Design and Development of Card Level – Smart Testing Jigs For the Solid State Auto-loaders of T-85 UG, Al-Khalid and Al-Khalid 1 Main Battle Tanks.

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Declaration

I certify that this research work titled *"Design and Development of Card Level – Smart Testing Jigs For the Solid State Auto-loaders of T-85 UG, Al-Khalid and Al-Khalid 1 Main Battle Tanks."* is my own work. The work has not been presented elsewhere for assessment. The material that has been used from other sources it has been properly acknowledged / referred.

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This thesis has been read by an English expert and is free of typing, syntax, semantic, grammatical and spelling mistakes. Thesis is also according to the format given by the university.

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Copyright Statement

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Abstract

Solid State Auto-Loader is a robust control systems in main battle tanks to enhance the firepower and maneuverability. The auto-loading mechanism consists of two subsections, the '*Motorized Mechanical Subsystem'* driven by several high power motors and solenoids along with the mechanical proximity switches. The other part is the '*Electrical Control Subsystem'* responsible for coordinated control of various operations carried out by mechanical subsystems. All these are controlled through Solid State Auto-Loader. The Solid State Auto-Loader (SSAL) is a Solid State system because that has eliminated the need of any mechanical relay and utilizes the latest Solid State Electronic Devices to provide all the control functionalities hence leading to more reliable system. The SSAL consists of three Units and all these units are interlinked with each other using CAN communication protocol. The SSAL consists of three units, *'Power Distribution Unit'*, *'Memory Unit'* and *'Ammo Unit'*. All these units uses various Electronic Circuit Boards, which are used to carry out all the operations of Auto-Loading. During the production of SSAL, these boards were needed to be tested for the proper functionality and performance. So a system is needed that can test these Electronic Circuit Boards to reduce the fault errors and ensure its proper functionality in least amount of time. This research presents the development of Smart Testing Jigs for testing of all the Electronic Circuit Cards used in SSAL of T-85 UG, Al-Khalid and Al-Khalid 1 Tanks for proper functionality of all its Electrical Controlled Outputs as well as Inputs from various sensors and switches. Testing is done autonomously without the intervention of a person and pin-points particular Input or Output Signal(s) that are malfunctioning.

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CHAPTER 1: INTRODUCTION

The research work in this dissertation has been presented in three parts. All the Electronic Circuit Cards used in three units of SSAL are divided in three categories and there are three testing jigs that will test these three categories of cards.

1.1 Background

Solid State Auto-Loader [1] [2] [3] is system that is used to control the pre-firing and firing mechanism. There are three units that control complete auto-loading process and these units are *Power Distribution Unit*, *Memory Unit* and *AMMO Unit* [4].

Power Distribution (PD) Unit is the main heart of SSAL. It consists of CPU board that generates and receive signals to ensure that all the processes are being carried out properly. There are several High Powered Motors and Solenoids Driving Cards that are used to drive different assemblies present in T-85 UG, Al-Khalid and Al-Khalid 1 Main Battle Tanks. There are several assemblies that includes *'CAROUSAL MAGAZINE assembly* [5] [6]*'*, *'HOIST and GUN LOCKING assembly* [7]*'*, *'FRAME and WINDOW assembly'*, *'RAMMER assembly* [8]*' and 'SOLENOID driving assembly'*. Carousal Magazine carries the three type of ammunition including 'HA' (Heavy Armor), 'HE' (High Explosive) and 'AP' (Armor Piercing). There are two parts of Ammo, one is 'Projectile' and the other one is 'Propellant'. Magazine, carrying both parts of ammo, rotates in both clockwise and counter clockwise direction to bring the required ammo to the loading line. Hoist Assembly is used to fetch the required Ammo from the magazine and bring it upwards, in front of the tank's barrel and get it ready for the loading purpose. Rammer Assembly is used for pushing the Ammo into the barrel. There are two steps of loading the Ammo in the barrel. First the Rammer pushes the projectile part of ammo into the barrel and after that it loads the propellant part of ammo. Frame Assembly is used for the guidance of shell ejection. It creates a path way that is directed towards the window which is used to eject the shell out of the tank after firing. Window assembly opens right when the ejection process is about to happen and immediately closes afterwards. All these assemblies are derived using HIGH power motors and solenoids. The power and all the signals used for driving these motors and solenoid are provided using PD Unit.

The Memory Unit is attached to and driven by the drive gear of Carousel Magazine, and is used to keep track of positions as well as Ammo types stored in each of the 22 Bins of Carousel

Magazine. It uses optical encoders along with encoded disk to keep track of Bins' positions and the information regarding the type of Ammo loaded in each Bin is saved in an EEPROM [9].

The third unit is AMMO Unit. It is used to display simultaneously the information regarding the number of each type of ammo currently available in Carousel Magazine as well as the number of empty bins for User's quick reference. In addition a single line alpha-numeric display is also provided to indicate currently selected Mode of Operation of Auto-Loader or to display any error/info message.

To test all the Electronic Circuit Cards for its proper functionality, a proper Automated Test Bench [10] is required that can test the boards from every aspect, ensure its proper functionality, performance and working and can pin point the issue if there is any problem or card is malfunctioning. All the cards used in SSAL are divided in three sets and to test these sets of cards, three Autonomous Jigs are dedicated to for this purpose.

1.1.1 Power Drive and Power Supply Module Board Testing Jig

Power Drive and Power Supply Module Board testing jig is designed to test two sets of Electronics Circuit Boards. These two sets include the Motor and Solenoid Driving boards that are also called Power Drive Module Boards and the main Power Supply Module board. There are five subsets of Power Drive Module boards which are as follow:

I. Frame and Window Driving Board
II. Hoist and Gun Lock Solenoid Driving Board.
III. Rammer Driving Board.
IV. Carousal Magazine Board.
V. Solenoid Driving Board.
VI. Power Supply Module Board.

1.1.1.1 Frame and Window Driving Board

This Power Drive Board is used to control the shell ejection process. Frame is used to capture the shell after firing and provides a guide way to throw it out of the tank and the window is used as the opening for shell ejection. The movement of these two assemblies are controlled by high powered motors.

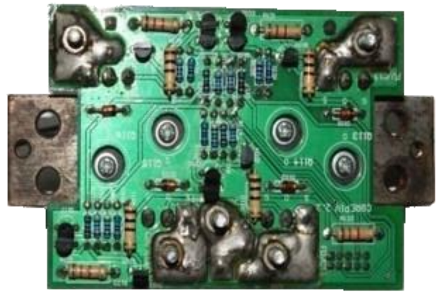

Figure 1: Power Drive Module Board-1

1.1.1.2 Hoist and Gun Lock Solenoid Driving Board

This Power Drive Module Board is used to control the up and down movement of Hoist along with the Gun locking solenoid. The Hoist is used to fetch the ammunition from the magazine and bring it in front of the barrel and make it ready for loading purpose. Also it is used to load the ammunition into the magazine. The ammo of any type is placed on the tray that the hoist is carrying, replenishment command is given and it takes the ammo to magazine. Gun locking solenoid is used to lock the gun at fix angle before it is ready for firing.

Figure 2: Power Drive Module Board-2

1.1.1.3 Rammer Driving Board

This Power Drive Module Board is used to control the movement of Rammer in the tanks. The Rammer is used to push the ammo from the tray into the barrel. Rammer moves in two direction in two different speeds. First it loads the projectile part, at a faster speed. Then it comes back and loads the propellant part in slow speed. It contains one and half bridges as per the requirement. The rammer moves forward in both speeds, i.e. fast as well as slow, but while moving back, it always comes in fast speed.

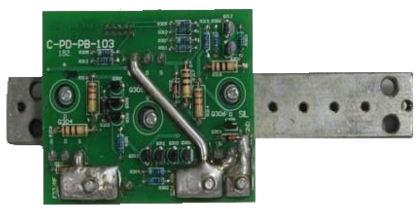

Figure 3: Power Drive Module Board 3

1.1.1.4 Carousal Magazine Board

This Power Drive Module Board is used to control the movement of magazine that carries the Ammunition of all the types. It can move the Magazine in both directions i.e. in slow speed as well as in fast speed. There can be 21 rounds of ammo stored in the magazine. The system always fetch the Ammo from the nearest possible location, so if the required ammo is either on left of right side, the magazine will rotate clockwise or counter-clockwise accordingly, to get the ammo from nearest bin.

Figure 4: Power Drive Module Board-4

1.1.1.5 Solenoid Driving Board

This Power Drive Board is used to derive all the solenoid used in different assemblies. Solenoids are basically used to lock the assemblies to cease their movement. There are solenoid to lock and unlock the movement of Magazine. When replenishment or fetching of ammo is under progress, it lock the magazine using solenoid so that it doesn't move while loading and unloading. Same way, solenoids are used to lock and unlock the hoist. Shell ejection assembly also uses solenoid to eject the shell out of the tank.

Figure 5: Power Drive Board-5

1.1.1.6 Power Supply Module Board

Power Supply Module board is used in the PD-Box to supply the required voltages to every module that are installed. It requires 24V input to power up and has 5 different outputs i.e. 5V, 12V, 24V, 28V and 36V. These outputs are used as the signals/Power for all the boards used in Auto-loader. In this supply, there is an additional feature of protection. If the supply sensing passage of high current, it cuts off the power of 24V and wait for the current to die down, if the current passing through it remains high, it will permanently shuts down the power supply for safety purposes.

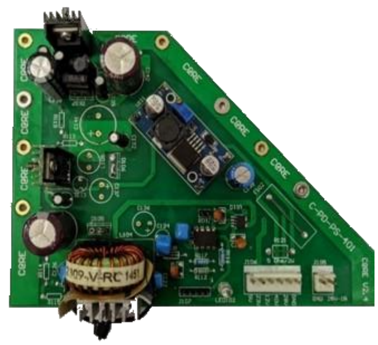

Figure 6: Power Supply Module Board

1.1.2 Ammo and Memory Boards Testing Jig

1.1.2.1 Ammo Controller Board

Ammo controller Board is used to control the Ammo display Board. Ammo Controller Board consists of an embedded processor that communicates with PD-Unit and Memory Unit and uses CAN communication protocol for this purpose. It gets the signals from the other two units through CAN protocol and send the signals forward to the Ammo Display Board to display the information. Information is related to the number of types of each ammo currently available in Carousel Magazine, different modes of operations or different error/info messages that CPU send for user quick reference.

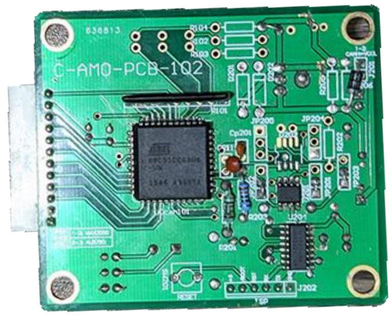

Figure 7: Ammo Unit Controller Board

1.1.2.2 Ammo Display Board

Information regarding the Number of each Type of Ammo currently available in Carousel Magazine as well as the Number of Empty Bins are simultaneously displayed on the Display Unit for User's quick reference. Type of Ammo currently under Loading Line is also indicated by Continuous Blinking of the respective Ammo Counter.

In addition, a single line alpha-numeric display is also provided to indicate currently selected Mode of Operation of Auto-Loader, Le. Auto-Loading Mode, Replenishment/ Unloading Mode and Semi-Auto Mode. The same alpha-numeric display is also used to indicate Error Code indicating the potential cause of stoppage, in case one is encountered, thus facilitating the user quick localizing and fixing the source of error.

Figure 8: Ammo Unit Display Board

1.1.2.3 Memory Board

Memory Board is used to keep track of positions as well as Ammo types stored in each of the 22 Bins of Carousel Magazine. It uses optical encoders along with encoding disk to keep track of Bins' positions, the information regarding the type of Ammo loaded in each Bin is saved in an EEPROM, During Replenishment Operation, after loading a specific type of Ammo in the Bin, the user indicates the type of loaded Ammo by pressing the respective push button that is provided on the Memory Unit.

Memory Board consists of an embedded processor that communicates with PD-Unit and Display Unit and provides information regarding Bin positions along with the Number and Type of Ammo currently present in Carousel Magazine as well as the Ammo Type currently under Loading Line.

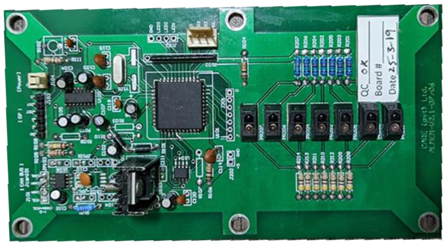

Figure 9: Memory Board

1.1.3 CPU and I/O Testing Jig

1.1.3.1 CPU Board

It is the brain of the SSAL, which controls the whole Auto-Loading process by sensing and generating signals. It communicates with the other controllers used in Memory and AMMO units through CAN Communication protocol and sends the messages and errors via Serial Communication. It consists of an arrangement of Micro-Controller and FPGA along with the external Flash. Each PPI has an Opto-isolator for signal voltage controlling and protection.

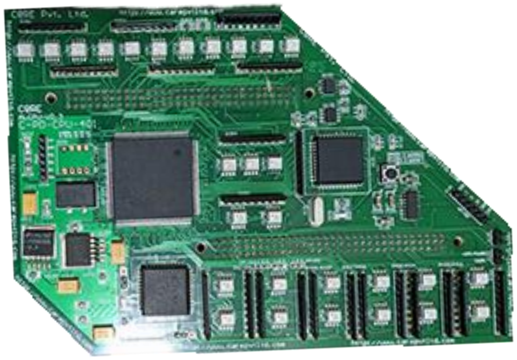

Figure 10: CPU Board

1.1.3.2 I/O Board

I/O board simply distributes and provides a path to transfer the input and output signals to the external six connectors of PD-Box Unit. Capacitors and Pull-up resistors are there to strengthen the signals so that it can easily travel through a long wire connections. There are almost 100 input/output signals that are controlled by the CPU.

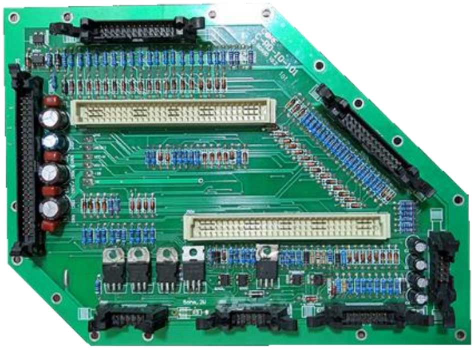

Figure 11: IO Board

Chapter 2: EXISTING TESTING PROCEDURES AND MOTIVATION OF RESEARCH

Initially, the testing of the Module Boards was done either manually or using basic test benches. There were test benches that were used to test just the inputs and outputs. Sometimes, issues were generated in the boards while testing on test benches. Even there was so less protection in the test benches that problems in the circuitry of test benches itself were generated while testing.

2.1 Existing Testing Procedures

2.1.1 Testing of Power Boards and Power Supply Boards

Initially, the Power Drive Module Boards were tested manually by giving 5V and other required signals and reading the corresponding outputs. The purpose of this test was to check if the circuitry on the board is working fine or not. If there were any problem or the output voltage was not detected, the workers had to troubleshoot the board manually. For load test, a motor was being connected at the output terminals to let the current pass through the MOSFET and the MOSFET drop was checked. The load test was the most dangerous test as the MOSFET will burn and burst if there is any issue with it while handling the high current. Also there were a lot of chances of the human errors while testing.

The Power Supply Module Boards were being tested by just reading the output voltages. For the load test, a load in the form of resistors had to be connected manually, that used to cause sparking, which could possibly damage the circuitry. If any problem/issue was detected in the working of power supply, troubleshooting had to be done manually to detect the exact problem.

2.1.2 Testing of AMMO Cards

Ammo cards were tested manually as well. After programming the controller board, the display board was attached to it, and observed visually. If Ammo display works fine, the boards were considered to be okay, otherwise troubleshooting was done manually. It was quite a difficult task as it was difficult to guess which board is faulty, the controller board or the display board. It was a time taking and difficult process. So a proper system was needed that could test the boards separately to check for the errors and pin point those faults.

2.1.3 Testing of Memory Cards

Testing of memory cards consisted of two parts, one was manual testing of the board, and the second one was in the modular form. The first part was tested manually by checking the voltages of regulators and opto-couplers and then the modular test was done on a jig that just used to test to test the opto-couplers and the EEPROM. It was a time taking task to test the board two times and if any error occurred in the board, it had to be checked manually. So to reduce this time and enhance the accuracy of testing, a proper system was required that could test the board in short time and in just one go.

2.1.4 Testing of CPU and IO Board.

CPU and IO were tested simultaneously. After programming the CPU board, it was then placed and attached on IO board and they both were tested on a test bench. This test bench used to test the board on a very basic level, i.e. these boards were tested just for the input and output signals. Also if there was any fault, it was hard to tell whether the problem is in IO board or in CPU board. So a smart system was required to test both the boards separately and reduce the testing and troubleshooting time.

2.2 Motivation of Research

Due to all the reasons mentioned above, there arose a need to design a system that can test all the circuitry of Solid State Auto-Loader catering all the requirements of cards testing, reduce testing time and increase the accuracy. For that purpose, it was planned to design testing jigs for testing all the circuitry of SSAL. All the Boards were divided into 3 different category and each category will have a separate testing jig.

The first category of boards consists of all the Power Drive Module boards and a Power Supply Module Board. These 6 boards will be tested on a single jig. The second category of boards include both the Ammo Unit cards along with the Memory Unit card. The Third category includes the CPU board and the IO board. These two boards will be tested on a separate jig.

2.3 Additional Features and Benefits

Few factors were listed before making the design of jigs that must have been incorporated in the design. The Jigs were designed by keeping few factors in mind which are mentioned below:

2.3.1 Testing from every aspect

The very first and the main aspect was to design the jigs that could test the cards for working of each and every part of pcb/circuitry and assure the proper functioning of the cards. Point out the errors in the boards (if any) and give us the result at the end of the test.

2.3.2 Reduce Testing Time

Another aspect was to reduce the testing time of the boards. Initially the testing used to take so long, and that was the main issue in the production line. A lot of man power was required for this purpose. So these jigs were to design to reduce the time as well as the man power.

2.3.3 Increase accuracy

These jigs were required to increase the accuracy of the testing. There were a lot of human errors in the testing of cards that were generated unintentionally. These issues normally increase the production time of system. For example if there is issue with the board, and that part of testing was neglected, that could damage the system, and later on took so long to identify and amend that problem. So a system was required to reduce these kind of errors and made the working of board almost 100 percent.

2.3.4 Portable design

While designing the 3D model of the Jigs, the aspect of portability was also kept in mind, i.e. if the jigs had to be moved from place to place, that won't be an issue. Normally the systems run on AC power, but a facility should be there that the jigs can be powered up using DC voltage, so that they can be used on field with the DC power taken from the tank.

2.3.5 For On-field use

Jigs were designed by keeping in mind that they can be used on field. While the testing of tanks, if any issue occurs in the cards, cards don't have to be brought to the labs for testing and debugging. Instead they can be tested right there on the field. So the design of the jigs should be portable that it can be taken anywhere. And for that purpose, it can be powered up using 24VDC-Input using the batteries in the tanks.

2.3.6 Low Cost

This was a challenging issue to reduce the cost. Everything and every design had to be kept in mind while designing. From the mechanical design to the electrical design, everything had to select careful to reduce the cost.

2.3.7 Upgradability

This aspect was related to the future. As there can be changes in the design of Circuit Boards used in Auto-Loader. If any change has to be incorporated in the design of jigs as per the change in the Circuit Boards, that won't be much of an issue. The circuit boards that had to be installed in the jigs had to be designed in such a way, that they can handle future modifications with little changes.

2.3.8 Extra Protection

This was an important aspect. The protection had to be added to protect the jigs as well as the boards under test from any kind of damage. For example, if any board have an issue of shortage with the ground, that shouldn't damage the circuitry of the jig. All those kind of possible protections had to be present in the jig to make the jigs durable. Also the jig or the board shouldn't get damaged upon wrong wiring connections. The jig should detect on its own about the wrong wiring connection and indicate that wrong connection on the display for the user.

2.3.9 Easy to Use

This had to be kept in mind while designing the jigs that these will be under use of different users that has very little or no information about the testing or troubleshooting of the Module Boards. Previously, it was impossible to test the boards by a new user, without having the knowledge about the circuitry of module boards. First they had to study the board, study the schematics, and know everything about how the module board works before troubleshooting the board. Even after that, it used to take a lot of time to troubleshoot and debug the module boards.

So to minimize this effort and time, there should be system that can be used by a new user to test the module boards easily.

CHAPTER 3: TESTING FLOW AND METHODOLOGY

Jigs are designed with a purpose to test the *Module Boards* that are installed in all the three units including *Power Distribution Unit*, *Memory Unit* and *Ammo Unit* of T-85, Al-Khalid and Al-Khalid 1 tanks. It provides a solution that gives the ability to find the faults in any of the module boards by analyzing all of its outputs. It's a totally autonomous system that will test the complete board on its own. The only human effort required is the correct wiring connections and the selection of right test from the menu, rest of the test will be performed automatically without human involvement.

3.1 Power Drive and Power Supply Module Boards Testing Jig

The Power Module Drive and Power Supply Module Boards Testing Jig is designed for the purpose of testing the *Power drive module boards* and the *Power supply module board* that are installed in the *Power Distribution Box* of T-85, Al-Khalid and Al-Khalid 1 tanks.

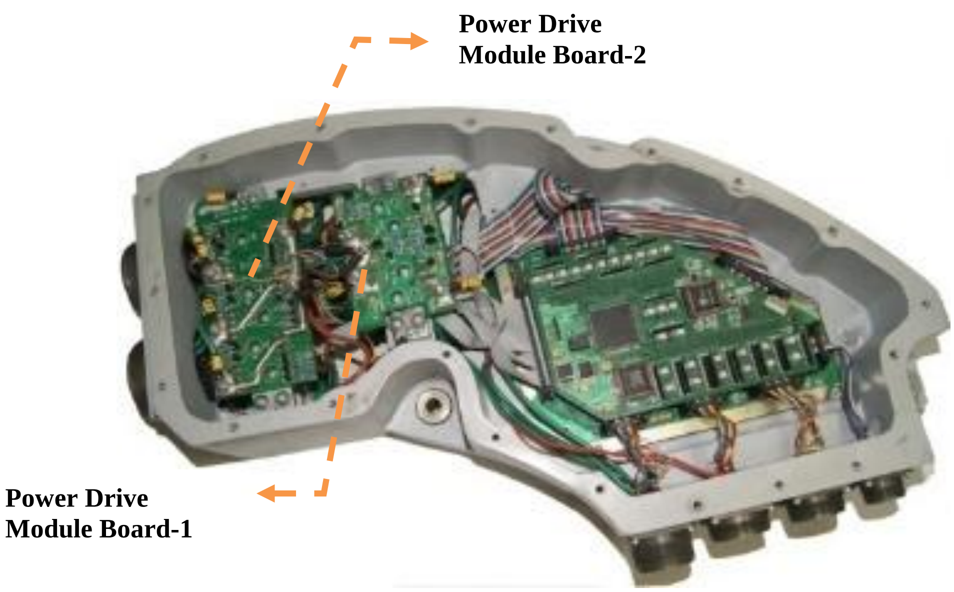

Figure 12: Side 1 of PD-box showing Installed Module boards

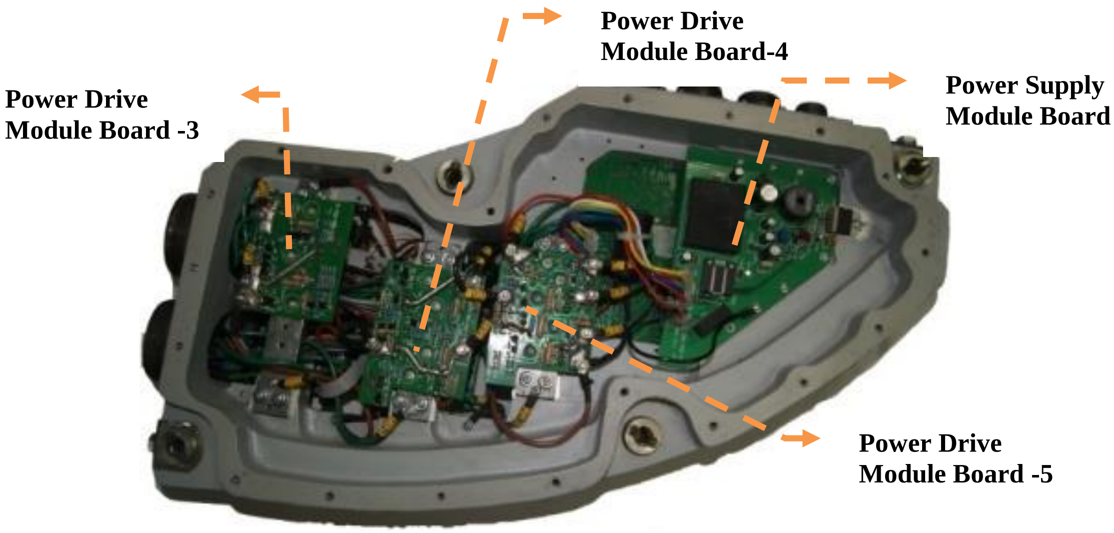

Figure 13: Side 1 of PD-box showing Installed Module boards

The system is based on programmable logic design, i.e. it uses a micro controller that makes decisions on its own. It generates the signals to perform all the required tasks. Selections between different module boards and different outputs of the module boards are done by high power relays, which gets signals from the microcontroller. After analyzing the outputs of module boards, it makes decisions whether the board is *OK* or *FAULTY*.

The Test Bench is a smart system i.e. it can sense if the wiring connections are wrong, or if the jig's power is short or if the wrong test is selected from the menu for any *Module Board.* The Power Drive Module Boards-Jig can test the following boards:

1. Power Drive Module-1.
2. Power Drive Module-2.
3. Power Drive Module-3.
4. Power Drive Module-4.
5. Power Drive Module-5.
6. Power Supply Module Board.

3.1.1 Power Drive Module-1 Testing:

Solid State Autoloader's Power Drive Module-1 drives Frame and Window motors in Auto-loading Process. There are 4 half bridges in this board which are the fundamental part of the circuitry. All the required signals will be given through controller using ribbon cable, and decisions will be made on the basis of outputs received. Following are the Output terminals of Power drive module board-1:

Table 1: Input Signals and Output Terminals of PDM-1 Board

INPUT SIGNALS	IDC PIN #	MOTORS	OUTPUT PIN#
MF1	2	Window open	C13
MF2	3	Window close	C14
MW1	4	Frame move up	F19
MW2	7	Frame move down	F20

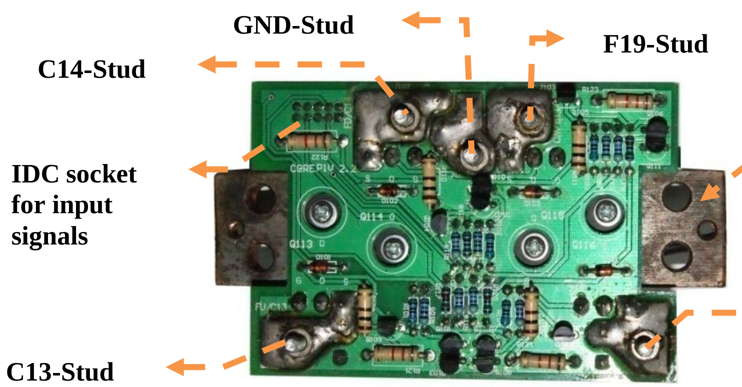

Figure 14: PD Unit

Figure 15: PDM-1 Board

To test the board, connect the ribbon cable for the input signals and make the other connections as per mentioned in the table that is given below and select the respective test from the display menu.

3.1.1.1 Wiring Connection:

Table 2: Wiring Connections for PDM-1 Board

Wiring Terminals	TA	TB	TC	TD	TE
Power Drive Module Board-1	C13	F20		F19	C14

3.1.1.2 Testing Flow

3.1.1.2.1 Shortage Detection Test

Input Short test is done by applying 5V to the input of Module Board instead of 24V. 5V volt regulator is used which has the shutdown capability upon the passage of high current. If the Input Terminal is short due to any reason, the regulator will shut down and no voltage will be detected in ADC.

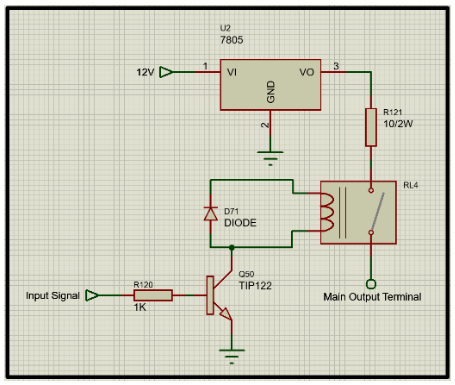

Figure 16: Input Short Test Circuit

3.1.1.2.2 MOSFET Leak Test

A test is performed to check whether there is any voltage coming out of the MOSFET to avoid any damage to the Jig's circuitry. Voltages are read from the Drain terminal of the MOSFET. If 24Vs are detected, that means the Drain and the Source are short internally, i.e. MOSFET is burnt or short. If any voltage less than 24V are detected, that means MOSFET has been leaked and will not work properly. It might get damaged on heavy load.

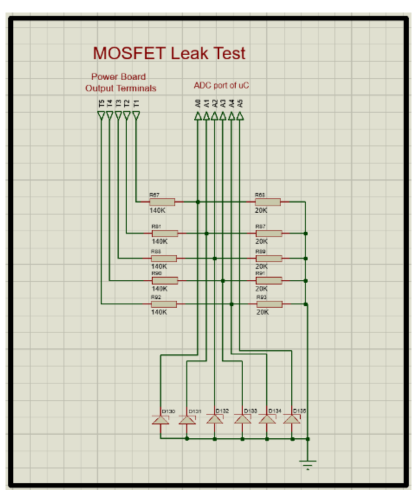

Figure 17: MOSFET Leak Test Circuit

3.1.1.2.3 Ground Test

Ground test in performed to check if any of the outputs is short. A voltage of 5v is applied on the output terminals, and that same voltage is read in the ADC Port of micro-controller. If any of the outputs is short, the Jig will detect it and stop the testing by showing an error on the display screen.

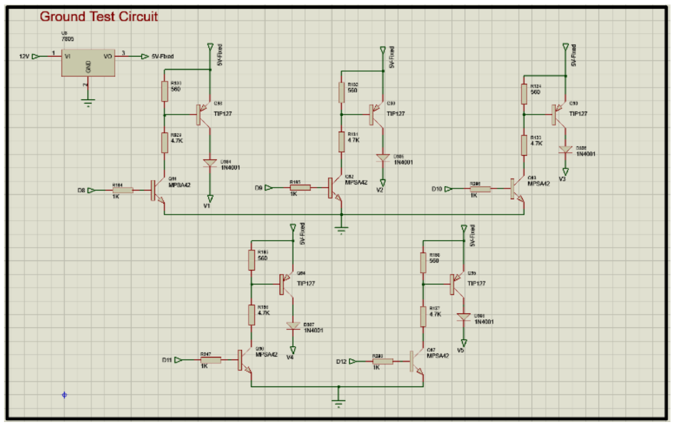

Figure 18: Ground Test Circuit

3.1.1.2.4 Signal Cable Test

Signal cable is used to send the signals to the power boards. It is being tested for the 12V and 36V signals. These signals are tested to check if they are short or not connected. This test can also be used to detect if the user has attached the cable to the Module Board or not.

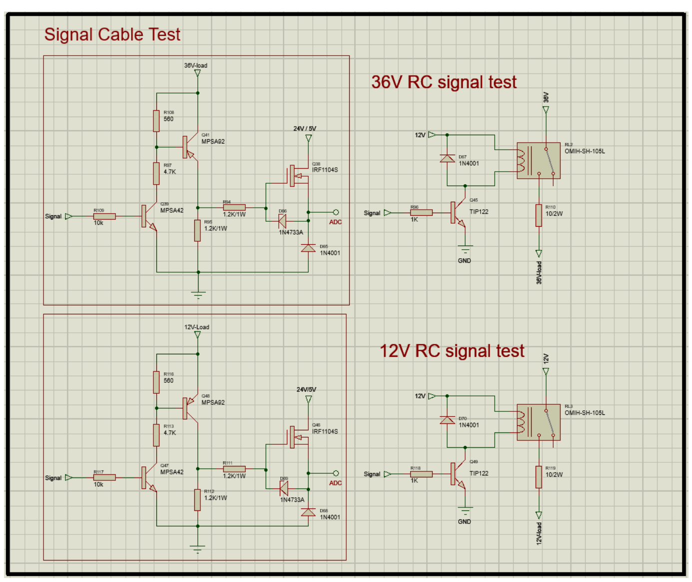

Figure 19: Signal Cable Testing Circuit

3.1.1.2.5 MOSFET Drop Test

MOSFET Drop test is performed to check if the MOSFET will work properly on extreme condition. Test is done by passing high current (15 Amps) through the MOSFET. The drop between the Drain and Source (Vds) is checked. If it is under the correct value than the test passes otherwise the test will be failed. Vds is increased if the resistance between the Drain and Source is high due to any reason and if the resistance is high, the MOSFET will likely to burn upon passage of high current as current is directly proportional to the resistance. As the Amperage increases, resistance will also increase, and that will produce enough heat to burn the MOSFET.

3.1.2 Power Drive Module Board-2 Testing

Solid State Autoloader's Power Drive Module-2 drives Hoist and Gun Lock solenoids in Auto-loading Process. There are 2 Full bridges and 2 half bridges in this board which are the fundamental part of the circuitry. All the required signals will be given through controller using ribbon cable, and decisions will be made on the basis of outputs received. Following are the Output terminals of Power drive module board-1:

Table 3: Input Signals and Output Terminals of PDM-2 Board

INPUT SIGNALS	IDC PIN #	SOLENOIDS	OUTPUT PIN#
MH1	3	Hoist up	F3
MH2	4	Hoist down	F4
MH4	6	Hoist down slow	F3, F4
MH3	5	Hoist up slow	F3, F4
MG1	1	Gun lock	E26
MG2	2	Gun unlock	E27

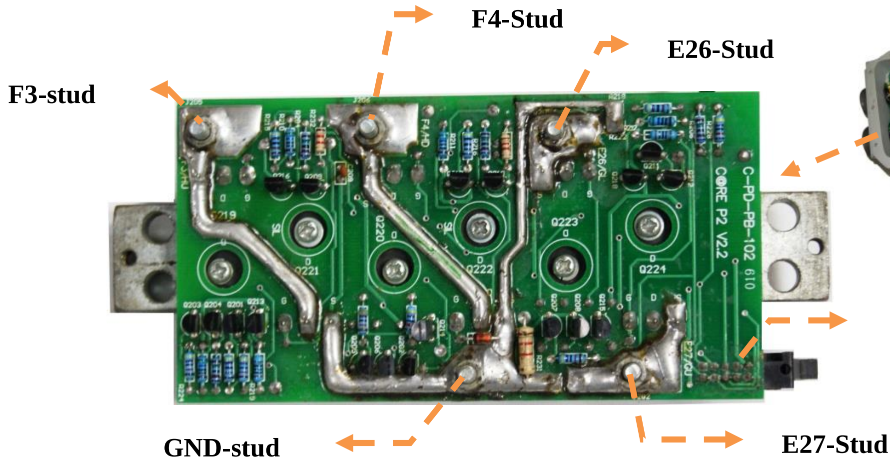

Figure 20: PD Unit

Figure 21: PDM-2 Board

To test the board, connect the ribbon cable for the input signals and make the other connections as per mentioned in the table that is given below and select the respective test from the display menu.

3.1.2.1 Wiring Connection:

Table 4: Wiring Connections of PDM-2 Board

Wiring Terminals	TA	TB	TC	TD	TE
Power Drive Module Board-2	F3	F4	E26		E27

3.1.2.2 Testing Flow

3.1.2.2.1 Shortage Detection Test

Input Short test is done by applying 5V to the input of Module Board instead of 24V. 5V volt regulator is used which has the shutdown capability upon the passage if high current. If the Input Terminal is short due to any reason, the regulator will shut down and no voltage will be detected in ADC.

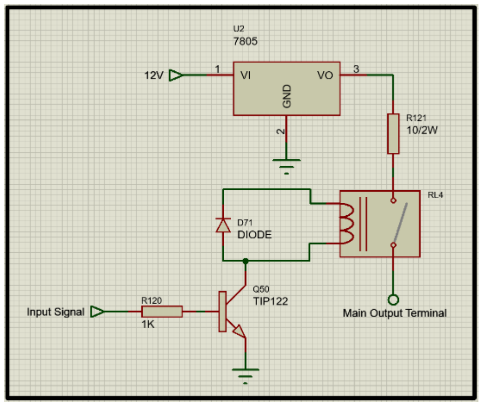

Figure 22: Input Short Test Circuit

3.1.2.2.2 MOSFET Leak Test

A test is performed to check whether there is any voltage coming out of the MOSFET to avoid any damage to the Jig's circuitry. Voltages are read from the Drain terminal of the MOSFET. If 24Vs are detected, that means the Drain and the Source are short internally, i.e. MOSFET is burnt or short. If any voltage less than 24V are detected, that means MOSFET has been leaked and will not work properly. It might get damaged on heavy load.

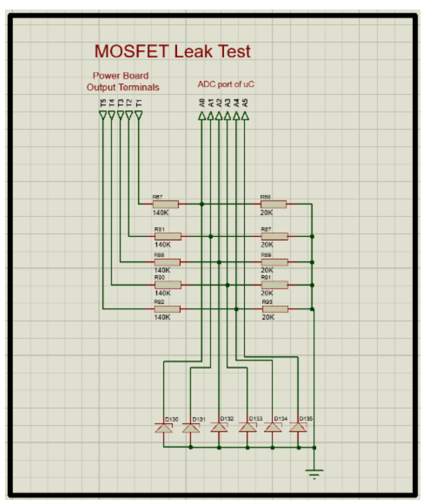

Figure 23: MOSFET Leak Test Circuit

3.1.2.2.3 Ground Test

Ground test in performed to check if any of the outputs is short. A voltage of 5v is applied on the output terminals, and that same voltage is read in the ADC Port of micro-controller. If any of the outputs is short, the Jig will detect it and stop the testing by showing an error on the display screen.

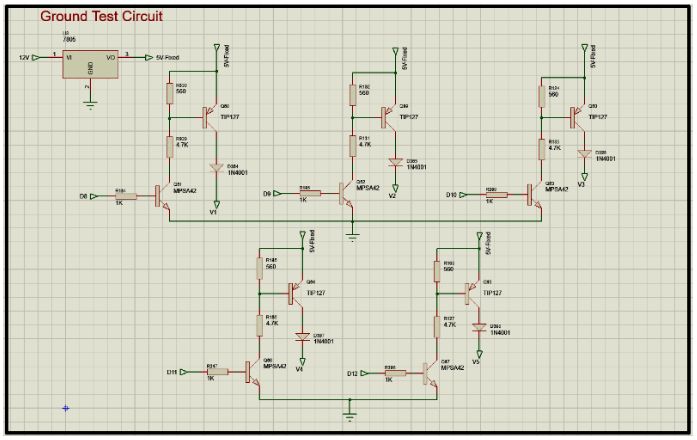

Figure 24: Ground Test Circuit

3.1.2.2.4 Signal Cable Test

Signal cable is used to send the signals to the power boards. It is being tested for the 12V and 36V signals. These signals are tested to check if they are short or not connected. This test can also be used to detect if the user has attached the cable to the Module Board or not.

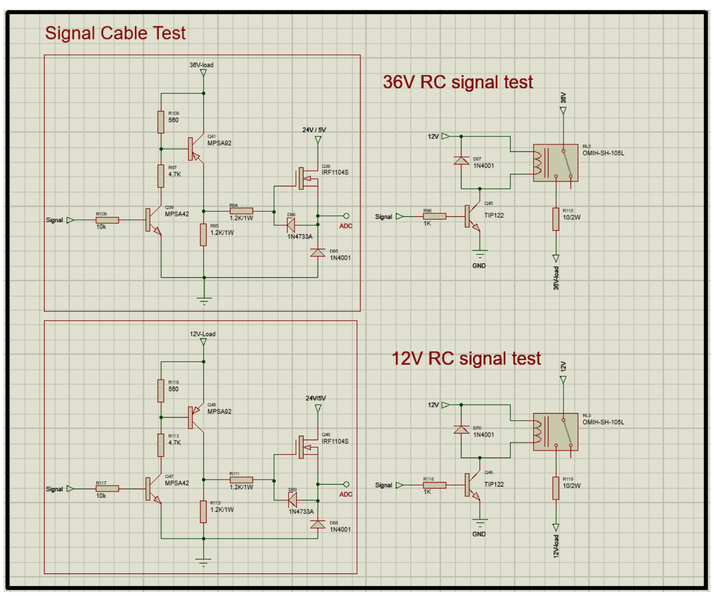

Figure 25: Signal Cable Testing Circuit

3.1.2.2.5 MOSFET Drop Test

MOSFET Drop test is performed to check if the MOSFET will work properly on extreme condition. Test is done by passing high current (15 Amps) through the MOSFET. The drop between the Drain and Source (Vds) is checked. If it is under the correct value than the test passes otherwise the test will be failed. Vds is increased if the resistance between the Drain and Source is high due to any reason and if the resistance is high, the MOSFET will likely to burn upon passage of high current as current is directly proportional to the resistance. As the Amperage increases, resistance will also increase, and that will produce enough heat to burn the MOSFET.

3.1.3 Power Drive Module Board-3 Testing

Solid State Autoloader's Power Drive Module-3 drives Rammer Motor in Auto-loading Process. There are 1 Full bridges and 1 half bridge in this board which are the fundamental part of the circuitry. All the required signals will be given through controller using ribbon cable, and decisions will be made on the basis of outputs received. Following are the output terminals of the Module Board:

Table 5: Input Signals and Output Terminals of PDM-3 Board

INPUT SIGNALS	IDC PIN #	RAMMER MOTOR DRIVER	OUTPUT PIN#
MR1	4	Rammer forward	F33
MR2	2	Rammer backward	F34
MR3	1	Rammer forward slow	F33, F34

Figure 26: PD Unit

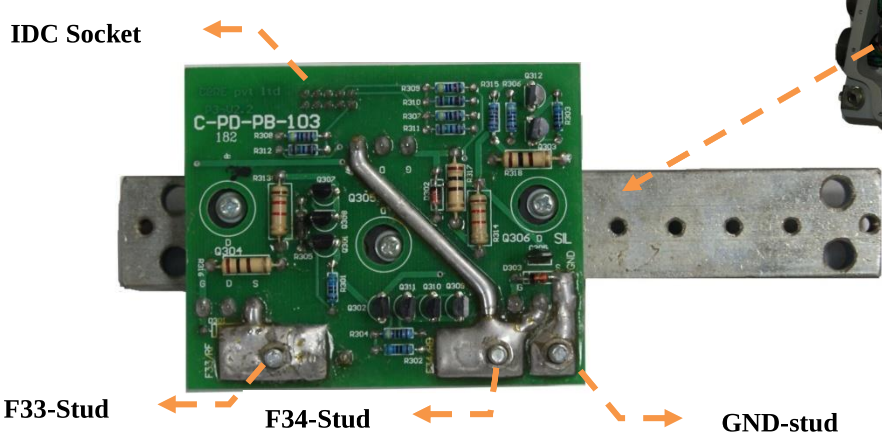

Figure 27: PDM-3 Board

To test the board, connect the ribbon cable for the input signals and make the other connections as per mentioned in the table that is given below and select the respective test from the display menu.

3.1.3.1 Wiring Connection:

Table 6: Wiring Connections of PDM-3 Board

Wiring Terminals	**TA**	**TB**	**TC**	**TD**	**TE**
Power Drive Module Board-3	F33	F34			

3.1.3.2 Testing Flow

3.1.3.2.1 Shortage Detection Test

Input Short test is done by applying 5V to the input of Module Board instead of 24V. 5V volt regulator is used which has the shutdown capability upon the passage if high current. If the Input Terminal is short due to any reason, the regulator will shut down and no voltage will be detected in ADC.

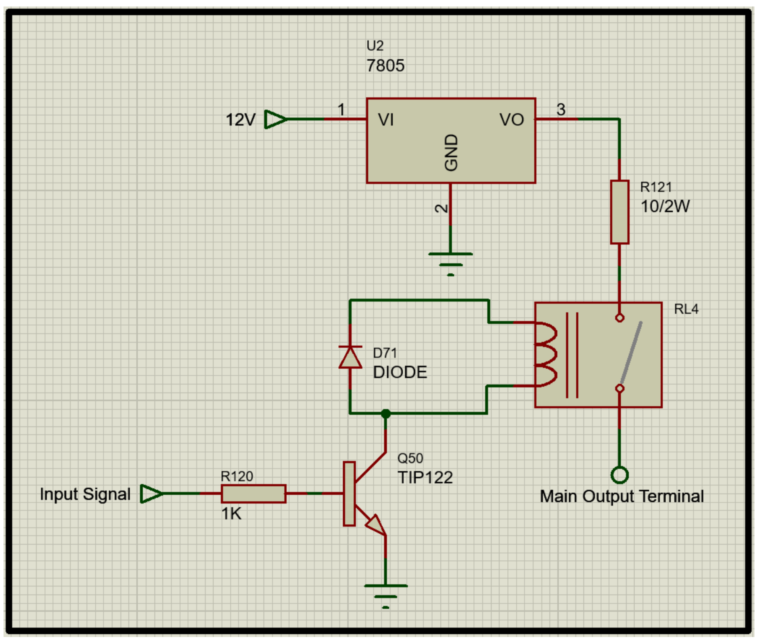

Figure 28: Input Short Test Circuit

3.1.3.2.2 MOSFET Leak Test

A test is performed to check whether there is any voltage coming out of the MOSFET to avoid any damage to the Jig's circuitry. Voltages are read from the Drain terminal of the MOSFET. If 24Vs are detected, that means the Drain and the Source are short internally, i.e. MOSFET is burnt or short. If any voltage less than 24V are detected, that means MOSFET has been leaked and will not work properly. It might get damaged on heavy load.

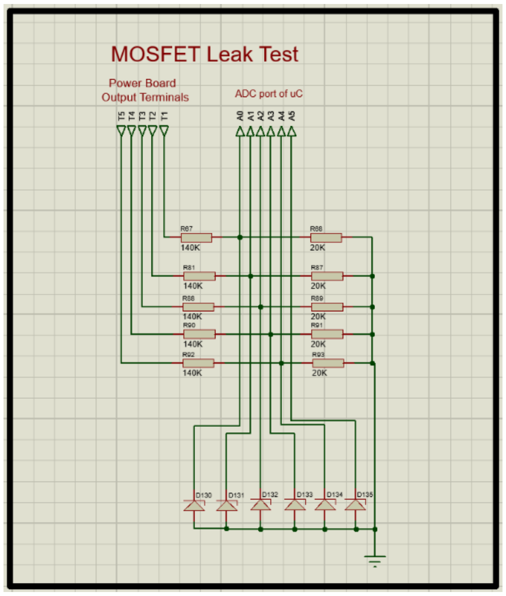

Figure 29: MOSFET Leak Test Circuit

3.1.3.2.3 Ground Test

Ground test in performed to check if any of the outputs is short. A voltage of 5v is applied on the output terminals, and that same voltage is read in the ADC Port of micro-controller. If any of the outputs is short, the Jig will detect it and stop the testing by showing an error on the display screen.

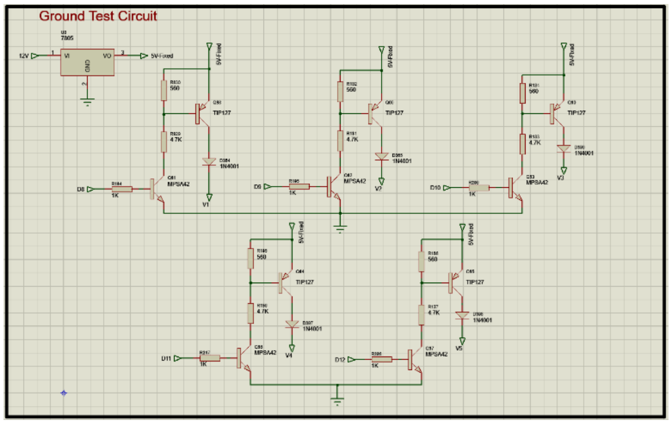

Figure 30: Ground Test Circuit

3.1.3.2.4 Signal Cable Test

Signal cable is used to send the signals to the power boards. It is being tested for the 12V and 36V signals. These signals are tested to check if they are short or not connected. This test can also be used to detect if the user has attached the cable to the Module Board or not.

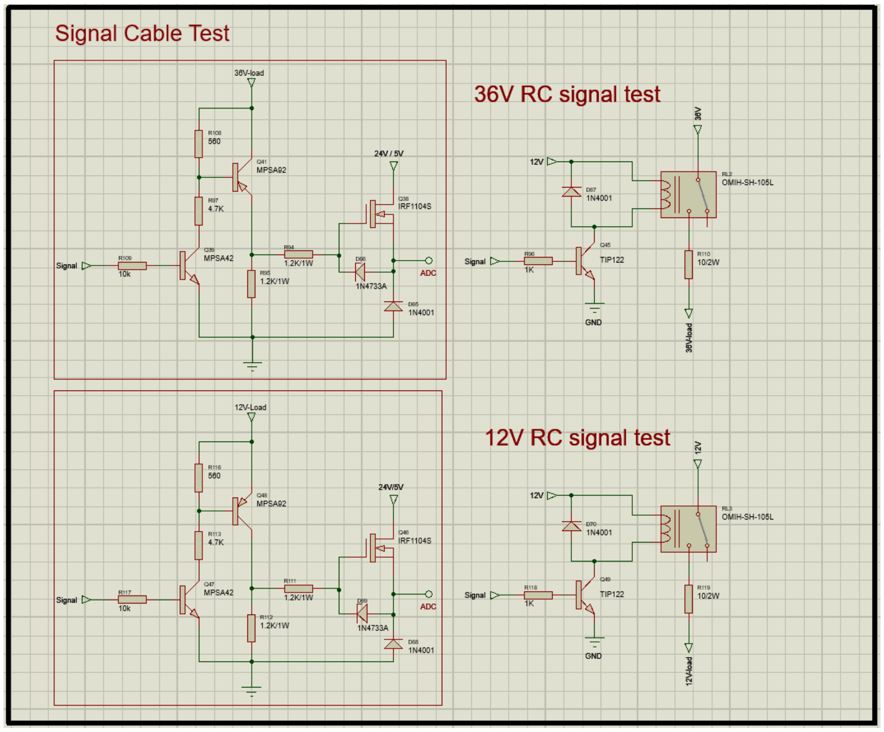

Figure 31: Signal Cable Testing Circuit

3.1.3.2.5 MOSFET Drop Test

MOSFET Drop test is performed to check if the MOSFET will work properly on extreme condition. Test is done by passing high current (15 Amps) through the MOSFET. The drop between the Drain and Source (Vds) is checked. If it is under the correct value than the test passes otherwise the test will be failed. Vds is increased if the resistance between the Drain and Source is high due to any reason and if the resistance is high, the MOSFET will likely to burn upon passage of high current as current is directly proportional to the resistance. As the Amperage increases, resistance will also increase, and that will produce enough heat to burn the MOSFET.

3.1.4 **Power Drive Board-4 Testing**

Solid State Autoloader's Power Drive Module-4 drives Carousal Magazine's Motor in Auto-loading Process. There are 2 Full bridges in this board which are the fundamental part of the circuitry. All the required signals will be given through controller using ribbon cable, and decisions will be made on the basis of outputs received.

Following are the Output terminals of Power drive module board-4:

Table 7: Input Signals and Output Terminals of PDM-4 Board

INPUT SIGNALS	IDC PIN #	SOLENOIDS	OUTPUT PIN#
MC1	**5**	**Carousal magazine CW fast**	**F31**
MC2	**3**	**Carousal magazine CCW fast**	**F32**
MC3	**4**	**Carousal magazine CW slow**	**F31**
MC4	**1**	**Carousal magazine CCW fast**	**F32**

Figure 32: PD Unit

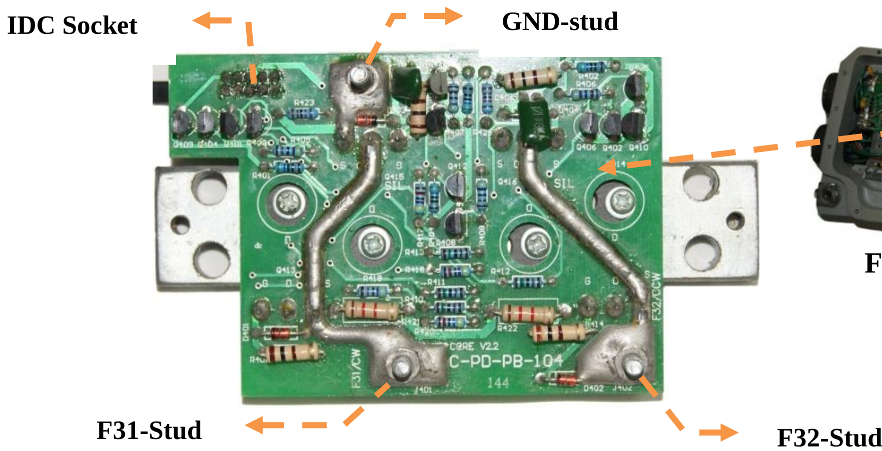

Figure 33: PDM-4 Board

To test the board, connect the ribbon cable for the input signals and make the other connections as per mentioned in the table that is given below and select the respective test from the display menu.

3.1.4.1 Wiring Connections:

Table 8: Wiring Connections of PDM-4 Board

Wiring Terminals	TA	TB	TC	TD	TE
Power Drive Module Board-4	F31	F32			

3.1.4.2 Testing Flow

3.1.4.2.1 Shortage Detection Test

Input Short test is done by applying 5V to the input of Module Board instead of 24V. 5V volt regulator is used which has the shutdown capability upon the passage if high current. If the

Input Terminal is short due to any reason, the regulator will shut down and no voltage will be detected in ADC.

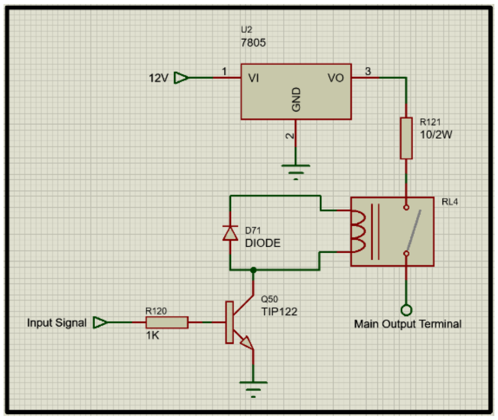

Figure 34: Input Short Test Circuit

3.1.4.2.2 MOSFET Leak Test

A test is performed to check whether there is any voltage coming out of the MOSFET to avoid any damage to the Jig's circuitry. Voltages are read from the Drain terminal of the MOSFET. If 24Vs are detected, that means the Drain and the Source are short internally, i.e. MOSFET is burnt or short. If any voltage less than 24V are detected, that means MOSFET has been leaked and will not work properly. It might get damaged on heavy load.

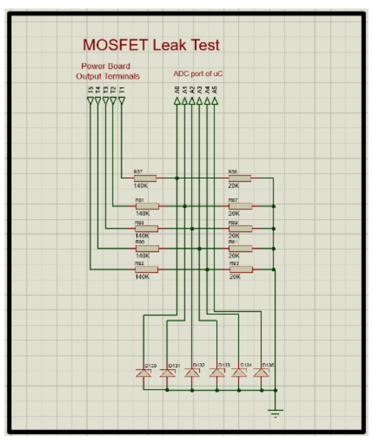

Figure 35: MOSFET Leak Test Circuit

3.1.4.2.3 Ground Test

Ground test in performed to check if any of the outputs is short. A voltage of 5v is applied on the output terminals, and that same voltage is read in the ADC Port of micro-controller. If any of the outputs is short, the Jig will detect it and stop the testing by showing an error on the display screen.

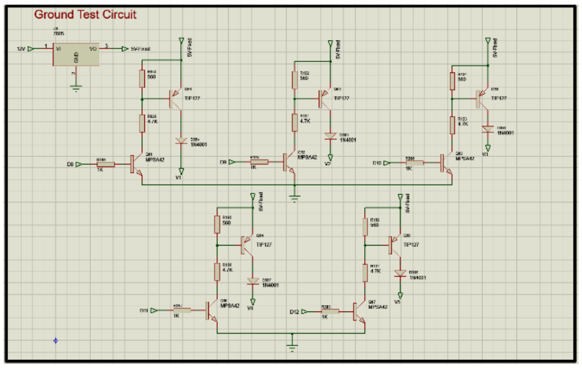

Figure 36: Ground Test Circuit

3.1.4.2.4 Signal Cable Test

Signal cable is used to send the signals to the power boards. It is being tested for the 12V and 36V signals. These signals are tested to check if they are short or not connected. This test can also be used to detect if the user has attached the cable to the Module Board or not.

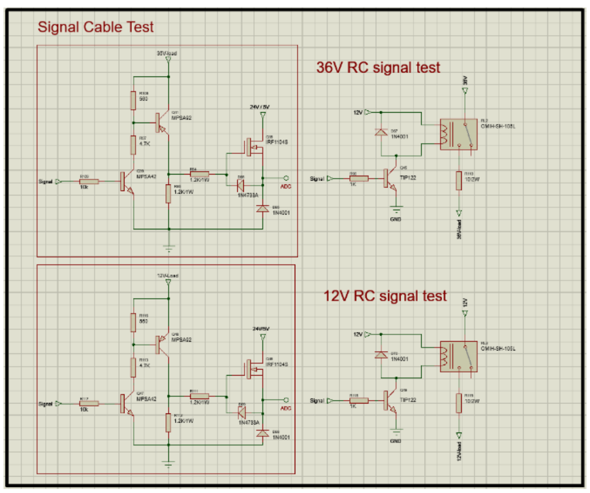

Figure 37: Signal Cable Testing Circuit

3.1.4.2.5 MOSFET Drop Test

MOSFET Drop test is performed to check if the MOSFET will work properly on extreme condition. Test is done by passing high current (15 Amps) through the MOSFET. The drop between the Drain and Source (Vds) is checked. If it is under the correct value than the test passes otherwise the test will be failed. Vds is increased if the resistance between the Drain and Source is high due to any reason and if the resistance is high, the MOSFET will likely to burn upon passage of high current as current is directly proportional to the resistance. As the Amperage increases, resistance will also increase, and that will produce enough heat to burn the MOSFET.

3.1.5 Power Drive Module Board-5 Testing

Solid State Autoloader's Power Drive Module-5 drives Solenoid in Auto-loading Process. There are 2 Full bridges in this board which are the fundamental part of the circuitry. All the required signals will be given through controller using ribbon cable, and decisions will be made on the basis of outputs received.

Following are the Output terminals of Power drive module board-5:

Table 9: Input Signals and Output Terminals of PDM-5 Board

INPUT SIGNALS	IDC PIN #	SOLENOIDS	OUTPUT
SSE1	5	Shell eject solenoid	C11
SH1	3	Hoist locking solenoid big	F16
SH2	4	Hoist locking solenoid small	F17
SC1	1	Carousal magazine locking solenoid big	F28
SC2	2	Carousal magazine locking solenoid small	F29

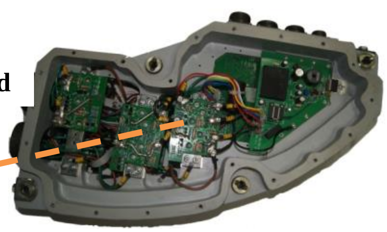

Figure 38: PD Unit

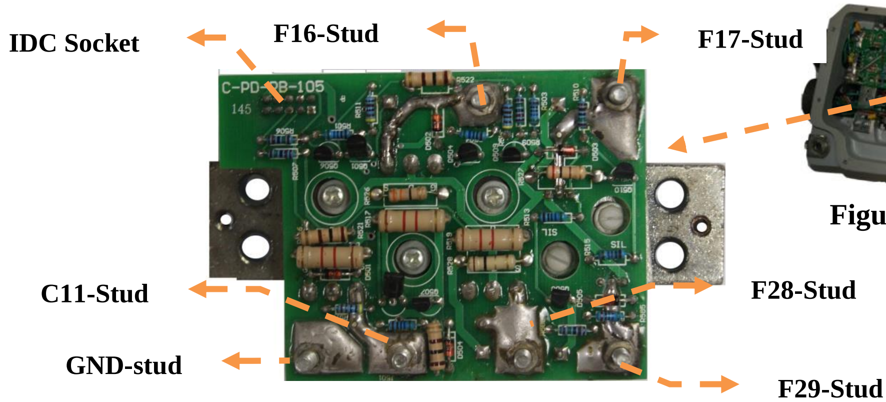

Figure 39: PDM-5 Board

To test the board, connect the ribbon cable for the input signals and make the other connections as per mentioned in the table that is given below and select the respective test from the display menu.

3.1.5.1 Wiring Connections:

Table 10: Wiring Connections for PDM-5 Board

Wiring Terminals	TA	TB	TC	TD	TE
Power Drive Module Board-5	C11	F28	F29	F16	F17

3.1.5.2 Testing Flow

3.1.5.2.1 Shortage Detection Test

Input Short test is done by applying 5V to the input of Module Board instead of 24V. 5V volt regulator is used which has the shutdown capability upon the passage if high current. If the Input Terminal is short due to any reason, the regulator will shut down and no voltage will be detected in ADC.

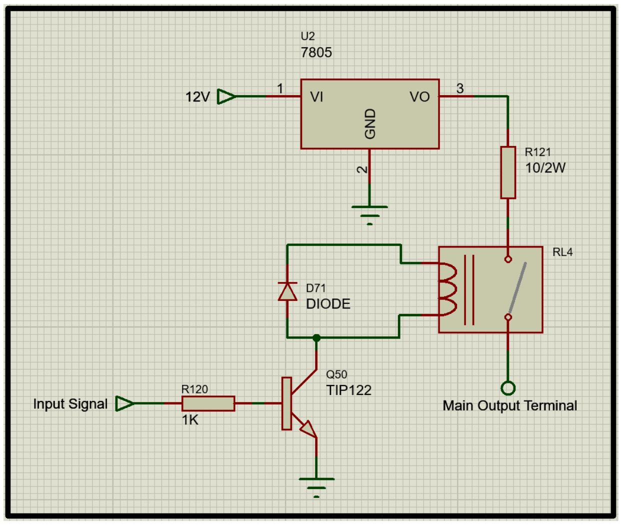

Figure 40: Input Short Test Circuit

3.1.5.2.2 MOSFET Leak Test

A test is performed to check whether there is any voltage coming out of the MOSFET to avoid any damage to the Jig's circuitry. Voltages are read from the Drain terminal of the MOSFET. If 24Vs are detected, that means the Drain and the Source are short internally, i.e. MOSFET is burnt or short. If any voltage less than 24V are detected, that means MOSFET has been leaked and will not work properly. It might get damaged on heavy load.

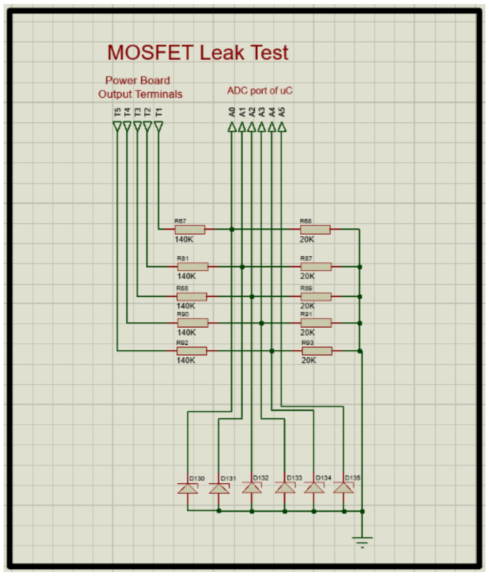

Figure 41: MOSFET Leak Test Circuit

3.1.5.2.3 Ground Test

Ground test in performed to check if any of the outputs is short. A voltage of 5v is applied on the output terminals, and that same voltage is read in the ADC Port of micro-controller. If any of the outputs is short, the Jig will detect it and stop the testing by showing an error on the display screen.

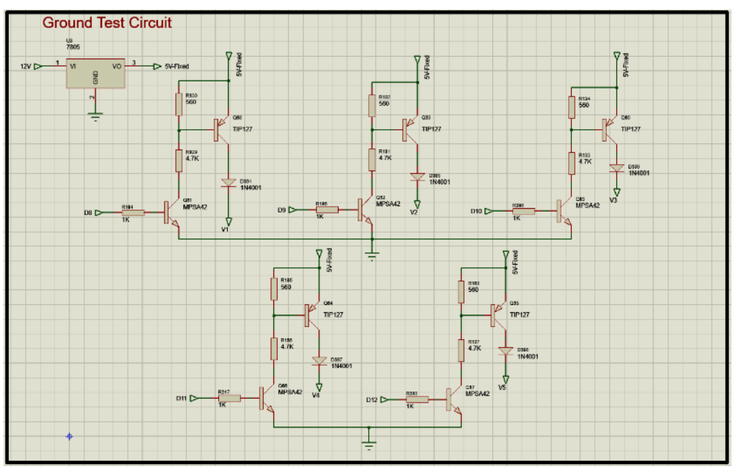

Figure 42: Ground Test Circuit

3.1.5.2.4 Signal Cable Test

Signal cable is used to send the signals to the power boards. It is being tested for the 12V and 36V signals. These signals are tested to check if they are short or not connected. This test can also be used to detect if the user has attached the cable to the Module Board or not.

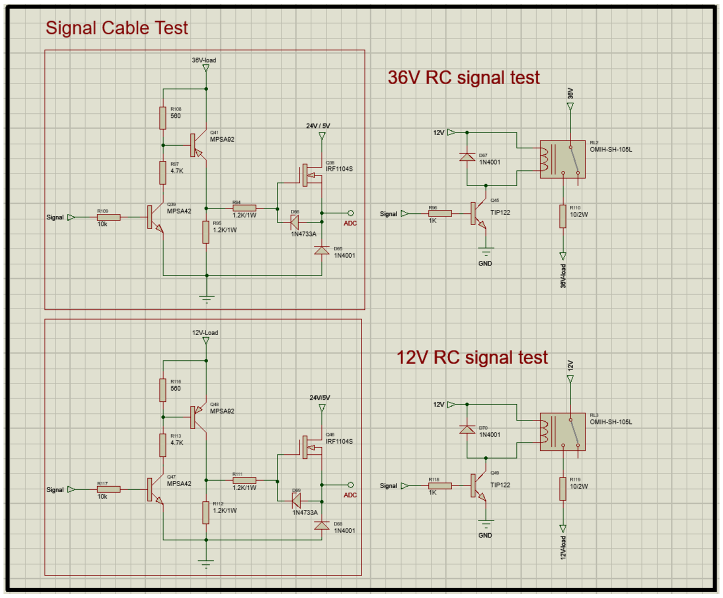

Figure 43: Signal Cable Testing Circuit

3.1.5.2.5 MOSFET Drop Test

MOSFET Drop test is performed to check if the MOSFET will work properly on extreme condition. Test is done by passing high current (15 Amps) through the MOSFET. The drop between the Drain and Source (Vds) is checked. If it is under the correct value than the test passes otherwise the test will be failed. Vds is increased if the resistance between the Drain and Source is high due to any reason and if the resistance is high, the MOSFET will likely to burn upon passage of high current as current is directly proportional to the resistance. As the Amperage increases, resistance will also increase, and that will produce enough heat to burn the MOSFET.

3.1.6 Compete wiring Chart for Power Drive Module Boards

All of the Power Drive Module Boards use 10 wired signal cables for the input signals that are used to drive the motors and actuators. All the boards have the same 10 wired ribbon cable but signals for them are not same. There are different signals on different pins of each signal cable. These signals include 5V signals used to drive the transistors, a 36V and a 12V signal to drive the MOSFETs. So to reduce the number of cables, a wiring scheme was designed. A scheme, where a single wire in the ribbon cable can provide multiple signals. Give below is the chart of the wiring scheme:

Table 11: Wiring Scheme Chart

1		1	2	3	4	5	6	7	8	9	10
2	P1 (4)		MF1 (P1)	MF2 (P2)	MW1 (P3)		36v	MW2 (P4)		24v	
3	P2 (4)	MG1 (P3)	MG2 (P4)	MH1 (P1)	MH2 (P2)	MH3 (P1)	MH4 (P2)		12v	36v	24v
4	P3 (2)	MR3 (P1)	MR2 (P2)		MR1 (P1)				12v	36v	24v
5	P4 (2)	MC3 (P1)	MC2 (P2)		MC1 (P1)		12v	24v		MC4 (P2)	36v
6	P5 (3)	SC1 (P3)	SC2 (P5)	SH1 (P2)	SH2 (P4)	SES1 (P1)				36v	24v

According to this chart, single wire can provide the required signals for the respective board. For example, pin 6 can provide 5V signal for the PDMB-2, a 35V signal for PDMB-1 and a 12V signal for PDMB-4. All the signals that highlighted with orange color, are the output signals of the Power Drive Module Boards for the purpose of sensing, i.e. on pin 7, PDMB-4 generates 24V signal for sensing purpose, on pin 9, PDMB-1 generates 24V signal and on pin 10, PDMB-2, 3 and 5 generates 24V signal.

3.1.7 Power Supply Module Board Testing

Power Supply Module board is used in the PD-Box to supply the required voltages to every module that are installed in SSAL. If all the voltages are not up to the mark, PD-Box won't be able to perform its required tasks. Power supply module board can also be tested on this Jig. It just requires the respective connectors to be connected and respective selection of test from the menu on display (To see how display works, go to section 8.), rest of the testing will be performed on its own. Each and every output is tested on heavy loads to check for faults as well as to ensure its maximum efficiency. This power supply has an additional feature of shutting down 24V if it draws current more than a certain limit. The test bench also tests this feature by drawing more current through 24V and calculates the time that Power Supply takes to shut down. After testing, a message will be shown on the display that will tell whether the power supply is OK or Faulty. If the Power Supply Board is faulty than it will also show which output is faulty.

Figure 44: PD Unit

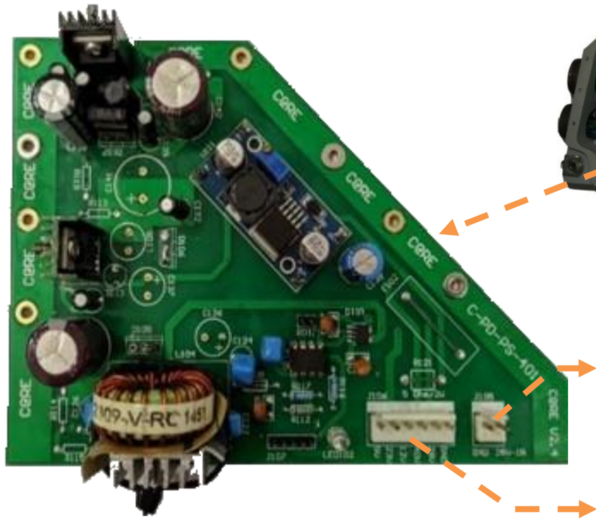

Figure 45: Power Supply Module Board

3.1.8 Complete Wiring Chart

Following chart shows the complete wiring connections for all the Power Drive Module Boards. Wiring for all the power drive module boards should be done according to this table:

Table 12: Complete Wiring Chart

	P1	**P2**	**P3**	**P4**	**P5**
TA	C13	F3	F33	F31	C11
TB	F20	F4	F34	F32	F28
TC		E26			F29
TD	F19				F16
TE	C14	E27			F17

3.1.9 Flow Chart of Power Drive Module Board Testing Coding Sequence

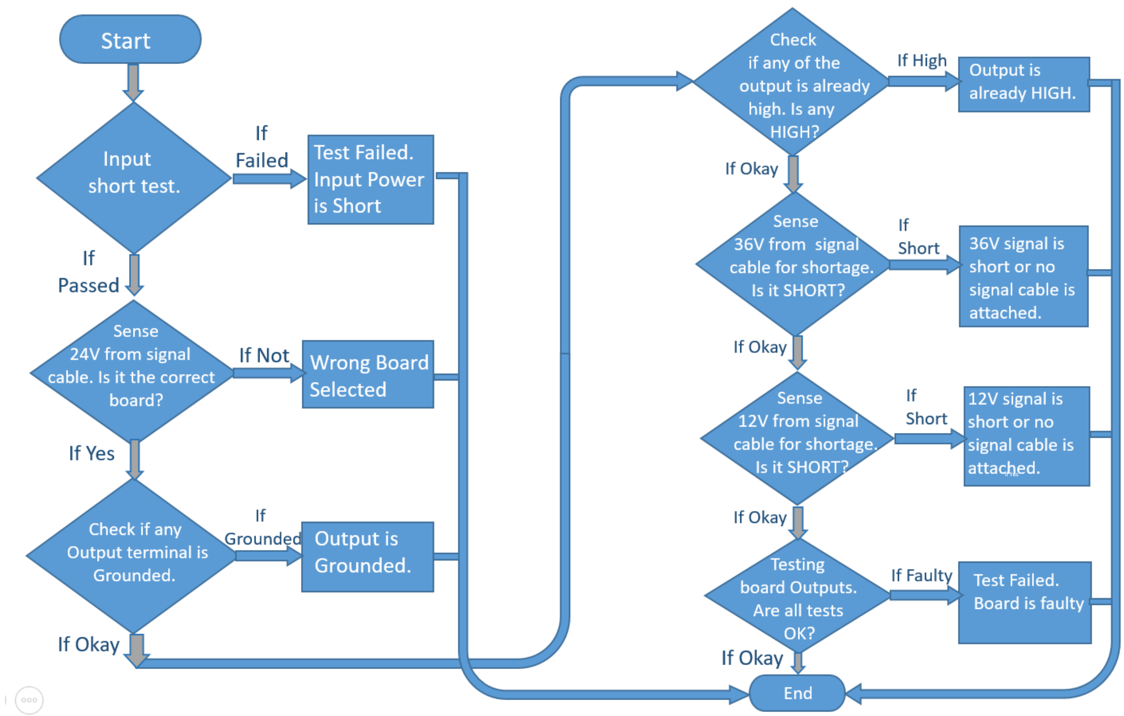

Figure 46: Coding Sequence of PDM testing

3.1.10 Flow Chart of Power Supply Module Board Testing Coding Sequence

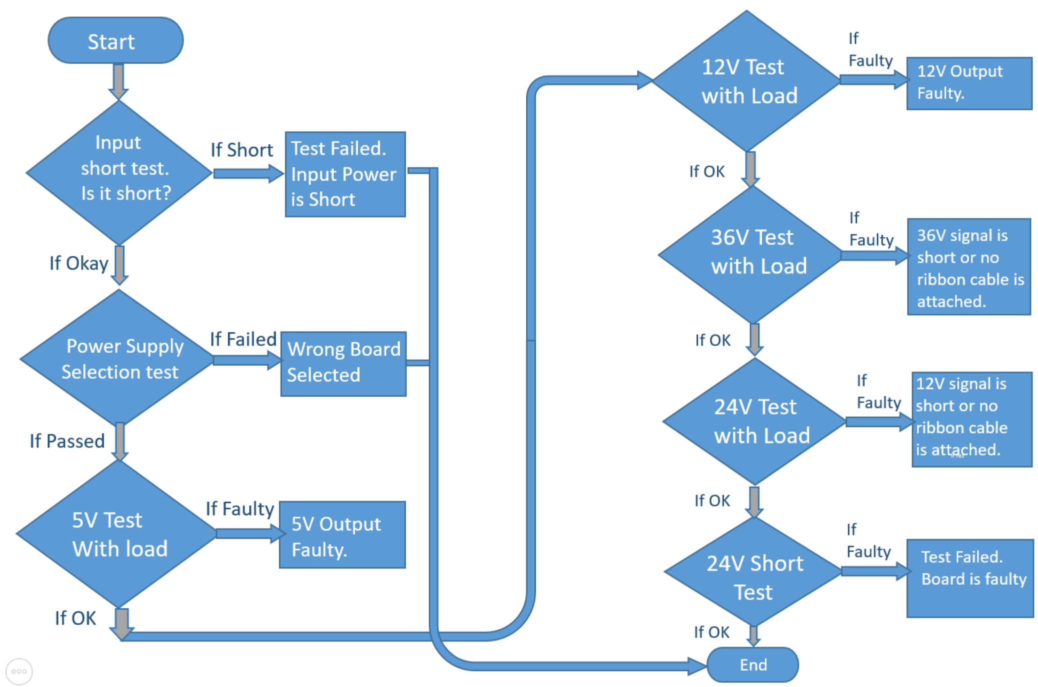

Figure 47: Coding Sequence of PSM Testing

3.2 AMMO and MEMORY Cards Testing Jig

The 'Ammo and Memory cards Testing – Jig' is designed to test the Ammo Cards that include a controller board and a display board and the Memory Unit card. Controller board in Ammo unit is normally named as 'Bottom board' whereas display card is named as 'Top Board'. All the three cards i.e. Ammo top board, Ammo bottom board and memory board are installed in the Ammo Unit and Memory unit of T-85 and Al-Khalid tanks, which is a part of Solid State Auto-loader.

The system is based on programmable logic design, i.e. it uses a micro controller that makes decisions on its own. It generates the signals to perform the all the required tasks. Selections between different module boards and different outputs of the module boards are done by using relays, which gets signals from the microcontroller. After analyzing the outputs of module boards, it makes decisions whether the board is *OK* or *FAULTY*. It's an autonomous system that will test the complete board on its own. The only human effort required is the correct wiring connections and the selection of right test from the menu, rest of the test will be performed automatically without human involvement.

The Ammo Unit and Memory Unit cards-Jig can test the following boards:

1. Ammo Bottom Board.
2. Ammo Top Board.
3. Memory Unit Board.

3.2.1 Ammo Controller Card Testing

The Ammo Controller Board is tested on the jig for to ensure its proper functionality. The detail about the testing of this Module Board is as follow.

3.2.1.1 Testing Sequence

3.2.1.1.1 Input Power Short Test

First test that is performed is input short test. As the test starts, it reads the input voltage using ADC, it reads both the input voltage as well as the output voltage of regulator. If there will be any shortage, the ADC will detect no voltage and the test will stop there displaying the cause of failure.

3.2.1.1.2 Can Communication Test

The next test is related to CAN Communication which is the main test of this controller board. All the information is received using this protocol. The test is performed by sending a heartbeat to the microcontroller present on the Ammo controller board, and in return the signals that are generated are read in the microcontroller of the jig. If the communication is successful, test passes, otherwise it will stop testing the board and will display the cause of error.

3.2.1.1.3 Reset Circuitry Test

This test is performed to check if this portion of the Ammo Controller card is working properly or not. To test it, a signal is given to the reset pin of the microcontroller and the status of all the pins are read. If the status of all the pins changes to high state, that will confirm the proper functionality of the Reset Circuitry on Ammo controller card.

3.2.1.1.4 Output Testing

This test is performed to test all the outputs of the board, that generated the signals, based on which the ammo display card works. Different signals are sent using CAN communication and status of all the pins are checked. If the controller reads the changing statuses of all the pins from high to low and low high, that shows the board is working completely fine, and the test passes.

3.2.2 Memory Board Test

The Memory Board is tested on the jig for to ensure its proper functionality. The detail about the testing of this Module Board is as follow.

3.2.2.1 Testing Sequence

3.2.2.1.1 Input Short Test

First test that is performed is input short test. As the test starts, it reads the input voltage using ADC, it reads both the input voltage as well as the output voltage of regulator. If there will be any shortage, the ADC will detect no voltage and the test will stop there displaying the cause of failure.

3.2.2.1.2 Can Communication Test

The next test is related to CAN Communication which is the main test of this controller board. All the information is received using this protocol. The test is performed by sending a heartbeat to the microcontroller present on the Ammo controller board, and in return the signals that are generated are read in the microcontroller of the jig. If the communication is successful, test passes, otherwise it will stop testing the board and will display the cause of error.

3.2.2.1.3 Button Test

This test is performed to check the proper functionality of all the buttons on the memory board that are used to select the three types of ammunition while replenishment i.e. AP, HA and HE. A signal is generated that act as a button signal, in return to which, memory board's controller generates signals that are read in an external microcontroller, on the basis of which, decision is made if the button section on the board is working properly or not.

3.2.2.1.4 Reset Circuitry Test

This test is performed to check if this portion of the Ammo Controller card is working properly or not. To test it, a signal is given to the reset pin of the microcontroller and the status of all the pins are read. If the status of all the pins changes to high state, that will confirm the proper functionality of the Reset Circuitry on Ammo controller card.

3.2.2.1.5 EEPROM Test

This test is performed to check if the EEPROM chip on the Memory controller board is working fine or not. First a random value is stored in the EEPROM (normally a virtual ammo is loaded in the magazine, that is done by saving a location in the EEPROM chip). Once the value has been stored in the EEPROM, the power to the microcontroller is cut off using a relay and after a small delay, power supply is again turn on. Upon powering up, the value that was being saved in the EEPROM is fetched and read in the external microcontroller using CAN communication protocol. If the value is still stored in the EEPROM chip that means the chip is working perfectly and the test is passed.

3.2.3 Flow Chart of AMMO Card Testing Code Sequence

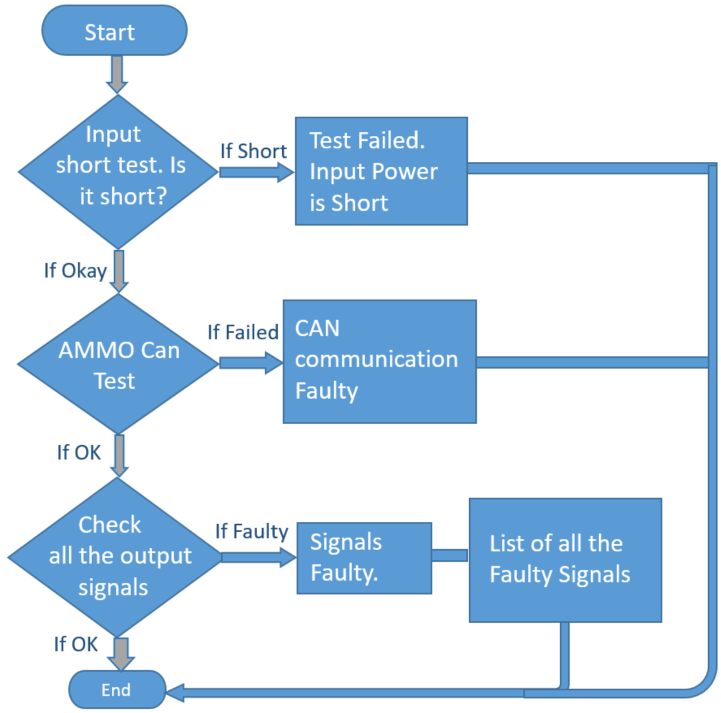

Figure 48: AMMO testing code sequence

3.2.4 Flow Chart of Memory Card Testing Code Sequence

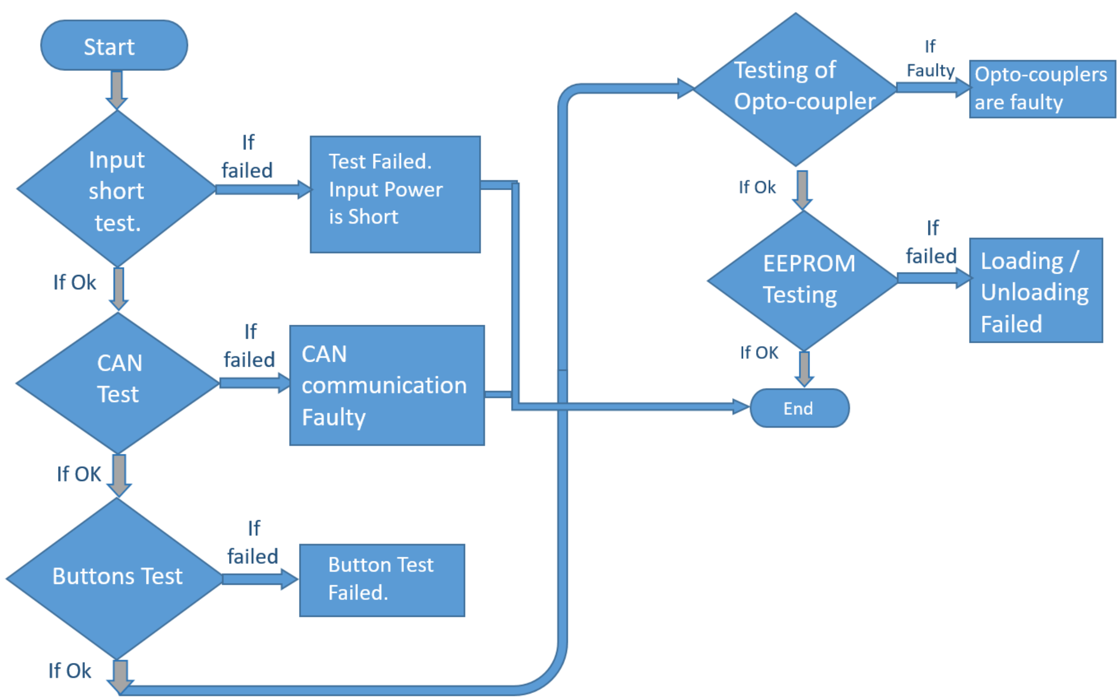

Figure 49: Memory Card Testing Code Sequence

3.2.5 Jig's Internal Layout

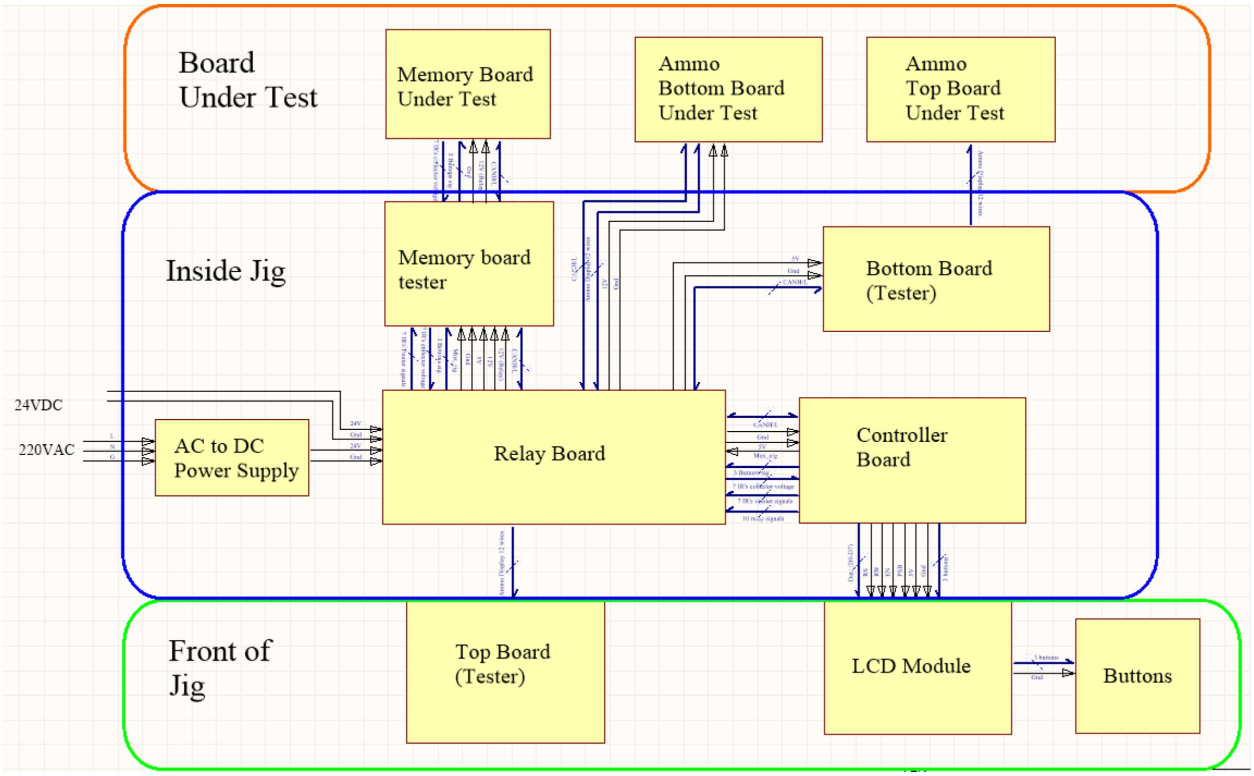

Figure 50: Jig's Internal Layout

3.3 CPU and I/O Testing Jig

CPU is the brain of the SSAL, which controls the whole Auto-Loading process by sensing and generating signals. It communicates with the other controllers used in other units through CAN Communication protocol and sends the messages and errors via Serial Communication. It consists of an arrangement of Micro-Controller and FPGA along with the external Flash. Each PPI has an Opto-isolator for signal voltage controlling and protection.

I/O board simply distributes and provides a path to transfer the input and output signals to the external six connectors of PD-Box Unit. Capacitors and Pull-up resistors are there to strengthen the signals so that it can easily travel through a long wire connections. There are almost 100 input/output signals that are controlled by the CPU.

3.3.1 CPU Testing Code Sequence

3.3.1.1 Input Short Test

First test that is performed is input short test. As the test starts, it reads the input voltage using ADC, it reads both the input voltage as well as the output voltage of regulator. If there will be any shortage, the ADC will detect no voltage and the test will stop there displaying the cause of failure.

3.3.1.2 CAN Test

The next test is related to CAN Communication which is the main test of this controller board. All the information is received using this protocol. The test is performed by sending a heartbeat to the microcontroller present on the Ammo controller board, and in return the signals that are generated are read in the microcontroller of the jig. If the communication is successful, test passes, otherwise it will stop testing the board and will display the cause of error.

3.3.1.3 Reset Circuitry Test

This test is performed to check if this portion of the Ammo Controller card is working properly or not. To test it, a signal is given to the reset pin of the microcontroller and the status of all the pins are read. If the status of all the pins changes to high state, that will confirm the proper functionality of the Reset Circuitry on Ammo controller card.

3.3.1.4 Inputs and Outputs Test

This test is performed to test all the outputs of the board, that generates the signals, based on which the ammo display card works. Different signals are sent using CAN communication and status of all the pins are checked. If the controller reads the changing statuses of all the pins from high to low and low high, that shows the board is working completely fine, and the test passes.

3.3.1.4.1 List of All the inputs

Table 13: Inputs of CPU Board

						INPUTS		
S.N.	INPUT	PPI	PORT	BIT	DIN CON	CPU FPGA PIN	TYPE	PURPOSE
1	F18	1	0	0	8B	P49	G/F	**Hoist lock sense, G for Unlocked, F for locked**
2	F15	1	0	1	8A	P56	28/F	**Hoist at Ground sense, 28 when at GND**
3	F10	1	0	2	9C	P45	28/F	**Hoist at REP position sense, F when at REP pos.**
4	F6	1	0	3	9B	P47	28/F	**Hoist at PROP position sense, F at PROP**
5	F44	1	0	4	9A	P46	28/F	**Hoist at PROJ position, F at PROJ posn.**
6	E19	1	0	5	10C	P43	28/F	**F when Gun is fully locked**
7	E21	1	0	6	10B	P42	28/F	**28 when locked**
8	E22	1	0	7	10A	P44	28/F	**28 when unlocked**
9	F36	1	1	0	5B	P68	G/F	**Magazine lock/unlock sensing**
10	F37	1	1	1	5C	P63	G/F	**Magazine lock/unlock sensing**
11	C12	1	1	2	4A	P73	G/F	**G if Spent case in sensing**
12	C8	1	1	3	4B	P70	G/F	**Shell Ejector Limit sensing**
13	C6	1	1	4	4C	P69	28/F	**Frame up sensing**
14	C3	1	1	5	3A	P75	28/F	**Frame down sensing**
15	F26	1	1	6	3B	P74	G/F	**Window open sensing**
16	F22	1	1	7	3C	P71	28/F	**Window close sensing**
17	F35	1	2	0	6A	P62	G/F	**Rammer position**
18	F43	1	2	1	6B	P60	G/F	**Rammer home sensing**
19	F8	1	2	2	6C	P61	G/F	**Rammer intermediate position.**
20	F12	1	2	3	5A	P64	G/F	**G all the way, F in retry region only**

21	C9	1	2	4	7C	P57	G/F	**Gun breach block sense, G when BBLK is open**
22	C10	1	2	5	7B	P59	G/F	**Gun Recoil sense**
23	A19	1	2	6	7A	P58	G/F	**Loading angle sense, G when at 4'30"**
24	D2	1	2	7	8C	P48	G/F	**Driver's Capula open sense**
25	B22	2	0	0	17B	P5	G/F	**Begin Dumping mode if G**
26	E12	2	0	1	17A	P18	28/F	**Case Auto/man switch sense, 28 if auto**
27	E7	2	0	2	18C	P15	G/F	**unload auto/man switch sense, F when at auto**
28	E8	2	0	3	18B	P3	28/F	**?**
29	E14	2	0	4	18A	P22	28/F	**Frame Down switch sense, 28 if pressed**
30	E17	2	0	5	19C	P11	28/F	**Frame Up switch sense, 28 if pressed**
31	E15	2	0	6	23C	P204	28/F	**Rammer back switch sense**
32	E29	2	0	7	19A	P16	G/F	**Rammer Fwd switch sense, G if pressed**
33	B13	2	1	0	14B	P30	28/F	**HA selector switch sense, 28 if at HA**
34		2	1	1	14C	P29	28/F	**AP selector switch sense, 28 if at AP**
35	B16	2	1	2	13A	P35	28/F	**HE selector switch sense, 28 if at HE**
36	B19	2	1	3	13B	P33	28/F	**REP selector switch sense, 28 if at REP**
37	E24	2	1	4	13C	P34	28/F	**Power sense , ELECTROMAGNET**
38	E25	2	1	5	12A	P40	28/F	**Power sense, ROUND SUPPLYING/RACK LIFTING/ACCESS OPENING**
39	E30	2	1	6	12B	P41	28/F	**Power sense, ROUND PUSHING**
40	E31	2	1	7	12C	P36	28/F	**Power sense, LIFT LOCKING**
41	E2	2	2	0	15A	P27	28/F	**F for Semi Auto mode, 28 in Auto mode**
42	E16	2	2	1	15B	P23	G/F	**Gun release switch sense, G if pressed**
43	A11	2	2	2	15C	P24	G/F	**connected with A11=A18 via mosfet**
44	B2	2	2	3	14A	P31	28/F	**Autoload button (ZcA1), 28 when pressed**
45	F9	2	2	4	16C	P17	28/F	**not used**
46	F23	2	2	5	16B	P20	28/F	**not used**
47	F5	2	2	6	16A	P21	28/F	**not used**
48	F13	2	2	7	17C	P4	28/F	**not used**
49	E24F	3	1	0	22A	P6		**Power sense input after fuse**
50	E25F	3	1	1	22B	P7		**Power sense input after fuse**
51	E30F	3	1	2	26C	P179		**Power sense input after fuse**
52	E31F	3	1	3	22C	P206		**Power sense input after fuse**

3.3.1.4.2 List of all the outputs

Table 14: Outputs of CPU Board

					OUTPUTS				
O/Ps	PPI#	PORT	BIT	TYPE	CONN	SOURCE	SIDE	BOARD	PURPOSE
B5	PPI4	0	0	LO 28/F	B5	A10		IO	**SPENT CASE INDICATOR LAMP**
E3	PPI4	0	1	LO 28/F	E3	A10		IO	**LOA READY LAMP**
E5	PPI4	0	2	LO G/F	E5	A10		IO	**CM STOP LAMP**
A2	PPI4	0	3	LO G/F	A2	A10		IO	**SIGNAL TO GCS**
A4	PPI4	0	4	LO G/F	A4	A10		IO	**SIGNAL TO GCS**
A6	PPI4	0	5	LO G/F	A6	A10		IO	**SIGNAL TO GCS**
A9	PPI4	0	6	LO 28/F	A9	A10		IO	**FIRE PERM. LAMP**
A8	PPI4	0	7	LO G/F	A8	A10		IO	**SIGNAL TO GCS**
A7	PPI4	1	0	LO G/F	A7	A10		IO	**CT1-7 IS CONNECTED TO CT1-19 VIA DIODE**
A18	PPI4	1	1	LO G/F	A18	A10		IO	**CT1-11=CT1-18 WHEN A18 IS 1**
MR2	PPI4	2	0	HI 28/F	F34	E30	BOTTOM	P3	**RAMMER BACKWARD FAST**
ENMR3	PPI4	2	1	HI G/F	F34	E30	BOTTOM	P3	**RAMMER FWD SLOW**
MG1	PPI4	2	4	HI 28/F	E26	E31	BOTTOM	P2	**GUN LOCK**
MG2	PPI4	2	5	HI 28/F	E27	E31	BOTTOM	P2	**GUN UNLOCK**
MF1	PPI5	0	0	HI 28/F	C13	E30	TOP	P1	**FRAME UP**
MF2	PPI5	0	1	HI 28/F	C14	E30	TOP	P1	**FRAME DOWN**
MW1	PPI5	0	2	HI 28/F	F19	E30	TOP	P1	**WINDOW OPEN**
MW2	PPI5	0	3	HI 28/F	F20	E30	TOP	P1	**WINDOW CLOSE**
SC1	PPI5	1	0	HI 28/F	F28	E24	BOTTOM	P5	**CAROUSAL SOLENOID BIG**
SC2	PPI5	1	1	HI 28/F	F29	E24	BOTTOM	P5	**CAROUSAL SOLENOID SMALL**
SH1	PPI5	1	2	HI 28/F	F16	E24	BOTTOM	P5	**HOIST SOLENOID BIG**
SH2	PPI5	1	3	HI 28/F	F17	E24	BOTTOM	P5	**HOIST SOLENOID SMALL**
SF1/SSE1	PPI5	1	4	HI 28/F	C11	E24	BOTTOM	P5	**SHELL EJECT SOLENOID**
ENMH3	PPI5	2	0	HI G/F	F4	E31	BOTTOM	P2	**HOIST UP SLOW**
ENMH4	PPI5	2	1	HI G/F	F3	E31	BOTTOM	P2	**HOIST DOWN SLOW**

3.3.1.5 EEPROM Test

This test is performed to check if the EEPROM chip on the Memory controller board is working fine or not. First a random value is stored in the EEPROM (normally a virtual ammo is loaded in the magazine, that is done by saving a location in the EEPROM chip). Once the value has been stored in the EEPROM, the power to the microcontroller is cut off using a relay and after a small delay, power supply is again turn on. Upon powering up, the value that was being saved in the EEPROM is fetched and read in the external microcontroller using CAN communication protocol. If the value is still stored in the EEPROM, it means the chip is working perfectly and the test is passed.

3.3.2 Flowchart of CPU Testing Code Sequence

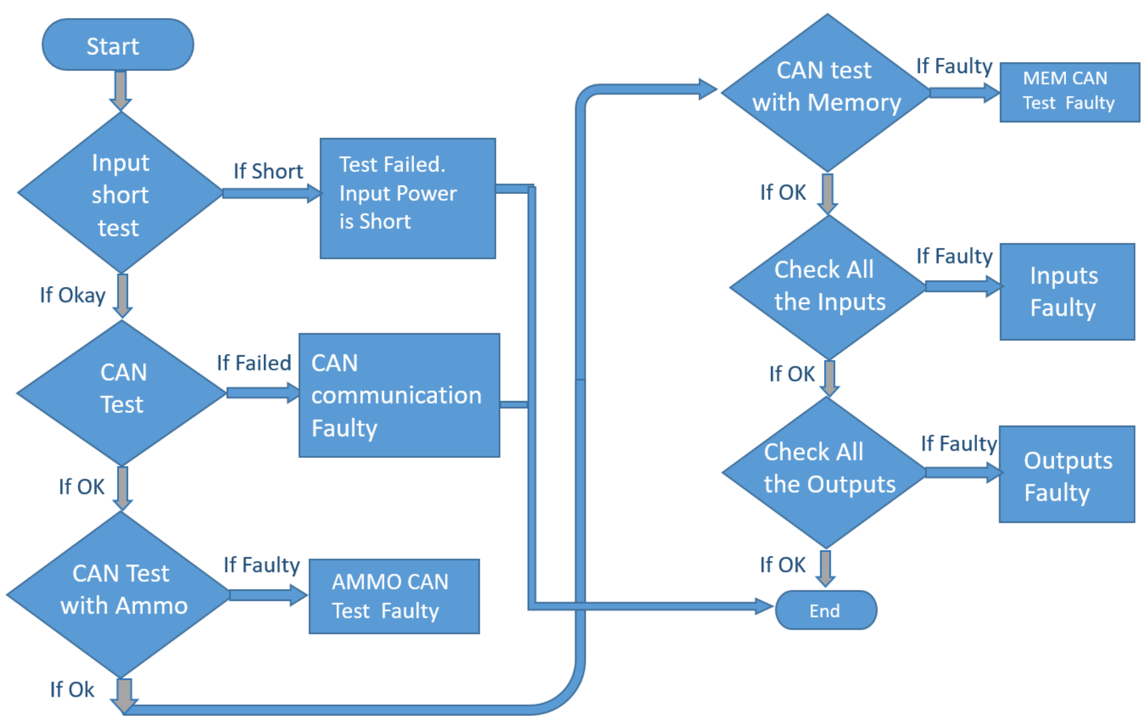

Figure 51: CPU Testing Code Sequence Flowchart

3.3.3 **I/O Testing Code Sequence**

3.3.3.1 Input Short Test

First test that is performed is input short test. As the test starts, it reads the input voltage using ADC, it reads both the input voltage as well as the output voltage of regulators. If there will be any shortage, the ADC will detect no voltage and the test will stop there displaying the cause of failure.

3.3.3.2 Inputs and Outputs Test

This test is performed to test all the outputs of the board, that generated the signals, based on which the ammo display card works. Different signals are sent using CAN communication and status of all the pins are checked. If the controller reads the changing statuses of all the pins from high to low and low high, that shows the board is working completely fine, and the test passes.

3.3.4 **Jig's Layout**

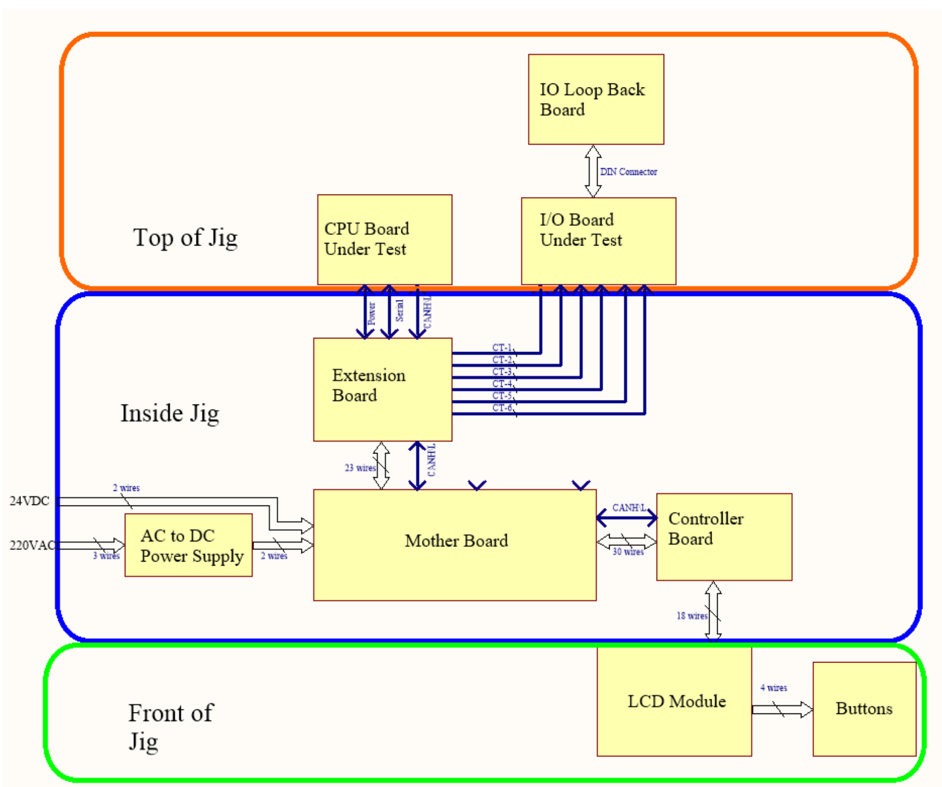

Figure 52: Jig's Layout

Chapter 4: Mechanical Design

4.1 Generic Mechanical Model of Jigs

The mechanical Jigs are designed in such a way that the structure should be modular as it has to be used on field. The structure is solid/rigid that it can be used under rough conditions. The designing is done according to the requirement that all the electronic circuitry can easily fit inside the mechanical box, all the PCBs can easily be placed on the top of jigs. For that purpose, special mounting according the Module boards are designed and fixed on the top of the Jig so that there can be no shortage of Module boards with the body of jig as well as the planning of wiring is kept easy. The front is designed keeping in mind the user experience.

The design is made in such a way that the user interaction is not an issue. There are 3 selection buttons in the front right side of the jig. Two buttons are used for up and down movement of cursor and one button is dedicated for the selection. Along with the buttons there is display module of 128x64 pixels for clear view. All the menu, test selection, and results are displayed on the Display Module. There is also a small button for resetting the Jig. On the left side, there is triple pole double throw toggle switch that is used to power up the Jig. Any person who is not familiar can use the Jig using the simplified interface.

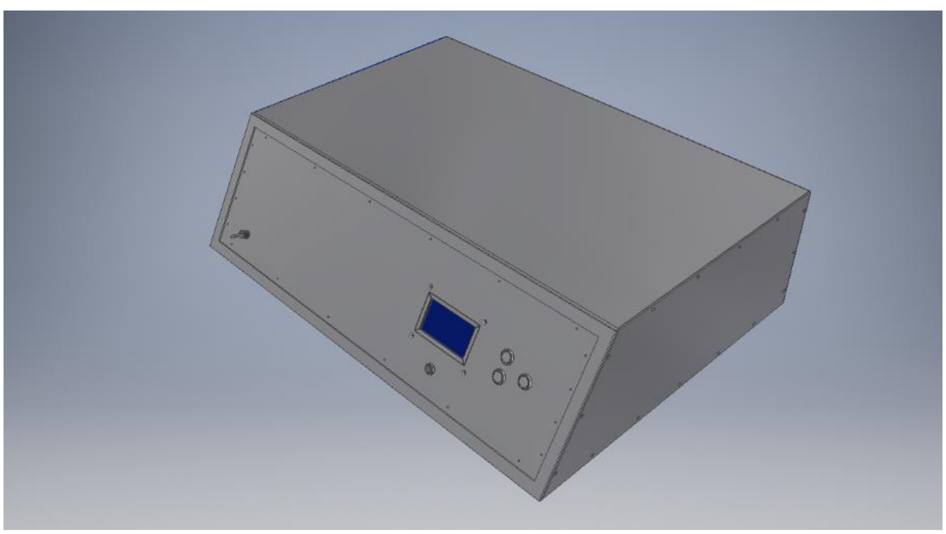

Figure 53: Generic Mechanical Model of Jig

4.1.1 Power Drive and Power Supply Module Test Jig

The Model is designed in such a way that the wiring connections is not an issue for the user. On the top left side, there is the mounting for Power Drive Module Board. There are wiring terminals around the mountings for the connections of Module Board. On the Top right side, there is mounting for Power Supply Module Board along with the DB-Connector on the top of it. The jig body is isolated from any kind of connection i.e. Body is kept non-grounded to eliminate any chances of shortage with the Module Boards.

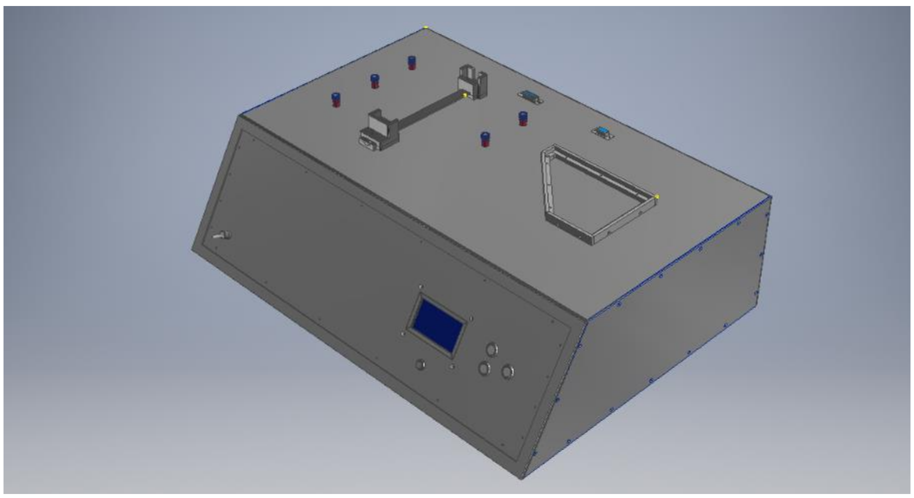

Figure 54: Mechanical Design of Power Drive Module Board Test Jig

4.1.2 Ammo and Memory Boards Test Jig

In this mechanical model of the Jig, for all the three Module boards placing mechanisms is on the top side of the jig. On the right most side, there is mounting for Ammo Controller Card along with the DB-15 Connector for the wiring connection. On the middle side, there is mounting dedicated to the Ammo Display Card along with the three row DB-15 Connector for the wiring connections.

On the left side, there is a sliding mechanism for the Memory Module Board. The Sliding mechanism consists of a housing that contains an ‘Opto-coupler Tester Board’ fit inside that is used to test the Memory Module Board. The Board under test goes inside the housing in a sliding manner and the rest of the test is done automatically after selecting the test form the menu. At the back side, there are two connectors for powering up the Jig. One is a two pin connector for DC-

Input and the other one is three pin connector for AC-Input. The jig can be powered up using both AC and DC power supply.

On the front side, there is toggle switch for turning the jig on and off, a LCD module along with the three push button to control the menu on the LCD module and a small push button just for the resetting purpose.

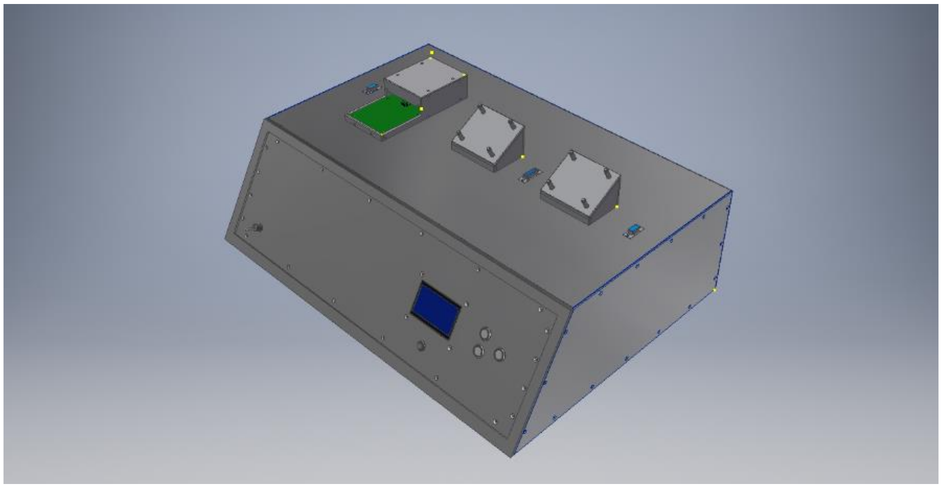

Figure 55: Mechanical Design of Ammo and Memory Cards Test Jig

4.1.3 CPU and I/O Test Jig

In this mechanical model of the Jig, for all the three Module boards placing mechanisms is on the top side of the jig. On the top left side there is a mounting for CPU board. It fits on CPU Loop back board using DIN connector, and that CPU loopback board is fitted inside the jig. And on the top right side, there is a mounting for I/O board, around which there are all the ribbon cable connectors for making the connection with IO board. The user just have to connect the IDC cable connectors to IO board and select the test from the menu, rest of the test will be performed autonomously.

At the back side, there are two connectors for powering up the Jig. One is a two pin connector for DC-Input and the other one is three pin connector for AC-Input. The jig can be powered up using both AC and DC power supply. On the front side, there is toggle switch for turning the jig on and off, LCD module along with the three push button to control the menu on the LCD module and a small push button just for the resetting purpose.

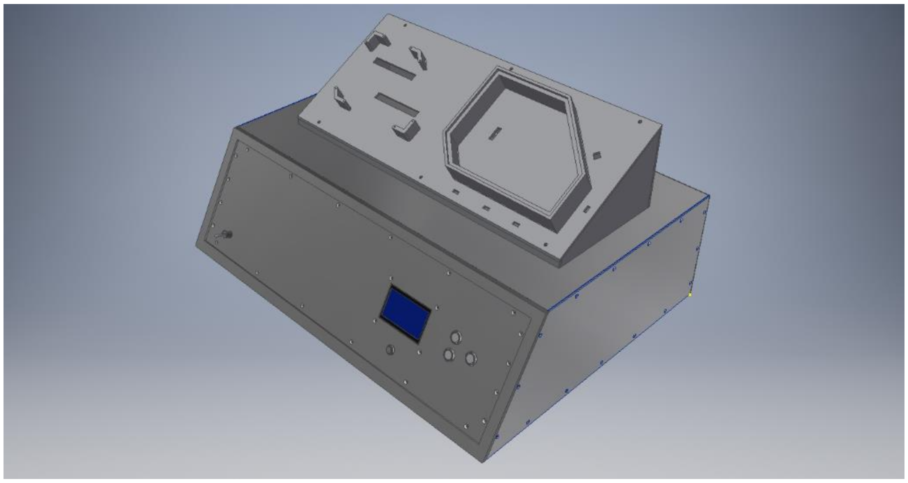

Figure 56: Mechanical Model of CPU and IO Testing Jig

Chapter 5: Results and Conclusion

A complete set of Autonomous Jigs dedicated to all the cards of Solid State Auto-loader has been designed. After the complete designing and testing of jigs, the result can be divided into different point.

1) The accuracy of the test has been increased to a greater extent as the Module Boards are tested on these jigs in depth. Each and every part of the Module Board is tested by the jig. Also there are no chances of false or wrong testing. Wrong signals can also damage the board. All the signals are generated through micro controller, so human errors are not possible. Wrong wiring protection and identification has also been added. If the user unintentionally makes any wrong wiring connection, the jig will automatically identify the wrong connection and will prevent from further damaging the board or the jig itself. So there are almost zero possibilities of wrong connection or giving wrong signals.
2) The testing time has been drastically reduced. Initially the board testing and troubleshooting could take from 20 to 30 minutes or more. Now after the development of the testing jigs, this time has been reduced up to 2-4 minutes. The micro controller has been used for testing the boards. It tests and takes the decisions in milliseconds, thus reducing the test time up to almost 95%.
3) The jigs points out all the faults whether they are related to the Input or the Output. Everything will be tested and displayed on the LCD Module at the front. So it will be easy to remove the faults from the boards.
4) Protection for the jig has also been added to avoid any damage to the Jigs. So if there is any issue with the board under test, that can damage the '*inside circuitry'* of the jig, the extra added protection will prevent the jig from getting damaged. There is shutting down feature in the jig that will shut down the power upon passage of high current or any kind of shortage.
5) These jigs can test all types of boards including T 85 UG, Al-Khalid and Al-Khalid 1 Tanks. No different setups are required to test different types of boards. The jigs will perform various tests in the start to ensure the type of Module Board to avoid any damage.
6) Boards are being tested on the jigs with the least intervention of any person, so the testing of the Module Boards has been made safer.

7) The jigs has been designed for the field purpose, so there might be the problem of the ‘No AC Connection’ on the field, as there are mostly DC voltages used. So to avoid this issue, the jigs has been designed in such a way that it can be run on both the 220VAC and 24VDC voltages.

Chapter 6: Goal and Future Work

6.1 Achieved

Initially, the goal was to design the testing jigs that can test all the Module Boards of Solid State Auto-Loader. For that purpose, three Indigenous Smart Testing Jigs have been designed for different Module boards. One Testing jig has been dedicated for the testing of all the Power Drive Module Boards and the Power Supply. This Jig has the ability to test the Module Boards on heavy load, as these Module Boards are used to drive heavy duty Motors and Solenoids. To test the circuitry, motors have been exchanged with heavy loads to ensure the proper working of Motor drivers. Same is the case with Power Supply Module Boards. Each output is tested using the amount of load that it can handle to ensure to proper working of each of its output. Second Jig is dedicated for the testing of Ammo and Memory Unit Board. In testing of Ammo Board, each and every signal that is used for running the Display Module Board, all the other sections including CAN communication, Input power etc. are tested thoroughly. While the testing of Memory card is done by testing both the emitters and collectors of all the Opto-couplers, the intensity of emitter. CAN Communication is also being tested for this board. The third jig is dedicated to the testing of CPU and IO board. All of the inputs and outputs (more than 100 IOs) are tested by generating signals and sensing the outputs. It also tests the CAN communication with the other two units i.e. Ammo and Memory Units. The results are displayed on LCD Display Module on the front after the completion of Test. All the errors are displayed that gives a proper guidance about the fault in the Module Boards.

All these jigs have been designed and tested completed. They have been inspected by the DGP (Army) and delivered to 609 Regional Workshop in Panoaqil, where they are being used on field by the army for the testing of faulty boards.

6.2 Future Upgradeability

These jigs have been designed in such a way that it can be upgraded in future. A lot of thought process and brain storming had been done to make these jigs easily upgradeable. All the modifications that are possible and can be required in future had already been thought of. There is room to make changes in the programming. The controller board that has been designed is generic.

There are already options for generating signals or extra sensing of signals. We can drive anything from these signals i.e. relays, ICs etc. We can sense digital signals, as well as analog signals. There are option for divider circuits for the purpose of sensing voltages. There is an option of CAN communication as well as Serial Communication in the controller. If anything is required that is not possible with the existing circuitry, post-designed circuits can also be added in the jig to make that task possible. All these additional features makes these jigs easily upgradeable.

Another feature has also been thought of, i.e. the debugging mode. This mode is useful for the troubleshooting and debugging of the boards under test. If their comes any fault in the Module boards, the jig will stop the testing at that point without turning off the driving signals, so that the debugging and troubleshooting can be done on Module Board.

Another future upgradability can be added of changing the loads in PDMB testing jig with the actual Motor that is being used in the tanks to drive the mechanical assemblies. By doing this the testing accuracy can be increased so much.

The size of the jigs can also be reduced for the better portability so that the jigs can easily be used in the field work. The design can also be modified in such a way that it can test the SSAL cards by simply connecting it with the tanks, i.e. the effort of taking the assemblies out of the tanks and Module cards out of the assemblies can be eliminated.

APPENDIX A

*The Code file is too large, so the files of code has been copied in the CD attached at the back of thesis.

REFERENCES

[1] AH Sharoni, LD Bacon; 1995, "Ammunition Loading Systems for Future Tanks", ARMOR.

[2] AH Sharoni, LD Bacon; 1987, "Automatic gun loading device for a tank", United States Patent (U.S. Patent No. 4,640,181).

[3] J Metz, M Pehker, E Zielinski; 1987, "Automatic loader For an Armored Vehicle Having a Rotatable turret", United States Patent (U.S. Patent No. 4,690,031).

[4] RJ Wyrembelski; 1999, "Display Implementation In The Abrams Main Battle Tank", Proc. SPIE 3690, Cockpit Displays VI: Displays for Defense Applications.

[5] JM Dabrowski, VP Daubar, RH Fryer, J Geraltowski, JR Underwood, RK Waid, JB Gilvydis; 1983, "Ammunition Storage And Transfer Mechanism", United States Patent (U.S. Patent No. 4,388,854).

[6] MD Golden; 1990, "Ammunition Magazine System", United States Patent (U.S. Patent No. 4,928,574).

[7] A Carlstedt; 2021, "Modelling Of Electromechanical Motors For Turret And Barrel Control In Main Battle Tanks", Royal Institute Of Technology School Of Engineering Sciences, Stockholm, 2021.

[8] J Balla, M Macko; Z Krist, CI Le; S. Timar, I. Kopecky; 2017, "Inserting Cartridges Using Electrically Powered Ramming Devices", 2017 International Conference on Military Technologies (ICMT).

[9] TY Chan, KK Young, C Hu; 1987, "A True Single-Transistor Oxide-Nitride-Oxide EEPROM Device", IEEE Electron Device Letters, Vol. Edl-8, No. 3.

[10] JH Escobar, J SachBe, S Ostendorff, HD Wuttke; 2012, "Automatic Generation Of An FPGA Based Embedded Test System For Printed Circuit Boards Testing", 13th Latin American Test Workshop (LATW)