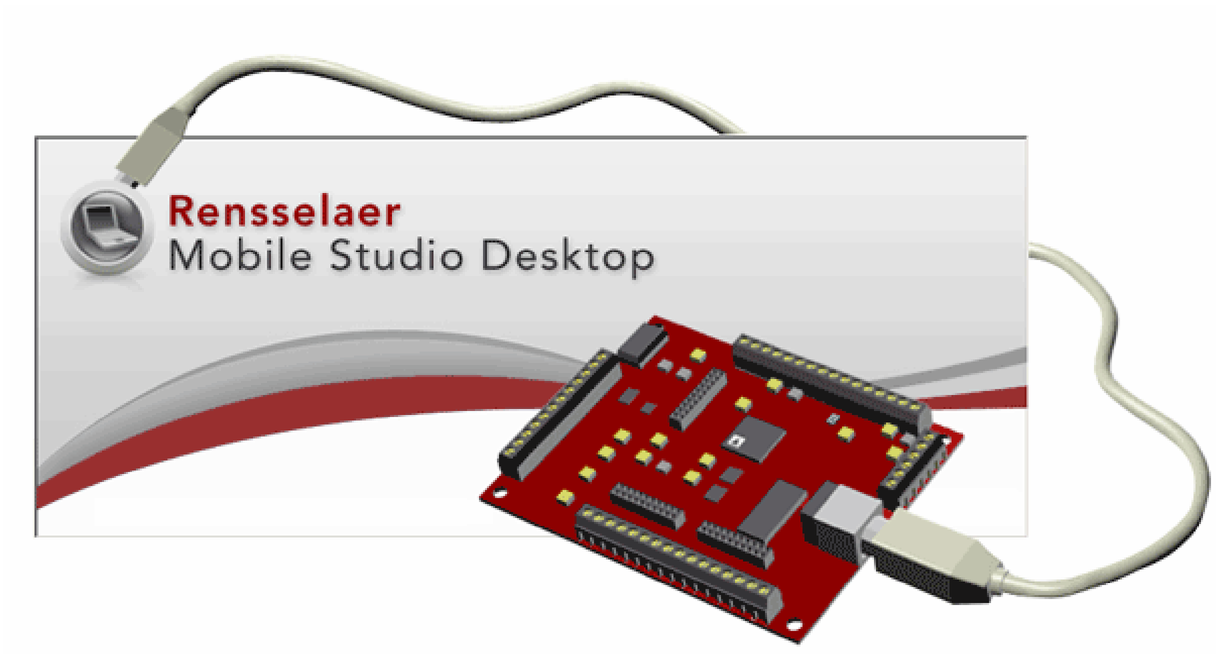
MOBILE STUDIO HARDWARE TO RE-ENGAGE STUDENTS IN HANDS-ON EDUCATION



PROJECT OVERVIEW

The "Mobile Studio" project is developing hardware/software and pedagogy which, when connected to a PC (via USB), provides similar functionality to that of the laboratory equipment (scope, function generator, power supplies, DMM, etc.). Our goal is to further expand the studio pedagogy (pioneered by Rensselaer with the help of HP) to have students learn with technology in mobile environments that are no longer limited by network access and equipment issues. Our aim is to develop and use educational technology to eliminate the boundaries between theories provided in a lecture and practice; apply concepts in directed problem sessions; and enable/encourage our students' "hands-on" exploration of engineering principles, devices, and systems that have historically been restricted to specific laboratory facilities.

Hardware Overview

The Mobile Laboratory hardware is based upon a small footprint (11.3 in^2), Rensselaer-designed printed circuit board (as shown in Figure 1). The board contains all the components required to implement a laboratory instrumentation system; including an oscilloscope (that has a 100KHz bandwidth), two independent function generators, 16 user-configurable digital I/O and 4 D/A outputs. In addition, limited power can be provided to external circuits needing +5v, +/-2.5v, or +3.3v. The hardware also offers the potential for a daughterboard to be connected to add functionality to the overall system.

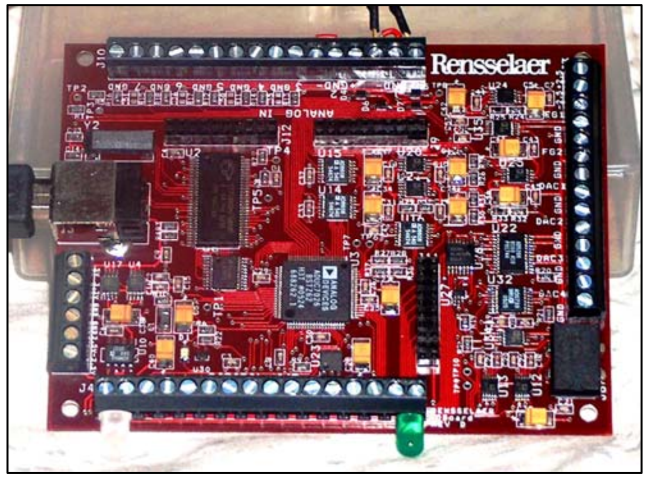


FIGURE 1 – Mobile Studio Laboratory Hardware Circuit Board

Power

A 5V power supply is provided by the PC on the same connector as the USB data port. A connected USB device can draw up to 500mA, which is more than enough for this hardware system. Using the USB eliminates the need for students to carry around a bulky wall wart and eliminates clutter (by requiring only one PC connection). Various regulators and an inverter circuit provide power to the digital and analog components on the board.

Digital Input/Output

The board has 16 digital channels, each of which can be individually selected as an input or an output. When a channel is set as an output, it can output a high voltage level of 3.3V (standard CMOS logic), and drive up to 1.6mA. When selected as an input, the channel is 5V tolerant which allows interfacing to TTL logic families. These digital pins can be used for various output modulation schemes (e.g. Pulse-Width Modulation, PWM) and as a logic analyzer; in addition to simple control and monitoring applications.

Analog Input

At the heart of the analog input system is a 1 MS/s, 12-bit analog-to-digital converter. The ADC is multiplexed to 12 channels, seven of which are available to the user via screw terminals mounted on the board. Channels 3 through 7 are able to read voltages between 0 and positive 2.5V. Channels 1 and 2 are enhanced with a front-end amplifier in order to more closely match a commercial oscilloscope's input capabilities (though any analog channel can be used in oscilloscope mode). The input range is -10V to +10V on these two channels, which is achieved via a digitally-adjustable gain circuit. These two enhanced channels can be operated in single-ended or differential mode and are designed with high input impedance to minimize the loading effects of the hardware on the circuit under test. Many standard oscilloscope features that are traditionally implemented in hardware, such as AC coupling, are implemented in firmware or software in order to minimize cost and increase flexibility.

Analog Output

Four independent digital-to-analog converters (DACs) are supplied to compliment the analog input capabilities of the hardware. The output range of the DACs is 0 to 2.5V, with 12-bit resolution. These can be used to provide a DC voltage to an external circuit, or to produce AC voltage in an arbitrary waveform generator configuration. All four channels are internally tied to analog input channels to allow the user to monitor the DAC output.

Waveform Output

Two independent function generator channels are provided on the board in addition to the DAC outputs. Each is capable of generating sine, triangle, and square waves at frequencies between 0.004 Hz and 100 kHz. These channels have adjustable DC offset and amplitude controls; similar to those available a bench top function generator. The phase of each generator can be varied to allow the output to be put in or out of phase or anywhere in between relative to the other channel. As with the DAC channels, these two channels are internally tied to analog input channels to monitor the output of each function generator.

Daughterboard Expansion

In addition to providing all of the aforementioned features, three vertical headers provide access for a daughterboard to interact with nearly all the capabilities of the board. A daughterboard can supply or monitor analog and digital signals to/from the main board, as well communicate with the user's PC through the main processor. One such daughterboard that is populated with multiple sensors for use in Physics courses has been developed at the time of this writing.

Software Overview

The PC software suite is designed to allow a collection of different features to easily communicate with a variety of on/off-board hardware. The components of the suite are grouped into three categories: the framework, the hardware interfaces, and feature displays.

Framework

The Mobile Studio Desktop application (shown in Figure 2) dynamically loads any features and interfaces that are available on a user's system, allowing for seamless addition and upgrading of components. Both the feature displays and the hardware interfaces abide by a set of "rules" which makes the interface between the two possible. A single feature display doesn't need to know the specifics associated with a particular hardware variant. Instead, it simply sends standardized commands to the framework; that then decides which hardware interface should be used to relay the commands. This makes the system flexible in meeting the expanding user needs and accommodating further hardware embellishments.

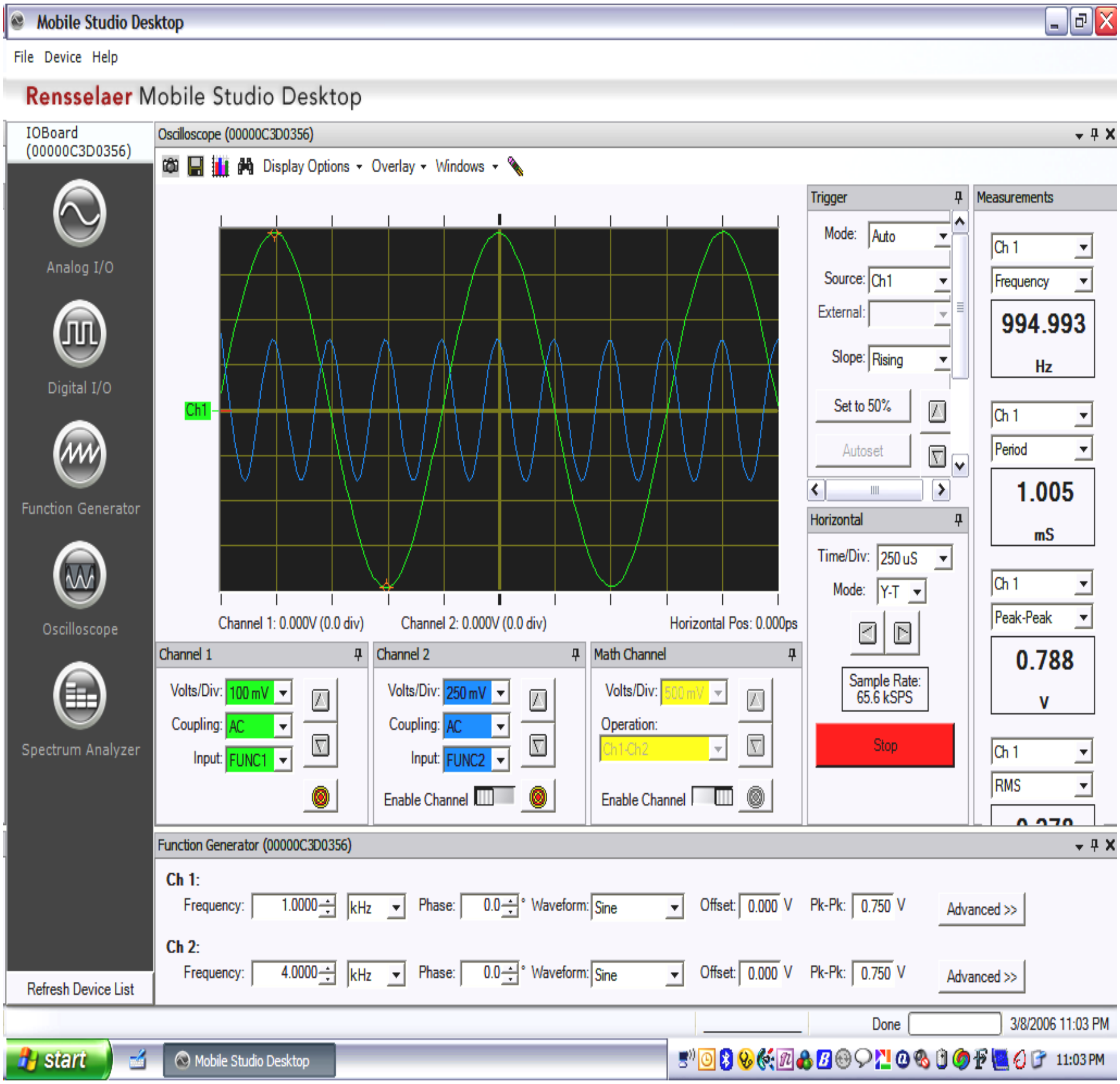


FIGURE 2 – The Mobile Studio Application Main Screen

The hardware interfaces take the standard commands and re-process them into a form that their specific hardware understands. Both the hardware interfaces and feature displays are implemented as DLLs allowing for further incorporation in other software environments. Once combined, the system is a powerful suite that allows virtually limitless expansion on both the hardware and software sides.

The framework application manages the list of currently connected hardware boards (since the software can simultaneously connect to multiple devices) and provides the graphical interface for the user to select which features they want to use in conjunction with each board. The application also manages the windows for each feature so that several features can be open at the same time; either from the same or different hardware.

Hardware Interfaces

A key goal in developing the software suite was to allow the feature displays to communicate with a variety of hardware; both that which currently is implemented and additional hardware which is yet to be realized. The individual hardware interfaces provide an identical interface to the rest of the suite; however the way in which each hardware interface handles the data is very different. The interfaces take the data provided to them from the feature displays and format it into the equivalent command set that their specific hardware understands.

Separating the hardware interfacing from the rest of the software yields a number of advantages; one such advantage is that numerous communication interfaces can be utilized. While the current hardware communicates over USB, the hardware interfaces are equally capable of handling a device which communicates over serial or TCP/IP. A second advantage is that a feature display can be written without any knowledge of future hardware. New feature displays can be developed that work with both new and old hardware without any additional development time. In addition to providing services to the software suite, the hardware interfaces can be used by 3rd party applications to also create software tailored to a specific task. In fact, an instrument driver VI has also been developed to utilize the Mobile Studio board in a National Instruments LabVIEW environment.

Feature Displays

The feature displays are the user interaction section of the software. They provide a graphical interface tailored to a specific functionality that the hardware can perform. For example, the Oscilloscope Feature Display provides the user with a screen that mimics a stand-alone oscilloscope; while the controls react as they would on a bench top counterpart. Five feature displays have been developed at this time; including displays for the Analog I/O, Digital I/O, Function Generator, Oscilloscope, and Spectrum Analyzer functionalities.

The Analog I/O display provides a voltmeter-like display for analog inputs. All of the available analog channels can be selected; while the readout updates at rates similar to those of a mid-range multimeter (10 Hz). A slider and readout are available for each DAC channel output; the setting from which produces a DC output voltage between 0 and 2.5V. The slider provides an easy interface method for either a standard mouse-and-keyboard PC or a pen-based (tablet) PC. The readout provides a digital display of the output value. The voltmeter display can be set to show the output of a DAC channel at the same time the user is changing the DAC output; in order to verify that the expected output is indeed the actual output.

The Digital I/O page (shown in Figure 3) provides a very basic interface to set the direction (in/out) and state of each digital pin and view the current state via a virtual LED/logic probe display. Please stay tuned, since this display will be upgraded to include digital modulation schemes such as PWM, as well as other options in the future.

The Function Generator display offers the ability to set the frequency, phase, waveform type, offset, and peak-peak level for each channel available on the connected hardware. In addition, a user can set the generator to automatically or manually sweep the frequency between two values (that can be chosen by the user).

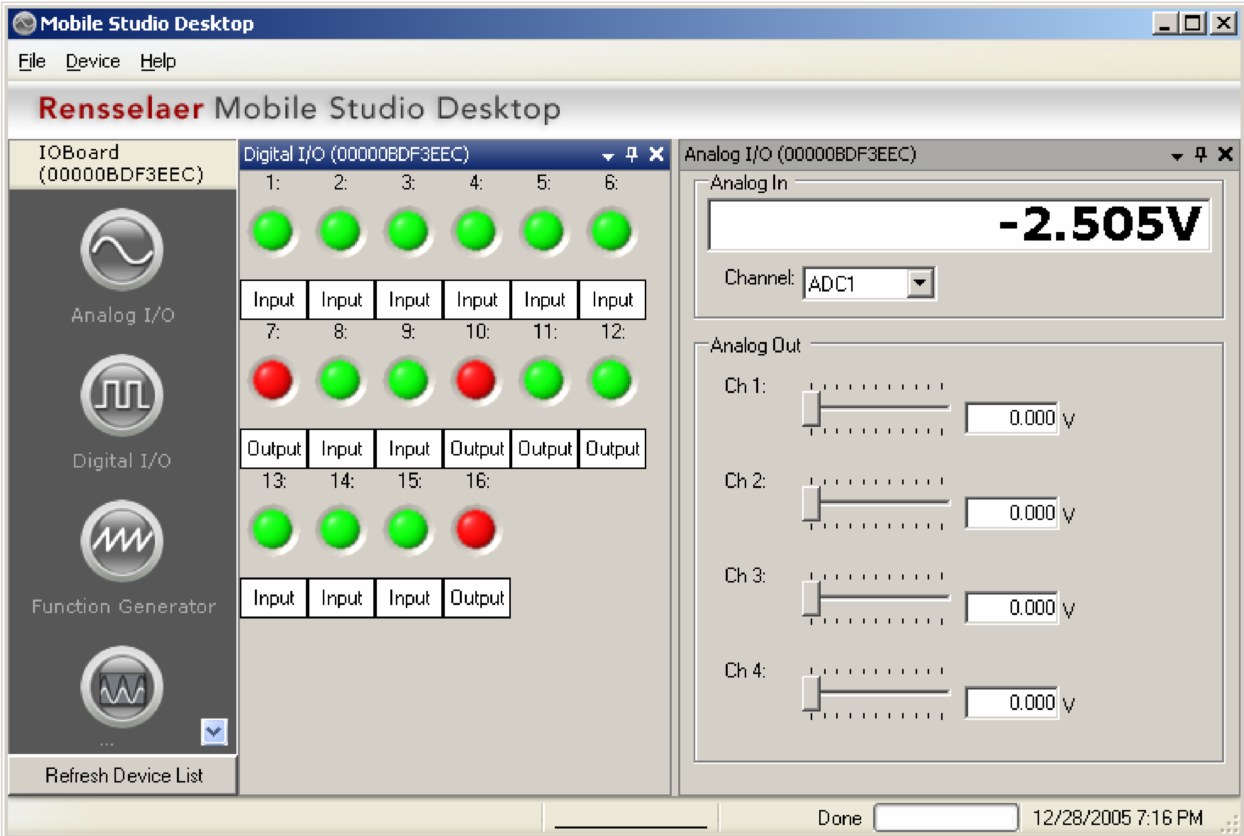


FIGURE 3 – The Digital I/O and Analog I/O Displays

Both the oscilloscope and spectrum analyzer displays are designed to mimic the actual instruments as closely as possible; while still exploiting the enormous advantages that a dynamic user interface on a PC provides in comparison to the fixed interface of a bench top instrument. Although the user "clicks" on something on the screen – instead of turning a physical knob – the proficiency garnered via the use of this PC-based scope will allow them to readily use a bench top scope with little, or no training.

The oscilloscope display is set up as a multi-color, dual-channel scope with an additional math channel. Triggering options include: Single-Shot, Normal (where the display is only updated when the trigger condition is met) and Auto (where the display is updated "un-triggered" when no trigger condition is met for a set amount of time). The user also has the option of turning off triggering for viewing non-cyclical signals. The trigger source can be selected to utilize either Channel 1, Channel 2, or any one of the digital input pins; similar to the "external trigger" option of a conventional scope. The slope of the trigger (rising or falling) and the trigger voltage level are both selectable. An option to set the trigger to 50% of the current signal is also available.

Any analog input can be chosen for viewing using either of the oscilloscope channels. For example, analog input pin 5 could be assigned to Channel 1, while the second function generator's output could be assigned to Channel 2. This functionality offers tremendous flexibility that is not typically found in bench top instruments. It allows the user to have a large collection of signals connected to the hardware at the same time; with an ability to easily select which input to observe. The software automatically adjusts the display to account for the differences between the various analog inputs. In addition to the standard "volts vs. time" display, the oscilloscope also includes a Channel 1 vs. Channel 2, commonly referred to as an "X-Y" display.

The oscilloscope feature display also includes a number of additions to aid the user in measuring a signal. A "Measurements panel" provides the user with the Frequency, Period, and Peak-Peak, RMS, and Mean voltage of either Channel 1 or Channel 2. Both time and voltage cursors are also available for use in a situation where the user wishes to measure something that is not directly available via the Measurements panel.

The Spectrum Analyzer Feature Display presents the user with a screen that mimics an entry-level, bench top spectrum analyzer. The user has the option of selecting a center frequency and span; or a start and end frequency. The vertical scale can be set manually or put into Auto mode. The user can select any available analog channel as the input source; as with the oscilloscope feature. User-controlled cursors are also implemented, along with automatically placed peak markers. A simple time-domain view is available to allow the user to ensure that the input signal appears as expected. Two separate collection modes are available. The first mode uses the hardware's maximum sample rate. The downside of utilizing this "high-speed mode" is that the buffer size is limited to 1k; since the buffer is implemented in hardware. This mode is good when a user wishes to see a wide spectrum of frequencies but is not concerned about resolution. The second mode uses a lower sample rate and allows for much larger buffers. Since the buffer is implemented in software, the user can select how large they wish the buffer to be. This mode offers far greater resolution; with the disadvantage of a lower maximum frequency.

Implementation and Utilization

One Year Ago

Studio pedagogy has historically needed dedicated spaces for courses incorporating laboratory instrumentation that are expensive to build, maintain and staff. Consequently, lab-equipped studio classrooms are both in high demand and in extremely short supply. Even with the more engaging studio environments, student learning is still impeded by space constraints, insufficient time for laboratory activities (particularly to do the in-depth probing that leads to an intuitive feel for system design), and poorly designed equipment that takes up a great deal of space. The equipment sets can't be brought home for individual study, thus limiting the time for hands-on explorations that students need to grasp the "big ideas" in engineering.

Today's students don't enter college with the same level of hands-on "tinkering" with hardware that prior generations exhibited. Lab experimentation provides a sense of where things deviate from theory, offering the opportunity to explore non-ideal conditions; while also giving students the chance to play with hardware and gain the experience that helps them support their subsequent design courses.

Today

Configuring a studio facility typically requires a large equipment allocation/expense and a specific space utilization plan. Renovation of existing facilities is currently cost-prohibitive for many schools, thus limiting the potential to leverage the advantages of the studio format. The hardware is being piloted in five courses at Rensselaer and Howard University - providing studio classrooms for curricula that used to offer courses in lecture only formats; currently involving Electrical Engineering, Computer Engineering, Physics and Rensselaer's core engineering program.

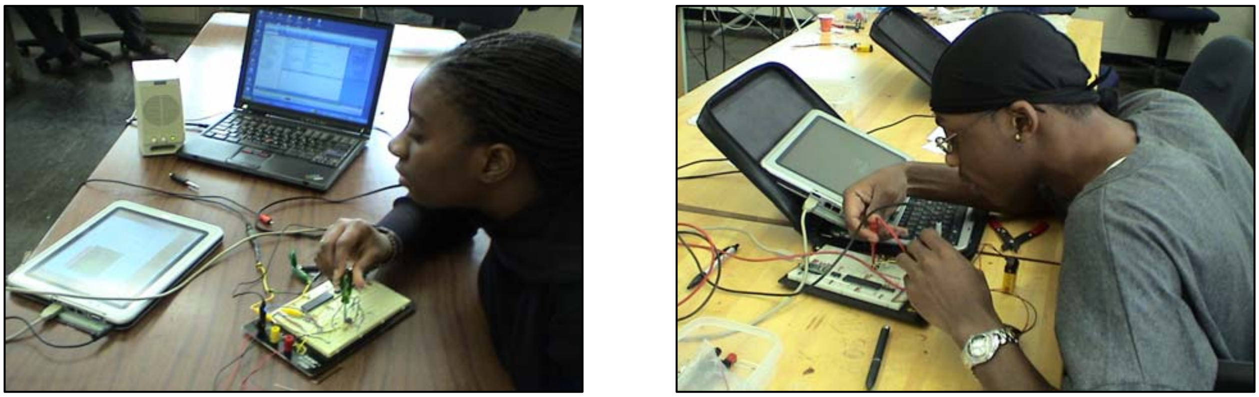


FIGURE 4 – Howard University Students Using the Protoboard Version of the Mobile Studio

As a wonderful testament to the project's achievements, Jason Coutermarsh (the undergraduate student developing the instrumentation board hardware) won first prize at Rensselaer's 2005 Undergraduate Education/Research Project Competition.

Day & Date	Topics and Activities in Class		Preparation		Assignments Due		In-class
			Reading	Prep	Probs	Report	Activities
M 1/17	Class	No classes *(Martin Luther King Day)*					
T 1/18 W 1/19	1	Course introduction, units, symbols and variables, ideal/practical sources and loads, power, Ohm's law	Chapter 1 & 2.1				1-1, 1-2
R 1/20	2	Resistance (series/parallel), switches, Kirchhoff's laws, equivalent circuits, V/I dividers, circuit reduction	2.2-2.6				2-1, 2-2 & V-divider module
M 1/24	3	PSpice introduction, potentiometers, electrical measurements, resistance bridges	2.7	EP-1			3-1 (PSpice) and E-1, (experiment info sheet)
T 1/25 W 1/26	4	Node-voltage & Mesh-current analysis methods	3.1, 3.2		HW1: 1-4, 1-22, 2.23, 2.48, 2-61		4-1, 4-2, Ckt. Solver module, & 4-3
R 1/27	5	Circuit solutions using node and mesh equations, Linearity, superposition	3.2, 3.3				4-3 (if needed) 5-1, 5-2
M 1/31	6	Superposition, maximum power (signal) transfer, Thevenin/Norton circuits	3.4, 3.5	EP-2	HW2: 3-5, 3-13, 3-17, 3.31, 3.33		6-1, 6-2 and E-2
T 2/1 W 2/2	7	Interface circuit design, dependent and controlled sources, statistical analysis	4.1, 4.2				7-1, 7-2
R 2/3	8	Circuits with dependent sources, Thevenin parameters and the transistor	4.3	EP-3		E-1 (due) (Format rec.)	8.1, 8.2, and E-3
M 2/7	9	Ideal Op-Amps, Op-Amp circuit analysis, Lab instrumentation, amplifiers	4.4, 4.5		HW3: 3-39, 3-50,		E-3 (cont), 9-1 & Op-

FIGURE 5 – Sample Circuits Course Syllabus
(Indicating Utilization of Mobile Studio Hardware)

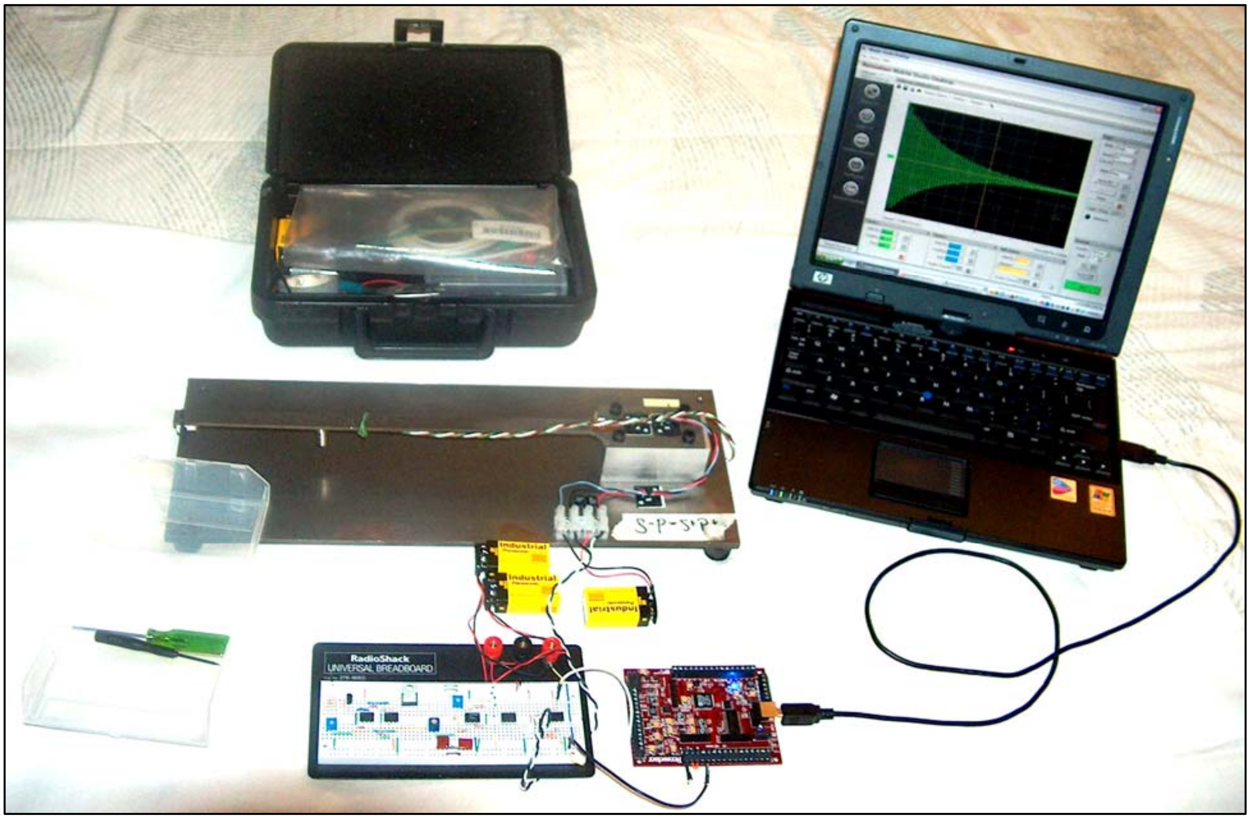


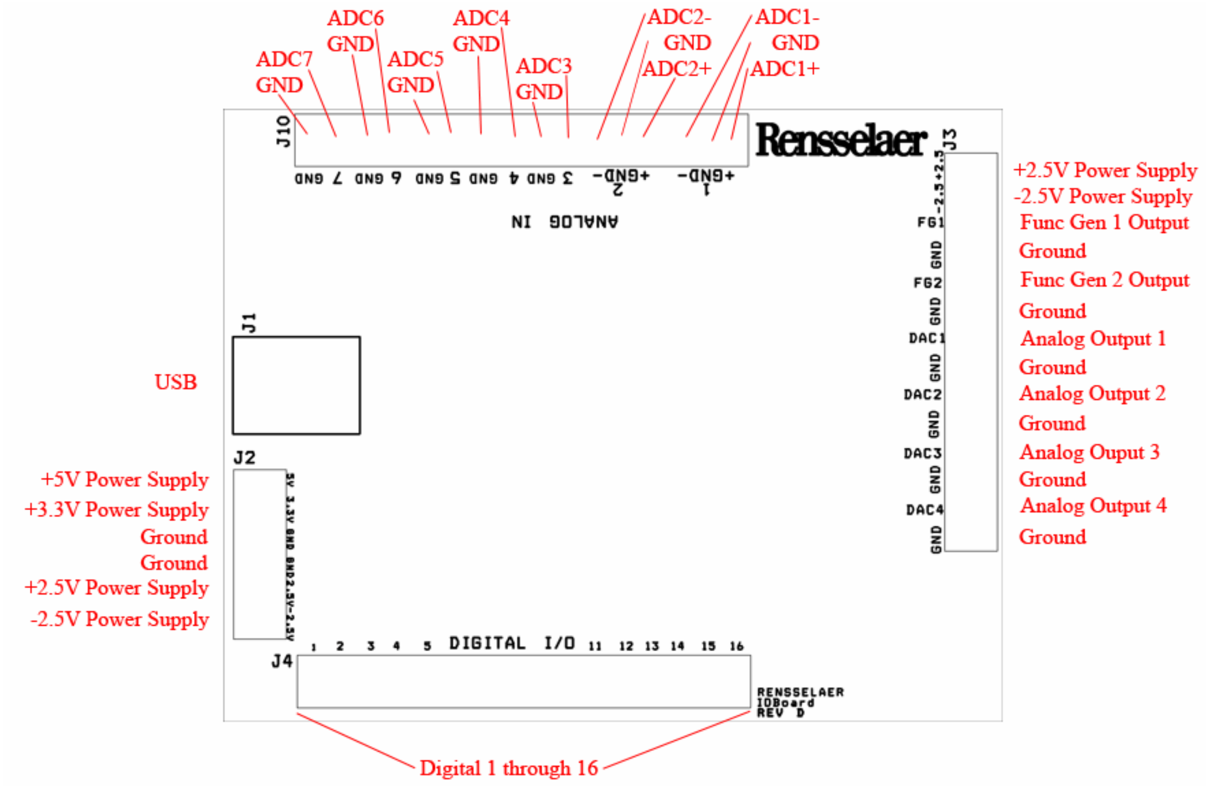
FIGURE 5 – Dynamic System Experimental Setup Using the Mobile Studio Hardware

One Year from Now

We will use the advanced mobile technologies to produce a new generation of classrooms that are more adaptive and less reliant on the construction of large facilities, allowing studio pedagogy to be readily deployed at a dramatically reduced cost. We plan to infuse the technology and pedagogy into Rensselaer's Physics and ECSE departments' large enrollment courses and expand the utilization of mobile studio classrooms campus-wide. Ultimately, we will develop the Mobile Studio practices and the technology into a model that can be readily adopted by home-schooling providers, community colleges, universities, and K-12 institutions (building on the pilot activities currently underway at Niskayuna, Schenectady, and Albany School Districts - in NY State) – to significantly impact student learning on a national scale. It is anticipated that the Mobile Studio hardware will be readily available for others at an estimated cost of less than $80/board; while the software will be made available to interested parties via Rensselaer's Academy of Electronic Media website.

Website Information:

- http://www.academy.rpi.edu/projects/hp/
- http://ioboard.rpi.edu



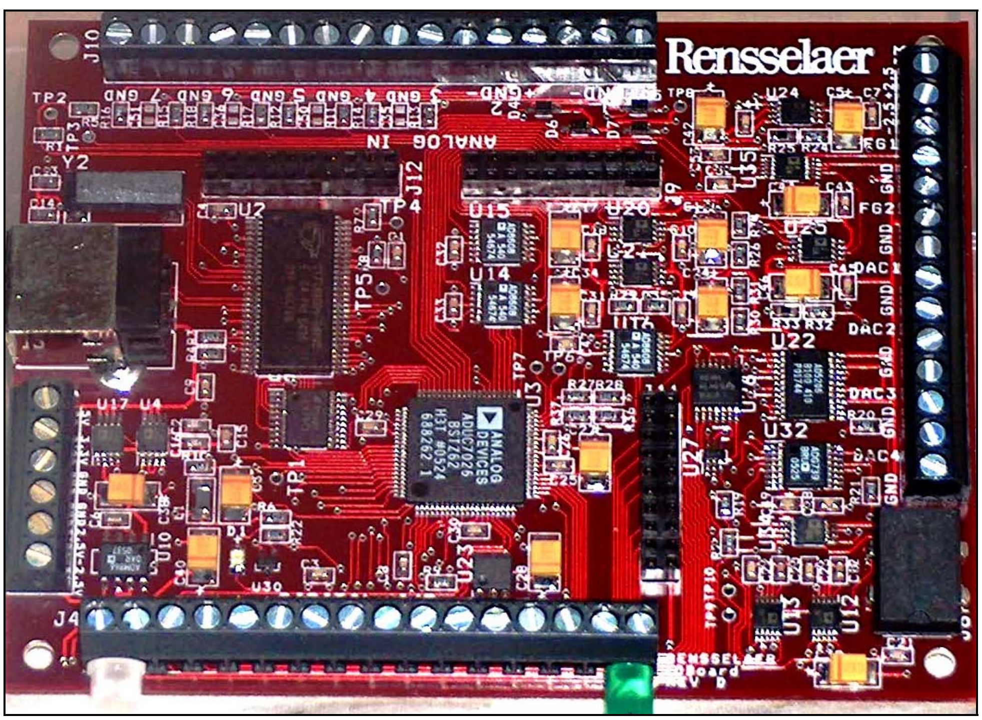


FIGURE 6 – Mobile Studio Board Layout and Connector Descriptions

Further Information

If you are interested in either adopting the mobile studio pedagogy or simply acquiring any number of the mobile studio hardware/software systems please notify us as soon as possible, since we will be embarking on another manufacturing cycle and would like to get as large a volume discount as possible. In addition, If you would like to garner additional insight as to how the mobile studio offers the ability to provide students with greater hands-on experience via in-class activities or hardware-based homework, please contact us directly at:

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