Autonomous Surface Vehicle

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***Abstract* — Every summer the Association for Unmanned Vehicle Systems International (AUVSI) hosts the Autonomous Surface Vehicle (ASV) competition. The Robotics Club at the University of Central Florida (UCF) annually participates in this competition which involves engineering a fully autonomous vehicle to perform the challenges set forth by AUVSI. Our senior design group chose to engineer the electrical integration system necessary for this ASV to compete in competition. This integration includes power regulation/distribution, power monitoring, vehicle safety, on-board and remote monitoring of system for vitals, and the processing of sensor data. The solution is expected to improve accuracy and efficiency with respect to maintenance and performance.**

***Index Terms* — Power regulation, sensor feedback, power monitoring, wireless communication, hot swapping.**

I. Introduction

Power regulation will efficiently control and distribute regulated and unregulated voltage throughout the vehicle for its onboard systems. This involves controlling three input sources as well as seamlessly hot swapping between two of these input sources. The vehicle will have protection from accidental reverse polarity as well as excess current draw. Our goal this year is to monitor all the vitals of our system including input voltages, input current, temperature, and humidity. We will have the ability to monitor the vitals through the on-board LCD screen, as well as a remote LCD screen.

The ASV is comprised of numerous sensors which include multiple vision systems, a compass, a global positioning system (GPS), Light Detection and Ranging (LIDAR), light, current, temperature and humidity. These systems are integrated in the vehicle by using multiple devices over several communication protocols. The processing power on the ASV consists of a computer, a field programmable gate array (FPGA), and a microcontroller. They utilize USB, serial, and I2C to communicate between each other and share information gathered from the sensors. All vision and some sensor processing is handled by the computer, which in turn directs the FPGA to send signals to motors/thrusters and other mechanical devices on the vehicle. In response to these signals the vehicle moves and performs specific tasks necessary for completing the overall competition.

In addition to our voltage and current sensors, we've added light, temperature, and humidity sensors to provide a more detailed diagnostic of the ASV. The light sensor has been designed to assist in color identification of objects. The four light sensors, composing the light detection assembly pack, each occupy a different navigational direction. They will interpret the amount of ambient light present and send this information to the microcontroller where it can be processed to determine which direction, with respect to the boat, the most amount of sunlight is coming from. If we detect it is affecting the "true" color of the object of interest we can adjust our software to compensate. The temperature sensors will detect whether the electrical components are creating too much heat for the electronics inside to work efficiently. The temperature obtained from these readings will then be used to control the fan speed through the FPGA. The E-Stop circuit is designed to have the ability to cut power to all moveable parts. Three E-Stop trigger locations will be located directly on the ASV and two additional triggers will be accessible via a remote panel and remote control. After considering the pros and cons of the E-Stop circuit from previous years we have decided to implement an emergency stop circuit that does not require any logic components. The exclusion of logic components will offer better protection, and allow the system to be in E-Stop mode when initial power is applied to the ASV. The E-Stop circuit is designed to operate using set and reset buttons. The reset button for our design purposes will only be accessible on board.

Another measure of safety protection that we have implemented is reverse polarity protection. When an input source is connected with the wrong polarity, the circuit will ensure that the electronics of the ASV are protected from any harmful side effects.

The ASV is designed to be more efficient. This is achieved through re-engineered vehicle safety, power regulation and distribution, while adding on-board and remote monitoring of vitals. These key aspects of our design are outlined below.

Our senior design team, in conjunction with the Robotics Club at UCF have decided that being able to display the diagnostic conditions of the ASV will be accomplished both through an on board LCD display and via remote. To realize this task we have selected to use MaxStream's XBee Pro 900 wireless modules. This form of wireless communication has proven to satisfy all of our core requirements in addition to exceeding our desired range of 900 feet, while requiring a sufficiently small amount of power in the process.

II. SAFETY

A. Emergency Stop

To provide safety to both human life and the ASV electrical components an emergency stop has been implemented. The most critical design feature of the E-stop is the self-latching relay. When there's current through the coil of the relay and the circuit is complete, our motor controllers and motors will have power. In the active state, the relay will be able to provide a path for the necessary current. If the need arises and the E-stop is triggered all power to our motor controllers and motors will be cutoff. This is done by pressing any of the E-Stop buttons which will physically break the E-Stop circuit. The only way to reactivate the circuit is by physically pressing the Reset button on the MAIN box.

B. Reverse Polarity

Many of the components composing the ASV have high current ratings. To protect our system in the event the batteries are connected with the wrong polarity we have implemented reverse polarity protection as seen in Figure 1.

When the battery is connected with the proper polarity current will flow and power will be transferred to the load. Note that for this case there's practically no voltage drop across the diode.

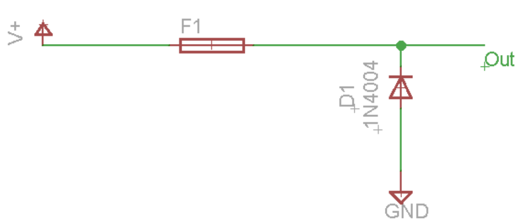

Fig. 1. Reverse Polarity Protection Using Parallel Diode.

However, when the battery is connected with the wrong polarity, the diode will get a forward potential difference of at least 0.7 V. This will force the diode to turn on, and consequently short the branch. This will result in a closed loop consisting of the battery, diode and the fuse. The current will rapidly increase and when it reaches the rating of the fuse, it will break it, resulting in an open circuit.

III. ASV POWER

A. Hot Swapping

To provide power to our boards, computer, motors, and all other devices we use different power sources. These power sources consist of a battery for all our logic circuitry, another battery for the motors, and shore power which comes from an 115V AC to 24V DC converter. In order to provide power continuously to the boat we designed a way of switching seamlessly between battery and shore power ("Hot swapping"). The circuitry designed for hot swapping is capable of sensing the presence of the shore power, and disconnects the batteries without disrupting the operation of the system. The main reason for this is that the ASV spends most of its time during construction and initial testing out of the water. To avoid the need for batteries and having to recharge them, this system allows us to have a permanent power source. This system also allows us to swap out batteries without having to power down the vehicle, mainly the computer. To implement these requirements the schematic in Figure 2 was employed.

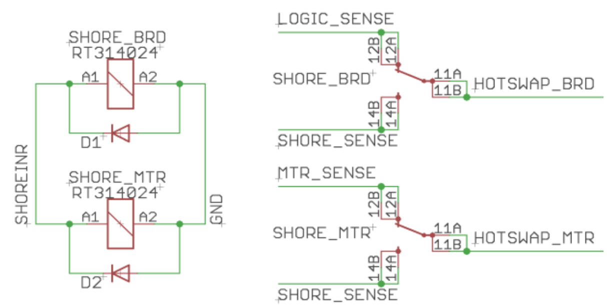

Fig. 2. Hot Swapping.

In this circuit we have two symmetric Form C relays. Battery (i.e. Logic_Sense and Mtr_Sense) and shore power (i.e. Shore_Sense) are connected as indicated in Figure 2 above. These relays will switch the power supply between the batteries and shore power. When shore power is applied and the shore power is on, the relay coils will be powered. As soon as the coils reach the threshold currents, the switches of the corresponding relays will switch, and the batteries will be disconnected, and power will be supplied solely from shore power.

B. Voltage Regulation

In order to supply the required voltages to various components on the ASV we have included the use of regulators into our design. The type of regulator and power supplied to each device is outline in Table 1.

TABLE 1
VOLTAGE REGULATOR

Regulators		
Power	**Devices**	**Reg. Type**
12V @ 4 A	Emer.Stop Relays LIDAR Wireless Bridge	Switching
12V @ 1.5 A	Power Relays	Switching
8V @ 1.5 A	Compass Cameras	Switching
5V@ 3 A	FPGA GPS Display RC Receiver Microcontroller Servos General IC's	Switching
3.3V @ 0.8 A	Xbee Wireless	Linear

C. Voltage and Current Sensing

Monitoring the power consumption of the vehicle will include voltage and current sensing. The microcontroller will read and multiply these values together to determine the power consumption. The information collected will be displayed on the external displays and also be available to the main computer. Knowing our power consumption under different loads will enable the team to determine an approximate run-time for the ASV. In addition, we can use this information to gather real time data particularly regarding the amount of current the motors are drawing while testing.

In order to sense voltages on the ASV we have connected the positive terminal of the power source to an analog to digital converter (ADC). Special consideration was implemented using this design to account for the innate restriction of the analog to digital converter to only compare voltages up to their input or reference voltage. For our application we used an ADC with a reference voltage of 5V DC. In order for this design to work we needed to bring all three of the power source voltages (Logic Batteries, Motor Batteries, Shore Power) down to a safe level for the ADC. A simple voltage divider using two resistors allowed for this. The logic power on the vehicle can operate using a wide voltage range of about 14V DC to 30V DC meaning that dividing this voltage by a factor of six would give the ADC an input range of about 2V to 5V DC. By using a voltage divider the calculations are easy for the microcontroller as it is a purely linear calculation.

Voltage sensing on the ASV is crucial to the vehicle for battery protection. Our major source of battery power comes from lithium polymer batteries. We have chosen these batteries because of their proven high energy to weight ratio. Each lithium polymer cell can range from 2.7V DC discharged to a full charge of 4.23V DC with the nominal voltage at 3.6V DC [2]. If for any reason these batteries drop below their safe operating range, we have immediate knowledge of the issue and can replace the batteries before they become damaged. The second source of power comes from shore power which consists of an AC to DC power supply with a known voltage or using two deep cycle batteries to avoid power regulation, malfunctions.

Current, the other half of the power equation, can be measured in multiple ways. In order to sense the low currents, for both logic and shore power, we have chosen to use the sense resistor method. This method will use the MAX9920 as seen in Figure 3 with the adjustable gain and analog output. Having the analog output reduces the amount of communication needed. The footprint for a printed circuit board using this sense resistor method is comprised of the sense resistor itself inline with an integrated circuit to measure the differential voltage and amplify the signal. For these current values, the sense resistors do not drop the voltage significantly and were therefore a good choice.

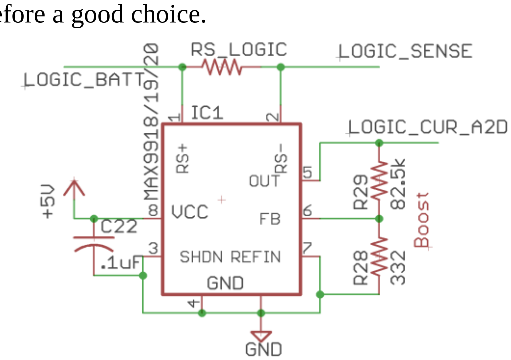

Fig. 3. Schematic for shore and logic current sensing

For the high current sensing we utilized the LEM CAS 15-NP. The nominal current rating on this device is 15 Amps which is closer to our current draw. In addition, it is capable of measuring up to 48 Amps with the device capable of withstanding currents up to 250 Amps meaning if the vehicle draws above 48 Amps we are not damaging the device. Another benefit is that it takes a standard 5V DC input and ground. We can determine the output voltage range of the device, 2.5V to about 4.5V, which is an acceptable range for the analog to digital converter. This device was chosen because it was able to integrate with the PCB board but had long exposed leads so we were able to hand solder a low gauge wire on the bottom to bring the current off of the board. Fig. 4 displays the schematic used to accomplish this task.

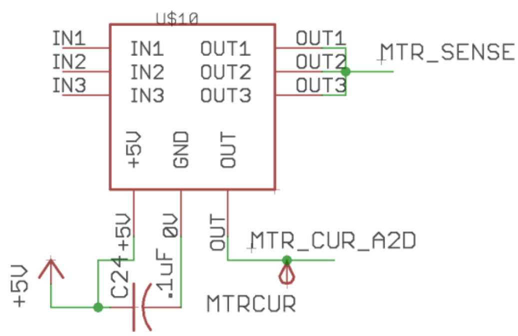

Fig. 4. Schematic for motor current sensing

IV. ASV Microcontroller

The design of our project requires that we be able to constantly monitor battery voltages, light intensity and temperature. Processing these various inputs will require some low level computing. For our computational needs we selected the ATMega328P microprocessor. The ATMega328P has four ports defined as analog to digital converters with 10 bits of resolution. For our purposes we have determined that a couple of bits will be disregarded due to noise or hysteresis, therefore we will only be looking at 8 bits of true resolution. With four channels, we will have as much bandwidth as we need for signal processing and then have some remaining should the need arise. The core speed of the ATMega328P is at 20 MHz with a total throughput of 20 MIPS. It also boasts a true read-while-write feature. It is easy to program using the ICSP versus adding USB functionality. This saves us board space, cost, and complexity as the ICSP programming is more than sufficient.

A. Power

It is important to provide clean power to the ATMega328P. This includes feeding it with a regulated 5V power and a steady voltage for its ADC reference. The 5V power line on the chip is not completely susceptible to small variations in the line but the ADC reference voltage is detrimental to the conversion of our analog signals; any perturbation on the line could potentially throw off the sensor readings. In order to provide the clean power needed for the ATMega328P careful consideration was made in selecting its accompanying hardware. The hardware selected accomplished filtering out the unwanted noise stemming from the voltage regulators.

A. I2C Interface

The I2C interface allows us to talk to multiple devices without the need for multiple nets on the board. The number of devices that can actually be hooked up on a given bus is determined by how each device on the bus is addressed. Figure 5 shows the hardware setup for any ports that will be used as a two-wire interface. In the figure, R_p is usually in the range of 1.8kΩ to 2.2kΩ. The outputs for this interface are “open-drain” drivers, which mean that it can drive its output low but not high. For that reason, one generally ties the outputs to V_{CC} via a resistor for a normally “high” output. The I2C interface allows us to have multiple devices on the network communicating via I2C. As our chosen microcontroller has only one I2C port this was a crucial setup into meeting our design requirements. We are utilizing the I2C bus for the A2D converters. We were going to also put the LCD screen on the I2C bus but determined that the screen refresh rate would be too slow as the I2C bus was also polling the A2D converters.

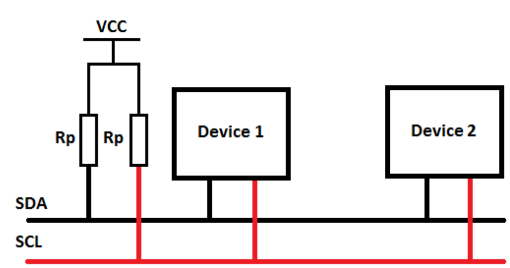

Fig. 5. Two-Wire hardware setup

IV. ASV FPGA

A Xilinx's Spartan3E (XC3S500E) FPGA was incorporated into our design for its added flexibility to the system. The FPGA's added flexibility stems from how the device executes code. An FPGA executes all lines of code at the exact same time, therefore greatly increasing the response time of our motors. The FPGA would be responsible for sensing analog pulse width modulated signals (PWM) and translating the information into digital values. This process will not include a hardware based digital to analog converter; it will all be implemented in code. The FPGA will also mux the digital value from the pulse width modulated signal with a similar value sent by the on-board intelligence as seen in Figure 6. This number will be in the same format as the converted PWM signal. This muxed number will be an 8 bit number that relates the spread of numbers between 0x00 to 0xFF to the spread of pulse widths between 1ms and 2ms. The 1ms to 2ms pulse width is based on the standard servo PWM format and is generally what motor drivers expect to receive. A pulse width of 1.5ms (or 0x80 in digital) would represent the state at which the motors do not do anything. The state to indicate full-forward is a pulse width of 2ms (or 0xFF in digital), while the state to indicate full-reverse is a pulse width of 1ms (or 0x00 in digital).

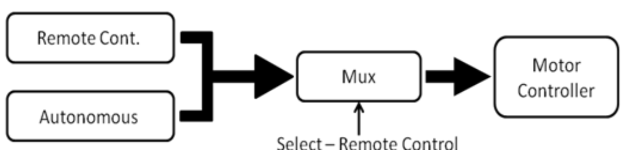

Fig. 6. Two-Wire hardware setup

A. Implementation of Asynchronous Serial

Computers, microcontrollers and FPGAs generally use a more common form of serial communication derived from the RS-232 standard. This derivation generally uses the Rx and Tx lines with a ground wire so that the transmitters and receivers can share the same ground reference.

The basis behind asynchronous serial is to have a start byte sequence that has to be recognized by the receiver in order to accept it as a valid packet. We chose to use asynchronous serial as it greatly simplifies the design of the system and thus does not require additional hardware implementation on the FPGA. Valid signals for the derived RS-232 protocols can get up to 25V therefore the challenge of using serial communication on an FPGA is to be able to accept such signals without damaging the internal circuitry. This is achieved by using a MAX232 which is a TTL converter. This chip will take the regular serial lines and convert them to levels that are safe for the FPGA.

V. ASV COMMUNICATION

The ASV consists of a number of sensors, motors, microcontrollers, and a computer that need to communicate with each other reliably. It is highly desirable to use a communication system that is both simple and reliable. In order to establish a reliable communication system both a wired and wireless platform were implemented.

A. Wireless Communication

Implementing a long range wireless form of communication, to transfer various sensor activities within the ASV, is crucial in gaining the utmost control and understanding of the ASV status. To satisfy our wireless requirements we used MaxStream's XBee module. This platform provided us with low power consumption, and satisfied our minimum 900 feet ("open-line-of-sight") distance range.

In order to ensure that we don't receive corrupted data over our wireless platform, we decided implement an error checking protocol. This system is based on an eight byte structure that combines two start bits (0x23 and 0x25, for "#" and "%") along with one byte for a command and four bytes of data. The eight byte is used as a checksum. Using this protocol we can eliminate erroneous data from our data stream.

B. Wired Communication

The wired communications within the ASV combined the use of multiple forms of technology to reach our desired specifications. We have connected the on board computer via USB to the RS-232 of the FPGA. The FPGA communicates to the microcontroller via RS-232. For simplicity and ease of compatibility with the various COTS sensors employed on the ASV we opted to use the RS-232 for interconnection between the microcontroller and the LCD displays. This topology was used for both on board and on our remote.

VI. ASV SENSORS

In order to provide various ASV feedback multiple sensors were implemented into our design. These sensors include temperature, humidity and ambient lights sensors.

A. Temperature

We will be providing temperature sensing for two different electrical boxes within the ASV, the MAIN box and the MOTOR box. The MAIN box contains all of the electrical circuitry for the ASV and the MOTOR box houses all of the motor controllers for our ASV. For the MAIN box we opted to use two Maxim's DS18S20 digital temperature sensor. This particular sensor provides a 9-bit Celsius temperature reading and communicates over a 1-wire bus. The 1-wire bus requires only one data line to communicate with our microcontroller. In addition it is accurate to ±0.5°C, over the range of -10°C to +85°C, which more than satisfies our needs. In addition the DS18S20 has a unique 64-bit serial code that allows for multiple temperature sensors of the same model to be connected to the same microcontroller. This feature allowed us to place another temperature sensor within the MOTOR box. There are two temperature sensors placed top and bottom of the board. From this we are taking an average to determine a mean temperature. Having the temperature insight into these boxes will provide us with a better understanding the environment within our electrical boxes.

B. Humidity

In order to better understand what is going on inside the MAIN box we have chosen to place Honeywell's HIH-5030 humidity sensor within the box. This sensor will read humidity values in the range of 10% to 90%, is compatible with our 5 V power supply and provides an accuracy of ±3.0% RH. We predict the humidity inside the box will be low but just to ensure our electronics are within their safe operating conditions.

C. Light Sensor

In previous competitions the ASV was required to recognize a colored buoy and navigate around this object. However, the amount of ambient light has been determined to play an important role in color identification. If there is less light the color appears darker than if there was a significant amount of light; in which the color would take on a lighter shade. To avoid the possibility of misreading a color we have implemented a method in which the true color can be properly established. In order to determine the direction in which the sun is coming from, four photo resistors were placed with one at each of the four navigational directions around a plastic project box (as seen in Fig. 7). The photo resistors to a voltage divider network. The midpoint of the voltage divider, V_o was used to measure the output signal. This voltage signal through an A2D and simple computer algorithm converted the voltage values to LUX values.

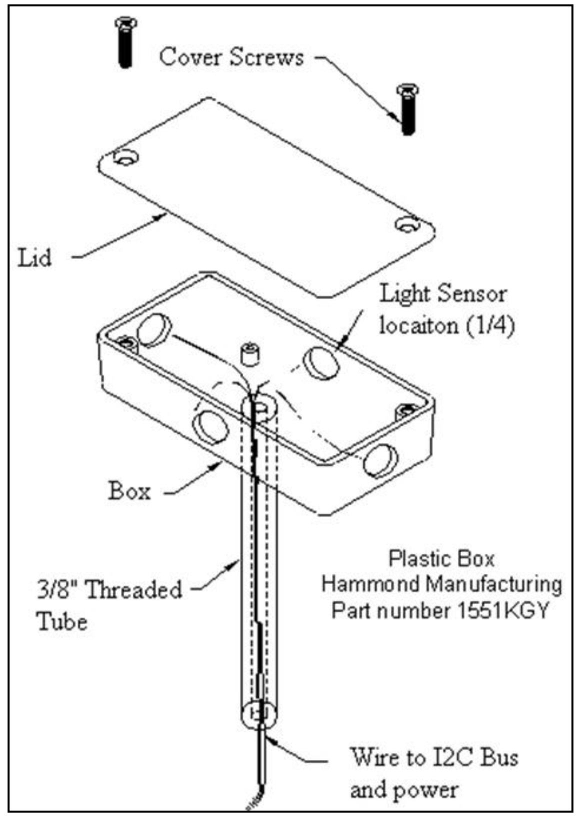

Fig. 7. Light Sensor Assembly

D. Dynamic Fan Control

The need to control our fan speed is primarily driven by our need to reduce our power consumption. In previous designs of the vehicle, fan speed was set to run at full blast regardless of the temperature within the system, which induces an unnecessary current draw on the system. The current fan being used is a high power and high airflow fan that can take up to 24V at a given time with a max current draw near 1A. This is achieved by connecting one of the outputs of the microcontroller to a FET driver, which then controls a FET. If at any given time our batteries were to drop to 20V, at 100% duty cycle, the maximum voltage the fan will receive is 20V, we chose not to provide a higher voltage thus we won't allow the fan to use up more power if the batteries are losing voltage. In this case we will prioritize the power going to the computer, microcontrollers and FPGA over the fan. In the event that the vehicle should reach a critical temperature in which the overall efficiency begins to drop, the fan will be at 100% duty cycle.

The voltage being supplied to the fan will stem from board power itself. This is unregulated power that is fed to the fan. The regulation of the fan speed will be determined by making sure that regardless of what the input voltage to the fan from board power is, the fan speed will remain constant. This will be monitored by using the temperature sensors strategically placed throughout the board to monitor board temperature itself. By figuring out what voltage the board power is really at, the FPGA, via the microcontroller can adjust the duty cycle appropriately. The voltage conversion in this case will be a step down DC to DC conversion; this is considered a buck setup.

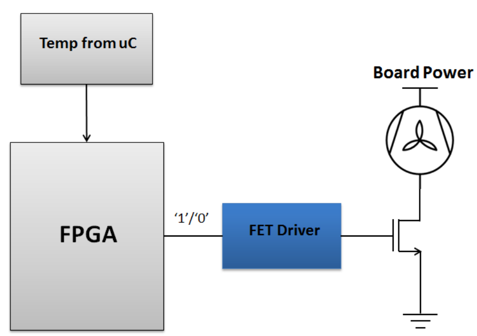

Fig. 8. Dynamic fan diagram

The microcontroller was not able to directly regulate the dynamic fan control due to its inherent switching frequency. The ATMega328P's PWM operated at 11MHz whereby our FET driver needed a switching frequency around 100kHz so as to not draw excessive current. In dropping the frequency of the microcontroller's PWM it altered all time dependent processes on the microcontroller. Thus as a workaround we now send the temperature value to the FPGA which then generates the necessary signal to drive our FET via the MIC4420, the FET driver.

VII. ASV Displays

Monitoring the vitals of the ASV was accomplished using two LCD displays, one on the MAIN box and another on our remote panel. These LCDs display the ASV vitals for multiple sensors. The LCD display has several interface options, such as I2C, and RS232. To ensure that the display is getting power only when we need to read measurements, we have the ability to reduce power consumption by reducing the backlight power, as well the main display power. Fortunately, this display has designated I/O pins for this purpose, so we control these settings using the microcontroller. We will use four buttons to control the LCD screen. The LCD will display current, voltage, power, temperature and humidity values, the system status, the time elapsed since the power has been changed to batteries, and the ambient light direction with respect to the boat.

VIII. Software Structure

The structure of our code follows the concept of finite state machines to simplify our processes on the FPGA. In order to actually use serial communication on an FPGA we had to bit bang the data lines. The process is highlighted below in figures 9 and 10. Every time we enter a new state we start eh sampling generator and loop through for as many times as there are bits in that particular process.

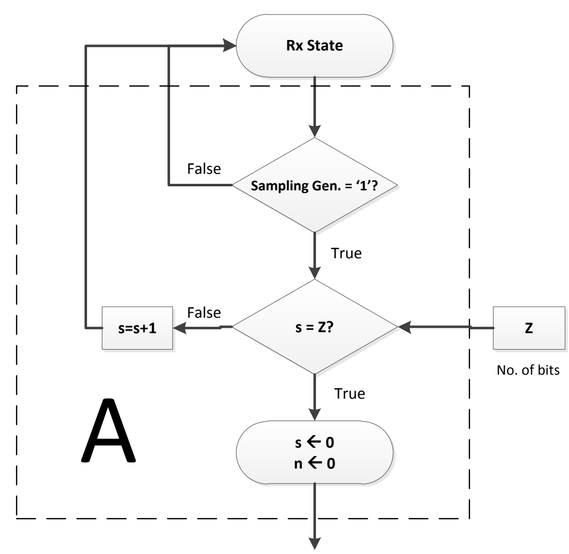

Fig. 9. State Machine Component used in FPGA UART

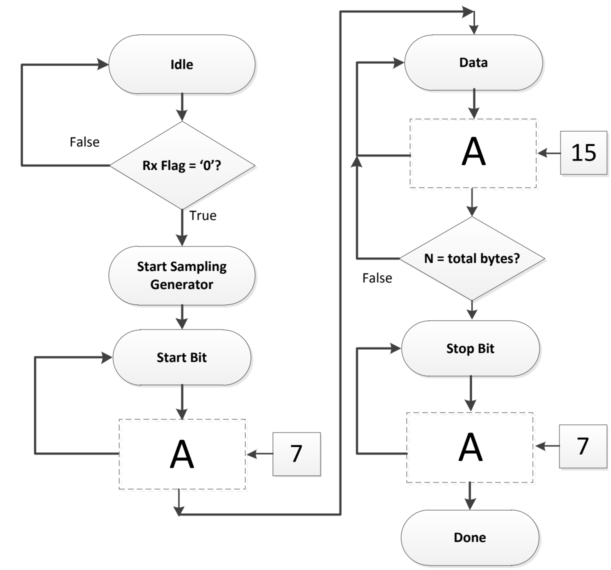

Fig. 10: Complete State Machine used in FPGA UART

VIV. Conclusion

The scope of our senior design project bestowed upon our group a greater understanding of how all our engineering classes contribute to the design and build process. We not only learned a lot about the design build process but the importance of communication, patience and understanding with respect to working as a group. We are confident that our designs will aid our team into mastering the upcoming competition challenges that await in this year's ASV competition.

Acknowledgments

We would like to thank all of our sponsors, including IST, Northrop Grumman and the SGA of the University of Central Florida for all of their grateful contributions, and the endless support from the Robotics club at the University of Central Florida.

References

[1] R. G. Keen, "Advanced Power Switching and Polarity Protection for Effects", 1999, http://www.geofex.com/Article_Folders/mosswitch/mosswitch.htm

[2] MaxAmps, "Lithium Polymer Charging/Discharging & Safety Information," http://www.maxamps.com/lipo-care.php

Mike Podel is an Electrical Engineering undergraduate student with a strong interest in Robotics. He will be graduating this semester with a BS in EE and will pursue his Masters at UCF in the fall of 2011. He has many years of experience including 3 years of working at Lockheed Martin and maintaining an active role at the Robotics Club at UCF; where as a group they engineer fully autonomous vehicles from the ground up and participate in competitions annually.

Christina Sylvia is an Electrical Engineering undergraduate student whose studies concentrate in EMF and Semiconductors. She is an active member of Tau Beta Pi and the Institute of Electrical and Electronics Engineers (IEEE). Upon completing her Bachelors degree she plans on pursuing both her Masters and PHD degree in the field of Biomedical Engineering with emphasis on NEMS devices.

Stanislaus Bernard was born in India in 1989. His family moved to Singapore in the year 1995, to Maryland, USA in 2000 and finally to Florida in the year 2004. He has always had a passion for all things electronic T.V.'s and fans). Stanislaus has already been accepted by UCF's M.S.E.E program for the Fall of 2011 and will pursue from a very young age (starting with the disassembling of radios, the specialization of power electronics.

Gor Beglaryan was born in Yerevan, Armenia in 1986. He moved to the US in 2005 and was accepted to UCF in Spring 2007. Electrical Engineering was a big change for Gor, since his original field of study in Armenia was Economics. During his years at UCF Gor took every challenge as an opportunity to acquire new knowledge, and enhance is critical thinking skills. He has been accepted to California State University of Northridge as a graduate student for Fall 2011, and will continue his education in EE specializing in Microwave and Antenna Engineering.