# Inductive Wireless Power Connector

## 1. Introduction

The objective of this senior design project is to design an inductive power connecter that will wirelessly charge an unmanned underwater vehicle. Our short term goal is to design an inductive power connector where the medium is through air and our long term goal is to eventually design an inductive power connecter where the medium is through water. An inductive power connector or an inductive power transfer system is used to power an object without any physical contact between the source and the object through magnetic induction. Essentially the power transfer is wireless. This technology uses inductive coils on the same resonant frequency and the theory behind mutual induction. We will base our design off of the Witricity Project done by the students and staff at Massachusetts Institute of Technology (MIT) but instead change the medium of transfer from air to water. Where they were able to transfer power over a distance of 2m in air; we will attempt as a goal to transfer power up to a 1m distance in water. We also want to design a smaller model than the one that used in their experiment. This design can be used for general purposes of wireless or contactless power transfer, but for the design of this project Northrop Grumman would like for us to design the core analog power portion of a system to wirelessly power an unmanned underwater vehicle from a base station without it having to come to the surface.

The next section in this proposal will be the Problem Definition section which will clearly state the problem of our project. Next will be a Current Status of Art section which will summarize previous and current work on inductive power transfer. After that will be our Engineering Approaches section which will describe our solutions to our problems. The following section will be Tasks and Deliverables where we state the tasks given for this project. Then there will be our Problem Management section where we give our timeline and budget and finally our Conclusion.

## 2. Problem Definition

In this project we have to design a system to transmit power wirelessly through water. The main purpose of the power transmission is to connect to and power up an Unmanned Underwater Vehicle (UUV). The scope of this problem is to improve or expand the range of travel of the UUV. UUVs are mainly used by the military, in research science and by some commercial companies. In the past UUVs have been used with residual batteries that limit the mission life of the vehicle and thus the need has arisen for the UUV to be recharged or remotely connected under water. This would allow more underwater time for the vehicle since it would not need to resurface or return to a particular position to be recharged.

Apart from making the system work under water it must work optimally in depths up to 300feet, we will attempt to transmit in a range of 1meter. In the design of this system the team must also design a device that works by inductively transmitting power through a particular medium; in this case, water. The team, in its initial design phase must understand how the system works in air and eventually design it work in water as the medium. The challenge would be to adhere to the safety requirements for transmission in air, keeping in mind the requirements that will arise underwater, and designing a system that should work best in both.

In moving forward with this project the team must keep in mind that the system must transfer 100 VDC with 10 amp of current, transmit in a radial range of up to 1 meter, and should have specific functional capabilities which include operation in temperatures between 28 and 120 degrees F and surviving in temperatures between -40 degrees and 160 degrees F. Our goal is to achieve an efficiency of about 80% for the system but since the in-air system (done by MIT) achieved a ~40% efficiency we would expect a comparative value.

We propose that in making the system even more efficient and self-sustaining, an interface be designed that will communicate remotely with an on-land computer or controller. This would be used to report on the status of the system, its current efficiency, and any problems that may occur. Since the system will work with inductively produced power we propose that the system must not interfere with electronic devices already on-board the charging station or other devices in surroundings and it also must transmit at an acceptable frequency, as to not interfere with other communication equipment in surroundings. Keep in mind that even though these proposals may be out of the range of our project the team hopes to have relevant research information and suggestions at the end of our work to make easy transition into any future work.

The Design Requirements are attached below.

## 3. Current Status of Art

As stated previously, the purpose of our project is to design a system to transmit power wirelessly through the medium of water. As such, it behooves us to research the current status of art (i.e. the existing products and/or technologies that serve the same purpose or perform similar tasks to the goal we are attempting to accomplish) so that as a group we may gain a much more robust understanding of the problem, of possible solutions and of potential solutions. At the very heart of our project is a phenomenon known as electromagnetic induction. When Michael Faraday discovered that voltage can be generated across a length of wire that was exposed to a perpendicular magnetic field flux of varying intensity, he opened the door for most of the more practical applications of electricity, and more importantly the generation of electricity itself. In fact, current methods of power generation would be impossible without the discovery of inductive power transfer, which paved the way for the development of generators and transformers. Additionslly Heinrich Hertz, the german physicist, furthered the work of Michael Faraday by expanding the theory of light put forth by Faraday and satisfactorily demonstrating the existence of electromagnetic waves via his famed experiment with the Hertz receiver. Consequently, contactless inductive power supplies are the new wave of “future” technology, as they eliminate the need for wires and cables, costly maintenance, and unnecessary safety precautions. The existing technologies utilize wireless inductive technology, with the medium being air instead of water. Studying these will be beneficial in discovering how to perform a similar task underwater.

The concept of wireless power transfer, while revolutionary, is not new. In fact, it is a discussion that has been in the back of the mind of many engineers for the past 100 years. There are many individuals and companies spanning a wide range of intellectual interests and industries that are currently developing methods in which transfer power in a contactless manner. Let us begin by discussing "non-traditional" methods of transferring power wirelessly, i.e. methods that do not utilize electromagnetic induction. Over the years, organizations such as NASA, ENTECH, and UAH have been experimenting with advanced receiver and converter techniques for laser wireless power transmission. The basic way this system of transmission functions is as follows:

- Solar radiation is collected in space and converted to electrical power
- The electrical power is converted into a form of laser radiation
- The laser radiation is wirelessly transmitted to an end-use location
- The laser radiation is recovered and converted back into electrical power

This concept would be fantastic for underwater transmission of power. It is still, however, very much in the experimental portion of its development, and no real time testing has been performed as of yet.

Another "non-traditional" method of transferring power wirelessly is doing so via radio signals. Powercast is a company dedicated to the use of radio waves as a means to power devices. In 2003 the company developed a transmitter module, named the Powercaster, that runs on conventional current and broadcasts a low power RF radio signal at a specific frequency across several feet of space. A receiver module known as the Powerharvester is built into the device being powered and has the capability to capture enough energy to recharge the batteries onboard the device, or remotely power the device altogether. Powercast claims that their circuit design can capture 70% of the theoretical power maximum anywhere within its range. While the concept is excellent and the performance reliable, Powercast seems to be at a disadvantage, however, due to the fact that it can only supply enough power for small devices, not near the scale of current day UUV's.

eCoupled is a technology developed by the company known as Fulton Innovation. eCoupled technology includes an inductively coupled power circuit that dynamically seeks resonance, allowing the primary supply circuit to adapt its operation to match the needs of the devices it supplies. It does so by communicating with each device individually in real time, which allows the technology to determine not only power needs, but also factors such as the age of a battery or device and its charging lifecycles, in order to supply the optimal amount of power to keep a device at peak efficiency. Fulton Innovation asserts that the advantages of eCoupled Technology are that it technology overcomes the limitations of spatial rigidity, static loads and unacceptable power losses. Additionally, it intelligently adapts to multiple loads (from milliwatts to kilowatts) and spatial configurations while maximizing energy transfer efficiencies by as much as 98%, making eCoupled technology comparable to hardwired connections in terms of energy costs. This claim should be taken with a grain of skepticism, however, when considering the unlikelihood of a 98% efficiency where A tightly transformer coupled power converter where the control-system power versus the major load power has an extremely large ratio.

There are also patents that showcase the concept of electromagnetic inductive power transfer. US Patent 6489745 (Contactless Power Supply) describes a mobile platform computer charger; it is designed to be used, for example, on airplane seatback trays. It consists of a receptor disposed within a computing device; when the computing device is placed on the mobile platform and the inductive coil is energized, it provides electrical current to power the computing device. The contactless power supply encompasses a shielding member that is installed in the computing device to protect components of the personal computer from any detrimental effects of magnetic fields produced by the inductive coil. Again, there are many advantages to this kind of design, such as increased mobility and portability, but it is only designed to induct relatively small amounts of electrical power and would not be useful for current UUV's.

One of the most relevant and successful design that exists comes from the MIT inductive power transfer experiment and project. MIT's Department of Physics, Department of Electrical Engineering and Computer Science, and Institute for Soldier Nanotechnologies (ISN) Team was able to light a 60W light bulb from a power source seven feet (more than two meters) away without the use of any physical wires or connection. They utilized self-resonant coils in a strongly coupled regime to transfer the power with 40% efficiency over two plus meters. Of course, this experiment demonstrates the most clearly that wireless power transfer is possible, plausible, and efficient, but again the distance the power can travel and the amount transmitted may end up being ideal for the design requirements we've placed on this project, since 80% efficiency is a goal and not a requirement.

Finally, **as it pertains specifically to underwater power transfer**, there is in fact a patented approach to designing an underwater wireless power delivery system that appears to be both relevant and viable for our overall project goal and purpose. US Patent 5301096 (Submersible Contactless Power Delivery System) describes a contactless power delivery system that supplies power between first and second conductors to provide a flexible power delivery for non-arcing coupling in hazardous and other environments, such as in underwater applications. This contactless power delivery system also delivers power when there is relative motion between first and second conductors, where relative motion is defined to be linear and/or rotational. The proposed invention has the unique ability to "deliver great quantities of electrical power underwater across larger water-filled gaps" during relative motion between the source and the load. These gaps are equivalent to air gaps in land-based systems. Thus the underwater contactless power delivery is accomplished by magnetic induction across a submerged radial interwinding space. In addition, using high operating frequencies with this contactless power transfer scheme would allow for some significant economic advantages. As one can see, this is clearly a the most useful current status of the art in that it clearly outlines and attempts to accomplish what our overall project hopes to achieve. This idea will be most useful in assisting our group in formatting solution approaches.

## 4. Engineering Approach

The study of wireless power transfer is relatively new to us and since recent times there have been a number of approaches that have been taken in bids to find the most beneficial, cost effective and safest way to create it. Today there are many studies that claim to know the best way to create wireless power. Some explore using radio frequency and others use inductive power transfer. However, some of the approaches that we found work relatively well in air but do not work very well in water. This project is definitely challenging us to look closely at the effects that water will have on our system and how best we can fashion our ideas to solve the problem at hand.

### Our Alternative

In our research we have found that an inductive power transfer system would be the most feasible, reliable, and cost effective method to use to fulfill our clients' needs. An inductive power transfer system with right packaging and some future minor changes in the design could be transferable for underwater use. In the scope of this project many of the classes that we have taken in the past gave us some necessary knowledge on working with inductive power. Physics, Energy Conversion, Electronics I and II, and Electromagnetic Theory has taught us about magnetic coupling, power transfers within a network, electronic hardware use and efficiency, and Maxwell's theory of transfer through a medium on an electronic level.

In our main approach we propose that we use a primary station that would eventually be hoisted onto and lowered underwater from either by a boat or deck / platform. In this station we would build the primary side of the system which would house the power supply, primary inductive coil, and direct current source. Through magnetic induction a field would be created and transmitted through the water and picked up the secondary conductor (coil) in the UUV. This field would ultimately be used to generate power by the secondary side of the system to run the UUV.

In understanding this project, we would first have to physically build the system in air, test it, and revise any problems that may arise. Once the system and its abilities are fully comprehended by the group we propose to move to the next stage. This next stage would include working in water; simulating it on software, and in the end building it to work in water.

This system would have to be successfully simulated before we move to physically building the device and for simulation we have plans to use Ansoft as well as experiment with MATLAB / Simulink software. In moving forward with this project the team will be required to learn more about Simulink in MATLAB and Ansoft so that we will be able to determine the best software to use in our project. We want to utilize the most user-friendly, time-efficient software that is available to us, so we will also leave room open to include other types of software programs that we come across.

**Other Alternatives**

There a couple of other methods that we may explore given resources and time which include a self-powered UUV that uses a turbine-like system. This system will use the underwater currents to propel a motor. Already a renewable energy source, tidal currents can be used to convert mechanical power into electrical power. In keeping with the wireless power transfer we would alternatively build a remote control interface with the UUV telling the motor when to turn on and off. The interface would give status reports on how much power is remaining and thus showing when the motor needs to be initiated.

Another approach that we feel may be viable is using a large air tube that would completely replace a water medium with an “in-air” medium. If we do eventually use this alternative we could again experiment with magnetic induction or consider other types of transmissions like radio waves or laser signals. Unfortunately, radio waves and laser signals, at particular frequencies that may be needed for the system, will not work directly in water so these options will only be explored if the air tube alternative is chosen.

## 5. Tasks and Deliverables

The scope of the wireless inductive power connector project is to prove and implement a design that transmits power wirelessly between a sending and receiving unit through water with a minimum of 1 meter distance between the two units.

In order to ensure that this project can successfully be completed, the overall project has been broken up into eight essential components to help us identify the milestones we need to reach. These components are as follows:

**a. Have the overall project proposal approved**

Before we can move forward with our project, we must first ensure that we have successfully mapped out how we plan to approach the problem and how we plan to execute our solution to the problem. By creating a proposal and having our proposal approved, we will be able to move forward in a focused, determined manner.

**b. Preliminary inductive power transfer in air research**

In order to be able to create a system that can work underwater, we first must gain a thorough understand of the existing technology in the field: inductive power transfer in air. We will research and test the methods already in existence to inductively transfer power in air, allowing us to better prepare ourselves for creating a system to operate in water.

**c. Underwater Research**

We will research numerous things that will have an effect on the inductive power transfer system when it is emerged in water. We will first research the effects that water (both salt water and fresh water) will have on the system. We will also research methods in which the system can be pressurized as it lowers to depths of 300 ft and beyond, and the effects that the surrounding water pressure will have on the operation of the system. We will also research the materials in which the system will be composed of both in the packaging material used and in the types of wires and coils used. We would like the system to be able to transmit the most power at the longest distance possible; our research into the materials that we use on the system will allow us to choose the combination of materials that will allow this goal to be possible.

**d. Create Schematics for inductive underwater power transfer**

Upon the completion of our research, we will create numerous schematics for an inductive underwater power transfer system. We will utilize all of the research that we have conducted to formulate these systems. Numerous systems will initially be created so that all possible combinations of elements will be utilized, allowing us to choose the best possible system design to move forward with. All schematic designs will be for the actual version of the overall requirements given to us by Northrop Grumman which include power transfer of 100 VDC and 10 Amps.

**e. Successfully simulate designs**

Once we have formulated numerous schematics for potential inductive underwater power transfer systems, we will simulate each system using a combination of MATLAB, Simulink, and Ansoft software simulation tools. In addition, these simulations will be done physically using breadboards for each of the schematic designs. We will be simulating our schematics for efficiency, accuracy, rate of transfer, distance of transfer, average system power loss, and average system power use. We will create a metric system to score each of our schematic designs in the aforementioned areas. Once we have successfully simulated and scored each of the schematics, we will then choose the system with the highest score to move forward with.

**f. Order necessary materials for model**

Materials purchased will be in accordance with the results of the research conducted on materials to create the system out of as well as any unique materials that may be necessary to build the specific system design that we have chosen to move forward with.

**g. Build and Test model**

We will build and test the chosen system, making adjustments to the design as necessary. By the end of the project, we hope to have a physical model that will transmit power underwater with a minimum distance of 1 meter between the sending and receiving units. On the day of the final presentations, a linear scaled version of the aforementioned functioning system will be presented.

**h. Write technical report**

Concluding the project, we will write a thorough technical report outlining every step in the completion of the project. We will report on the research that we have conducted and the results drawn from that research, the formulation of our schematic designs, the reasons for which we chose the final system design, and the steps we took to transform our system design from its original software implementation to a functioning hardware implementation. We will also include any troubles that we may have run into along the way as well as how we were able to overcome those troubles. This report will be presented to Northrop Grumman at the conclusion of the project in April.

When our project is complete, we will be able to provide the schematic for the system for which we chose to move forward with, a technical report outlining all details of the project, and a scaled prototype of the system.

## 6. Project Management

*Timeline*

| Tasks | Start Date | End Date | Duration (Days) |
|---|---|---|---|
| 1. Have the overall project proposal approved | 10/29/2008 | 12/10/2008 | 42 |
| 2. Preliminary inductive power transfer in air research | 11/3/2008 | 12/15/2008 | 42 |
| -- Build and test model | 12/1/2008 | 12/15/2008 | 14 |
| 3. Underwater Research | 11/16/2008 | 1/7/2009 | 52 |
| -- Effects in water | 11/16/2008 | 12/1/2008 | 15 |
| -- Pressurization | 11/16/2008 | 1/7/2009 | 52 |
| -- Packaging Materials | 11/16/2008 | 1/7/2009 | 52 |
| 4. Create Schematics for inductive underwater power transfer | 12/20/2008 | 1/15/2009 | 26 |
| 5. Successfully simulate design | 1/16/2009 | 1/31/2009 | 15 |
| 6. Order necessary materials for model | 2/1/2009 | 2/15/2009 | 14 |
| 7. Build and test real life model | 2/16/2009 | 4/10/2009 | 53 |
| 8. Write technical report | 1/7/2009 | 4/10/2009 | 93 |

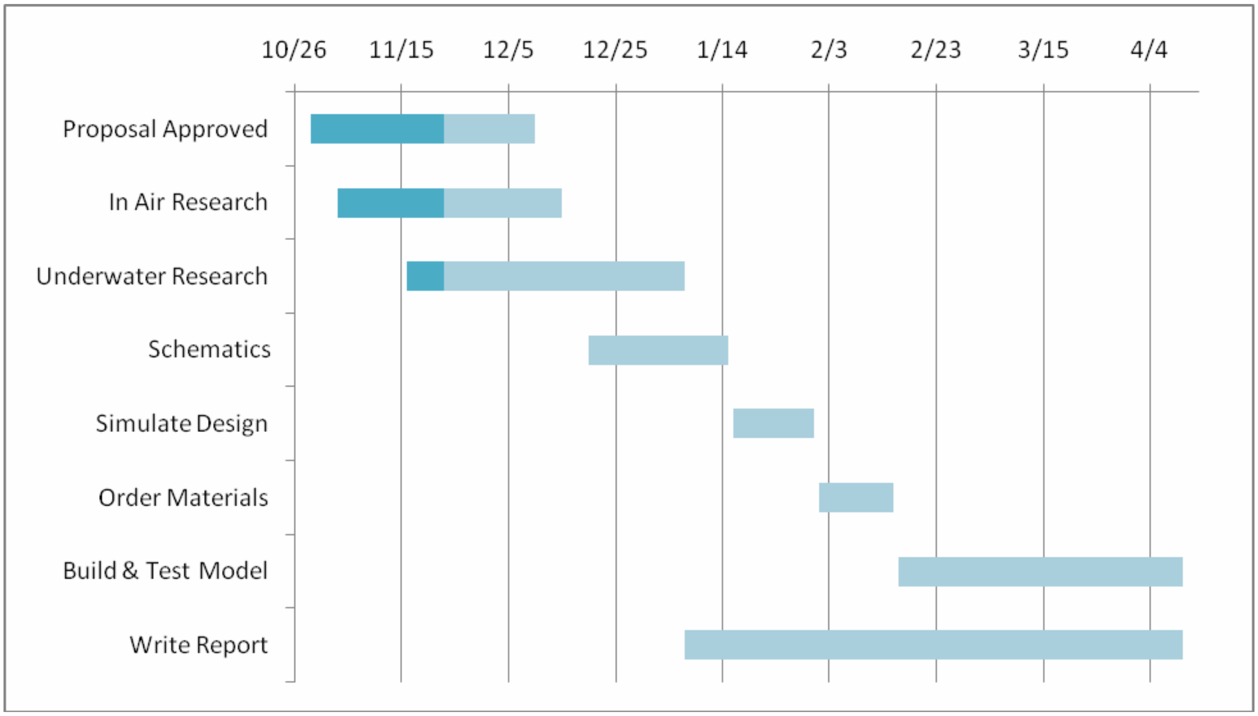


*Figure 1: Gantt Chart for Tasks*

*Budget*

Materials- $700

Misc.-$300

**Total = $1,000**

Note: Where the materials will be used for the model and include but not limited to:

- Ansoft Free
- MATLAB $99.00
- Wires $50
- Magnets $150
- Battery $50
- Packaging $150
- LED's and Circuit Boards $100
- Electronic Devices Free

## 7. Conclusion

To put it briefly our purpose for this design project is to design an inductive power connecter that will wirelessly charge an unmanned underwater vehicle. Our immediate goal is to design an inductive power connector where the medium is through air for our better understanding of how the system works. Our eventual goal is to design an inductive power connecter where the medium is through water. The system must transfer as much power as possible using a source of 100 VDC with 10 amps, transmit in a radial range of up to 3 feet and should maximize efficiency with a goal of 80%. We plan to do this by inductive power transfer, which we found to be the most feasible, reliable, and cost effective method. The circuit should be successfully bread boarded and reasonable simulation models are desirable before we move to manufacturing the device. As for simulation we have plans to use MATLAB / Simulink as well as experiment with Ansoft software. There a couple of other methods that we might investigate given resources and time which include a self-powered UUV that uses a turbine-like system and a large vacuum tube that would completely replace a water medium with an "in-air" medium. We plan to have the model up and running by April 10, 2009 while under a budget of $1000. We intend to write a technical report that explains our design. The team will also be challenged to show on paper that a 25 year lifespan submerged in sea water is feasible based on our research and findings.

## 8. References:


1. "Goodbye Wires…" MIT News. < http://web.mit.edu/newsoffice/2007/wireless-0607.html> October 23, 2008.
2. "Wireless power, charging technology may unplug Apple's iPhone" Apple Insider. http://www.appleinsider.com/articles/08/04/08/wireless_power_charging_technology_may_unplug_apples_iphone.html October 29, 2008.
3. "eCoupled Technology" Fulton Innovation <http://www.ecoupled.com/> October 29, 2008.
4. "Remote power, How it works" Powercast, simply wire-free. <http://powercastco.com/technology/ > October 30, 2008.
5. "Radio Frequencies Help Burn Salt Water" Breibart.com. <http://www.breitbart.com/article.php?id=D8RIRI600&show_article=1 > November 3, 2008.
6. "Advanced Receiver/Converter Experiments for Laser Wireless Power Transmission" Solar Power from Space (SPS04) and 5th Wireless Power Transmission (WPT5) Conference. <http://www.stretchedlensarray.com/Papers/SPSLaser.pdf>
7. "US Patent 5301096 - Submersible contactless power delivery system" <http://www.patentstorm.us/patents/5301096/fulltext.html> April 5, 1994
8. "US Patent 6489745 - Contactless power supply" <http://www.patentstorm.us/patents/6489745.html> December 3, 2002

## DESIGN REQUIREMENT LIST

| | |
|---|---|
| **Design Project Title:** | Wireless Underwater UUV Power Connector |
| **Team Name:** | S.A.A.M.ay09 |
| **Team Members:** | Andrea Berkeley, Shanika Brumfield, Amanda Dean, Matthew Taylor |
| **Date:** | 11/16/2008 |
| **Version No.** | 3 |

| Requirements | Descriptions | Sources |
|---|---|---|
| **Overall Function** | To recharge an unmanned underwater vehicle remotely and without use of wires or cables. | Team S.A.A.M.ay09 |
| **Performance** | • Function in sea water and fresh water at depths up to at least 300 feet<br>• Transfer 100 V DC, 10 amp<br>• Have a minimum of 80% efficiency<br>• Function in temperatures between 28 and 120 degrees F<br>• Survive in temperatures between -40 degrees and 160 degrees F<br>• Show on paper that a 25 year life submerged in sea water is feasible<br>• Should be able to recharge vehicle with 30 minute time frame<br>• Distance between Recharging Station and UUV must be at least 3 ft (1 meter) | Northrop Grumman Corporation (Sponsor) |
| **Cost** | $700-$1000 (Design and Manufacturing of Project) | Team S.A.A.M.ay09 |
| **Safety** | Must operate in water without risk of electrocution and/or electrical shortages | Team S.A.A.M.ay09 |
| **Compliance** | • Must not interfere with electronic devices already on-board UUV or electronics onboard the charging station<br>• Must transmit at acceptable frequency, as to not interfere with other communication equipment involved when launching the UUV<br>• Must not interfere with radar; must not give up charging station or UUV marine location | FCC<br>IEEE<br>Team S.A.A.M.ay09 |
| **Interfaces** | Computer interface above sea level that will intuitive, user-friendly, and constantly display status updates pertaining to the efficiency of the power connection. | Team S.A.A.M.ay09 |

| | | |
|---|---|---|
| | Also will display strength of wireless connection. | |
| **Energy, Power, and Environment** | • Transfer 100 VDC, 10 amp<br>• Provide sufficient energy to allow the UUV to operate submerged, continuously for (tbd) hours<br>• Radius of Operation: minimum 3 ft<br>• On station time: maximum 30 minutes | Northrop Grumman Corporation (Sponsor)<br><br>IEEE<br><br>U.S. Navy |
| **Lifespan** | 25 Years | Northrop Grumman Corporation (Sponsor) |
| **Size, Weight, Maintenance** | Between 25-30 lbs, 10in x 10in x 10 in (Rough estimate) | Team S.A.A.M.ay09 |
| **Timeline and Schedule** | • Complete the Design Requirement Form(s) by October 22, 2008<br>• Develop a clear set of Functional Requirements October 22, 2008<br>• Research Current Status of Art by October 31, 2008<br>• Produce Project Timeline by November 1, 2008<br>• Develop Problem Statement by November 7, 2008<br>• Generate alternative solutions by November 16, 2008<br>• Complete Project by early mid April 2009 | Team S.A.A.M.ay09 |