

SENSORS & TRANSDUCERS

PREREQUISITES: MODULE 04: OP-AMPS II; MODULE 8: HYBRID CIRCUITS; MODULE 11: MICROCONTROLLERS III; OTHER MODULES MAY ALSO BE HELPFUL, DEPENDING UPON THE SENSOR OR TRANSDUCER OF INTEREST.

OUTLINE OF MODULE 13:

What you will learn about in this Module:

- Electro-optical devices
- Temperature, humidity, pH
- Force and Pressure
- Position and displacement (linear and angular potentiometers & encoders)
- Velocity and Acceleration
- Liquid Level
- Hall effect sensors
- Signal quality and noise reduction techniques

What you will build in the lab:

If you are registered for this course, the PC board that you need is already built for you. You will need to check out the ME4XX test circuit board from one of the instructors. The schematic for this board is in Modules 8 and 11, so that you can build this circuit if you need to, or if you would like to modify the circuit for other purposes. You will program the PIC16F877 microcontroller chip on the ME4XX board to read an analog signal from several sensors, then display the result on the LCD display. You can select from several sensors: temperature, pressure, magnetic flux (Hall effect), phototransistor, potentiometer to measure position.

INTRODUCTION:

The marriage between electronics and the Real World involves sensors and transducers. Basically, almost any signal in nature can be converted into a voltage or an electrical current, and then it can be managed by our familiar and well-behaved electronics. The real trick in almost all of experimental science is to understand how well and how accurately the natural signal is being transduced. Getting a good signal and transforming it into a voltage or current is the whole trick, and things are relatively easy after that. There are some scientists who would disagree, asserting that getting the signal is easy, and the “hard” part is manipulating the data on a computer...well, in my opinion these sorry folks just need to get a little more sunlight. Opinions vary, but trust me, getting a good signal from nature is very challenging indeed. Not surprisingly, nature is very good at acquiring and making sense out of signals. That is what your five senses are all about, and there are many stunning examples in the natural world. One of the most interesting and strange is the ability of insect antenna to detect chemicals very selectively and at

very low concentrations. Those are the key performance metrics of any sensor: selectivity and sensitivity. Selectivity means how well does your sensor detect the signal that you are interested in, and ONLY the signal that you are interested in, without confusing it with something else. Sensitivity means just what it sounds like: how small of a signal can you reliably detect with your sensor, or how small of a *change* in the signal can you detect. Humans are notoriously bad at differentiating and identifying chemicals by smell, whereas most of the rest of the living world is a chemical world, communicating by way of chemical signals. This is true even for very large and complex animals, such as dogs. We also lack very good electro-chemical sensors, so this is an area of very active research. Here is where things get a bit strange. Recently it was discovered that insect antenna, which are known to be superb chemical detectors, can be connected directly to high input impedance amplifiers and used as highly sensitive and selective chemical detectors. Some of these antenna can give reliable detection signals for chemical concentrations as low as a few ppb (parts per billion). Antenna from moths, blow flies, and parasitic wasps have been used in chemical detector research, and the antenna from the parasitic wasps can even be “programmed” to be most sensitive to certain chemicals of interest, such as RDX (also known as cyclonite, the high-explosive component of many common military explosives). Dogs can be easily trained to detect very low levels of many substances, such as illicit drugs, explosives, or other contraband substances. Our primitive technology for chemical detection aside, we have developed superb sensors for many other physical phenomena, such as light intensity, pressure, force, acceleration, temperature, magnetic field strength, displacement and velocity, and so on. It will be impossible to cover all sensor technologies in this module, so the readings will cover the major sensor technologies, and the laboratory exercises will give you some experience with inexpensive and readily available solid-state sensors.

READINGS FROM HOROWITZ AND HILL (H&H): *ART OF ELECTRONICS*

9.10 (opto-electronics)

Chapter 15: Introduction

15.01-15.09 (introduction to sensors)

ADDITIONAL READINGS & INTERNET RESEARCH:

Allegro Microsystems App Note 27702A: Linear Hall Effect Sensors

Allegro Microsystems Data Sheet for part # A3515: Linear Hall Effect Sensor

National Semiconductor Data Sheet for part # LM35: CMOS Temperature Sensor

In this module you will have the opportunity to use the A3515EUA linear Hall Effect sensor to measure magnetic field strength, and the LM35DZ CMOS precision centigrade temperature sensor to measure temperature.

SELF QUIZ

1: What is the maximum magnetic flux that you could measure with the A3515EUA Hall Effect Sensor? Assume that you are powering the device with +5 V.

2: Draw the pinout for the A3515EUA Hall Effect Sensor, and how you would connect it to one of the TLC4545 ADCs that you used in modules 11 and 8:

3: Using only a single-sided voltage supply (0 and +5 VDC), what is the useable temperature measurement range for the LM35DZ CMOS temperature sensor?

4: Draw the pinout for the LM35DZ CMOS temperature sensor, and how you would connect it to one of the TLC4545 ADCs that you used in modules 11 and 8:

PLEASE ANSWER THE ABOVE QUESTIONS AND E-MAIL TO THE INSTRUCTOR
(no need to mail the sketches, just discuss them with the instructor before building the circuits)
“I have neither given nor received aid on this examination, nor have I concealed any violation of the Honor Code”

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LABORATORY PROJECTS

- 1- The laboratory exercises for this module are very simple. You will need to check out one of the ME4XX test circuit boards that you used in Modules 11 and 8. You will modify the test board slightly to allow you to connect either a Hall Effect Sensor, or a Temperature Sensor, or both (depends on how interested you are in this module). We have a very limited number of these boards, so please check them out only for the day you intend to use them.
- 2- Draw out and discuss your proposed schematic with one of the instructors before actually modifying the ME4XX test circuit board...this may help you to avoid doing unnecessary damage to the circuit.
- 3- **TEMPERATURE:** Ask one of the instructors for an LM35DZ CMOS temperature sensor (we keep them in stock in our lab). After verifying the circuit connections you wish to make with one of the instructors, you can go ahead and modify the circuit board as necessary. Basically, you will only need a connection to ground, to +5V, and a signal to ADC#2. Each board has three 16-bit ADCs on board, and two of them are already connected to potentiometers (#0 and #1), but #2 is not in use, so you should connect to that one. It is accessible via pin#4 on the 20-pin ribbon connector that connects to the LCD display (verify this on the schematic). It should be a non-connected violet wire on the ribbon cable, just sitting there waiting for you to do something with it. You'll need to pull +5V and ground from the board as well...discuss this with one of the instructors.
- 4- The data sheet will tell you the factory calibration for the temperature sensor in units of milliVolts per degree centigrade. Your assignment: start with the source code for module8 (module8.txt), and modify the source code so that the output on the LCD display is the measured temperature, in degrees centigrade. Remember: you need to measure the voltage from ADC #2, so you will need to write some new code just to do that.
- 5- Go around and test the temperature of things: a cold soda can, an incandescent light bulb, the engine block of a car that has just been turned off, the palm of your hand, Vicegrip's forehead, whatever. Be sure to avoid getting the temperature sensor wet. We can provide you with a silicone-coated temp sensor if you want to make wet measurements. Longer lead wires will make it easier to make measurements.
- 6- **MAGNETIC FLUX DENSITY:** Ask one of the instructors for an Allegro A3515EUA Hall Effect Sensor (we keep them in stock in our lab). After verifying the circuit connections you will make with one of the instructors, you can go ahead and modify the circuit board as necessary. Basically, you will only need a connection to ground, to +5V, and to ADC#2. Each board has three 16-bit ADCs on board, and two of them are already connected to potentiometers (#0 and #1), but #2 is not in use, so you should connect to that one. It is accessible via pin#4 on the 20-pin ribbon connector that connects to the LCD display (verify this on the schematic). It should be a non-connected violet wire on the ribbon cable, just sitting there waiting for you

- to do something with it. You'll need to pull +5V and ground from the board as well...discuss this with one of the instructors.
- 7- The data sheet will tell you the factory calibration for the sensor in units of milliVolts per Gauss. Note that the measurement is offset, such that zero Gauss results in an output of 2.5 V. This conveniently allows a single supply voltage to provide measurements for positive and negative flux values, thus simplifying your circuits quite significantly. Your assignment: start with the source code for module8 (module8.txt), and modify the source code so that the output on the LCD display is the measured magnetic field strength, in Gauss. You will need to display both positive and negative numbers, depending on the orientation of the magnetic field with respect to the sensor. Be careful which types of variables you use in your source code. Remember: you need to measure the voltage from ADC #2, so you will need to write some new code just to do that.
 - 8- Map the magnetic field strength around a few magnets. Be sure to be mindful of the orientation of the sensor, as the flux lines curve in space.
 - 9- Can you use this sensor as a digital compass? The earth's magnetic field strength at our latitude (the barren foul-smelling icy wastelands of Michigan) is about 500 mG. Go ahead and try it. You might be able to detect true north and south if you play around a bit, but to make a real digital compass you would need two sensors, rotated 90 degrees to one another (why is this???). Is there some way to get around this using only one sensor?
 - 10- You might want to brush up a bit on your basic physics to do some more interesting experiments. If you want to "amplify" the magnetic signal, you can try using something called a "flux concentrator". An iron nail works pretty well as a flux concentrator. Place the Hall Effect Sensor next to a bar magnet (off to the side, between the poles). Imagine the flux lines streaming from pole to pole in approximately elliptical paths. Place the sensor near the side of the bar magnet such that the plane of the sensing element is normal to the flux lines. Do this on a non-metallic desk surface. Now, while holding everything in place, bring a nail close to the sensor, parallel to the flux lines with the point of the nail pointing directly at the center of the sensor. What happens to the measured magnetic flux density? Can you conceive of a flux concentrator that would improve the performance of your compass?

If you would like to try a different type of sensor, you are certainly welcome to request assistance from one of the instructors.

When you are finished, you should remove your modifications from the ME4XX test circuit board, and replace your program with a simple one that just lists your lab group members, so that it is clean and ready for the next group to use.

FEEDBACK

Was this Module useful and informative?

Is there a topic that should get more or better coverage?

In what way can this Module be improved:

Content: _____

Depth of Coverage: _____

Style: _____

Any additional comments that will help us to improve this course:

If you prefer, you may e-mail comments directly to Bob Dennis: yoda@umich.edu