Development of Hammer Blow Test Device to Simulate Pyrotechnic Shock

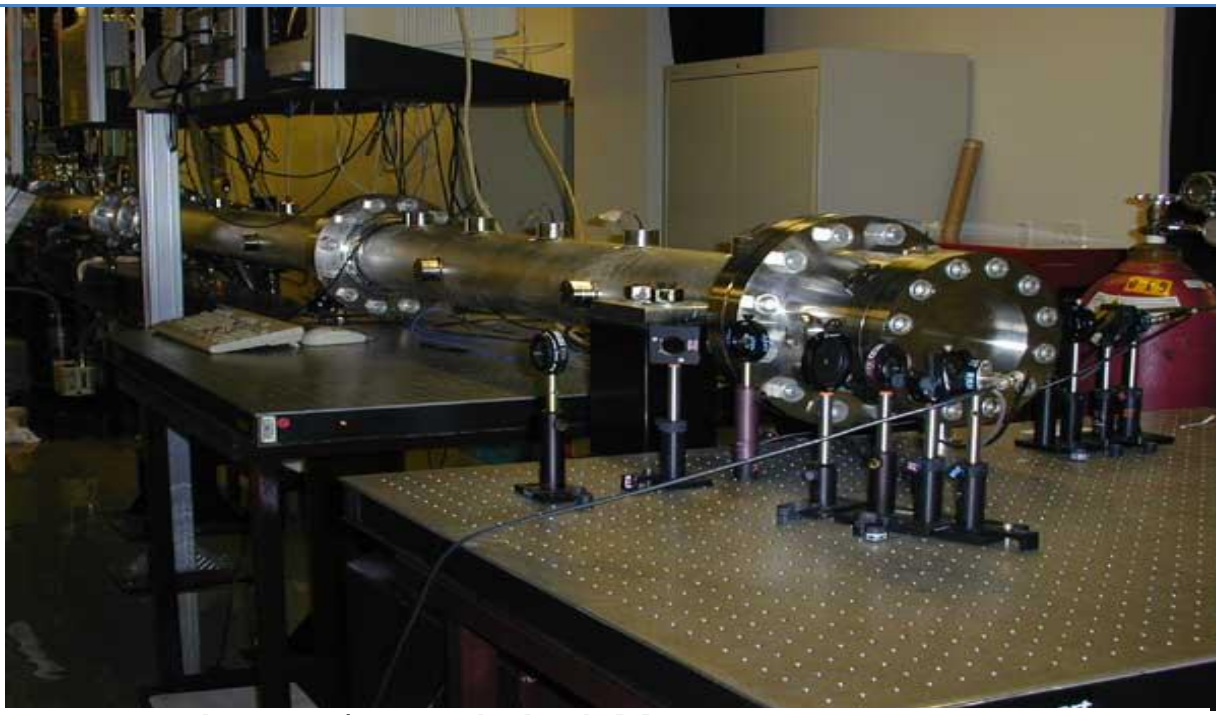

Figure 1- Optical Section of Kinetic Shock Tube[8]

Deliverable Name: Project Plan and Product Specification

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Abstract

A fundamental goal of this project is to facilitate the testing of electronic components subject to high frequency, high acceleration shock loadings. These shock loadings are often difficult to recreate in a test environment due to the complex acceleration time history of the pulse. For example, shock created by pyrotechnic charges for staging events in spacecraft . Since the shock time history is quite complex it is easier to describe how a structure responses to the pulse rather than to describe the shock motion. This response is captured in a Shock Response Spectrum (SRS) which plots the peak acceleration response of a large number of single degree of freedom systems excited by the pulse under an assumed damping. The primary hurdle in a test environment is then in generating a suitable shock response spectrum equivalent to that of the pyrotechnic shock. This project seeks to develop a standardized method of modeling and testing, in a reliable manner, electronic components to a specified pyrotechnic SRS shock. At the completion of the project a functional prototype as well as a tailored modeling system is expected. This plan provides a method of forward progress as well as the constraints on the project.

1 Introduction

The project for the development of a hammer blow test device to simulate pyrotechnic shock was brought to the university by the Harris Corporation. Pyrotechnic shock testing is used to determine the effect of shock on electronic equipment. This testing is done to verify that products can sustain any shock they may encounter during their life. Harris has brought this project forward due to the time and money lost by their current test procedures. Their desire is for development of test procedures and modeling methods to accurately replicate pyrotechnic shock loading. Ultimately, the end product will allow for a more precise test setup and elimination of trial and error methods used in the current test procedures. A schedule was developed for this deliverable as well as resource allocation and tentative time schedules. This serves to keep the project moving forward and progressing steadily.

2 Project Definition

2.1 Background research

Pyrotechnic induced shock can potentially be devastating to electronic equipment. Increasing use of pyrotechnics as a means for mechanical actuation warrants increasing need to validate the effects they have on system components. These shocks were often ignored, yet further work by Moneing has shown critical failures induced by pyrotechnic shock. [1] Mathematical and computational models have difficulty with the computational resources required. In particular the FEM analysis has difficulty modeling the high frequency characteristics of pyrotechnic shock. The requirement of a large number of tests has proven to be an inefficient method of modeling these shock responses. Computational methods often yield much more conservative results due to the sacrifice in processing power. [4]

Not only is this shock difficult to recreate in a testing situation, it is also difficult to model particularly as a function of time. Irvine recommends the use of the Shock Response Spectrum, or SRS, [3] to estimate the damage potential a shock may have. The SRS facilitates the analysis of shock on the component, rather than trying to analyze the extremely short duration, transient shock in the time domain. The SRS shows peak acceleration of a pre-determined series of natural frequencies that would be imparted by a certain shock. [3]

The rapid decay, transient nature, and extreme frequencies are difficult to simulate using a shaker to induce vibrations. Mechanical shock inputs such as pneumatic and hammer blow tests can yield optimal results, yet are time consuming in their tuning. [4] Additionally, the shock imparted often cannot be subjected directly to the component in testing, but through a mounting which could have substantially different mechanical properties thereby hindering the accuracy of the results. [3] High acceleration shock loadings are more accurately created by explosives; however, this is rarely done in practice due to the obvious dangers. [4]

Works by Chu and others have noted significant sources of error in accelerometer measurements in pyrotechnic shock. Actual pyrotechnic explosions can excite piezoelectric accelerometers at their natural frequency. [5] Replicating the pyrotechnic shock mechanically, as opposed to simulating with real pyrotechnics, can potentially solve any issues encountered with accelerometer measurements.

Tests done to electronic components by Luhrs have focused mostly on using a drop test to simulate pyrotechnic shock. He notes the discrepancies between using a drop test and shaker test as opposed to identical testing on a simulated spacecraft structure with a shock induced by pyrotechnics. No equipment failures occurred, until 2500g peak acceleration was reached, where crystal oscillators began to fail. On the other hand, a simulated spacecraft structure test setup experienced no failures until upwards of 7000g peak acceleration. [5] Findings by The Harris Corporation agree with Luhrs in that the drop test was overestimating the shock accelerations. [2]

2.2 Need Statement

This project requires collaborative effort in order to re-design and produce a suitable testing apparatus and modeling system. This is required to reduce the inefficiencies of the current trial and error methods employed by Harris Corp. for testing electronic components in regards to high load, high frequency shocks. [2]

The current shock testing method is lacking in terms of the quality of results, efficiency, accuracy, and repeatability.

2.3 Goal Statement & Objectives

Design a test apparatus and modeling system for Harris Corp. with a clear and concise method for accurately simulating shock responses.

Objectives:

- Research and explore alternative testing methods
- Devise systematic approach to maximize repeatability
- Develop computational modeling method for test standardization
- Find suitable shock load sensors for hands-on testing
- Explore possible apparatus designs; Material selection
- Design selection base upon feasibility, budget, and constraints
- Produce prototype and modeling method.

3 Constraints

In order to clarify the project and highlight key factors, the team's first contact via teleconference with Robert Wells at Harris Corp. was spent reviewing the initial information he sent and defining the project to develop a clear problem statement and corresponding goals. Both from the conversation and the parameters of the project laid out in the launching presentation, an extensive constraints list does not seem viable. Rather than creating an entirely new testing apparatus for shock testing, the primary issue faced by Harris is not that the current hammer blow test is not an effective means of generating the desired pyrotechnic shocks, but that it is currently inefficient due to required trial and error time beforehand. Therefore, if we were to focus our efforts on better modeling the current system and finding ways to reduce the number of necessary trial runs, our constraints are then limited only to the current models used for testing. The two suggested and used by Harris Corp., according to Mr. Wells, are a hammer drop test and an air hammer test [4]. We were provided the links to the exact patents detailing each method of testing. For the hammer drop test [6] and the air hammer test [7], the overlapping constraints requested by Harris are:

- Device capable of testing unit between 5-50 lbs
- Must accommodate a parcel of dimension up to 16" L x 16" W x 12" H
- Must generate SRS pyrotechnic shocks of up to 5000g peak and 10kHz (max levels for mid field range shocks)
- Response must be captured by an analysis system
- Test parameters must be controllable through accessible software tool (Matlab)
- Project expenses must stay within allotted budget ($4000)

In regards to the budget, we were told there is the chance that if an acceptable business case were made to demonstrate the necessity for extra funding, it may be provided on the decision of Harris Corp.. Other typical constraints regarding the size of the machine, the required material used, and so forth, are not included in this section because to this point, no such constraints exist. We are planning to make use of sensors and software available at the school to the highest extent we can.

The material choice, for example, is purposefully not a constraint as it represents a variable of the shock generation process that we are able to explore as a way to better control the parameters of shock testing.

		Engineering Requirements						
Customer Requirements	Weight factor	Material Selection	Size	Accuracy	Cost	Programming	DAQ	
Minimal Cost	2.5	9	9	3	9	1	3	
Ease of use	5			1	3	9	9	
Durable	5	9			3	3		
Accurate	5	1	1	9	3	9	9	
Size	2		9		9			
Software	5			9	3	9	9	
	Raw Score	72.5	45.5	102.5	101	152.5	142.5	616
	Relative Wt %	11.77	7.39	16.64	16.31	24.76	23.13	
	Rank	5	6	3	4	1	2	

Table 1 - House of Quality Matrix - Engineering Requirements vs. Customer Requirements

3.1 Design Specifications

Identifying design specifications as separate entities from the above constraints proved difficult due to their similarities. In particular, given that our best solution may result in tailoring their current testing, we would not have our own design specifications to consider, but instead those of the working apparatus to consider and preserve. Therefore, many of the constraints appear as design specifications as well, because if, in the course of altering or modifying the current equipment, we fail to preserve the current effectiveness of SRS generation, we will have only solved one problem to create another one.

As mentioned above, some of the physical attributes in particular are left out of this discussion due to being important variables that may provide the sought parameters that make the testing more predictable and programmable. This includes features such as the thickness and sizes of the plates for the hammer drop test, or the materials and sizes used for the tunable resonant fixture in the air hammer test [4].

Geometrically, the test must accommodate the same max sized units (16” L x 16” W x 12” H) and support the range of weight (5 – 50 lbs) without affecting the test results. Additionally, it must still have ports to access sensors and data acquisition wiring. The total space the machine can occupy has not been limited, but naturally will be considered with respect to ease of loading test units and maintaining reasonable dimensions so as to not clutter a test environment. The software we develop must produce the SRS curves with a certain amount of precision and accuracy. It must first be able to convert from the time domain to the frequency domain for analysis. Following the guidelines of NASA pyrotechnic shock testing, Mr. Wells pointed out that the resolution in the natural frequency spectrum for the test must fall within a 1/6 octave band [5]. The natural frequency tolerance for natural frequencies less than 3 kHz is ± 6 dB, and this applies to all testable electronics components used by Harris Corp. [3]. Finally, at least 50 percent of the SRS magnitudes shall exceed the nominal test specification, which is to ensure the established factors of safety still apply since this testing is designed to create the maximum possible shocks to meet this requirement.

3.2 Performance Specification

The performance specifications are a much more clear set of objectives. Regardless of what the apparatus used, many things must be accomplished by the test. It must be able to create and then model in software a maximum level, matching SRS curves on a consistent basis. In addition, it must be able to do so for different masses without losing accuracy or precision. It must save the time previously spent in trial and error by providing modeling software that controls the test parameters. The frequency range must stay in the resolution set by company standards, and by extension, NASA and military standards. The information must displayed in a software that can be accessed by the company to perform analysis reliably.

These constraints may be modified as the project progresses and we develop a greater understanding of an achievable end goal. However, the design and performance specifications account for the current testing methods that do work. In order to provide a viable solution for

Harris Corp., these conditions will at the very least have to be maintained to preserve the integrity of the testing and subsequent data analysis.

4 Methodology

Our method is broken down to key components of the project. These components are further broken down into their constituents. These constituents constitute our key aspects in formulating a correct and proper design plan that will lead into the prototyping phase. The attached Gantt Chart also details task dependencies, assigned resources, and tentative dates for each constituent, as well as the components they belong to. Milestones, meetings, and deliverables are also shown. We began with the background phase that consisted of deciphering and digesting the information provided by the sponsor, as well as any information deemed to be relevant to grasping an understanding of the underlying theories and methods. Leading up to this deliverable, the specifications phase was also completed. Our next obstacles are to brainstorm and hopefully observe a demonstration of the current testing setup and modeling. Then we will begin developing a testing apparatus and modeling system that is more efficient in providing conclusive results.

4.1 Schedule

The schedule for this design project can be found in Appendix 1. This schedule should be considered tentative after the end of 2014, as we have little information about what will be required from that point forward. Up until the end of 2014, the schedule is mostly concrete with the exception of presentation dates that are subject to availability.

4.2 Resource Allocation

Below is the table that provides the necessary information for the Gantt Chart. Also included is the resource allocation, as well as the period of time allotted for each task.

WBS	Task Name	Duration	Start	Finish	Resource Names
1	**Design**	**79 days**	**9/7/14**	**12/25/14**	**All**
1.1	**Background**	**20 days**	**9/7/14**	**10/2/14**	**All**
1.1.1	SRS Pulses	11 days	9/7/14	9/19/14	Chase,Chad,Sponsor
1.1.2	Standards	4 days	9/14/14	9/17/14	Charles,Nathan,Sponsor
1.1.3	Resonance	11 days	9/17/14	10/1/14	All
1.1.4	Tuning (SDM)	7 days	9/18/14	9/26/14	Charles,Chase
1.1.5	Current Methods	4 days	9/22/14	9/25/14	All
1.1.6	**Modeling**	**9 days**	**9/18/14**	**9/30/14**	**All**
1.1.6.1	Analytical (Computer)	5 days	9/18/14	9/23/14	Charles,Nathan
1.1.6.2	Experimental (D.A.Q.)	7 days	9/22/14	9/30/14	Chad,Chase
1.1.7	Code Of Conduct	0 days	10/3/14	10/3/14	All
1.1.8	Needs Assessment	0 days	9/26/14	9/26/14	All
1.2	**Specifications**	**11 days**	**9/27/14**	**10/10/14**	
1.2.1	Design Specs	5 days	9/27/14	10/2/14	Chad,Nathan
1.2.2	Performance Specs	7 days	10/2/14	10/10/14	Chad,Nathan
1.2.3	Project Plan	0 days	10/10/14	10/10/14	All
1.3	**Brainstorming**	**14 days**	**10/6/14**	**10/23/14**	
1.3.1	Pulse Generation	7 days	10/6/14	10/13/14	Chad
1.3.2	Measurement Methods	13 days	10/8/14	10/23/14	Chase
1.3.3	Scheduling	7 days	10/6/14	10/14/14	Charles
1.3.4	Current Method Demo	0 days	10/21/14	10/21/14	Sponsor,All
1.4	**Development**	**14 days**	**10/24/14**	**11/12/14**	
1.4.1	Testing Apparatus	5 days	10/24/14	10/29/14	Chase,Nathan
1.4.1.1	Dimension & Physical setup	5 days	10/28/14	11/3/14	Chase,Nathan
1.4.1.2	Material Selection	9 days	11/1/14	11/12/14	Charles
1.4.1.4	Resonance Response	9 days	11/2/14	11/12/14	Chad
1.4.5	**Modeling**	**7 days**	**11/1/14**	**11/11/14**	
1.4.2.1	Tuning Calculations	4 days	11/1/14	11/4/14	Chase
1.4.2.2	Pulse Generation	5 days	11/4/14	11/7/14	Chad
1.4.2.3	Response Spectrum Generation	5 days	11/6/14	11/11/14	Charles
1.4.2.4	Software Selection	2 days	11/8/14	11/8/14	Nathan,Charles,Sponsor
1.5	**Reporting**	**71 days**	**9/18/14**	**12/25/14**	
1.5.1	**Staff Meeting**	**71 days**	**9/18/14**	**12/25/14**	**All**
1.5.2	**Website**	**57 days**	**10/1/14**	**12/18/14**	**Nathan**
1.5.2.1	Initial Design	26 days	10/1/14	11/5/14	

1.5.2.2	Final Design	40 days	10/25/14	12/18/14	
1.5.3	**Presentations**	**49 days**	**10/14/14**	**12/22/14**	**All**
1.5.3.1	Midterm Presentation	0 days	10/14/14	10/14/14	
1.5.3.2	Midterm II Presenation	0 days	11/11/14	11/11/14	
1.5.3.3	Final Presentation	0 days	12/22/14	12/22/14	
1.5.4	Midterm Report	0 days	10/21/14	10/21/14	Charles,Nathan
1.5.5	Final Report	0 days	12/5/14	12/5/14	Chad,Chase
1.5.6	Peer Evaluation I	0 days	10/28/14	10/28/14	
1.5.7	Peer Evaluation II	0 days	11/25/14	11/25/14	
2	**Prototyping**	**90 days**	**1/10/15**	**5/15/15**	**All**
2.1	Scale Model	9 days	1/10/15	1/21/15	Nathan,Chase
2.2	CAD Model	5 days	1/17/15	1/22/15	Charles,Chad
2.3	Primary Data Comparison	2 days	1/21/15	1/22/15	All
2.4	**Analytical Methods**	**10 days**	**2/7/15**	**2/19/15**	
2.4.1	MATLAB Model	6 days	2/7/15	2/13/15	
2.4.2	MathCAD Model	8 days	2/10/15	2/19/15	
2.5	**Production**	**30 days**	**4/4/15**	**5/15/15**	
2.5.1	Machine Parts	7 days	4/4/15	4/13/15	
2.5.2	**Acquire Instrumentation**	**3 days**	**4/7/15**	**4/9/15**	
2.5.3	Assembly	7 days	4/14/15	4/22/15	
2.5.4	Test & Refine	14 days	4/28/15	5/15/15	
2.6	**Final Product**	**0 days**	**5/15/15**	**5/15/15**	
2.6.1	Final Product Presentation	0 days	5/15/15	5/15/15	

Table 2 - MS. Project Task List with detailed information

5 Conclusion

The hardship of this particular project will be the creation of a program that will determine the test parameters for the shock testing. We will do future work under the assumption that we will stay with Harris Corp.'s current test method using a hammer test. They are happy with this current test method and seek a more efficient means to utilize it. From here we will continue research into the creation of the SRS curves and what it will take to mimic them under test conditions. The focal point of this research will be to determine the effect on chosen parameters such as size, weight, and material on the size and shape of the curve. This will help us with the creation of a modeling program to simulate these shock tests.

6 References

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[7] Stuckey, Raymond L. Pyrotechnic Shock Machine. International Business Machines Corporation, assignee. Patent US 5400640 A. 28 Mar. 1995. Print.

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7 Appendix

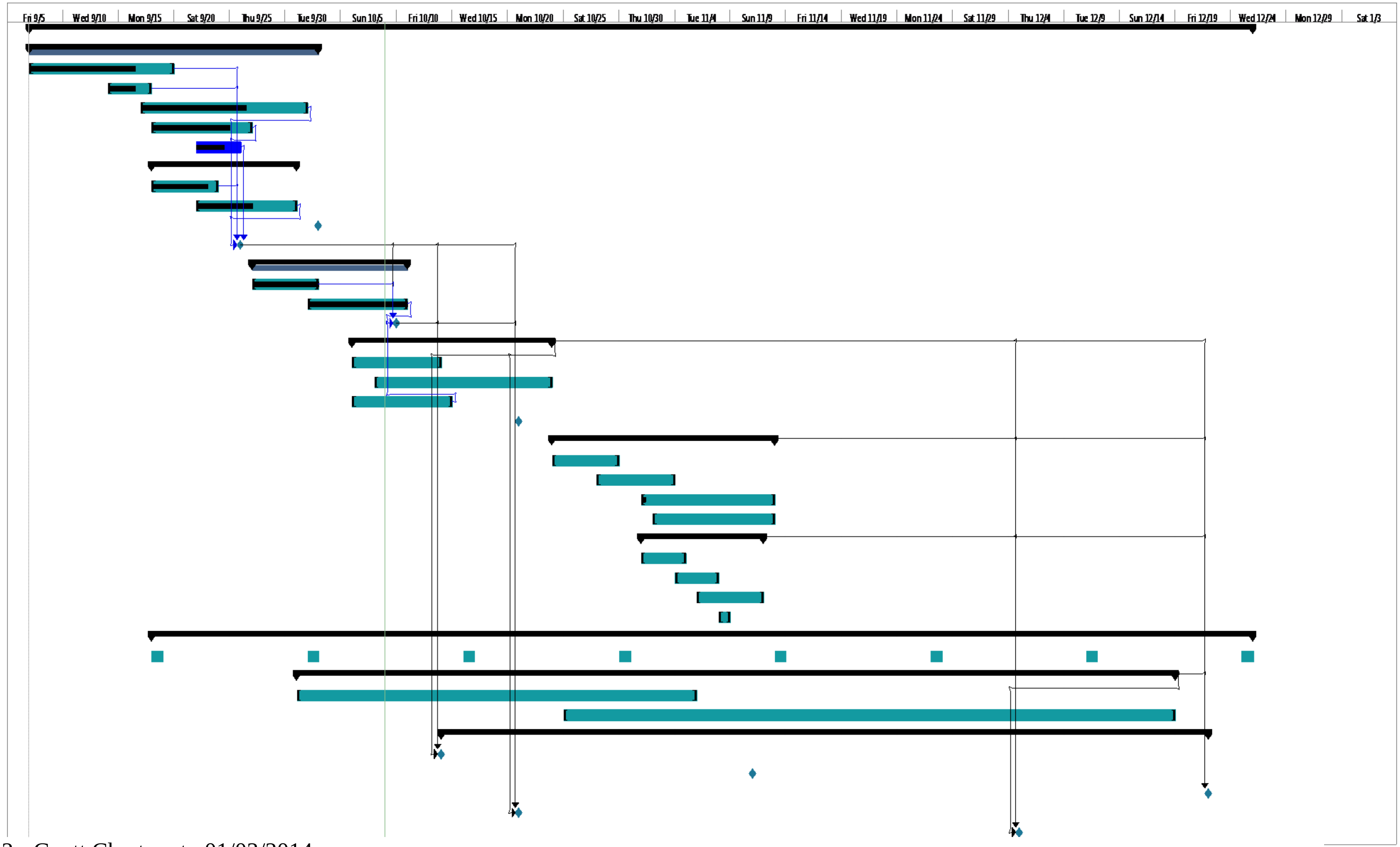

Figure 2 - Gantt Chart up to 01/03/2014

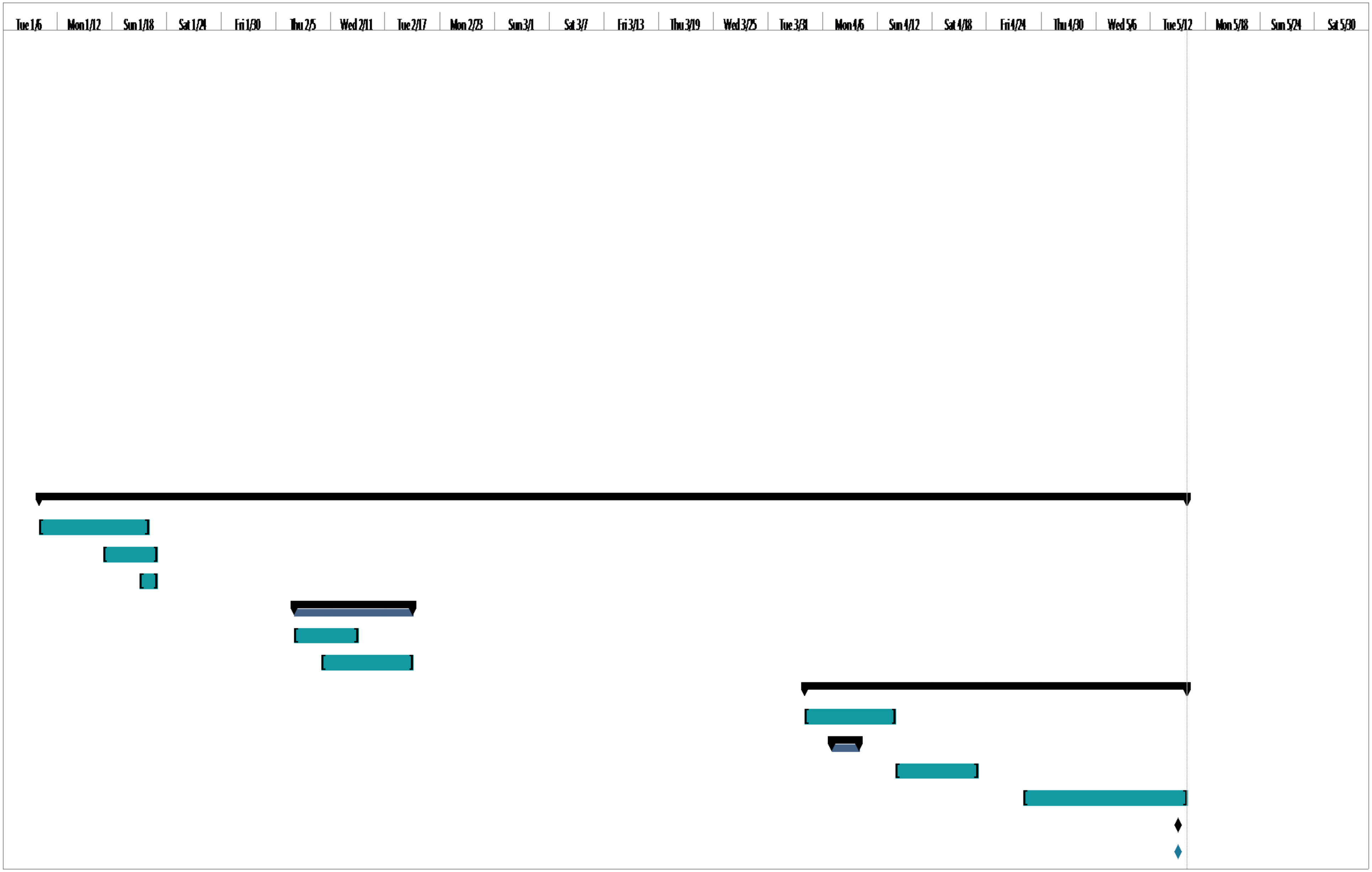

Figure 3 - Gantt Chart up to 5/30/2015

	WBS	Task Name	Duration	Start	Finish	Resource Names
1	**1**	**Design**	**79 days**	**9/7/14**	**12/25/14**	**All**
2	**1.1**	**Background**	**20 days**	**9/7/14**	**10/2/14**	**All**
3	1.1.1	SRS Pulses	11 days	9/7/14	9/19/14	Chase,Chad,Sponsor
4	1.1.2	Standards	4 days	9/14/14	9/17/14	Charles,Nathan,Sponsor
5	1.1.3	Resonance	11 days	9/17/14	10/1/14	All
6	1.1.4	Tuning (SDM)	7 days	9/18/14	9/26/14	Charles,Chase
7	1.1.5	Current Methods	4 days	9/22/14	9/25/14	All
8	**1.1.6**	**Modeling**	**9 days**	**9/18/14**	**9/30/14**	**All**
9	1.1.6.1	Analytical (Computer)	5 days	9/18/14	9/23/14	Charles,Nathan
10	1.1.6.2	Experimental (D.A.Q.)	7 days	9/22/14	9/30/14	Chad,Chase
11	1.1.7	Code Of Conduct	0 days	10/3/14	10/3/14	All
12	1.1.8	Needs Assessment	0 days	9/26/14	9/26/14	All
13	**1.2**	**Specifications**	**11 days**	**9/27/14**	**10/10/14**	
14	1.2.1	Design Specs	5 days	9/27/14	10/2/14	Chad,Nathan
15	1.2.2	Performance Specs	7 days	10/2/14	10/10/14	Chad,Nathan
16	1.2.3	Project Plan	0 days	10/10/14	10/10/14	All
17	**1.3**	**Brainstorming**	**14 days**	**10/6/14**	**10/23/14**	
18	1.3.1	Pulse Generation	7 days	10/6/14	10/13/14	Chad
19	1.3.2	Measurement Methods	13 days	10/8/14	10/23/14	Chase
20	1.3.3	Scheduling	7 days	10/6/14	10/14/14	Charles
21	1.3.4	Current Method Demo	0 days	10/21/14	10/21/14	Sponsor,All
22	**1.4**	**Development**	**14 days**	**10/24/14**	**11/12/14**	
23	1.4.1	Testing Apparatus	5 days	10/24/14	10/29/14	Chase,Nathan
24	1.4.1.1	Dimension & Physical setup	5 days	10/28/14	11/3/14	Chase,Nathan
25	1.4.1.2	Material Selection	9 days	11/1/14	11/12/14	Charles
26	1.4.1.4	Resonance Response	9 days	11/2/14	11/12/14	Chad
27	**1.4.5**	**Modeling**	**7 days**	**11/1/14**	**11/11/14**	
28	1.4.2.1	Tuning Calculations	4 days	11/1/14	11/4/14	Chase
29	1.4.2.2	Pulse Generation	5 days	11/4/14	11/7/14	Chad
30	1.4.2.3	Response Spectrum Generation	5 days	11/6/14	11/11/14	Charles
31	1.4.2.4	Software Selection	2 days	11/8/14	11/8/14	Nathan,Charles,Sponsor
32	**1.5**	**Reporting**	**71 days**	**9/18/14**	**12/25/14**	
33	**1.5.1**	**Staff Meeting**	**71 days**	**9/18/14**	**12/25/14**	**All**
42	**1.5.2**	**Website**	**57 days**	**10/1/14**	**12/18/14**	**Nathan**
43	1.5.2.1	Initial Design	26 days	10/1/14	11/5/14	
44	1.5.2.2	Final Design	40 days	10/25/14	12/18/14	
45	**1.5.3**	**Presentations**	**49 days**	**10/14/14**	**12/22/14**	**All**
46	1.5.3.1	Midterm Presentation	0 days	10/14/14	10/14/14	
47	1.5.3.2	Midterm II Presenation	0 days	11/11/14	11/11/14	
48	1.5.3.3	Final Presentation	0 days	12/22/14	12/22/14	
49	1.5.4	Midterm Report	0 days	10/21/14	10/21/14	Charles,Nathan

	WBS	Task Name	Duration	Start	Finish	Resource Names
53	**2**	**Prototyping**	**90 days**	**1/10/15**	**5/15/15**	**All**
54	2.1	Scale Model	9 days	1/10/15	1/21/15	Nathan,Chase
55	2.2	CAD Model	5 days	1/17/15	1/22/15	Charles,Chad
56	2.3	Primary Data Comparison	2 days	1/21/15	1/22/15	All
57	**2.4**	**Analytical Methods**	**10 days**	**2/7/15**	**2/19/15**	
58	2.4.1	MATLAB Model	6 days	2/7/15	2/13/15	
59	2.4.2	MathCAD Model	8 days	2/10/15	2/19/15	
60	**2.5**	**Production**	**30 days**	**4/4/15**	**5/15/15**	
61	2.5.1	Machine Parts	7 days	4/4/15	4/13/15	
62	**2.5.2**	**Acquire Instrumentation**	**3 days**	**4/7/15**	**4/9/15**	
64	2.5.3	Assembly	7 days	4/14/15	4/22/15	
65	2.5.4	Test & Refine	14 days	4/28/15	5/15/15	
66	**2.6**	**Final Product**	**0 days**	**5/15/15**	**5/15/15**	
67	2.6.1	Final Product Presentation	0 days	5/15/15	5/15/15	

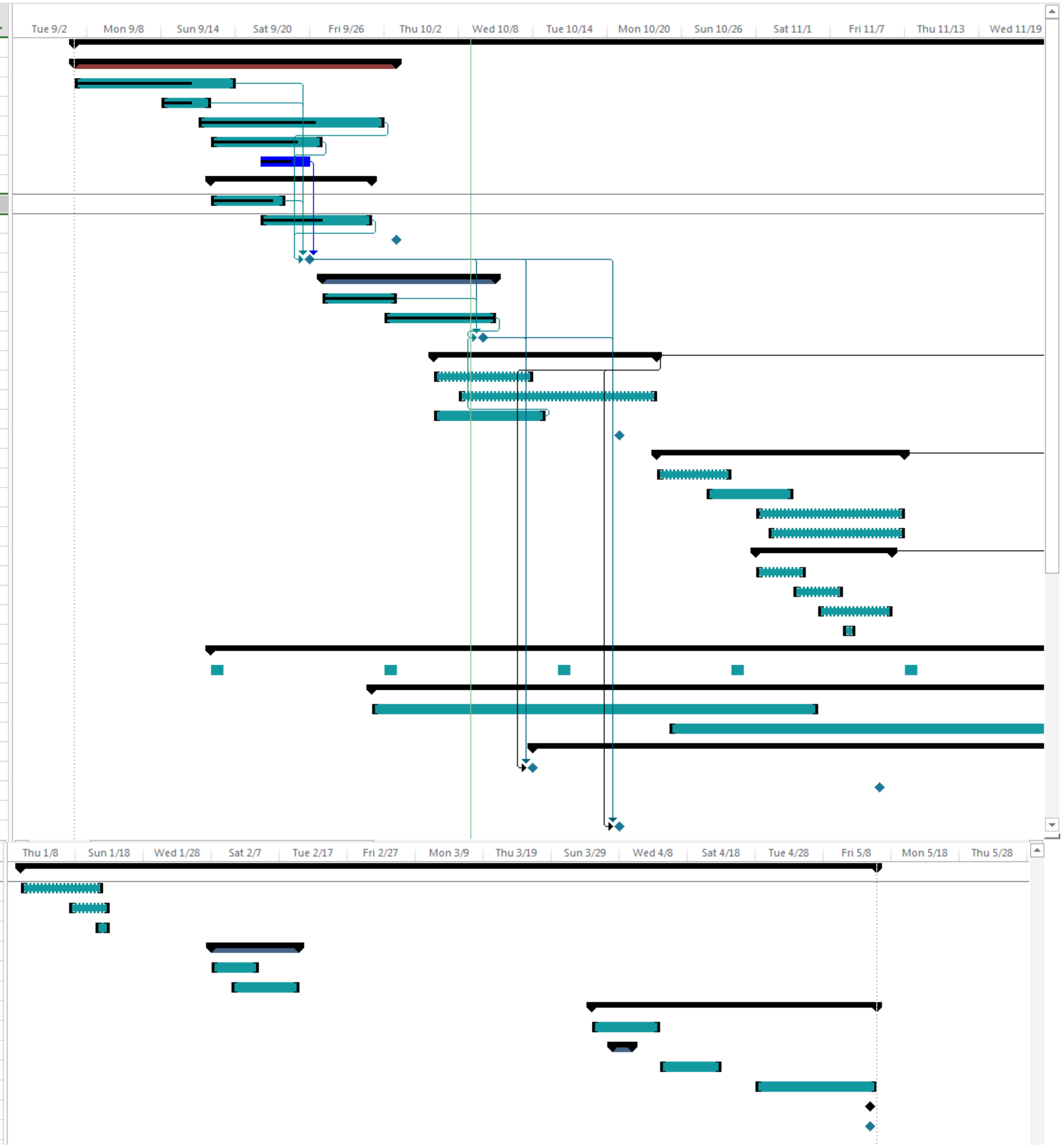

Figure 4 - Combined complete Gantt Chart