AC 2007-598: PROJECT GUISE: CURRICULAR INTRODUCTION AND RESOURCES FOR TEACHING INSTRUMENTATION

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Project GUISE: Curricular Introduction and Resources for Teaching Instrumentation

Abstract

Project GUISE (General-purpose, Universal Instrumentation System for Education) is a computer-based laboratory instrument combining LabVIEW virtual-instrumentation software and custom external hardware developed with support of the National Science Foundation under grant DUE 9952292. Descriptions of its development have been previously published. However, an opportunity to use Project GUISE in the curriculum had not yet occurred at that time. It was created expressly to support a senior-level course in instrumentation and measurement systems, but only recently did that course gain sufficient interest and enrollment to be taught. Project GUISE has now had its introduction to the instructional setting; students have used it to create instrumentation applications such as thermocouple thermometers, a weighing scale using an aluminum cantilever instrumented with a strain gage, a displacement-measurement system using an LVDT, and an optically-coupled isolation amplifier. Other experiments (such as design and test of a carrier amplifier and measurement of the common-mode rejection ratio of the Project GUISE instrumentation amplifier) will be available for the next offering of the instrumentation course. Curricular resources written for Project GUISE include tutorials and background information on the subjects of the experiments, a spreadsheet for design of thermocouple thermometers, and a hardware description (including schematics) of the Project GUISE instrument that may be used in conjunction with upper-level courses in electronics. The proposed paper will describe the curricular introduction of Project GUISE (including student reactions to its use) and accompanying curricular resources and reference materials (including virtual-instrument software).

Brief history of project

Project GUISE was developed as part of a collection of unique computer-based laboratory instruments with support of the National Science Foundation under grant DUE 9952292. These instruments, combining custom external hardware and LabVIEW virtual-instrumentation software (National Instruments, Austin, TX), were built on the model of Project TUNA, a Bode analyzer developed as a class project in a second-semester junior electronics course[1]. The other instruments developed under this grant were integrated into regular curricular use some time ago; however, Project GUISE was described in earlier work[2,3] but it not introduced into curricular use until 2005 because the course for which it was intended (EENG 4302, Measurement and Instrumentation Systems) did not gain sufficient student interest before then for it to have been offered.

Project GUISE instrument hardware

Project GUISE is a collection of basic instrumentation-system building blocks. Instrumentation systems are constructed by connecting the appropriate blocks using external cabling and, in some cases, additional external electronic components.

Hardware is controlled by a LabVIEW VI running on a host computer. A multifunction data-acquisition (DAQ) card serves as the interface between the VI and the Project GUISE hardware. Project GUISE requires an external dc power supply furnishing ±15V at 400mA.

Photographs of the Project GUISE instrument and a complete hardware description are available at:

http://ee.uttyler.edu/David_Beams/Projects/NSF DUE9952292/Project GUISE/Project_GUISE.htm

The various hardware building blocks of the Project GUISE instrument are:

1. A variable-gain (×1, ×5, ×10, and ×50) instrumentation amplifier. The instrumentation amplifier has maximal input-bias currents of 2nA and input-offset voltages of 150μV. Independent adjustments for maximizing common-mode rejection ratio (CMRR) are incorporated for voltage gains of ×1, ×5, and ×10; measured CMRR exceeds 90dB at 100Hz.
2. An electronic cold-junction compensator (LT1025) for thermocouples. Types R, S, J, K, T, and E thermocouples are supported. The compensated thermocouple voltage is amplified by a dc-coupled amplifier with gain of ×50.
3. Two independent variable-gain ac/dc-coupled single-ended amplifiers (Amplifiers 0 and 1). Each amplifier has a selectable voltage gain of ±1, ±5, ±10, or ±50. Amplifier 0 has provision for a user-adjustable dc offset of ±10V. The amplifiers' input impedances are greater than 1MΩ and their nominal output resistances are 470Ω.
4. Four single-pole, double-pole double-throw (SPDT) analog switches. The four switches are grouped into two pairs of switches with each pair having a common TTL-level control signal input. The switches may be used for construction of such circuits as switching-type phase-sensitive demodulators or chopper-stabilized amplifiers.
5. A voltage-controlled quadrature oscillator with cosine and sine outputs and TTL-level sine- and cosine-synchronous square-wave outputs. The sinusoidal signals have an amplitude of 5V and are current-limited to ±50mA and may be used for driving LVDTs and ac-excited bridges. The oscillator frequency range is 100Hz to 10kHz.
6. A precision unity-gain full-wave rectifier. The rectifier may be used for recovery of a dc voltage from an ac waveform when phase-sensitive dc recovery is not necessary.
7. Connections to two analog input channels of the DAQ card. Each analog input channel can be connected directly to an external signal source, or the external signal may be filtered by a Butterworth two-pole low-pass filter with unity dc gain and cutoff frequency of 4.3Hz before it is passed to the DAQ card. The selection of direct or filtered connection is made from the front panel of the VI.

Figure 1 shows the resources available within the Project GUISE instrument. Figure 2 is a diagram of the front panel connections of the Project GUISE instrument. Most connections to the Project GUISE hardware are BNC connectors.

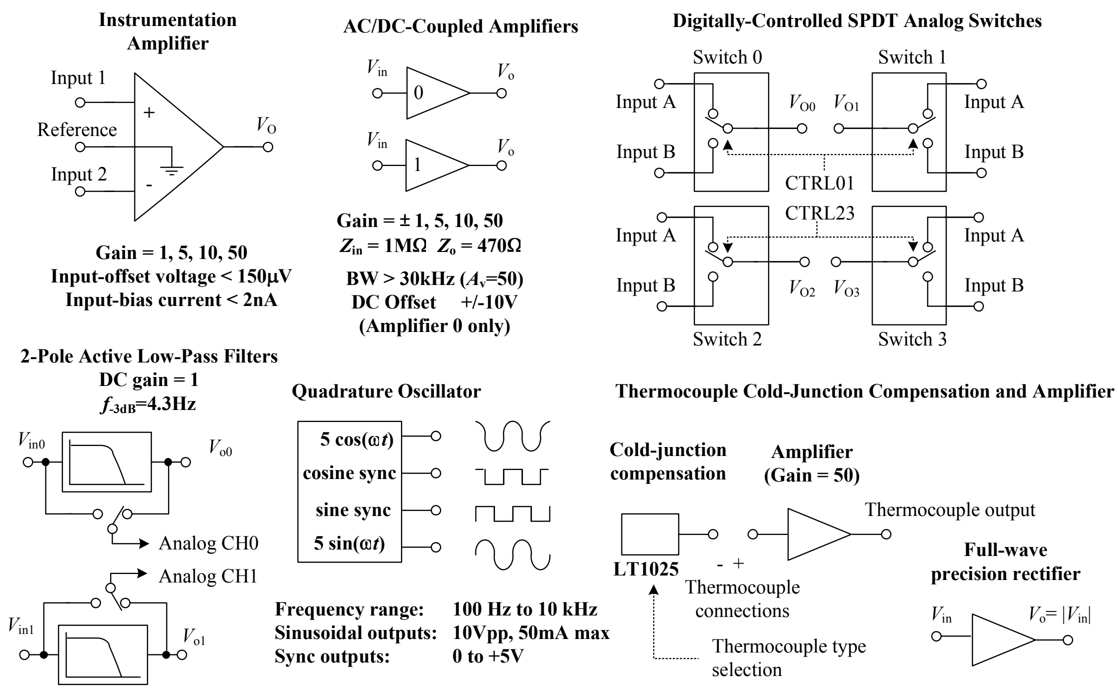

Fig. 1. Hardware resources available within the Project GUISE instrument. Connections shown as open circles represent BNC connectors on the front panel of the instrument.

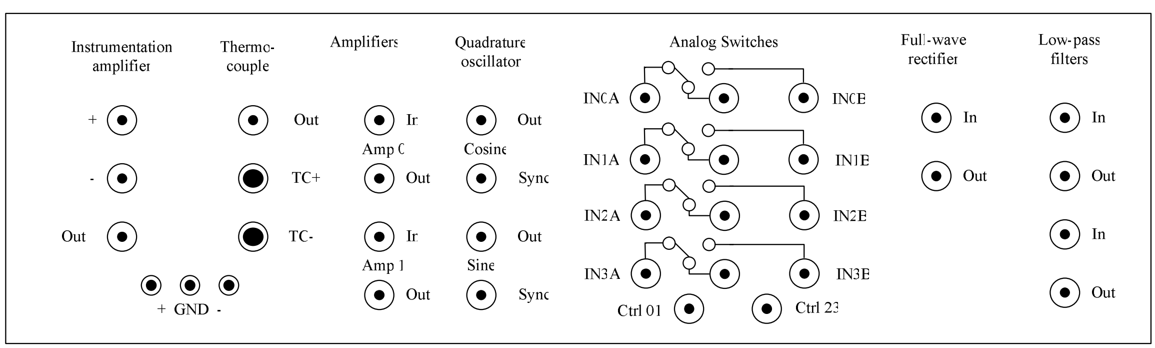

Fig. 2. Front-panel connections of the Project GUISE instrument. Power (+, GND,–) connections below the instrumentation and thermocouple amplifiers are used to allow these circuits to be powered by a power supply isolated from the remainder of the Project GUISE instrument.

Project GUISE virtual instrument programs

A "generic" Project GUISE VI controls the instrument hardware, acquires readings from the analog inputs of the data-acquisition card, and transforms these raw readings into measurements. Some custom VIs have been developed for specific applications (e.g., a scale using an aluminum cantilever and a strain gage). Figure 3 shows the front panel of the generic VI. Control functions of the VI are:

1. Instrumentation amplifier voltage gain;
2. Thermocouple type;
3. Isolated/non-isolated power connections for the instrumentation amplifier and thermocouple amplifier;
4. Voltage gain, ac/dc coupling, polarity, and dc offset for Amplifier 0;
5. Voltage gain, ac/dc coupling, and polarity for Amplifier 1;
6. Quadrature oscillator frequency;
7. Quadrature oscillator calibration (slope and offset) adjustments;
8. Independent controls for direct or low-pass-filtered connection of external signal voltages to channel 0 and channel 1 of the DAQ card;
9. Direct or low-pass-filtered connection of an external signal voltage to channel 1 of the DAQ card;
10. Calibration constants (quadratic, linear, and constant) to map the raw voltage readings of analog channels 0 and 1 of the DAQ card to measured quantities.

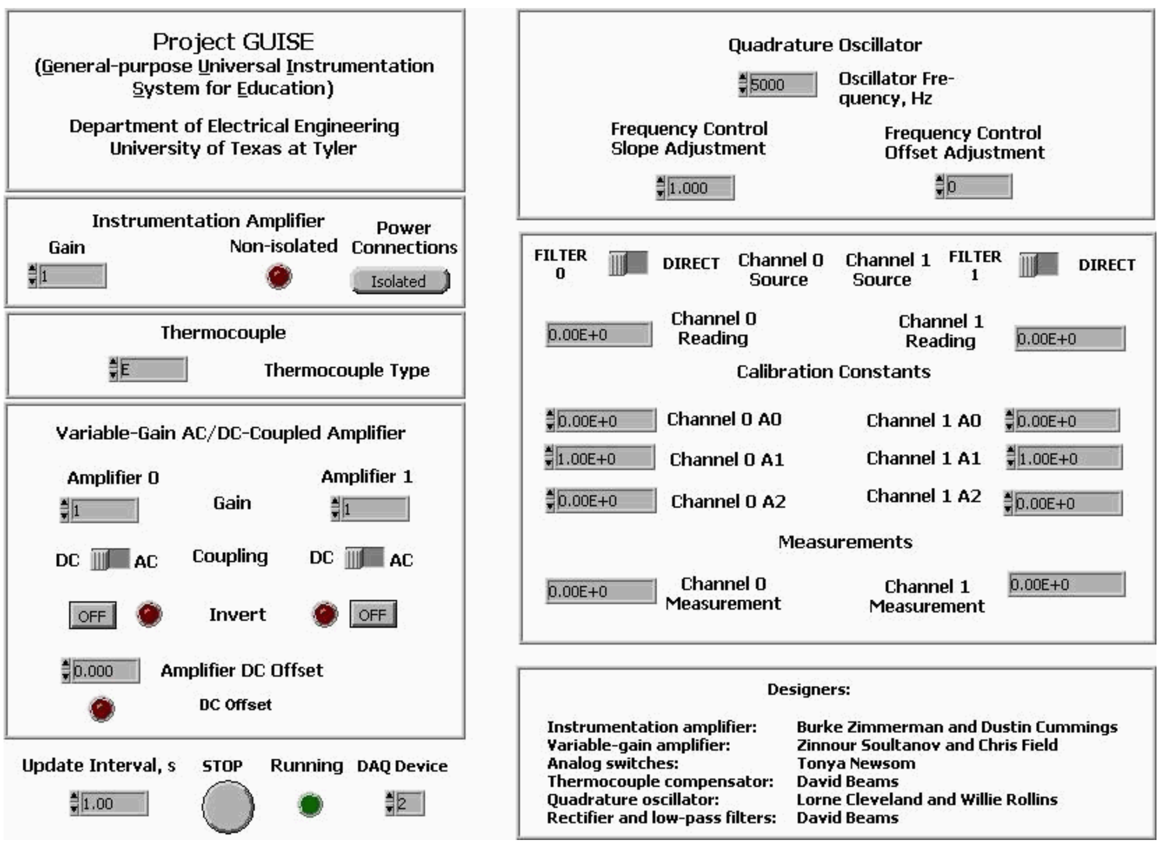

Fig. 3. Front panel of the generic Project GUISE VI.

Data-acquisition card requirements

Project GUISE requires the following resources in the DAQ card:
1. Two analog-to-digital converter inputs with ±10V input voltage ranges;
2. Two digital-to-analog converter outputs with ±10V output voltage ranges;

3. Two independent 8-bit digital I/O ports.

The Project GUISE instrument was originally designed to use the PCI-1200 Multifunction I/O card but has been replaced by the PCI-6025E (both from National Instruments).

Project GUISE curricular introduction

The structure of EENG 4302 did not include a separate laboratory component; use of Project GUISE was therefore incorporated as a laboratory component of homework assignments.

Students performed laboratory exercises on the following topics:

- Principles of switching phase-sensitive demodulation
- Thermocouple thermometer
- Linear variable differential transformer (LVDT)
- Optically-coupled isolation amplifier
- Load cell and dc-coupled strain-gage amplifier

Switching-type phase-sensitive demodulation: the theoretical section of this procedure describes various forms of switching phase-sensitive demodulators. Students then constructed an active phase-shift network driven by the quadrature oscillator to produce a constant-amplitude, variable-phase sinusoid. The analog switches and low-pass filters were used to construct different forms of phase-sensitive demodulators. Students were asked to compare the dc output voltages of the phase-sensitive demodulator to the values predicted in the theoretical background. Fig. 4 below shows the configuration of the Project GUISE instrument to implement a switching phase-sensitive demodulator using two SPDT switches. The phase-shift network shown in Fig. 4 allows phase of the output voltage to be varied relative to the input voltage through a range of approximately –1° to –138° with an excitation frequency of 250Hz.

Thermocouple thermometer: the background section of this procedure gives an introduction to thermocouples, including a table of thermocouple data from Holman[4]. Cold-junction compensation by means of a reference thermocouple and by an electronic cold-junction compensator (LT1025) is introduced. Figure 5 shows the outline of the system presented in the laboratory exercise which students are asked to implement using Project GUISE. This exercise did not include a connection diagram of the Project GUISE instrument since the detailed configuration of the thermometer would depend upon the temperature range and the type of thermocouple.

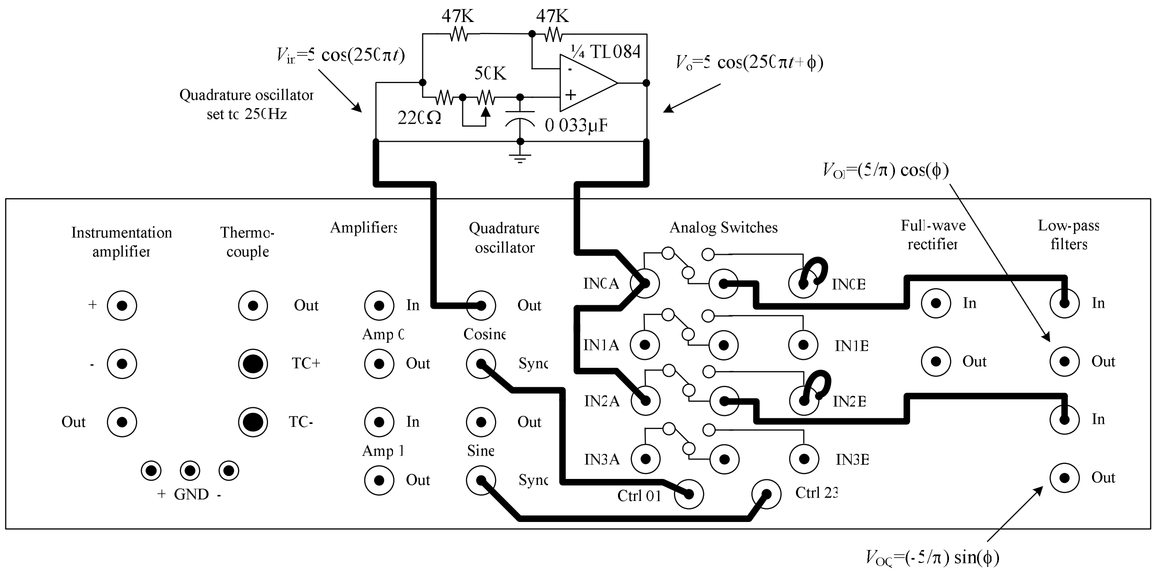

Fig. 4. Project GUISE instrument configured to illustrate phase-sensitive demodulation with two SPDT analog switches actuated by cosine and sine sync signals. The heavy lines represent coaxial cables. The small loops shown at switch inputs IN0B and IN2B indicate that the terminals of these BNC connectors are short-circuited to each other. Input voltages to analog channels 0 and 1 of the data-acquisition card are taken from the outputs of the low-pass filters.

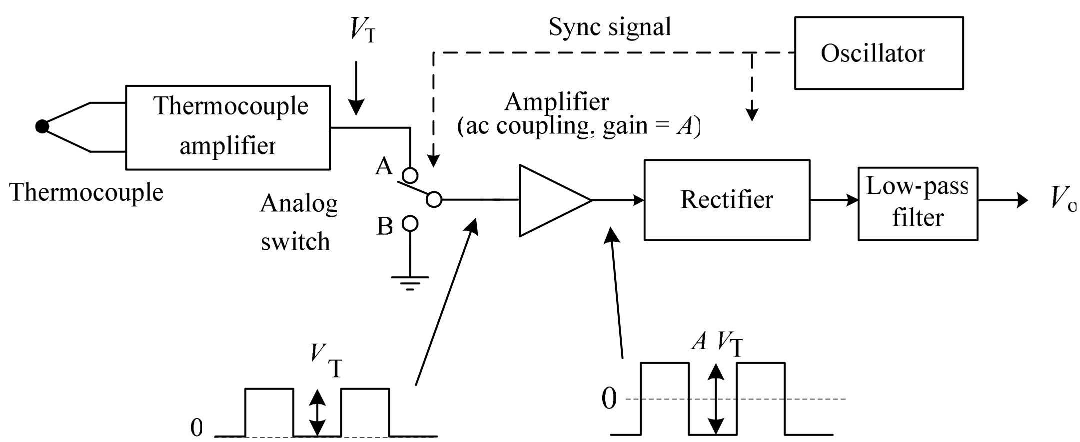

Fig. 5. Block diagram of a thermocouple thermometer from a Project GUISE laboratory exercise. Detailed design (choice of thermocouple type, amplifier voltage gain, and rectifier type) and appropriate connections to the Project GUISE instrument were left as exercises for the students.

An Excel design worksheet for the thermocouple thermometer is shown in Fig. 6. This worksheet allows users to test the performance of their designs by entering the temperature range, thermocouple type, voltage gain of the chopper-stabilized amplifier, and dc-recovery method (full-wave asynchronous rectifier or half-wave or full-wave synchronous rectifier).

Thermocouple type:		
Thermocouple (J, K, T, E)	*K*	
Thermocouple V_T vs. T polynomial coefficients	-1.0321E-07	Cubic (T^3)
	2.7707E-05	Quadratic (T^2)
	3.9247E-02	Linear (T^1)
	-8.7364E-03	Constant (T^0)
Temperature scale		
Maximum temperature:	100	C
Minimum temperature:	-100	C
Cold-junction temperature:	0	C
V_{TC} (maximum temperature)	3.813	mV
V_{TC} (minimum temperature)	-3.830	mV
TC amplifier gain	51	V/V
V_T (maximum temperature)	194.5	mV
V_T (minimum temperature)	-195.3	mV
Amplifier		
Amplifier 0 gain (1, 5, 10, 50)	50	V/V
Amplifier 1 gain (1, 5, 10, 50)	1	V/V
Amplifier output (T max)	9.72	Vpp
Amplifier output (T min)	9.77	Vpp

		Conversion gain, Vo (dc) / Vin (pp)
Rectifier types		^
Precision full-wave rectifier	1	0.5
Half-wave synchronous rectifier	2	0.25
Full-wave synchronous rectifier	3	0.5
Rectifier		
Rectifier type (1-3)	3	
Rectifier conversion gain	0.5	V/V
Low-pass filter output voltage		
DC output at max temperature	4.861	V
DC output at min temperature	-4.884	V
ADC input voltage range		
Maximal input voltage	10.0	V
Minimal input voltage	-10.0	V
Amplifier output voltage range		
Max amplifier voltage	28.0	Vpp

Fig. 6. Excel design worksheet for Project GUISE thermocouple thermometer. Cells with heavy borders are parameters entered by the designer.

Direct readout of temperature from the Project GUISE VI was accomplished by use of calibration constants also computed with the design worksheet. Students tested their completed thermometers against a reference thermocouple thermometer.

LVDT: This exercise includes a theoretical section that derives the LVDT secondary ac voltage (magnitude and phase) as a function of frequency, secondary load resistance, winding inductances, and mutual inductances. An E-200 LVDT (Schaevitz Sensors, Hampton, VA) mechanically linked to a micrometer dial served as the test article. The laboratory exercise required students to build three networks using the Project GUISE instrument to measure the following parameters as the core position of the LVDT was varied:

1. Impedance of the primary winding;
2. Impedance of the series-connected secondary windings;
3. AC output voltage (magnitude and phase) of the LVDT.

Measured data were to be compared to published expectations[5], and the sensitivity of the LVDT (in V/V/mm) was compared against manufacturer's specifications. Figure 7 shows the connection of the Project GUISE instrument to measure the output voltage vs displacement characteristics of the LVDT.

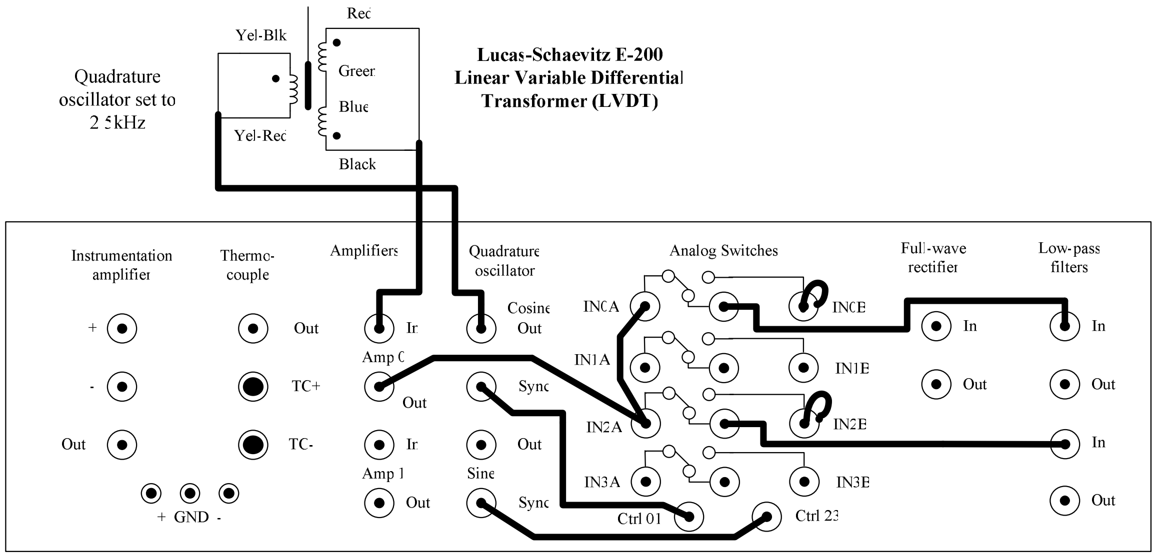

Fig. 7 Displacement measurement with an LVDT.

Optically-coupled isolation amplifier: Significant differences in ground potentials between a sensor and its signal conditioner may occur in some instrumentation applications. A differential amplifier may not be suitable in these cases; the ground-potential difference may exceed the common-mode voltage range of the amplifier, or may be sufficiently large to damage or destroy the amplifier [6]. Isolation amplifiers are appropriate in such instances. There are multiple approaches to making an isolation amplifier (e.g., transformer coupling, capacitive coupling, or optical coupling). The EENG 4302 curriculum included the construction and test of an optically-coupled isolation amplifer using an MCT9001 dual optoisolator, some additional circuitry, and the Project GUISE instrument. Figure 8 below shows the completed isolation amplifier. Students were required to construct the amplifier, test it, and calibrate it so that the output voltage (read on analog channel 0 of the DAQ card) equaled signal voltage V_b measured at the Wheatstone bridge.

Load cell and dc-coupled strain gage amplifier: This theoretical background of this exercise gives an introduction to strain gages drawing upon published academic and industrial resources.[7,8] This is followed by a design exercise in which students were to design a scale reading masses up to 500g. A load cell incorporating a B101 aluminum cantilever with 125AD bonded metal-foil strain gage (Vishay Measurements Group, Raleigh, NC) and 1% tolerance resistors was constructed. An Excel design worksheet was provided to allow students to compute the expected deflection of the cantilever and the resulting change in resistance in the strain gage as a function of the mass suspended from the free end of the cantilever. The Project GUISE instrument was used to amplify, digitize, scale, and display the reading. The strain-gage amplifier was dc-coupled, partly for simplicity but also partly to allow students to experience first-hand typical drift problems associated with high-gain dc-coupled amplifiers.

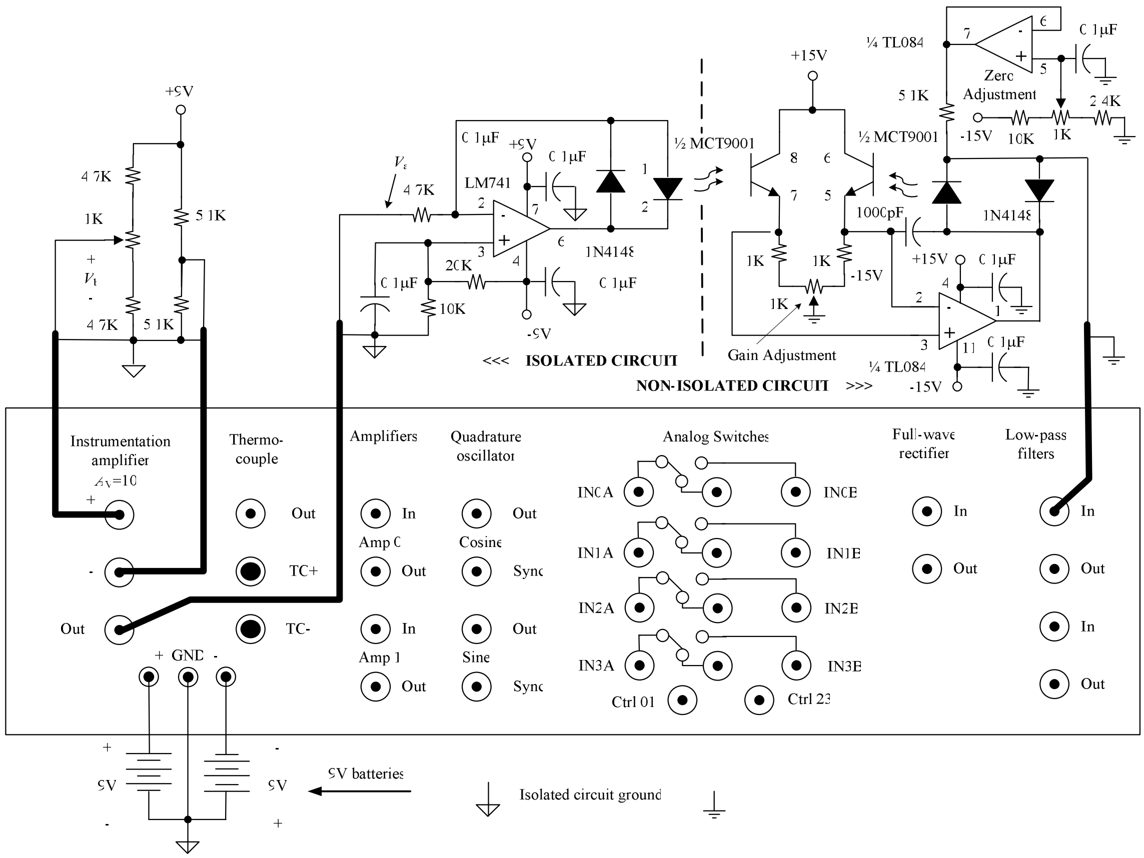

Fig. 8. Optically-coupled isolation amplifier. Batteries (9V) are used as the power supply for the isolated side of the circuit.

Student reaction to Project GUISE

The 15 students who utilized Project GUISE in 2005 were asked for their reactions to it. An assessment instrument consisting of 12 statements was administered; students were asked to state their level of agreement with the statements on a Likert scale where a rating of 1 indicated strong disagreement and 5 indicated strong agreement. Table 1 summarizes the results. The first seven statements in Table 1 are statements to which agreement would indicate a favorable reaction to Project GUISE; agreement with the remaining five statements would indicate an unfavorable opinion. (The order of the statements in Table 1 does not reflect their order in the questionnaire). On balance, students showed agreement with all statements reflecting a favorable reaction to Project GUISE. By comparison, students showed a (small) measure of agreement with only one of the negative statements ("the time spent on Project GUISE was disproportionate to the learning gained from it"). The mean agreement with positive statements was 3.91, whereas the mean agreement with negative statements was 2.44. The difference is evidence that the students perceived Project GUISE as beneficial.

Table 1. Summary of student responses to curricular use of Project GUISE

Evaluation criterion	Rating
1 Project GUISE was beneficial in understanding the principles of instrumentation systems.	3.87
2 The theory sections of the Project GUISE project descriptions were useful.	4.07
3 The Project GUISE hardware was convenient to use.	4.33
4 I would have preferred fewer homework problems and more work with Project GUISE.	3.53
5 I would recommend using Project GUISE again the next time this course is offered.	4.27
6 The time devoted to Project GUISE exercises was time well-spent.	4.00
7 The Project GUISE virtual instrument program was self-explanatory and easy to use.	3.33
8 The time spend on Project GUISE was disproportionate to the learning gained from it.	3.13
9 I would have preferred more traditional homework problems in place of Project GUISE.	2.33
10 The theory sections of the Project GUISE descriptions added nothing to the course.	2.40
11 Project GUISE had too little functionality for this course.	2.07
12 Connection of Project GUISE hardware with cables was cumbersome and difficult.	2.27

New GUISE curricular materials for 2007

The next offering of the instrumentation course is scheduled for summer, 2007. New curricular materials available include an exercise in measurement of common-mode rejection ratio (CMRR) of the instrumentation amplifier. The configuration of Project GUISE for this exercise is shown in Fig. 9 below. Also included among the new exercises for 2007 is the design of a scale using a load cell and carrier amplifier.

Conclusion

The Project GUISE instrument has provided a platform to provide students with laboratory experience in a number of areas related to the design of instrumentation. It was well-received in its curricular introduction, and its role will be expanded in the next offering of the course for which it was created.

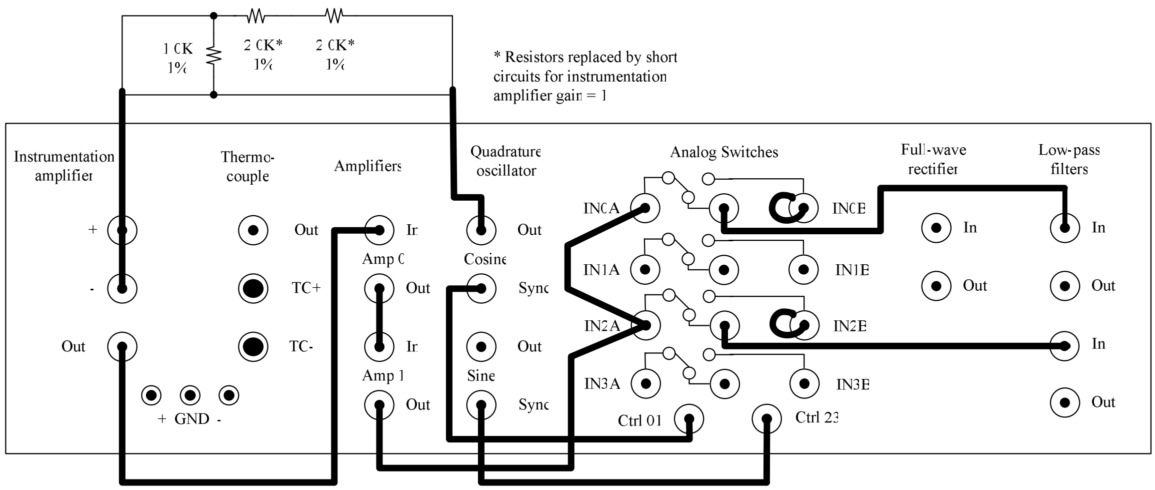

Fig. 9. Connection of the Project GUISE instrument for an exercise in measurement of CMRR of the instrumentation amplifier. The quadrature oscillator provides a sinusoidal common-mode signal to the instrumentation amplifier; the output of the instrumentation amplifier is itself amplified by Amplifier0 (ac-coupled, gain=50) and Amplifier 1 (ac-coupled, gain=10), and the resulting signal is synchronously detected with a switching phase-sensitive demodulator. This was the experimental configuration used to determine the CMRR stated earlier for the instrumentation amplifier.

Acknowledgement

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