UNIVERSIDAD SAN FRANCISCO DE QUITO USFQ

Colegio de Ciencias e Ingenierías

Upgrading the data acquisition system of WCDs used in LAGO Project, phase 1: building and testing of the data acquisition interface board

Proyecto de Desarrollo e Implementación.

Bryan André Talavera Villaseñor

Ingeniería Electrónica

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Bryan André Talavera Villaseñor

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Nombre del profesor, Título académico	Dennis Cazar, PhD en Física
Firma del profesor	______________________________

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Firma del estudiante: ____

Nombres y apellidos: Bryan André Talavera Villaseñor

Código: 00107758

Cédula de Identidad: 171420878-0

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RESUMEN

El presente trabajo muestra los primeros pasos para el desarrollo de un nuevo Sistema de Adquisición de Datos (DAS) para los Detectores Cherenkov de Agua (WCD) usados en la Colaboración LAGO. El DAS se basa en la tarjeta open source RedPitaya. Dos circuitos impresos (PCBs) han sido desarrollados: Una tarjeta de extensión para interconectar la RedPitaya con un Fotomultiplicador (PMT) y con sensores ambientales; una tarjeta de polarización para para interconectar la RedPitaya a un Fotomultiplicador de Silicio (SiPM). Se desarrollaron modulos Software en LabView y Matlab para probar el DAS. Se muestra una primera aplicación del sistema: la determinación del punto de trabajo de un PMT y un SiPM.

Palabras clave: LAGO, Detección de partículas, SIPM, PMT, Sistema de adquisición de datos, RedPitaya.

ABSTRACT

In this work, we present the first steps in the development of a new Data Acquisition System (DAS) for Water Cherenkov Detectors (WCD) used by the LAGO Collaboration. The DAS is based on the open source board RedPitaya. Two printed circuit boards (PCBs) have been developed: An extension board to interconnect RedPitaya with a photomultiplier tube (PMT) and environmental sensors and a biasing board used to interconnect RedPitaya to a Silicon Photomultiplier (SiPM). Software in LabView and Matlab was developed to test the DAS. We show a first application of this system: setting the working point of the PMT and SiPM.

Palabras clave: LAGO, Particle detection, SIPM, PMT, Data acquisition system, RedPitaya.

Upgrading the data acquisition system of WCDs used in LAGO Project, phase 1: building and testing of the data acquisition interface board

Bryan Talavera*, Dennis Cazar*, for the LAGO Collaboration†
* Universidad San Francisco de Quito USFQ, Colegio de Ciencias e Ingenierías "El Politécnico"

† The Latin American Giant Observatory (LAGO) see the full list of members and institutions at http://lagoproject.org/collab.html
E-mail: bryan.talavera@estud.usfq.edu.ec

Abstract—In this work, we present the first steps in the development of a new Data Acquisition System (DAS) for Water Cherenkov Detectors (WCD) used by the LAGO Collaboration. The DAS is based on the open source board RedPitaya. Two printed circuit boards (PCBs) have been developed: An extension board to interconnect RedPitaya with a photomultiplier tube (PMT) and environmental sensors and a biasing board used to interconnect RedPitaya to a Silicon Photomultiplier (SiPM). Software in LabView and Matlab was developed to test the DAS. We show a first application of this system: setting the working point of the PMT and SiPM.

Resumen—El presente trabajo muestra los primeros pasos para el desarrollo de un nuevo Sistema de Adquisición de Datos (DAS) para los Detectores Cherenkov de Agua (WCD) usados en la Colaboración LAGO. El DAS se basa en la tarjeta open source RedPitaya. Dos circuitos impresos (PCBs) han sido desarrollados: Una tarjeta de extensión para interconectar la RedPitaya con un Fotomultiplicador (PMT) y con sensores ambientales; una tarjeta de polarización para para interconectar la RedPitaya a un Fotomultiplicador de Silicio (SiPM). Se desarrollaron modulos Software en LabView y Matlab para probar el DAS. Se muestra una primera aplicación del sistema: la determinación del punto de trabajo de un PMT y un SiPM.

Index Terms—LAGO, Particle detection, SIPM, PMT, Data acquisition system, RedPitaya.

I. Introduction

LAGO is an extended cosmic rays observatory composed of Water Cherenkov Detectors (WCD) placed throughout Latin America [1]. One of the LAGO goals is to design and build new high-performance, low cost Data Acquisition System (DAS) for particle detectors. WCDs used for astroparticle detection whiting LAGO Project are high speed Data Acquisition Systems [2], which process and store electrical signals generated by Photo Multiplier Tubes (PMTs) when astroparticles (muons, electrons, etc) hit the WCD. Nowadays, high performance data acquisition systems like RedPitaya are available at a very low cost (<300USD). RedPitaya consists of two fast analog input channels with a 125MSPS ADC and a System on Chip (SoC) (FPGA plus uC), USB, Ethernet and HDMI interfaces and SD bay to load a Linux Operating System[3]. In order to interconnect the PMT with RedPitaya, an interface board providing bias voltages, control voltages and interconnection with sensors must be developed. WCDs developed by the LAGO Project use mainly PMTs particle sensors. PMTs are widely used in High Energy Particle Detection (HEPD). These devices are solid, reliable and are based on a well-known technology; on the other hand, they are expensive, sensible to magnetic fields and use high voltages (aprox. 2000V) to operate [4]. Years ago, a silicon version of a PMT was developed, the Silicon Photo Multiplier (SiPM). These devices are small, cheap and need a low voltage to operate (max 70V) [5]; but their characterization shows temperature dependence of breakdown voltage and cross-talk [6], [7]. Nevertheless, they are a valid alternative to astroparticle detection. The LAGO Project plans to incorporate scintillator detectors plus SiPMs to develop a Hybrid WCD. The present work describes the development of two prototype of boards; first one is an interface board between the RedPitaya and the PMT and second one is a Multiple SiPM bias board used to connect SiPM's signal to the RedPitaya. A test software was developed in LabView to test the system before connecting RedPitaya. A first application of the system is described, i.e, finding the working point of a 9" R5912 Photonis PMT and a SensL MicroFC-60035 SiPM. Preliminary data acquired through the RedPitaya is also reported.

II. Hardware Design

Two boards were designed for this project. The first board provides all bias voltages for the PMT, an interface connection to the RedPitaya and extension connectors of serial ports for the positioning, pressure and temperature sensors. The second board is an 8 channel board, it provides the biasing voltage to up to 8 SIPMs and an amplification stage of the signal generated by SiPMs.

A. PMTs Extension Board

This board is divided into three main blocks: biasing voltage generation for the PMT; high voltage control (setting and readout) and interconnection to the GPS, pressure and

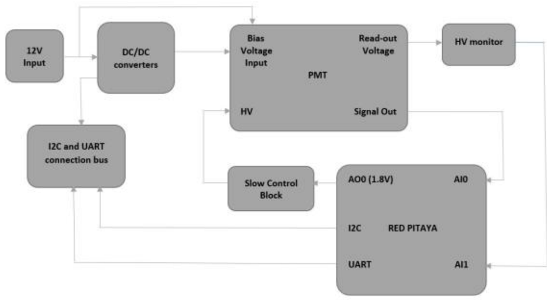

Figure 1. PMT's circuit block diagram. This block diagram shows how the board will serve as an interface to connect the Red Pitaya and all environmental sensors

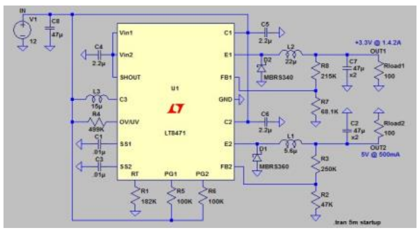

Figure 2. First DC-DC converter schematic. LT8471 is configured as a 12V to 3.3V (channel 1) and 5V (channel2) Sepic converter.

temperature sensors trough serial interface (UART and I2C) . The block diagram is shown in Figure 1. This board should implement:

- DC-DC converter block: Consists of two LT8471 [8], both with two channels and configured as 12v to 3.3V @ 1.5A (Figure 2); 5V @ 400mA, 3.3V @ 400mA and -3.3V @ 400mA (Figure 3) to bias the PMT, OPAMs and all environmental sensors.
- PMT's HV control block: The Red Pitaya generates a 0-1.8V PWM signal. A 0-2.5V conditioning circuit is used to amplify this signal and, with a Hamamatsu C20 power supply, generate the HV for the PMT. The actual HV applied to the PMT is monitored from a pin called "Vread-out" of the PMT base that gives a DC signal from 0 to 5V; using a voltage divider this signal is limited to 3.8V, which is the maximum input voltage of the RedPitaya's analog inputs.
- I2C and UART connector bus: The board has four I2C serial connectors to plug-in a wide variety of sensors such as temperature, pressure, humidity, etc; and one UART extension for the GPS. All sensors are biased with the 3.3V generated by the extension board.

B. SIPMs Bias Board

This board is modular and it has 8 input channels. Up to 8 SiPMs can be biased independently, and, since the SiPM power consumption is very low [9], up to 4 boards (32 channels) can be connected in a daisy chain with only

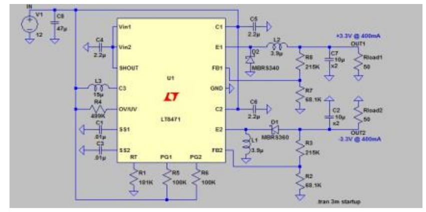

Figure 3. Second DC-DC converter schematic. LT8471 is configured as a 12V to 3.3V (channel 1) and -3.3V (channel 2) dual converter.

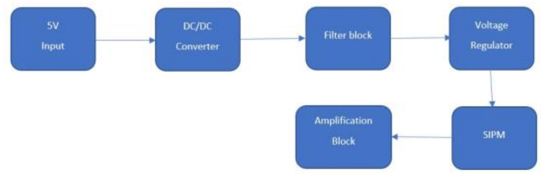

Figure 4. SIPM's circuit block diagram.

one of them providing the DC voltage. The block diagram of this board is shown in Figure 4. This board must implement:

- DC-DC converter block: Consists of a LT3571 [10], an up-to 75V DC-DC converter for APD biasing. This converter is configured to provide 45V (Figure 5). Voltage is limited to 45V for safety reasons because the SENSL MicroFC 60035 STM SIPM must be biased at maximum 30V, but if other SIPMs are used, a higher voltage may be needed.
- Voltage control block: Consists of a precision voltage regulator to set the bias voltage.
- Filter block: Consists of two signal filters to eliminate interference and eliminate all AC signals. Coupling capacitors are used as protection for the SIPMs.
- Amplification block: Consists of an AD8012 [11] configured as a non inverter amplifier with a gain of 10 in order to fit the maximum input voltage of the RedPitaya (+/- 1V)

III. Software Design

A. Data Acquisition Software

Signal acquisition is done using a real-time oscilloscope (Keysight MSOX2012A) that is connected through USB to

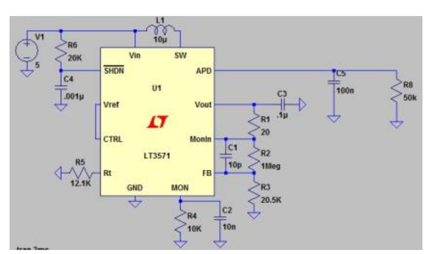

Figure 5. 5V to 45V DC/DC converter. An LT3571 is used because is an IC designed specifically for APD biasing.

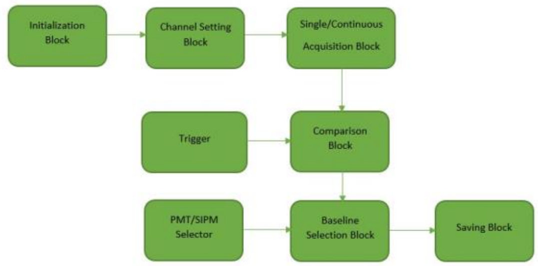

Figure 6. Acquisition Software block diagram.

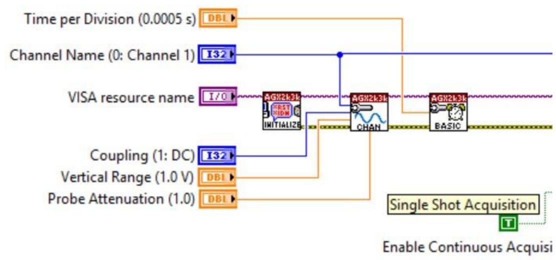

Figure 7. Channel configuration block diagram. All values set in the user interface are reflected on the oscilloscope window.

a PC running a LabView test software. The software was designed to work with all Keysight 20xx, 30xx and 40xx series and can be easily modified to work with other oscilloscopes. All drivers are available at the National Instruments website. The block diagram of the acquisition software is shown in Figure6.

Figure 7 shows the initialization and channel configuration blocks. Here, the serial communication between the oscilloscope and the PC is established. Channel configuration involves volts/div, time scale, probe attenuation, trigger, and coupling. Setting the trigger value allows us to discriminate

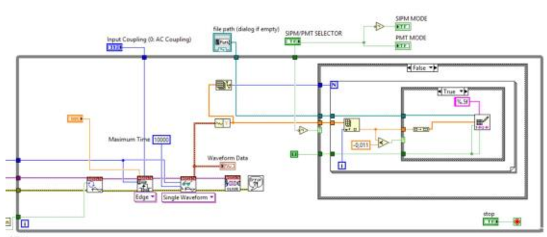

Figure 8. Pulses acquisition block diagram. All images on the oscilloscope window are displayed on the user interface.

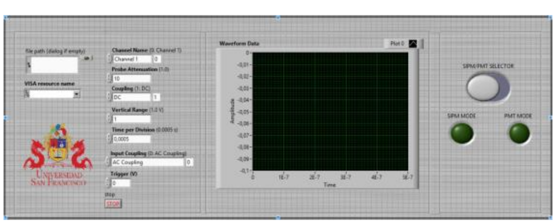

Figure 9. Data acquisition software user interface. Channel configuration and operation mode must be selected before running the program

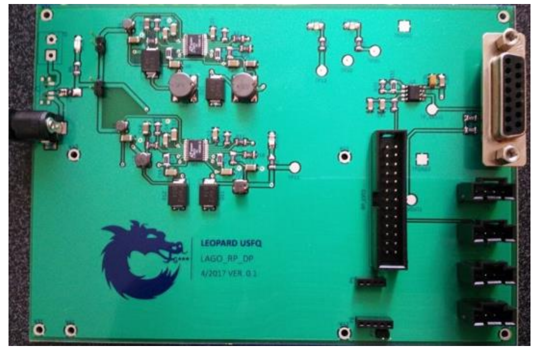

Figure 10. PMT Extension Board

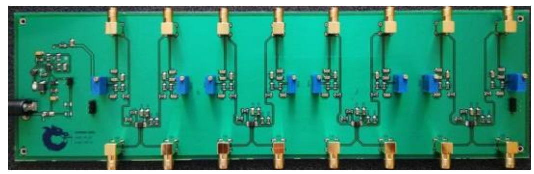

Figure 11. SIPM Bias Board

"dark pulses" from HEP (High energy particles) pulses and is used to determinate the working point (Bias voltage and Trigger value).

Figure 8 shows the acquisition type, comparison, baseline and saving blocks. The acquisition can be set as single acquisition or continuous acquisition. Also, a baseline must be established to filter the DC component and save only the pulses in the saving block. All data is saved in a ".txt" file.

Figure 9 shows the user interface, where the channel settings and detector type are selected (PMT or SIPM).

B. Data Processing Algorithm

All pulses acquired are saved in a text file. To implement a pulse counting module (useful to find the working point of the PMT and SiPM) MatLab was used. The post processing module implements a baseline and a filter in order to eliminate noise and implement pulse counting. The filter is a smooth filter, this will clean all interference captured by the acquisition software. Also, it will make the pulses easy to detect with a peak detector algorithm. This algorithm returns the number of pulses acquired with a specific High Voltage (HV) and Trigger value, a histogram showing Pulse Height Distribution (PHD) is also generated.

IV. Results

A. System testing

Figure 10 and Figure 11 show the PMT extension board and the SIPM bias board respectively. A simple protocol for testing the board proper functioning is established. This protocol must check:

- Visual inspection of the board: checking if components have the correct values and are soldered correctly.

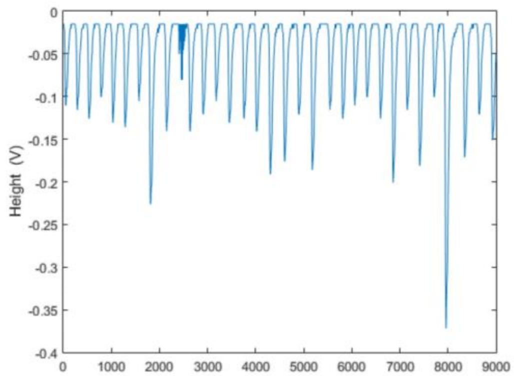

Figure 12. Pulses acquired with the PMT.

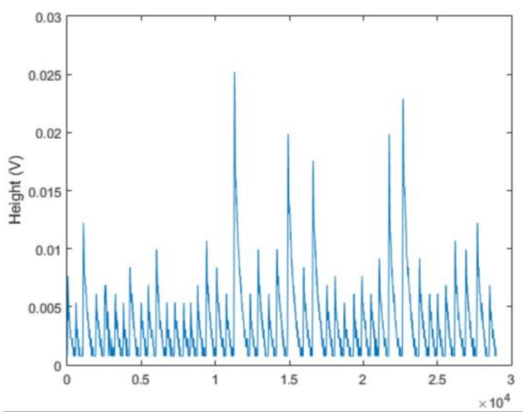

Figure 13. Pulses acquired with the SIMP. Pulses are positive because they are taken directly from the anode. Pulses are negative if taken directly from the cathode

- Checking Output Voltages: All bias voltages are in the correct value (3.3V, -3.3V, 12V and 5V for the PMT's Extension Board and 45V for the SIPM's Board) A set of test points and LEDs was included for this task.
- Test with Load: Testing boards functionality with resistive load simulating the actual components.
- HV Control Voltage Test: For the PMT Extension Board it is necessary to test the HV Control block by using an external power source before using the Red Pitaya PWM signal.
- Bias Voltage set: For the SIPM's Board it's necessary to check that all trimmers are working correctly.
- Finally, connect the Red Pitaya, the PMT and SIPM to begin the acquisition.

B. Acquisition software testing and first pulses acquired

After following the protocol listed above, the system can be set to acquire pulses with the PMT and the SIPMs. The Software developed is used to acquire pulses for short time. Figure 12 and Figure 13 show the pulses acquired with the PMT and a SIPM respectively.

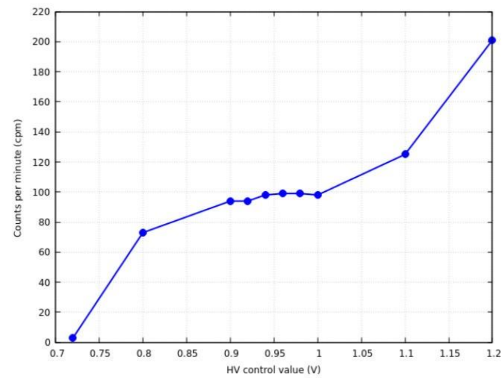

Figure 14. Counts per minute versus HV Control value. Flat region denotes the working point for this PMT

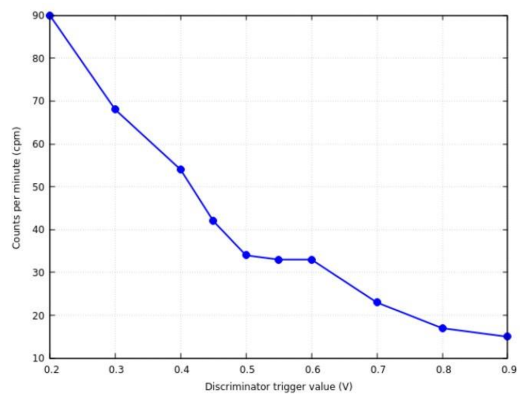

Figure 15. Counts per minute versus Discriminator Trigger value. Flat region denotes the correct trigger value to separate dark current from signal current.

C. Determining the PMT and SIPM working point

For both PMT and SIPM, it is necessary to find the proper HV or bias voltage and the Trigger value. These two parameters determine the so-called "working point". When working point is found the number of pulses detected per minute is constant (does not depend on the setup of the WCD) and it becomes easy to discriminate "dark pulses" from signal

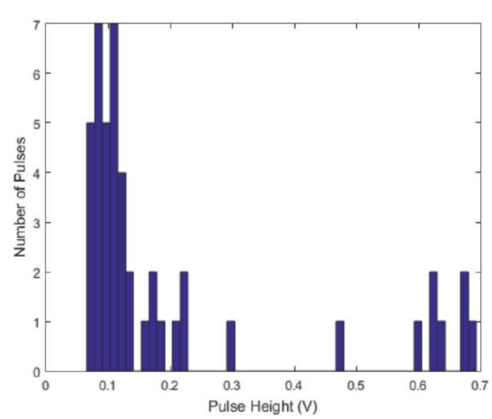

Figure 16. Histogram of pulses heights at working point. Dark current (left) and Signal current (right) can be easily distinguished.

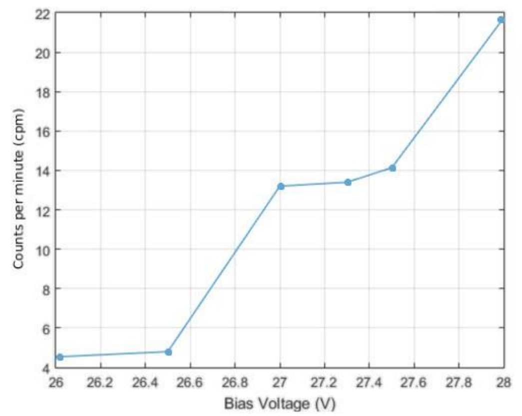

Figure 17. Counts per minute versus Bias Voltage value. Flat region denotes the working point.

pulses [12].

That is why two kind of measures are performed. First we set a low discriminator threshold (about 30mV for the PMT) and sweep HV values from 40% to 70% of the total control voltage. Figure 14 shows number of counts per minute against HV Control value; the flat region is the optimum HV. With the optimum HV value, we sweep the Trigger value as we did with the HV value. Figure 15 shows the number of counts per minute against Discriminator Trigger Value; combining both flat regions we find the working point.

A Pulse Height Distribution Histogram (Figure 16) is constructed with pulses acquired at the working point to verify that we have a clear separation between dark pulses and Signal pulses.

For the SIPM, the threshold is set to 10mV and the bias voltage sweep must be in the operation range (At most 5V over the Voltage breakdown value), from 25V to 30V. The same process used to find the PMT's working point is performed for the SIPMs. Figure 17 shows the number of counts per minute against Bias Voltage.

V. Conclusions

- The present work shows that a new DAS system for particle detection based on Red Pitaya is a valid alternative to new generation of electronics for WCD of the LAGO Project.
- The use of commercial products, Open Source SW and Low-Cost oriented design makes it possible to have a high performance DAS system at a reasonable cost. This feature is very important for building a WCD detection array (more than 3 WCDs) and/or upgrading a WCD with limited funds.
- An independent test SW was developed in order to compare data taking by a high speed oscilloscope with the RedPitaya. No significant difference in data were found.
- The DAS system can be used to acquire signals from other types of particle detectors, in particular, plastic scintillators with SiPMs as light sensors. In this way we, can implement a Hybrid Particle Detector; two plastic scintillators can be used to trigger WCD, or the SiPMs signals can be used in data post-processing
- DAS system power supply is a DC voltage 12V@2A. Several types of power supply can be used, from conventional electric network to solar panels or wind turbines (or even batteries), which allow to build a stand-alone WCD without modifying the HW.
- The PMT's working point obtained is: HV=1400V and Trigger= 500mV. The SIPM's working point obtained is: Bias voltage=27.3V and Trigger= 50mV

VI. Acknowledgments

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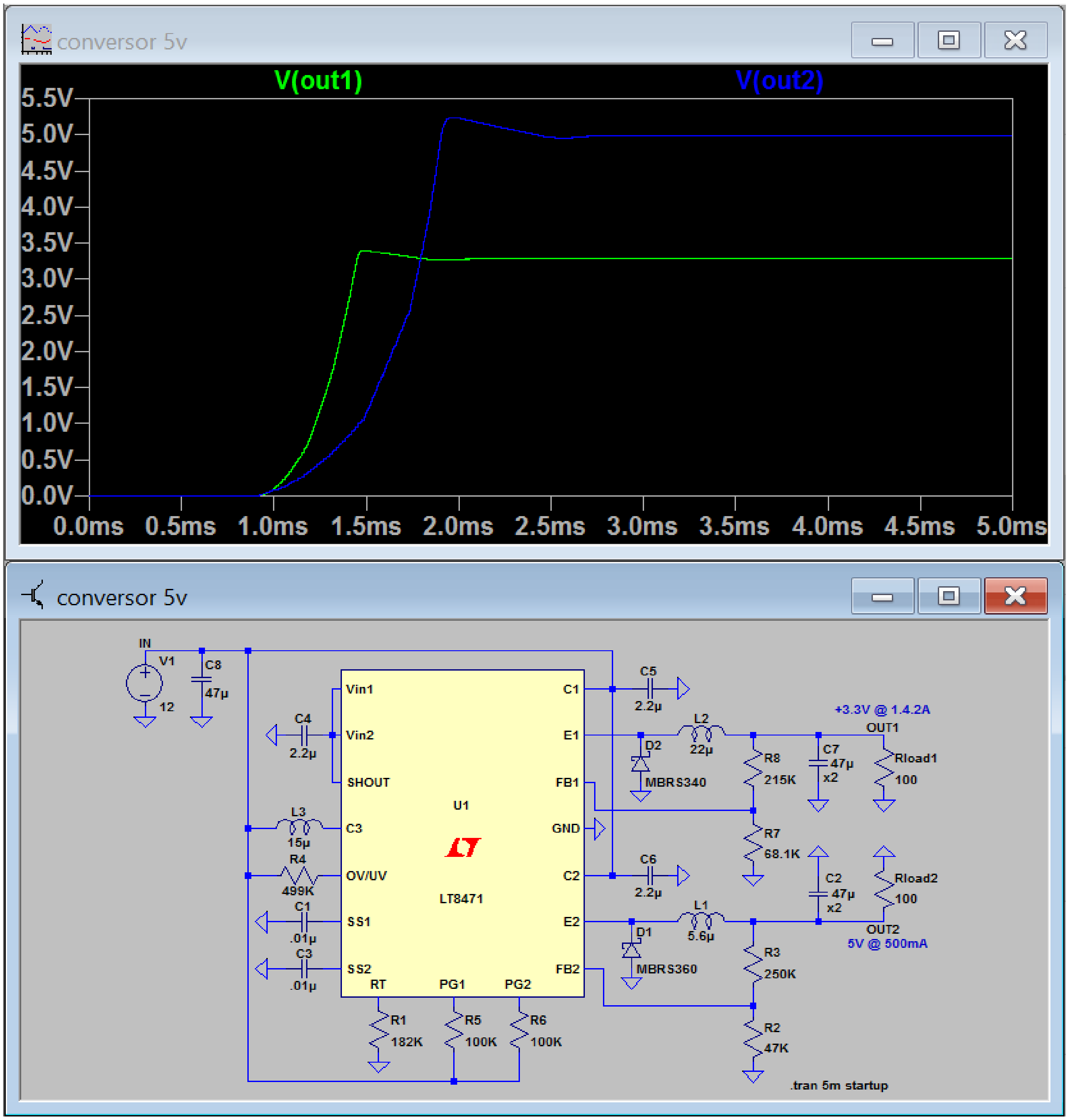
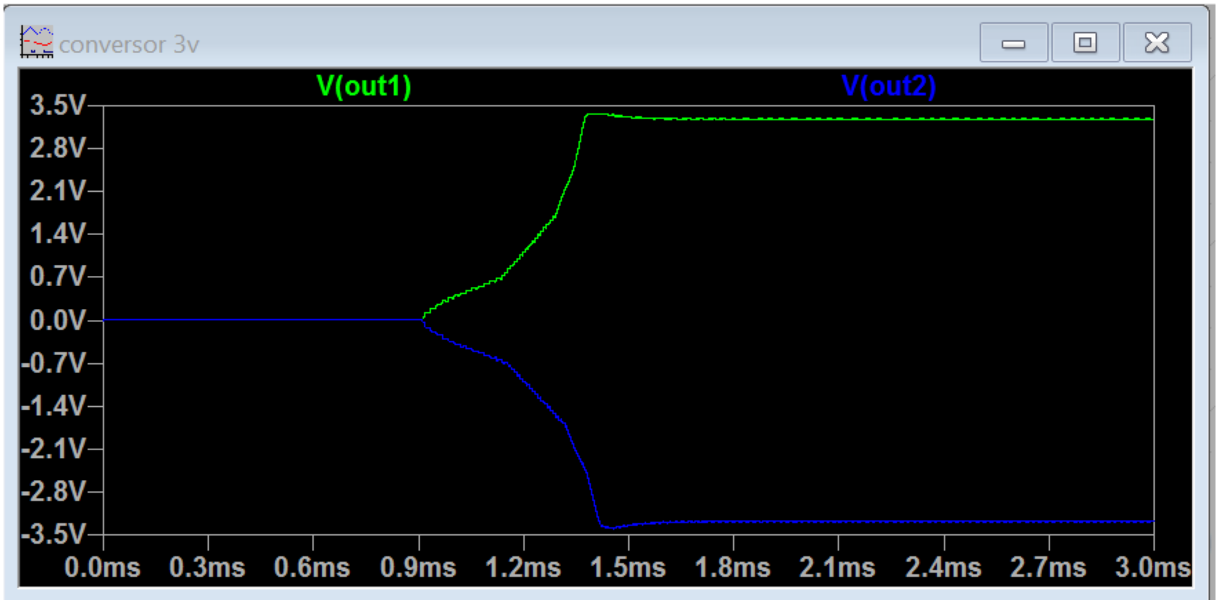
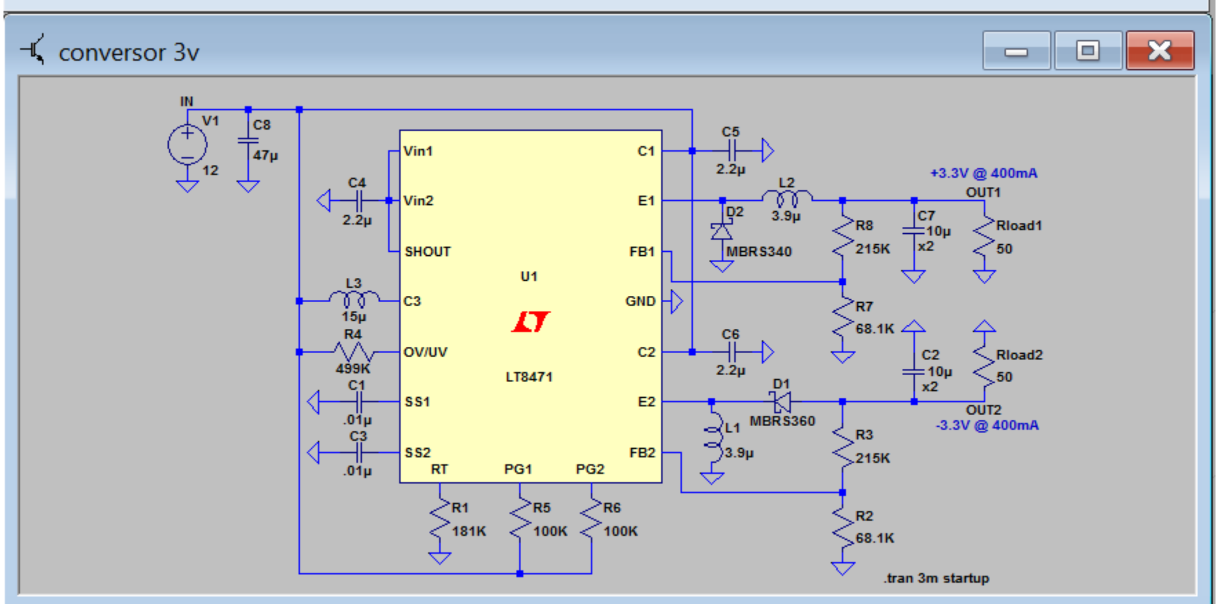
ANNEXED A: 12V TO 5V AND 3.3V CONVERTER SIMULATION



ANNEXED B: 12V TO -3.3V AND 3.3V CONVERTER SIMULATION





ANNEXED C: 5V TO 45V CONVERTER SIMULATION