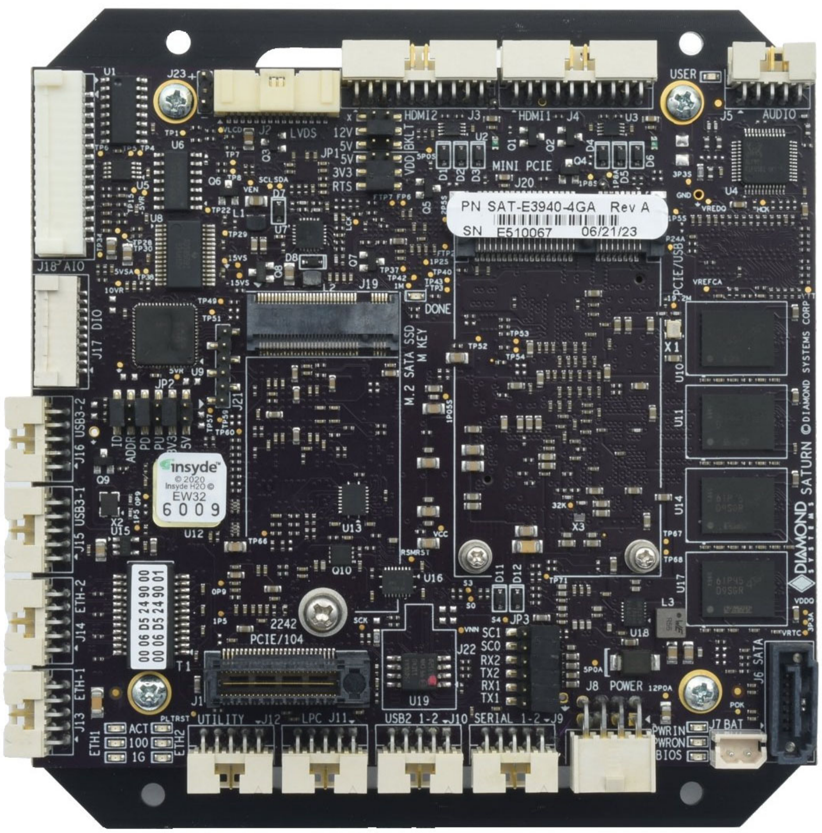
SATURN

PCIe/104 Expandable Rugged Single Board Computer
with Intel "Apollo Lake" E3950 Processor



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1 IMPORTANT SAFE HANDLING INFORMATION

WARNING!

ESD-Sensitive Electronic Equipment

Observe ESD-safe handling procedures when working with this product.

Always use this product in a properly grounded work area and wear appropriate ESD-preventive clothing and/or accessories.

Always store this product in ESD-protective packaging when not in use.

<u>Safe Handling Precautions</u>

The Saturn SBC contains a high number of I/O connectors with connection to sensitive electronic components. This creates many opportunities for accidental damage during handling, installation and connection to other equipment. The list here describes common causes of failure found on boards returned to Diamond Systems for repair. This information is provided as a source of advice to help you prevent damaging your Diamond (or any vendor's) embedded computer boards.

ESD damage – This type of damage is usually almost impossible to detect, because there is no visual sign of failure or damage. The symptom is that the board eventually simply stops working, because some component becomes defective. Usually the failure can be identified and the chip can be replaced.

To prevent ESD damage, always follow proper ESD-prevention practices when handling computer boards.

Damage during handling or storage – On some boards we have noticed physical damage from mishandling. A common observation is that a screwdriver slipped while installing the board, causing a gouge in the PCB surface and cutting signal traces or damaging components.

Another common observation is damaged board corners, indicating the board was dropped. This may or may not cause damage to the circuitry, depending on what is near the corner. Most of our boards are designed with at least 25 mils clearance between the board edge and any component pad, and ground / power planes are at least 20 mils from the edge to avoid possible shorting from this type of damage. However these design rules are not sufficient to prevent damage in all situations.

A third cause of failure is when a metal screwdriver tip slips, or a screw drops onto the board while it is powered on, causing a short between a power pin and a signal pin on a component. This can cause overvoltage / power supply problems described below. To avoid this type of failure, only perform assembly operations when the system is powered off.

Sometimes boards are stored in racks with slots that grip the edge of the board. This is a common practice for board manufacturers. However our boards are generally very dense, and if the board has components very close to the board edge, they can be damaged or even knocked off the board when the board tilts back in the rack. Diamond recommends that all our boards be stored only in individual ESD-safe packaging. If multiple boards are stored together, they should be contained in bins with dividers between boards. Do not pile boards on top of each other or cram too many boards into a small location. This can cause damage to connector pins or fragile components.

Power supply wired backwards – Our power supplies and boards are not designed to withstand a reverse power supply connection. This will destroy each IC that is connected to the power supply (i.e. almost all ICs). In this case the board will most likely will be unrepairable and must be replaced. A chip destroyed by reverse power or by excessive power will often have a visible hole on the top or show some deformation on the top surface due to vaporization inside the package. **Check twice before applying power!**

Overvoltage on analog input – If a voltage applied to an analog input exceeds the design specification of the board, the input multiplexor and/or parts behind it can be damaged. Most of our boards will withstand an erroneous connection of up to ±35V on the analog inputs, even when the board is powered off, but not all boards, and not in all conditions.

Overvoltage on analog output – If an analog output is accidentally connected to another output signal or a power supply voltage, the output can be damaged. On most of our boards, a short circuit to ground on an analog output will not cause trouble.

Overvoltage on digital I/O line – If a digital I/O signal is connected to a voltage above the maximum specified voltage, the digital circuitry can be damaged. On most of our boards the acceptable range of voltages connected to digital I/O signals is 0-5V, and they can withstand about 0.5V beyond that (-0.5 to 5.5V) before being damaged. However logic signals at 12V and even 24V are common, and if one of these is connected to a 5V logic chip, the chip will be damaged, and the damage could even extend past that chip to others in the circuit.

Bent connector pins – This type of problem is often only a cosmetic issue and is easily fixed by bending the pins back to their proper shape one at a time with needle-nose pliers. The most common cause of bent connector pins is when a PC/104 board is pulled off the stack by rocking it back and forth left to right, from one end of the connector to the other. As the board is rocked back and forth it pulls out suddenly, and the pins at the end get bent significantly. The same situation can occur when pulling a ribbon cable off of a pin header. If the pins are bent too severely, bending them back can cause them to weaken unacceptably or even break, and the connector must be replaced.

2 INTRODUCTION

SATURN is a 4.5” x 4.0” PCIe/104-expandable SBC based on Intel Apollo lake x7-E3950 processor with a PassMark™ rating of approximately 2100. It features 4GB Non-ECC / 8GB ECC DDR3L memory soldered on board, conduction cooling, Minicard socket, M.2 socket, two Gigabit Ethernets, multiple simultaneous display support, and -40 to +85C operation.

In addition to its integrated analog and digital I/O, Saturn provides significant I/O expansion capability using a PCIe/USB minicard socket and a PCIe/104 OneBank connector with 4 PCIe x1 links available. Therefore Saturn is an excellent choice for applications that require high levels of I/O.

Previous models of Saturn were based on the x5-E3940 processor. The product has been upgraded, and only the E3950 processor models are available as of the date of this user manual.

2.1 Models

Model number	Processor / speed	RAM	Data Acquisition	Stock Status
SAT-E3950-4GA	X7-E3950 / 1.60 GHz	4GB Non ECC	Analog + Digital I/O	Stocked
SAT-E3950-4GD	X7-E3950 / 1.60 GHz	4GB Non ECC	Digital I/O	Min Order Quantity
SAT-E3950-8GEA	X7-E3950 / 1.60 GHz	8GB ECC	Analog + Digital I/O	Min Order Quantity
SAT-E3950-8GED	X7-E3950 / 1.60 GHz	8GB ECC	Digital I/O	Min Order Quantity

Model SAT-E3950-4GA is normally available in stock. The other models are not stocked and are available to order. A minimum order quantity, typically 50 units, is required to satisfy factory production policy.

2.2 Features

♦ Processor	"Apollo Lake" x7-3950, Quad Core, 1.6GHz, 12W TDP
♦ Memory	On board 8GB DDR3L ECC (optional) / 4GB non-ECC (standard)
♦ Ethernet	1 10/100/100 Mbps direct from processor using I210 PHY
	1 10/100/1000 Mbps from 1:4 PCIe switch using I210 PHY
♦ SATA	1 port, direct from processor to standard SATA connector
	1 port, direct from processor to M.2 2242 connector
♦ USB	2 USB 2.0 ports to standard header
	2 USB 2.0 / USB3.0 ports to standard header
	1 USB 2.0 port on Mini card socket
	2 USB 2.0 ports to One Bank PCIe/104
♦ LCD	Dual channel LVDS, using eDP to LVDS Bridge
♦ HDMI	2 ports direct from processor
♦ Audio	HD Audio with Line In, Mic In, Line Out
♦ Serial ports	2 ports with RS232/RS422/RS485 capability
	1 port with RS232 capability
♦ Data Acquisition	16 16-bit analog inputs with 250KHz maximum sample rate
	4 16-bit analog outputs with waveform generator
	22 digital I/O lines with programmable direction (16 DIO on N models)
	8 32-bit counter/timers
	4 24-bit PWMs
♦ Expansion	1 Full-size MiniCard socket with PCIe x1 and USB2.0
	1 M.2 2242 socket with SATA
	One Bank PCIe/104 with 4 PCIe x1, 2 USB2.0

2.3 Operating System Support

- Windows 10 64-bit, Linux 64-bit OS support
- Driver packages and ready-to-run board-support packages (BSPs) are available for each OS

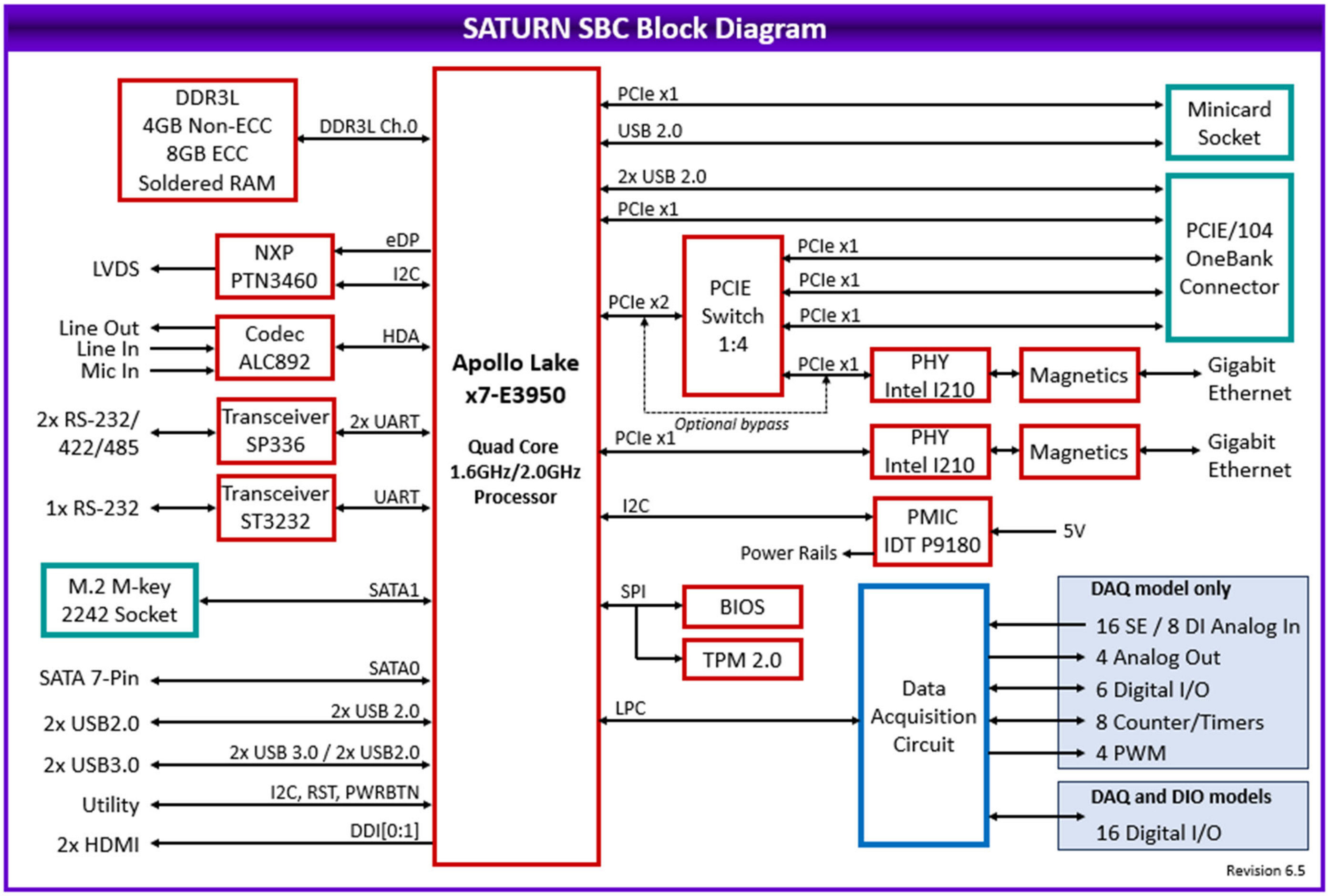
2.4 Mechanical, Electrical, Environmental

♦ Form factor	4.5"W x 4.0"H / 114 x 102mm
♦ Cooling	Conduction cooling, heat spreader
♦ Power	+5VDC in
♦ Operating Temp	-40°C to +85°C at outer surface of heat spreader
♦ Environmental	Designed to meet the following conditions:

- Shock: MIL-STD-202G, Method 213-B, Table 213-1 Condition A, 50G / 11ms half sine, non-operational
- Vibration: MIL-STD-202G, Method 214A, Table 214-1, Condition D, 11.95G random vibration, 15 minutes per axis, operational

3 FUNCTIONAL OVERVIEW

3.1 Block Diagram



3.2 Feature Descriptions

This section describes the key subsystems of the Saturn SBC.

3.2.1 Processor and Chipset

Saturn SBC is based on Intel Atom processor x7-E3950 (“formerly known as Apollo Lake”). It is a quad core, 64-bit processor with a maximum frequency of 1.6GHz.

3.2.2 Memory

The design employs DDR3L memory down configuration with ECC. The design supports a single channel memory interface with either 4GB non-ECC or 8GB ECC DDR3L RAM.

3.2.3 Ethernet

The board provides two Gigabit Ethernet ports. One port is derived directly from processor’s x1 PCIe lane using an external I210 controller. The second port is realized from 1:4 PCIe switch lane using I210 controller. The board also includes the necessary magnetics for both the ports. Ethernet interface is terminated on a latching connector, not an RJ-45 jack.

On-board LEDs are provided for Link, Activity, and Speed. The LEDs are located along the board edge near the Ethernet connector. The GbE ports use dual row,2x5 2mm pitch latching connectors. The connector does not provide access to the LED signals.

3.2.4 SATA

The board offers two SATA ports, both derived from the processor. One port is connected to an industry-standard vertical 7-pin SATA connector that accepts cables with latching. The second port is connected to M.2 2242 size, M-key socket. An M3 spacer and screw are provided to secure the SSD to the board.

3.2.5 Display

The board offers three display output options: two HDMI and one LVDS.

The HDMI ports are directly from the processor and are made available on two separate dual row 2x10 2mm pitch latching connectors. Two HDMI ports support HDMI 1.4b, maximum resolution is up to 3840x2160 @ 30Hz.

LVDS interface is obtained using an eDP to LVDS converter with the NXP PTN3460. The LCD backlight control is provided by a PWM circuit. Both single channel and Dual channel LCDs are supported. VDD voltage can be selected from 5V or 3.3V and Backlight Voltage can be selected from 12V or 5V.

LCD data signals are terminated on a 2x15 1mm pitch latching while LCD Backlight control & enable signals are terminated on a 1x6 1.25mm pitch latching connector. LVDS display supports upto1920x1200 @ 60 Hz resolution in dual LVDS bus mode.

By default, Single channel 1366x768 resolution LCD is enabled.

Tested LCD modules: Saturn is tested with the following sample LCDs:

10.1” 1366x768 Single Channel Display from Seeed Technology Co., Ltd. Part# 104990066

21.5” 1920*1080 Dual Channel LCD from AUO, Part# M215HTN01.1

3.2.6 Audio

The board provides HDA compatible audio controller ALC892. Audio I/O signals include stereo line in, stereo line out and mono mic in. The analog audio signals are made available on a dual row 2x5 2mm pitch latching connector.

3.2.7 Minicard Socket

Saturn provides expansion for one full size (51mm length) PCIe / USB Minicard socket. The socket supports mPCIe add on cards. Minicard interface support PCIex1 lane port and one USB2.0 port. Access to SIM card signals are not provided. If an LTE modem needs to be used, please select a module with a SIM socket.

Saturn provides 2 M2 4.55mm spacers and M2 screws to secure the installed minicard onto the board.

Refer the below link for Minicard modules available from Diamond systems.

http://www.diamondsystems.com/products/minicards.php

3.2.8 USB

The board offers seven USB 2.0 ports and two USB 3.0 ports directly from the processor.

One USB 2.0 port is connected to the Mini card socket, two are made available on dual row 2x5 2mm pitch latching connector, and another two are available on one bank PCIe/104 connector.

USB 3.0 ports are available on 2nos of dual row, 2x5 2mm pitch latching connectors along with USB2.0 ports. The USB3.0 and USB2.0 port mappings are as below:

USB3.0 Ports		
Port Number	Function	Connector
Port 0	USB3.0 port 1	J15
Port 1	USB3.0 port 2	J16
USB2.0 Ports		
Port Number	Function	Connector
Port 0	USB3.0 port 1 fallback	J15
Port 1	USB3.0 port 2 fallback	J16
Port 2	MiniCard socket	J20
Port 3	PCIe/104 Link 1	J1
Port 4	PCIe/104 Link 2	J1
Port 5	USB2.0 port 1	J10
Port 6	USB 2.0 port 2	J10

3.2.9 Serial Ports

The board provides 3 serial ports from the processor. Two serial ports support RS-232/422/485 protocols using Exar SP336 multiprotocol transceivers. Protocol selection is done with a jumper block. TX/RX 121-ohm line termination resistors for RS-422/485 operation are also controlled by jumpers.

One serial port supports fixed RS-232 protocol using an RS-232 transceiver or 3.3V logic level "UART" operation. Only signals TX and RX are provided. The RS-232 port is also used as console redirection for debug/development purposes.

The two multi-protocol serial ports are terminated on a 2x5 2mm pitch latching connector. The fixed RS-S232 port is made available on the utility connector.

3.2.10 Data Acquisition

Saturn models ending in "A" include a high-quality data acquisition subcircuit containing analog input, analog output, and digital I/O features. This circuit is controlled by an FPGA attached to the processor via the LPC bus.

Features of the DAQ subcircuit include: 16 single-ended / 8 differential analog inputs with 16-bit resolution, programmable input ranges, and 250KSPS maximum throughput; 4 analog outputs with 16-bit resolution, programmable output ranges, and waveform generator capability; 22 digital I/O lines with selectable 3.3V/5V logic levels, selectable pull-up/down resistors, and programmable direction; 8 32-bit up/down counter/timers; and 4 24-bit PWM circuits. The data acquisition circuit is described in more detail in a later chapter in this manual.

3.2.11 RTC Backup Battery

An onboard 2032 coin cell battery holder and battery are provided on the bottom side of the board, accessible through a cutout in the heat spreader. A 1x2 connector is also provided on the top side to enable the use of an external battery for rugged applications or easier field replacement.

Batteries are rated in milli-ampere hours (mAh). The battery life on a single-board computer can be calculated by dividing the battery's capacity by the average RTC current in a power-off state and considering external factors that may affect the battery life and discharge capability, such as ambient temperature. The RTC battery current consumption on Saturn is 6uA with the RTC voltage at 3.0V while the system is in a mechanical off (G3) state at room temperature. This data can be used to estimate the battery life. The voltage of the battery can affect the RTC accuracy. In general, when the battery voltage decays, the RTC accuracy also decreases.

With an average 6uA current drain, if the battery storage capacity is 190 mAh (assumed usable) the expected battery life will be: 190,000 µAh / 6 µA = 31,667 h = approximately 3.6 years.

Any external battery connected to Saturn should meet these specifications: Typical 3.0V; Max: 3.2V; Min: 2.0V

The board can boot and function properly without a backup battery installed.

3.2.12 Trusted Platform Module (TPM)

The board contains Infineon's SLB 9670XQ2.0 TPM module featuring a fully TCG TPM 1.2/2.0 standard compliant module with an SPI interface. TPM can be used as a root of trust for platform integrity, remote attestation, and cryptographic services.

3.2.13 PCIe link routing

Apollo lake processor supports 4 PCIe 2.0 ports and 6 lanes can be allocated over those 4 ports. Bypass option is provided for I210 Gbe Controller 2 by removing PCIe switch for the configuration where PCIe switch and PCIe/104 connector is not used.

The PCIe port mapping is as below:

PCIe Port No.	Lane Width	Port Termination
Port 1	X2	1:4 PCIe Switch • Three x1 lanes to one bank PCIe/104 connector • One x1 lane to I210 Gbe controller 2
Port 2	x1	I210 Gbe controller 1
Port 3	x1	One bank PCIe/104 connector Port1
Port 4	x1	Minicard socket

3.2.14 PCIe/104 OneBank Expansion

The board offers expansion over one bank PCIe/104 connector with taller 22mm stacking height to ensure clearance over an installed minicard module on the main board.

The PCIe/104 OneBank specification supports up to four x1 PCIe links on the PCIe/104 connector, and all four links are supported on Saturn. Link 1 offers full-bandwidth operation due to its direct connection to the processor. Links 2-4 share a single PCIe link via a 1:4 PCIe switch (which also drives a second Gigabit Ethernet controller). I/O boards that require full PCIe bandwidth should be installed in the first position (direct mounting on Saturn) to gain access to the first PCIe link.

The PCIe lane mapping on the one bank PCIe/104 connector is as below:

PCIe Lane No.	PCIe Connection
Lane 0	Directly from the processor
Lane 1	Indirectly from the processor via a 1:4 PCIe switch
Lane 2	
Lane 3	

5VDC from the input power connector is directly connected PCIe/104 connector so that the board can either powered by input power connector or PCIe/104 one bank connector. Option to disconnect 3.3V to the PCIe/104 connector is provided.

PCIe/104 I/O boards providing a wide variety of I/O capabilities are available from many manufacturers around the world. Refer to the below link for example PCIe/104 based modules from Diamond Systems:

Quad/Octal serial port modules with / without opto-isolation:
http://www.diamondsystems.com/products/emeraldmm8el

Quad PCIe minicard carrier board:
http://www.diamondsystems.com/products/e104mpe

3.2.15 Utility

The board offers two 2x5 utility connectors, one with LPC bus interfaces for external IO expansion and another with Serial Port (RS232), Power Button, Reset button and I2C interface.

Out of the two connectors, one provides 500mA fused 3.3V and 5V and the other connector provide 500mA fused 3.3V.

3.2.16 LED Indicators

The board provides the following LED indicators. All LEDs are located near to a board edge or their respective features. The blue LED is located along the lower edge of the board. All LEDs are labeled in silkscreen with their function.

PWRIN:	Green LED when Input supply 5VDC is applied
PWRON:	Green LED when board is powered on
BIOS:	Green, connected to a GPIO line on the processor; this LED is off during power-up and is turned on in the BIOS to indicate a successful system BIOS startup.
Ethernet:	6 Green LEDs, 1 each for Link, Activity, and Speed per port
DONE:	FPGA is configured successfully.
USER:	Blue, User LED, controlled by processor FPGA

3.2.17 BIOS Features

The BIOS provides the following key features:

- Boot from LAN (PXE) as well as USB and SATA ports
- Free boot sequence configuration to allow different boot sequences as first, second and third boot devices
- Support multi display mode. HDMI and LVDS can be active simultaneously
- Console (display and keyboard) redirection to one or more COM ports
- DSC-configurable default settings in battery-less configurations; the necessary BIOS customization tool must be provided
- Customizable splash screen
- Quiet boot option
- Enable/disable for individual COM ports.
- LPC interface for DAQ FPGA
- Wake on LAN for on-board Ethernet, minicard socket
- Single BIOS to support various memory configurations and processor variants
- Integrated verb table for ALC892 Audio codec
- BIOS LED to indicate successful BIOS initialization
- Supports standard BIOS hotkey. This includes ESC key to enter BIOS menu etc
- Password protection
- Field upgradeable via a Shell/Windows utility

3.2.18 Power Supply

Saturn requires only +5VDC input voltage as per the PCIe/104 Specification. An auxiliary +12VDC input pin is provided on the input power connector to feed the LCD backlight power connector on the board. This 12V is not used anywhere else on the board.

Saturn supports ACPI for pushbutton on/off control. It supports Standby mode with an optional +5VSB input. In standby mode, the board may be powered on via Wake on Lan feature on one Ethernet port.

The 5V supply on the PCIe/104 connector is routed directly to the input power connector, so that the board may obtain its input power from either the input power connector or from a power supply installed on the bus connector.

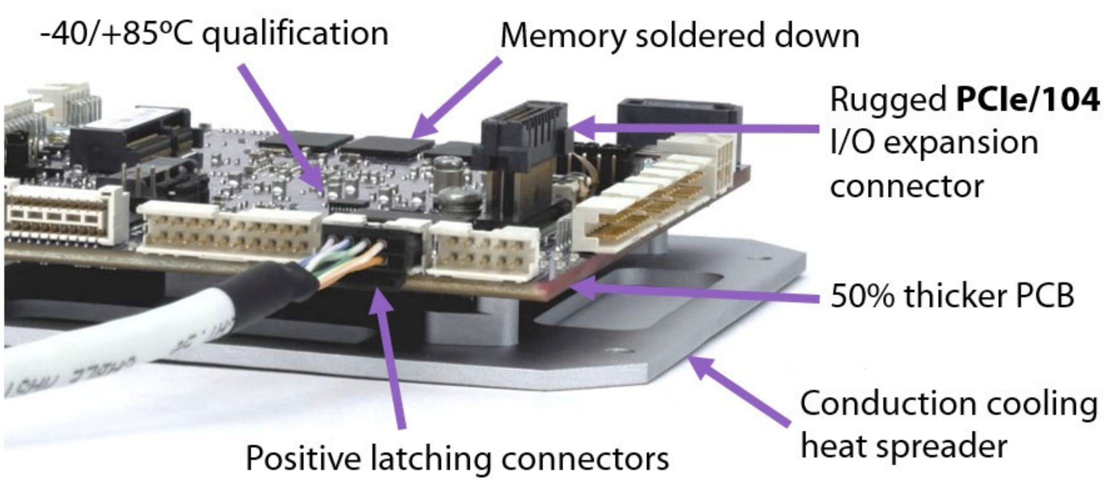
All required supply voltages for the board's circuitry are derived from the 5V input. These power supplies are sized to support the highest expected load from the board's circuitry plus installed add-on modules:

5V	3.3V	Feature
2.0A	0.5A	PCIe add-on modules
	1.3A	PCIe Minicard add-on modules
	1.5A	M.2 Sata SSD
1.4A	0.7A	LCD power
0.9A		LCD backlight
	0.05A	DAQ connector
	0.05A	Utility connector
1.0A		USB 2.0 ports x2
1.8A		USB 3.0 port x2

3.3 Rugged Design

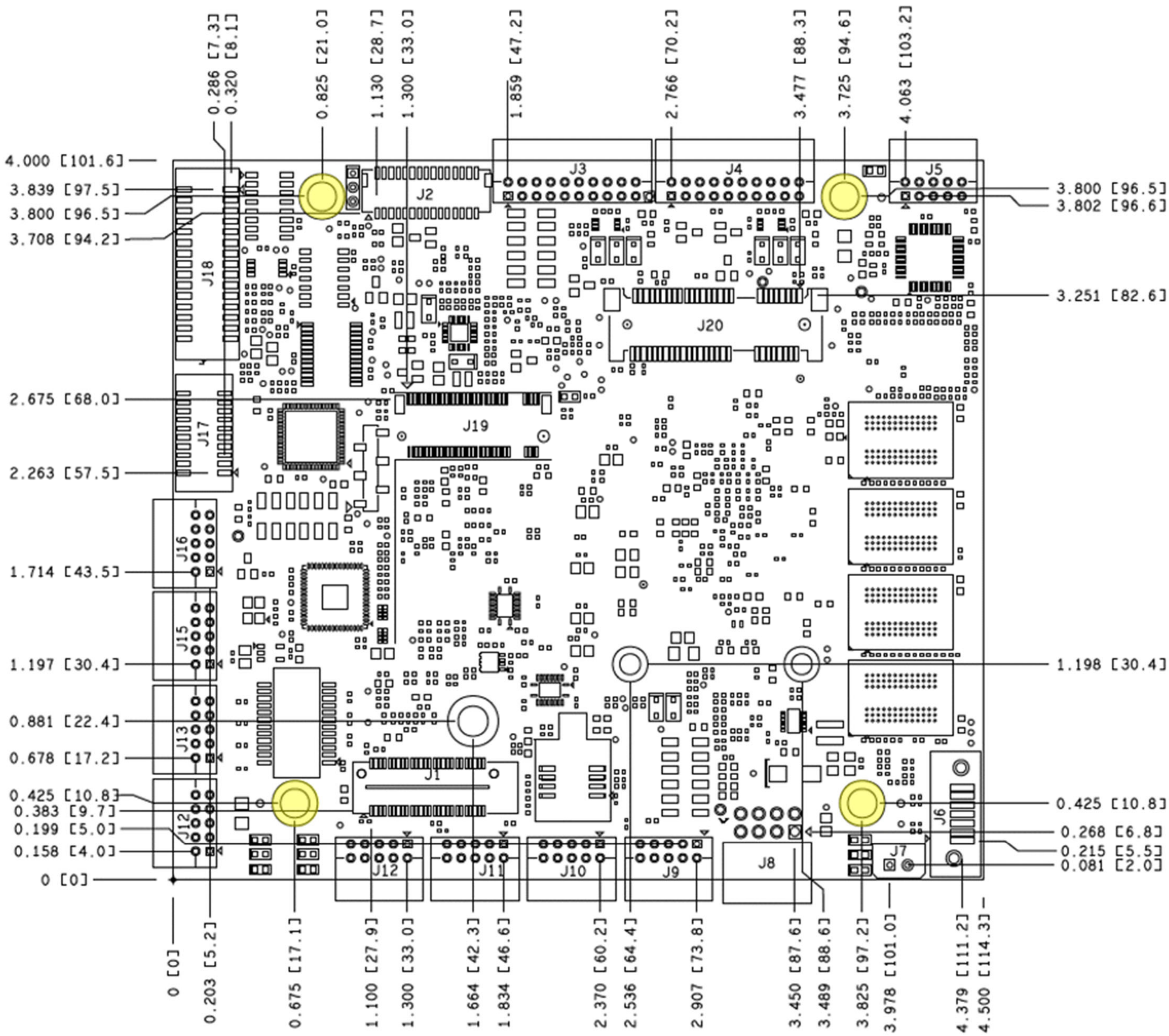
Saturn is designed from the ground up with a comprehensive set of features to meet the challenges of rugged environments and applications:

- Memory is soldered down to avoid problems that can occur with commercial style SODIMM type memory modules
- The 50% thicker PCB increases rigidity and improves reliability of fine pitch and high-ball-count BGA solder joints
- All I/O connectors are latching for increased ruggedness
- A bottom-side heat spreader provides more efficient cooling than a traditional heat sink. Processor and memory chips are both thermally connected to the heat spreader. In addition, the exterior surface features recessed thermal pads for improved thermal connectivity to the system enclosure.
- All components are rated and/or tested to ensure reliable -40 to +85ºC operation



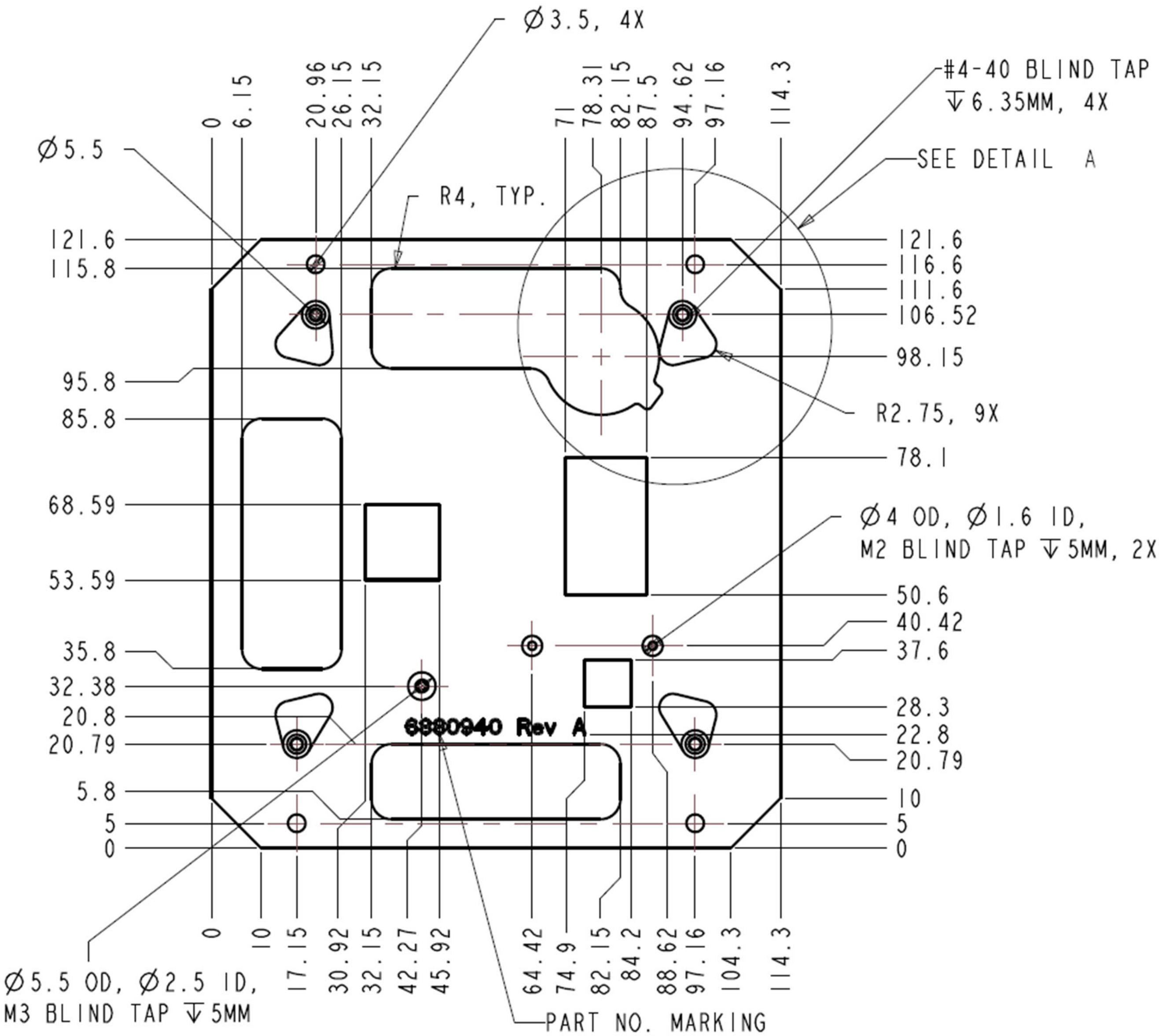
4 BOARD MECHANICAL DRAWING

Below is a mechanical drawing of the Saturn PCB. Dimensions are in inches and [mm]. Connector dimensions indicate the center of the pad for pin 1. The 4 highlighted mounting holes toward the board corners are the standard PC104 mounting holes and are used to mount the board onto the heat spreader shown in the following page.

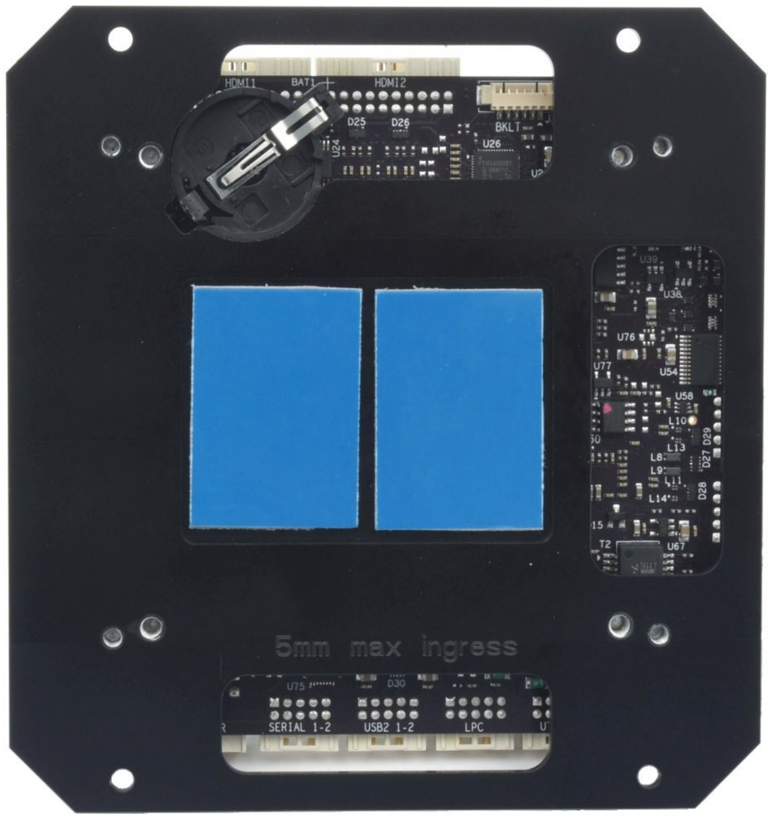


Mechanical Drawing

The drawing below shows the Saturn heat spreader, viewed from the top side (as if looking through the board). The Saturn PCB assembly is fixed to the heat spreader via the 4 #4-40 standard PC104 mounting holes shown in the drawing.



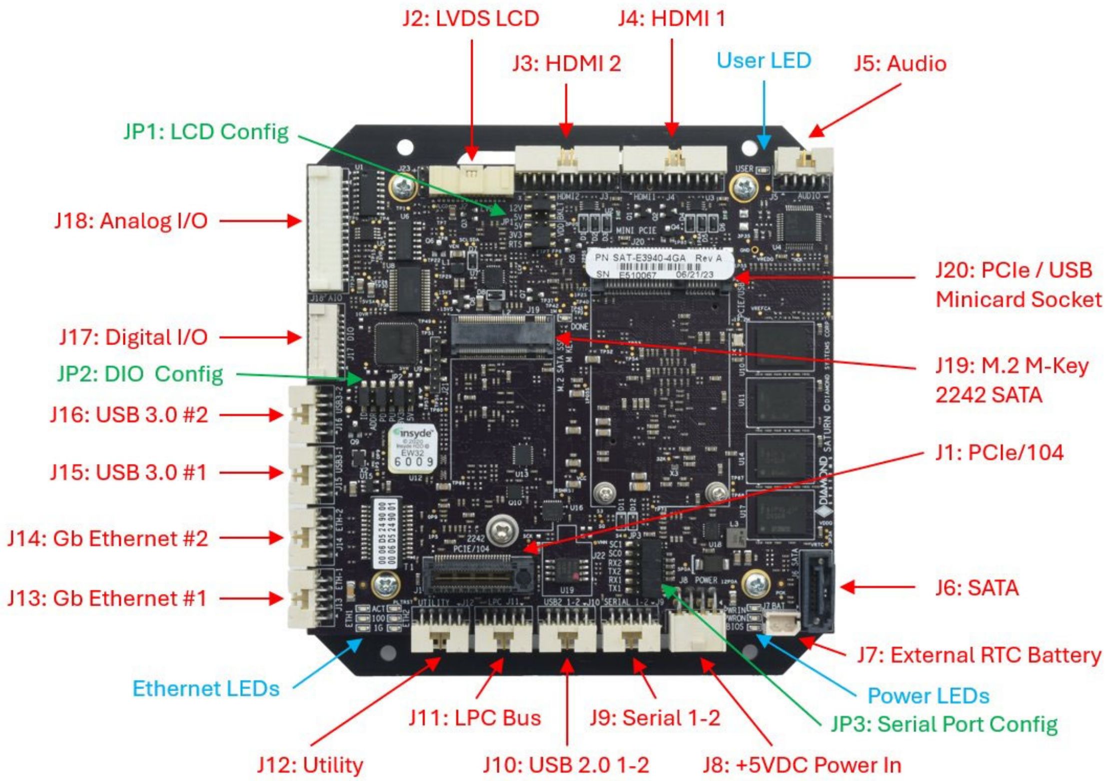
A bottom view of the Saturn board with heat spreader is shown below. An opening is provided for easy access to the CR2032 RTC backup battery if replacement is needed. (The battery is normally installed in the as-shipped configuration.) The photo shows the integrated thermal pads providing enhanced thermal connection to the enclosure surface. **The blue protective pad liners must be removed prior to installation to enable the thermal pads to transfer heat properly to the enclosure.**

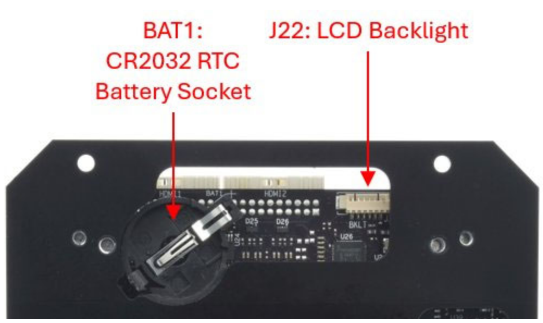


5 I/O CONNECTOR LIST

Connector	Function
J1	PCIe/104 OneBank expansion
J2	LVDS LCD
J3	HDMI2
J4	HDMI1
J5	Audio
J6	SATA Standard
J7	External Battery
J8	Power In
J9	Serial Ports 1-2
J10	USB2 Port x2
J11	LPC Bus

Connector	Function
J12	Utility
J13	GbE Ethernet1
J14	GbE Ethernet2
J15	USB3 Port1
J16	USB3 Port2
J17	Digital I/O
J18	Analog I/O
J19	M.2 M-Key Sata 2242
J20	Minicard Socket
J21	FPGA JTAG
J22	LVDS backlight





6 I/O CONNECTORS

6.1 Connector Pin-out and Signal Description

6.1.1 Power In (J8)

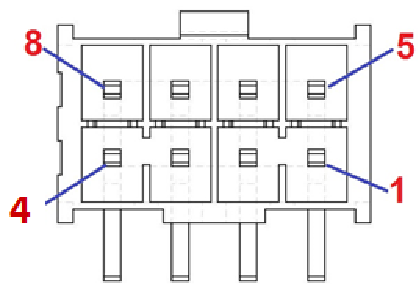
Input power may be supplied through the connector J8. All the required supply voltages for the board are derived from the 5V input. The +12V input is optional and necessary only to drive LCD backlight.

Ground	**1**	**5**	+12V(Optional)
Ground	**2**	**6**	+5V
Ground	**3**	**7**	+5V
Ground	**4**	**8**	+5V

Connector: Samtec IPL1 series with longer PCB pins for better PCB soldering on Saturn's thicker PCB

Mating Cable: DSC no. 6980512

The following diagram depicts the Front View of the Power Connectors. Note that this pinout convention used by Diamond Systems is different than what is shown on the Samtec datasheet.



Mating Side View of Power Connector

6.1.2 External Battery (J7)

To maintain the on-board real-time clock (RTC), Saturn has an on-board coin battery holder and by default a CR-2032 size battery is installed. It is possible to connect an external battery via connector J7 for longer battery life or long term maintainability.

1	VBAT
2	Ground

VBAT = +3.0V nominal, min 2.0V, max 3.2V

Connector used is 22-05-7025 right angle type friction lock pin header.

Mating cable: DSC 6980524

6.1.3 Serial Ports (J9)

Serial ports 1 and 2 are provided on a connector which can be configurable for RS-232, RS-422, or RS-485 modes. The pinouts of the connector are as below:

RS-232

TX1	**A01**	**B01**	RTS1
RX1	**A02**	**B02**	CTS1
GND	**A03**	**B03**	GND
TX2	**A04**	**B04**	RTS2
RX2	**A05**	**B05**	CTS2

RS-422

TX1+	**A01**	**B01**	TX1-
RX1+	**A02**	**B02**	RX1-
GND	**A03**	**B03**	GND
TX2+	**A04**	**B04**	TX2-
RX2+	**A05**	**B05**	RX2-

RS-485

TX1/RX1+	**A01**	**B01**	TX1/RX1-
NC	**A02**	**B02**	NC
GND	**A03**	**B03**	GND
TX2/RX2+	**A04**	**B04**	TX2/RX2-
NC	**A05**	**B05**	NC

Connector Type: 2x5 2mm pitch latching RA TH header, Amphenol# 98464-G61-10ULF

Mating Cable: DSC no. 6980601

Serial port 3 (RS232 only) is part of utility connector. Please refer utility connector section for pinouts.

6.1.4 USB 2.0 Ports (J10)

The USB2.0 connector provides access to two USB 2.0 ports. The pinouts are as below:

Key	**A01**	**B01**	Shield
USB0 Pwr-	**A02**	**B02**	USB1 Pwr-
USB0 Data+	**A03**	**B03**	USB1 Data+
USB0 Data-	**A04**	**B04**	USB1 Data-
USB0 Pwr+	**A05**	**B05**	USB1 Pwr+

Connector Type: 2x5 2mm pitch latching RA TH header, Amphenol# 98464-G61-10ULF

Mating Cable: DSC no. 6980602

6.1.5 Utility (J12)

The utility connector provides access to power button, reset signal, I2C port, Serial Port. It provides fused 3.3V and 5V power that can be used for powering customer auxiliary circuitry.

The pinout of the Utility connector is below:

RS232 TXD	**A01**	**B01**	I2C Clock
RS232 RXD	**A02**	**B02**	I2C Data
Ground	**A03**	**B03**	Power Button
5V Fused 0.5A	**A04**	**B04**	Ground
3.3V Fused 0.5A	**A05**	**B05**	Reset

Connector Type: 2x5 2mm pitch latching RA TH header, Amphenol# 98464-G61-10ULF

Mating cable: DSC no. 6980609

6.1.6 LPC (J11)

The LPC connector provides access to the LPC bus in the case that a customer desires to develop a custom I/O board using the LPC bus interface.

3.3V Fused 0.5A	**A01**	**B01**	Ground
LPC Frame	**A02**	**B02**	LPC AD0
LPC Clock	**A03**	**B03**	LPC AD1
LPC SERIRQ	**A04**	**B04**	LPC AD2
PLTRST	**A05**	**B05**	LPC AD3

Connector Type: 2x5 2mm pitch RA TH header, Amphenol# 98464-G61-10ULF.

Mating cable: DSC no. 6980609

The 3.3V and 5V pin on this connector is connected to the system 3.3V and 5V rail through polyswitch resettable fuses. Each fuse is rated for ~500mA maximum sustained current. If DC current exceeds this value, the polyswitch will heat up and create a high resistance to limit current flow. The current is reduced to the level required to maintain the resistance, maintaining a safe steady state protection condition. When the overload is removed, the polyswitch will cool down and return to normal low-impedance mode.

6.1.7 Ethernet (J13, J14)

The board provides two gigabit Ethernet ports accessed on two identical connectors with identical pinouts. The pinout is shown below:

Chassis Gnd	**A01**	**B01**	Key
DA+	**A02**	**B02**	DA-
DB+	**A03**	**B03**	DB-
DC+	**A04**	**B04**	DC-
DD+	**A05**	**B05**	DD-

Connector Type: 2x5 2mm pitch latching RA TH header of Amphenol# 98464-G61-10ULF

Mating Cable: DSC no. 6980604

6.1.8 USB 3.0 Port (J15, J16)

The USB3.0 connector provides access to USB 3.0/USB2.0 ports on two identical connectors. The pinouts of one of these connectors is as below:

USB1 SSRX-	**A01**	**B01**	Shield
USB1 SSRX+	**A02**	**B02**	USB1 Pwr-
USB1 Pwr-	**A03**	**B03**	USB1 Data+
USB1 SSTX-	**A04**	**B04**	USB1 Data-
USB1 SSTX+	**A05**	**B05**	USB1 Pwr+

Connector Type: 2x5 2mm pitch latching RA TH header, Amphenol# 98464-G61-10ULF

Mating Cable: DSC no. 6980603

6.1.9 SATA (J6)

The board provides access to SATA interface through a standard 7-pin connector. The pinout of this connector is as below:

1	Ground
2	SATA TX+
3	SATA TX-
4	Ground
5	SATA RX-
6	SATA RX+
7	Ground

Connector Type: 7-position vertical through connector, Molex# 0678008025.

Mating Cable: Standard HDMI cable

6.1.10 Audio (J5)

The board provides access to HDA interface on q 10 pin connector. The pinout is shown below:

LineOut-L	**A01**	**B01**	LineOut-R
GND_Audio	**A02**	**B02**	GND_Audio
LineIn-L	**A03**	**B03**	LineIn-R
GND_Audio	**A04**	**B04**	GND_Audio
NC	**A05**	**B05**	MIC_IN

Connector Type: 2x5 2mm pitch latching RA TH header of Amphenol# 98464-G61-10ULF

Mating Cable: DSC no. 6980608

6.1.11 HDMI (J3, J4)

The board provides access to two HDMI ports on two identical connectors. The pinout is shown below:

Data 2+	A01	B01	GND
Data 2-	A02	B02	Data 1+
GND	A03	B03	Data 1-
Data 0+	A04	B04	GND
Data 0-	A05	B05	Clock+
Ground	A06	B06	Clock-
CEC (NC)	A07	B07	Reserved
DDC Clock	A08	B08	DDC Data
GND	A09	B09	+5V
Hot Plug Detect	A10	B10	Chassis ground

Connector Type: 2x10 2mm pitch latching RA TH header of Amphenol# 98464-G61-20ULF.

Mating cable: DSC no. 6980605

6.1.12 LVDS LCD (J2)

LVDS LCD display is available on a 30-pin connector.

VDD 5V/3.3V	1	2	VDD 5V/3.3V
VDD 5V/3.3V	3	4	VDD 5V/3.3V
CLK+ Odd	5	6	CLK+ Even
CLK- Odd	7	8	CLK-Even
Ground	9	10	Ground
D0+ Odd	11	12	D0+ Even
D0- Odd	13	14	D0- Even
D1+ Odd	15	16	D1+ Even
D1- Odd	17	18	D1- Even
D2+ Odd	19	20	D2+ Even
D2- Odd	21	22	D2- Even
D3+ Odd	23	24	D3+ Even
D3- Odd	25	26	D3- Even
Ground	27	28	Ground
DDC CLK	29	30	DDC DATA

Connector Type: 2x15 1mm pitch RA SMT shrouded header, Molex# 5015713007.

Mating cable: Custom cable depending upon the target display. The LCD end of the cable will be different for each LCD or LCD family. Because of the wide variety of LCDs and the fact that many applications do not require a display, this cable is not included in the Saturn standard cable kit CK-SAT-01. DSC cable no. 6981213 may be used as the starting point for this cable, with the LCD end to be modified by the customer as per the LCD requirements.

If Single channel LCD is used, use the Odd channel signals and leave the Even channel signals unconnected.

6.1.13 LCD Backlight (J22)

The LCD panel power is jumper-selectable for 3.3V (default) or 5V. The brightness control for the LCD backlight has a weak pull-down resistor to ensure maximum brightness when it is not connected externally. This signal may be controlled by a PWM pin from the processor. A jumper selects the source of the brightness signal to this pin.

1	Power +5V/+12V, jumper selectable
2	Power (same as pin 1)
3	Ground
4	Ground
5	Enable (GPIO output), 0 = off, open circuit = on
6	Brightness, 0-5VDC variable; 0V = max, 5V = min

Connector Type: 1x6 1.25mm pitch SMD RA header of Molex# 053261-0671.

Mating cable: Custom cable depending upon the target display. Because of the wide variety of LCDs and the fact that many applications do not require a display, this cable is not included in the Saturn standard cable kit CK-SAT-01. DSC cable 6981210 may be used as the starting point for this cable, with the LCD end to be modified by the customer as per the LCD requirements.

6.1.14 Analog I/O (J18)

The VIO pins on the analog and digital I/O connectors are tied together on the board and provide access to jumper-selectable 3.3V / 5V system voltage rail through a polyswitch resettable fuse. The fuse is rated for ~100mA maximum sustained current.

Ain 0	1	2	Ain 8
Ain 1	3	4	Ain 9
Ain 2	5	6	Ain 10
Ain 3	7	8	Ain 11
Ain 4	9	10	Ain 12
Ain 5	11	12	Ain 13
Ain 6	13	14	Ain 14
Ain 7	15	16	Ain 15
Analog Ground	17	18	Analog Ground
Aout 0	19	20	Aout 1
Aout 2	21	22	Aout 3
Analog Ground	23	24	DIO C0
DIO C1	25	26	DIO C2
DIO C3	27	28	DIO C4
VIO (fused)	29	30	Digital Ground

Connector type: 2x15 contact right angle latching connector SM30B-ZPDSS-TF

Mating cable : DSC no. 6981504

6.1.15 Digital I/O (J17)

VIO (fused)	1	2	DIO A0
DIO A1	3	4	DIO A2
DIO A3	5	6	DIO A4
DIO A5	7	8	DIO A6
DIO A7	9	10	DIO B0
DIO B1	11	12	DIO B2
DIO B3	13	14	DIO B4
DIO B5	15	16	DIO B6
DIO B7	17	18	DIO C5
Ground	19	20	Ground

Connector type: 2x10 contact right angle latching connector SM20B-GHDS-GAN-TF.

Mating cable : DSC no. 6980501

6.1.16 Analog Circuit Calibration (J23)

A 1x3 2mm pin header is provided for Analog IO calibration for factory use. In normal conditions the customer should not need to access this connector.

1	Voltage for calibration
2	NC
3	Aground

Connector used is 1x3 2mm Vertical Pin Header.

Mating cable: Factory test cable

6.1.17 MiniCard Socket (J20)

The board provides access to PCIe mini card interface via Mini card socket. For the connector shown below, all TX/RX signals are with respect to the host. TX on the socket drives RX on the installed module, and RX on the socket is driven by TX on the installed module. The two mounting standoffs at the far end of the module installation site are not connected to ground. The pinout of the connector is shown below:

	1	2	+3.3V
	3	4	Gnd
	5	6	+1.5V
Clkreq-	7	8	
Gnd	9	10	
PCIe 1 Clk-	11	12	
PCIe 1 Clk+	13	14	
Gnd	15	16	
	KEY		
	17	18	Gnd
	19	20	Disable-
Gnd	21	22	PCIe Reset-
PCIe 1 RX-	23	24	+3.3V
PCIe 1 RX+	25	26	Gnd
Gnd	27	28	+1.5V
Gnd	29	30	SMB Clk
PCIe 1 TX-	31	32	SMB Data
PCIe 1 TX+	33	34	Gnd
Gnd	35	36	USB2 D-
Gnd	37	38	USB2 D+
+3.3V	39	40	Gnd
+3.3V	41	42	WWAN LED-
Ground	43	44	WLAN LED-
	45	46	WPAN LED-
	47	48	+1.5V
Pull-up to +3.3V	49	50	Gnd
	51	52	+3.3V

Connector Type: SMT 52 position 0f 0.8mm pitch for full size mPCIE modules

Mating Cable: NA

6.1.18 FPGA JTAG (J21)

A 1x6 2mm Pin header is provided for FPGA programming at the factory and is not normally accessed by the customer. Pinouts is shown below.

1	3.3V
2	Ground
3	TCK
4	TDO
5	TDI
6	TMS

Connector used is 1x6 2mm Vertical Header.

Mating cable: Factory test cable

6.1.19 M.2 SATA Socket (J19)

The board provides mass storage support via an M.2 socket that supports SATA modules of size 2242. For the pinouts shown, all TX/RX signals are with respect to the host. TX on the socket drives RX on the installed module, and RX on the socket is driven by TX on the installed module. The mounting standoff at the far end of the module installation site is not connected to ground.

The pinout of the connector is shown below:

Gnd	1	2	+3.3V
Gnd	3	4	+3.3V
	5	6	
	7	8	
	9	10	
	11	12	
	13	14	
	15	16	
	17	18	
	19	20	
Gnd	21	22	
	23	24	
	25	26	
Gnd	27	28	
	29	30	
	31	32	
Gnd	33	34	
	35	36	
	37	38	DEVSLP
Gnd	39	40	
SATA_RX+	41	42	
SATA_RX-	43	44	
Gnd	45	46	
SATA_TX-	47	48	
SATA_TX+	49	50	
Gnd	51	52	
	53	54	
	55	56	
Gnd	57	58	
	KEY		
	67	68	
Gnd	69	70	+3.3V
Gnd	71	72	+3.3V
Gnd	73	74	+3.3V
Gnd	75		

Connector Type: SMT 67 position with 0.5mm pitch for PCIe/104 one bank expansion of Samtec# ASP-129646-22

Mating Cable: NA

6.1.20 PCIe/104 (J1)

The board provides expansion to PCIe/104 via a One-Bank connector. The connector provides access to four x1 PCIe lanes, two USB2.0s, ATX power & control signals, +3.3V & +5V power rails and SMBus interfaces. The pinout of the connector is shown below:

USB-OC#	1		2	PCIe Reset#
+3.3V	3		4	+3.3V
USB_1+	5		6	USB_0+
USB_1-	7		8	USB_0-
Ground	9		10	Ground
PCIe1 Tx+	11		12	PCIe0 Tx+
PCIe1 Tx-	13		14	PCIe0 Tx-
Ground	15		16	Ground
PCIe2 Tx+	17		18	PCIe3 Tx+
PCIe2 Tx-	19		20	PCIe3 Tx-
Ground	21	+	22	Ground
PCIe1 Rx+	23	5	24	PCIe0 Rx+
PCIe1 Rx-	25	V	26	PCIe0 Rx-
Ground	27	T	28	Ground
PCIe2 Rx+	29	A	30	PCIe3 Rx+
PCIe2 Rx-	31	B	32	PCIe3 Rx-
Ground	33		34	Ground
PCIe1 Clk+	35		36	PCIe0 Clk+
PCIe1 Clk-	37		38	PCIe0 Clk-
+5VSB	39		40	+5VSB
PCIe2 Clk+	41		42	PCIe3 Clk+
PCIe2 Clk-	43		44	PCIe3 Clk-
Ground(Dir)	45		46	PWRGOOD
SMB Data	47		48	NC
SMB Clk	49		50	NC
SMB Alert#	51		52	PSON#

Connector Type: SMT 52 position with 0.64mm pitch for PCIe/104 one bank of Samtec# ASP-129646-22

Mating Cable: Board to board connection only

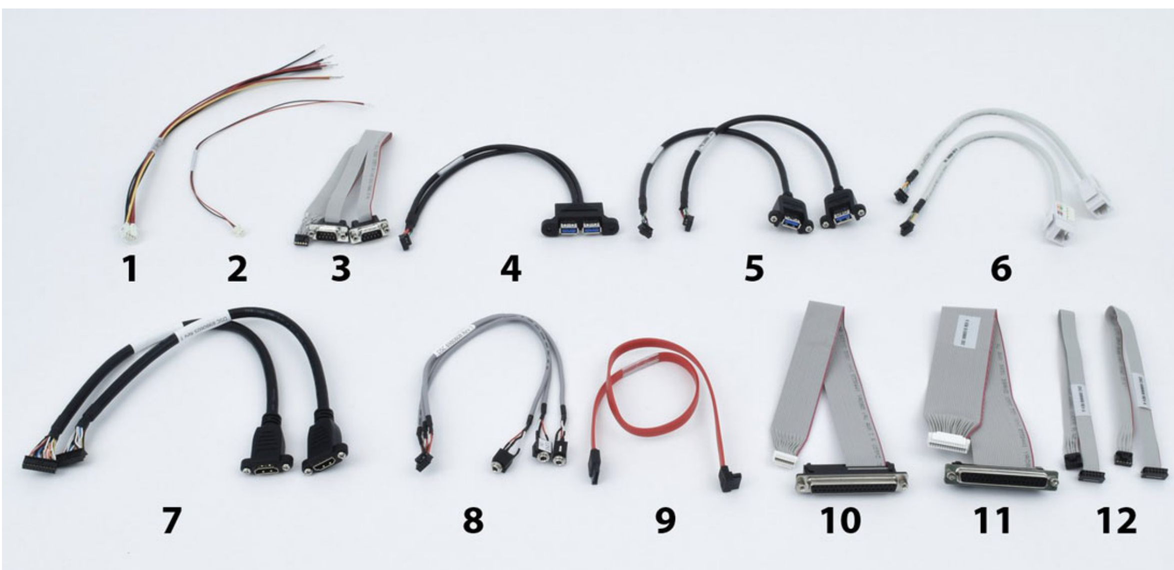
6.2 List of Connectors

The following table provides a summary of all I/O connectors on the board.

Function	Manufacturer	Part no.	Description	Mating part	Mating Cable
Power in	Samtec	ASP-194529-01	2x4 box header T/H Right angle .1" pitch	IPD1-04-D-K	6980512
External battery	Molex	22-05-7025	2 pos. 2.54mm pitch Vertical latching	0050375023	6980524
Serial ports	Amphenol	98414-F06-10ULF	10 Pos 2mm Pitch T/H Vertical Angle Latching	10073599-010LF	6980601
USB 2.0	Amphenol	98464-G61-10ULF	10 Pos 2mm Pitch T/H Right Angle Latching	10073599-010LF	6980602
USB 3.0 / 2.0	Amphenol	98464-G61-10ULF	10 Pos 2mm Pitch T/H Right Angle Latching	10073599-010LF	6980603
Ethernet	Amphenol	98414-F06-10ULF	10 Pos 2mm Pitch T/H Vertical Angle Latching	10073599-010LF	6980604
HDMI	Amphenol	98464-G61-20ULF	20 Pos 2mm Pitch Right Angle Latching	10073599-020LF	6980605
SATA	Molex	0678008025	Conn Header 7pos Vert T/H	Generic	Generic
Audio	Amphenol	98464-G61-10ULF	10 Pos 2mm Pitch T/H Right Angle Latching	10073599-010LF	6980608
Utility & LPC	Amphenol	98464-G61-10ULF	10 Pos 2mm Pitch Right Angle Latching	10073599-010LF	6980609
Digital I/O	JST	SM20B-GHDS-GAN-TF	20 Pos 1.25mm Pitch SMT Right Angle Latching	GHDR-20V-S	6980517
Analog I/O	JST	SM30B-ZPDSS-TF	30 Pos 1.5mm Pitch SMT Right Angle Latching	ZPDR-30V-S	6980518
LVDS LCD	Molex	5015713007	Conn Header SMD R/A 30pos 1mm	5011893010	NA
LCD backlight	Molex	053261-0671	6 Pos 1.25mm Pitch Right Angle	0510210600	NA

7 I/O CABLES

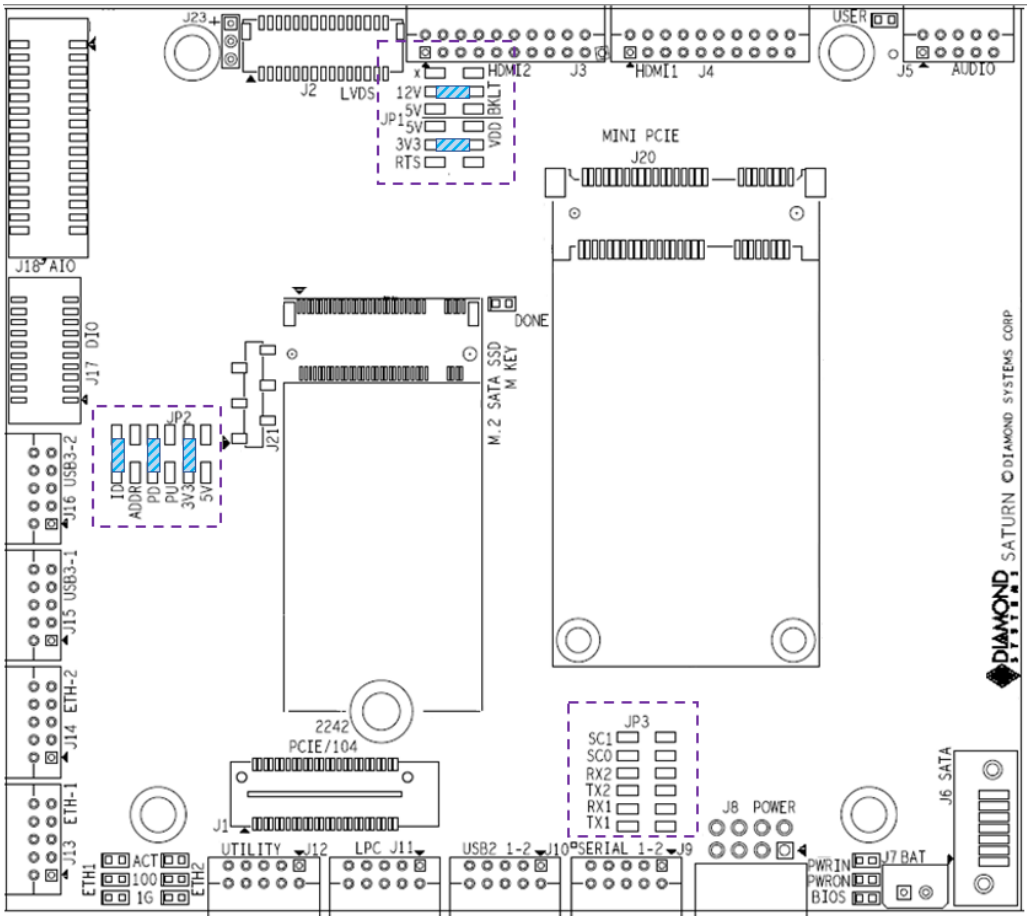
Photo No:	Cable Part No	Description	Saturn Connector
1	6980512	Power in	J8
2	6980524	External Battery	J7
3	6980601	Serial Port	J9
4	6980602	USB2.0	J10
5	6980603	USB3.0	J15, J16
6	6980604	Ethernet	J13, J14
7	6980605	HDMI	J3, J4
8	6980608	Audio	J5
9	6989101	SATA	J6
10	6980517	Digital I/O	J17
11	6980518	Analog I/O	J18
12	6980609	LPC, Utility	J11, J12



I/O Cables

8 JUMPER DESCRIPTION

The following drawing shows only the connectors and jumper blocks on the board. The default jumper positions are shown in blue.



Default Jumper locations

Jumper	*Description*
JP1	LVDS LCD VCC and Backlight
JP2	DIO PU/PD, Voltage, Address
JP3	Serial Port protocol and termination

8.1 LVDS Backlight and LVDS VDD (JP1)

Jumper block JP1 configures the voltage supply for the LCD backlight and LVDS VDD.

By default, LVDS backlight is provided with +12V and the LVDS VDD is provided with 3.3V.

Position	*Function*	*IN*	*OUT*
12V*	***LCD Backlight Voltage***	***12V***	-
5V	LCD Backlight Voltage	5V	-
x	-	-	-
5V	LCD VDD Voltage	5V	-
3V3*	**LCD VDD Voltage**	**3.3V**	-
***Default Mode**			

8.2 Digital IO and Address (JP2)

Jumper block JP2 configures the Voltage level for Digital IO and Pull up/down. It also selects the base address for Data acquisition FPGA.

By default, Digital IO is 3.3V and pulled down. FPGA base address is set to 0x280 and USB3.0/2.0 Port 0 is Host by default.

Position	*Function*	*IN*	*OUT*
ID	USB3.0/2.0 Port0 Mode	***Host***	Device
ADDR	FPGA Base Address	*0x240*	**0x280**
PD	DIO Pull Down Enable	***Enabled***	Disabled
PU	DIO Pull Up Enable	Enabled	Disabled
3V3	DIO Voltage Level	***3.3V***	-
5V	DIO Voltage Level	5V	-
***Default Mode**			

8.3 Serial Port Configuration (JP3)

Jumper block JP3 configures Serial Port1-2 protocol and termination select during RS422/485 mode.
By default, Serial ports are set to Internal loopback mode and terminations are disabled. **The protocol selection is superseded by DAQ software settings.**

Position	*Function*	*IN*	*OUT*
SC1	Ser Port1-2 Mode select1	Refer Table Below	-
SC0	Ser Port1-2 Mode select0	Refer Table Below	
RX2	Serial Port2 RX Termination	Enabled	***Disabled***
TX2	Serial Port2 TX Termination	Enabled	***Disabled***
RX1	Serial Port1 RX Termination	Enabled	***Disabled***
TX1	Serial Port1 TX Termination	Enabled	***Disabled***
***Default Mode**			

Serial port Mode selection Jumpers (Detailed):

SC1	*SC0*	*Protocol*
OUT	***OUT***	***Internal Loopback***
OUT	IN	RS485
IN	OUT	RS232
IN	IN	RS422

9 BIOS KEY FEATURES

The BIOS on Saturn provides access to many valuable features. These instructions show how to enter the BIOS and set up features.

9.1 Entering the BIOS

The BIOS may be entered during startup by repeatedly pressing the **ESC** key on an attached keyboard during the booting process. Toggle the key repeatedly soon after a power-on or reset until the BIOS screen appears.

After a specific period during startup (generally a few seconds), the BIOS will ignore the **ESC** key. If the system does not respond expectedly after pressing the **ESC** key, user can simply reset the board (or power down) and try again.

Enter the **Setup Utility** to go to the BIOS Menu page. To save any BIOS changes press **F10** key.

9.2 Restoring Default BIOS Settings

While making changes to the BIOS settings, the new settings are stored in SPI flash. If the user wants to restore the BIOS settings to default state, follow the procedure listed below.

1. Connect a keyboard to the USB keyboard port and connect a monitor.
2. Reboot the CPU (reset or power-down and power-up).
3. Enter BIOS may be entered during startup by toggling the **ESC** key on an attached keyboard
4. Enter to **Setup Utility** and press **F9** key to reset the BIOS to defaults
5. Press F10 to save he BIOS changes

9.3 Upgrading BIOS using SHELL Utility

Please follow the below steps for BIOS programming through SHELL Utility.

1. Connect USB drive with BIOS Programming utility and BIOS file.
2. Toggle the key repeatedly soon after a power-on or reset until the BIOS screen appears.
3. Enter the **BOOT Manager**, enter Internal EFI Shell to launch shell-based file systems to boot to shell.
4. Once booted to shell, identify which is the file system for USB flash disk. It can be fs0 or fs1 or fs2. You can check this by pressing page up button.
5. Then follow the below commands entering to the folder.
   H2OFFT-Sx64.efi <BIOS_filename>.bin -BIOS
6. While BIOS is getting programmed, the status will be displayed. Wait for 100% completion and switch-off the board.
7. Turn-on the board, confirm the BIOS programming by checking BIOS version in BIOS menu.

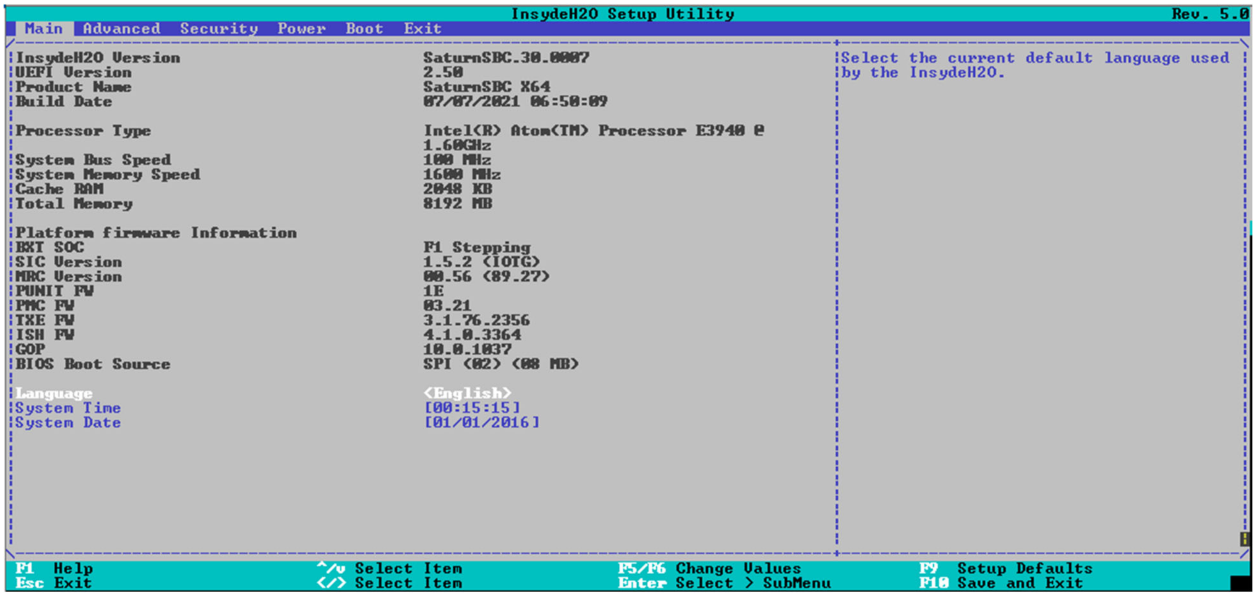
9.4 LED

A green BIOS LED has been provided to indicate that the board has been booted to BIOS GUI. The location of the BIOS LED is being shown in the Board Layout Section.

9.5 Setting the Date and Time

To set the date and time in the BIOS, select **Main** menu, then enter the date and time at the top of the screen. This screen also displays the CPU speed and memory capacity of the board.

Use **TAB** key to select Hour or Minutes or Second.

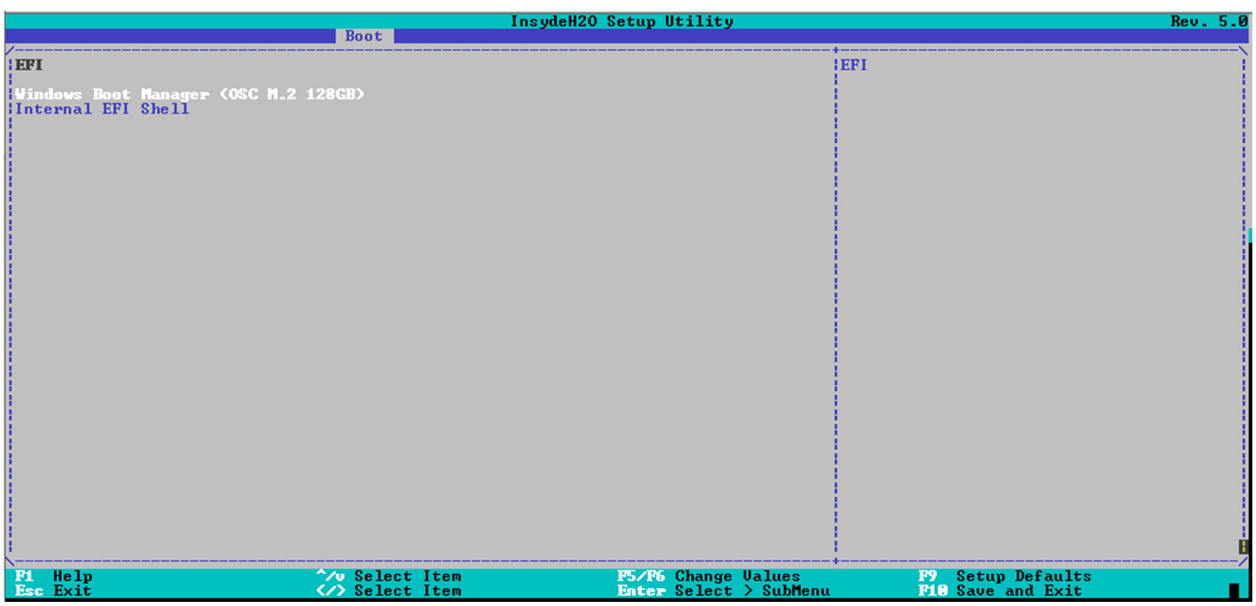


9.6 Boot Priority

To select Boot devices and priority, go to the **Boot** menu and select **EFI**. Only devices which are connected to the board will appear in the list of options. Therefore, if the user wants to select a hard drive or USB device as the boot devices should be connected first, then boot up and enter the BIOS, then select it as a boot device.

If this menu option does not appear on the screen, it means that the on-board flash drive is not enabled, and either no boot devices are attached, or the CPU does not recognize any attached boot devices.

The user can change the boot devices priority using **+ / -** key.



10 GETTING STARTED

This section describes the steps needed to get Saturn SBC up and running quickly. For first time orders it is strongly recommended to purchase a complete development kit (DK). This kit includes:

- Saturn SBC
- Cable Kit (CK-SAT-01) with all cables needed for the I/O, except the LCD and backlight.
- M.2 SATA disk module with Windows or Linux OS preprogrammed
- USB memory stick with a backup copy of the OS and related documentation
- 12VDC AC adapter with US 3-prong plug

For customers who already have a Saturn board and cables and just want to purchase the software, It is available as a “software development kit” (SDK). The SDK includes the items shown in blue text above.

The Windows SDK includes a single OS license. Further duplication of this SDK on additional Saturn boards requires purchasing of licenses from Microsoft. The Linux SDK requires no license and may be copied and reused repeatedly with no additional charge.

10.1 Development Kit

Model Number	*Description*
DK-SAT-E3950A-LNX64	Development Kit, Saturn SBC with DAQ, Linux 64-Bit BSP
DK-SAT-E3950A-WE1064	Development Kit, Saturn SBC with DAQ, Windows 10 64-Bit BSP
SDK-SAT-E3950A-LNX64	Software Development Kit for Saturn SBC, Linux 64-bit OS
SDK-SAT-E3950A-WE1064	Software Development Kit for Saturn SBC, Windows 10 64-bit OS

10.2 Quick Setup

1. Attach HDMI cable 6980605 to J3 and USB2 cables 6980602 to J10 as needed.
2. Attach display, keyboard, and mouse (if needed) to the cables.
3. Connect power (+5V) to power input connector J8 using external power supply with power cable 6980512. The input connector and cable keyed to prevent incorrect connection. Use the Red wires for +5V and Yellow for +12V (only if LCD is required) and Black to ground.

   WARNING: Attaching the power connector incorrectly will destroy the Saturn SBC!
4. For a quick verification that the system is set up and working properly, if no boot device is attached, the system will boot to BIOS mode and EFI Shell.

10.3 Boot Device Options

Saturn can boot from SATA or any of the available USB ports or PXE (10/100 Ethernet Port only). Either a M.2 SATA SSD or an externally powered SATA HDD can be connected to the SATA port. DSC will provide a M.2 SATA with pre-loaded OS.

The Boot device selection and priority are configured in the BIOS **Boot** menu. Only devices which are connected to the SBC will appear in the list of options. Therefore, if user wants to select a hard drive or USB device as the boot device, the SBC should be connected first, then boot up and enter the BIOS, then select it as a boot device.

The following are a few examples for boot scenarios.

- Install an externally powered SATA hard drive directly on the SATA connector (J6).
- Attach a M.2 2242 SATA device on the M.2 socket (J19)
- Attach a bootable USB device to one of the USB ports (J10,J15,J16).
- PXE boot over Ethernet (J13, J14)

10.4 Installing OS and Booting

Ensure that SATA data cable and power cable are connected to SATA HDD OR M.2 2242 SATA SSD is connected. Follow below steps to install Windows 10 operating system in SATA HDD.

- Connect a USB drive to a USB port of (J10/J15/J16) Saturn board having Windows 10/Ubuntu installation image.
- Boot the Saturn board to BIOS setup using **ESC** key
- Enter **Boot Manager** and Select USB drive to boot to OS Setup
- If not booted, make Sure that SATA HDD/SSD detected under **Advanced -> South Cluster Configuration -> SATA Drives**
- Windows 10/Ubuntu installer would start running. Follow the instructions in the installer.
- Upon successful installation, boot to Windows 10/Ubuntu and install the necessary drivers.

10.5 Software driver overview

Saturn SBC supports Windows 7/8.1/10 and Linux operating systems. Software and Hardware Development kits contain a SATA DOM installed with either Windows 10 or Linux. All the necessary I/O drivers are also available as part of the Development Kit. Please contact Diamond Systems for more details.

Some of the drivers that are required with the Windows 10 operating system are given below. These drivers are available for download from Diamond Systems' website.

http://www.diamondsystems.com/support/product.php?product=saturn

11 VIDEO FEATURES

Saturn SBC offers three video output options: 2 HDMI and one LVDS Display, and all the three outputs can be active at any time.

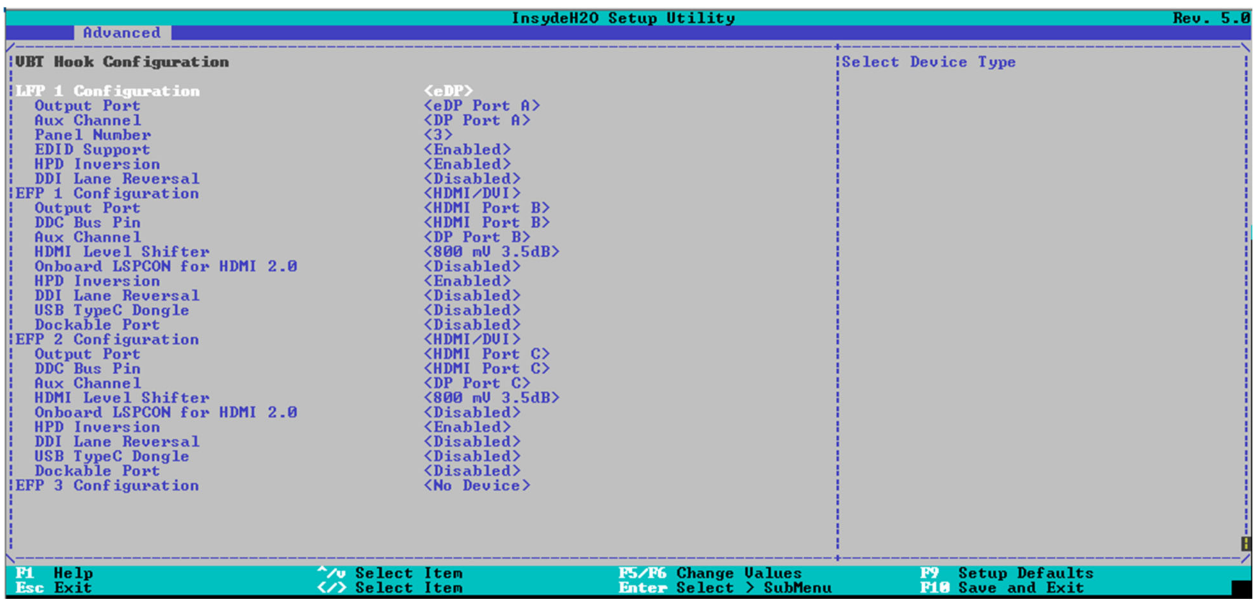
The HDMI ports supports a maximum resolution of 3840x2160 @30Hz.

An eDP to LVDS converter provides a dual-channel LVDS LCD output. Maximum LVDS resolution is 1920 x 1080 x 60Hz x 24bpp. The LCD backlight control is provided by a PWM circuit. LCD backlight power and control are on a separate latching connector.

The BIOS supports options for selecting Single channel /Dual Channel, Color Depth, resolution, and brightness control.

By default, the BIOS will support 7 EDID configuration Emulation as shown in below table. The correct resolution needs to be selected based on the LCD used. Please contact DSC for the EDID values OR one can use PTN3460 DPCD utility for changing the configuration.

1. **Advanced -> Uncore Configuration -> VBT Hook Configuration**



EDID N0	Resolution	EDID Description
0	1024 x 768 @60Hz	NXP Generic
1	1920 x 1080 @60Hz	NXP Generic
2	1920 x 1080 @60Hz	NXP Generic
3	1600 x 900 @60Hz	Samsung LTM200KT
4	1920 x 1080 @60Hz	Samsung LTM230HT
5	1366 x 768 @60Hz	NXP Generic
6	1600 x 900 @60Hz	ChiMei M215HGE

12 SERIAL PORTS AND SYSTEM CONSOLE

12.1 Configuration

Saturn SBC supports total 4 serial ports. All the 4 ports support RS-232/422/485 modes. The modes can be configured in BIOS. Both TX and RX termination selection option are available under BIOS menu.

12.2 Console redirection

Connect any of the Saturn serial ports to PC. In BIOS menu, go to **Advanced** settings menu, then in Remote Access Configuration enable the Remote access feature. Then select the serial port. User should see the BIOS setup menu in the PC console.

13 DATA ACQUISITION CIRCUIT

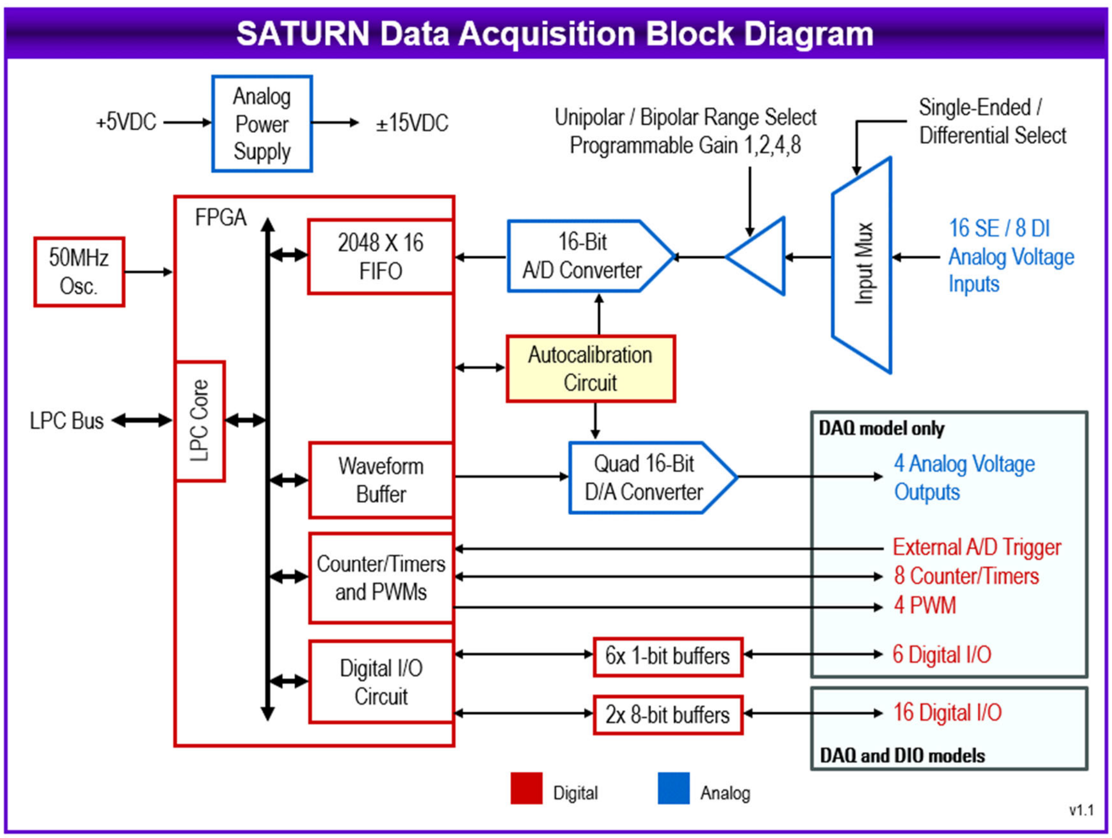
13.1 Overview

Saturn contains a data acquisition subsystem consisting of A/D, D/A, digital I/O, and counter/timer features. The circuit is controlled by an FPGA and connected to the SBC via the LPC bus.

The A/D section includes a 16-bit A/D converter, 16 analog input channels and a 2048-sample FIFO. Input ranges are programmable, and the maximum sampling rate is 250 KHz. The D/A section include 4 16-bit D/A channels. The digital I/O section includes up to 22 lines with programmable direction. The counter/timer section includes 32- bit counter/timer to control A/D and a 32-bit counter/timer for user applications.

High-speed A/D sampling is supported with interrupts and a FIFO. The FIFO is used to store up to 2048 A/D samples. An interrupt occurs when the FIFO reaches a user-selected threshold. Once the interrupt occurs, an interrupt routine runs and reads the data out of the FIFO. In this way the interrupt rate is reduced by a factor equal to the size of the FIFO threshold, enabling a faster A/D sampling rate and lower software overhead.

The A/D circuit uses the default ISA / LPC I/O address range 0x280-0x28F (base address 0x280). The address can be changed in the BIOS if needed.



All data acquisition features are supported by Diamond's Universal Driver software, available for free download here (registration with click-through license agreement is required):

http://www.diamondsystems.com/products/dscud

User documentation for Universal Driver may be found here:

https://diamondsystems.gitbook.io/user-manuals/universal-driver/dscud-sw-user-manual

The following sections include detailed register bit descriptions for explanation purposes. All programming of the DAQ circuit should be done using Universal Driver for ease of use and time savings.

13.2 DAQ Feature Summary

Feature	Description
A/D channels	16 single-ended channels or 8 differential channels 16-bit resolution Programmable input ranges (see table below)
D/A channels	4 16-bit analog voltage outputs Programmable output ranges (see table below)
DIO Lines	22 lines: 1 8-bit port, 14 1-bit ports Programmable direction 3.3V / 5V logic levels Pull-up / pull-down resistor configuration
Counter/Timers	8 32-bit counter/timers with up/down counting
PWM	4 24-bit PWMs with 0-100% duty cycle control
Watchdog timer	Dual stage timer with warning pulse prior to reset: Counter A – 16 bit delay timer, 10KHz clock Counter B – 8 bit warning pulse, 10KHz clock

13.3 Interrupts

The FPGA supports LPC interrupts from the analog input circuit, D/A fault indicator, digital I/O, and two counter/timers. Register bits ADINTEN, FINTEN, DINTEN, T2INTEN, and T3INTEN enable/disable interrupts for the individual sources. When an INTEN bit is 1, interrupts for that circuit are enabled. However, 0 disables the interrupt feature. The LPC bus interrupt level is selected with register bits IRQ3-0.

When a circuit is requesting interrupt service, its corresponding status bit DINT, ADINT, T2INT, or T3INT is high. Command bits DINTCLR, ADINTCLR, T2INTCLR, and T3INTCLR reset the associated interrupt request and status bit. In contrast to other command registers in this design, any or all of these command bits may be set simultaneously to clear multiple interrupt requests simultaneously.

Register bit ADINT=1 and an interrupt occurs when ADINTEN=1 and one of the following occurs:

FIFOEN	SCANEN	Action
0	0	Interrupt occurs after each A/D conversion completes (ADBUSY goes low).
0	1	Interrupt occurs after each A/D scan completes (ADBUSY goes low).
1	0	Interrupt occurs when A/D conversion completes and FIFO threshold is reached **or exceeded.**
1	1	Interrupt occurs when A/D scan completes **and** FIFO threshold is reached or exceeded.

T2INT=1 and an interrupt occurs when T2INTEN=1 and counter/timer 2 counts down to 0. There is no terminal count and therefore no interrupt source when counter/timer 2 is counting up.

T3INT=1 and an interrupt occurs when T3INTEN=1 and counter/timer 3 counts down to 0. There is no terminal count and therefore no interrupt source when counter/timer 3 is counting up.

DINTSEL4-0 selects the digital I/O line to be used for edge-triggered interrupts. The selection is as follows:

0-7	Port A 0-7
8-15	Port B 0-7
16-21	Port C 0-5

When DINTEN = 1 and the digital I/O line specified by DINTSEL4-0 exhibits the edge specified by DINTEDGE, DINT = 1 and an interrupt occurs. DINTEDGE = 1 means rising edge, and 0 means falling edge. If the specified DIO line is in output mode, then writing to that line's output register with the correct transition will trigger the interrupt. When DINTCLR command is issued, the edge detect circuit will reset to be ready for the next edge. Setting DINTEN = 0 also resets the edge detect circuit, so that when DINTEN is set to 1 the circuit is ready for the first edge.

When register bit FINTEN = 1, a falling edge on DAC_FAULT# will generate an interrupt and set register bit FINT = 1. The interrupt request is cleared, and FINT = 0, by writing a 1 to command bit FINTCLR or generating a reset. The interrupt routine is responsible for clearing the fault condition on the AD5755 to cause the fault pin to reset to 1.

14 A/D CIRCUIT

14.1 A/D Basics

Saturn uses a 16-bit A/D converter. This means that the analog input voltage can be measured to the precision of a 16-bit binary number (1 part in 65536). The maximum value of a 16-bit binary number is 2^{16} - 1, or 65535, so the full range of numerical values that a 16-bit A/D converter can yield is 0 – 65535 (0x0000 – 0xFFFF).

In its most basic form, an A/D converter compares the input voltage to a reference voltage, and the number it reports is the ratio of the two voltages times the theoretical full scale value (65536). Because the top end of the range would represent a ratio of 1, and this would require one extra bit (i.e. 0x10000), the theoretical top end of the range is not actually measurable. Thus all input ranges will be 1 LSB less than the nominal full scale range.

The smallest change in input voltage that can be detected is $1/(2^{16})$, or 1/65536, of the full-scale input range. This smallest change results in an increase or decrease of one in the A/D code, and is referred to as one Least Significant Bit (1 LSB).

The full-scale range is the difference between the maximum nominal input voltage and the minimum input voltage. For example, a +/-10V input range has a full-scale range of 20V, but a maximum nominal input voltage of 10V. This distinction is important. The maximum input voltage limits the range of the input signal, while the full-scale range is used to calculate the value of 1LSB. The value of 1LSB on an A/D converter is always the full-scale range divided by the number of steps. So for an input range of +/-10V on a 16-bit A/D converter, 1 LSB = 20V / 65536 = 305uV.

14.2 Unipolar and Bipolar Inputs

Saturn can measure both unipolar (positive only) and bipolar (positive and negative) analog voltages. Any combination of unipolar and bipolar inputs can be used. The A/D circuit and supporting driver allow for changing the input range on a per-reading basis as well as a “set and forget” basis, so that you can work with input signals with different ranges at the same time.

14.3 Single-Ended and Differential Inputs

A single-ended input is an input that has one signal wire with the voltage to be measured and a ground connection to tie the signal source and the A/D to the same ground potential for measurement reference. The measured value is the difference between the input signal and the ground reference. The ground connection may be a second wire connected between the source and the A/D circuit, or it may be via a common tie point of the two devices’ power supplies. In general for best quality / lowest noise measurements, power ground should not be part of the circuit, so in most cases a second ground wire will be connected between the signal source’s ground reference and an analog ground pin on the Saturn A/D connector. If multiple signals are coming from the same source, then a single ground wire from that source is usually sufficient for all the signals.

A differential input is an input that uses two wires to carry the signal. The A/D measurement is the difference between these two signals. In this case, the low side of the signal does not need to be physical tied to ground or even at ground potential. Differential signals can “float”, giving more freedom in connection schemes and also helping to reduce noise (because the low side is not tied to ground). For example, a differential signal with V+ = 4V and V- = 3V will yield and A/D reading of 1V, while V+ = 3V and V- = 4V will yield a reading of -1V.

One very important consideration when using differential inputs is that there are still upper and lower limits to the absolute voltages that can be presented to the circuit for accurate readings and to prevent damage. Typically these limits match the circuit power supply rails. On Saturn, the limit for both the + and – inputs is +/-15V. Any input voltage beyond these limits can cause damage to parts of the analog input circuit.

One other important issue is voltage drift due to stray capacitance. If the input signal is floating, i.e. it has no connection to any ground reference, then over time its own ground reference can easily drift away from the A/D circuit ground, causing its output voltages to exceed the input range of the A/D even though the differential voltage is still within range. For example a battery-operated device not having any real world ground connection and outputting +/-1V could build up charge to the point where its actual output voltages are 50V above the ground potential of the A/D circuit, causing erroneous readings. So a differential input signal still needs a ground reference wire tied between the signal source device and the A/D circuit, in order to prevent this drift. So a differential input typically has 3 wires: V+, V-, and Ground. A single ground wire is usually sufficient for multiple differential signals coming from the same source circuit.

14.4 Input Signal Wiring

When using single-ended inputs, any signal can be connected to any input channel. You can select the input range one time for all channels or you can select it individually each time you perform an A/D conversion. However in most cases all inputs will be tied to sequential channels starting with channel 0, for programming convenience.

On Saturn, as with most A/D circuits, each leg of a differential input requires a dedicated input channel. Thus while Saturn supports 16 single-ended analog inputs, it can only support 8 differential inputs. When using differential inputs, the + and – inputs must be tied to channels whose numbers are 8 apart, i.e. 0 and 7, 1 and 8, etc. The low numbered input channel is used for the + input, and the high numbered channel is used for the – input.

Saturn's A/D circuit can be configured for all single-ended or all differential inputs, not a mix of both. If you have a mix of signals, then select differential mode, and for each single-ended input the corresponding – input channel must be tied to analog ground. For example, a differential input may be tied to channel 0 (+ input) and channel 8 (- input). Then a single-ended input may be tied to channel 1 (+ input), and the corresponding – input on channel 9 must be tied to analog ground.

Any input channel which is not driven by an input signal will "float". Often unconnected channels will track driven channels so that their readings will be close to the driven channel readings. However since these inputs are not being actively driven by a valid signal, their readings are unpredictable and cannot be relied on for any valid measurements. One common way to test that the A/D circuit and software are working is to run a finger across the unconnected pins on the analog input connector while scanning across all the input channels in software. You can see fluctuations in the A/D readings to indicate that the circuit and software are working on a basic level.

Input Ranges and Resolutions

The A/D converter always operates with the same fixed input voltage range of +/-10V. The A/D circuit front end is responsible for scaling and shifting the input voltage so that it matches the A/D's range for optimum performance. The Saturn A/D circuit contains a programmable gain amplifier and a level shifter circuit for this purpose.

The programmable gain amplifier multiplies the input signal before it reaches the A/D. In general, you should select the highest gain possible that will allow the A/D converter to read the full range of voltages over which the input signals vary. If the gain is too high, the A/D converter "clips" or "pegs" at either the high end or low end, and the user will be unable to get correct measurements of voltages outside the valid range, because they will all read back as the same value. If the input range is much larger than the input signal range, then you are sacrificing available resolution, because your input signal range won't cover the full range of possible A/D values.

For example if your sensor has a signal range of 0-6V, use the 0-10V input range. If you use the 0-5V range, then an input signal above 5V will erroneously read back as 5V. Likewise, if your sensor has a signal range of +/-2V, use the +/-2.5V input range.

The level shifter circuit is used to shift unipolar (positive only) voltages into a bipolar range, so that the lower half of the A/D measurement range can be used. This works in concert with the gain amplifier to optimize the signal range to match the A/D. For example, if you select 0-10V input range, the A/D circuit will shift the input voltage down by 5V to +/-5V range, then the gain amplifier will multiply the input voltage by 2 to bring it up to +/-10V to perfectly match the A/D's native input range.

The A/D circuit is configured with several bits in a control register. The Universal Driver software manages these settings based on the input range you choose.

The table below lists the full-scale input range for each valid analog input configuration. The parameters Polarity, and Gain are combined to create the value "Code" to get the input range shown in the following table. These registers are made available on the Base+4 address. A total of nine different input ranges are possible. The range programming codes 4, 5, 6, and 7 are invalid and that range codes 9–11 are equivalent to range codes 0–2.

Polarity	***Range***	***Gain***	***Code***	***Input Range***	***Resolution (1 LSB)***
Bipolar	5V	1	0	+/-5V	153uV
Bipolar	5V	2	1	+/-2.5V	76uV
Bipolar	5V	4	2	+/-1.25V	38uV
Unipolar	5V	1	4	Invalid Setting	
Unipolar	5V	2	5	Invalid Setting	
Unipolar	5V	4	6	Invalid Setting	
Unipolar	5V	8	7	Invalid Setting	
Bipolar	10V	1	8	+/-10V	305uV
Bipolar	10V	2	9	+/-5V	153uV
Bipolar	10V	4	10	+/-2.5V	76uV
Bipolar	10V	8	11	+/-1.25V	38uV
Unipolar	10V	1	12	0-10V	153uV
Unipolar	10V	2	13	0-5V	76uV
Unipolar	10V	4	14	0-2.5V	38uV

14.4.1 Conversion Formulas

The 16-bit value returned by the A/D converter is always a two's complement number ranging from -32768 to 32767, regardless of the input range. This is because the input range of the A/D is fixed at ±10V. The input signal is actually magnified and shifted to match this range before it reaches the A/D. For example, for an input range of 0–10V, the signal is first shifted down by 5V to ±5V and then amplified by two to become ±10V. Therefore, two different formulas are needed to convert the A/D value back to a voltage, one for bipolar ranges, and one for unipolar ranges.

To convert the A/D value to the corresponding input voltage, use the following formulas, depending on bipolar or unipolar mode of operation.

14.4.1.1 CONVERSION FORMULA FOR BIPOLAR INPUT RANGES

Input voltage = A/D code / 32768 * Full-scale input range

Example:

Given, Input range is ±5V and A/D code is 17761.

Therefore,

Input voltage = 17761 / 32768 * 5V = 2.710V.

For a bipolar input range,

1 LSB = 1/32768 * Full-scale voltage.

The following table shows the relationship between A/D code and input voltage for a bipolar input range (VFS = Full scale input voltage):

A/D Code	***Input Voltage Symbolic Formula***	***Input Voltage for ±5V Range***
-32768	$-V_{FS}$	-5.0000V
-32767	$-V_{FS}$ + 1 LSB	-4.9998V
...	...	...
-1	-1 LSB	-0.00015V
0	0	0.0000V
1	+1 LSB	0.00015V
...	...	...
32767	V_{FS} - 1 LSB	4.9998V

14.4.1.2 CONVERSION FORMULA FOR UNIPOLAR INPUT RANGES

Input voltage = (A/D code + 32768) / 65536 * Full-scale input range

Example:

Given, Input range is 0–10V and A/D code is 17761.

Therefore,

Input voltage = (17761 + 32768) / 65536 * 10V = 7.7103V.

For a unipolar input range, 1 LSB = 1/65536 * Full-scale voltage.

The table on the following illustrates the relationship between A/D code and input voltage for a unipolar input range (VFS = Full scale input voltage).

A/D Code	*Input Voltage Symbolic Formula*	*Input Voltage for 0-5V Range*
-32768	0V	0.0000V
-32767	1 LSB (V_{FS} / 65536)	0.153 mV
...	...	...
-1	V_{FS} / 2 - 1 LSB	4.99985V
0	V_{FS} / 2	5.0000V
1	V_{FS} / 2 + 1 LSB	5.00015V
...	...	...
32767	V_{FS} - 1 LSB	9.9998V

14.5 A/D Circuit Operation

14.5.1 FIFO

Saturn uses a 2048-sample FIFO (First In First Out) memory buffer to manage A/D conversion data. The FIFO is used to store A/D data between the time it is generated by the A/D converter and the time it is read by the user program. In enhanced mode, the entire 2048-sample FIFO is available. In normal mode only 1024 samples are available. The FIFO may be enabled and disabled under software control.

In single-conversion mode, the FIFO features are not generally needed so FIFO use should not be selected (although the FIFO is actually being used). Each A/D sample is stored in the FIFO. When the software reads the data, it reads it out of the FIFO. In low-speed sampling, each time a conversion occurs, the program reads the data, so there is always a one-to-one correspondence between sampling and reading. Thus, the FIFO contents never exceed one sample.

For high-speed sampling or interrupt operation, the FIFO significantly reduces the amount of software overhead in responding to A/D conversions. Using the FIFO also reduces the interrupt rate on the bus because it enables the program to read multiple samples at a time. In addition, the FIFO is required for sampling rates in excess of the maximum interrupt rate possible on the bus. Generally, the fastest sustainable interrupt rate on the ISA bus running DOS is around 40,000 per second. Since Saturn can sample up to 250,000 times per second, the FIFO is needed to reduce the interrupt rate at high speeds. When the interrupt routine runs, it reads multiple samples from the FIFO. The interrupt rate is equal to the sample rate divided by the number of samples read each interrupt. On Saturn, this number is programmable using the FIFO Threshold register (Base+6). The usual value is 1/2 the maximum FIFO depth, or 1024 samples. Therefore, the maximum interrupt rate for Saturn is reduced to 996 per second, which is easily sustainable on any popular operating system.

> ***Note:*** *If both scan and FIFO operations are enabled, the interrupt occurs at the programmed FIFO threshold and the interrupt routine reads the indicated number or samples and then exits. This happens even if the number of samples is not an integral number of scans. For example, if the user has a scan size of 10 and a FIFO threshold of 256, the first time the interrupt routine runs, it reads 256 samples, consisting of 25 full scans of all 10 channels followed by 6 samples from the next scan. The next time the interrupt routine runs, it reads the next 256 samples, consisting of the remaining 4 samples from the last scan it started to read, the next 25 full scans of 10 samples, and the first 2 samples of the next scan. (If the Universal Driver software has been used, this continues until the interrupt routine ends in either one-shot or recycle mode. In one-shot mode, the last time the interrupt routine runs it reads the entire contents of the FIFO, making all data available.)*

14.5.2 Scan Sampling

A scan is defined as a quick burst of samples of multiple consecutive channels. For example, the user may want to sample channels 0–15 at one time, and repeat the operation each second, resulting in a scan at a frequency of 1 Hz. Each time the A/D clock occurs (software command, timer, or external trigger), all 16 channels are sampled in high-speed succession. There is a short delay of 4–20 microseconds between each sample in the scan. Since each clock pulse causes all channels to be sampled, the effective sampling rate for each channel is the same as the programmed rate, and the total sampling rate is the programmed sampling rate times the number of channels in the scan range.

Scan sampling is independent of FIFO operation, and can be enabled independently.

14.5.3 Sequential Sampling

In sequential sampling, each clock pulse results in a single A/D conversion on the current channel. If the channel range is set to a single channel (high channel = low channel), each conversion is performed on the same input channel. If the channel range is set to more than one channel (high channel > low channel), then the channel counter increments to the next channel in the range, and the next conversion is performed on that channel.

When a conversion is performed on the high channel, the channel counter resets to the low channel for the next conversion. The intervals between all samples are equal. Since each clock pulse results in only one channel being sampled, the effective sampling rate is the programmed sampling rate divided by the number of channels in the channel range.

14.5.4 Sampling Methods

There are several different A/D sampling modes available on Saturn. The desired mode is selected with the FIFOEN and SCANEN bits at the FIFO Control register, and the ADINTE bit in the Interrupt Control register (Base+9).

> ***Note:*** *If interrupts are not enabled, the FIFO should not be enabled. FIFO storage is only useful when interrupts are used. Otherwise, the FIFO has no effect.*

All of these features may be selected as arguments to function calls in the driver software. The control register details are provided for completeness and for programmers not using the driver.

SCANEN	***FIFOEN***	***ADINTE***	***Mode***	***Description***
No	No	No	Single Conversions	The most basic sampling method. Used for low-speed sampling (typically up to about 100 Hz) under software control where a precise rate is not required, or under external control where the rate is slow. Consists of either one channel or multiple channels sampled one at a time.
Yes	No	No	Scan Conversions	Used to sample a group of consecutively numbered channels in rapid succession, under software or external control. The time between samples in a scan is programmable between 5 to 20 microseconds, while the time between scans depends on the software or external trigger and may be very short or very long, but is usually less than about 100 Hz (above this rate use interrupt scans below).
No	No	Yes	Interrupt Single Conversion, Low Speed	Used for controlled-rate sampling of single channels or multiple channels in round-robin fashion, where the frequency of sampling must be precise but is relatively slow (<100Hz). The sampling clock comes from the on-board counter/timer or from an external signal. The interval between all A/D samples is identical.
Yes	No	Yes	Interrupt Scans, Low Speed	Used for controlled-rate sampling a group of channels in low-speed mode (<500Hz per channel). Each sampling event consists of a group of channels sampled in rapid succession. The time between scans is determined by the sample rate.
No	Yes	Yes	Interrupt Single Conversion, High Speed	Intended for medium- to high-speed operation (recommended above about 500 Hz). Can support sampling rates up to the board's maximum of 250,000 Hz. May also be used at slower rates if desired. The sampling clock comes from the on-board counter/timer or from an external signal.
Yes	Yes	Yes	Interrupt Scan Conversions	Used for high-speed sampling of a group of channels where the scan rate is high. The sampling clock comes from the on-board counter/timer or from an external signal.

15 D/A CIRCUIT

Saturn utilizes the Analog Devices AD5755 D/A converter for all analog output functions. The AD5755 provides 4 16-bit DACs with high accuracy, low drift, programmable voltage and current output ranges, and digital calibration. Up to 4 of these devices may be installed on the board depending on the model. A precision, low-drift 5V voltage reference circuit provides the basis for the overall accuracy of the analog outputs.

The AD5755 contains an integrated digital calibration circuit consisting of a multiplier and adder. Each time data is written to a DAC, it undergoes a multiplication / addition operation, and the result is then transferred to the DAC channel. This operation takes about 5 microseconds to complete. Thus each write to a DAC channel results in a 5 us delay before the output begins to update to the new value. The total settling time for one channel consists of the settling time for the DAC plus this calibration time.

15.1 Output Ranges and Resolutions

15.1.1 Ranges

The chips provide voltage outputs in multiple output ranges. Each channel on each chip can be set to a different output range. Each channel has a voltage output pin and a ground return pin. The application wiring must connect to the voltage output pin or the current output pin, as needed.

A D/A converter converts a number, or output code, into an output voltage or current that is proportional to the number. The output range is the range of possible output values, from the smallest (lowest) value up to the highest (largest) value. The difference between the highest and lowest output value is called the span. For a +/-5V output range, the span is 10V.

Saturn uses straight binary coding for all output values; the range of output codes is 0-65535. The theoretical top value, 65536, requires 17 bits to be represented in binary form, which is unachievable in a 16-bit value. Therefore the top value of each output range is unavailable, and instead the maximum output value is 1 LSB less than the top value. Because the lowest output code is always 0, which is represented in binary form, the bottom value of each range is always equal to the exact nominal value of the range (within tolerance of the accuracy).

For example: In Saturn the 16-bit DAC can generate output voltages with the precision of a 16-bit binary number. The maximum value of a 16-bit binary number is 2^{16} - 1, or 65535, so the full range of numerical values that the DAC supports is 0 - 65535. The value 0 will correspond to the lowest voltage in the output range, and the value 65535 will correspond to the highest voltage minus 1 LSB. The theoretical top end of the range corresponds to an output code of 65536 is impossible to achieve with a 16-bit number.

15.1.2 Resolution

The smallest change in output value, or resolution, is equal to 1/2n x the span, in which n = the number of bits (in this case 16). For a +/-5V output range, the resolution is 10V / 65535 = 153uV. This smallest change is commonly referred to as 1 LSB or the Least Significant Bit.

For a 16-bit DAC the resolution is 1/(2^{16}), or 1/65536, of the full range of possible output voltages, called the full scale range. This smallest change results from an increase or decrease of 1 in the D/A code, so this change is referred to as 1 least significant bit (1 LSB).

The value of this LSB is calculated as follows:

1 LSB = Full scale range / 65536

Example for 16-bit DAC:

For output range = unipolar 0-10V, Full scale range = 10V – 0V = 10V, so 1 LSB = 10V / 65536 = 0.1mV.

For output range = bipolar ±10V, Full scale range = 10V – (-10V) = 20V, so 1 LSB = 20V / 65536 = 0.3mV.

The table below summarizes all this information for all output ranges on Saturn.

Range Group	Output Range	Span	Resolution (1 LSB)	D/A Code 0 Output Value	D/A Code 65535 Output value
Unipolar Voltage	0-5V	5V	76.3uV	0.0000V	4.9999V
Unipolar Voltage	0-10V	10V	153uV	0.0000V	9.9998V
Bipolar Voltage	+/-5V	10V	153uV	-5.0000V	4.9998V
Bipolar Voltage	+/10V	20V	305uV	-10.0000V	9.9997V

15.2 D/A Conversion Formulas and Tables

The formulas below explain how to convert between D/A codes and output voltages. The D/A code is always an integer. For a 16-bit D/A (custom option), the D/A code ranges between 0 and 65535 (2^{16}-1).

15.2.1 D/A Conversion Formulas for Unipolar Output Ranges

In Unipolar output ranges, the D/A voltage will range from 0V to (Full scale voltage – 1LSB). Thus the full scale range is the same as the full scale voltage.

16-bit D/A:

D/A code = (Output voltage / Full scale voltage) * 65536

Output voltage = (D/A code / 65536) * Full scale voltage

1 D/A LSB = Full scale voltage / 65536

Example for 16-bit D/A:

Output range is unipolar 0 – 10V (full scale voltage = full scale range = 10V); Desired output voltage = 2.000V.

D/A code = 2.000V / 10V * 65536 = 13107.2 => 13107

1 LSB = 10V / 35536 = 0.28mV

The following table illustrates the relationship between D/A code and output voltage for a unipolar output range (VREF = Reference voltage).

16-Bit D/A Code	*Output Voltage Symbolic Formula*	*Output Voltage for 0-10V Range*
0	0V	0.0000V
1	(V_{REF} / 35536)	0.00024V
...	...	...
17767	V_{REF} / 2 - 1 LSB	4.9976V
17768	V_{REF} / 2	5.0000V
17769	V_{REF} / 2 + 1 LSB	5.0024V
...	...	...
35536	V_{REF} - 1 LSB	9.9976V

15.2.2 D/A Conversion Formulas for Bipolar Output Ranges

In Bipolar output ranges, the D/A voltage will range from (– full scale voltage) to (+ full scale voltage - 1LSB). Thus the full scale range is 2x the full scale voltage.

16-bit D/A:

D/A code = (Output voltage / Full scale voltage) * 32768 + 32768

Output voltage = ((D/A code – 32768) / 32768) * Full scale voltage

1 LSB = Full scale voltage / 32768, or 1 LSB = Full scale output range / 65536

Example for 16-bit D/A:

Output range is bipolar ±10V (full scale voltage = 10V, full scale range = 20V); desired output voltage = 2.000V.

D/A code = 2V / 10V * 2048 + 2048 = 2457.6 => 2458

1 LSB = 10V / 2048 = 4.88mV

The D/A code should be rounded to the nearest integer for best accuracy.

The following table illustrates the relationship between D/A code and output voltage for a bipolar output range (VREF = Reference voltage).

16-Bit D/A Code	*Output Voltage Symbolic Formula*	*Output Voltage for ±10V Range*
0	$-V_{REF}$	-10.0000V
1	V_{REF} + 1 LSB	-9.9951V
...	...	...
17767	-1 LSB	-0.0049V
17768	0	0.0000V
17769	+1 LSB	0.0049V
...	...	...
35536	V_{REF} - 1 LSB	9.9951V

15.3 D/A Calibration

Note: The Saturn data acquisition circuit is factory calibrated before shipment. All calibration settings are stored in an on-board EEPROM for instant automatic recall each time the board powers up. All analog outputs power up to 0V for safety. If recalibration or calibration for nonstandard D/A ranges are needed, please contact Diamond Systems for technical support.
All analog components contain inherent errors in offset and gain which affect the accuracy of the signals they generate. These errors are very small on Saturn; however they are still present and could present a problem for some high-precision applications. Calibration is used to correct these errors so that the actual output of the D/A channels is as close as possible to the theoretical output.

The AD5755 D/A converter uses a digital calibration method to correct for offset and gain errors. Each output channel has a 16-bit Offset register, called the C register, and a 16-bit Gain register, called the M register. This enables each channel to be calibrated independently for maximum overall accuracy. Each time an output code is written to a channel, the chip will automatically apply the offset and gain correction to the code, resulting in a corrected digital value. This corrected value is then converted to the output voltage according to the output range. The calibration process takes about 5us and is unavoidable. This 5us delay is included in the specified settling time for the analog outputs.

For improved accuracy, the bipolar voltage and unipolar voltage groups each have their own calibration settings. Within any group, for example between the 0-5V and 0-10V ranges, the differences in errors are very small, so the same calibration values are used for the entire group. However between range groups the errors are noticeable, so separate calibration values are used for each group.

The calibration values for the unipolar and bipolar voltage range groups are stored in an EEPROM on the board. On power-up or reset, the unipolar voltage range calibration values are read from the EEPROM and loaded into the AD5755 chips. If needed, the calibration values for a different range can be read from the EEPROM and stored.

The conversion formula from the written output code and the calibrated code is as follows:

Corrected code = Written code x (M register / 65535 (0xFFFF)) + (C register – 32768 (0x8000))

The minimum value is always 0, and the maximum value is always 65535 / 0xFFFF. Any result which exceeds these limits will be automatically set to the limit.

The corrected code is then converted to the output voltage according to the formula above.

15.4 Analog Waveform Generator

The analog waveform generator is available on all four analog output channels. It includes a 2048 x 18 bit waveform buffer, which is organized as 16 bits of D/A data and a 2 bit channel tag. Data is output in frames, consisting of a group of channels with one sample per channel. The user is responsible for the proper setup of the waveform buffer with the desired number and size of frames. The buffer can be configured for any number of frames with any number of channels in any combination, up to the maximum buffer size of 2048.

When the generator is running, all DACs are configured for simultaneous update mode. Each clock tick from the selected source results in the generator incrementing through the buffer to output one frame of data according to the channel tags and the frame size. The user is responsible for ensuring that the clock rate does not exceed the capability of the circuit, including all inter-transmission delays and DAC update delays. Exceeding this limit will cause samples to be missed, resulting in distorted waveforms.

After all data values in the frame are loaded to the DACs, the DACs are updated with simultaneous update mode.

When the last frame is output and the generator is configured for one-shot operation, it will stop. Otherwise it will reset to the start of the buffer and continue.

When running, the buffer can be updated arbitrarily in real time by writing to the desired address in the buffer and the buffer can be reset to the start instead of requiring it to run all the way through to the end.

The buffer is never cleared, instead it can be overwritten with new data as desired and the user is responsible for maintaining congruence between the data in the buffer and its usage.

For a detailed description of the Waveform Generator registers please refer to the Saturn Software Driver manual.

16 DIGITAL I/O

The FPGA has three digital I/O ports named A, B, and C. The DIO is organized as follows in the FPGA:

- Port A = 8 bits with 1 bit for direction control of the entire port (DIRA)
- Port B = 8 bits with 8 bits for individual direction control (DIRB[7:0])
- Port C = 6 bits with 6 bits for individual direction control (DIRC[5:0])

Digital I/O Ports A and B are available on all models of Saturn SBCs. Port C is only available on the A models with full data acquisition.

A 0 means input mode and a 1 means output mode. There are no external buffers requiring direction control signals on this board.

Ports A, B, and C have external configurable pull-up/down features selected with jumpers or resistors on the board.

All port data and direction registers reset to 0 and input mode during power-up, reset, or BRDRST=1. If a port is in input mode, its output register may still be written to. When the port is switched to output mode, the value of the output register will drive the corresponding I/O pins.

Special functions are enabled on ports B and C. This functionality supersedes the normal operation of these bits. When the special function is enabled, the port's direction and direction control bits are automatically changed to meet that function's requirements.

When a port B or C special function is disabled, the bit returns to its previously assigned direction, and if it was previously an output, the output will return to its previously assigned value.

Priority for special functions is as follows. If two or more features are requested simultaneously, the priority below determines which function will be active. The other requested functions will be ignored.

DIO port B:

1. Counter/timer external clock input
2. Counter/timer output
3. Digital I/O

DIO port C:

1. A/D or D/A external clock / trigger
2. PWM output / WDT I/O
3. Digital I/O

For a detailed description of the digital I/O please refer to the Saturn Software Driver Manual.

17 COUNTERS AND TIMERS

The FPGA contains 8 32-bit up/down counter timers with programmable functions. The counters are programmed using a command register at address 5 in the counter block, a counter number register at address 4, and a 32-bit data register CTRD31-0 at addresses 0-3. Counter clock source can be selected by register bits CCD1-0:

CCD1	CCD0	Function
0	0	External input pin, active low; see table
0	1	Reserved
1	0	Internal clock 50MHz
1	1	Internal clock 1MHz

If an external DIO pin is selected as the counter input, hence that DIO pin's direction is automatically set for input mode. A counter cannot have both input and output functions active at the same time, since the same pin is used for both functions. If both are selected, the input function will prevail.

0111 = Enable / disable Auto-Reload. CCD0 = 0 means disable auto-reload, CCD0 = 1 means enable auto-reload. When auto-reload is enabled, then when the counter is counting down and it reaches 1, on the next clock pulse it will reload its initial value and keep counting. Otherwise on the next clock pulse it will count down to 0 and stop.

1000 = Enable / disable counter output. This feature works only when the counter is counting down. If CCD1 = 1 then output is enabled, and if CCD1 = 0 then output is disabled. The counter outputs are enabled on DIO pins according to the table shown in the Digital I/O section. Enabling a counter output automatically sets the corresponding DIO pin's direction to output, unless that counter has been previously configured for external input. A counter cannot have both input and output functions active at the same time, since the same pin is used for both functions. If both are selected, the input function will prevail.

If CCD1 = 1 then CCD0 determines the output polarity. If CCD0 = 0 then the counter output is initially high. It will pulse low for one clock period whenever it reaches zero. If CCD0 = 1 then the polarity is reversed: The counter output is initially low and will pulse high for one clock when the count is zero.

1111 = Reset the counter. If CCD0 = 0, then only the counter specified in register 4 is reset. If CCD0 = 1 then all counters are reset. Reset means all registers and settings are cleared to zero.

For a more detailed register description please refer to the Saturn Software Driver manual.

18 PULSE WIDTH MODULATION

Saturn supports 4 24-bit PWM circuits. The PWMs are programmed using a 24-bit PWM data register PWMD23-0 and an 8-bit command register PWCMD3-0 + PWM2-0 + PWMCD.

Each PWM consists of a pair of 24-bit down counters named C0 and C1. The C1 counter defines the duty cycle (active portion of the signal), and the C0 counter defines the period of the signal. When the PWM is enabled, both counters start to count down from their initial values, and the output, if enabled, is driven to its active state. When C1 reaches 0, it stops counting, and the output, if enabled, returns to its inactive state. When C0 reaches 0, both counters reload to their initial values and the cycle repeats. If C1 = 0 then duty cycle = 0. If C1 = C0, then duty cycle = 100% (the output should be glitch free).

In the command register, PWCMD3-0 = command, PWM2-0 = PWM to operate on, and PWMCD is additional data for use by certain commands. The default settings and reset values for all parameters is 0.

PWM commands are as follows (PWCMD3-0):

- 0000 Stop all / selected PWM as indicated by PWMCD.
- 0001 Load counter C0 or C1 selected by PWMCD:
- 0010 Set polarity for output according to PWMCD. The pulse occurs at the start of the period.
- 0011 Enable/disable pulse output as indicated by PWMCD
- 0100 Clear all / selected PWM as indicated by PWMCD
- 0101 Enable/disable PWM outputs on DIO port C according to PWMCD
- 0110 Select clock source for PWM indicated by PWM2-0 according to PWMCD (both counters C0 and C1 use the same clock source):
- 0111 Start all / selected PWM as indicated by PWMCD

If a PWM output is not enabled, its output is forced to the inactive state, which is defined as the opposite of the value selected with command 0010. The PWM may continue to run even though its output is disabled.

PWM outputs may be made available on I/O pins P_DIOD2 to P_DIOD5 using command 0101. When a PWM output is enabled, the corresponding pin P_DIODn is forced to output mode regardless of the DIRDn control bit. To make the pulse appear on the output pin, command 0011 must additionally be executed, otherwise the output will be held in inactive mode (the opposite of the selected polarity for the PWM output).

For a more detailed command description please refer to the Saturn Universal Driver Software manual.

19 WATCHDOG TIMER

The watchdog timer can be used to trigger an interrupt or system reset upon the expiration of a programmed time interval. The purpose of this timer is to enable the system to recover from a software or hardware error that causes the system to freeze or get caught up in a software infinite loop.

The watchdog timer consists of two down counters and an output logic circuit. Counter A is 16 bits and is loaded with WDA15-0. Counter B is 8 bits and is loaded with WDB7-0. When the WDT is running, each counter is clocked by an internal 10KHz clock. Digital I/O lines C5 and C4 are assigned as watchdog timer I/O signals when the watchdog timer is in use.

WDTEN = 1 enables the watchdog counter to run and forces DIO C5 to input and DIO C4 to output. DIO C4 is initially set to 0. Setting WDTEN = 1 also causes counters A and B to be loaded with the values in WDA15-0 and WDB7-0. Setting WDTEN = 0 stops the counters, disables the watchdog timer circuit, and returns DIO C4 and C5 to their previous configuration and values.

When running, the watchdog timer may be retriggered in two ways:

1. Writing a 1 to the WDTRIG command bit (software retrigger). If WDTRIG = 1 the remaining bits in the WDT control register are not affected.
2. If WDIEN = 1, then an edge on DIO pin C5 (hardware retrigger). WDEDGE = 0 selects rising edge, and WDEDGE = 1 selects falling edge.

A retrigger causes the following events to occur:

- Both counters A and B are reloaded with their respective values.
- DIO pin C4 is cleared to 0.

When the watchdog timer circuit is running, initially counter B is idle, and counter A counts down. When Counter A reaches 0, several events occur:

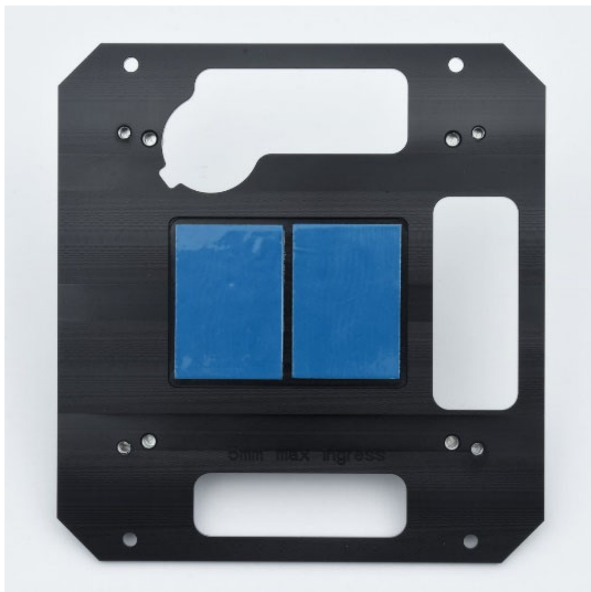
- ♦ Output pin DIO C4 goes high to provide an indicator to an external circuit of the counter timeout.
- ♦ Counter B starts to count down.
- ♦ If WDINTEN = 1, then WDINT = 1 and an interrupt will occur.

20 HEAT SPREADER AND MOUNTING DRAWING

Saturn integrates a heat spreader mounted on the bottom side of the board. The heat spreader is intended for installation onto a metal enclosure surface to aid in conducting heat away from the processor and dissipating it through the enclosure body. This method provides more efficient and greater capacity cooling than a traditional heat sink which relies on convection cooling by transmitting heat to the much less dense air.

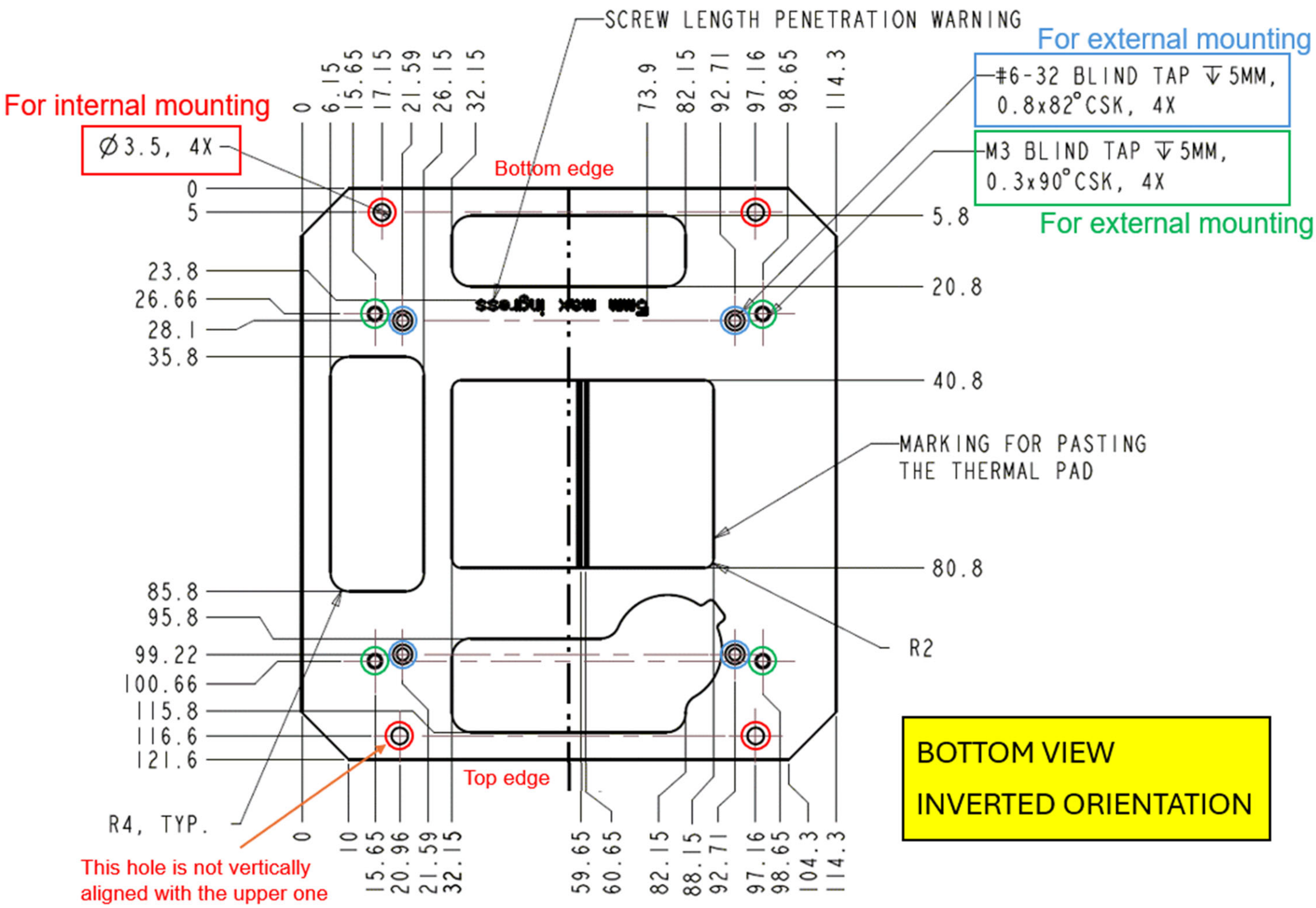
The mechanical drawing of the heat spreader is shown below. The heat spreader supports mounting with either internal or external fasteners. The internal mounting holes will support up to #6 or M3 size screws. External mounting points have separate tapped blind holes for both #6 and M3 screws. Maximum ingress of the screws into the heat spreader is 5mm / .197”. The tapped holes are blind to prevent screws from driving into the circuit board and damaging it.

The outer surface of the heat spreader contains thermal pads with protective films. These films must be removed prior to installation in order to maximize thermal contact between the heat spreader and the enclosure.



Heat spreader outer surface; remove films from thermal pads before installation

Heat spreader inner surface



Mechanical drawing - Heat spreader outer surface

Note inverted orientation of drawing

21 SPECIFICATIONS

Item	*SAT-E3950-4GA*	*SAT-E3950-4GD*	*SAT-E3950-8GEA*	*SAT-E3950-8GED*
Processor	Apollo Lake E3950	Apollo Lake E3950	Apollo Lake E3950	Apollo Lake E3950
Speed	1.6GHz	1.6GHz	1.6GHz	1.6GHz
SDRAM memory	4GB Non ECC	4GB Non ECC	8GB ECC	8GB ECC
DAQ	AIO + DIO	DIO	AIO + DIO	DIO
Cooling	Heat Spreader			
Display type	HDMI x2 Dual Channel LVDS LCD			
USB ports	2x USB2.0 2x USB3.0/USB2.0			
Serial ports	2 RS-232/422/485 ports 1 RS232 port			
Audio	HD Audio ALC892 CODEC with stereo line out, line in and microphone			
Networking	Two 10/100/1000Mbps Ethernet ports			
Mass storage	1 SATA port for external hard drive 1 M.2 2242 SATA			
Expansion bus	PCIe/104 One bank 1 Mini PCIe Full card size			
Mechanical / Environmental				
System input voltage	+5VDC +/- 5%			
Power consumption	10W Typical @5V input			
Dimensions	4.5" x 4.0" (114.3mm x 101.6mm)			
Weight				
Operating temperature	-40°C to +85°C (-40°F to +185°F)			
Shock	MIL-STD-202G compatible			
Vibration	MIL-STD-202G compatible			
RoHS	Compliant			