Prime Technology LLC
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A New Approach to Tank Level Measurement Using Absolute Pressure Sensors

A Description of Prime Technology's Absolute Pressure Tank Level System
April 11, 2005

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Prime Technology has developed a new, novel approach to tank level measurement through the use of absolute pressure sensors. Pressure sensing tank level systems have been readily available for many years. The novelty in this design, however, is the use of absolute sensors rather than differential sensors as the sensing elements.

Differential sensor based systems used "ported" pressures to assess the differential pressure from the weight of the contents in the tank in relation to the reference ambient pressure. To measure these two pressures using one differential sensor required the design to accommodate the piping of at least one of the relevant pressures to the location of the sensor. This creates a complex mechanization that leads to trapped air, difficulty in calibration and installation problems. It also had limited success due to the limitations in legacy pressure sensors in regard to accuracy and durability. Differential pressure sensors are inherently less durable since the pressure medium is required to react to pressures from both sides and therefore has difficulty in surviving pressures in excess of the anticipated or in pressures that are extremely unbalanced.

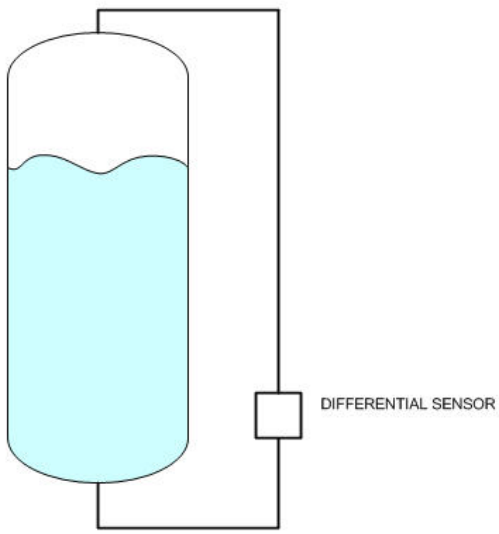

Figure 1: Typical Differential Pressure Set Up.

Prime's design utilizes three absolute pressure sensors and measures the differential electronically. This allows the use of more robust sensors and eliminates the requirement of having both pressures "ported" to physically one sensor. Prime's system applies a reference sensor to the top of the tank, above the liquid level, and two sensors at the bottom of the tank, below the lowest tank level. The sensors at the bottom of the tank are redundant merely to add to the longevity of the system without the need for sensor replacement. One of these two sensors can fail completely without any effect to the performance of the system.

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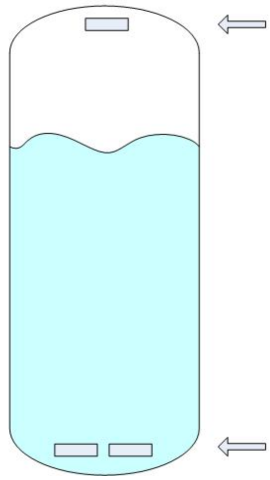

Figure 2: Prime Absolute Pressure Set Up

Prime's sensors are far more accurate then legacy systems and have far greater reliability. The sensor accuracy is one tenth of one percent as a stand-alone device. The Mean Time Between Failure (MTBF) is five hundred thousand hours for each sensor.

System Description

The Prime Technology Absolute Pressure Tank Level System (APTLS) 9299-00-0000 is designed to meet ASTM F2044-00 and Electric Boat's IDD number SC-SSGN-IDD-726-005. This Absolute Pressure Tank Level Indicator System reduces the required maintenance and complexity of the Tank Level Sensor System and thereby increases the system's MTBF. The APTLS is also modular in design to reduce the Mean Time To Repair (MTTR). The system accuracy is less than 1%.

The Prime Technology APTLS 9299-00-0000 consists of the following modules:

- One Three Channel Chassis — part number 04-9299-0000
- One Pressure Sensor Interface Module — part number 9299-92-0000
- One Power Supply Module — part number 92-9211-050
- Two Smart Indicators, — part number 9212-04-001
- Two Absolute Pressure Sensors (0 to 50 psia 0.1%) — part number 8101-04-0001
- One Absolute Pressure Sensor (0 to 50 psia 0.1%) — part number 8101-04-0000

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System Overview

The functional block diagram for this system is shown in figure 1. The System consists of a chassis, a Power Supply Module, a Pressure Sensor Interface Module (PSIM), Pressure Sensors and two Smart Indicators. Reference the outline drawing of figure 2 for the chassis mechanical outline. The design is derived from Prime Technology's Model 9211, which was originally designed and qualified for use on the Virginia Class Submarines.

The APTLS is powered from 115 VAC 60 Hz power.

Power Supply Module

The power supply module consists of an AC to DC power supply, fuse and holder, AC power on indicator, power on/off switch, set switch, alarm acknowledge switch, test potentiometer, test switch, up/down switch and cloning port connector. The AC to DC power supply converts 115vac 60hz, switched, fused power into unregulated +24vdc that is used by the modules in the panel.

The test potentiometer, test switch, and channel select switch are used in conjunction to apply a test signal to the channel selected. The alarm acknowledge switch is used to reset the local alarm lamp when an alarm is on. When the switch is moved into the alarm acknowledge position, and an alarm exists, the alarm indicator on the power supply module turns off. The set and UP/DN switches are used for setup of the alarm levels on the indicator modules as well as other selectable features. The cloning port (patented by Prime Technology) is used to clone the curve characteristics of the Smart Indicator located in the channel one position to the Smart Indicator to be attached to the cloning port.

Chassis Interfaces and Signal flow

The chassis design is very similar to Prime's Model 9211 product that has been qualified to Submarine requirements on multiple platforms. Two additional connectors were added to the

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APTLS to accommodate the interface to the additional inputs from the absolute pressure sensors and the interface to the Ships Control Station.

The chassis consists of all connectors used to interface to the pressure sensors and the host system. It also includes the motherboards that are used to interface with all the Smart Indicators and Pressure Sensor Interface Modules (PSIMs).

The interface for the pressure sensors is made through connector J6. The pressure sensor's inputs are taken from J6 and applied to the motherboard of the PSIM. The signal is then applied to the PSIM for processing. After being processed by the PSIM, the pressure signal is sent to the two Model 9212 Smart Indicators. The functionality of the PSIM and the Smart Indicators will be discussed in greater detail in their respective sections.

The interface to the 5% and 95%, tank level relay contacts are made through connector J4.

The interface to the Tank Level's retransmission signal is made through connector J3 and J5. Connector J5 also supplies the interface to the Tank Level Fail Relay contacts, which indicate a failure of the system in response to the system's internal Built-In-Test (BIT).

The 115vac 60-hertz power to the APTLS is supplied through connector J1. The chassis ground connection is made through a stud on the bottom of the chassis.

The chassis is designed to be bulkhead mounted. The access plate to the inside of the chassis is located on the rear. The reason for this is to ensure that once a tank curve address (discussed in future sections) is selected for a particular tank, it cannot be easily changed. The connectors are located on the bottom of the chassis.

The motherboard used with the Smart Indicators consist of a set of 8 dip switches which are used to set the curve address and two normally closed relays with dual redundant contacts that have a 1 amp current rating (inductive) @ 115 VAC 60 Hz. There are three normally closed relays with a single contact. Also included on the motherboard are the connectors that interface with the Smart Indicator and chassis. Although the motherboards for the two receivers are identical, only the Smart Indicator that is doing tank curve correction will have relays tied to the output connector.

Pressure Sensor Interface Module (PSIM)

Reference figure 3 for the mechanical configuration and figure 4 for the functional block diagram for the PSIM. The PSIM consists of a front bezel, chassis, rear connector cover, and a printed wiring board. The chassis, rear connector cover, bezel and cover are derived from the Prime Technology Model 9212's mechanical design. The mechanical interface connectors to this module are the same as the Model 9212. The printed wiring board is also of the same mechanical interface, but the electronics are different.

The electrical interface to the PSIM is made thru the connectors mounted on the back of the module.

The power is supplied from the unregulated +28vdc supply that comes from the power supply module. The unregulated 28volt input is supplied to an isolated DC/DC converter that generates regulated plus and minus 15vdc and +5vdc.

The analog input to the PSIM consists of (1) an input impedance matching circuit that terminates the input signals, (2) a multiplexer that selects an input signal for processing, (3) a differential amplifier circuit, and (4) an A/D converter.

The pressure sensor's interface is as follows. The high sides of the sensors are supplied with regulated +15vdc thru a sensor health sensing circuit. The low sides of the sensors are applied to the input termination circuitry. The sensor input is then applied to a multiplexer that is controlled by the microprocessor. The microprocessor uses the multiplexer to select from a number of inputs. The inputs to the multiplexer consist of the sensor inputs (top, bottom A and B), Built In Test (BIT) voltages, simulated potentiometer input and power supply sense voltage. The selected signal is then applied to a 24-bit A/D converter and then serially sent to the microprocessor for processing.

The two sensors use the same analog circuitry for processing. By using the same analog processing circuits for the top and bottom sensors, any error that is added to the signal by the analog circuit is removed. Once the top and bottom sensors are digitized, the signal will be corrected to remove any non-linearity errors inherent in the sensors. This is accomplished by sampling the sensors curve characteristics, storing the information and curve fitting the sensor's curve to fit a straight line. The difference between the two corrected sensors signals is then used by the microprocessor. The top sensor signal is subtracted from the bottom sensor. This difference signal is proportional to the tank height. The tank height signal is then processed for digital serial transmission to the Model 9212 Smart Indicators via the PSIM's isolated RS422 port. The signal is sent to the Smart Indicators digitally to ensure no additional errors are encountered by D/A to A/D conversions that would have been experienced using an analog signal. The Smart Indicators perform further processing before displaying the data. The processing for the Smart Indicators will be described in their respective sections.

An A/B switch on the front of the PSIM is used to select one of two sensors (sensor A or sensor B) on the bottom of the tank.

A circuit is included in the PSIM to check on the absolute pressure sensor's health. The sensor's operational status is checked to see if the current being generated by the sensors are within the 4 to 20 mA range. If the sensor circuit opens, shorts or goes out of this range, a yellow LED is illuminated on the PSIM and the a sensor fail message is sent to the appropriate Smart Indicator. The Smart Indicator asserts the Fail Tank Level Relay. Once the sensor Fail Acknowledge switch is initiated, the LED will change from yellow to red and Sensor Fail acknowledge message is sent to the Smart Indicator. The Smart Indicator de-asserts the Fail Tank Level Relay. The red LED will stay illuminated until the APTLS is powered down and the sensor repaired. Two LEDs are used to indicate which of the two sensors in the bottom of the tank are in use.

PSIM Display

The PSIM will be calibrated by entering into the calibrate mode of operation. This is accomplished by asserting the Set and Up switches during power up when the selector switch is in the proper location to select the PSIM. The PSIM will step through the setup functions. The operations manual will aid the user in how to utilize this function.

PSIM Calibration

The calibration data needed is the minimum and maximum pressure inputs. This will be used to set the offset and span.

The calibration sequence is as follows. First pressure is applied to the sensors. The starting pressure will be 15 psia. The next pressure will be full scale. This establishes the maximum and minimum inputs. This calibration will be done for each sensor. This information will be stored in memory so that a curve correction of the sensors input can be performed. Next a pressure difference equal to the pressure for max tank height will be applied. The higher pressure will be to the sensor on the bottom of tank. The nominal pressure for both sensors will be 75 psia with the bottom pressure being 75 psia + pressure required to simulate a full tank. The sensor curve data will have to be performed twice, once for sensor A and once for sensor B.

This calibration routine should allow the offset, and scaling errors of the sensors to be eliminated. The actual accuracies will be evaluated when system testing is performed.

Smart Indicator Module

Reference figure 5 for the mechanical configuration for the Smart Indicator module. The mechanical configuration of this module is exactly the same as that used on Virginia Class submarines. The electrical interface is also the same. Some circuit changes and software were made to accommodate added functionality of this design. The Smart Indicator used for this application will be usable for any former applications using Smart Indicators. The standard, or former, Smart Indicator will not be usable for this application due to the added functionality.

The changes required to the Model 9212 Smart Indicator design include (1) software updates to allow for serial data to and from the PSIM, (2) update software to provide additional relay controls.

The Smart Indicator has both a digital and analog input available for use with a variety of sensor technologies. The signal from the PSIM is applied to the Smart Indicator via the RS422 input. The microprocessor curve corrects the signal based on curve information that is stored in the Smart Indicator's memory. The curve corrected signal is compared to the 95% and 5% tank level settings and displays the tank volume on the four digit LED display and the percent of maximum tank volume on the bargraph. The 95% and 5% relay output control lines are set accordingly.

An analog signal and a serial RS422 signal are available for retransmission. The digital signal meets the NSSN interface requirements document number SEA03J-IRS SCS/TLI NSSN except for the parity requirement of this specification. The Virginia Class Submarine is using this serial link with the parity exception. This signal is available thru the J6 connector. The analog retransmissions available are 0-200 uA, 4-20 mA, 0-5 DCV and 0-10 DCV, -10-+10 DCVs.

The curve address for the tank being used is selected by reading the 8 dipswitches on the Smart Indicators motherboard. The address is applied to the Smart Indicator's microprocessor thru a parallel port on the microprocessor.

The Smart Indicator's voltage regulator circuit develops three voltages;+12vdc, -12Vdc and +5vdc. A 2.5 volt reference is developed from the 5vdc source for use by the A/D.

A power monitoring circuit is used to turn the processor on only when power is within an appropriate range.

The memory used on in the Smart Indicator consists of 3 serial modules consisting of 8 Kbytes of serial nonvolatile memory. This memory is used to store the tank curves that the Smart Indicator uses for tank correction.

A Built In Test (BIT) feature is available as part of the Smart Indicator's software. This test is used to test if the serial message is being received from the PSIM. The microprocessor will receive a message approximately every 250ms from the PSIM. If the signal is not received within one second, The Tank Level Fault relay will be asserted. The message contains fault codes that the Smart Indicator uses. The Smart Indicator sends a message to the PSIM approximately every 200ms. If the message is not received with in one second, the PSIM will cause the Tank Level Fault Relay to be asserted.

Absolute Pressure Sensors/Sensors

The APTLS uses three sensors; two in the bottom of the tank and one external at the top of the tank. The reason for two sensors at the bottom is for redundancy. The two submersible absolute pressure sensors have an integral cable vulcanized to the sensor body while the external sensor does not. The sensors are designed to give accuracy over a 0 to 50 degree c range of 0.1%. The accuracy number includes all errors (hysteresis, repeatability, non-linearity etc.).

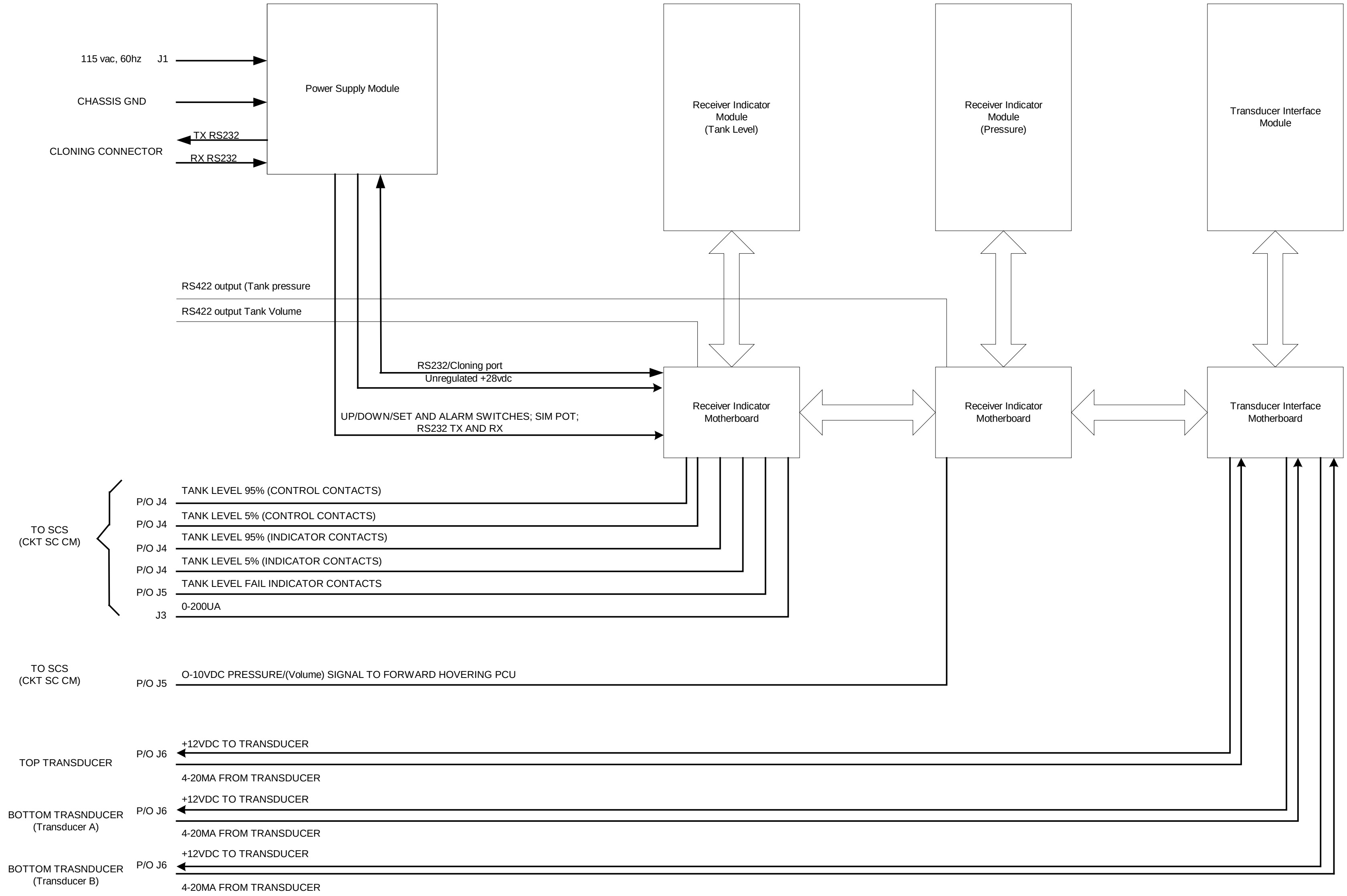
System Accuracy

The system calculated volumetric accuracy is less than 1%. This assumes the sum of the worst-case errors for sensors and Tank Level instrumentation. It is expected that the actual performance should be much better.

Qualification

This product has been qualified for use on board the Trident SSGN Upgrade program as a stand-alone system. A full qualification was performed including all physical and EMI testing as typically required for a critical application aboard a U.S. Navy Submarine.

Pressure Tank Level System
Figure 1



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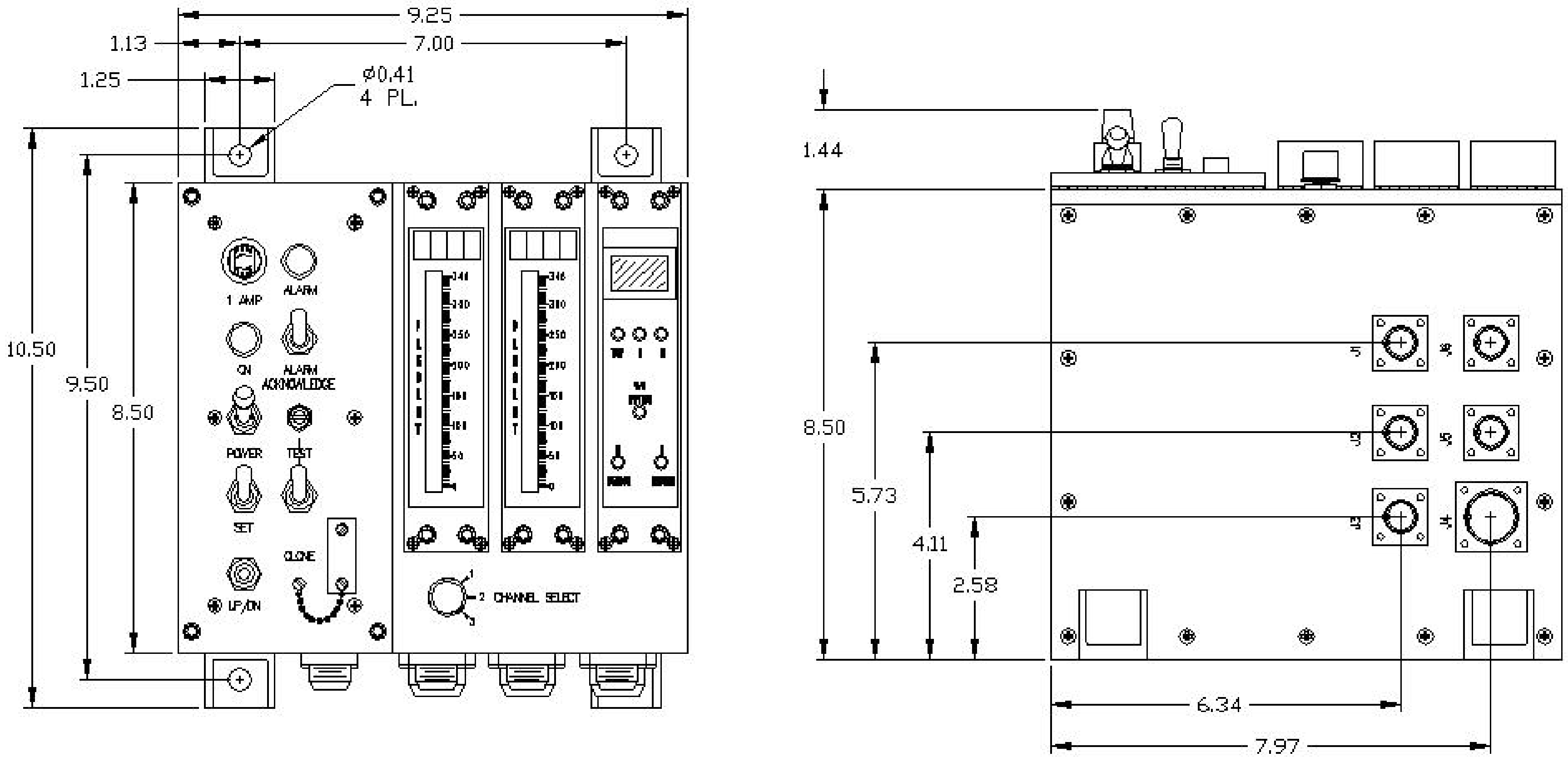

Figure 2: Chassis Mechanical Outline.

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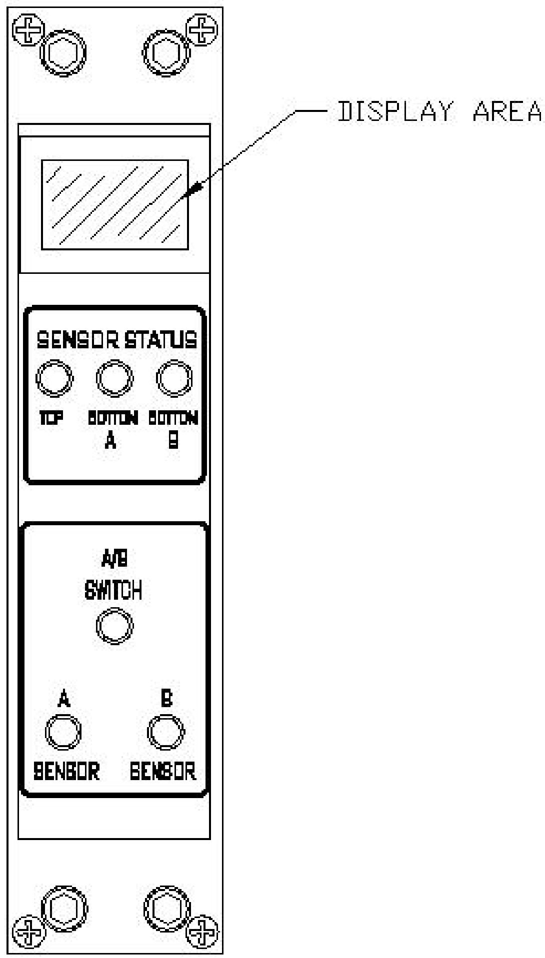

Figure 3: Pressure Sensor Interface Module Outline.

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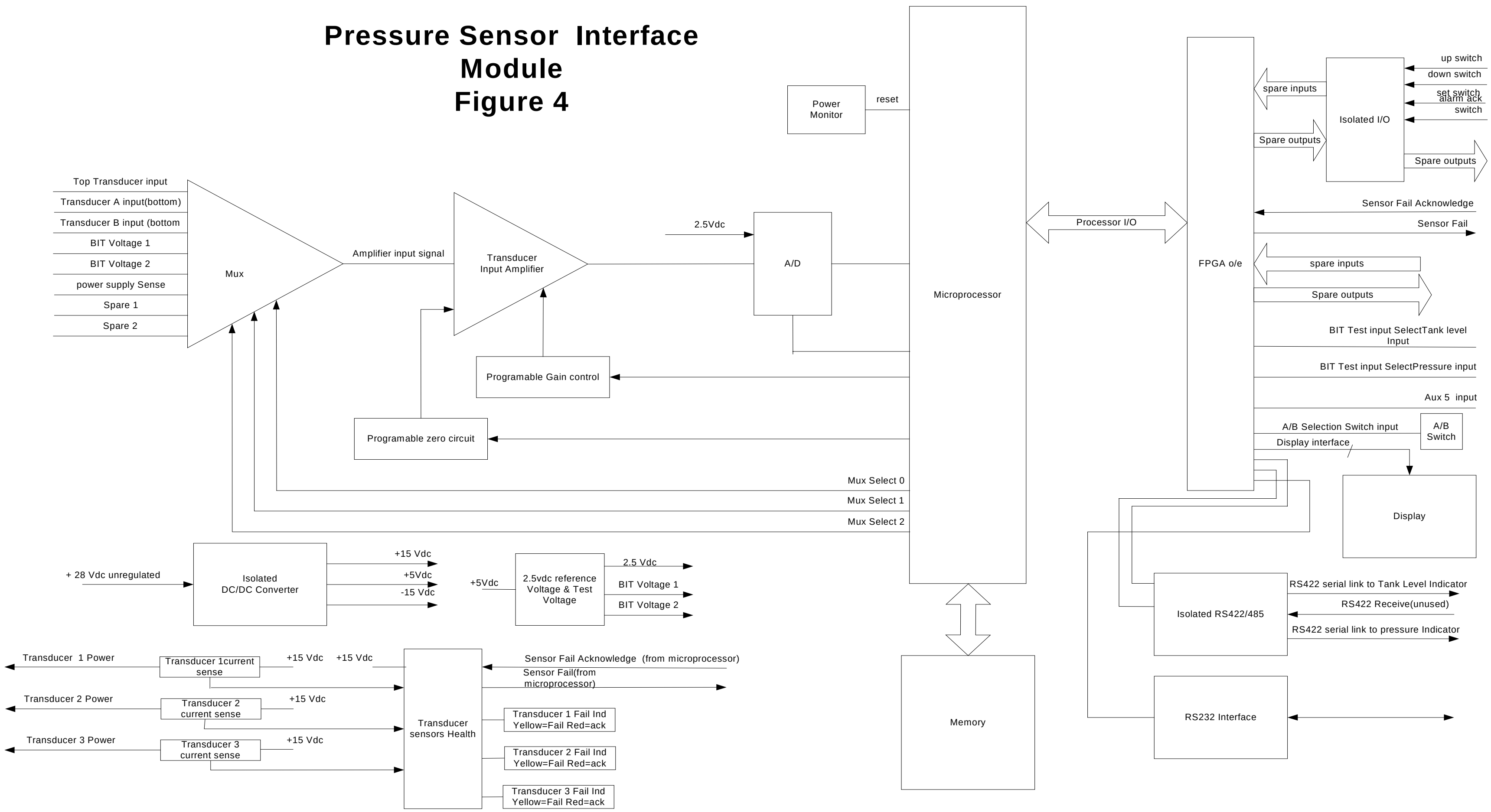
Pressure Sensor Interface Module
Figure 4



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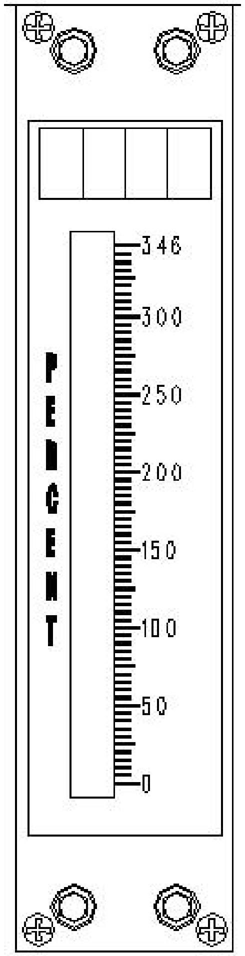

Figure 5: Smart Indicator Module.

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