AC 2011-250: LAB EXPERIENCE FOR CIRCUITS CLASSES IN A SIMPLIFIED LAB ENVIRONMENT

Claudio Talarico, Eastern Washington University

Claudio Talarico is an Associate Professor of Electrical Engineering at Eastern Washington University. Before joining Eastern Washington University, he worked at University of Arizona, University of Hawaii and in industry, where he held both engineering and management positions at Infineon Technologies, IKOS Systems (now Mentor Graphics), and Marconi Communications. His research interests include design methodologies for integrated circuits and systems with emphasis on system-level design, embedded systems, and complex SOCs. Talarico received a PhD in Electrical Engineering from the University of Hawaii at Manoa, and he is a member of IEEE. Contact him at ctalarico@ewu.edu

Min-Sung Koh, Eastern Washington University

MIN-SUNG KOH obtained his B.E. and M.S. in Control and Instrumentation Engineering in the University of ULSAN, South Korea, and his Ph. D in Electrical Engineering and Computer Engineering at Washington State University. He was with KEPCO (Korea Electric Power Co.) for 9 years before enrolling in the Ph. D. program at Washington State University. In KEPCO, he worked at the NPP (Nuclear Power Plant) as a nuclear engineer. In the Fall '02 quarter he joined the department of Engineering and Design at Eastern Washington University, where he has taught several courses in Computer Engineering Technology and Electrical Engineering. Currently, he is an associate professor of Electrical Engineering at Eastern Washington University. His research interests are in the areas of speech and image signal processing, signal processing in communication systems, photoacoustics, and embedded systems.

Esteban Rodriguez-Marek, Eastern Washington University

Prof. Rodriguez-Marek is an Associate Professor in the Engineering & Design Department at Eastern Washington University.

Lab Experience for Circuits Classes in a Simplified Lab Environment

Abstract

Circuit theory, analog electronics and digital electronics are essential classes for EET/CET/EE curricula and require students to complete various labs in order to gain the necessary hands-on experience they need when entering the job market. In order to provide this hands-on experience, traditional labs for circuit theory, analog electronics, and digital electronics require a number of measuring and signal-generating instruments, such as power supplies, multi-meters, oscilloscopes, function generators, etc. Learning to use proficiently the many instruments found in a typical lab is both a time consuming and challenging task. Unfortunately, students who would like to spend time outside class working on labs and projects are restricted by the significant cost of the equipment. Furthermore, students enrolled in distance learning programs, due to their remote location, struggle even more to find the opportunity to gain the required hands-on experience. This paper is a case study to analyze the feasibility of handling labs for circuit related classes through an alternative approach based on a simplified lab environment, which can be located virtually anywhere. The lab environment we analyzed is the Digilent's Electronics Explorer Board powered by the WaveForms software. The single board includes various devices used in traditional analog/digital classes such as power supplies, function generators, oscilloscopes, logic analyzer, multi-meters, etc. As a case study, this paper introduces some experiment we have developed to test the simplified lab environment.

Introduction

Learning to use the various instruments and devices that equip a typical electronics laboratory is both very challenging and time consuming. Based on our experience most students need much more time than the typical two-hours per week provided by classes such as circuit theory, analog electronics and digital electronics. Unfortunately, students who would like to spend more time outside of class working on labs and projects cannot afford to do so, due to the significant cost of the equipment. This issue is even more problematic for students enrolled in distance education programs. Over the last couple of decades, somehow "justified" by the extraordinary growth of the field of integrated circuits, the common trend has been to significantly reduce the number of hours that students spend in laboratory and increase the the number of hours students spend using circuit and logic simulators. Although there is no doubt that simulators are an essential component of today's design and analysis process, and they are the predominant tools in every engineering workplace, we believe that the lack of hands-on experience obtainable in a traditional electronics laboratory setting, affect students' ability to effectively master the use of simulators. Successful usage of any simulator relies on the capability of the user to adequately model the many non-idealities that characterize the various devices composing the circuit to simulate. In order to grasp and understand the effect of the various devices' non-idealities there is no better way than observing and characterizing the behavior of the physical circuit in action.

In this paper we attempt to address the pedagogical challenge of providing students with satisfactory hands-on experience by analyzing the viability of using a simplified lab environment called Electronics Explorer (EE) Board. The EE board is commercialized by Digilent and can be purchased for 399 USD (academic price) or 299 USD (student price).

The lab environment is built around a large solderless breadboard and provides a high speed USB2 connection through which is possible to have the board communicate to any PC, and take advantage of the free PC-based WaveForms™ software that makes it easy to acquire, store, analyze, produce and reuse analog and digital signals.

The Electronics Explorer Board includes oscilloscopes, waveform generators, power supplies, voltmeters, reference voltage generators, and thirty-two digital signals that can be configured as a logic analyzer, pattern generator, or any one of several static digital I/O devices. All of these instruments can be connected to circuits built on the solder less breadboards using simple jumper wires. Figure 1 shows a picture of the Electronics Explorer Board.

In our opinion the main advantage of having a lab environment built around a breadboard is the possibility for students to have the flexibility to run their experiment by: 1) using only traditional lab. instruments, 2) using a mix of PC based and traditional instruments, and 3) using only PC based instruments. Another advantage this approach has over simulations is that the students can physically build circuits. This allows them to make and learn from wiring mistakes, failure to connect the power lines, etc. The WaveForms software is extremely intuitive to use and the design of the GUI provides the user a "feeling" close to the one perceived when using traditional instruments.

In the rest of this paper we present our experience in using the Electronics Explorer Board in five simple case studies: two circuit theory lab experiments, two analog electronics lab experiments and finally one digital electronics experiment.

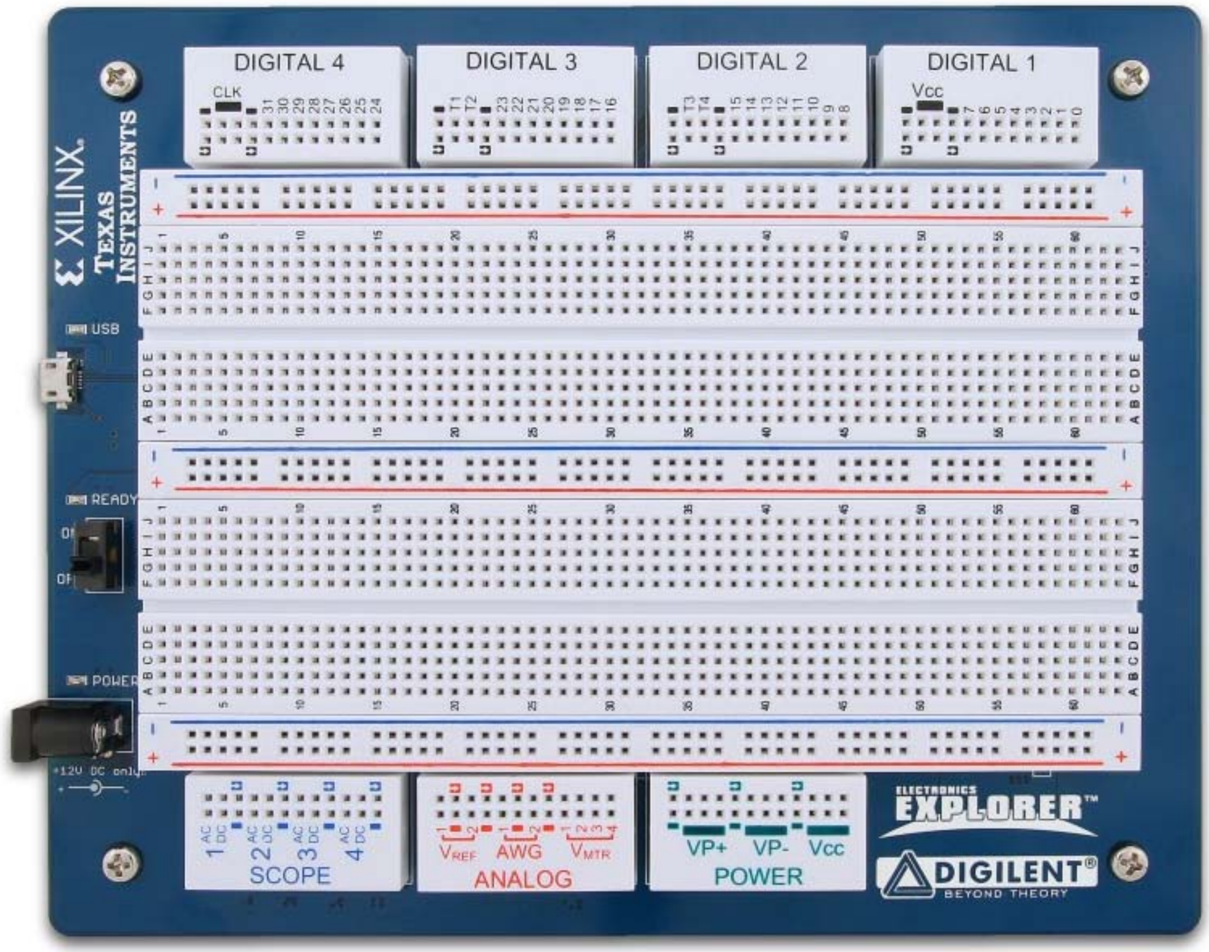


Figure 1. Electronics Explorer Board by Digilent

Examples of Circuit Theory Labs

The goal of the first experiment is to analyze the voltages developed across the resistors of a voltage divider, and it requires only a DC power supply, and two voltmeters.

The EE board provides: 1) one triple output supply (one positive supply VP+ programmable from 0 to +9V with independent current limit setting up to 1.5 A; one negative supply VP- programmable from 0 to -9V with independent current limit setting up to 1.5 A; and one fixed selectable 5V/3.3V supply voltage VCC with independent current limit setting up to 2 A), 2) two programmable +/- 10V reference voltages Vref and 3) four voltmeters. Figure 2 shows the voltage divider circuit and the nominal value of the components used.

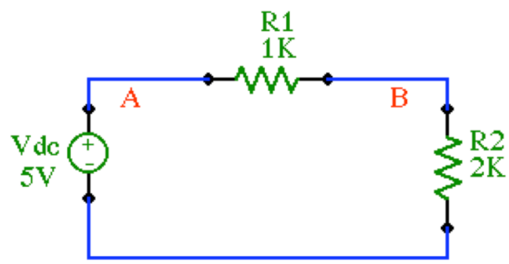


Figure 2. Voltage Divider Circuit

Figure 3 illlustrates the setting used to analyze the voltage divider circuit. The 5V dc voltage driving the circuit is provided through the supply voltage VP+ (note: this is the only supply ON), the voltage V_A is measured by the voltmeter 1, and the voltage V_B is measured by the voltmeter 2. The values measured are consistent with expectations.

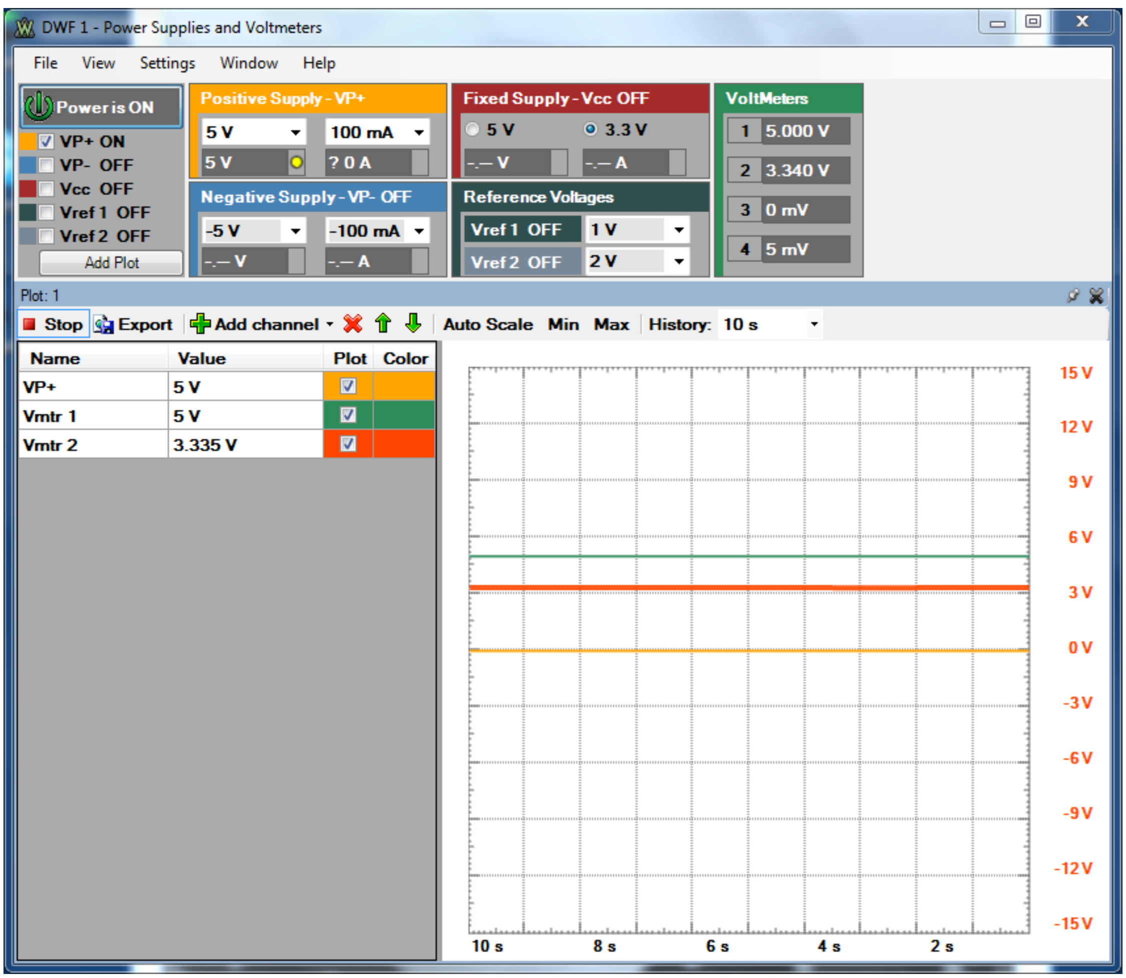


Figure 3. Lab settings for the voltage divider experiment

The voltmeters provided by the EE board do not allow the experimenter to measure the voltage across two points directly. All measurements are with respect to ground. Although this is not a major issue, it is definitely not how a real voltmeter works. Another shortcoming we noticed in the current version of the software is the fact that when plotting the value of various voltages over a certain observation period (in the example shown in figure 3 we used an observation period of 10s and sampled the value of the voltages at intervals of 1s), the autoscale feature is not working properly. Only the last voltage observed (for the example shown in figure 3 the value from the voltmeter 2) is in the correct scale. This shortcoming can be circunvented by either observing the measurements one voltage at the time as shown in figure 4 to 6, or by exporting the measurements as shown in figure 7.

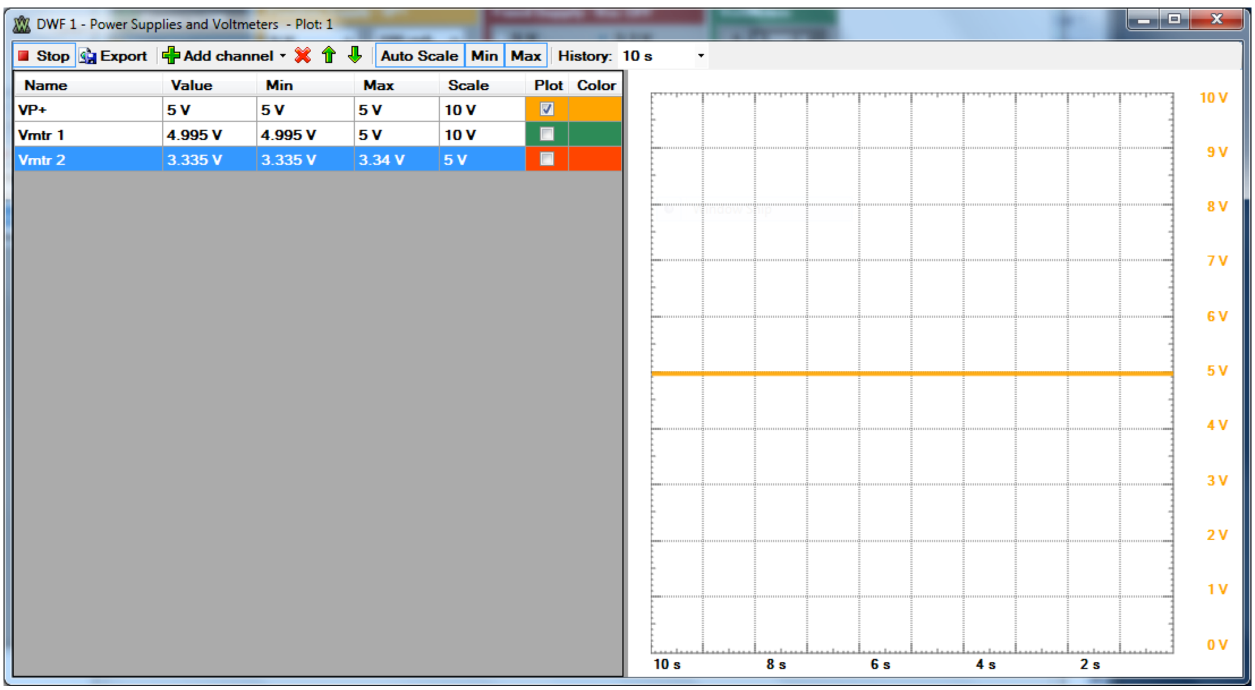


Figure 4. Voltage plot of the supply voltage VP+

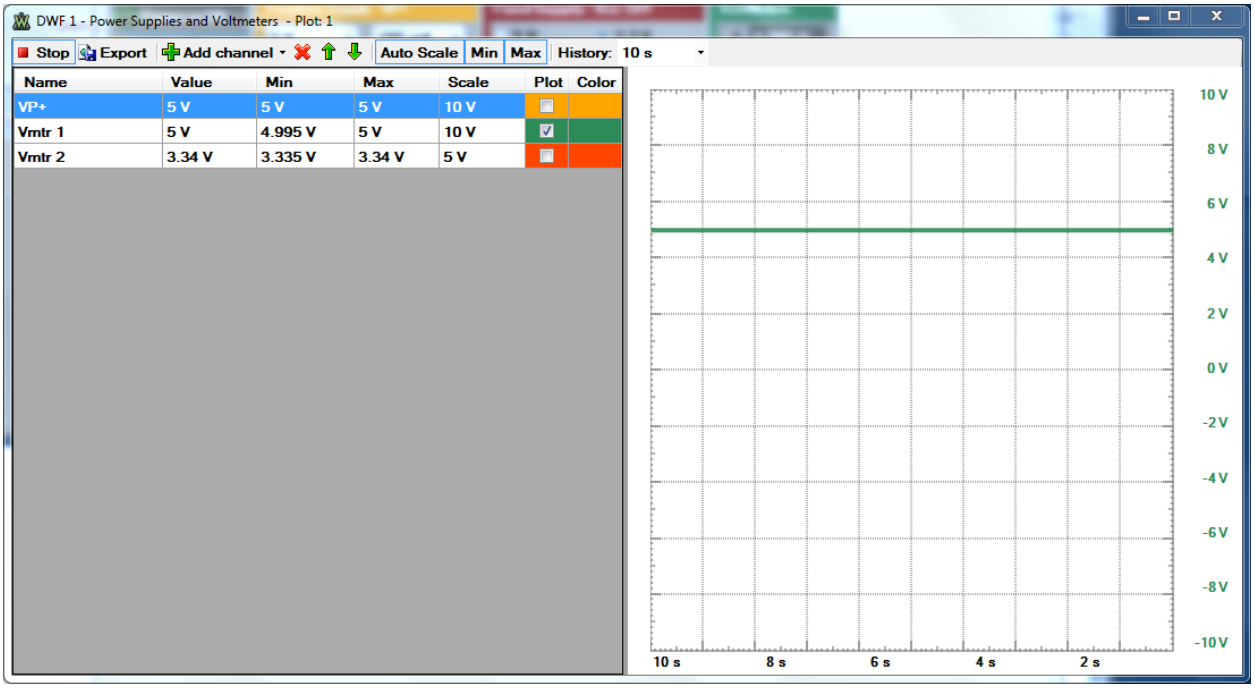


Figure 5. Voltage plot of the voltages measured by voltmeter 1 (V_A)

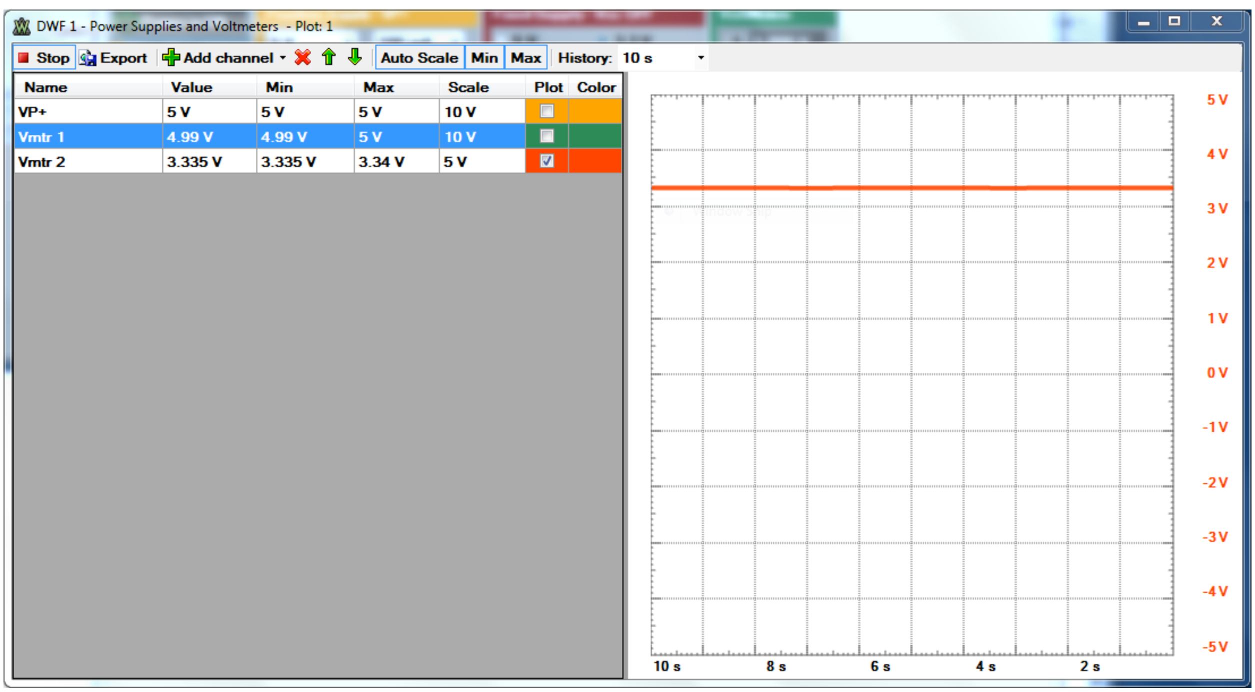
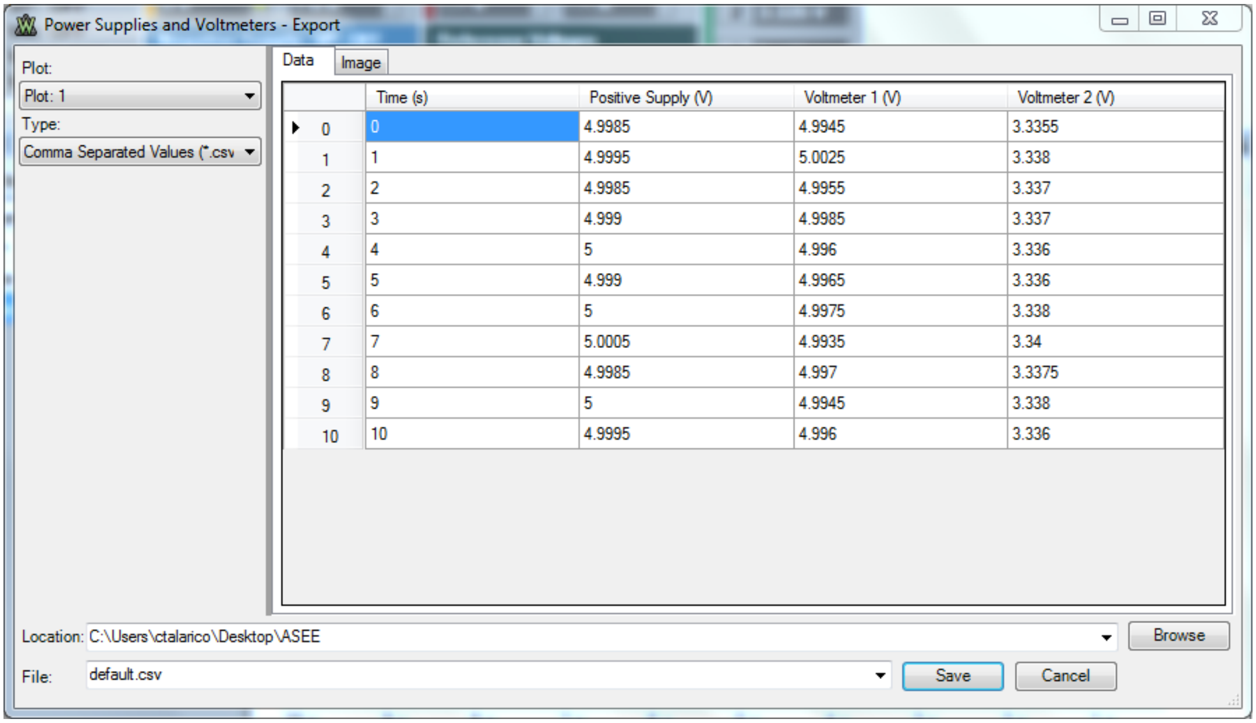


Figure 6. Voltage plot of the voltages measured by voltmeter 2 (V_B)



	Time (s)	Positive Supply (V)	Voltmeter 1 (V)	Voltmeter 2 (V)
0	0	4.9985	4.9945	3.3355
1	1	4.9995	5.0025	3.338
2	2	4.9985	4.9955	3.337
3	3	4.999	4.9985	3.337
4	4	5	4.996	3.336
5	5	4.999	4.9965	3.336
6	6	5	4.9975	3.338
7	7	5.0005	4.9935	3.34
8	8	4.9985	4.997	3.3375
9	9	5	4.9945	3.338
10	10	4.9995	4.996	3.336

Figure 7. Exporting the voltage measurements performed on the voltage divider circuit

The goal of the second experiment is to measure the time constant of a simple RC circuit and observe how the time constant changes when the value of the resistor in the circuit is increased. This experiment requires the use of a waveform generator, and an oscilloscope. Figure 8 shows the circuit analyzed in the second experiment.

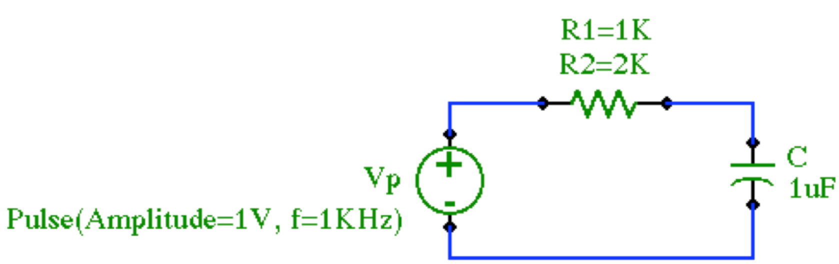


Figure 8. RC Circuit driven by a periodic 50% duty cycle square waveform

The EE board provides a 2-channel Arbitrary Waveform Generator and a 4-channel, 40MSamples/s Oscilloscope. Figure 9 illustrates the setting used for the waveform generator., while Figure 10 illustrates the oscilloscope traces used to measure the time constant of the two circuits. The time constant is given by the time taken for the voltage across the capacitor to charge from 0 to 0.63V. The results obtained are consistent with the components tolerances and meet expectations.

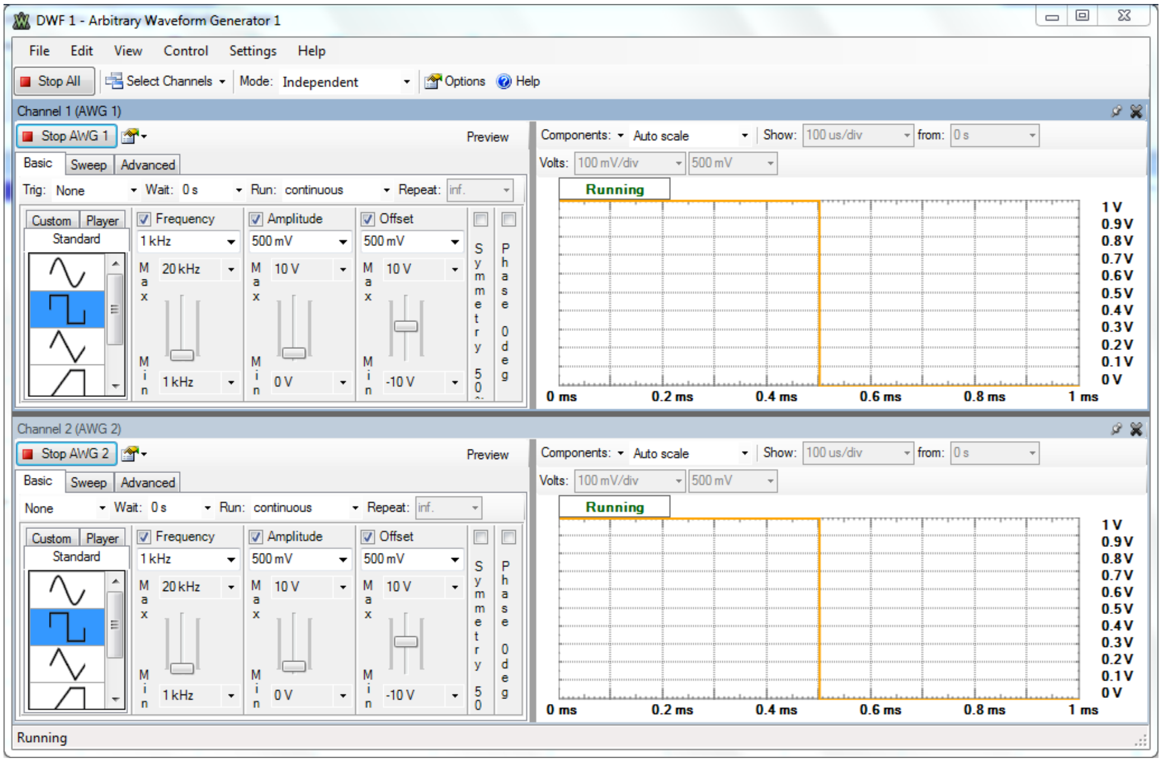


Figure 9. Waveform generator settings

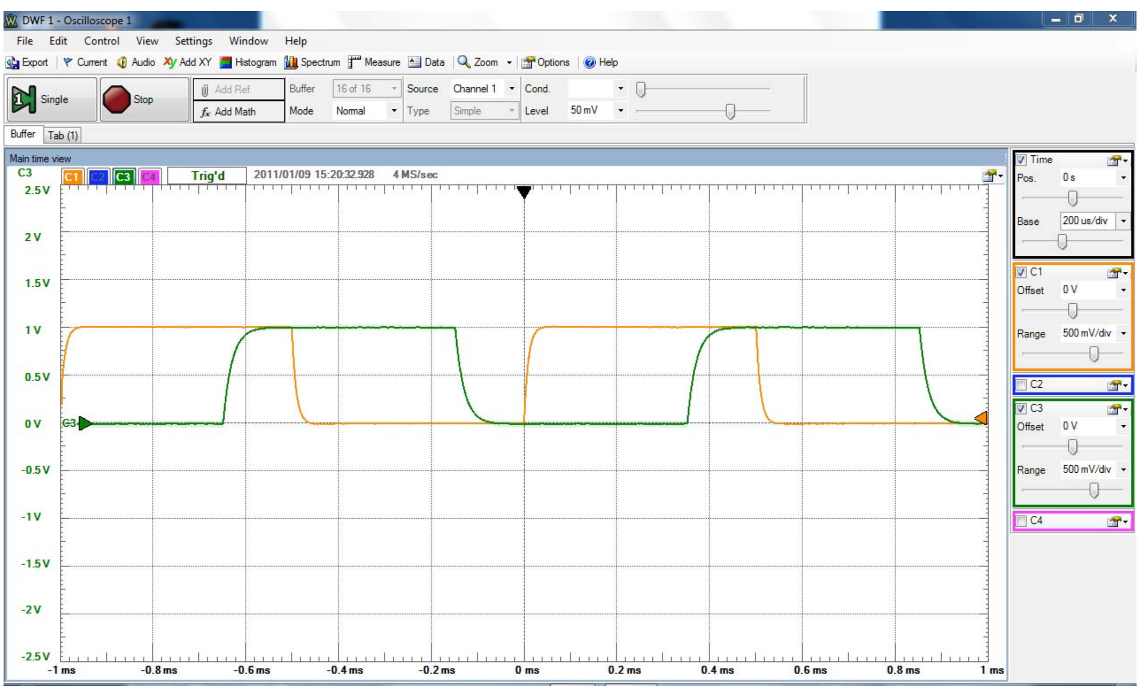


Figure 10. Oscilloscope traces used to measure the two RC circuits time constants

Examples of Analog Electronics Labs

The goal of the third experiment is to analyze the behavior of the single wave rectifier circuit shown in Figure 11 and measure the forward voltage drop across the diode. The instruments used in this experiment are a waveform generator producing a sine wave of 10V of amplitude and 1KHz of frequency, and an oscilloscope.

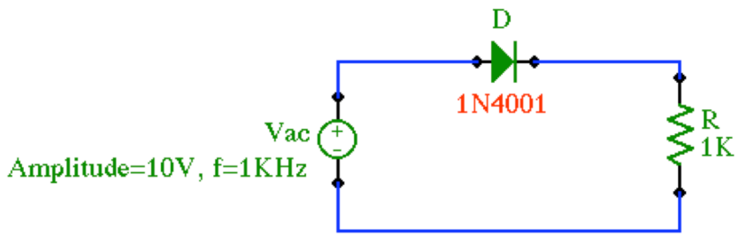


Figure 11. Single wave rectifier driven by a sine wave of 10V of amplitude and 1KHz of freq.

Figure 12 illustrates the setting used for the waveform generator to produce the required driving signal. Figure 13 shows the input and output signal traced by the oscilloscope. The input signal is traced on channel 4 of the oscilloscope. The output signal is traced on channel 3 of the oscilloscope.

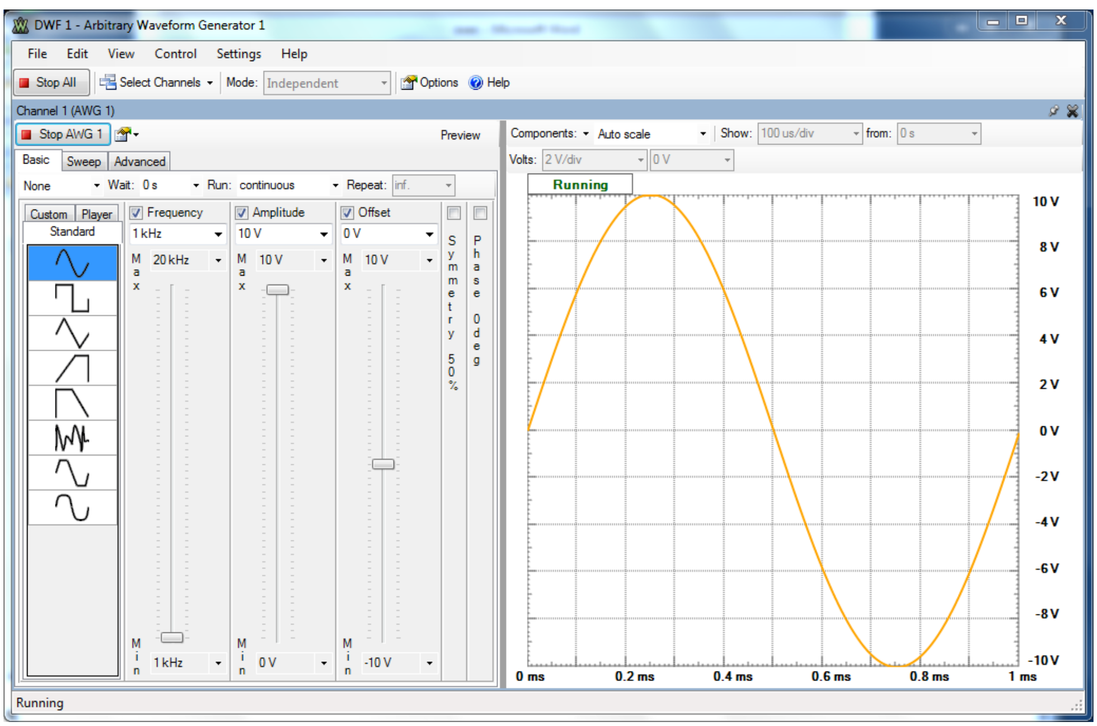


Figure 12. Waveform generator settings

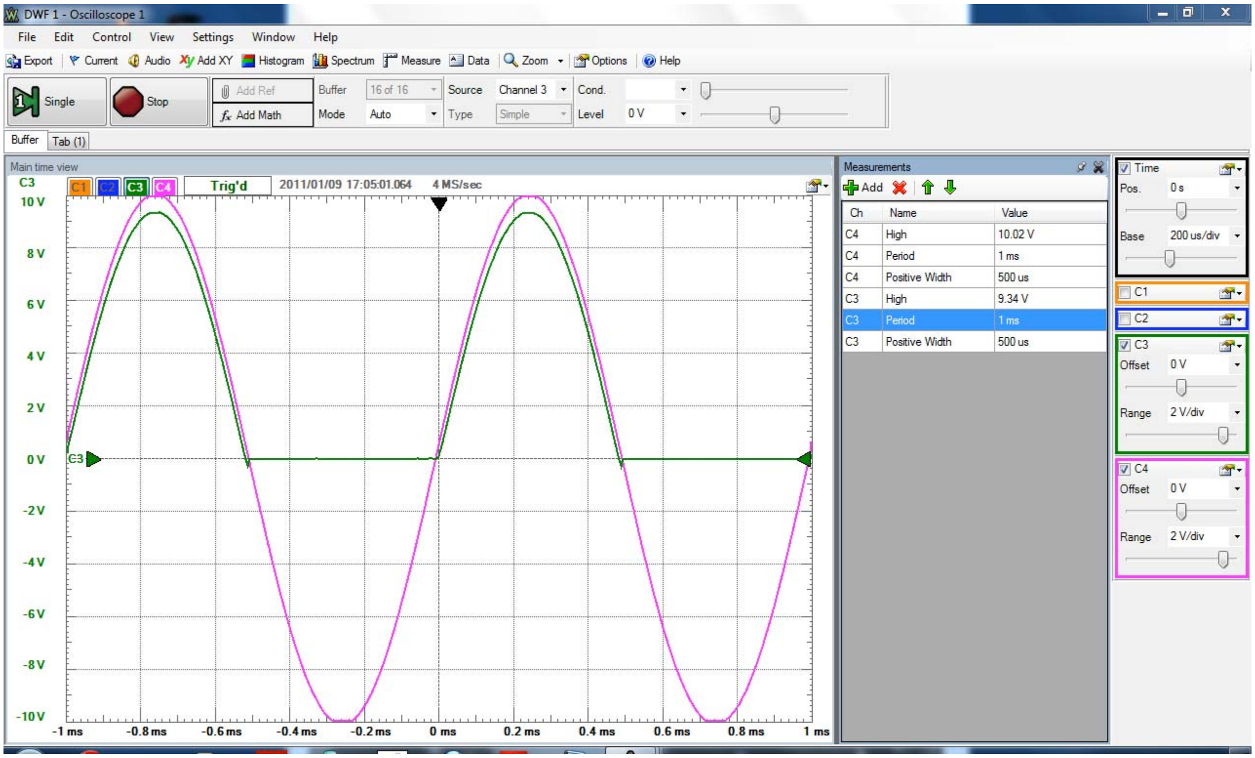


Figure 13. Single wave rectifier circuit: oscilloscope traces

The forward voltage drop across the diode measured at the peak of the output is 0.68V (the nominal voltage drop is 0.58V). The results obtained are consistent with expectations.

The goal of the fourth experiment is to measure the gain and bandwidth of an op amp based inverting amplifier circuit. The circuit is shown in Figure 14.

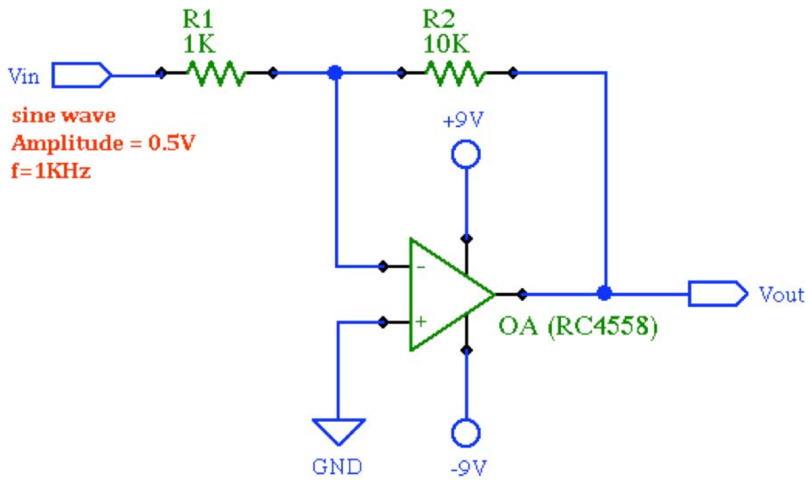


Figure 14. Inverting amplifier

The instruments used in this experiment are: a positive power supply of 9V dc, a negative power supply of -9V dc, a waveform generator producing the driving input signal (a sine wave of 0.5V of amplitude and 1KHz of frequency) and an oscilloscope to trace the output signal. Figure 15 shows the power supply settings. Figure 16 shows the waveform generator settings. Figure 17 shows the input and output signal as traced by the oscilloscope.

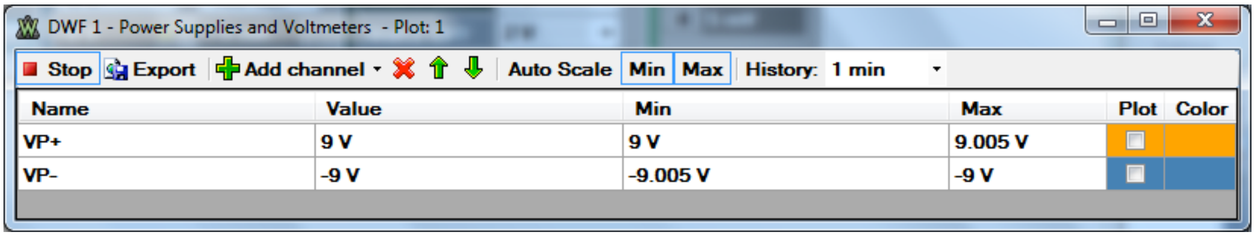


Figure 15. Power supply settings used for the amplifying circuit

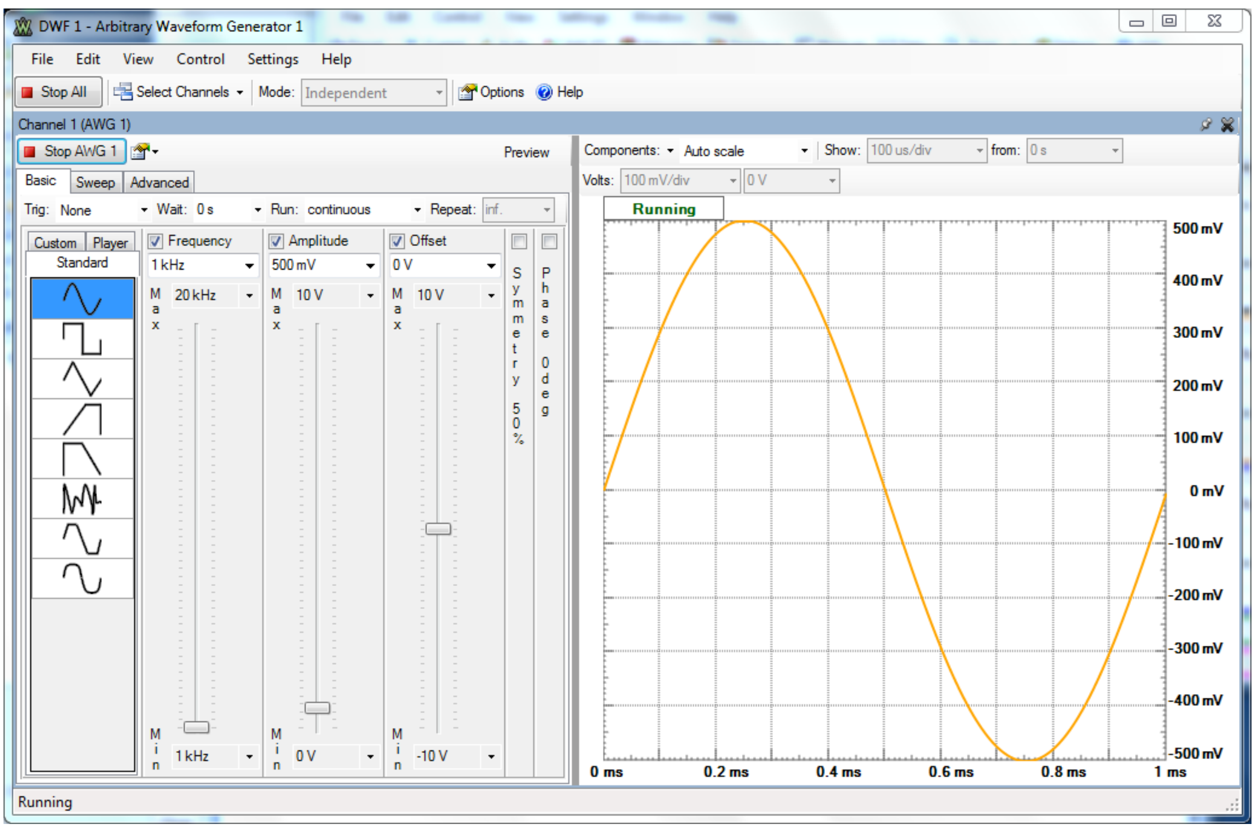


Figure 16. Waveform generator settings

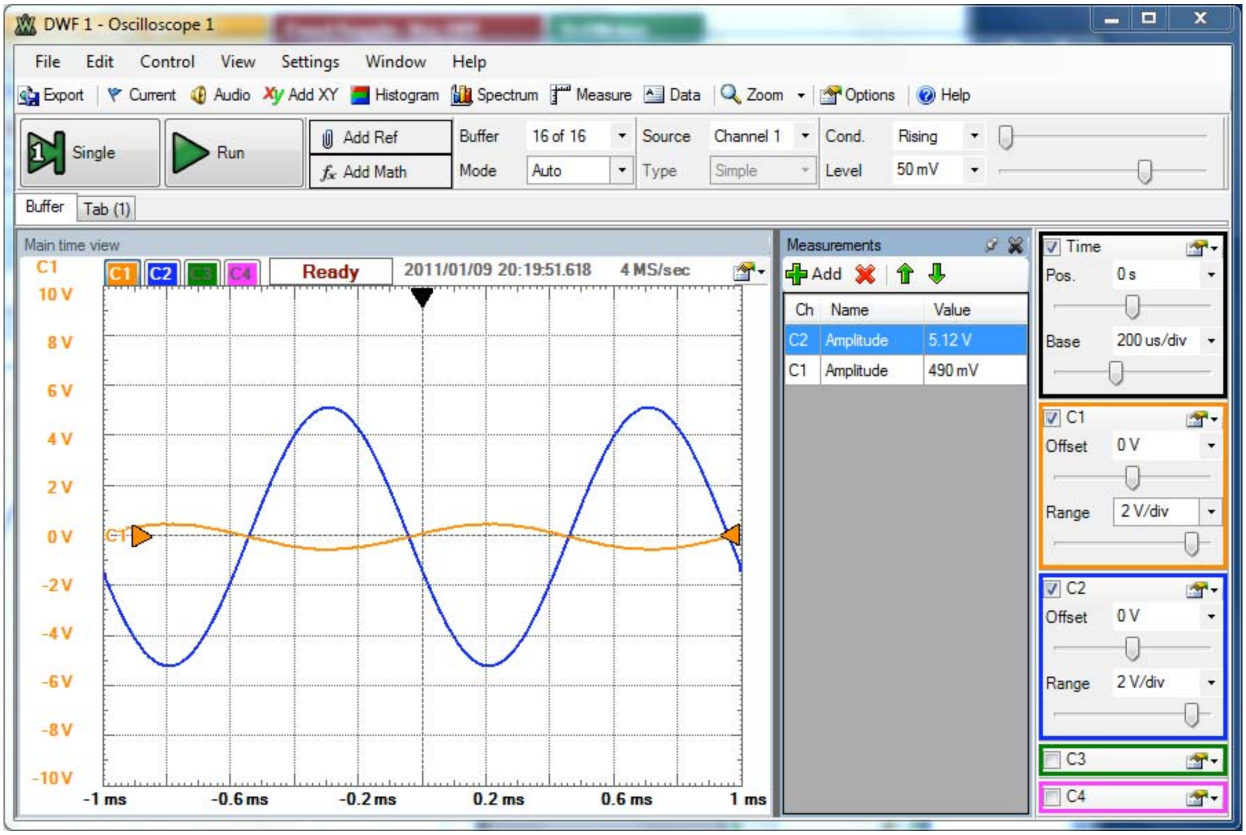


Figure 17. Oscilloscope traces

Using the oscilloscope traces we see that the circuit behaves as an inverting amplifier and its gain is approximately 10 as expected. In addition, using the frequency sweep feature of the oscilloscope we can plot the Bode diagram of the circuit and measure its 3dB bandwidth (approximately 692 KHz). The bandwidth can be either measured visually or numerically by exporting the Bode plot values in a tabular form. The Bode plot of the circuit is shown in Figure 18.

Example of Digital Electronics Lab

The goal of this last experiment is to verify the correct functionality of a rising edge detector. This experiment requires the use of a pattern generator, a logic analyzer and an oscilloscope to check the effective quality of the digital signals. Figure 19 shows one possible logic representation of the rising edge detector. In practice the circuit has been implemented using one 7474 TTL integrated circuit (dual D-type positive edge triggered flip flop with preset and clear), and one 7400 TTL integrated circuit (quad 2-input nand gates). The EE board provides a 32-channel pattern generator and a 32-channel logic analyzer. The pattern generator is capable of producing signals between 100 mHz and 50 MHz with a duty cycle programmable between 0% and 100% and a phase shift programmable between 0 deg. and 360 deg. The clock used for data acquisition by the Logic Analyzer can be internal (100 MHz) or external. The digital pins are supplied at 3.3 V, and they have 16 mA drive strength.

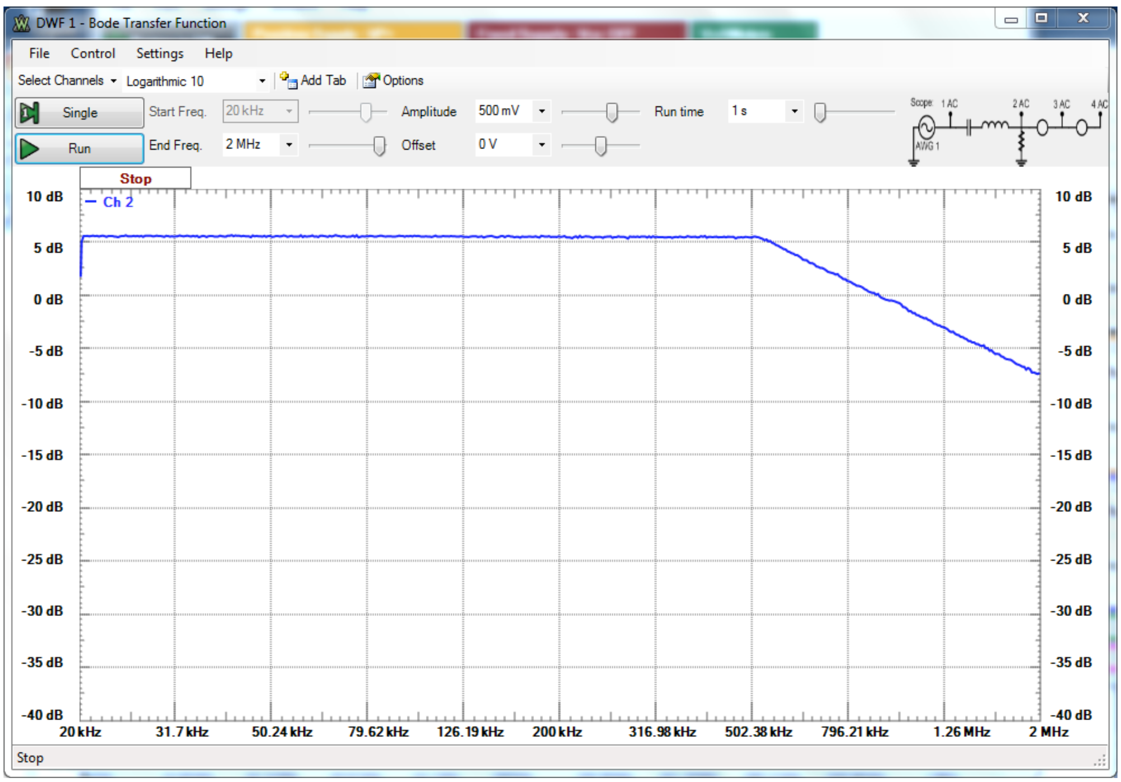


Figure 18. Bode plot for the amplifying circuit considered in the forth experiment

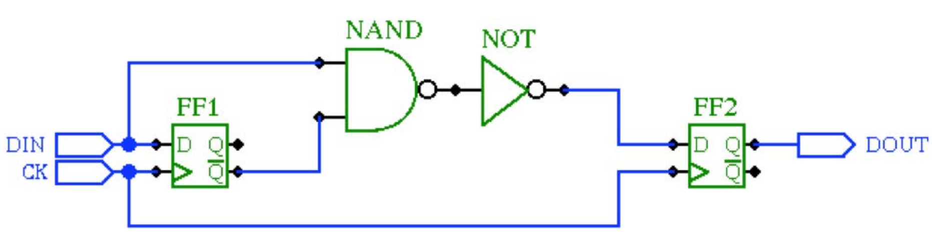


Figure 19. Edge Detector Logic

Figure 20 shows the setting of the pattern generator. Figure 21 shows the input and output waveforms obtained using the Logic Analyzer. Figure 22 depicts the real shape of the input and output waveforms as traced by the oscilloscope.

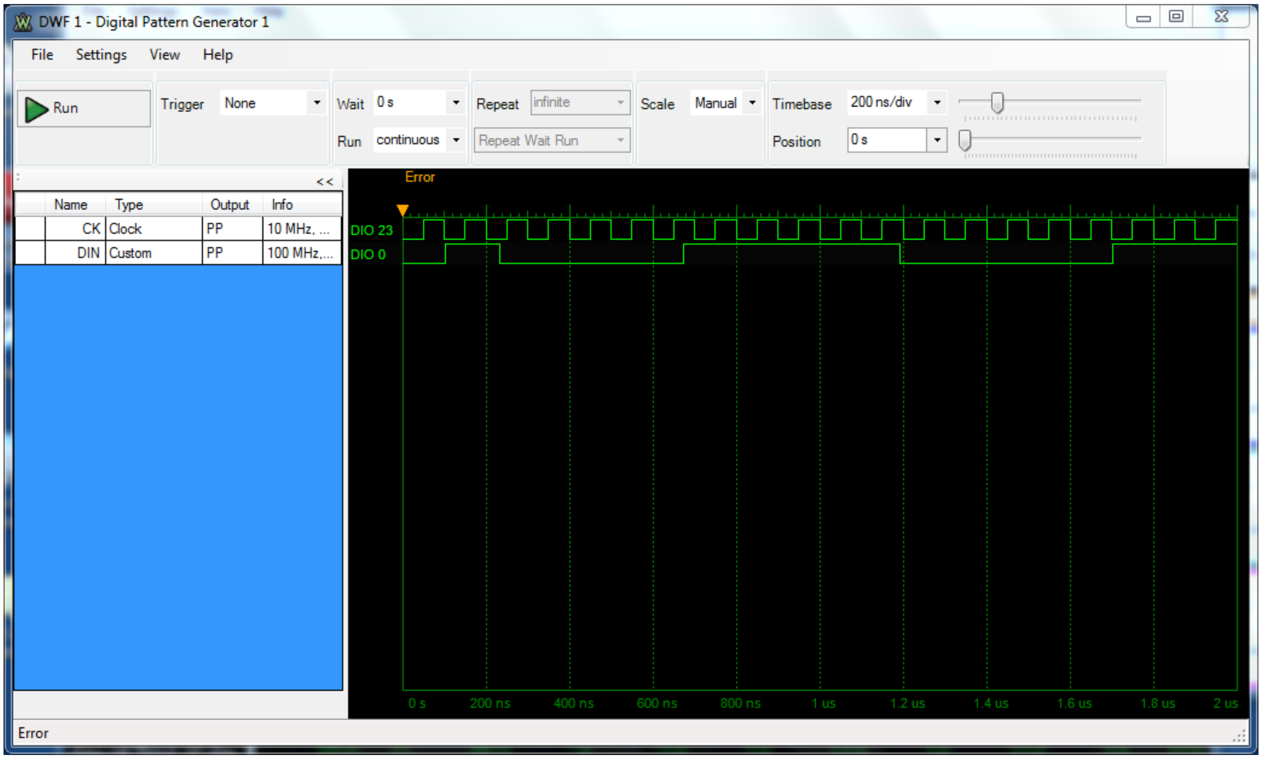


Figure 20. Input signal patterns

Since the digital pins of the pattern generator are supplied at 3.3V and we built the edge detector using TTL integrated circuits the effective shape of the signals in the circuit do not reach the ideal full swing. Nevertheless, the behavior of the circuit is functionally correct and still within the TTL allowed margins. The clock signal CK is traced on channel 2 of the oscilloscope, the input data DIN is traced on channel 3 of the oscilloscope, and the output signal DOUT is traced on channel 4 of the oscilloscope.

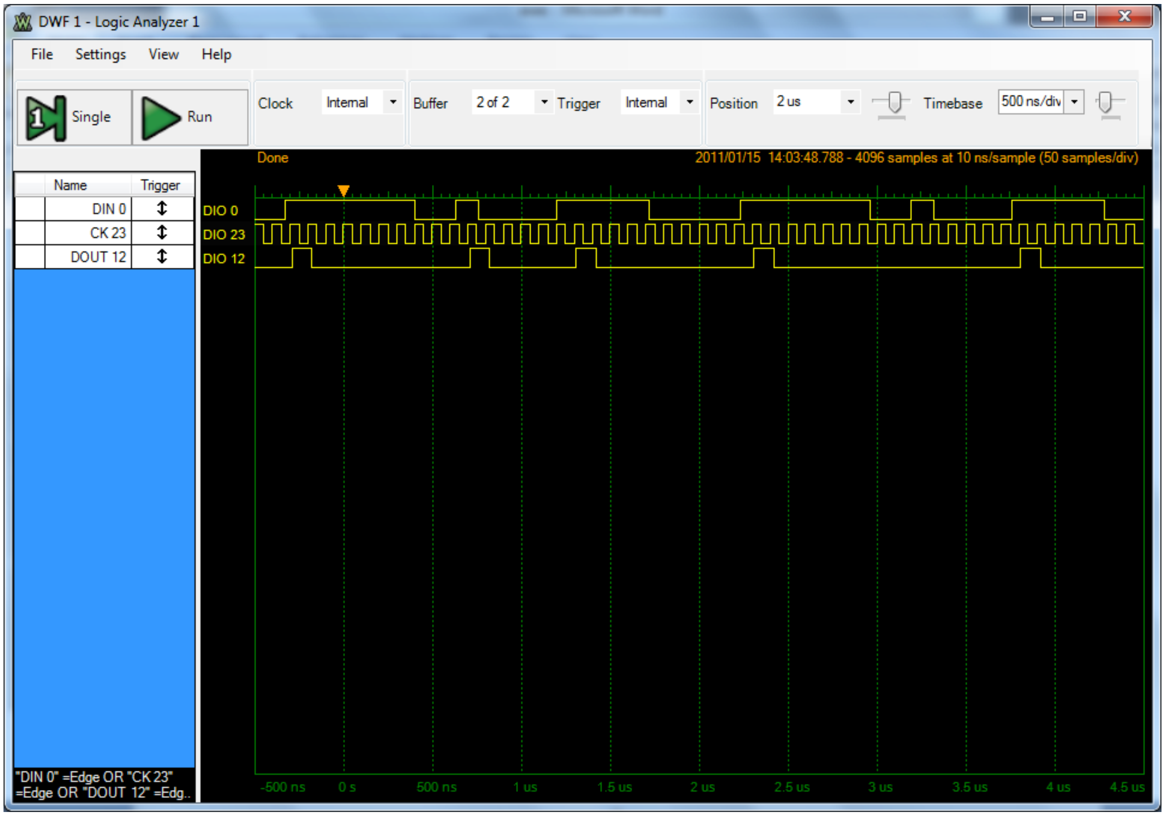


Figure 21. Waveforms monitored using the Logic Analyzer

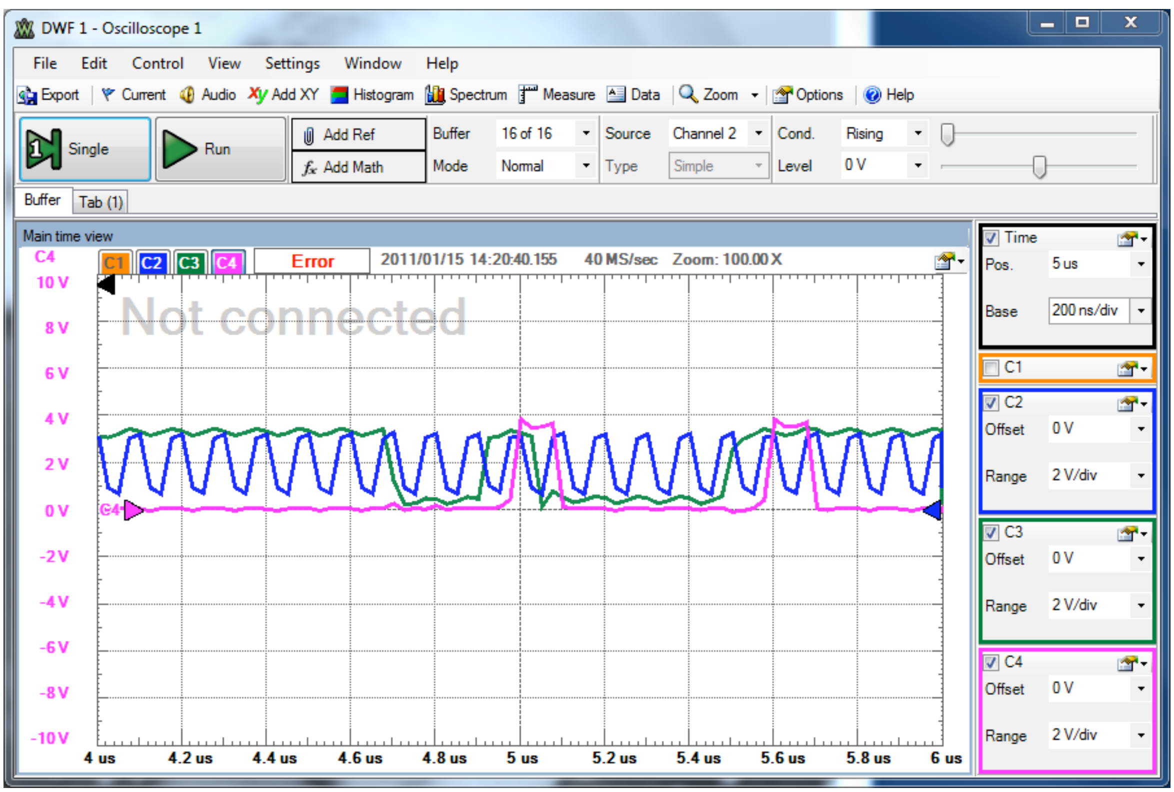


Figure 22. Waveforms monitored using the Oscilloscope

Conclusions

In this paper we analyze the viability of handling labs for circuits related classes using a simplified lab environment, which can be located virtually anywhere. The lab environment is built around a large solderless breadboard that allows communicating in real-time with a number of PC based instruments including oscilloscopes, waveform generators, power supplies, voltmeters, pattern generators, and logic analyzers. We successfully used the lab environment for 5 simple case studies: two circuit theory lab experiments, two analog electronics lab experiments, and a digital electronics lab experiment.

Bibliography

[1] K.C. Smith, Laboratory Explorations for Microelectronic Circuits, Oxford University Press, 1998

[2] S. Franco, Electric Circuits Fundamentals, Oxford University Press, 1999

[3] A. Agarwal and J.H. Lang, Foundations of Analog and Digital Electronics Circuits, Morgan-Kaufmann, 2005

[4] Electronics Explorer Board, http://www.digilentinc.com/, Digilent

[5] WaveForms Software, http://www.digilentinc.com/, Digilent