Session 2559

A Laboratory-Based Instrumentation Course for Non-EE Majors

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Abstract

An instrumentation course that is required of second semester sophomores majoring in mechanical and industrial engineering at Western New England College is described. It is intended that students completing this course can easily learn to use more sophisticated electrical and computer-based measuring systems in junior and senior level mechanical and industrial engineering labs, and if necessary design their own measuring systems for project work in the senior year.

Courses of this type run the spectrum of specialized electronics courses similar to what EE's might take to courses utilizing sophisticated software packages and ready-made interfaces. This course is best described as being in between these two extremes. The students are not expected to be experts at electrical design or computer interfacing upon completion, but they will have experienced first-hand some of the issues involved. This will hopefully make them more intelligent and effective users of the available tools for measurement that are currently available.

The first half of the course covers electrical signal conditioning, including simple filters, bridges, and difference amplifiers. The properties of the transducers are also studied. Students are given laboratory exercises where they design such circuits to convert signals from thermistors, strain gauges, and thermocouples to signals suitable for digitization. Students must not only learn the principles of the transducers and simple circuits; they must deal with having only certain parts available.

The second half of the course covers the digital side of measuring systems. Students learn the basics of A-D and D-A conversion, and do one or two experiments using these devices. They also learn the basics of handshaking I/O. In the last experiment, students write a simple BASIC program to accomplish handshaking input with their A-D converter using two simple ports.

The paper includes details on the experiments, a description of the student reporting requirements, and feedback from students and engineering faculty on the course.

I. Introduction and context

Western New England College (WNEC) is a small private institution in Springfield, Massachusetts. The engineering school offers four programs: Biomedical, Electrical, Industrial, and Mechanical Engineering. The overall full-time enrollment in engineering is approximately 270 students. The primary objective of the engineering school is to offer quality undergraduate programs that lead to successful engineering practice by our graduates. (Graduate efforts are limited to part-time evening programs.)

All four engineering programs have identical requirements for the first three semesters. Therefore, all students take a first course in circuit theory, including a lab component, during the first semester of the sophomore year. The circuits course includes DC circuit analysis, simple op amp circuits, and first order transient analysis. Required courses in the second semester vary greatly by program. All mechanical engineers and some industrial engineers are required to take CPE240, Computer Instrumentation and Measurements. (The I.E. program has two tracks, and only one of those tracks requires CPE240.) Students are expected to take this course in the second semester of the sophomore year. Because of the relative size of the Mechanical and Industrial Engineering programs, the vast majority of the students are Mechanical Engineering majors. The first circuit theory course is a pre-requisite to CPE240.

Historically, the course was initiated in the early 80's in response to the increased use of PC's to take measurements on non-electrical systems. There was extensive laboratory curriculum development at that time, mostly in the area of digital circuits and A/D and D/A conversion. Typical transducers were covered in the lecture portion of the course, but the labs were primarily devoted to digital and analog circuit analysis and testing. During much of the 90's the course was taught by adjuncts and there was little evolution of the course. In particular, students never actually got any data into a computer, and received little "hands on" experience with transducers.

II. Course Philosophy

Approaches to this type of course vary greatly among engineering programs. One option is to make the course an electrical/electronics course for non-majors emphasizing topics such as op amp circuit design, digital circuit design, and A/D and D/A conversion. The topics covered are generally also covered in EE courses, but organized in a different way. The advantage of this approach is that successful students get a good understanding of the underlying principles of electronic instrumentation. The disadvantage is that the linkage between those principles and what they later do in mechanical laboratories is missing, because the students get little "hands on" experience with transducers. Up until 1998 the CPE 240 course at WNEC fit the above description.

Modern instrumentation uses software such as LabVIEW to acquire data from many different types of systems. These measuring systems often involve the use of special-purpose interfacing boards or equipment. Many engineering schools are introducing the use of this type of measurement as early as the freshman year to get the students used to using PC's in their discipline and to facilitate data gathering and analysis. Chen[2] is one of many authors who have reported this type of effort. This approach allows the student to concentrate on the experiment being performed, but does not force the student to understand what is really involved in getting valid data from a physical system or process into electronic, and eventually “computer ready” form. It also does not help the student understand what the software in the PC is actually doing to exchange information with the outside world.

Although there was not much change in CPE240 during the 90’s at WNEC, there was considerable discussion among the engineering faculty as to what students should learn from the course, and especially what the students should be doing in the lab. Some faculty, both in EE and ME, were concerned that using ready-made interfaces taught the students how to “point and click” rather than helping them learn what was going on. Other faculty in both departments believed that learning the guts of the electronics was a waste of time for students not majoring in electrical engineering. A compromise approach was attempted in the Spring of 1998, and further developed the following year. In short, the approach taken was to teach the transducers, electronics, and computer topics on an “as needed” basis to support new or significantly revised laboratory experiments.

III. Course Description

The “list of topics covered” in the lecture portion changed very little from previous versions of the course. These are listed in Table I. The course text, Process Control and Instrumentation Technology by Johnson, was retained, but was used as a reference rather than a course textbook.. The topics were interchanged in a way that directly supported the lab experiments. Table 2 lists the six experiments, along with the lecture topics that were covered in class shortly before the experiments were started. The primary course objective is still for the students to understand the basics of instrumentation and to be able to apply them. It is hoped that organizing the course around lab experiences involving actual transducers will better enable the students to accomplish those objectives.

Transducers
Thermistors
Thermocouples
Strain Gauges
LVDT’s
Analog Signal Conditioning
Level shifters
Difference Amplifiers
Bridges
Filters
A/D and D/A conversion algorithms
Computer I/O Ports
Software (sense loop & interrupt I/O)

TABLE 1
Lecture Topics

LAB EXPERIMENT	SUPPORTING TOPICS
Thermistor	Temperature sensing, voltage division, thermal time constant
Simple Low-Pass Filter	AC steady-state analysis
Thermocouple	Difference amplifiers, level shifters
Strain Gauge	Wheatstone bridge
A - D converter	Digital signals, simple logic, conversion algorithms
Data Acquisition	I/O Ports, handshake I/O, sense loop software

TABLE 2
Lab experiments and supporting class material

As an example, the thermocouple lab is included in the appendix. The students are given the topology for the signal conditioning circuit, but must decide on resistor values to use. The circuits used have been covered in class, as have thermocouples and the use of thermocouple tables. The students must meet the specification using available parts. Students are required to complete the pre-lab design and turn it in for grading before the lab is done. (Students not doing this are required to do the lab at a later date, and incur severe grade penalties.) This allows the instructor to review the designs and advise students if they need to make corrections. Students can then test their design in the lab, comparing observations to what they expect to see. The lab report consists of a quantitative technical memo describing how well their design met specifications and agreed with what they expected. Appropriate back-up material is required as appendices. (It is believed that requiring formal lab reports in this course would be excessive, given that it is three credits.) The labs are graded by the instructor, and include 25% for technical writing. This type of experiment is not unlike those reported by Bachnak[1].

The last two labs involve the digital side of measuring systems. First, students wire and test an A/D converter chip. The last lab involves connecting the A/D converter output to a parallel port and writing software to input the data and do a small amount of processing on it. It was decided to use basic I/O ports (on an Intel 8255) to accomplish this. In order to have the students check for new data being ready before inputting it (handshaking), QBASIC running under DOS was used. This requires the students to explicitly program the handshaking loop and perform a masking operation. DOS was used rather than Windows because it was necessary for the students to access the ports directly from their own program to accomplish the objectives of the exercise.

IV. Observations and Assessment

It was discovered that prior to taking this course most students had not been asked to do a design to a specification using a list of available parts. It was also discovered that many students had not had to design, debug and test a system that had multiple functional blocks. The majority of students initially had trouble breaking the design into functional modules and designing or testing them separately before putting them together. This became evident because many students came for extra help in completing the pre-labs. Problems in breaking down a system into functional blocks were particularly evident in the lab when the circuit was constructed and didn't work immediately. Improving student competence in these areas, along with improving the students' ability to interpret and present data, were objectives that were not initially planned; however, they seem to have been achieved in most cases.

Student evaluations done at the end of the course were quite positive with respect to the quality of instruction and the usefulness of the lab assignments as an aid to learning. However, considering the audience and the objectives of the course, this information isn't particularly relevant. What is important is whether seniors in mechanical and industrial engineering have found the experience gained in CPE 240 useful in doing the higher level work in junior and senior laboratories in those disciplines. Because the vast majority of students in the course are mechanical engineering majors, a survey was conducted of the current ME seniors. (Most of those students took CPE 240 in the Spring of 1998; not all of the experiments listed above were incorporated at that time.) The vast majority of the 21 responses received indicated that the course had been of some use. (Two students circled "waste of time.") Facets of the course that received the most positive marks were the strain gauge lab and the exercise of general engineering skills such as data interpretation and technical writing. No student made a positive comment about the AC filter experiment.

Because the ME department is the primary customer of this effort, feedback from the Mechanical Engineering faculty was also solicited by the instructor. According to the department chair, the students seem to have a better understanding of the measurement systems they are using in junior and senior level ME lab experiments than they used to.

V. Challenges

The course is intended to be taken immediately after the circuit theory course, so that the basic concepts of DC circuit analysis in general and op amp circuits in particular are reasonably fresh in the students' minds. Because CPE 240 is not a pre-requisite for any mechanical or industrial engineering courses besides ME lab, students who are behind will often chose CPE 240 as the course to postpone. It has been observed that students who have not studied circuits in the past year find the course very difficult. (The basics of circuit theory are reviewed in class on an as-needed basis, but very quickly.) The School of Engineering plans to start offering a section of this course in the Fall; that should help the above situation somewhat because students that get out of sequence will only be off by a semester, not a year.

Another challenge is that since the students have elected a major other than EE, studying circuits for another semester is often not at the top of their priority list. The students do the work, but the enthusiasm for getting a circuit or a program to function correctly is often missing. (For some reason, most students really seem to enjoy the A/D converter lab.) One thing that will be attempted in the Spring of 2000 is allowing the students to keep either the thermocouple or strain gauge conditioning circuit together so that it can be connected to the A/D converter and eventually to the computer. It is hoped that seeing the entire measuring system operational will improve motivation. Future plans also include adding more transducers to the lab sequence. Of particular interest are LVDT's and pressure measuring devices.

Acknowledgment

The Mechanical Engineering faculty has been very supportive of improvements to this course. This includes sharing their expertise about transducers and measuring systems, helping to find the needed equipment (often on short notice), providing useful feedback, and generally being encouraging of the efforts made. Profs. Karplus, Khosrowjerdi, and Veronesi have been particularly helpful. Prof. Karplus' suggestions in preparing this manuscript are also acknowledged.

References

1. R. Bachnak, "Laboratory Experiments in Instrumentation and Control," 1999 ASEE Annual Conference Proceedings, Session 2259.

2. C. Chen, "Using LabVIEW in Instrumentation and Control Course," 1998 ASEE Annual Conference Proceedings, Session 1559.

3. C. Johnson, <u>Process Control and Instrumentation Technology,</u> Fifth Edition, Prentice Hall, 1997.

Biography

Steve Crist is a Professor of Electrical Engineering at Western New England College in Springfield, Mass. Before coming to Western New England in 1991, he was with the Electrical Engineering Department at West Virginia Institute of Technology (now part of West Virginia University). He received his B.S. degree in Electrical Engineering from R.P.I in 1969, and his Masters and Ph.D. in Electrical Engineering from Arizona State University in 1974 and 1976, respectively.

APPENDIX

EXPERIMENT #3
THERMOCOUPLE WITH SIGNAL CONDITIONING

PRE-LAB

This experiment deals with a type T thermocouple. You will be measuring temperatures between 0° C and 100°C. The "reference temperature" will be the temperature of the EE lab, which is approximately 22° C.

1. Determine from the thermocouple table in the text what range of difference voltages you will be measuring at the thermocouple output.

2. Design an op amp difference amplifier (diff. amp.) so that the RANGE of output voltage of the diff. amp. is 150 mv, ±10%. Use available resistors only, as listed below.

3. Assume that the thermocouple leads are connected to the diff. amp. in such a way that temperatures less than room temperature result in a negative output, and temperatures above room temperature result in a positive output. Design a signal conditioning circuit as shown on the next page so that 0° C yields a voltage of 0 Volts, and 100° C yields a voltage of 5 Volts. Again, use available resistors.

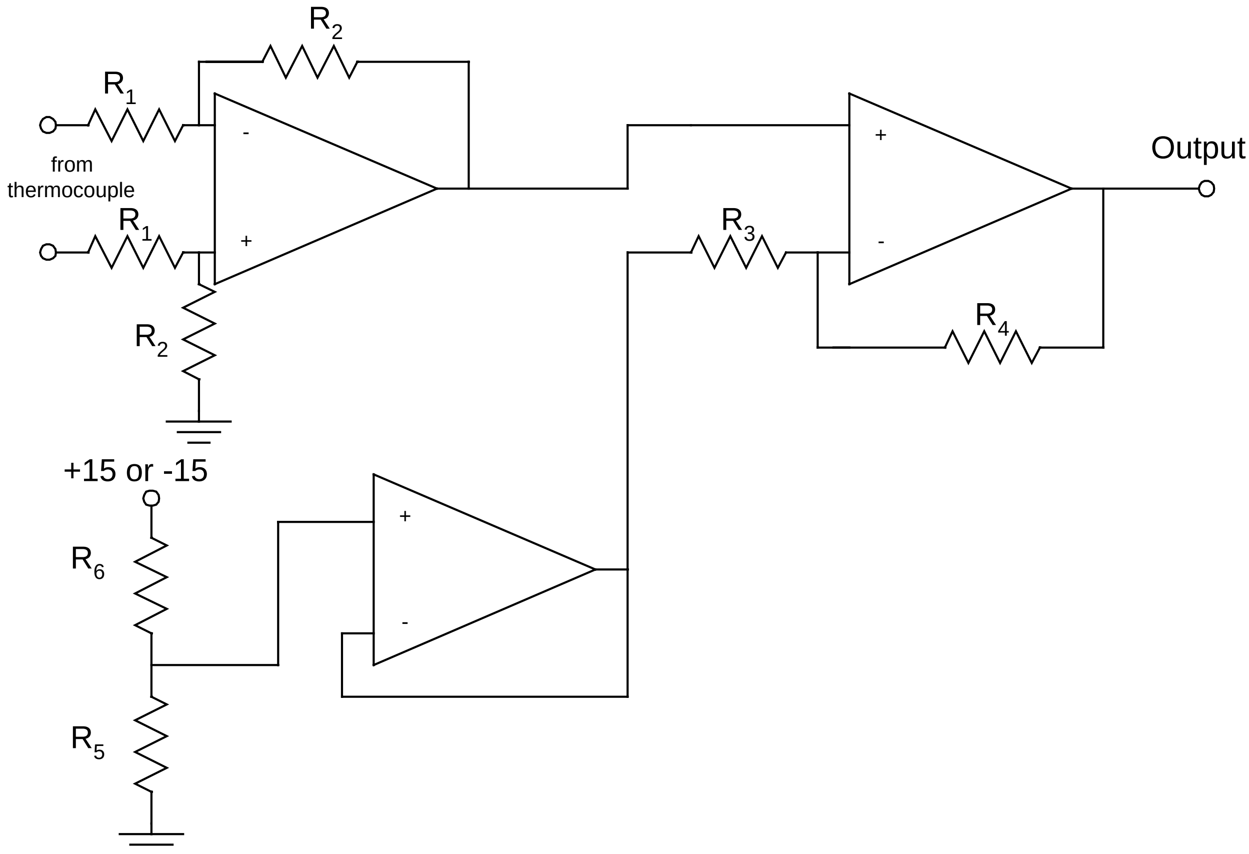
4. Obtain a plot of system output voltage vs. temperature. Use the actual resistors you chose, not the values you might have initially calculated.

The available resistors are as follows.

1K	1.2K	1.5k	1.8K	2.2K	2.7K	3.3K	3.9K	4.7K	5.6K	6.8K	8.2K
10K	12K	15K	18K	22K	27K	33K	39K	47K	56K	68K	82K
100K	120K	150K	180K	220K							

The complete schematic is on the next page. The ±15 V power supplies are not shown, but they must be connected for the op amp circuits to work..

APPENDIX



LAB DATA

1. Build your circuit and apply ± 15 V. See the last page of this handout for op amp pin connections. Connect the two circuit inputs together with a wire (short them) and note the output voltage of the diff. amp. with the DMM set on maximum sensitivity. Ideally it should be zero; if it isn't, it's due to inherent offsets in the op amp.

2. Connect the thermocouple to your circuit and measure the output voltage with the DMM. If it is not close (within 10%) to what you expected, check your circuit and/or ask the instructor to look at your circuit.

3. Take your circuit and thermocouple to the beaker area to get additional data points.

APPENDIX

REPORT

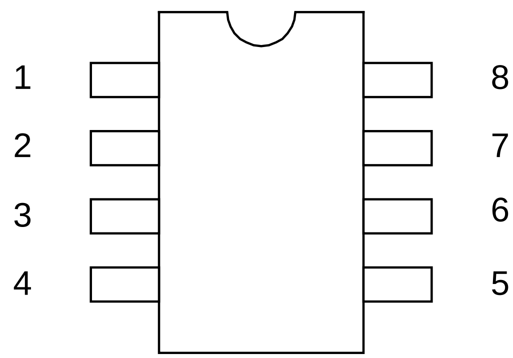
Your tech memo should comment on how well your observed data agreed with what was specified, and how well your observed data agreed with what you expected for the component values you chose. As appendices, you should include:

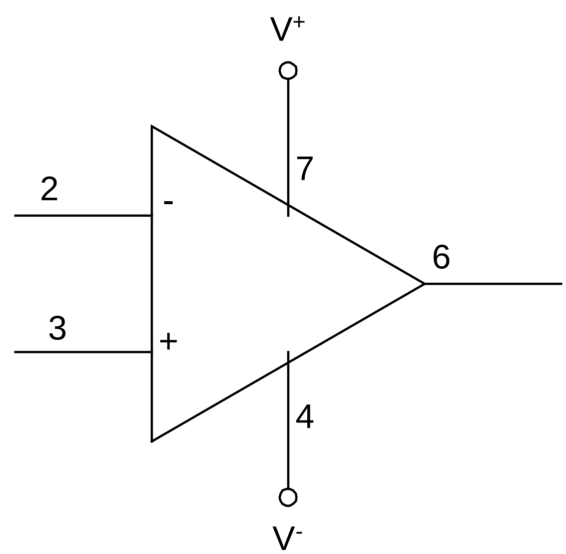
1) Raw Data, equipment list

2) Original graded pre-lab

3) Corrected pre-lab, if needed

4) An Excel graph with the expected **and** observed output vs. temperature superimposed.





op amp pin definition