Developing a multi-functional test stand

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degree of

**BACHELOR OF SCIENCE IN ELECTRICAL ENGINEERING**

by

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# DISCLAIMER

This thesis is submitted as partial and final fulfillment of the cooperative work experience requirements of Kettering University needed to obtain a Bachelor of Science in Electrical Engineering Degree.

The conclusions and opinions expressed in this thesis are those of the writer and do not necessarily represent the position of Kettering University or Magna Electronics, or any of its directors, officers, agents, or employees with respect to the matters discussed.

# PREFACE

This thesis represents the capstone of my five years combined academic work at Kettering University and job experience at Magna Electronics. Academic experiences in Kettering University proved to be valuable assets while I developed this thesis and addressed the problem it concerns.

Although this thesis represents the compilation of my own efforts, I would like to acknowledge and extend my sincere gratitude to the following persons for their valuable time and assistance, without whom the completion of this thesis would not have been possible:

1. Mike Myers – Validation Engineer
2. Joe Borowitz – Validation Engineer
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5. Jeff Sparks – Senior Engineering Technician
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# INTRODUCTION

The life cycle of an automotive product has a number of distinct stages with a specific purpose and goal. The Process Validation Stage is the final stage of testing that a product must go through before it can be shipped to the customer. The goal for this stage is to ensure that the production process meets the quality standards determined by the customer and that the product can endure several tests designed to expose the product to various environmental conditions. These conditions can have devastating effects on the life span of the product and functionality. The majority of this document pertains to the Deployable Running Board(DRB) controller produced by Magna Electronics and the preparation involved to accomplish this environmental testing in a timely manner. Figure 1 shows the base concept behind the DRB and its intended purpose. The module is supposed to receive a command when the door of the vehicle is opened and extend the armature allowing the user to step onto the running board.

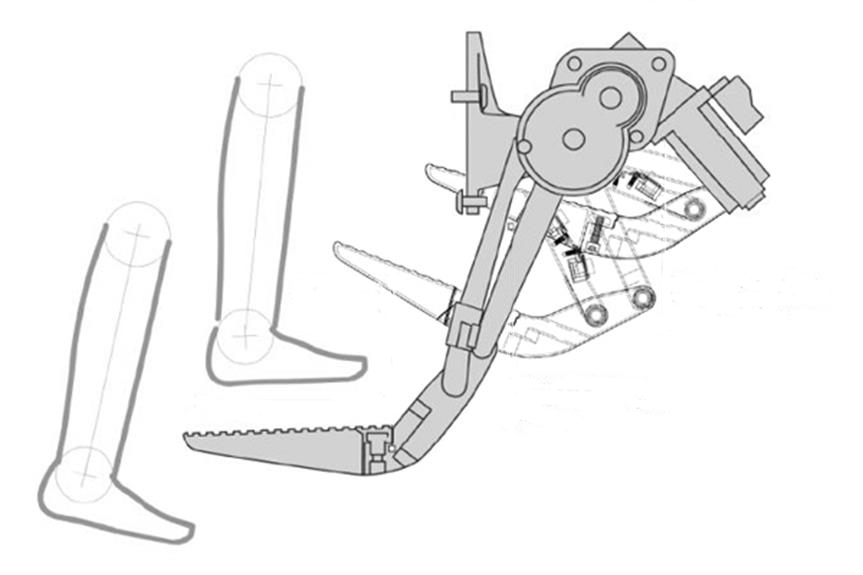


Figure : Deployable Running Board Diagram

## Problem Topic

The electrical test stands for the Deployable Running Board (DRB) Program do not have the capability to complete environmental testing within the desired timeline. A delay in the testing timeline due to the outdated test stands will increase the overall cost of the environmental testing and decrease product profitability.

## Background

In the first quarter of 2013, Magna Electronics restructured the company into two different engineering divisions. The choice was also made to split products between these two divisions with the first division acquiring the most lucrative product and the second division acquiring the rest. As a result, this product split would require the DRB program to be manufactured in a different facility and qualifies as a change in the manufacturing process. A re-validation would be required by the customers before they will accept the finished products.

The existing test stands have limited functionality and capacity that will not meet the required timeline to reduce unnecessary costs. The functionality of one stand can test one part type out of five and the other can test two out of five. Only 60% of the part types are covered between the two stands. Figure 2 shows a graphical representation of the current configuration versus the desired configuration that was pre-determined by the Validation Engineering Manager. The capacity of each stand is limited to eight modules simultaneously but some tests require 18 modules to be operated during tests. The current setup would require the tests to be run three separate times to satisfy the requirements. The two test stands must be re-designed to accommodate the improved functionality and increased capacity to meet the criteria that is needed to complete the environmental testing in a timely manner.

GMT900 & K2XX (GM)

8 Modules

Ford  
JLR

8 Modules

Test Stand 1

Test Stand 2

Existing Configuration

Desired Configuration

GMT900 K2XX

Ford

JLR

Toyota

9 Modules

GMT900  
K2XX  
Ford  
JLR

Toyota

9 Modules

Test Stand 1

Test Stand 2

Figure : Comparison of what exists and what is needed

## Criteria and Parameter Restrictions

* Add supporting architecture to cover 100% of all DRB module types to include the following major customers:

Ford

General Motors

K2XX Platform

GMT900 Platform

Jaguar Land Rover (JLR)

Toyota

* Increase capacity from 8 modules per test stand to 9 modules per test stand
* Minimize cost of re-design to keep within $15,000 budget

## Methodology

The limitation of resources and time required a systematic approach to problem solving that was vital to the success of the project. The systematic approach in this case involved understanding the function of an existing test stand instead of designing and building from scratch. The following approach was used to complete the project:

1. Understand how the existing test stands function to apply concepts on new design
   1. Shadow the lead engineer to understand the interaction between the module and test stand
   2. Convert existing documentation into a user friendly format to get an insight on the existing construction
   3. Examine existing test stands to understand the wiring, layout, and test function
2. Understand the module functionality to discern testing principle
   1. Examine module schematics to secure a list of all inputs and outputs to be tested
   2. Meet with software lead to understand normal operation of each module type
   3. Contact lead electrical designer to gather load characteristics and simulate real world application
3. Gather specific upgrade criteria developed by Validation Manager to avoid deviation from final goal
4. Research implementation options to expand capability and capacity of test stands
   1. Meet senior Validation Engineers to accumulate possible COTS(Commercial Off The Shelf) solutions
   2. Determine serviceability of parts from existing test stand to remain within budget
5. Develop purchasing list and total cost to evaluate budgeting concerns
   1. Compare and contrast cost solutions that meet upgrade specifications to single out   
      best solution
   2. Construct a BOM(Bill of Materials) and vendor quotes to achieve exact cost of upgrades
   3. Submit a PO(Purchase Order) to be approved by the Validation Manager and the Program Manager
6. Re-design layout of test stands to accommodate chosen method of implementation
   1. Cross reference inputs and outputs of all module types to compose common interfaces to the test stand
   2. Reconfigure wiring and layout to contain upgrades while improving accessibility for maintenance
   3. Construct pin map for the Validation Software Engineer to avoid delays in software completion date
7. Begin constructing new test stands to allow time for confidence testing
   1. Submit ESR(Engineering Service Request) to acquire needed technicians
   2. Update new and accurate documentation to facilitate readability and expandability
8. Begin confidence testing of completed test stand to verify functionality
   1. Test each part location individually to avoid confusion on multiple failure modes
   2. Fix failure modes as they appear to eliminate further complications
   3. Test all locations simultaneously to confirm increase of capacity
   4. Run mock testing to build confidence of overall design
   5. Make final adjustments to hardware or software if any issues surface during confidence testing
9. Duplicate the fully functional and fully tested stand and complete confidence testing
10. Begin Environmental Testing

## Overview

# TEST STAND DEVELOPMENT

Developing a test stand in most conditions involves the understanding of the module under test but in this case it also required a deep understanding of the existing test stands. The nature of this project had an added effort at every stage with extra variables. The first step was to gather all the known resources for the project to recognize any limitations set by the resources available. The next part is creating a high level architecture that can satisfy all the requirements and provide a guide for stand construction. The final step was to construct and test the stands to ensure that they had been assembled correctly and that all defects are found and fixed.

## Gather Resources

The first step of this project was to gather all the resources associated with the test stands and the DRB modules to include hardware, documentation, and people. These resources were critical to understanding how the stands were assembled, how they interfaced with the module and what limitations would translate into a design constraint.

The hardware was the resource that proved to be the least difficult to acquire and included the original test stands that functioned enough to complete the previous environmental testing. The testing was not accomplished in an efficient manner because the test cycles needed to be ran three times due to the limited capability of the test stands. Since the budget for this upgrade was so limited, the upgrade of the two stands would require the reuse of many of the components used in the old stands. Figure 3 shows the original stand and load rack that was analyzed for component content and circuit structure. The hardware of the module provided an insight into the hardware interface of the test stand while the module software gave an insight into the capabilities of that hardware. The stand allowed us to get a characterization of the loading effects of the motors used in real world application.

|  |  |
| --- | --- |
| Test Stand | Load Rack |

Figure : Hardware Resources

The documentation proved to be the most difficult resource to gather and evaluate. The module schematics shown in Figure 4 were very straight forward and easily accessible. However, the test stand documentation was so inadequate that an experienced technician could not understand the basic assembly of the electrical interface between the module and the stand. Part of this documentation is shown in Figure 4 and shows insufficient detail of the main electrical interface to the module. The severe confusion of this documentation led to the rejection of it as a possible resource. Contrary to this, the module documentation demonstrated to be an extremely useful resource for architecture development and signal consolidation.

|  |  |
| --- | --- |
| Test Stand Documentation | Module Schematics |

Figure : Document Resources

The best resource available was the engineers that built the stand. Unfortunately, the validation hardware engineer was “let go” shortly after the beginning of this project but the validation software engineer was still available as a primary resource. The first challenge for this project was to comprehend how the stand interacted with the modules under test and the validation software engineer was able to fulfill this need. This was the engineer that wrote the software that currently existed on the stand. This meant that he knew exactly how all of the tests operated and what signals needed to be measured.

The collection of all resources and insights provided a clearer understanding of how the stand functioned and interacted with the modules. Although there was an obvious shortfall to the adequacy of the hardware and documentation, the Validation Software Engineer proved to be the single greatest asset and allowed us to approach the system level architecture from a near clean state.

## Test Stand Layout

The most important part of the entire project was having a concise and cohesive architecture to reference. Without a good architecture, the development and construction of the stand would have delays from last minute design changes. This could have a detrimental effect on the main goal of the project and delay completion of the testing. The consolidation of common signals would facilitate a concise architecture concept that can be realized through the construction of the stand and validated through confidence testing.

#### Consolidate Signals

The signal differences between the variants were very few but the previous version of test stand had a different pin layout for each variant. This means that the stand was using more pins than necessary and could easily be consolidated to using the same pin for the same functions. Figure 5 shows a comparison between the different variants and is easy to distinguish what signals are common and which are unique. This reduced the number of unique harness pin layouts needed to test all modules from four to two. During the consolidation of these signals it was discovered that the LED signals from the JLR and Ford module were not being monitored or tested. This required a further addition of circuitry and functionality to the architecture.

|  |  |
| --- | --- |
| Ford | JLR |
| GM – K2XX | Toyota |

Figure : Signal Comparison

The CAN (Controller Area Network) configuration also limited the testing capability and required an upgrade to accommodate production level software. In short, only one module could communicate through CAN at one time because they all shared the same identification frame. To accommodate the switching between communication modes as well as switching between modules, the concept of a switch matrix was introduced and investigated as a viable option. The switch matrix allowed the communication lines to be switch in and out as needed during the testing. Figure 6 shows how the matrix card works by connecting and disconnecting nodes. This allowed us to route all the communication signals to a common pin and reduce the variations in harness wiring.

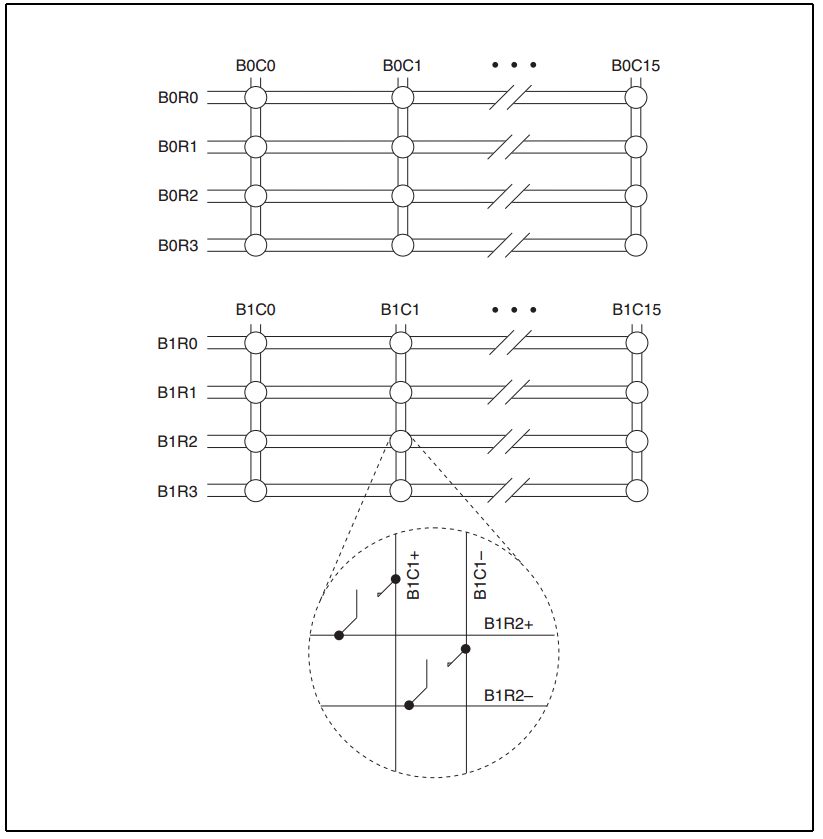


Figure : Switch Matrix Card Concept

#### Conceptualize Architecture

Once the signals were consolidated, the overall architecture of the stand needed to be developed. A high level architecture was imagined in Figure 7 and served as the primary reference for the test stand layout. The functional sections of this architecture was developed separately as the documentation shows in Figure 8 and then optimized for space and maintenance.



Figure : Test Stand Architecture

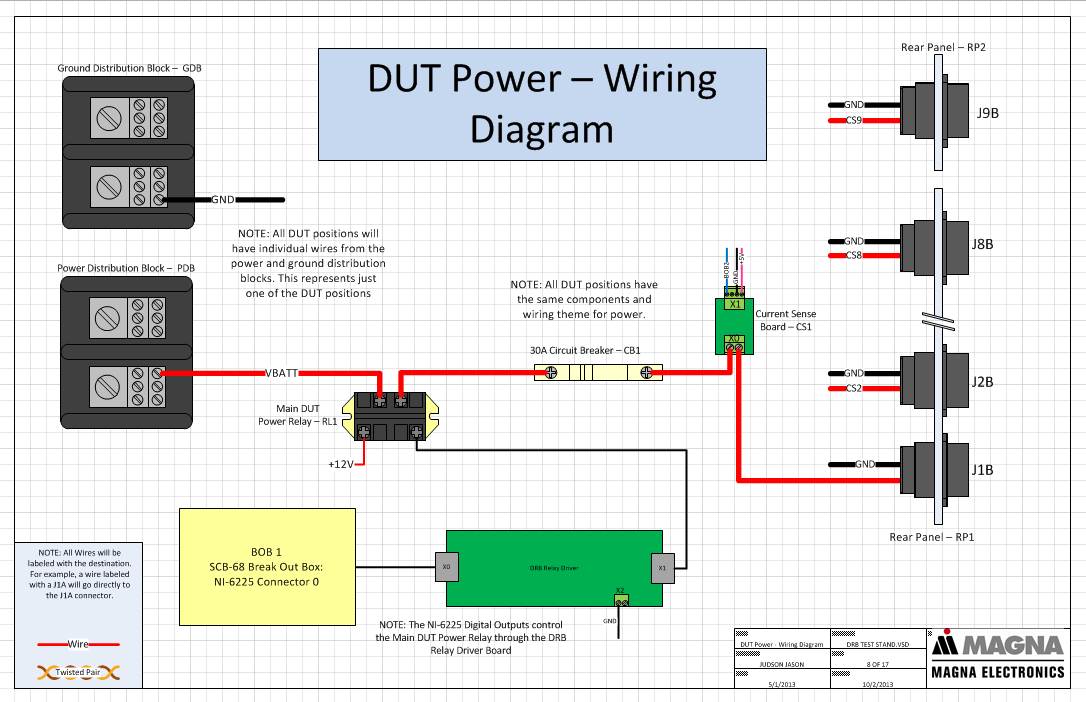


Figure : New Documentation

## Assembly and Confidence Testing

The assembly of the test stand was the most uncomplicated part of the entire project. At this point, the only thing required was to follow the layout given in the documentation and spend the time to assemble the components. Before any action was taken, a complete list of needed components was ordered and can be referenced in Table 1 which is a complete cost analysis. Once the parts were received the old stands were completely dismantled to ensure a complete rebuild and avoid the temptation to take a shortcut. The entire assembly (Figure 9) took about two weeks for both stands and required the assistance of three technicians.

About a week afterward the confidence testing in Figure 10 was completed with minor delays. The structured approach to testing all combinations of modules, loads, and harnesses allowed the management of one issue at a time and advocates a quicker solution.

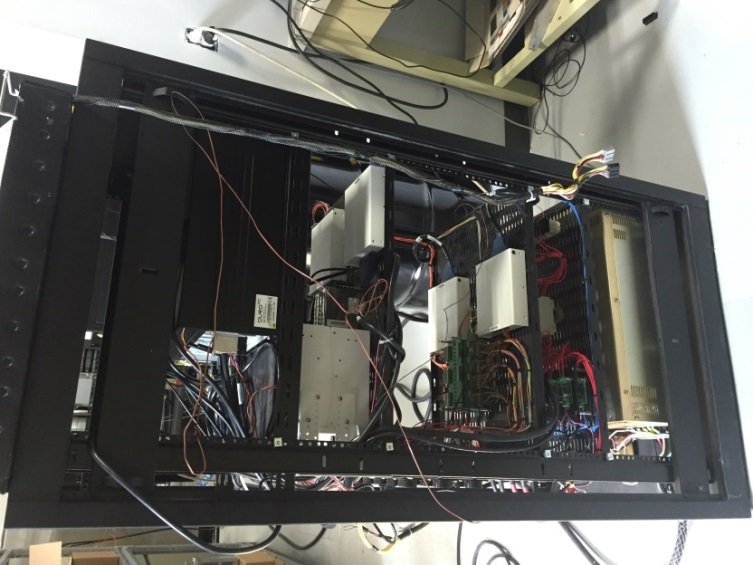


Figure : Completed Test Stand Assembly



Figure : Confidence Test Plan

# MODULE TESTING

The process for any type of testing that is required by a customer involves a “test plan” that defines the tests to be accomplished, quantity to be tested, and the criteria for customer acceptance.

## Test Plan

For this particular project, a modified test plan was generated to reduce cost and time invested. Figure 11 shows the modified test plan for General Motors K2XX platform and a very similar approach was taken towards all other variants of the module. During the test plan development, it was discovered that a couple variants would cost more money than expected to complete the testing so changes were made and those variants were no longer included in the line move.

The Toyota variant was going to require four months of thermal shock testing to satisfy the customer specifications. This requirement would have extended the total testing time by almost 6 weeks which was unacceptable to meet the planned timing. The cost for this testing was estimated in the range of $18,000. The management team decided to eliminate the line move for this variant and keep the production in its current setup.



Figure : GM K2XX Test Plan

## Test Results

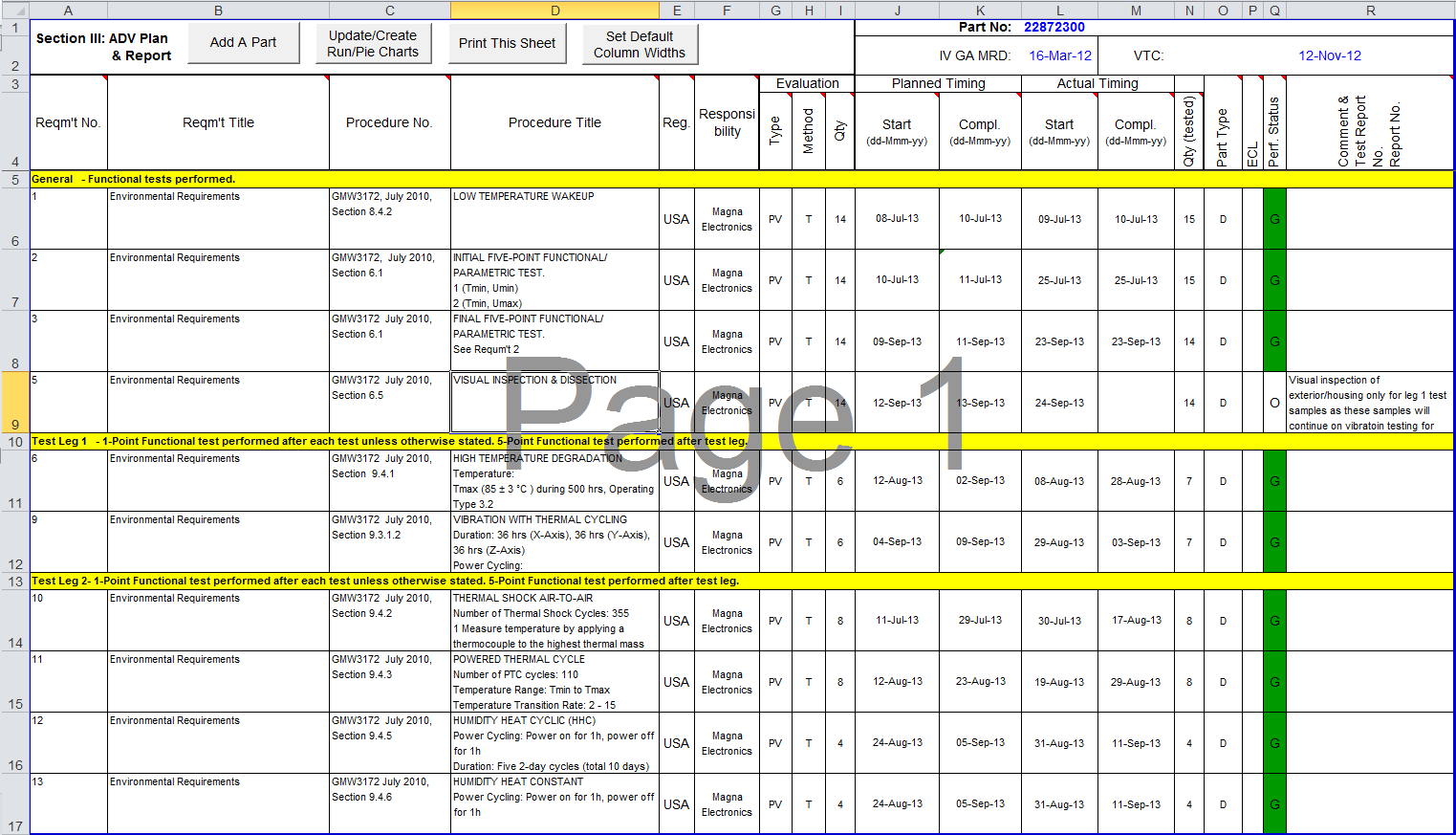


Figure : GM K2XX Test Tracking Results

# CONCLUSIONS AND RECOMMENDATIONS

The main concern with the DRB program was the ability to complete a plant transfer in a timely manner. Because of underperforming test stands with limited capabilities the aggressive timing could not be met. The goal of this project was to upgrade the test stand while taking the opportunity to expand the functionality. Through the course of this project many changes were made to the original plan but the end design still allowed for greater flexibility and expandability.

The recommendations provided are idealistic in nature with the viewpoint that a design is done once and reused multiple times. These designs have a very large upfront cost in both money and time but will save money due to the reduction of the total resources needed to accomplish the same set of tasks.

## Conclusions

#### Supported Variants

* The new test stand can support all module types with the exception of the Toyota variant.
  + The stand has been rigorously tested for all module types by the Validation Team.
  + The stands have also completed validation testing that will be sent to multiple customers (FORD, JLR, GMT900, K2XX)

#### Module Capacity

* The stand is also fully capable of testing nine modules simultaneously as opposed to its previous capability of eight
  + The stand has been rigorously tested for all part locations by the Validation Team. Further proof can be seen in Appendix B
  + The stand has completed all of the environmental testing and has reduced the number of test cycles needed by 30%

#### Budget Criteria

* The entire project was just barely over the $15,000 budget completed testing before the target completion date of October 20, 2013.
  + The total dollar amount spent was $717.27 over budget *See Table 1*
  + The environmental testing completed the last test on October 08, 2013

Table 1: Hardware Cost Analysis

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Manufacturer Part#:** | **Description:** | **Quantity:** | **Unit Cost:** | **Total:** |
| 778739-01 | NI PXI-2529 | 2 | $2,240.00 | $4,480.00 |
| 196762-01 | NI TB-2636 | 2 | $287.00 | $574.00 |
| 779630-01 | NI PXI-6229 | 1 | $1,015.00 | $1,015.00 |
| 779756-01 | NI PXI-1033 Chassis | 2 | $1,139.00 | $2,278.00 |
| 778948-01 | PXI-103x and PXIe-107x Rack Mount Kit | 2 | $170.00 | $340.00 |
| 192061-02 | SHC68-68-EPM Shielded Cable | 4 | $139.00 | $556.00 |
| 778933-01 | PXI Filler Panel | 2 | $52.00 | $104.00 |
| 206226-1 | 500 Ohm Metal Film Resistor | 100 | $0.13 | $13.10 |
| HSMS-2822-BLKG | 15V Schottky Diode | 50 | $0.64 | $32.15 |
| 206837-1 | 24 pin Amphenol Connector | 50 | $4.30 | $215.00 |
| 206226-1 | 7 pin Amphenol Connector | 50 | $4.75 | $237.50 |
| 206227-1 | 7 pin Amphenol Panel Connector | 3 | $5.23 | $15.69 |
| 206838-1 | 24 pin Amphenol Panel Connector | 5 | $4.79 | $23.95 |
| 211825-1 | 13 pin Amphenol Panel Connector | 10 | $8.83 | $88.30 |
| PA-1102-BT | 2 Rack Unit Panel | 2 | $18.20 | $36.40 |
| G7L-1A-BUB-J-CB-DC12 | Omron 12VDC 30A Relay | 1 | $18.43 | $18.43 |
| HWS30-5/A | TDK Lambda 5V 6A Power Supply | 1 | $54.54 | $54.54 |
| HWS30-12/A | TDK Lambda 12V 2.5A Power Supply | 1 | $54.54 | $54.54 |
| 47065T167 | Aluminum Extrusion 1.5" x 3" | 4 | $67.30 | $269.20 |
| 47065T16 | End Cap for 3" Aluminum Extrusion | 6 | $1.80 | $10.80 |
| 2834T34 | 3" Rubber Wheel Caster | 4 | $10.65 | $42.60 |
| 47065T19 | Aluminum Extrusion 90 Degree Bracket | 12 | $6.94 | $83.28 |
| 8975K238 | Aluminum Extrusion 1" x 2" | 2 | $45.39 | $90.78 |
|  | Wire |  |  | $1,831.29 |
|  | Crimp Tool | 1 |  | $1,425.00 |
|  | Wire |  |  | $1,827.72 |
| **Total** |  |  |  | **$15,717.27** |

## Recommendations

The following section includes two recommendations of two very different natures. The first being a compulsory change to the stands electrical measurement circuitry and the second is more of an idealistic proposal to the future design of test stands in general. In either case further detail for both recommendations will be discussed in APPENDIX A: RECOMMENDATIONS IN DETAIL

#### Redesign module interface circuitry

Design high impedance interface circuitry to reduce the effect of the monitoring circuits on the module operation.

**Benefits:**

* High impedance measurement circuits will reduce the effect that the test stand circuitry has on the module during operation
* The test stand interface circuitry will no longer be in question during troubleshooting activities

**Disadvantages:**

* The best solution will increase development cost by added components, retooling cost for PCB changes and extra labor
* The interface changes are not absolutely necessary to complete testing and may be considered a waste of time and resources.

#### Modularization of project specific hardware

Convert the current test stand development cycle into module based designs that interchange between test racks. Design modules to support standalone use as a portable load device. See *Appendix B* for detailed solutions.

**Benefits:**

* Designing to meet Validation and Electrical engineering needs reduces total engineering time and cost per project by having one design.
* Modular designs are easily interchangeable and permits module swapping that reduces down time.

**Disadvantages:**

* Meticulous cooperation between departments is critical to meet all needs
* Initial demand will be greater than the supply and will increases tension between departments
* Limited space for test module may not account for all inputs and outputs of tested devices which will require a second module developed

# REFERENCES

# GLOSSARY

# APPENDICES

## APPENDIX A

### RECOMMENDATIONS IN DETAIL

The intended purpose for this section is to expand on the recommendations outlined previously and give some specific examples on how to implement the ideas.

##### Interface Circuitry

The first week of testing revealed some intermittent issue with the DRB module where the module would not deploy the load. Looking back at Figure 1 you can see that the deployed position is when the running board is in place. This non-deploy issue started an investigation into the test stand and module. It was during this investigation that the team discovered the effect of the test stand interface with the operation of the module during a load detection phase.

The module will try to detect a load before trying to deploy or stow. The investigation of a non-deploy resulted in Figure 12 that shows a difference in voltage during the open load detection phase of the motor start-up. The two signals are the same module during a command to deploy. The difference between the two overlapping signals is the test stand. One signal has the test stand measurement circuitry connected while the other signal has the circuitry removed.

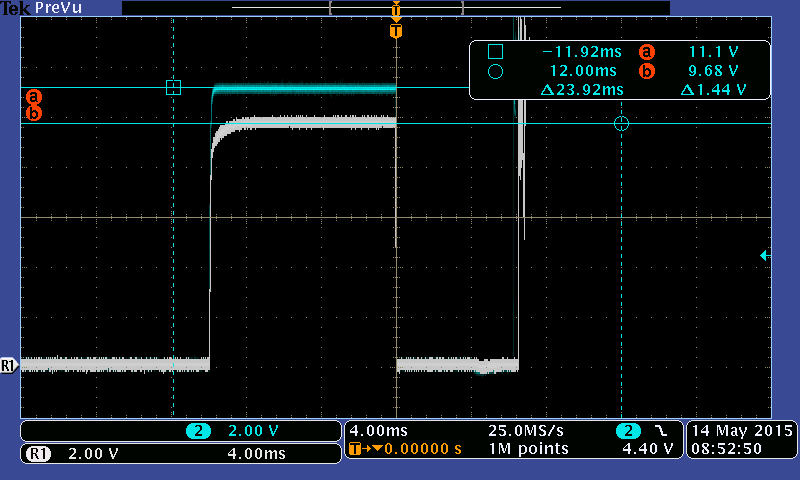


Figure 13: Open Load Detection Signal

Figure A- : Open Load Detection Signal

After examining the schematics and narrowing the circuit down to the key components for open load detection, an outline can be achieved and seen in Figure 13.

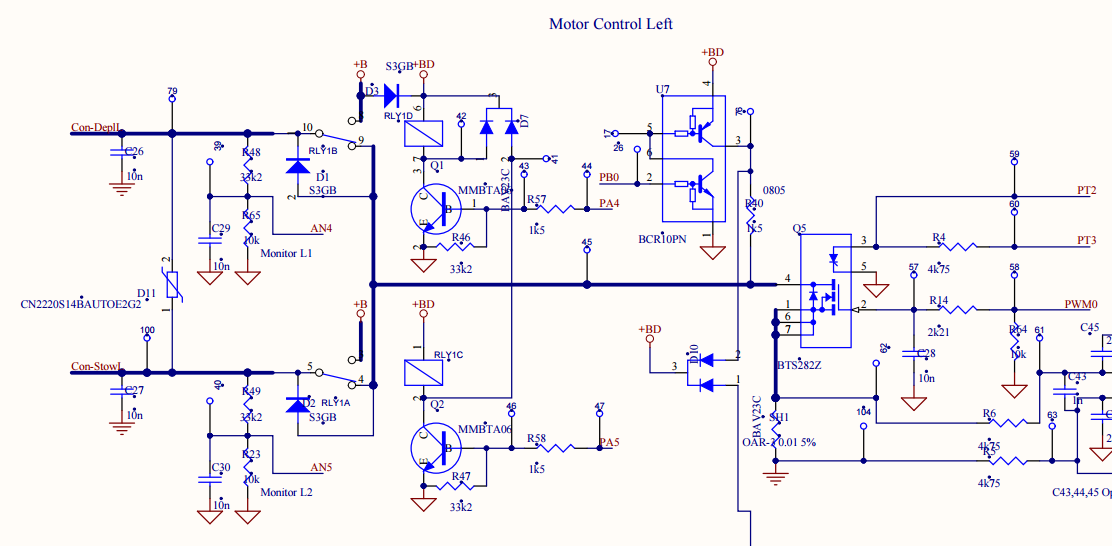


Figure 14: DRB Module Schematics, Open load detection circuitry outlined in red

A representative circuit can be developed, simplified, and segregated into the functional sections and expanded further to include the test stand circuits as shown in Figure 14.



Figure : DRB Controller with Test Stand Circuit

The test stand interface circuitry is low impedance and affects the measurement of the signals and may also affect the functionality of the DRB module. An analysis of one interface circuit, Deploy and Stow Signals, shows that given a worst case condition the voltage level seen by the test stand and the module will drop considerably. **Error! Reference source not found.** shows the conversion of the representative circuit into a condensed and simplified circuit to make it much easier to understand how the test stand circuit can affect measurements.



Figure : Interface Circuitry Analysis

Using the condensed circuit and assigning variables for the components we can get Equation (1) which is a simple voltage divider.

(1)

With some algebraic manipulation we can get to Equation (2) which will allow us to understand how to achieve a worst case tolerance stack-up.

(2)

Since the worst case is a minimum voltage and the relationship with the representative circuit is inversely proportional, the resistor values for R2 and R3 must be at the lowest limit while R1 must be at its highest tolerant limit.

(3)

Figure 12 shows the Deploy signal recorded with and without the test stand. It is easy to see the difference of voltage during the open load detection. The difference or Delta between the two signals during this phase is about 1.44V. It is important to note that the difference in voltage does not occur during the motor control portion of the signal. The reason for this is that portion in the DRB controller the does the open load detection has an extra resistor that can be seen in **Error! Reference source not found.**. This resistor is also referred to in **Error! Reference source not found.** as R1.

The next step was to try and duplicate the conditions that cause the voltage difference in a simulation and compare that simulation to the actual measured value. The representative circuit was duplicated using Cadence PSpice and most of the functional part can be seen in Figure 16.

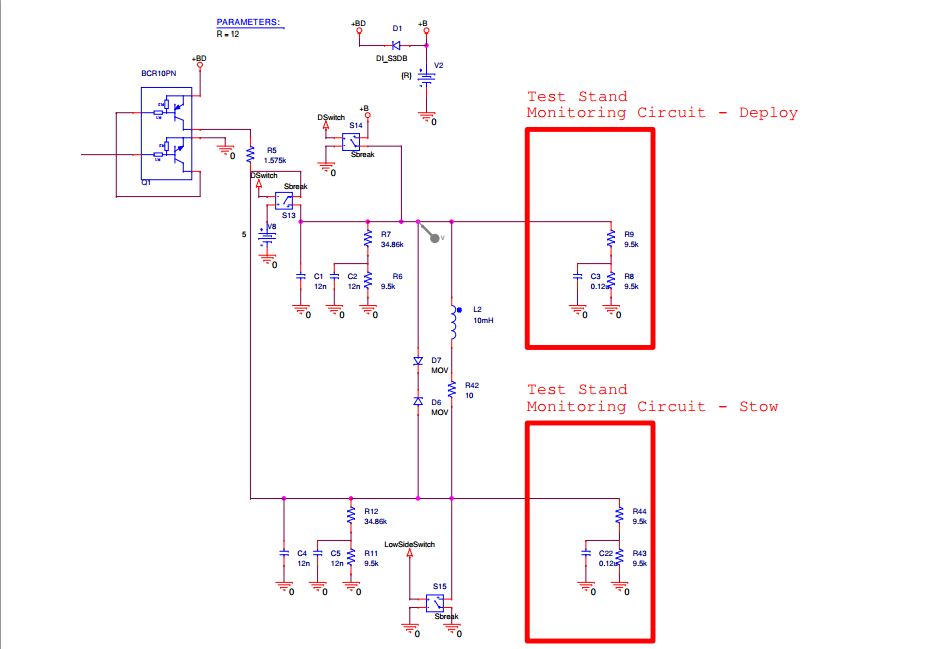


Figure 17: DRB Module Simulation Schematics, Test Stand Circuitry outlined in red

Deploy Voltage without monitoring circuitry

Deploy Voltage with monitoring circuitry

~1.446Vdc Δ

Deploy Voltage without monitoring circuitry

Deploy Voltage with monitoring circuitry

~1.44Vdc Δ

Figure : Scope Vs. Simulation

##### Modularizing Project Hardware



Figure : Modular Test Rack Concept

## APPENDIX B

### RELATIONSHIP TO ELECTRICAL ENGINEERING PROGRAM OUTCOMES

*Program Outcome a*. An ability to solve electrical engineering problems by applying knowledge of such fundamental and advanced mathematics as calculus, differential equations, linear algebra, probability and statistics, and science and engineering principles.

*Program Outcome b*. An ability to design and conduct experiments in electrical engineering, as well as to collect, analyze and interpret data to reach appropriate conclusions.

*Program Outcome c*. An ability to design an electrical system, component, or process to meet desired technical, environmental, safety and economical specifications.

This project met this outcome by requiring analysis of an already functioning system with the intent on upgrading the interaction from a system level and electrical interface level that could meet the economic needs of the project.

*Program Outcome d*. An ability to participate and contribute in multi-disciplinary team activities.

This project required interaction between multi-disciplinary team to understand the existing system. The electrical team helped understand the loading characteristics while the software team provided insight to product functionality. Ordering parts, requesting assistance from technicians, and running the tests also required the interaction with people of varying skillsets.

*Program Outcome e*. An ability to identify, formulate, and solve engineering problems.

*Program Outcome f*. An understanding of professional and ethical responsibility and the consequences of failing in it.

*Program Outcome g*. An ability to communicate effectively in both oral and written fashion.

*Program Outcome h*. The broad education necessary to understand the impact of engineering solutions in a global and societal context.

*Program Outcome i*. An appreciation for the need for, and preparedness to engage in life-long learning.

*Program Outcome j*. A knowledge of contemporary social, economical and political issues and their impact on engineering profession.

*Program Outcome k*. An ability and experience in using the techniques, skills, and modern engineering tools necessary for engineering practice.

*Program Outcome l*. A knowledge of computer science and computer engineering, and engineering sciences necessary to analyze and design systems containing hardware and software components.

#### Standardization of configurable hardware

Develop a standardized test stand that may be configured through software rather than building specific hardware for each module type.

**Benefits:**

* Development of a reconfigurable test stand saves weeks of time spent building a new test stand for each project
* Utilizing common reconfigurable hardware saves thousands of dollars spent purchasing separate hardware for each project
* Standardization of hardware design reduces troubleshooting complications and time due to intimate knowledge of test stand architecture

**Disadvantages:**

* Development reduces available assets needed by a critically manned department
* Development skillset requires additional training to introduce new circuit development techniques
* Introducing standard design practices requires directed participation that inhibits creative thinking