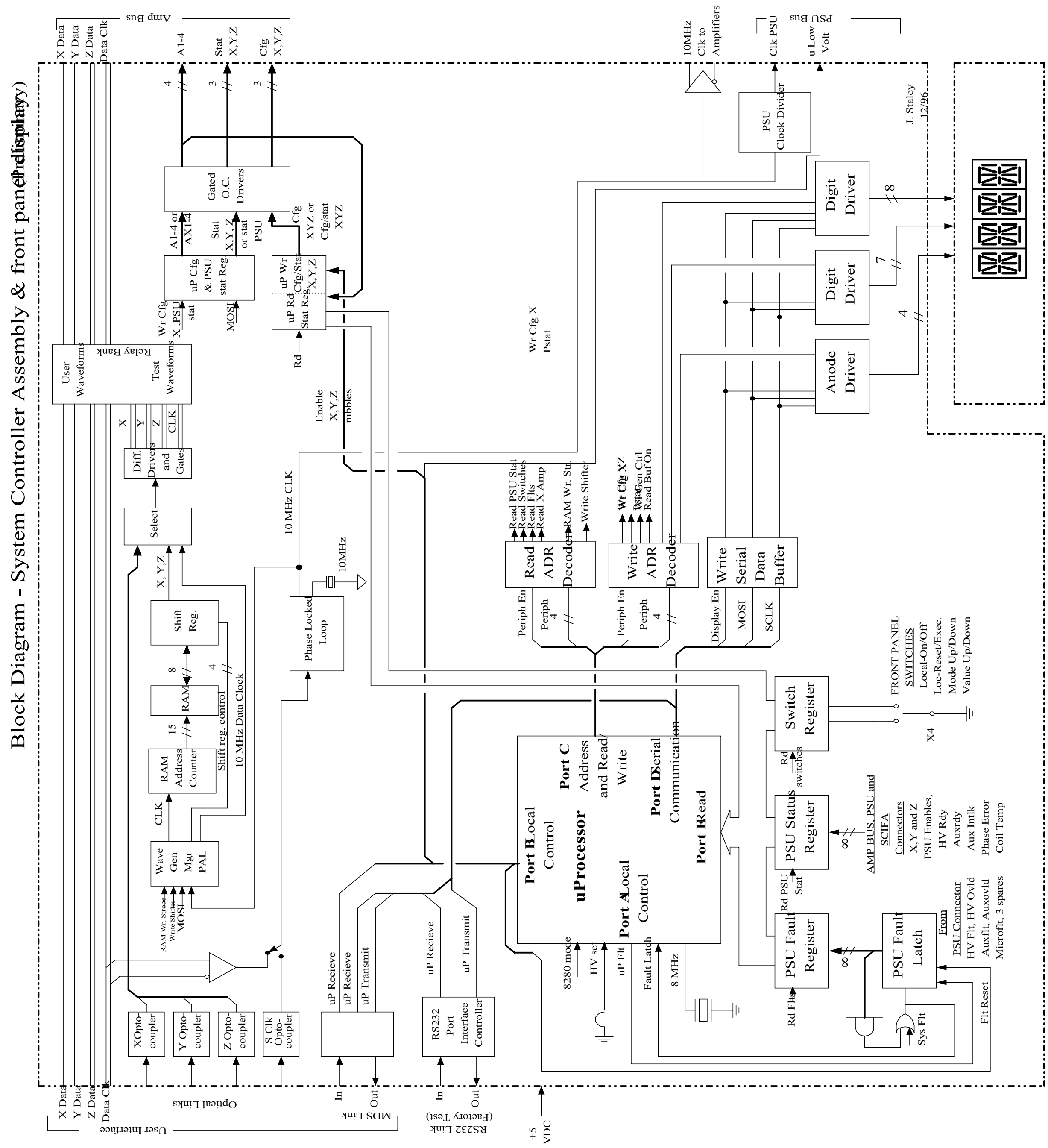


GRADIENT AMPLIFIER BLOCK DIAGRAM
ILLUSTRATION 1-1

2- SYSTEM CONTROL ASSEMBLY (SCA)

The SCA provides the following functions:

- Communication to and from the host (MRI) system.
- Communication and control of the amplifiers.
- Control and alarm management of the system PSU



SCA BLOCK DIAGRAM
ILLUSTRATION 2-1

2- SYSTEM CONTROL ASSEMBLY (SCA) (continued)

Communication Interface

Fiber-optic and/or wired serial communication links from the host system transmit data and control commands to the gradient amplifier system. Waveform data is transmitted to the amplifiers, with a synchronizing clock. The SCA supports an RS232 transceiver for factory test. Both of the serial links are managed by the Microprocessor that sorts and translates incoming commands, creating 4 bit encoded nibbles for the amplifiers, control bits for the power supply or returning status nibbles to the user. See Illustration 2-1 SCA Block Diagram

The Configuration/Status Word

The Configuration/Status Word (4 bits wide) satisfies the control and monitoring requirements of the system. When writing, the nibble *configures* the amplifiers for one of 16 possible operating modes. When reading, the word returns the operating *status* of the amplifiers. Selection of these modes is determined by the processor, and the appropriate logic state of the Config/Status line. The configuration word is routed to the amplifier bus.

Test Waveforms

Provision is made to generate waveforms for use in testing amplifier parameters. Waveform equations are generated by the processor and stored in a RAM. A PAL provides the write and read control functions for the address counter and parallel-serial shift register, and the required data clock. A relay bank selects between test and user waveforms. Wave-form data is shifted serially onto the X,Y or Z data lines with the same format as data from the user.

Microprocessor

The microprocessor provides all of the necessary control and communication functions for the system. It has a self contained program ROM and 5 I/O ports. The ports are functionally designated as follows:

PORT	FUNCTION
A (Hybrid, 8 lines)	Local control
B (Write only, 8 lines)	System Control
C (R/W, 8 lines)	Used for Write only, decodes addressees for display, status and alarm words.
D (R/W, 6 lines)	Serial Communication, display on.
E (Read only, 8 lines)	Reads 8 data registers.

2- SYSTEM CONTROL ASSEMBLY (SCA) (continued)

The µprocessor I/O lines are described as follows:

Port A:

Fault Latch - Input generated by any fault in the PSU or amplifiers. Processor responds.
Microprocessor Fault - Output asserted if the microprocessor is unable to execute its program.

Port B:

Gradient Transmit - Output control line that enables the output fiber optic transmitter.
Fault Reset - Output control line resets all fault latches in the system.
Gradient Transmit - Output control line that enables the input data from the RS232 wired port for factory test.

Port C (used as write only):

Peripheral 0-3 - Output control lines (4) used to enable one of 16 register addresses.
Peripheral enable - Output line that enables the 16 address strobes.
Micro HV enable - Output line that enables the high voltage on command.
Micro On - Output line that turns on the power supply.

Port D:

Micro RXD - Used as an input line for serial data from the fiber optic or RS232 wired links.
Micro TXD - Used as an output line for serial data to be transmitted by the fiber optic or wired RS232 links.
MISO - Unused input line.
MOSI - (Master Out Slave In) used as an output line for serial data to display registers and waveform generator.
SCLK - Used as an output line for a synchronizing clock for MOSI.
Display On - Used as an output line to enable the 7 segment display registers.

Port E:

Read D0 through 7 - Input lines used as a parallel 8 bit data bus.

Microprocessor clock - The microprocessor clock is a crystal controlled 8 MHz self contained module.

2- SYSTEM CONTROL ASSEMBLY (SCA) (continued)

MHz Clock

The 10 MHz clock is generated by a phase-locked loop. When active, serial data-clock from the host synchronizes the 10 MHz clock. When no “S-clock” is present, the loop is controlled by a 10 MHz crystal.

PSU management.

The SCA functions as the PSU manager. The PSU On/off occurs after the SCA determines there are no alarms from any axis. PSU and alarm status information are supplied to the processor from the PSU. In the event of a PSU fault, a latch is asserted enunciating a system fault. The system fault is applied to each of the amplifiers disabling their operation. The latch must be reset by the processor before operation can resume.

The PSU clock is generated on the SCA board. The 10 MHz is divided to 200 kHz or to 100kHz, with 10% or 65% duty cycle options. Frequency and duty cycle options are selected using jumpers.

Power Requirements

Supply Voltage:	+5 VDC +/- 3% @ 2.0 Amp Max. +/-50mV pk-pk ripple
RS-232 supplies:	Created internally by RS-232 driver/rcvr chip (MAX-232)

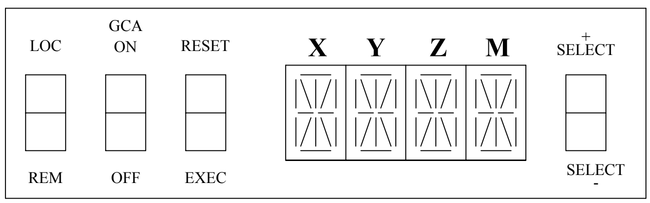
MDS (customer specified communication) Link

The MDS link consists of a ring structure of fiber-optic transmitters and receivers. Data packets are sent out from the customer master device and passed through each of the slave devices in the loop. After passing through the last slave device the data packet is sent back to the master to insure that the link functions properly. Each slave scans the message as it goes by. The slave addressed by the message must then reply (or take some action) as indicated.

3- SCA FRONT PANEL

The front panel is shown below. It consists of four alpha-numeric displays and four switches. In addition, there is a green LED to the right of the display which indicates the presence of +5V logic power for the display.

SCA Display



Front panel switches

The SCA front panel switch functions are described below.

LOCal *or* **REM**ote — When in remote, the system will respond to the control interface only, the other front panel switches remaining inactive. However the display will annunciate the status of the amplifiers. In local mode, all switches are active.

GCA ON *or* **OFF** — ON - Momentary activation turns the amplifiers and high voltage ON *if no error condition exists*. Compensation will be set according to the configuration menu.

OFF - Momentary activation turns the amplifiers and high voltage OFF.

RESET *or* **EXEC**ute — The execute switch is active when one of the following types of displays are active:

- Status display. Pushing EXEC will cause the display to enter the *menu* mode.

- Sub-menu title. Pushing EXEC button will enter the sub-menu and display it's first option.

- Menu option with a programmable value. The setting of the value may be changed with the VALUE switch. Pushing EXEC button will store *all of the new settings on the active menu* and put them in effect.

- Momentary action item. Pushing the EXEC button while such an item is displayed will execute the function.

The RESET switch has multiple function:

3- SCA FRONT PANEL (continued)

RESET *or* **EXEC**ute (Continued)

- When the display is in status mode, RESET acts as “Error Reset”. The SCA will attempt to reset the error condition, if present, on the PSU and MDS link, then an “Error Reset” command will be issued to the amplifiers.

- When in menu mode, *and a function, such as internal waveform generation*, is active, pushing RESET deactivates the function (for example, stops the internal waveform generator, when running).

- When in menu mode, *and some parameters have been changed, but not yet stored*, RESET will reset the previous settings.

- When in menu mode and none of the last two conditions are true, pushing RESET button exits the menu mode.

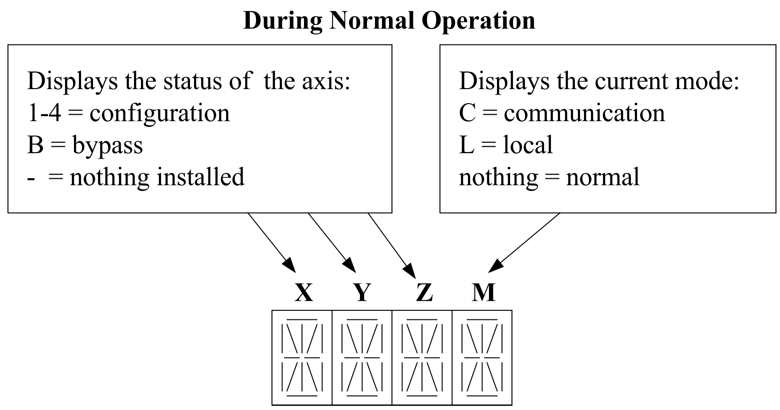
+SELECT *or* **-SELECT**

When in menu mode, this switch causes the display to scroll through a list of selections within the current level of the menus. Scrolling forwards or backwards is controlled by the direction of the switch.

Certain menu items have a parameter. When the given item is selected, the display indicates the current setting of the parameter. For such items, a *static* display indicates that the value displayed is the currently effective setting. Using the switch **+** or **–** will cause the displayed value to increase or decrease, and the display to start *blinking*. Then, pushing the EXEC switch will store and enable the selected parameter. Pushing the RESET switch restores the original value.

4- FRONT PANEL DISPLAY

The front panel annunciator will display messages depending upon whether the system is operating normally, or whether an error condition exists.



The first three digits display the status of the X, Y and Z axes. 1 through 4 signify compensation options “1-4” which correspond to preset values to optimize the gradient coil in use. “B” means that the amplifier is by-passed, or disabled, allowing the remaining axe(s) to operate normally. A dash in the space means that the system does not recognize the presence of an amplifier.

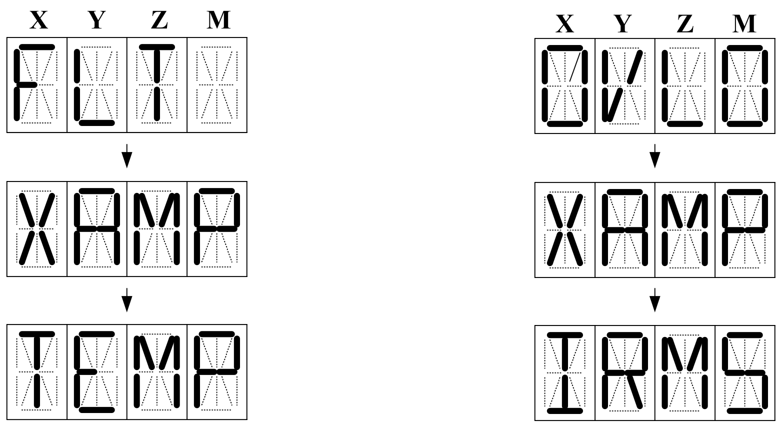
There are two types of error in the system: *overload* and *fault*. *Overload* errors result in the amplifier being disabled, but not the PSU. *Fault* errors disable (or prevent enabling) both the amplifier and the PSU.

When an error occurs, the display will sequentially display a message, depending on the error:

4- FRONT PANEL DISPLAY (continued)

Sample Display Sequences

for FAULT error for OVERLOAD error



Display codes

The following table is a description of the SCA display codes. They include error codes, test wave-forms, configuration and status codes.

	Display Indications			Display Meanings
Item	First "word"	Second "Word"	Third "Word"	Partial listing of the Remote Mode Display will similar to the Local Mode List
No.	XYZM	XYZM	XYZM	
1	◇◇◇			System is in Remote Stand-By mode
2	◆◆◆			System is in Remote High Voltage coming up.
3	□□□			System is in Remote, Amps are Ready in Configuration; 1.
4	▣▣▣			System is in Remote, Amps are Ready in Configuration; 2.
5	✲✲✲			System is in Remote, Amps are Ready in Configuration; 3.
6	⌘⌘⌘			System is in Remote, Amps are Ready in Configuration; 4.
7	◊◊◊			System is in Remote, Amps are Ready in Configuration; By-Pass.
8	▣▣▣			System is in Remote, No Amps are

				installed.

4- FRONT PANEL DISPLAY (continued)

Auxiliary Power Supply

The auxiliary power supply printed circuit board is located within the SCA. It consists of three DC-DC converter modules, that supply regulated 48V, ± 15V DC, and 5V DC for the entire system. The input power for the board is rectified, unregulated line voltage from the power supply. The output voltages are routed to the amplifiers via shielded cables.

The auxiliary voltage specifications are as follows:

+15 VDC ± 3%, 1.5A max., 1.0A nom., 6.0 A surge
-15 VDC ± 3%, 1.5A max., 1.2 A nom., 6.0 A surge
+ 5 VDC ±3%, 5.0 A max., 4.5A nom., 6.0 A surge
+48 VDC ±5%, 4.5A max., 4.0A nom., 8.0 A surge

5- HIGH VOLTAGE POWER SUPPLY UNIT (PSU)

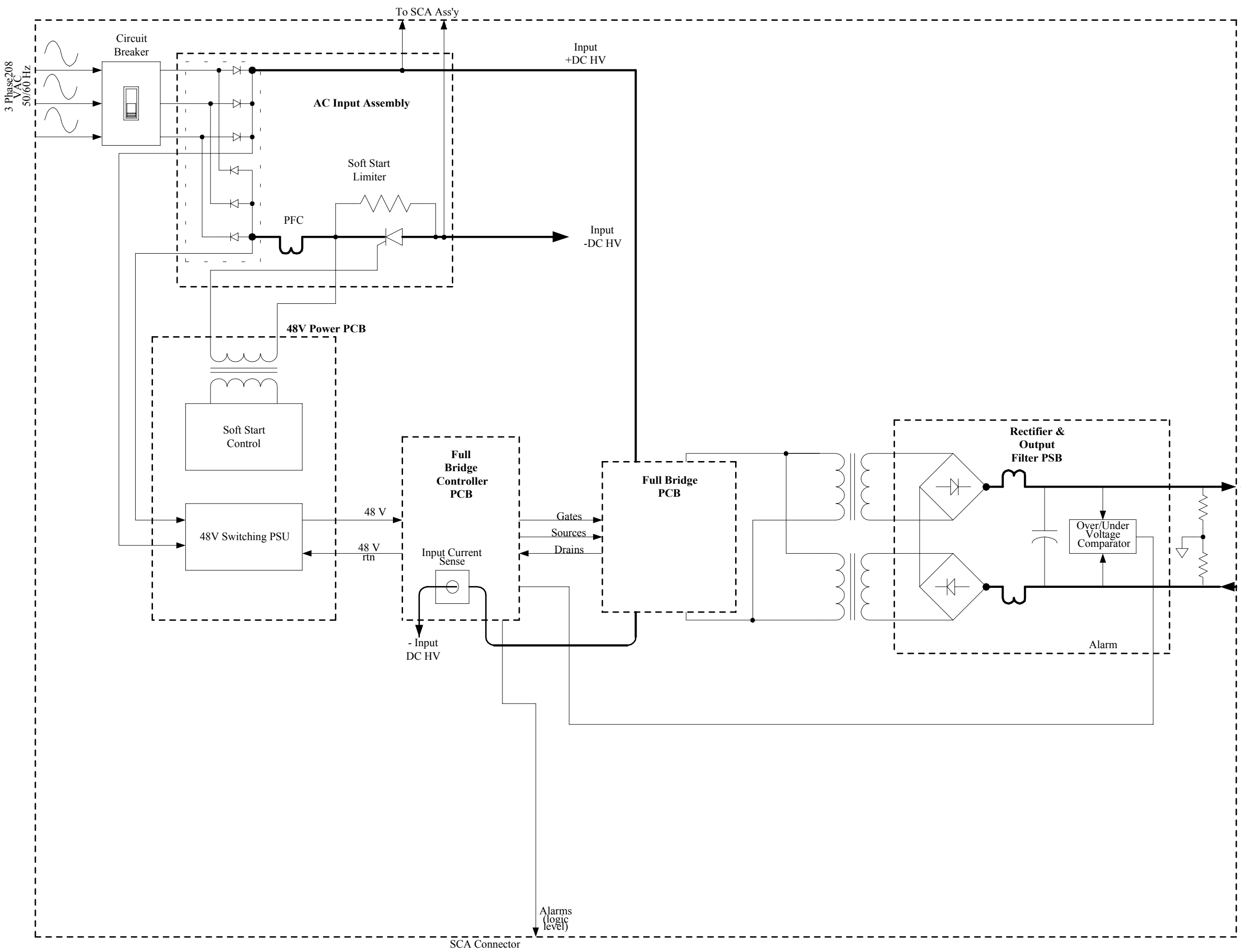
The high voltage power supply provides high-voltage to the amplifiers. It is located below the SCA.

High Voltage Power	370 ± 10 VDC
Power output:	10 kW maximum
Power input:	12 kW maximum
VA input	13.5 kVA maximum

Connectors located in the rear:

Mains field wiring	3 phases and protective earth
HV power	3 high voltage connectors

+ 5 V operation is verified by a green LED visible behind the front panel.



5- HIGH VOLTAGE POWER SUPPLY UNIT (PSU) (continued)

The PSU is a field replaceable unit. Referring to the above block diagram, the input rectifier, soft start assembly, and filter provide unregulated DC power for the DC to DC converter, and input power for the auxiliary PSU located in the SCA. The full bridge PCB is controlled by the Full-bridge controller assembly, which generates PWM pulses controlling, through its four drivers, high voltage bridge to generate 360-380 VDC.

The DC-DC converter consist of 5 printed circuit boards:

AC Input
48V Auxiliary Supply.
Full-bridge controller
Full-bridge

Rectifier & Output Filter

AC Input

The AC input board interconnects the input rectifiers, circuit breaker and soft-start SCR. It also provides support for the input MOVs and soft-start series resistors. It provides rectified line voltage for the HV and auxiliary voltage switching regulators.

48V auxiliary supply.

The 48V auxiliary supply is a daughter board to the Full-bridge controller. This board performs the following functions:

- Provides 48V DC for the Full-bridge Controller.
- Controls the soft start SCR
- Activates the main circuit breaker trip coil if the temperature of the converter or the soft start assemblies exceeds 85° C

Full-bridge Controller

The full-bridge controller provides the following functions:

- Pulse Width Modulator (PWM) for the HV bridge.
- Opto-coupled output drivers with de-saturation protection.
- Current sensor for current feedback
- High voltage regulation.

5- HIGH VOLTAGE POWER SUPPLY UNIT (PSU) (continued)

Full Bridge board

The full-bridge PCB provides the following functions:

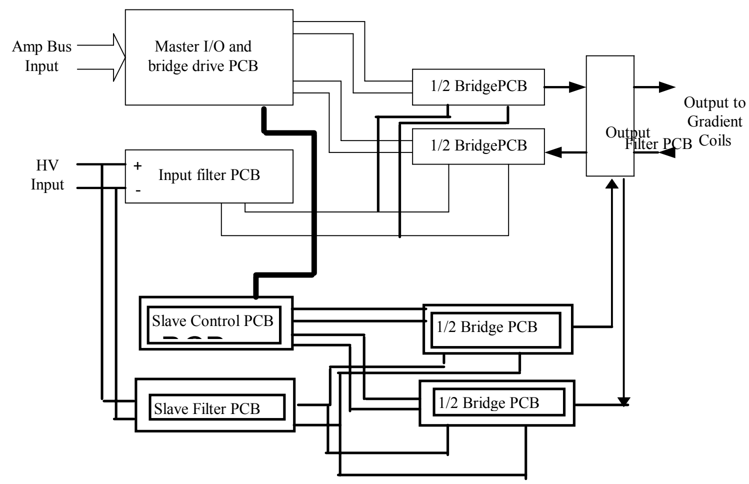
Inter-connects the driver circuitry to the Power mosfets.
Snubbing for the mosfets.
Inter-connection points for high voltage input, output transformers and filter inductors.
Filtering and energy of the unregulated rectified line DC input voltage.

Output rectifier and filter board

The Output Rectifier and filter board rectifies the 100kHz switched output of the transformer. The rectified output(s) are applied to ferrite output inductors. An output capacitor storage bank completes the filter system. A mid-point reference to ground is established using two 4.3k ohm resistors. RFI filtering is provided prior to the HV DC output terminals at the rear of the PSU.

6- GRADIENT AMPLIFIER

The X,Y, and Z gradient amplifiers are identical assemblies located below the power supply in the AN8280G-TK system. Illustration 6-1 shows the functional elements of the amplifier.



GRADIENT AMPLIFIER BLOCK DIAGRAM
ILLUSTRATION 6-1

The amplifier is a FRU. Its elements are an input filter board, two half bridge boards, an I/O control board and an output filter board, all mounted to a heat sink. Referring to the block diagram above, the HV DC is applied to the high voltage connector to the input filter board. The input filter consists of a bank of electrolytic capacitor and an RFI filter. The HV power is then fed to the half bridge boards of the master and slave modules.

Control signals, sent from the system control assembly, select the configuration of the amplifier. The status of the amplifier is returned to the SCA via the Amplifier Bus cable, controlled by a microprocessor located on the I/O control board. The 10 MHz clock, generated on the SCA, is also provided to the amplifiers on the Amplifier Bus cable. When divided down by the programmable logic, it synchronizes the 100 kHz pulse width modulators.

The waveform information is sent in serial form over the amp bus cable and is routed to a D/A converter located on the I/O control board. This converts the data to analog format, 5 volts full scale, and represents the desired output current of the amplifier. From this signal is subtracted the measured output current signal . The resulting error signal is combined with feedback signals for the voltage and current compensation to produce a dynamically compensated current demand signal. This is fed to the inner loop and pulse width modulator circuitry. The open loop bandwidths of the loops is approximately 10 kHz, and the resulting closed loop has the specified bandwidth of the amplifier. The outer loop provides high precision and stability while the inner loop enables fast response.

6- GRADIENT AMPLIFIER (continued)

The pulse width modulator (PWM) digital loop converts the analog current demand signal to a digital format and produces an output current proportional to the demand. A bridge switch alternately connects the output drive point to the positive and negative HV power supply. This produces a voltage waveform at the output drive point which has a fixed frequency of 100 kHz but with a duty cycle (fraction of the period at the positive value) which is modulated to give an average value equal to the desired output voltage.

The pulse width modulation circuitry consists of a current measurement Hall effect device which produces a voltage equal to the scaled value of the current, which is compared with the desired current and with a synchronized saw-tooth waveform. The offset and slope of the saw-tooth waveform are adjusted for the power supply voltage, output voltages, and filter inductor values to give an accurate output current under all conditions. The timing of the saw-tooth waveform is derived from the 100 kHz clock.

The output of the pulse width modulation comparator represents the desired state of the bridge. When it is high, the bridge impresses positive HV voltage across the output filter. When it is low, the bridge impresses negative voltage across the load. The output drive point voltage is then applied to a low pass filter . Each half bridge is connected to the load through a large inductor located on the heat sink inside the inductor shield. Filter capacitors located on the output filter board connect from inductor output to ground, and from one side of the load to the other. The resulting load voltage is passed through the output filter board for final output RFI filtering and is routed to the output terminals, labeled +/- in the block diagram, physically located on the rear of the amplifier.

A precision current shunt is mounted near the output filter board. The output current signal sampled by the shunt, as well as the output voltage signal, are filtered on the output filter board and routed to the I/O control board. The current shunt signal is amplified and common mode voltage rejected by circuitry on the I/O control board under the RF shield. The output current and voltage signals are then used in the compensation and current comparison circuitry described previously to produce the control loops. These signals are also buffered, filtered, and made available on the front panel to monitor the output of the amplifier.

The amplifiers are identified electronically as X, Y, or Z by their connection via the Ampbus cable. Two ID bits are connected to ground at the PSU SCA end of the cable, and are pulled up to +5V through resistors at each amplifier. The wires in the Ampbus cable are clipped open; ID2 between the X and Y amplifiers, and ID1 between the Y and Z amplifiers. This means that the X amplifier sees both signals low, the Y amplifier sees ID1 low and ID2 high, and the Z amplifier sees both signals high. This tells the amplifier which position it occupies in the system, and allows it to pick the proper control and data information to perform its function. Incoming data to the amplifier includes timing signals, configuration and current waveform. Outgoing data gives amplifier status. Details of the Ampbus cable are given in the System Control Assembly section.

6- GRADIENT AMPLIFIER (continued)

The Amplifier Status codes, reported for the X, Y, and Z amplifiers as codes AA, Ab, and AC on the front panel of the SCA, are as follows:

Status Codes X, Y, Z-Amp's A4 A3 A2 A1	Amplifier Status Condition
0	GCA not ready, no auxiliary voltage present
1	System Ready, GCA load compensation value #1
2	System Ready, GCA load compensation value #2
3	System Ready, GCA load compensation value #3
4	System Ready, GCA load compensation value #4
5	GCA not ready, auxiliary power present, HV off
6	GCA not ready, configured
7	Amplifier in Bypass Mode
8	unused
9	Power Module Fault (Over Current or Loss of Clock)
A	GCA not ready, not configured, HV on
B	Power module heatsink Temperature Fault
C	High voltage not present fault

D	unused
E	unused
F	RMS Current Overload

Amplifier Configuration Register

The following table describes the configuration settings, including compensation and gain, of the amplifier. Gain settings change both the output scaling and the current monitor settings.

Configuration	Application (Nominal full scale output current)
1	Signa Contour, 150 Amps
2	Spare, 150 Amps
3	Spare, 200 Amps
4	Signa 1.0/ 1.5T, 200 Amps

REVISION HISTORY

REV	DATE	AUTHOR	PRIMARY REASONS FOR CHANGE
0	Oct 3, 1997	J. Wolak	Initial version for SGD production introduction.
1	Dec 17, 1997	J. Wolak	Removed the references to some factory adjust pots
2	October 13, 1999	K. Keshena	Changed to use a Proprietary header.