<u>EE 403W Critical Design Review:</u>

S.P.I.R.I.T. II Rocket Timer

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Abstract

The project that we have undertaken for EE 403W during spring semester 2001 is to design a timer for the SPIRIT II rocket, which has a tentative launch date of November 2002. For the design, two Evaluation Boards (68HC11 microprocessors) will be used as a fail-safe timing system. The timer is capable of timing twelve events that need to be programmed into the timer to help conduct wind experiments in mesosphere. An RC circuit will be designed to eliminate voltage spikes as well as voltage supply drops above or below 5 V, which would cause the HC11 to malfunction. The RC circuit design will be fabricated on a PC board, and this PC board and the two 68HC11 microprocessors will be encased in a vibration-resistant box inside the payload. Once inside the payload the timer can be programmed via external serial or LAN line cables, allowing the timer to be adjusted from outside the rocket with SPIRIT owned equipment or a PC. A financial estimate and Gantt chart are included in the appendix to help organize the budget and maintain a time schedule for the entire length of the project.

Introduction

Our task is to design a main rocket timer for the payload of the SPIRIT II rocket. SPIRIT (Student Projects Involving Rocket Investigation Techniques) is a student-run organization at Penn State in which students gain hands-on experience building a complex payload for the rigorous sounding rocket environment. The successful launch of the SPIRIT I rocket included a student-built transmitter, PCM encoder, and four student experiments. The payload structure and rocket systems were also student built. The objective of the SPIRIT II rocket, which has a tentative launch date of November 2002, will be to conduct wind experiments in the mesosphere.

The timer for SPIRIT II will trigger timed events to occur during the 10-15 minute launch. Some of the events include pyrotechnics, the deployment of a balloon used for wind experiments using a GPS tracking system, and other specified events. According to our technical contact, Professor Tim Wheeler, there are up to twelve timed events that need to be sequenced during the rocket flight.

Our group has selected an HC11 microprocessor-based design for the timer. This solution is the most realistic and feasible. The SPIRIT II timer design meets the following specifications:

- Reliable and accurate to 0.33 seconds
- High vibration and low atmospheric pressure sustainability
- Output user-defined enable levels
- Output Square timing pulses

Other factors that our design considers include designing a circuit to regulate power spikes and outages and correcting these problems to ensure satisfactory timer operation. For reliability reasons, two HC11 microprocessors will be used in the event that one of the HC11 chips fail. We will use a digital logic design so that when one of the chips fails, it will turn off, preventing extraneous outputs. All of the circuits that need to be designed for the SPIRIT II timer will be fabricated on a PC board and encased in a box to secure the timer inside the payload. The final specification of the SPIRIT II timer is that it must be remotely changeable using LAN lines. These specifications have been considered in our design.

In the following sections, our design solution of the SPIRIT II rocket timer will be discussed in further detail. Also included is a statement of work, a cost analysis for the entire project, and a Gantt chart that maps out our project schedule.

Statement of Work

The team will develop the SPIRIT II rocket Timer that meets the technical specifications given by the SPIRIT II group. We design and build the timer, and will also write user's guide that will give all users the ability to understand and reconfigure the Timer.

The deliverables of this project are:

- A working Timer capable of withstanding the forces and vibrations of high-speed travel, with 12 events and an accuracy of 0.33 seconds.
- An instructional procedure for reprogramming the Timer.
- A copy of the HC11 assembly code.
- Test results verifying the satisfactory operation of the Timer.

Responsibilities:

Mike: Code writing and debugging

Steve: Code writing and debugging

Travis: Power systems and control

Chris: Schematics and board layout/fabrication (Help with power and code)

Matt: Schematics and board layout/fabrication (Help with power and code)

Rationale

The team chose to use HC11 Trainer Boards over the P-Brain HC11 Microcontroller used in the initial design proposal. The comparison chart below summarizes the pros and cons of each piece of equipment.

	P-Brain	**Trainer Board**	**Edge**
Cost	$136 Each	$80 Each	Trainer Board
Memory	256 bytes RAM, 2Kbytes EEPROM	256 bytes RAM, 512 bytes EEPROM	P-Brain
Re-programmability	Controlled by switches	Controlled by jumper blocks	Push
Size	Small module (50 Pins)	Large board (output pins)	P-Brain
Implementation	Needs 1 PC Board	Needs 1 PC Board	Push
Complexity of PC Board	Multiple Layers	1 Layer	Trainer Board
Cost of PC Board	Expensive	Cheap	Trainer Board
Programming/Testing Platform	486 based PC with Motorola PCBUG11 Software	Any computer with Terminal Program	Trainer Board

In the cost category, the Trainer Board has a significant advantage. By saving money on the microprocessor, we can reallocate our funds to other areas, such as PC Board fabrication. The P-Brain has a larger amount of memory, but we have determined that even with less memory, we can fit the entire program on the Trainer Board. Since re-programmability is difficult for both solutions, this did not factor into our decision. The P-Brain module is significantly smaller than the trainer board, however the PC board needed for the P-Brain would be 2-4 layers, and would cost a lot more money than the single layer board that would be required for the Trainer Boards. Finally, to test and program the P-Brain module, a 486-based PC is required at the test site. Since the Trainer Boards have a built in monitor program, any PC with a terminal program will work. Due to the advantages that the trainer board offers, as well as budgetary constraints, we have decided that we will be using the Motorola Trainer Boards to build our timer.

The team chose using the IGBT relays because if they malfunction they are driven low. We considered mechanical relays, finding drawback with their bulky size and their questionable reliability in high vibration environments. We also considered solid-state electrical relays, finding drawback with their latching in the ON position. The IGBT provides a space-effective, error free solution choice for relays.

We chose implementing an AA battery backup system to power the boards in event of main power failure. This system is a very cost effective solution with no moving parts that would be hurt by vibration. The AA batteries are cost-effective, readily accessible and do not need recharging. We considered using a remote control battery, finding drawback with high cost and recharge requirement. The AA battery backup system provides the easiest and most stable solution to bypass main rocket power failure.

We chose to have Bob Wilson to help us with board fabrication. Bob Wilson, an employee at the ARL, does board layout and design. Meeting with Bob we found that he was the most affordable and helpful aiding us with board fabrication. We considered Joe Portelli, also employed by the university, finding drawback with his high price. We also considered using an online source, AP Circuits, finding drawback with their limited knowledge of specific questions about board design. They take the finalized Gerber file and fabricate the board but do not provide answers to questions on how to obtain the best Gerber file. Bob Wilson provides the most convenient and affordable solution to fabricating a PC board.

Implementation

Our Project implementation can be broken down into three main tasks: the Timer, the alternate power supply, and the PC board that holds it all together. Figure I shows the basic Timer block diagram.

The first task to be solved was the alternate power design. Since it was necessary for the system to be in operation regardless of rocket conditions, a simple battery operated system that provided uninterruptible power throughout the flight was a logical choice. To implement this alterative power supply only when needed was the major challenge in designing this task. The solution is to put a diode between the back-up battery and the rocket power source, the theory being that when the rocket voltage fell below +15V the diode would become forward biased and supply the Timer with the back-up voltage. To keep the back-up battery from operating the Timer when not in flight, a latching switch will be placed between the back-up battery and the Timer. Capacitors were implemented on the main voltage source for safety reasons because there are no ideal diodes: they require a few microseconds to forward bias, which could allow a voltage drop, if the main power supply fails. A voltage regulator will also help keep a constant voltage going to the Timer, but its main function is to allow the back-up battery to be at a lower voltage that rocket power. Timer outputs control the gate of an IGBT semiconductor, which then sends +15V to each of the experiments. The use of IGBTs allows the Timer to be isolated from the rest of the rocket.

The next task was to design that actual timer system. Two Motorola M68HC11EVBU Trainer Boards, based on the Motorola MC68HC11E9 microcontroller will be used as the "brain" for the timer. To accomplish the actual timing, a very simple algorithm was developed. The microcontroller will simply count overflows of the built in Free-Running Counter. The Free-Running Counter overflows approximately every 0.5 seconds, which means that to program the timer, a simple mathematical conversion must be made. Two processors are used to provide a fail-safe timer. Both Trainer Boards run the same program in parallel with each other. All events are tied together with OR gates. There are two main types of failures that can be detected: Computer Operating Properly (COP) failures and Clock Monitor failures. The COP is a watchdog timer that will be used to ensure that the processor runs the program properly. The Clock Monitor checks the clock speed of the crystal oscillator to ensure that it is running at the proper rate. If either the COP or the Clock Monitor fail, the processor will reboot itself to a special part of code that will shut itself off, ensuring that the failed processor will not trigger events improperly. To make the processor shut itself off, an IGBT is attached to the power line of the Trainer Board. The control line of the IGBT is attached to the output of a T Flip-Flop. If the processor fails, it will execute a small portion of code that will force it to toggle the T Flip-Flop, which turns off the IGBT and shuts down the failed processor.

To make the final design compact and reliable, we decided to get a PC board fabricated so that all parts could be soldered onto the board for a tight fit. Calling the contacts Ms. Kinsenwether provided, we were able to find several companies that were eager to serve us. In conducting interviews with some of the companies, we found that our budget would not support a full outsourcing of this task. We were then able to find a University employee who could do the board within our budget. For this person to complete the board we are giving him schematics, device numbers and pin configurations. He is going to use the information and produce a Gerber file of the board layout, which will be used to program the milling machine. With the board completed, we will then use the Industrial Engineering lab to populate and complete the PC board.

Conclusion

The SPIRIT II Sounding Rocket Project is a long-duration research project that embodies the hard work of a team of Penn State undergraduate students. These students will spend over 3 years engineering different experiments that will be able to measure the winds in the mesosphere. While each experiment may differ in its purpose, many share a common reliance on the SPIRIT II Timer. The Timer may not be the most important part of the SPIRIT II project, but without a properly working timer the SPIRIT II project will fail in its attempt to successfully measure the winds in the mesosphere.

Our group clearly understands the importance of the SPIRIT II Timer, and the profound effects the timer will have on the entire SPIRIT II project. In adherence to these beliefs and the parameters set forth by our sponsor, the Timer will:

- Signal up to10 events, within .33 seconds precision, either with an enable level or a square timing pulse
- Function through both power spikes and power interruptions
- Function through the high vibrations and low atmospheric pressures up to 120 km altitude
- Have timing signals programmable remotely via a serial port to PC/laptop
- Have the initial time (T_0) set to rocket liftoff
- Fit within the space requirements of a 4” x 6” card

While we have put forth the maximum effort to insure the proper design and functionality of the Timer, we have not overlooked the financial planning included in this project. We designed a Timer that is efficient, cost-effective, and fits within the budget restraints of the project. We are confident in the strength of our initial design, as well as our ability to engineer and construct the SPIRIT II Timer.

Appendix

Financial Calculations

Wages:	15 Weeks @ $350/Weeks @ 5 engineers	= $26,250.00
Fringe:	15% of Total Wages	= $3,937.50
Overhead:	40% of (Total Wages + Fringe)	= $12,075.00
Parts List:	2xM68HC11EVBU Trainer Board @ $80.00 Each	= $160.00
	4xPALCE20V8H-25PC/4 PAL @ $1.00 Each	= $4.00
	2x100µF Capacitor @ $0.75 Each	= $1.50
	14xTO-220AB IGBT @ $2.50 Each	= $35.00
	1xDigital Voltage Regulator @ $5.00 Each	= $5.00
	2xPower Diodes @ $4.00 Each	= $8.00
	Miscellaneous Materials (PC board, etc.) @ $200	= $400.00
	Actual Cost of Parts	= $613.50
Parts estimate:	200% of Actual	= $1,227.00
Profit Margin:	10% of Total cost of Project	= $4,348.95
Total Cost of Project:		**= $47,838.45**

*Price information for Motorola M68HC11EVBU taken from EE department at Pennsylvania State University

*Price information for PC Board obtained from Electrical Engineer Bob Wilson.

*All other prices were obtained from the vendor, Allied Electronics at the web site: http://www.alliedelec.com/