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Hardware Design Document for Load Cells Supervision at 3.6 m Telescope

AAA-BBB-CCC-nnmmm-0001

Issue 1.0
Date: /09/2007

keywords: (up to five)

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	Name	Date	Signature
Released:	Releaser's Name		
	Name	Date	Signature

CHANGE RECORD

Issue	Date	Affected Paragraphs(s)	Reason/Initiation/Remarks
1.0	28/09/2007	All	Creation

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1. INTRODUCTION

This document describes the development of a Load Cell monitoring system on the 3.6m Telescope Dome. Each wheels or Bogies is equipped with a ***L****oad* ***CE****ll* ***R****eadout* ***MO****dule* (***LERO***) which is basically a signal conditioning circuit. Several such modules can be monitored and controlled by a base station. The system measures pressure in the wheel, converts it to an analog voltage signal, amplifies and filters the analog signal, converts it to a digital signal, processes and, finally, transmits it in Serial format (EIA422) to Multiplexer Server (MOXA) which is accessed using wireless links.

1.1 PURPOSE

Measurements of surface deformation are commonly used to monitor the health of any structure. Resistive strain gauges, such as Load Cell or Pressure Sensor, are the most popular way of measuring such deformation. Every Load Cell has its non-lineal transfer curve and it could be measured using a signal conditioned digital display (IPM500 – see []) with a cost around USD 500. In the 3.6 m Telescope DOME, four-teen bogies will be installed and each will have two load cells, too much expensive. For that reason, a new signal conditioning system will be designed for that purpose. By the other hand, it is useful to monitor the health of remote structures from a central monitoring and control station at a low cost. With recent advances in wireless networking this is now feasible. Wireless networks offer several advantages over traditional wired setups:

- ***Low Cost***: LERO, Router and Access Point are relatively cheap.
- ***Wireless Connectivity***: eliminates the need for laying costly and disconnection-prone cables from remote sites to the monitoring station.
- ***Fast Deployment, Flexible Topology***: since the sensor network does not require any fixed infrastructure and forms its own network (an ad-hoc network), it can be deployed very fast. Similarly the number and location of the monitoring sites can be dynamically changed without any efforts to reconfigure the network.
- ***Minor Development Efforts***: the only significant development effort required is a signal conditioning circuit and software that interfaces the strain gauge sensor with the mote.
- ***Low Maintenance & Operating Cost*** : since LERO's consume very little power, are robust, and can be reprogrammed and calibrated from a remote location, they require very little on-site maintenance.

1.2 APPLICABLE DOCUMENTS

The following documents, of the exact issue shown, form a part of this document to the extent specified herein. In the even of conflict between the documents referenced herein and the contents of this document, the contents of this document shall be considered a superseding requirement.

1. AAA-BBB-CCC-nnmmm-0001, Issue 1, dd/mm/yyyy --- Document Title
2. AAA-BBB-CCC-nnmmm-0001, Issue 1, dd/mm/yyyy --- Document Title
3. AAA-BBB-CCC-nnmmm-0001, Issue 1, dd/mm/yyyy --- Document Title

1.3 REFERENCE DOCUMENTS

A reference document is a document to which reference may be specifically made in order to point the reader information useful for the understanding of topics related to the referring document, but which is not directly binding on it in the sense of an applicable document. Each reference document shall be mentioned in the following text.

The following list is an example. Add items to or subtract item from it.

The following documents are referenced in this document.

4. AAA-BBB-CCC-nnmmm-0001, Issue 1, dd/mm/yyyy --- Document Title

1.4 ABBREVIATIONS AND ACRONYMS

You may wish to add items to, or subtract items from the following list.

The following abbreviations and acronyms are used in this document:

LSM	La Silla Management
LSO	La Silla Observatory
N/A	Not Applicable
TBC	To Be Confirmed
TBD	To Be Defined

2. OVERVIEW

The system consists in a base module called **LOAD CELLS READOUT MODULE** (**LERO**) which measures the force on the wheel or Boggies. This analog signal is converted to digital and processed by a microcontroller. A data frame is sent using RS422 format to a Serial Device Networking (MOXA). The MOXA is interfaced with a MIMO Router and MIMO Wireless Access Point. The following figure 1 shows the basic configuration for the monitoring system

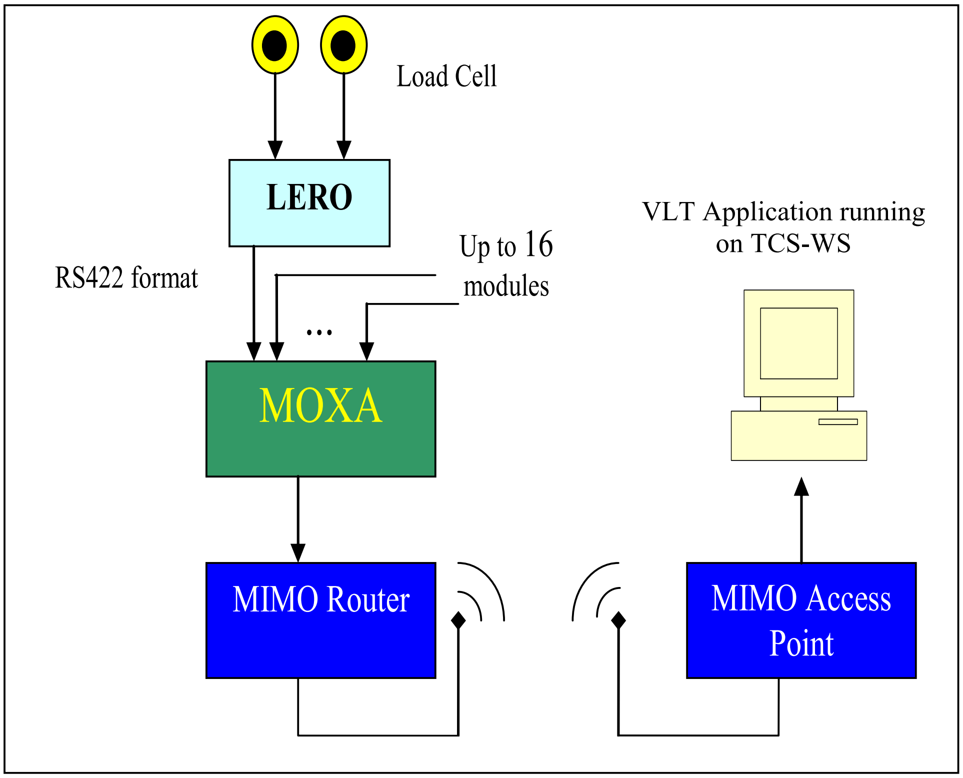

Figure 1: Basic configuration for the Load Cells Supervision

2.1 LOAD CELLS READOUT MODULE (LERO)

This unit is the heart of the all the system used for acquiring the load information on each Boggies. This module has the goal of converter the analog signal to digital signal, process it and, transmit it using some serial format to MOXA interface. **LERO** can be subdivided in the following parts:

- Signal Conditioning
- Digital Processing
- Data transmission

The following figure shows with more details what is explained above:

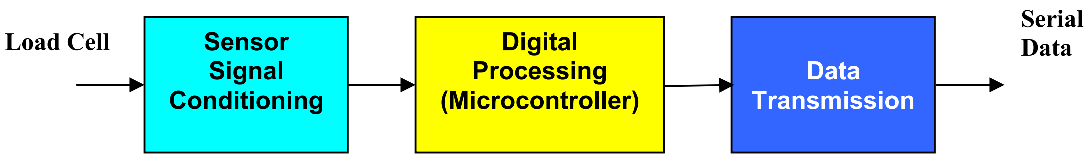

Figure 2. LERO System used for each Boggies

2.1.1 SENSOR SIGNAL CONDITIONING

The output of many modern bridge type sensors, such as a load cell, contains errors that must be eliminated. One major source of error is variation of sensor ***span*** and ***offset*** from device to device and their respective drifts with temperature. These drifts can be non-linear. Another source of error is the nonlinearity of the sensor output with applied stimulus. Signal conditioning electronics can also introduce its own errors.

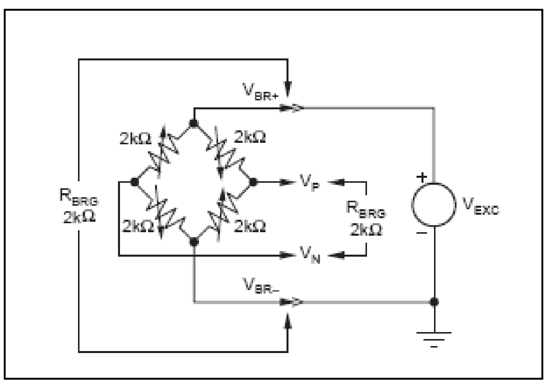

Figure 3. Typical Bridge Sensor

A typical bridge pressure sensor is shown in Figure 3. For a given bridge excitation voltage (VEXC), the output voltage of the bridge (VP − VN) is a voltage proportional to the pressure applied to the sensor.
Span is the scale factor for VP − VN at full-scale pressure input relative to the bridge excitation (VBR+ − VBR−). Span is also called FSO (Full-Scale Output), **FSS** (Full-Scale Sensitivity), Sensitivity, or Gain. For example, with a bridge excitation voltage of 5V, a 2mV/V **FSS** implies that the bridge output will be
10mV at full-scale pressure Offset, also known as Zero, is the output of the bridge (VP − VN) with zero pressure applied. Often a bridge sensor's Zero may be equal to or greater than its FSS for a given excitation voltage. Figure 4 graphically illustrates the definition of Span and Offset.

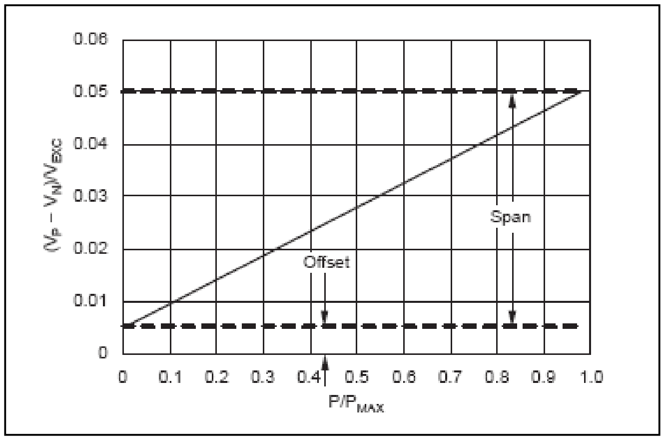

Figure 4. Example of Span and Offset

2.1.1.1 MATHEMATICAL MODEL OF A BRIDGE SENSOR

Generally, one can describe each span, offset and nonlinearity parameters as polynomials of *Nth* degree either vs. temperature or vs. input stimulus. In practice it is rarely necessary to compensate higher than 2nd-order errors and span, offset and nonlinearity can be approximated with 2nd-order equations for each. Assuming that sensor nonlinearity is constant with temperature, these equations can be combined together into a mathematical model given by equation 1. Since bridges are ratiometric sensors, KBRIDGE(P,T) is the sensitivity of the sensor relative to the excitation voltage in V/V. It is a single function of two variables input stimulus P (such as pressure or flow) and temperature T and seven coefficients. The coefficients n0 to n6 are the model parameters.

$$K_{BRIDGE}(P,T) = n_0 + n_1 T + n_2 T^2 + (n_3 P + n_4 P^2)(1 + n_5 T + n_6 T^2) \qquad \textbf{(1)}$$

Calibrating the sensor requires performing second order curve fits over three measurement points for nonlinearity and temperature drifts of span and offset. This involves making span and offset measurements at three different temperatures. Generating the model for sensor output nonlinearity versus applied stimulus involves making a zero-scale, mid-scale, and full-scale measurement and performing a second order curve fit. Figure 5 illustrates the sensor signal conditioning system. The sensor and temperature calibration measurements are made through this system with KLIN = 0. Making the measurements in this manner has an advantage in that the errors in the signal conditioning system are lumped together with the sensor. Thus, the system errors will also be eliminated during the calibration process.

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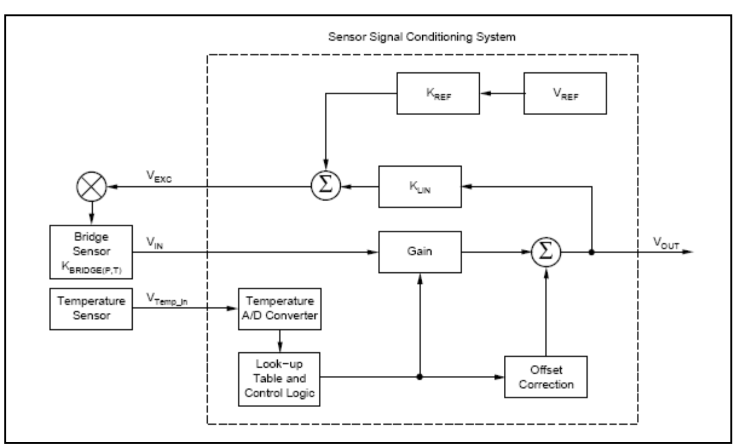


Figure 5. Sensor and Signal Conditioning System

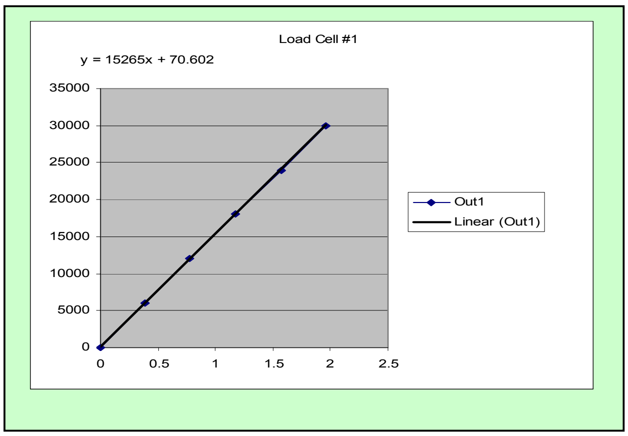
2.1.1.2 PREVIOUS STUDY PHASE

The maximum output of the Wheatstone bridge is very small, and it cannot be increased by changes in the bridge. Hence, it is necessary to amplify the output signal of the bridge so that it can be further processed. Before choosing the sensor signal conditioning, some considerations must be considered:

- Load Cell
- Precision Range

For this application, the range of measurement will be limited around 5 to 12 Ton. When taking three different certificates of calibration for the FUKE Load Cell which will be used for our application and by applying a lineal approximation, is possible to do the following analysis:

X: Compression Voltage
Y: Load in [lb]
Rated Output: 1.9641 mV/V



Load Cell #1
Transfer Function:

Y [lb] = 15265**X** [mV/V] + 70.602

Load 1[Lb]	Out1 [mV/V]
0	0
6000	0.3867
12000	0.778
18000	1.1718
24000	1.5675
30000	1.9641

For the other Load cells is possible to get a similar transfer function.

LOAD CELL # 2 → **Y** [lb] = 15257**X** [mV/V] + 68.173

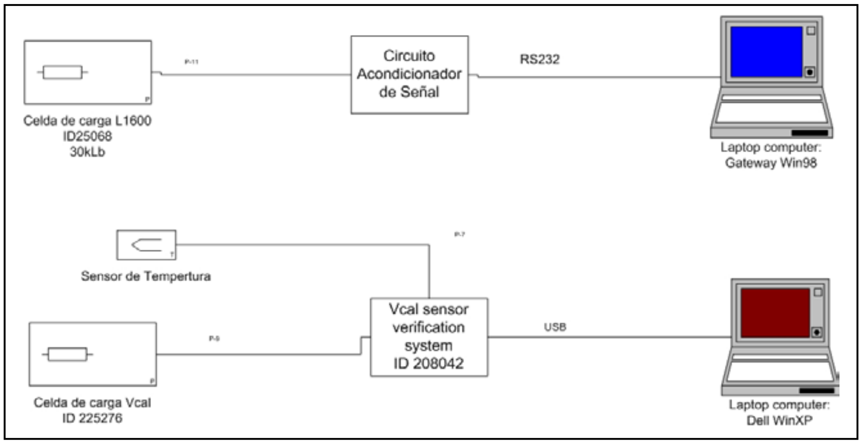
LOAD CELL # 3 → **Y** [lb] = 15209**X** [mV/V] + 52.440

These equations show a similar slope and offset which may be approximated according the following function:

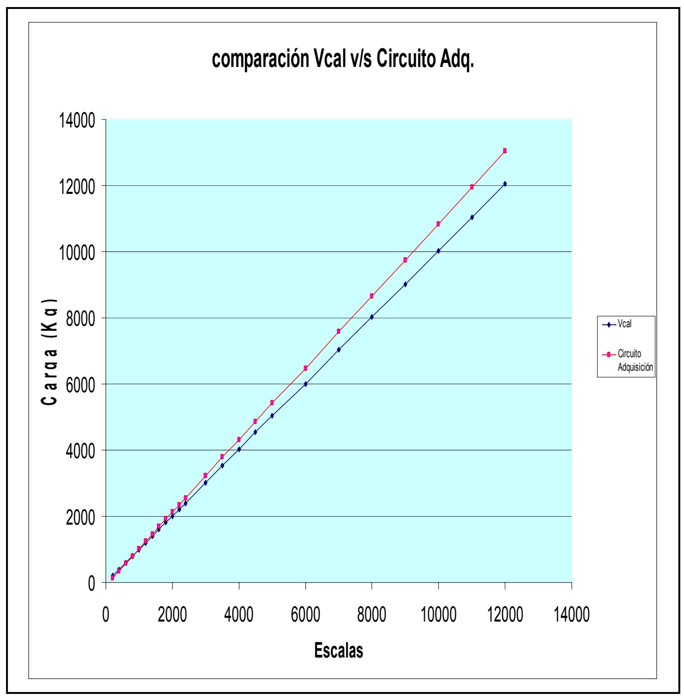
$$Y[lb] = \begin{cases} \overline{slope}\, X * FAC1 & X \in \{0, X1\} \\ \overline{slope}\, X * FAC2 & X \in \{X1, X2\} \\ \overline{slope}\, X * FAC3 & X \in \{X2, X3\} \end{cases} \quad \textbf{(2)}$$

- For **SLOPE**, by taking the certificate of calibration for all the Load Cells is possible to have an adequate value.
- **FAC1**, **FAC2** and **FAC3** should be a factor around 0.92 to 0.95. For getting this factor, a **LERO** basic prototype using an Instrumentation Amplifier with a Microcontroller was designed and compared with a calibrated Load Cell. (See Figure X).

- For this approximation, the temperature **T** was ignored.



DISPLAY FUTEK	Vcal (Kg) Calibrated Load Cell	Basic LERO (Kg)
200	203	125
400	402	336
600	605	562
800	800	783
1000	1000	1010
1200	1200	1243
1400	1401	1459
1600	1608	1690
1800	1810	1913
2000	2007	2122
2200	2200	2338
2400	2400	2551
3000	3015	3220
3500	3525	3780
4000	4025	4324
4500	4540	4858
5000	5040	5433
6000	6000	6470
7000	7030	7586
8000	8020	8643
9000	9025	9744
10000	10020	10837
11000	11050	11954
12000	12060	13046



In this chart is possible to notice a little offset between the Calibrated cell and the basic LERO which can be corrected by software. As conclusion, by using the Instrumentation Amplifier as signal conditioning and a lineal approximation of first order for the range to be used, the system accomplish with all the requirements for doing a precision monitoring of the load cells.

2.1.1.3 SIGNAL CONDITIONING CIRCUIT

I. **Using an Instrumentation Amplifier**: As was said above, Load Cell gives an analog voltage which is proportional to the pressure applied. Unfortunately, this is a very small nonlinear signal and it must be appropriately amplified and conditioning. There are several solutions for solving this problem and the alternative more common is to use an *Instrumentation Amplifier* (IA). The Instrumentation Amplifier (IA) is normally used for sensor signal conditioning. A typical IA used to realize this function is the AD8230. The AD8230 is a low drift, differential sampling and precision instrumentation amplifier. Auto-zero reduces offset voltage drift to less than 50nV/°C. The AD8230 is well-suited for thermocouple and *bridge transducer* applications. The figure 2 shows a typical configuration normally used for these applications. A complete description can be found in [1].

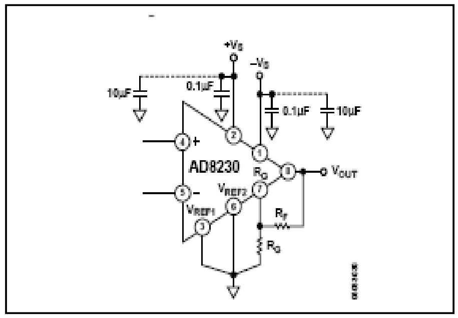


Figure 2.Typical Configuration bride transducer application

II. **Using a Programmable Sensor Conditioner**: The Texas Instruments **PGA309** integrated circuit chip is an example of a sensor signal conditioning system. The gain, and offset correction are implemented with 16-bit digital-to-analog converters (DACs). The sensor temperature can be monitored using an external or internal diode and onboard 16-bit delta-sigma converter. Adjustment of the linearity feedback factor (K_{LIN}) is accomplished using a 7-bit DAC. The block diagram for this device is shown in Figure x. The end result of a calibration using this device is that a sensor with initial deviations up to 50%, nonlinearity errors on the order of 4%, and gain drifts on the order of 20% of span are calibrated to have a total error less than 0.1 %. A complete description can be found in [2].

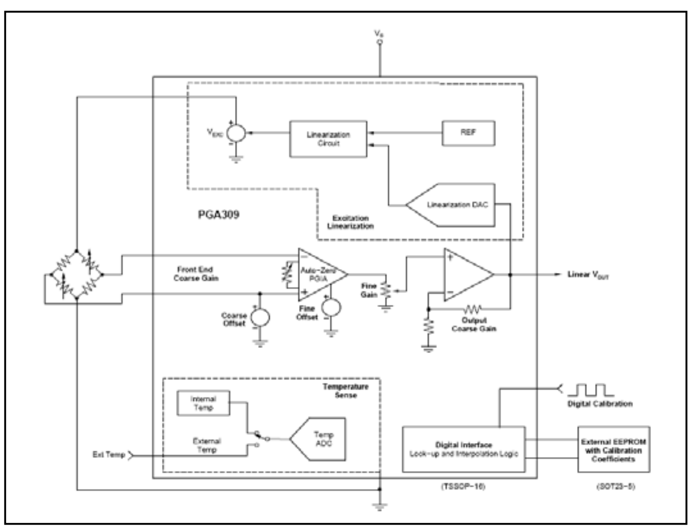


Figure 8. Block Diagram of PGA309 Integrate Sensor Signal Conditioning System

The alternative II gives a precise signal conditioning for all the pressure range to be applied to the load cell. However, as was seen above, when using the Instrumentation Amplifier the non-linear correction can be calculated by the Microcontroller using the equation 1.
A basic prototype using PGA309 was developed with interface to a microcontroller. The following figure shows the system implemented.

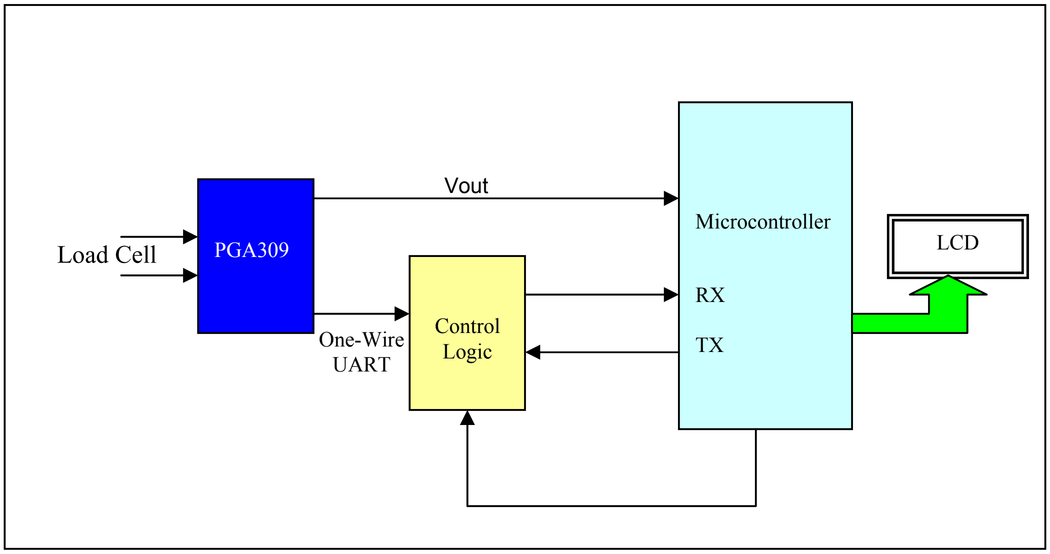


Figure 9. Block Diagram of Signal Conditioning circuit

When using the programmable amplifier (PGA) rather than a simple OP-AMP, as it has the following advantages:

- ***Programmable Gain***: the gain of the amplifier can be changed dynamically, without any change in the hardware. This is useful in changing the dynamic range of the system. For example, we may choose to double the resolution (and have a range of only ±1000µstrain) by simply doubling the gain.
- ***Programmable Offset***: the offset of the amplifier can be changed dynamically, without any change in the hardware. By setting the offset in the middle of the range, it can divide the ADC input range to a virtual negative part.
- ***Ease of Calibration***: due to the adjustable gain and offset, the calibration of the transducer becomes very easy and can be done from a remote location.
- ***Temperature Compensation***: the programmable amplifier has an in-built temperature sensor which can be used for temperature compensation (Alternatively, external temperature sensor can be used for compensation.). The temperature compensation can be done by providing a table of gain and offset to be used for different temperatures.
- ***Bridge Excitation***: the programmable amplifier has an in-built voltage regulator which can be used as a constant voltage source for the Wheatstone bridge.
- ***Over-Scale and Under-Scale Limits***: the programmable amplifier has in-built over/under-scale protection circuit which can be used to limit the output of the amplifier within some percentage of the ADC range. This not only helps in protection of ADC but also helps in over-scale or under-scale indication or fault diagnosis.

A prototype was implemented using the Load Cell FUTEK with a compression output 2.0499 mV/V @ 10Klb and R_{Brigde} of 370 Ohms. The design parameters were calculated using the PGA309 calculator which is available on the TI-web page. This test shows a linearization range from 0 lb to 10000 lb (0 to 4523Kg) which was completely one-to-one with the real weight showed by the system of FUKE measurement.

2.1.2 DIGITAL PROCESSING

After conditioning the load cell signal, analog-to-digital conversion and a software pre-processing are needed. The better alternative for implementing this system is to use a **MICROCONTROLLER**. A microcontroller is an inexpensive single-chip. Single-Chip computer means that the entire computer system lies within the confines of the integrated circuit chip. The microcontroller on the encapsulated sliver of silicon has features similar to those of our standard personal computer. Primarily, the microcontroller is capable of storing and running a program (its most import feature). The microcontroller contains a CPU (central processing unit), RAM (random-access memory), ROM (read-only memory), I/O (input/output) lines, serial and parallel ports, timers and A/D (analog-to-digital) converter and sometimes D/A (digital-to-analog) converter.
Microchip Technology's series of microcontrollers is called PIC chips. Microchips secured a trademark for the name PIC. Microchip uses PIC to describe its series of PIC microcontrollers. More information can be found in [3]

2.1.2.2 PIC MICROCONTROLLER

Microchip provides solutions for the entire performance range of 8-bit and 16-bit microcontrollers, with a powerful architecture, flexible memory technologies, comprehensive easy-to-use development tools, complete technical documentation and post design-in support through a global sales and distribution network. Microchip's PIC18 MCUs are ideal for applications requiring 10-16 MIPS performance, with up to 128KB program memory, ranging from 18-100 pins. PIC18 Microcontrollers feature:

- C compiler efficiency
- High performance architecture
- Cost-effective offerings for both small and large memory sizes
- Flexibility of self programming Flash
- Industry leading peripheral set including advanced communication peripherals and protocols (CAN, USB, ZigBee™, TCP/IP)
- Socket, software and peripheral compatibility, providing scalability for complex embedded designs.
- NanoWatt Technology.

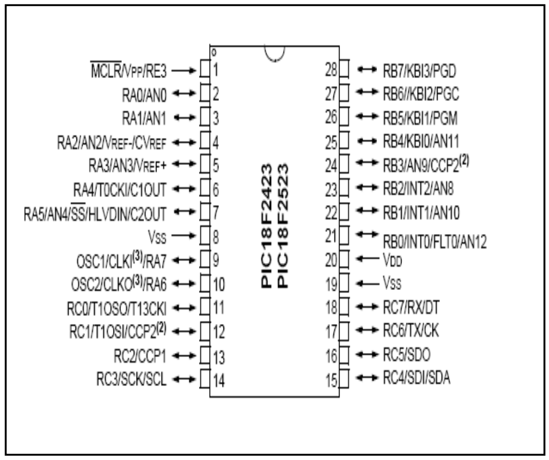
Within PIC18 MCU family, the PIC18F2523 has special characteristics which fulfill the necessary requirements for our particular application.

Technical Characteristics:

- 12-bit, up to 13-channel Analog-to-Digital. Converter module (A/D):
  - Auto-acquisition capability
  - Conversion available during Sleep
  - Dual analog comparators with input multiplexing
  - High-current sink/source 25 mA/25 mA
- Three programmable external interrupts
- Four input change interrupts
- Up to 2 Capture/Compare/PWM (CCP) modules, one with Auto-Shutdown (28-pin devices)
- Enhanced Capture/Compare/PWM (ECCP) module (40/44-pin devices only):
  - One, two or four PWM outputs
  - Selectable polarity
  - Programmable dead time
  - Auto-shutdown and auto-restart
- Master Synchronous Serial Port (MSSP) module supporting 3-wire SPI (all 4 modes) and I2C™ Master and Slave modes

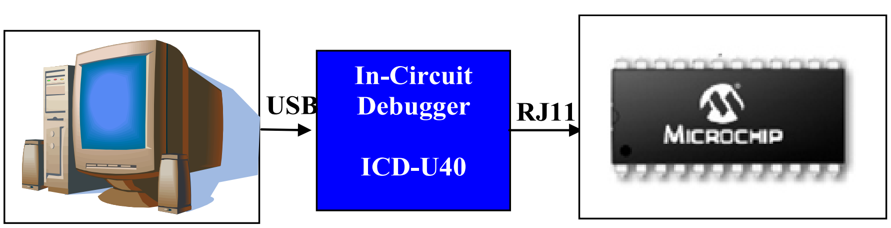
- Enhanced USART module:
  - Supports RS-485, RS-232 and LIN 1.2
  - RS-232 operation using internal oscillator block (no external crystal required)
  - Auto-wake-up on Start bit
  - Auto-Baud Detect

The following figure shows the pins distribution for PIC18F2523.



2.1.2.3 PIC COMPILER

The ***CCS C Compiler*** was developed exclusively for the PIC® MCU - making it the most optimized compiler for Microchip parts. The compiler has a generous library of built-in functions, preprocessor commands, and ready-to-run example programs to quickly jump-start any project. Drivers for real-time clocks, LCDs, A/D converters, and many more are innate features to the CCS C Compiler.
This compiler uses an In-Circuit debugging and programming for the PIC Family called ICSP. In-System Programming (ISP) is a technique where a programmable device is programmed after the device is placed in a circuit board. In-Circuit Serial Programming (ICSP) is an enhanced ISP technique implemented in Microchip's PICmicro® One-Time-Programmable (OTP) and FLASH RISC microcontrollers (MCU). Use of only two I/O pins to serially input and output data makes ICSP easy to use and less intrusive on the normal operation of the MCU.
The CCS ICD is a complete ***In-Circuit Debugging and Programming*** solution for Microchip's PIC16Fxx and PIC18Fxx PIC® MCUs. The ICD can debug all PIC16 and PIC18 targets that support debug mode for debugging. It also provides in-circuit serial programming (ICSP) support for all flash chips.
The CCS ICD units work with CCS' PCW debugger or CCS' stand-alone ICD control software. The PCW debugger is robust and integrated with the PCW and PCWH Compiler and provides very detailed debugging information at the C level. The stand-alone control software allows to program target chips using ICD's ICSP. The control software also is updating the ICD unit firmware without having to remove the chip from the ICD unit.The figure X shows the interface between the In-Circuit Debugger and Microcontroller.



2.1.2.4 ACQUISITION SOFTWARE ON THE PIC MICROCONTROLLER

Basically, the PIC microcontroller will have the task of acquiring the analog voltage, process it, and sent it to Serial-Ethernet MOXA. A flow diagram for the software to be implemented, based on the Instrumentation Amplifier as signal conditioner, is showed in Figure X y.

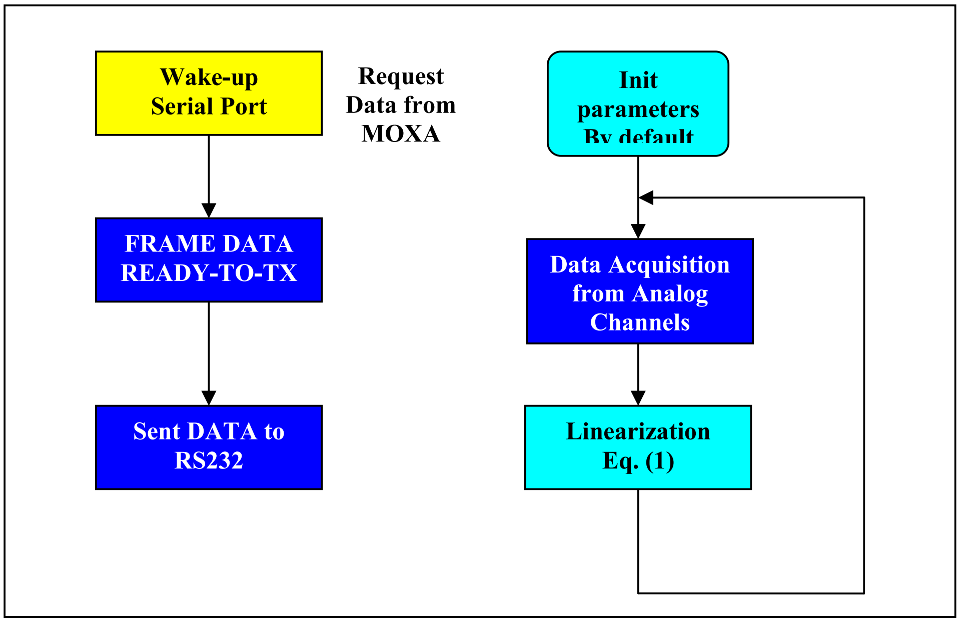


Figure 10. Algorithm used for signal processing (AD8230)

For the PG309 case, a previous calculus is needed to perform and these parameters must be stored on the EEPROM. On power-up, the PGA resets all its internal registers and reads the EEPROM for the configuration data. Hence, it is necessary to have the EEPROM and ensure that proper configuration data is written in it. The PGA also reads the relevant ***fine gain*** and ***fine offset*** adjust parameters.

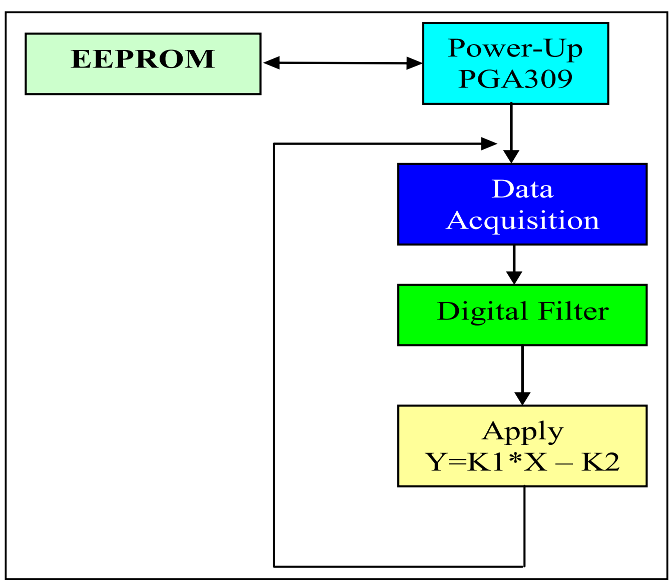


Figure 11. Algorithm used for signal processing (PGA309)

2.1.3 SERIAL DATA TRANSMISSION

The Serial Data Transmission is the last part for the **LERO** system. This transmission must accomplish the minimum robustness requirements. The 422 and 485 standards, as they are known today, are balanced data-transmission schemes that offer robust solutions for transmitting data over long distances and noisy environments, as is the case of the 3.6m Telescope. The official titles for these two standards are ANSI TIA/EIA-422 and TIA/EIA-485, respectively, and are revised periodically by the TR-30.2 DTE-DCE Interfaces and Protocols Subcommittee to the Telecommunications Industry Association (TIA) TR-30 Data Transmission Systems and Equipment Committee. The RS prefix, which has been used for many years on both standards, is no longer in use. Generally, it is thought that this prefix means Recommended Standard, but actually it means Radio Sector. For identification, 422 and 485 suffice.
The balanced-voltage digital interface is shown in Figure X. The driver (or generator) is labeled D, the receiver is labeled R, and the termination impedance is Z_T. The termination impedance should be equal to the characteristic impedance of the cable, Z_O, and is used only once at the end of the cable. Because matching termination impedance to Z_O often is difficult to achieve and is application dependent, typically, +/-20% is sufficient. Also, up to nine additional receivers can be placed along the cable from points A and B to points A' and B', respectively. No restriction on maximum cable length is imposed by the 422 standard. Taking this into account, systems of up to 1 km are not uncommon, with signaling rates no higher than about 100 kbps. Speed and cable lengths work against each other. In other words, the longer the cable, the slower the signaling rate must be, while data can be transmitted faster on shorter cables. As a rule of thumb, the data signaling rate (in bps) multiplied by the cable length (in meters) should not exceed 108. For example, a system with a cable measuring **500 m** should not transmit data at speeds greater than **200 kbps** (108/500).

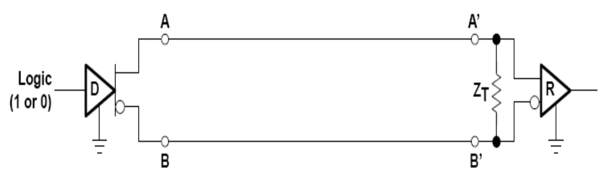


Figure X. Balanced-Voltage Digital-Interface Circuit

2.1.3.2 DATA TRANSCEIVER ADM2490E

The ADM2490E is an isolated data transceiver with ±8 kV ESD protection and is suitable for high speed, full-duplex communication on multipoint transmission lines. It is designed for balanced transmission lines and complies with ANSI TIA/EIA RS-485/422. The device employs Analog Devices, Inc., *i*Coupler technology to combine a 2-channel isolator, a 3-state differential line driver, and a differential input receiver into a single package. The differential transmitter outputs and receiver inputs feature electrostatic discharge circuitry that provides protection to ±8 kV using the human body model (HBM). The logic side of the device can be powered with either a 5 V or a 3 V supply, whereas the bus side requires an isolated 5 V supply.
The device has current-limiting and thermal shutdown features to protect against output short circuits and situations where bus contention could cause excessive power dissipation.

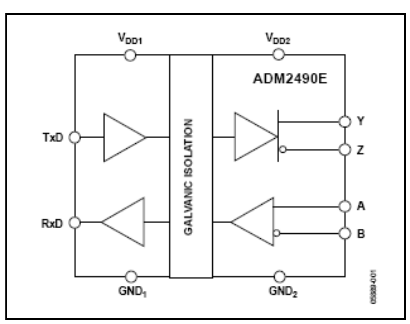


Figure X Functional Block Diagram

3. WIRELESS INTERFACE

Each LERO modules installed on every Bogie will send the data transmission to the MOXA interface in EIA422 format. The MOXA will scan the sixteen-ports and it will be sent to MIMO Router installed in the Telescope DOME. This Router will transmit the data to MIMO Access point which will be accessed remotely by TCS-WS in the Control Room.

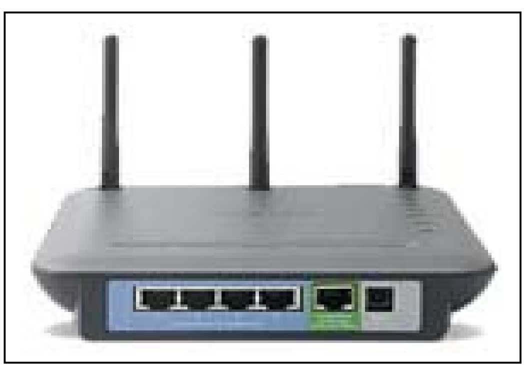
3.1 MIMO Router

Router is a device that forwards data packets along networks. A router is connected to at least two networks, commonly two LANs or WANs or a LAN and its ISP's network. Routers are located at gateways, the places where two or more networks connect. There are several companies that offer several ROUTER alternatives. For example, Amazon offers this **D-Link Super G with MIMO Wireless Router** which has the following characteristics:

- Double XR (2XR) technology for whole house coverage
- Built-in packet prioritization engine maximizes VoIP clarity
- New quick router setup wizzard
- Advanced security features
- Great performance for multiple simultaneous network users

3.2 MIMO ACCESS POINT

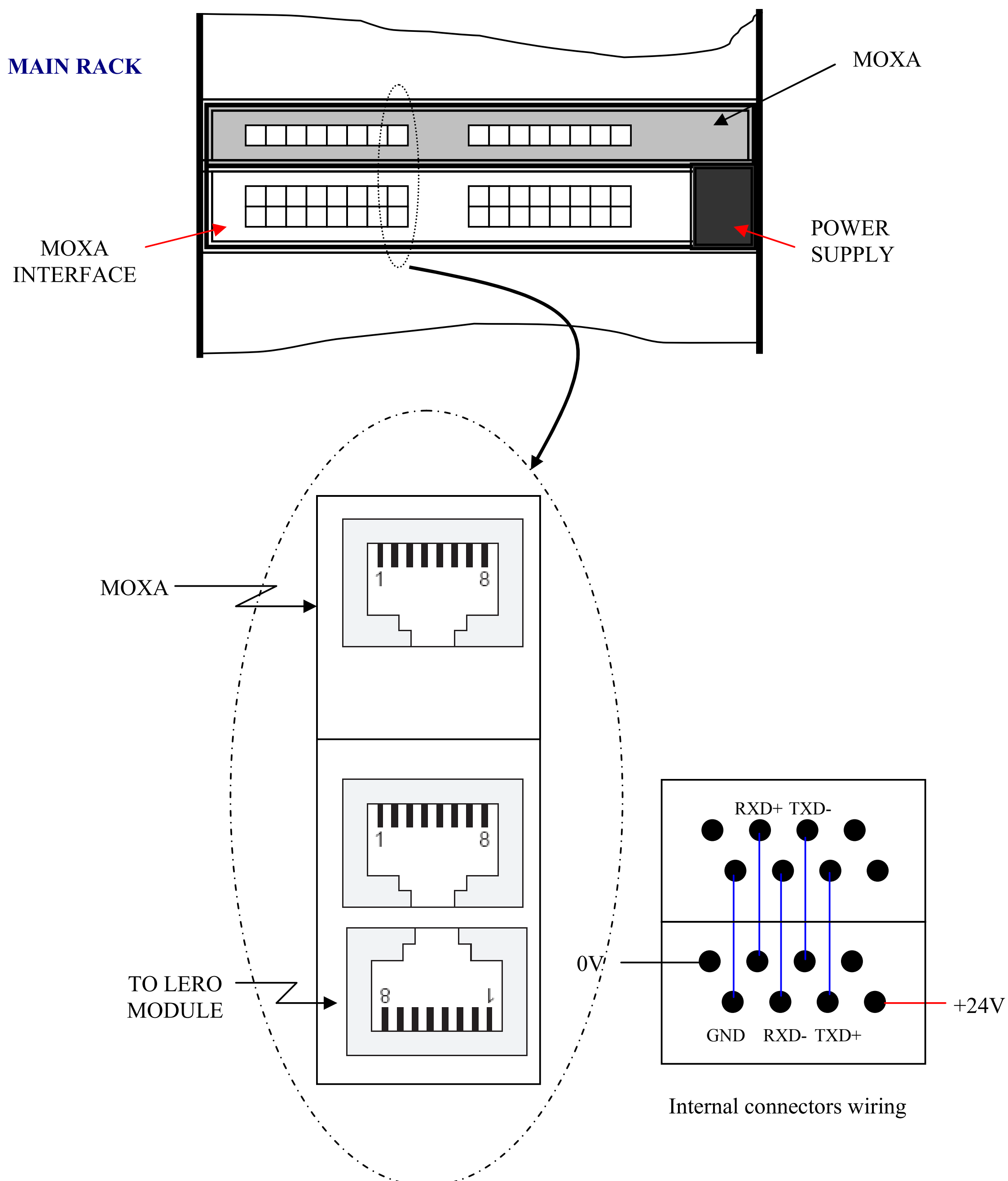
Wireless **access points** (APs or WAPs) are specially configured nodes on wireless local area networks (WLANs). Access points act as a central transmitter and receiver of WLAN radio signals. Access points used in home or small business networks are generally small, dedicated hardware devices featuring a built-in network adapter, antenna, and radio transmitter. Access points support Wi-Fi wireless communication standards. An example for Access Point to be used is shown in the following figure.



- The Belkin Pre-N Router uses revolutionary smart antenna technology to boost wireless network speed and range far beyond that of today's standard 802.11b/g and 802.11a wireless networking technologies.
- The Belkin Pre-N Router offers backward compatibility with existing 802.11g and 802.11b, to provide seamless integration into existing wireless networks. Its advanced technology enables Belkin Pre-N products to significantly improve the performance of standard 802.11g and 802.11b devices in the mixed network environment.

4. MOXA-LERO INTERFACE

Each LERO module needs to be supply with a DC voltage around +24[Volts]. A previous interface with the EIA422 outputs must be performed by adding the DC Voltage. The following figures show with more details how will be implemented:

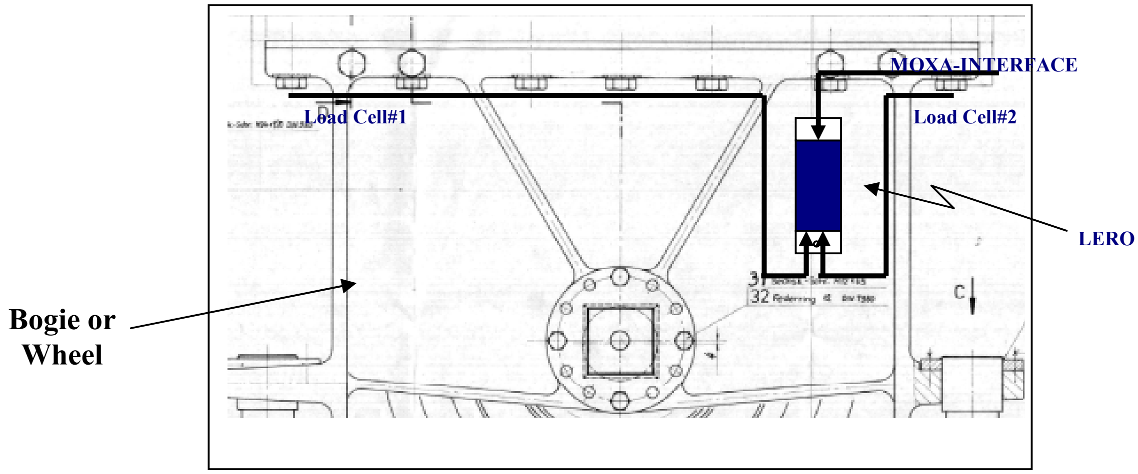


Internal connectors wiring

5. STUFF INSTALLATION

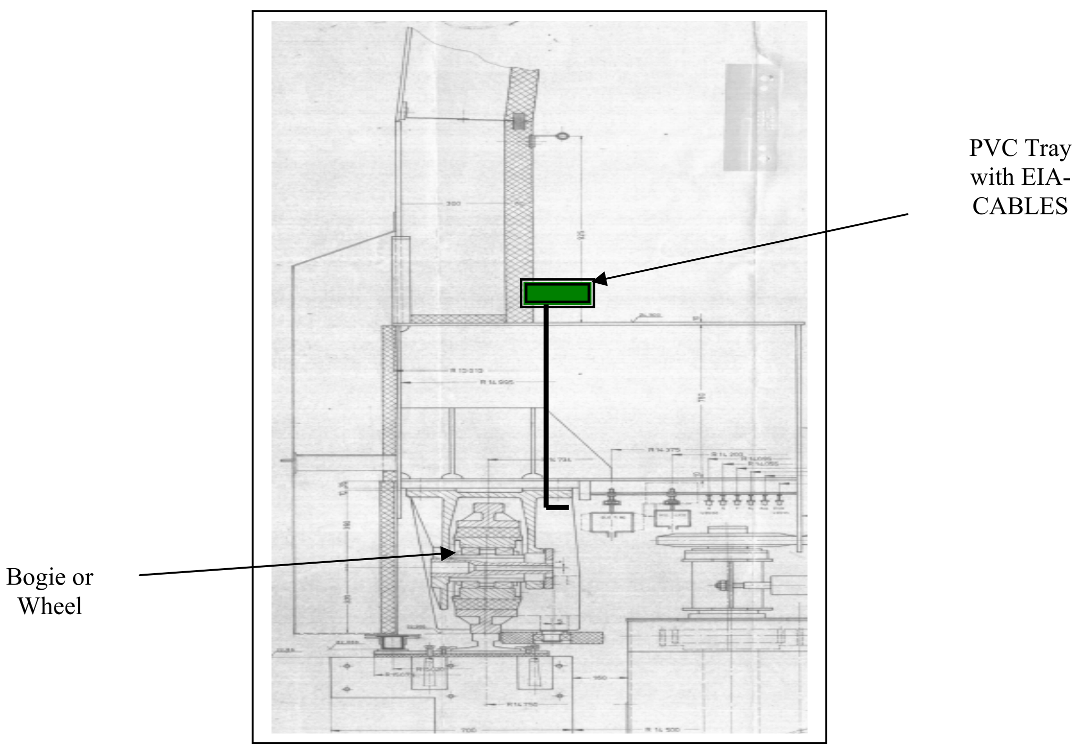
5.1 LERO MODULE

This module will be installed on the Bogie or Wheel, such that will have easy access for its installation and it MUST be dismounted when the Bogie or Wheel needs to be changed.



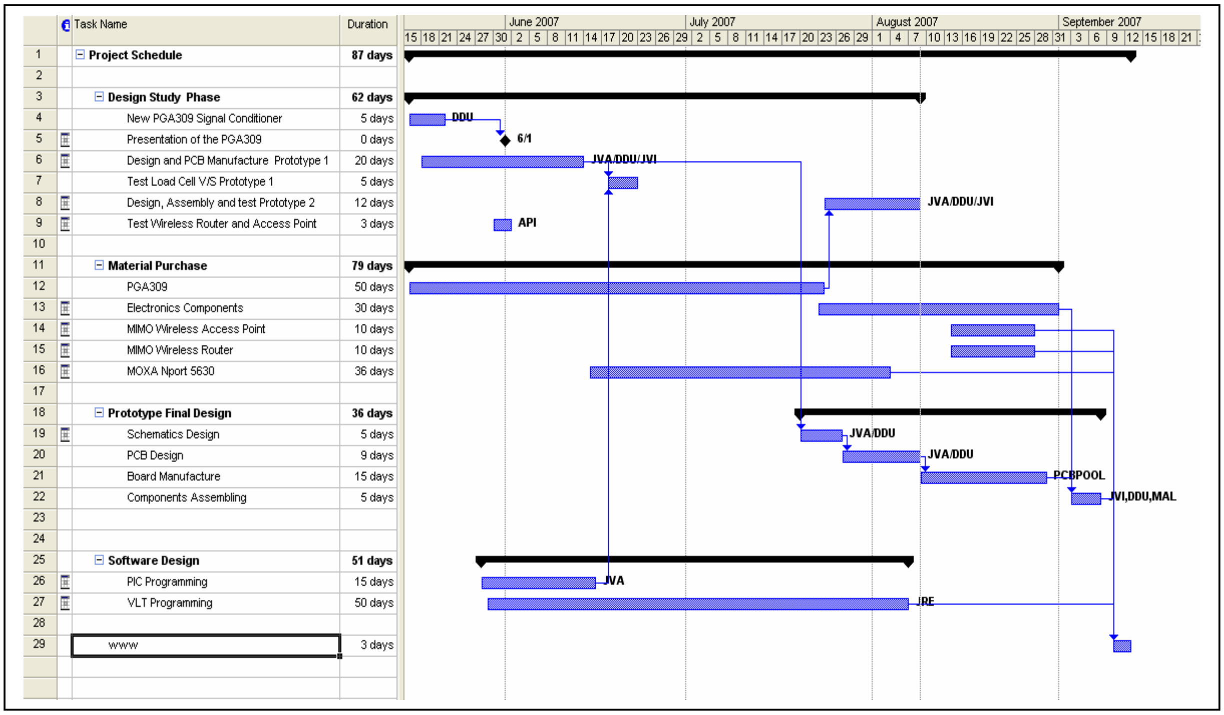
Both the Load cell and MOXA-Interface connectors will be RJ12 and RJ45 respectively which are easy for its connection/disconnection.

5.2 MOXA-LERO WIRING to BOGIE

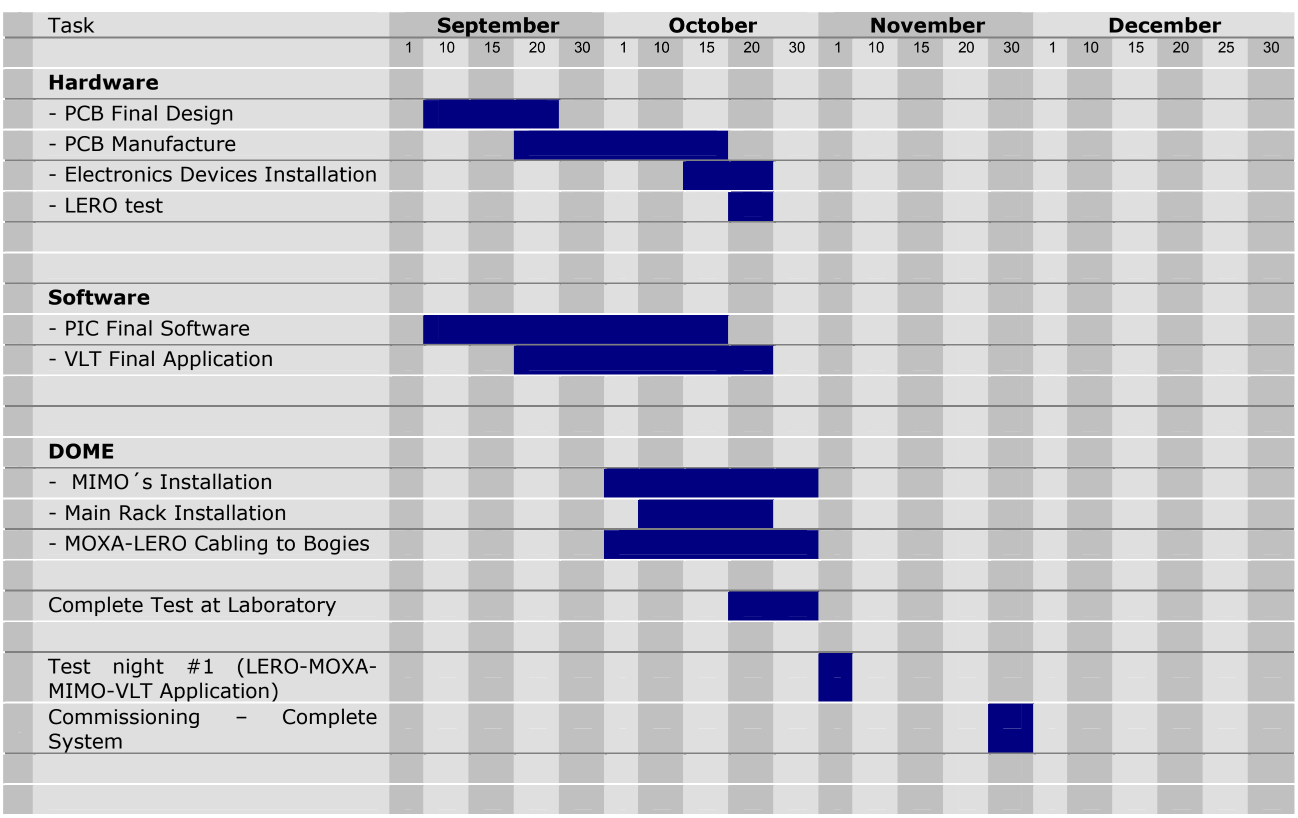


6. SCHEDULE

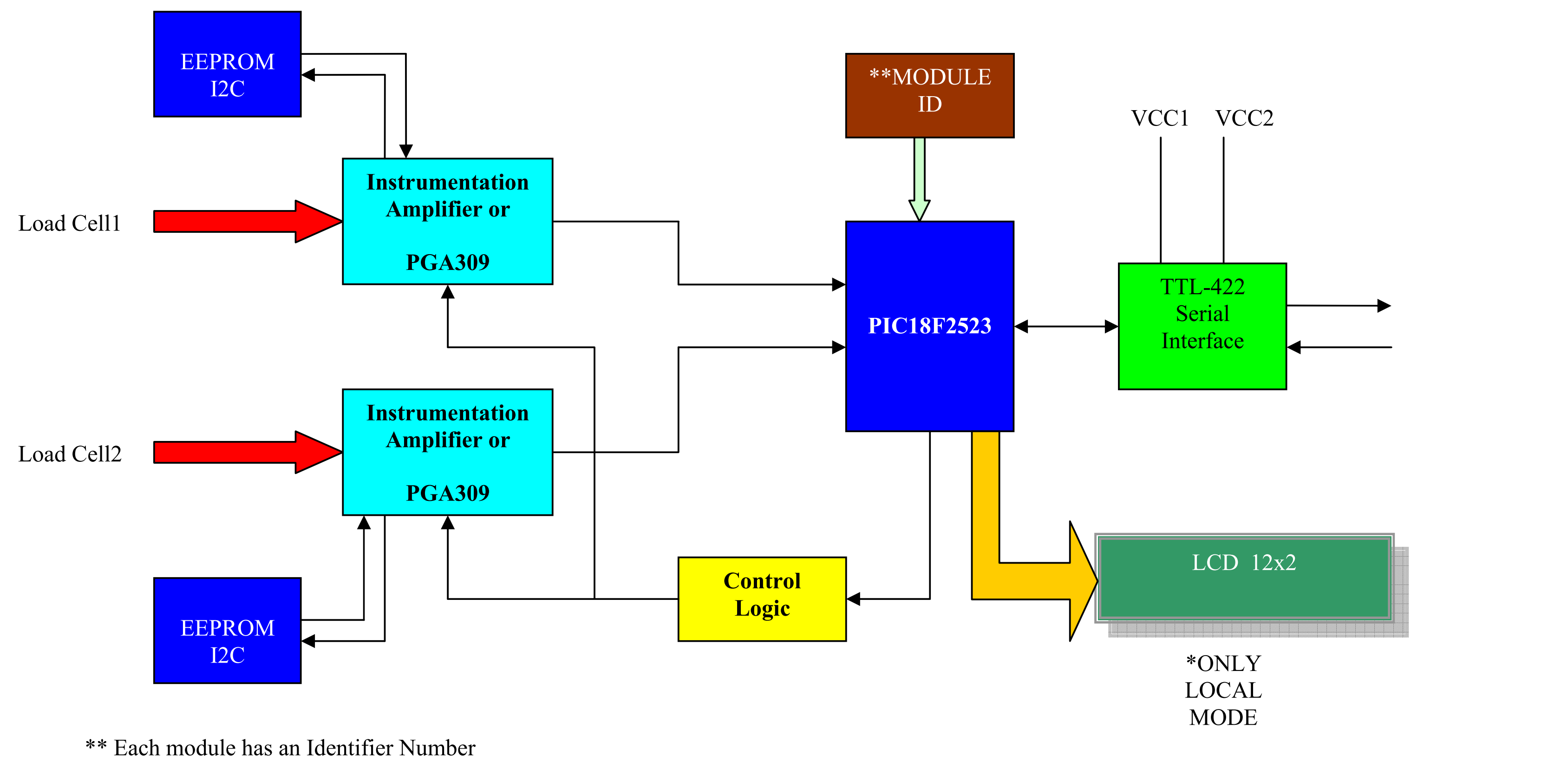
PHASE I (Completed)



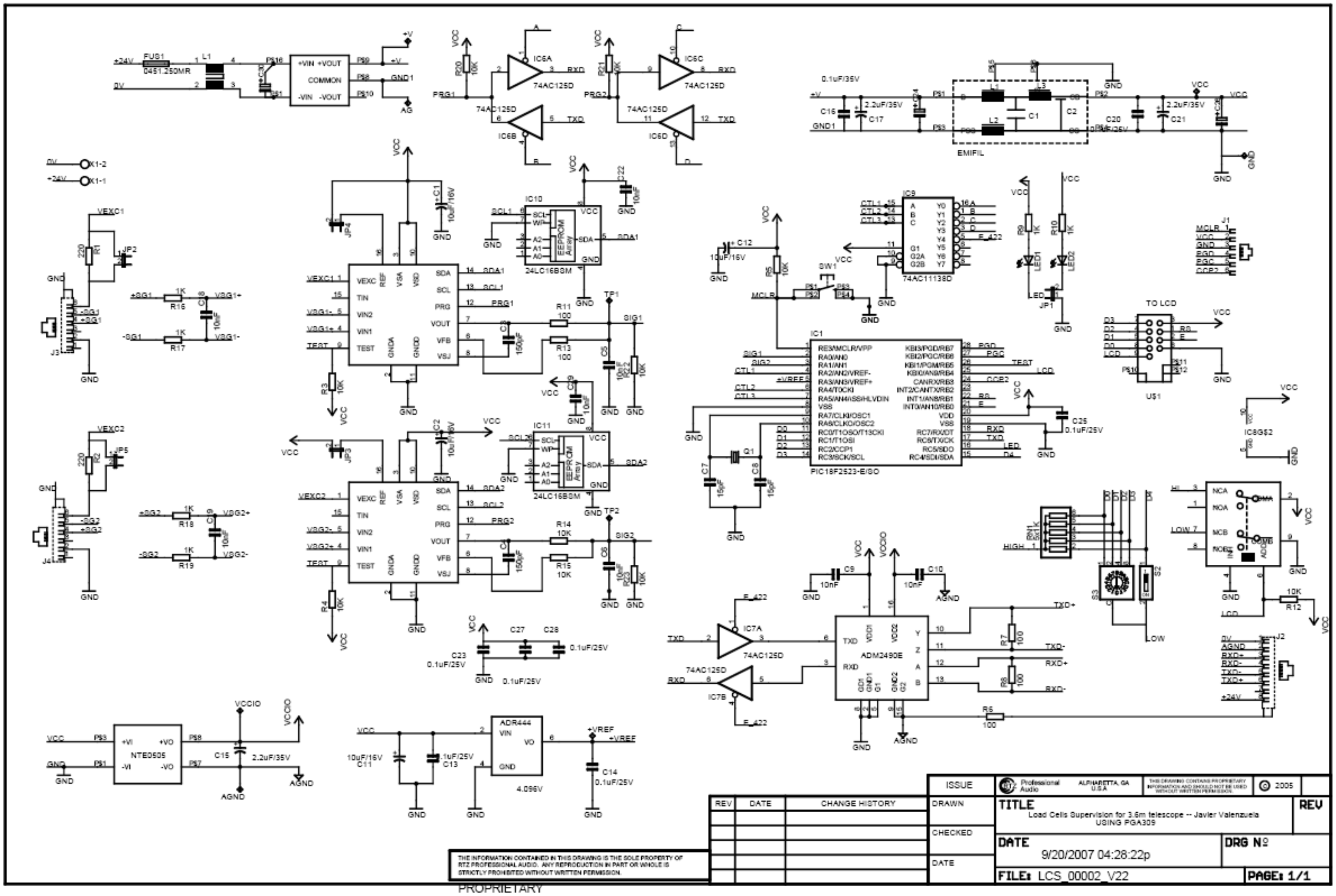
PHASE II



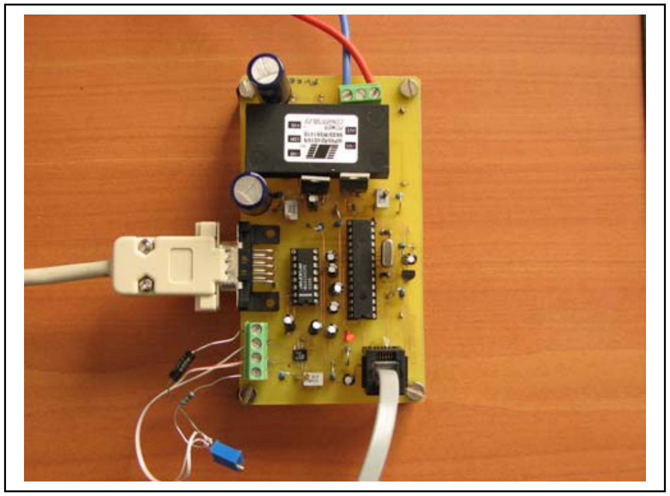
A. SIGNAL CONDITIONING DIAGRAM (LERO)



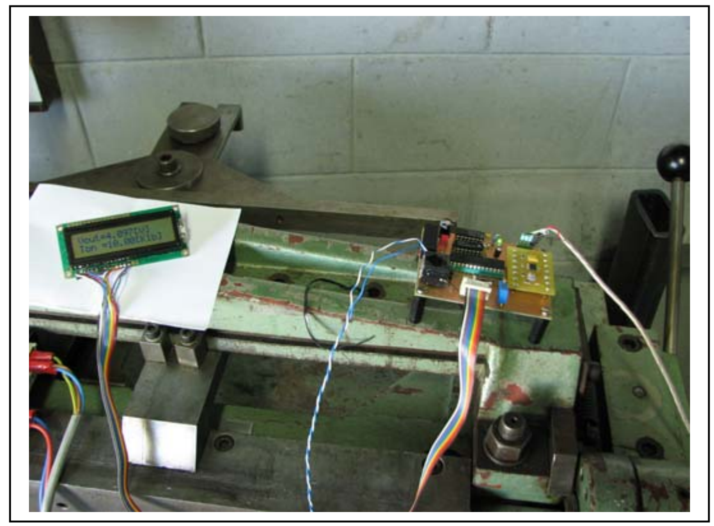
B. SIGNAL CONDITIONING CIRCUIT



C. PROTOTYPES I – II



Prototype I using an Instrumentation Amplifier



Prototype II using a Programmable Amplifier (PGA309) with LCD Option

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