

Physics 115

Electronics and Instrumentation

Laboratory Manual

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Introduction

Electronics are a part of every modern laboratory. Physics, chemistry, biology, and geology all utilize electronic devices to measure and record various phenomena. Whether you need to measure temperature, light intensity, magnetic fields, humidity, charged particles, time, or strain, all can be measured using readily available transducers.

The goal of this course is not to turn you into an electronics whiz. Rather, it is a survey course that will introduce you to the broad range of electronic devices and techniques that are commonly used in laboratories today. While we will spend some time on historical and fundamental devices, such as transistors and A/D chips, we will focus most of our attention on practical and useful devices: op amps, computer-integrated data acquisition cards, and specialized integrated circuits (ICs). Our goal is to instill in you a degree of comfort and familiarity with electronics that will be useful in designing experiments, building simple circuits, and understanding the behavior of complex circuits. By the end of the semester you should be comfortable in developing computer-controlled data systems where you have conditioned the signal of interest using your newfound electronic skills and collect the data on the computer using the LabVIEW software package.

I have chosen not to include much theory in this manual. First of all, all of the information would be repetitious because the same information will be in your textbook and/or lecture notes. Second of all, I've tried to prevent this manual from being a self-contained cookbook. Forcing you to use your notes and textbook will, in the end, make you more self-reliant.

Half of the experiments in this manual will take one lab section. The remaining half will require multiple sections to complete. These expanded experiments (Labs II, IV, VI, IX, X, and XI) will be worth twice the others. See the course syllabus for more information.

Because the LabVIEW software package is commonly encountered in research and industrial laboratories, there is a recommended text in the bookstore that teaches the details of it. We also have a couple of copies of the LabVIEW text in the lab to use.

This manual will also likely serve as a reference for future classwork, particularly in Physics 116, Advanced Electronics and Instrumentation. I suggest that if you are planning on taking this course, you hold onto this book.

This is the third edition of this manual, the earlier editions were each used for two years, and most of the mistakes and typos have been resolved. This edition addresses two main issues. First, it is only available electronically; it is not for sale in the bookstore. This allows for corrections and changes and saves the students some money. Secondly, it addresses new hardware that we are using in the lab as well as for a rather significant upgrade in LabVIEW.

Safety

In general, the electronics that one encounters in this class are no more dangerous than those one may encounter upon replacing a 9-V battery in a household electronic device; most electronics textbooks do not even discuss safety hazards. In fact, the biggest risk to one's health in this class is mechanical rather than electrical: dropping an instrument or computer on your foot.

However, one must still be careful to avoid exceeding tolerances on all devices. Over-powered resistors can get very hot very fast and can leave a blister on one's fingers if touched. Transistors are famous for "popping" when improperly wired. The shrapnel from one could scratch the cornea of your eye; an experience that your contact lens wearing friends will assure you does not feel good. While we don't normally solder in this class, if you find that you need to, make sure you borrow a pair of safety glasses from the stockroom. Soldering flux or molten solder would be very unpleasant in an eye (as Dr. DeGraffenreid can attest to).

However, one should not take a cavalier attitude towards electronics. There are many cases one will encounter in the laboratory where high voltages are a part of the experiment. Care needs to be taken in such a case; a current of a few milliamperes through your heart can cause severe problems. If you find yourself working on high voltages, it is a good practice to have your arm grounded so that if you touch the high voltage with your hand, the current won't cross through your body.

In fact, it is a good practice to use grounding straps at all times when working with electronics. This is not necessary for your own safety, but rather for the safety of the devices you are working with; static discharge can be deadly for many semiconductor devices. Unfortunately, we don't have grounding straps to go around. Luckily, we use generally inexpensive components. If you find yourself using high-end components in your final project, please ask about borrowing a grounding strip to use.

Measurement Instruments

Multimeters

We will normally use benchtop digital multimeters (DMM) in this course, although we do have some handheld digital and analog multimeters available if needed. The theory behind multimeters, particularly analog meters, is very interesting but unfortunately we don't have time to cover it in this course. If you are interested in finding out more information regarding them, refer to your textbook. There are two models of benchtop Keithley multimeters that we will commonly use in the lab: the Model 2000 and the Model 179(A). The Keithley Model 2000 will be our primary instrument, but for measurements we will also need to use the 179(A). The Tektronix Model #2236 Oscilloscope also has a built in multimeter that we might occasionally use for DC voltage measurements.

The specifications of the primary meters are listed below:

		Model 2000	Model 179A
	Digits	6 ½	4 ½
RANGE	DCV	0.1 μ V – 1 kV	10 μ V – 1.2 kV
	ACV	0.1 μ V – 750 V	10 μ V – 1.0 kV
	DCA	10 nA – 3 A	10 nA – 20 A
	ACA	1 μ A – 3 A	10 nA – 20 A
	Ω	100 $\mu\Omega$ – 120 M Ω	100 m Ω – 20 M Ω
	Frequency	3 Hz – 500 kHz	– NA –
Input Impedance	DC	10 G Ω	1 M Ω
	AC	1 M Ω	1 M Ω

Clearly the Model 2000 is a more precise instrument. It can also be computer interfaced via GPIB if desired. Its main drawback is its complexity. For most purposes 6 ½ digits is overkill and just slows down the refresh rate. From the front panel you can decrease the number of digits displayed. The Model 2000 can only measure currents up to 3 amperes, whereas the Model 179A can go up to 20 amperes. This isn't usually a concern in this course where we usually work with currents less than 1 ampere. Several copies of the Model 2000 user's manual are available for review and it is also available in pdf format on the Electronics Laboratory Resource Page.

Our analog multimeters are the Tripplett 630-NS. The Tripplett meters can be used to measure AC and DC voltages and DC currents. While the controls for the Tripplett meters indicates resistance can be measured, we no longer keep batteries in these meters that are required to power the resistance measurements. Make connections between the common and V· Ω ·A inputs (unless you are measuring currents higher than 1.2 A, in which case you use the 12A input and the common).

Oscilloscope

The most widely used instrument in the lab is probably the oscilloscope. In this lab, we will be using the Tektronix Model 2236. This is a fairly advanced analog “scope” with a number of useful features, including a built in period/frequency readout. We also have a classroom set of Tektronix Model TDS1002 scopes and two “high end” scopes: the TDS 3044B and the DPO 4054. These will only be used sporadically in 115; while the digital scopes are have somewhat more power and flexibility, they can also be misleading if you are not familiar with the basics of making measurements with an analog scope. User manuals for all digital scopes are available on the Electronics Laboratory Resource Page.

While the exact operation of oscilloscopes varies widely, the most important elements of the front end are basically unchanged. While your textbook has a brief section describing the operation and use of oscilloscopes, I would also like to refer you to “The XYZ’s of Oscilloscopes,” published by Tektronix (one of the leading oscilloscope manufacturers). There are several copies of this available for use in the classroom and is also available in pdf format on the Electronics Laboratory Resource Page. I suggest that you read this manual before using the oscilloscope.

Workstations

ELVIS Lives! The most common tool in 115 is the National Instruments ELVIS workstation. These workstations integrate a breadboard (prototyping board), power supplies, waveform generators, and computer interface into a single package. Many of the features can be controlled via the workstation’s front panel or by software on the computers; we will generally use the front panel. See the Electronics Laboratory Resource Page for the ELVIS User’s Guide.

Breadboards

The most convenient way to design and troubleshoot a new circuit is to first design it on a “breadboard”. Breadboards can be of the stand-alone variety, have built in power supplies (we have a large collection of these that might be useful for your projects), or may be bundled with additional stuff for easy access (like our ELVIS stations and the Protoboards that preceded them). All are handy because circuits can be wired up without the use of soldering irons, or wire wrapping tools. Be careful not to use wires that are too thick for the board. Forcing oversized wire into the board may permanently bend the spring contacts: leading to poor connections, no connections, or even possible short circuits to other rows.

We will discuss how to use the board in class.

Power Supplies

We will generally use the built-in power supplies that are on the ELVIS workstation or on the powered breadboards. So far, these supplies have proven to be rather stable sources of DC power. The ELVIS workstations have five supplies built into it: +5 V, +15 V, -15 V, and variable positive and negative voltages. The powered breadboards have +5 V, +15 V, and -15 V sources. Additionally we have other fixed and variable sources available if needed.

Function Generators

We will use Tektronix AFG3022 Arbitrary Waveform Generators to produce the AC signals that we will use in this course. These generators will be shared between adjacent groups, as they have dual outputs that can be independently controlled. It can produce sinusoidal, square, triangle, and many other signals with frequencies up to 25 MHz. It can be programmed to produce a certain signal without turning the signal on. It has the capability of producing user-defined waveforms also.

We have a couple of high performance Agilent 33120 waveform generators that can produce signals up to 15 MHz. These instruments can do the traditional sinusoidal, square, and triangle-waves, but can also do sawtooth, cardiac, exponential decay, and user defined waveforms.

The ELVIS also has a built in function generator, that is useful for “low frequency” applications. It is limited to less than 30 kHz signals and should not be used as a primary source.

We also have a classroom set of WaveTek function generators. The WaveTek produces frequencies from < 1 Hz to 2 MHz. DC offset voltages may be applied to all of the previously listed waveforms. The square-wave also has a variable duty cycle. The WaveTek also has a TTL output jack for digital timing purposes.

Lab I: Basic DC Circuits

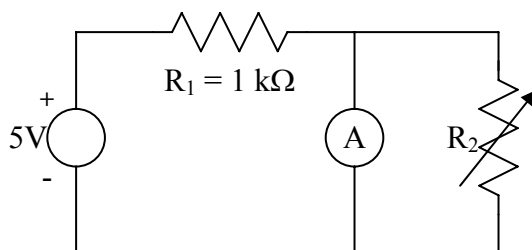
Introduction

This set of experiments will introduce you to some basic DC circuits and give the chance to get some experience using the meters and the breadboards.

Procedure

1. Measure the internal resistance R_m of an analog ammeter.

a. Build the following circuit:



Initially, the resistance of R_2 (a decade resistance box with a resolution of $0.1\ \Omega$ or less) should be “near infinite” resistance.

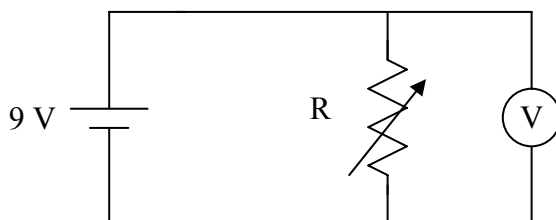
b. Measure the ammeter current.

c. Adjust R_2 such that ammeter current drops to one half the initial value. The ammeter resistance now equals R_m .

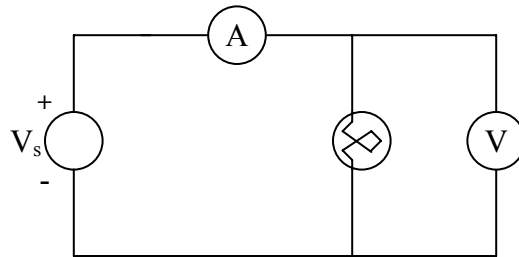
d. In the write up, list the internal resistance R_m and prove why this method works.

2. Measure the series resistance R_e of a 9-V battery.

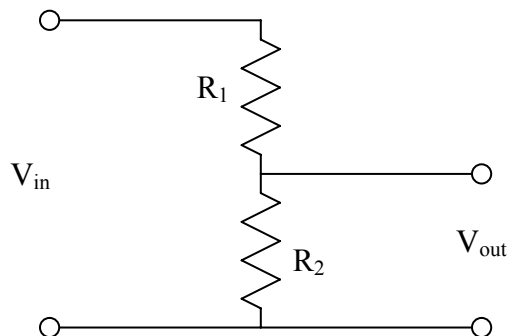
a. Build the following circuit, using the same decade box as above:



- b. Start with the decade box at “near infinite” resistance. Measure the voltage on the DMM.
 - c. Decrease resistance until the DMM reading falls by one half. The value of the resistance at this level is R_e .
 - d. Report internal resistances and prove to me why this method works.
3. Measure resistance of a lamp.
 - a. Measure the resistance of a lamp directly using the DMM.
 - b. Build the circuit below to measure the resistance of a lamp, using ELVIS's positive variable supply as the voltage source.



- c. Measure the V-I characteristics of the lamp. Do not exceed 10 V on the lamp.
 - d. Will a lamp work as a resistor in a pinch? Plot the I-V characteristics and compare to an ideal resistor. Discuss your thoughts of the behavior in the write up.
4. Voltage Dividers
 - a. **Design** a circuit with the following form.



Select R_1 and R_2 so that they add to $\sim 5 \text{ k}\Omega$ (within 10%) and the gain of the circuit is 0.33 (within 2%). You may have to combine resistors to get a system that meets these requirements.

- b. Build your design. Does it work as you expect?
- c. Design and build a variable -5 to $+5 \text{ V}$ supply using two 9-V batteries and a $1 \text{ k}\Omega$ potentiometer. Hint: Other components may be required.
- d. Show me your working circuit.

Lab II: Basic AC Circuits

Introduction

The purpose of this experiment is to introduce you to some simple AC circuits. These circuits are commonly used to condition electronic signals. Examples of conditioning include integrating, differentiating, and filtering signals.

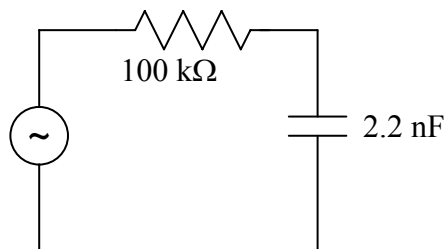
Procedure

1. Comparison of Amplitudes

- a. Connect a $100\text{ k}\Omega$ resistor across the waveform generator's output (with the DC offset off).
- b. Set the generator to a $\sim 1\text{ kHz}$ sine-wave, with a peak-to-peak voltage of 1 V .
- c. Measure the rms voltage with the DMM. Does this value make sense? Why or why not?
- e. Repeat with triangle- and square-waves. Do these values of the V_{rms} make sense? Why or why not?
- f. For fun, replace the Tektronix generator with a WaveTek. Examine the waveforms again. How do the generators compare to each other? Which is better to use in this class?

2. Charging of a capacitor.

- a. Build the following circuit:

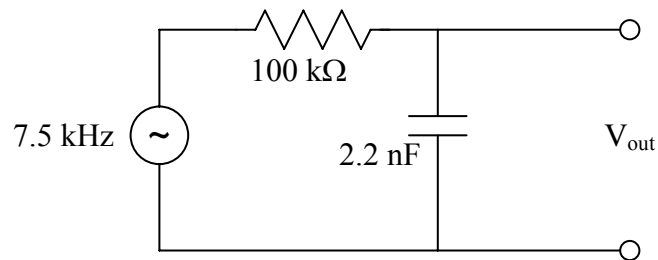


- b. Set the generator to a $\sim 400\text{ Hz}$ square-wave and adjust the amplitude and DC offset so that the output switches from 0 to 1.5 V .

- c. Measure the voltage across the capacitor C using the oscilloscope. Setup the oscilloscope to display both the input and output waveforms “simultaneously.”
- d. Using only the waveforms, determine the time constant τ (the time it takes for the voltage to drop to $1/e$ the initial value) for the circuit. How does this compare the theoretical value for the given circuit elements?

3. Integrator Circuit

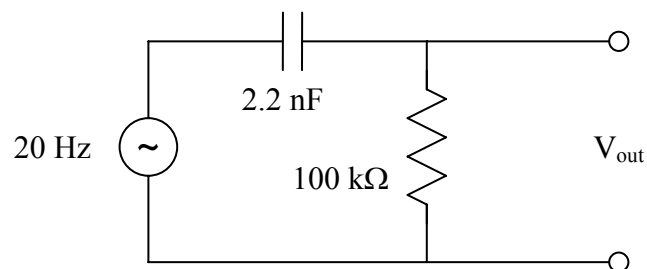
- a. Build the following circuit with a square-wave driving signal.



- b. Record (i.e. sketch in your notebook) the input and output waveforms. Does the output make sense? Does this vary at all from the expected value?
- c. Instead of a square-wave, try using sine- and triangle-waves. Does this circuit “integrate” properly? (Note: you may have to play some “tricks” with the oscilloscope to do this.)

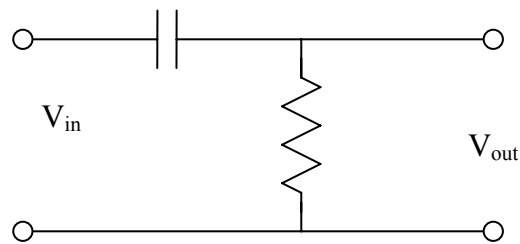
4. Differentiator Circuit

- a. Build the following circuit with a square-wave driving signal.

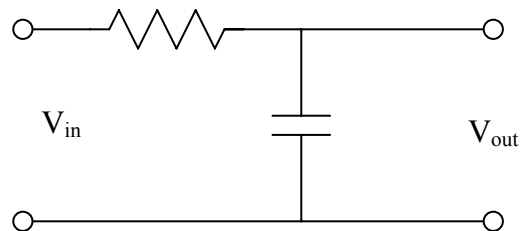


- b. Record (i.e. sketch in your notebook) the input and output waveforms. Does the output make sense? Does this vary at all from the expected value?
 - c. Instead of a square-wave, try using sine- and triangle-waves. Does this circuit “differentiate” properly?
5. Build the following three circuits. Based on what we learned in lecture, build the circuits so that the cutoff point is in the ballpark of 75 kHz. For each circuit, I would like you to measure the gain and phase shift over the range 50 Hz – 2 MHz. Choose your steps carefully: fine enough to show details, but course enough that you finish in reasonable time. In the write-up, compare the gain curve that you measured to what you theoretically predict.

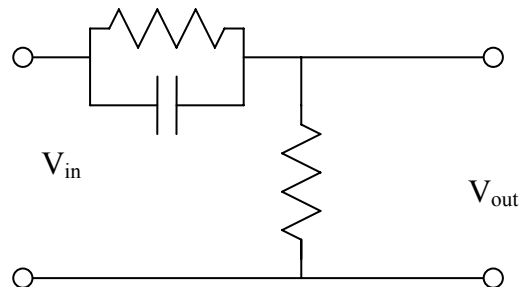
a. High Pass:



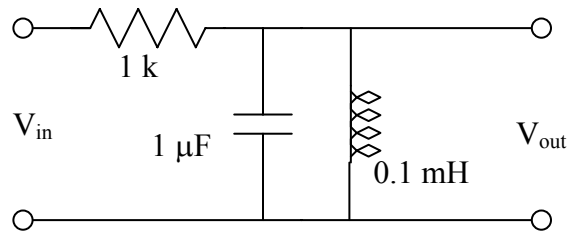
b. Low Pass:



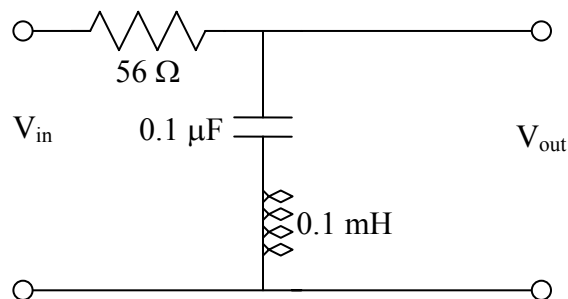
c. High Emphasize:



6. Build the LRC circuit below. Measure the transfer function of this filter. What is the FWHM of the transfer function? How does this compare to the RC bandpass filter you designed in your homework assignment? Which might be considered more useful?



7. For the circuit in part 6 replace the resistor with ones one order of magnitude higher and one magnitude lower and measure the characteristic curve. How does the response (i.e. central frequency, bandwidth, transmission maximum) change?
8. The following circuit is called a notch filter. Measure its characteristics. In your write-up describe a situation where this might be useful.



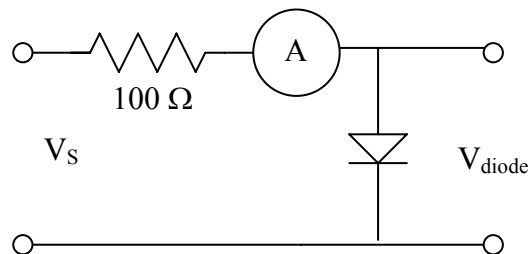
Lab III: Diodes

Introduction

In this lab, you will characterize several varieties of diodes and build some basic and useful diode circuits.

Procedure

1. Measure the I-V characteristics of a 1N914 diode. Use the following circuit to measure the voltage. Pick a resistor of high power tolerance so that it does not burn up. You should be able to use ELVIS's positive variable power supply for the source voltage.



For the negative bias case, use the negative variable voltage source. Keep “an eye” on the resistor to make sure that you don’t overload it. Plot your results for your write-up (I as a function of V). Prepare a second plot focusing on the region where the curve changes the most. What is the diode voltage drop in the forward direction? Estimate the forward and reverse resistances from this plot.

2. Build a half-wave rectifier. In the write-up show me the circuit layout. Sketch the input and output on the same graph. Hint: looking at input and output on the scope at the same time will help this. Add a capacitor to the rectifier output. How does the output voltage change? Again, plot the input and output
3. Build a full-wave rectifier. In the write-up show me the circuit layout. Sketch the input and output on the same graph. See the note at the end of this paragraph regarding how to measure the output voltage. Add a capacitor to the output and observe how the output changes. Sketch what you see. You cannot observe the input and outputs simultaneously with this circuit because the output is not grounded. To properly measure the output voltage, use

channels A and B on the scope to measure the voltages on either side of the load resistor. Use the Add and Invert functions on the oscilloscope to display the difference in voltage between the two ends of the load resistor. I can bring over our fancy 4 channel scope to really show the entire behavior: input and differential output at the same time.

4. Build a voltage clamp, as we discussed in class, with a variable voltage. Systematically study its behavior and report what you find in the write-up.
5. Measure and plot the **reverse** bias characteristic curve for a Zener diode (with a voltage of your choice) as you did earlier (part 1 with negative supply). Note the type (#, and V_z) of the diode.
6. Build a clipper with two Zener diodes. Where might this be useful?

Bonus experiment (if time permits)

Use the same circuit above to measure the forward biased characteristic curves of at least two different colored LEDs: red and green. Discuss the difference. Does the light output reflect the I-V characteristics?

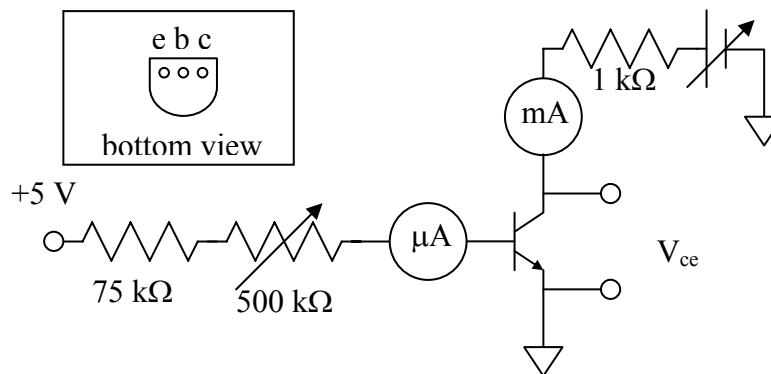
Lab IV: Bipolar Junction Transistors and Voltage Regulators

Introduction

In this lab, we will be using the 2N4124 general-purpose npn bipolar junction transistor. We characterize the 2N4124 in a common emitter configuration and build several useful circuits. We will also observe the performance of an integrated circuit voltage regulator.

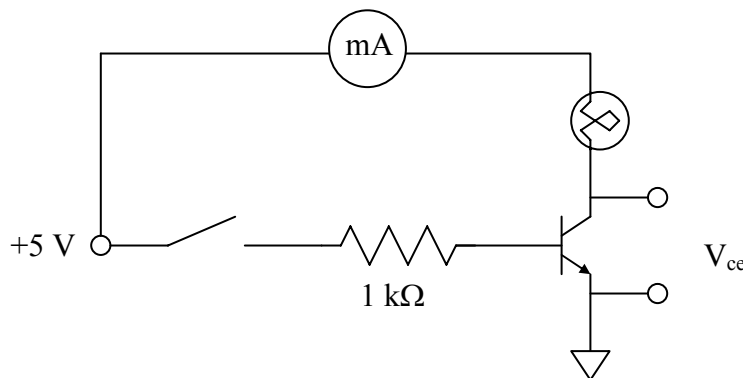
Procedure

1. Characterization of the 2N4124 in CE configuration.



Build the above circuit. For a fixed I_b , record V_{ce} and I_c as you vary the voltage on the collector. Use the positive variable supply for the variable voltage on the collector side. Do not exceed the transistor ratings (see data sheet). Try to do this for $I_b \approx 10, 20, 30, 40, 50 \mu\text{A}$. Observe how the value of β varies depending on the value of I_b and V_{ce} .

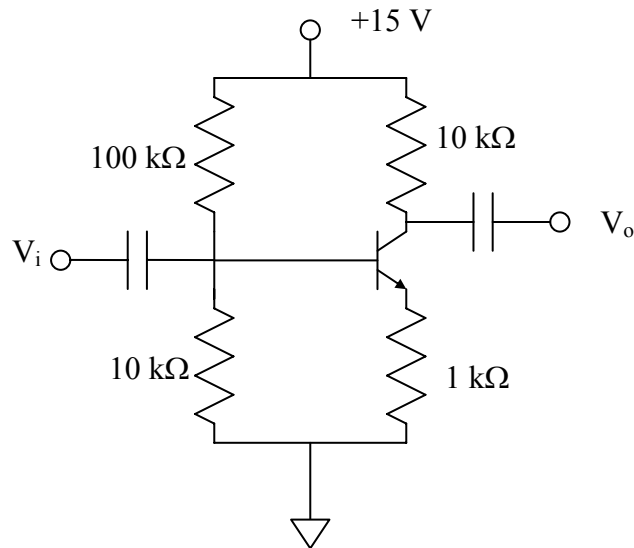
2. Build the following BJT switch:



Activate the switch by inserting or removing the wire connecting the +5 V to the 1 kΩ resistor. Take note of the values of I_c and V_{ce} for the two cases

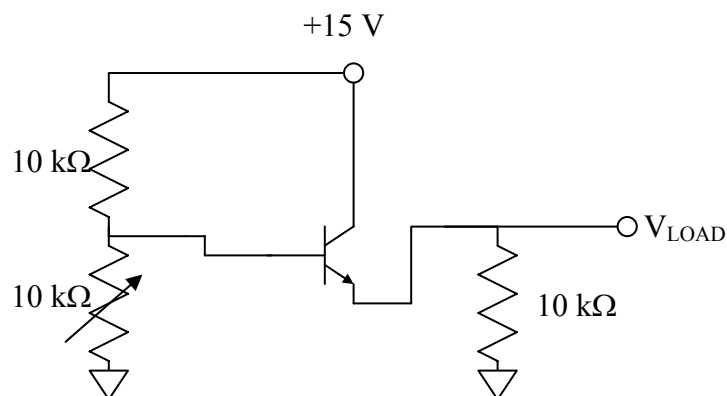
(on/off). Do these values make sense given what we know about the switch circuit? Why?

3. In the homework you will design your own CE amplifier. For you to see how one works, build the following circuit:



Use the largest capacitors you can find for the input and output. Measure the gain of the amplifier up to about 2 MHz. Does this amplifier behave as you would expect?

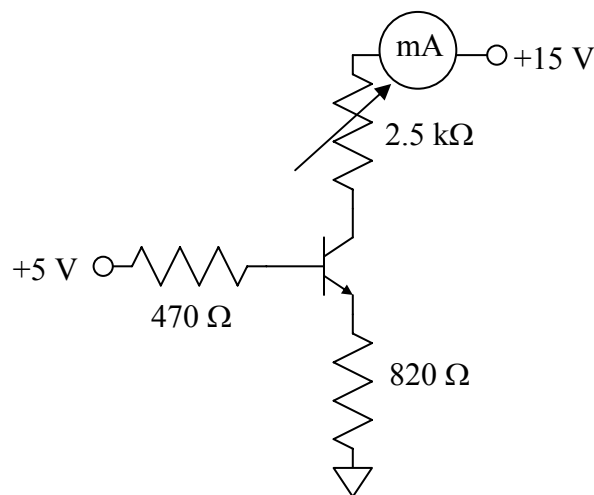
4. Build the emitter follower (a.k.a. common collector amplifier) circuit shown below. This amplifier is often called a power amplifier for reasons that will hopefully be clear soon.



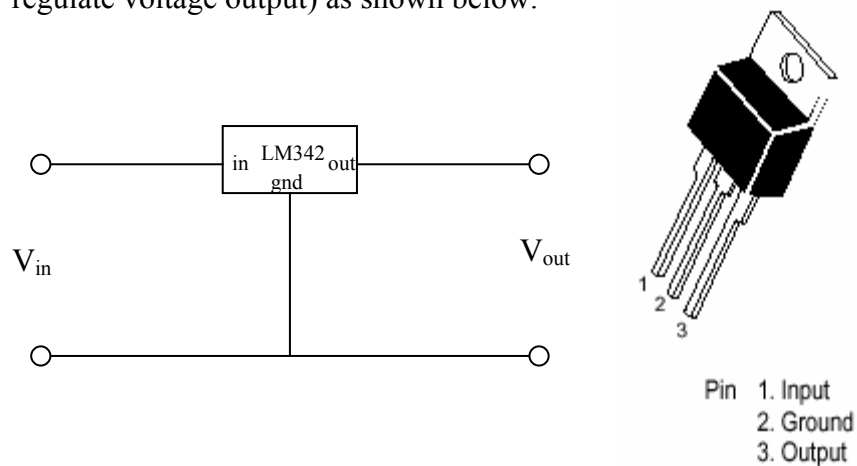
Measure the voltage across the load as you adjust the decade box from 1 kΩ to 10 kΩ. Now remove the amplifier and measure the voltage across the

loaded voltage divider over the same range of resistance. Compare the measured load voltages to the ideal voltage divider model with a variable R_2 . Discuss your observations.

5. Constant current source. This circuit produces a nearly constant current through a load resistor connected to the collector. The collector current I_c is controlled by the base current in this circuit. Measure the current as you vary the load resistance from 0 to $2.5\text{ k}\Omega$. Use a decade resistance box for the variable resistor.



6. Integrated circuit voltage regulators. There are many families of chips used to regulate voltages. We will be using the LM340 family. These are high accuracy fixed voltage, three-terminal regulators very closely related to the LM78XX series discussed in the textbook. Connect the LM342P5.0 (5.0 regulate voltage output) as shown below.



Use the function generator for the input voltage source, you will need to vary the offset voltage. For the LM342 to work, the average voltage must be $\sim 2\text{ V}$ above the regulation value, so make sure that the DC offset is set high enough for the regulator to work. Observe the input and output on the oscilloscope for different DC offsets, sinusoidal and triangular ripple, and with varying ripple magnitude. What happens if a portion of the input waveform drops below the $V_{\text{out}} + 2\text{V}$ threshold? It makes things easier to observe if V_{in} and V_{out} are displayed on the oscilloscope simultaneously.

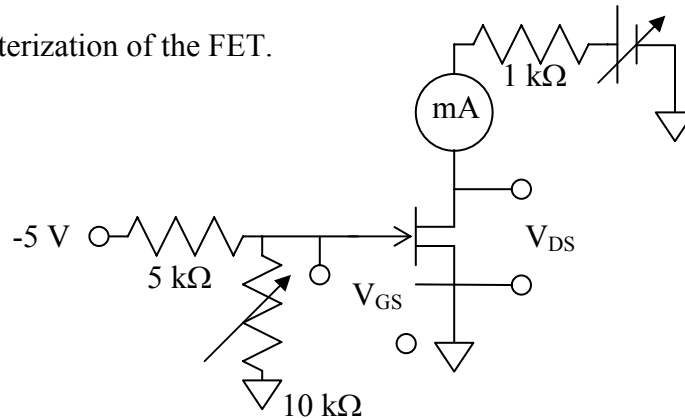
Lab V: Junction Field Effect Transistors and Feedback

Introduction

In this lab, we will be using either the 2N5458 or the 2N3958 general-purpose JFET. They are similar in performance, but the 2N3958 is a dual device: it has two JFETs on each package. We characterize the JFET and build a common source amplifier. We will also see the effect of feedback on a common emitter amplifier built with a 2N4124 BJT.

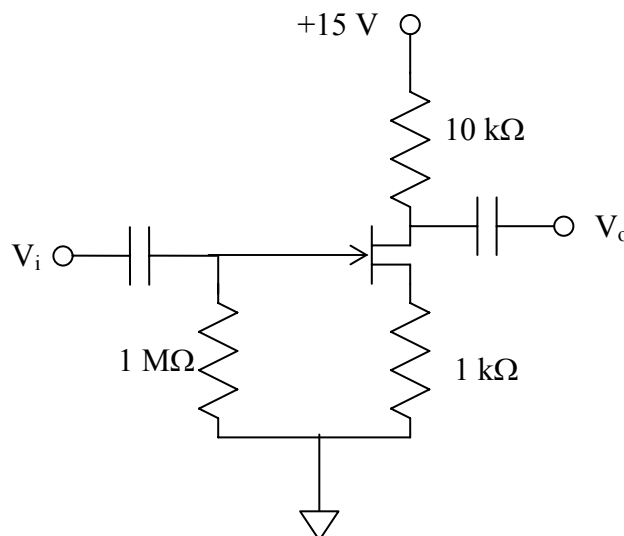
Procedure

1. Characterization of the FET.



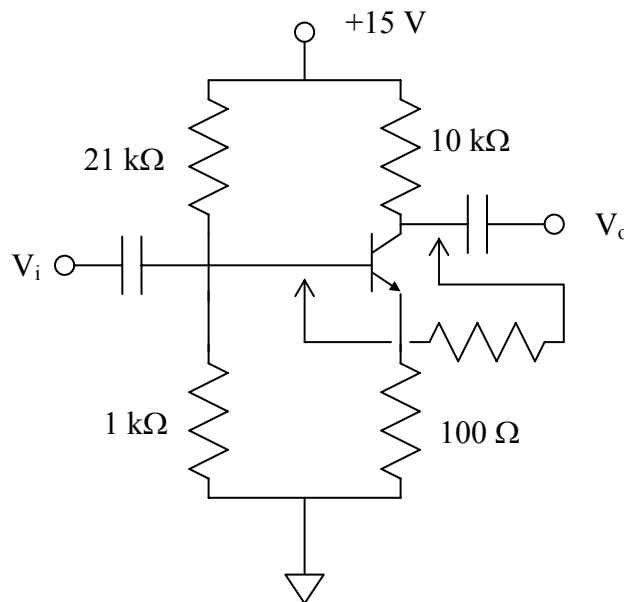
Build the above circuit, use the datasheet for the appropriate JFET to identify the terminals. For a fixed V_{GS} , record V_{DS} and I_D as you vary the voltage on the drain. Do not exceed the transistor ratings (see datasheet). Try to do this for $V_{GS} \approx 0, -0.3, -0.6, -1, \text{ and } -2 \text{ V}$. Pay special attention in the region where V_{DS} is between 0 and 1 V.

2. Build the following FET amplifier:



Use the largest capacitors you can find for the input and output. Measure the gain of the amplifier up to about 2 MHz. Does this amplifier behave as you would expect?

3. Build the following BJT amplifier. Use the largest capacitors you can find. Measure the gain as a function of frequency with a sine-wave. Make sure the amplitude to the input signal is small enough that the output isn't clipped due to the circuit's high gain! Also observe the output when driven by a triangle-wave. Note the frequency when the output triangle is distorted.



Add the feedback network (a 20 kΩ resistor). Measure the gain as a function of frequency. Again observe the output when driven by a triangle-wave. At what frequency is the triangle wave distorted?

Lab VI: Operational Amplifiers

Introduction

In this experiment, we will be building many different circuits that will demonstrate the usefulness and simplicity of using operational amplifiers.

Procedure

For the first several parts of any of the amplifiers will work. It is not until parts 4 and 5 that you will need to be careful of the type of op-amp you will be using. Because of the high gains of these circuits, you might need to use a voltage divider to step-down the input voltage.

1. Amplifiers

- Build an inverting amplifier with a theoretical gain of -100 .
- Build a non-inverting amplifier with a theoretical gain of $+100$.
- Measure the gain of these circuits using both AC and DC inputs.

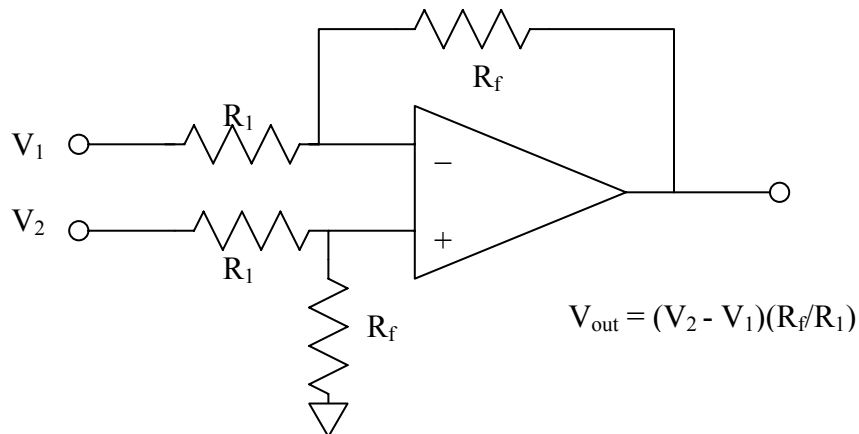
2. Mathematical Functions

- Build a dual input voltage adder with the following behavior:

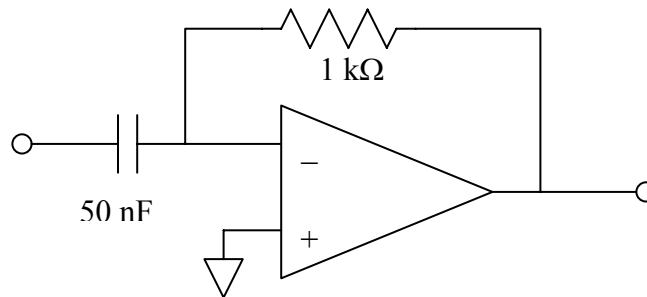
$$V_{\text{Out}} = -(V_1 + 2V_2)$$

Add use two different DC voltages to verify the behavior of this circuit. Also try adding an AC signal to a DC signal.

- Build the following difference amplifier and verify its behavior:

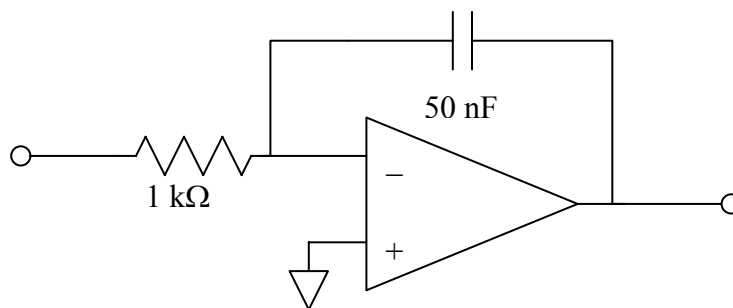


- c. Build the following differentiator circuit:



Observe the input and output with 1 kHz sine, triangle, and square-waves. Do your measured values make sense given what you know about the differentiator circuit?

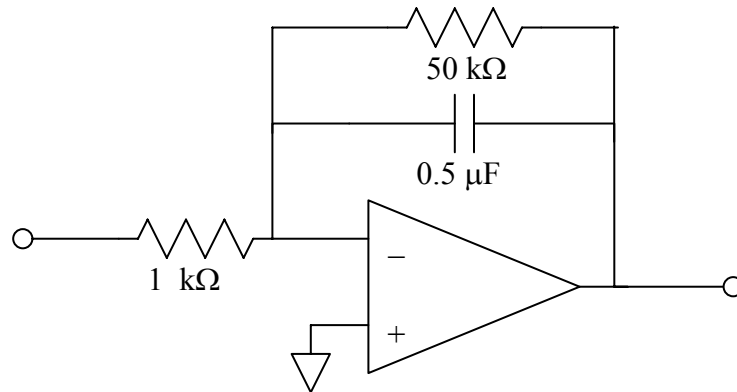
- d. Build the following integrator circuit:



Observe the input and output with 1 kHz sine, triangle, and square-waves. Do your measured values make sense given what you know about the integrator circuit?

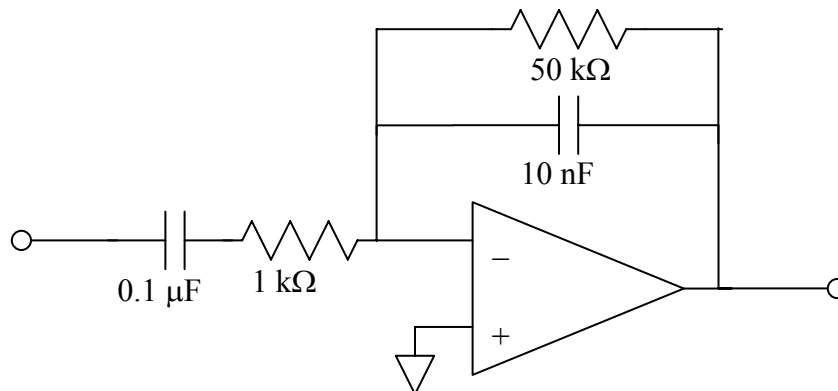
3. Filters

- a. Build the following amplifier with a low frequency gain of 50 and a high frequency roll-off (i.e. low pass filter):



Measure the gain as a function of frequency. What is the approximate cutoff frequency? How does it compare to the theoretical value?

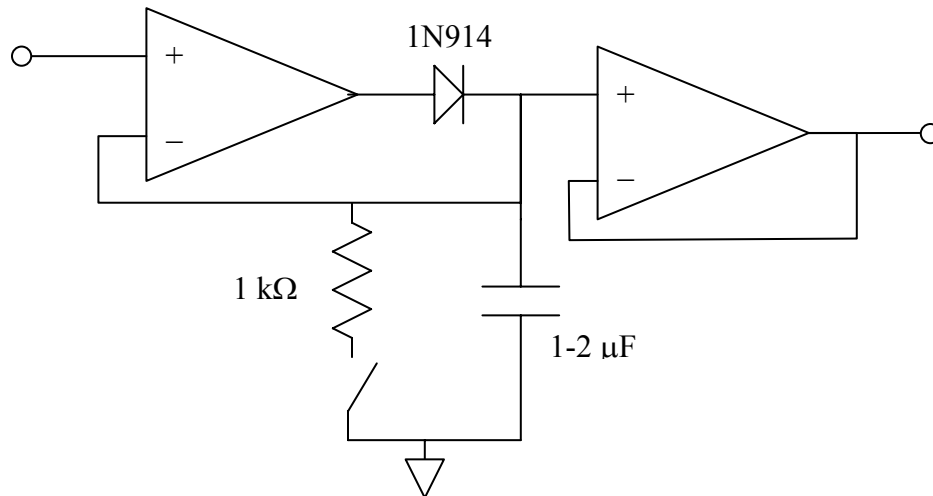
- b. Build the following bandpass filter:



Measure the gain as a function of frequency. In your write-up, calculate the theoretical transfer function and compare it to what you observed.

4. Peak detector circuit

- a. Build the circuit shown below. The output of this circuit will track the maximum value of the input. The output is reset by closing the switch to short the first feedback loop to ground through the 1 kΩ resistor. In this circuit, you may want to use the 353 amplifier because it contains two independent amplifiers (2 x 351) on a single chip. NOTE: the 353 amplifier does not have the same pin-outs as the other amplifiers!



By varying the input voltage, verify the operation of this circuit. This circuit is best observed by watching the trace of the input and output signals on the oscilloscope using a 0.5 s/div timebase.

5. Offset voltage compensation

- a. Build inverting amplifiers with nominal gains of -100 using the 741, 351, and 411 amplifiers. Determine the actual gain by applying a small known DC voltage to the inverting input and measuring the output.
- b. Measure the output voltage of the above circuits when the input voltage terminals are shorted. From this determine the offset voltage (V_{os}). How do the values you measure compare to the data sheets? Using the manufacturers instructions, compensate for and cancel V_{os} . How low can you get the output voltage to be?

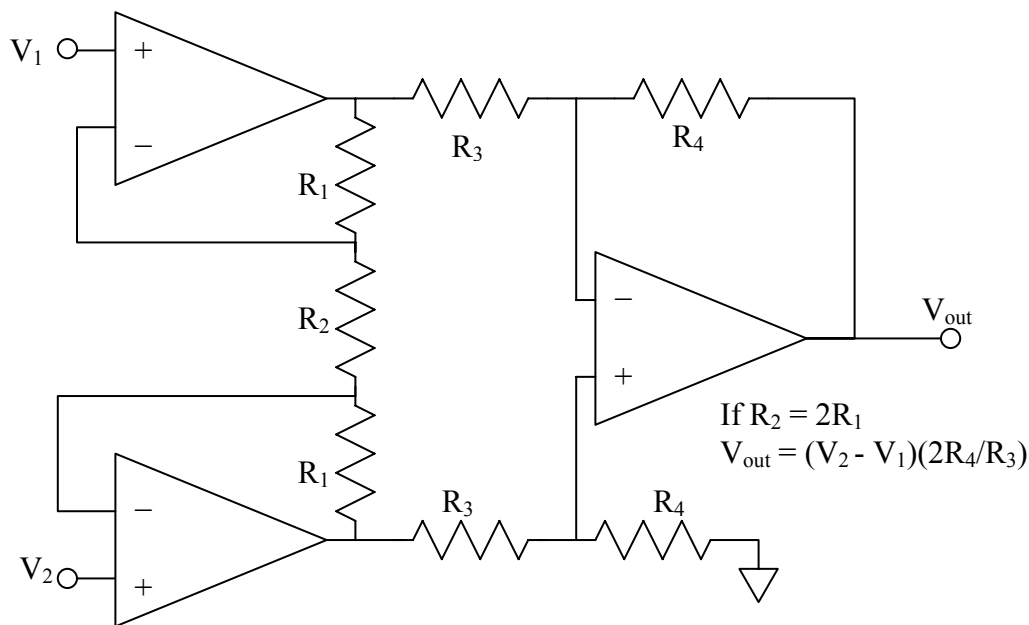
Lab VII: Instrumentation Amplifiers and Transducers

Introduction

In this lab you will build “instrumentation amplifiers” and use them to amplify the input of two different kinds of transducers. The transducers you will use are pairs of Hall sensors and phototransistors. We will be using pairs of each because instrumentation amplifiers are best suited for measuring the difference between two quantities. The transducer data sheets are located in Appendix D.

Procedure

1. In the last experiment, we built a difference amplifier. This amplifier, while it was simple, suffered from low input impedance ($Z_{in} = R_1$), essentially eliminating one of the best features of op amps. Also the gain equation only holds if the two pairs of resistors are perfectly matched. A better approach is the “three-amp” difference amplifier. The input impedance of this circuit is very high, because of the buffers on the inputs, but, as in the single-amp difference amplifier, to get the desired gain, care must be taken to ensure that the resistors are carefully matched. Build this circuit with a gain of ~ 10 . Test the circuit by applying “known” voltages to V_1 and V_2 . Don’t break apart your circuit; you will need it for part 3.



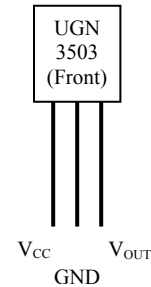
2. Build an instrumentation amplifier using the AD524 or the INA101. These chips have the desired high input impedance and the AD524 has several built in gain settings (it doesn’t come cheap). Hook up your chip according to the data sheet instructions for a gain of 10. Verify the gain with known input voltages.

- Build each of the two transducer systems below. Get a “feel” for how instrumentation amplifiers can work to cancel background signals and to make differential measurements. We have laser pointers, flashlights, and magnets to use in this experiment.

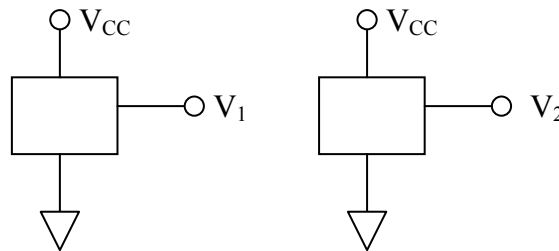
Transducers

Hall Sensors – UGN3503

These sensors provide a voltage proportional to the magnetic field normal to the face of the sensor. At $B = 0$, $V_{OUT} \approx V_{CC}/2$. A north pole approaching the face will drive the voltage high; a south pole will drive the voltage low. The supply voltage (V_{CC}) is 5 V. The typical response of the sensor is 1.3 mV/G. The UGN3503 responds to alternating magnetic fields up to 23 kHz.



We will use two sensors next to each other, front-to-back. Such an arrangement will allow us to measure the $\Delta B/\Delta x$, i.e. the rate of change of the magnetic field. The circuit will be as follows:



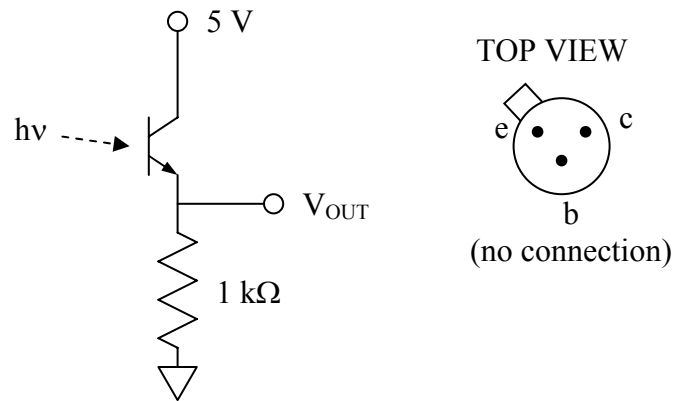
Use the built in +5 V to power the Hall sensors.

Move a bar magnet around the pair of sensors and see if the field gradients you observe make sense given what you know about magnetic fields.

Phototransistors

The absorption of light at the base drives a base current in the transistor that is proportional to the intensity of light on the active surface. Similar to a traditional BJT, when the phototransistor is properly biased, the collector current is proportional to the base current. The result is the phototransistor has internal gain, making it more sensitive (albeit at a cost of response speed) than photodiodes. We have chosen the phototransistor simply because we have many more of them than photodiodes.

The circuit is shown below. Use the +5 V to power the phototransistor. Build two of these circuits and measure the signal as you modify the relative intensity of the light on them and see if your circuit behaves as you expect. Use a laser pointer on one of the phototransistors to drive it into saturation (i.e. the base current deviates from linear response). What happens? If you were trying to measure the intensity of the light accurately, how would you work around this problem? Can you do it with electronics? Or will you have to resort to using optics?



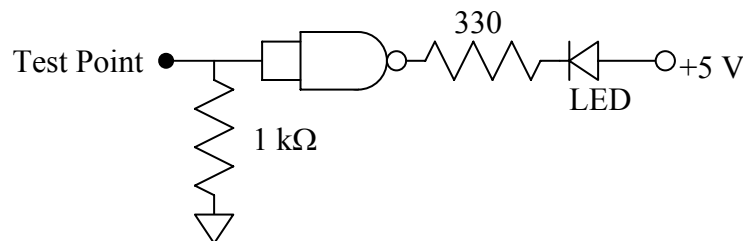
Lab VIII: Introduction to Digital

Introduction

In this lab, you will be building some very basic circuits to familiarize yourself with the behavior of digital electronics. You will also be using the 555 oscillator in both the astable (oscillator) and monostable (one-shot) mode.

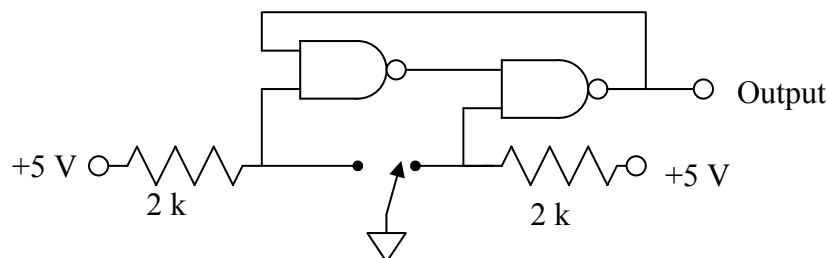
Procedure

1. Logic probes are used to test the logic (high/low, 1/0, T/F) at points within a digital circuit. Your ELVIS has several built in logic probes, but they are unpleasant to use – stay away from them and stick with the handheld models. However, building a very simple one ourselves proves to be a nice exercise in understanding digital circuits. The circuit below is a simple and useful probe:



What is the purpose of the 1 kΩ resistor connected to the test point? What would happen if it were removed? In your write-up describe to me why this circuit works.

2. Use your logic probe to produce truth tables (i.e. verify that they do what they are supposed to do) of a NOT gate (inverter), a NOR gate, a NAND gate, and one “compound gate” of your own design. Use the textbook and the TTL databook to find the necessary circuit diagrams.
3. Throwing switches can cause problems in digital circuits. Because you want to make sure that a) there is no “noisy” turn on and b) you *must* avoid undefined states while the switch is being thrown. The bounceless switch shown below resolves these problems.



Use a wire as the switch. Describe the action of this switch, using your logic probe to test the output. Use what you've learned about digital logic to explain to me in your report why this circuit works the way it does.

4. Use the 555 timer in its astable mode to build an oscillator operating at 10 kHz with a duty cycle of about 30%. Observe the output waveform on the oscilloscope. Wire the output to one of the built-in pots and use it as a voltage divider to drive a small speaker.

Note: for reasons not clear to ANYBODY, the duty cycle of the 555 is in terms of the percentage of time off. Usually, duty cycle refers to percentage of time on.

5. Use the 555 in the monostable mode and build a one-shot with a 2 second long period. Trigger the one-shot with your bounceless switch. Use a logic probe (homemade, built-in, or handheld, it doesn't matter to me) to observe the behavior. For the one-shot to work properly, the trigger must go back to HI logic prior to the end of the one-shot pulse.

Lab IX: Digital Circuits

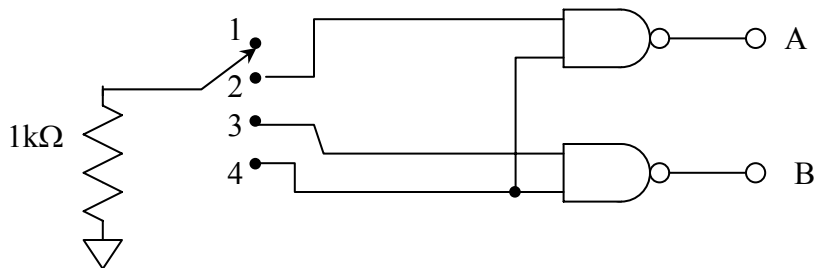
Introduction

In this lab, you will be building some fairly simple circuits to familiarize yourself with digital circuits. Static circuits you will be using are encoders, decoders, BCD-seven segment LED decoders. You will be building some fairly simple dynamic digital circuits as well, including build delay flip-flops (DFF), toggle flip-flops (TFF), and a divide-by-16 counter from J-K flip-flops (JKFF).

Procedure

1. Build a 4-2 encoder. That is, build a circuit that will but out a specific 2-bit code depending on which of the four possible inputs is selected. The truth table and the circuit are shown below. Test the circuit to make sure that behaves properly:

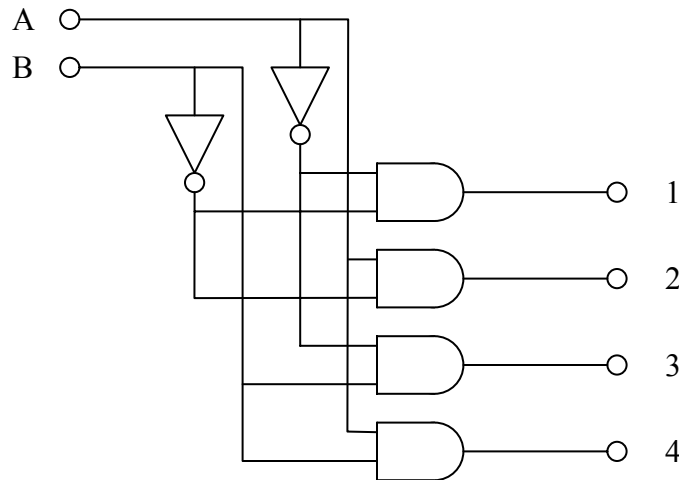
Input				Output	
1	2	3	4	A	B
On	-	-	-	0	0
-	On	-	-	1	0
-	-	On	-	0	1
-	-	-	On	1	1



Use a wire as the four-way switch. You can use LEDs with 500 Ω resistors as simple logic probes. Does this circuit behave as you expect? Do not disassemble your circuit; you will use it in part 3.

2. Build a 2-4 decoder that will take 2-bit inputs and drive one of 4 lines. The truth table and circuit are shown below.

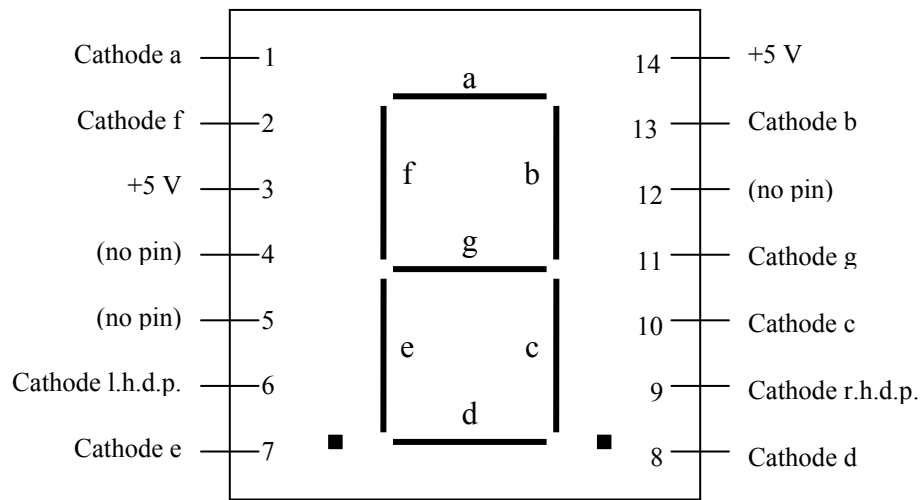
Input		Output			
A	B	1	2	3	4
0	0	1	0	0	0
1	0	0	1	0	0
0	1	0	0	1	0
1	1	0	0	0	1



Wire the inputs to the logic switches to the +5 and GND lines on the ELVIS to select the states of A and B. Wire outputs 1-4 to LEDs (with resistors) as logic indicators.

3. Now connect the encoder and the decoder and see if the data properly sent. Connect the A/B outputs on the encoder to the A/B inputs on the decoder. Does your action with the switch drive the correct LEDs on the logic indicators? Why would two circuits like this be useful? Why not just run four wires directly? Think about this in terms of needing to send more than four possible signals.
4. We will now use one of the more useful chips available: the 7447, a BCD to 7 segment LED decoder. This is used to drive a 7 segment LED used to indicate numbers on a panel. Notes on the BCD numbering system are at the end of the procedure.

We will be using a MAN-72 (or compatible) display. It is a common device used to display numbers on a panel. It is made up of 7 segments that light up to form numbers that a reader can understand. Below is a sketch of what the pins and the LEDs look like:



The lettering of the individual LEDs is industry standard and allows fairly easy interchange of components. The MAN-72 does not have any internal resistance in series with the LEDs so you **MUST** have a small series resistor each cathode and the decoder output. Resistors of value $400 - 700 \Omega$ will suffice. This prevents the forward bias current from getting to high and burning out the LEDs.

Connect the 7447 decoder according to the datasheet and connect to the MAN-72. Set the logic state of the inputs for the 7447 by wiring them to ground and +5 V. Can you count from 0 (0000) to 9 (1001) in binary? What happens if you put binary values that are larger than 1001? Don't break this down, you'll need it in a later part of this experiment.

Note that the MAN-72 is a "common anode" type display. That means that the LED elements will light when the cathode goes to LO logic. If you want to see this in action, use a logic probe to test the logic going into the MAN-72. This implies that you need to have a decoder specifically for common anode displays when using a MAN-72 or related display. Common cathode displays require decoders intended for them also.

The 7447 has the ability to blink on and off, can you figure out how to do it by looking at the data sheet. It can also be set to blank the display for 0000 input (rather than display a 0). Can you figure out how to do this? A big part of this lab is to learn how to read data sheets.

5. Build a Delay Flip-Flop (DFF) from a JK Flip-Flop. Verify the truth table for the DFF. The data sheet for the JKFF in the Appendix.

6. Build a Toggle Flip-Flop (TFF) from a JK Flip-Flop. Verify that the TFF toggles the output as the clock triggers it using one of the logic switches to drive the clock manually. Then drive the clock with a 1 kHz TTL signal from your function generator. What happens if $J = K = 0$?
7. Build a “divide-by-16” counter using JKFFs. Wire the Q_A , Q_B , Q_C , and Q_D to the logic indicators on the Protoboard. Use a logic switch to drive the counter. Are you counting properly as you keep throwing the switch? Drive the input with a 0.5 Hz TTL signal from the function generator and observe the logic display. Does the circuit behave differently when using the TTL signal? Any ideas why?

Increase the TTL input to 10 kHz and simultaneously observe the input and Q_C on the oscilloscope. Sketch the waveforms that you see and explain what you are seeing.

8. Wire up a BCD-7 segment decoder (7447) that you used the other day with a MAN-72 display, if you didn't leave it on your board. Connect the output of the divide by 8 to the inputs on the 7447 and see if you can “count” in decimal numbers.

BCD Numbering System

As you are aware, it is often difficult to handle large numbers in binary code. A system has been developed that simplifies the notation used for large numbers, Binary Coded Decimal (or BCD). In this code, we use 4 bit words to describe a digital equivalent. Each decimal “order” is independently coded in binary and is offset from the other orders by a space. As in decimal notation, leading 0's are usually not written. The numbering systems is as follows:

Decimal	BCD Equivalent
0	0000
1	0001
2	0010
3	0011
4	0100
5	0101
6	0110
7	0111
8	1000
9	1001
10	0001 0000
11	0001 0001
12	0001 0010
43	0100 0011
287	0010 1000 0111

Lab Aside: Intro to LabVIEW

In this experiment, you will go through a LabVIEW tutorial that is based on material provided by National Instruments, but modified by me. It is important that everyone become familiar with using LabVIEW so make you and your partners each get a turn using the computer. The tutorial can be found on the Resources Page when we get to this part of the class.

Many of you have experience in programming computers so I will not spend time discussing data types in class. I will spend only a little bit of time discussing the different kinds of structures that you will encounter. If you have any questions about them, please see me or find resources on National Instruments website or elsewhere. If you don't understand the different kinds of data you encounter in programming, you will never get a very good handle on what the programs are supposed to do.

For an additional solo practice session, go through the included "Getting Started with LabVIEW" and "LabVIEW Fundamentals" resources. You can access them from the LabVIEW dialog box that pops up when you first run LabVIEW. They can also be accessed from the Help system. They aren't the most user friendly things, but they do contain a lot of useful information.

As you go through the activities, feel free to play around with the VI's you build. Add extra features, make changes to the output, have some fun. HOWEVER, for the sake of the students following you, please DO NOT WRITE OVER any sample VI's that come with LabVIEW. In fact, be careful and make sure that you save all your own VI's a unique folder (i.e. D:/labview/bobandsarah_f99/)

In the experiments that follow, you will be given several projects to build. The instructions are to guide you, but you are responsible for developing your own code. You should submit your VI's to me via e-mail after completion, along with any other information that is asked for (data files, comments, etc.).

Lab X: LabVIEW Projects

Introduction

You will be performing the following exercises using LabView. Make sure that everyone in the group understands the program. Your write-up for this week's experiment will be the VIs themselves and the output files that I have asked you to prepare using LabView. Send these all to me in a single email. You will be graded on whether you completed the asked tasks, your program's organization and usability. To this end, make sure that your VIs are labeled and the default values of controls are reasonable.

The best way to learn a program is to use it. Feel free to come in and play with it. We will be using LabView more in the future when we start using computer data acquisition (DAQ).

Projects

1. Build a VI that generates and displays a sinusoidal wave using simple mathematical tools (not using the waveform generator that comes with the program). You should use the "get time in seconds" VI to get the time. This VI outputs the time in a time stamp data type. It can't be directly used in mathematics, it has to be converted into a floating point number; use the conversion tools in the numeric palette to do this. Put the calculations into a while loop that will allow this data to be generated until a "stop" button is depressed on the front panel. You will want to have a delay inside the while loop so that you don't generate data at a ridiculous rate. Consider the options for doing the timing carefully – one choice is much better than the others. The VI should have controls on the front panel for amplitude, frequency, and DC offset. Is there a difference between placing these controls inside or outside of the while loop? Name this project1.vi.
2. Modify the VI in project one by giving the user the option of adding random noise to the sinusoidal signal. This should involve the random number generator. You will want to use a case structure to control whether noise gets added or not. The noise should cause deviation from the sine wave in either direction and its amplitude should be variable from zero to no more than the amplitude of the sine wave itself. Your chart should be modified to display both the noisy signal and the noise. Name this project2.vi.
3. Create a VI that reads in the 1D spreadsheet file named testfile1.txt that is available for download on my website. You can use either the express VI or the read from spreadsheet VI on this; however, the express VI requires a correct file path. The advantage for the read from spreadsheet is that if a path isn't given, it allows you to browse for the desired file. Once the data is loaded, display it using an array indicator and graphically. Identify and

display the following items: the number of elements in the array, the maximum of the array, the average of the array, and the standard deviation of the array. Also square the individual elements of the array and take the tangent of each element (assume the values in the array are in units of degrees). Build a 2D array that has three columns, the first containing the original data, the second the squares, and the final the tangent values. Export this 2D array to a spreadsheet file and also using the express VI for writing data. Both can be opened in Excel or notepad – the express VI has a lot more information, but can be a bit more challenging to figure out. *Project3.vi*.

4. 4. In this VI, you will be creating another waveform, but this time, you will be using a For loop (instead of the while we used earlier) and you will also get the chance to use the formula node. The formula node is used to perform more complex mathematical operations without cluttering the diagram with wires and functions. It essentially uses a box of text based code to do the math. Build a VI that calculates the following function:

$$y = \left[\sin\left(\frac{x}{3}\right) + 0.5 \cos(2x) \right] e^{-\frac{x}{75}}$$

Do this for $x = 1, 2 \dots 100$. I would like you to perform the calculations using the formula node AND with the graphical wiring of functions. Plot the results of each method. Calculate the difference between the two values for each value of x and display the average and standard deviation of them. Name it, yes you guessed it: *project4.vi*.

5. Build the VI described in the document *peakdetect.pdf* on my website. Actually, you will only be graded on the content thru the end of page 7. Adding the markers on the graph is strictly optional. Data files are available on my website: *spectral1.txt*, *spectra2.txt*, *hydrogen.txt*.

Lab XI: LabVIEW DAQ Projects

Introduction

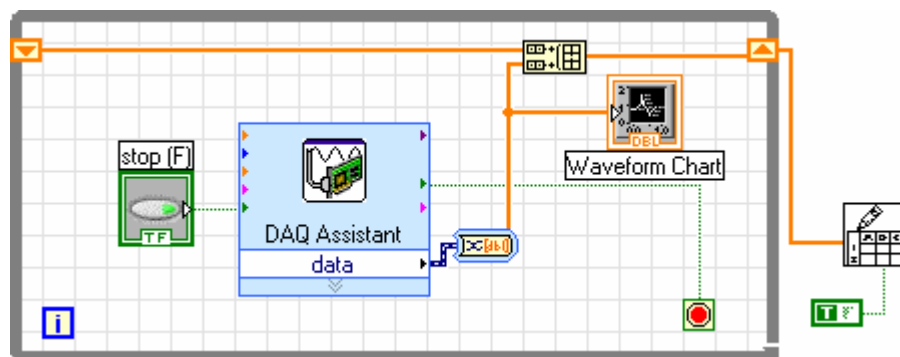
We will be building several projects using DAQ cards and LabVIEW. We will be using LabVIEW to input and output data in several ways: single point, waveform (N-samples), and continuous. We will be using the DAQ Assistant to configure the channels. The DAQ Assistant is an Express VI that asks what type of data to collect (or output), on which channel, and the kind of collection (or output). After the options are configured, the VI compiles the appropriate code to handle what you've requested, but it keeps this stuff hidden from you. It simplifies things, but also takes away some flexibility when trying to optimize performance. Fortunately, for the kinds of things we're interested in, it won't be an issue.

Projects

1. Build a selectable voltmeter VI. On the front panel, create a knob that will allow you to select from one of four possible channels (0-3) to "sample" the voltage at the channel (i.e. single point) and display it. You will want to use a **case** structure for selecting the channel; each case will have a different DAQ Assistant VI in it. Have the selected output display on the front panel (but only the selected one), along with the channel number, and the time that the data was collected. Save your VI as DAQ1_name.vi.
2. Starting with the VI from project 1, add a **sequence structure** to the VI along with a while loop so that when you run the VI, no recording is made until you depress a button that you also add called "Sample". To do this, the while loop should run and hold until you press the "sample" button, which then forces the VI to move to the next step in the sequence, the data recording. Save your VI as DAQ2_name.vi.
3. The problem with single point acquisition is that the software controls the data collection. This can limit the speed of the data collection. If the DAQ Assistant is configured to collect a waveform, or N-samples, the system is configured to collect the data at a specific rate for a specific number of samples and collect the data using the built in memory on the DAQ Card, the buffer, so that you don't have to shuttle configuration information back and forth between the software and the card.

Build a VI that will collect waveforms on two channels. The waveforms should have a sample rate of 50 kS/s and collect for three seconds. Use the Signal Manipulation Palette to convert the data from the DDT data type to a 2D array of scalars, with each column representing a channel. Plot the channels using the Waveform Chart.

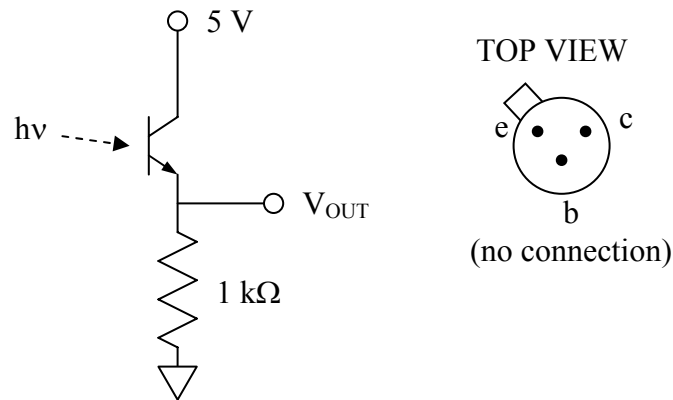
Build a VI that acts like a strip chart recorder by using the continuous collection option. A strip chart recorder is a device that was once very common in laboratories. A piece of paper rolled under a pen that moved as the input voltage changed. This allowed researchers to record voltage changes as a function of time. Put a waveform chart inside of the while loop that the DAQ Assistant creates for you to display the data as it is collected. As you configure the DAQ, the number of samples field indicates that number of samples that will be sent to the software from the buffer at one time. The bigger this number, the “blockier” the data comes out. Have the DDT data converted to a 1D array. Save the entire set of data by appending (concatenating) the most recent output data to the past data by using a shift register and the build array feature. See figure below. Save your VI as DAQ4 *name*.vi.



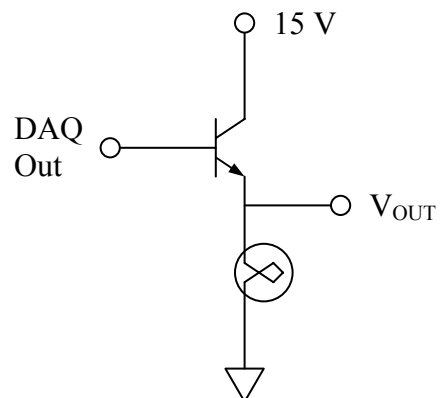
- $$V_{out}(t) = 2 + 3 \sin(0.5 \mathbf{H} \mathbf{z} \cdot 2\pi t) - 0.5 \cos(10 \mathbf{H} \mathbf{z} \cdot 2\pi t)$$

40

7. Design a VI that will allow you to power and monitor a light bulb. Use a phototransistor located about 2" from the light bulb to monitor the light intensity coming off of the bulb as your VI steps up the light bulb voltage in 0.25 V steps from 0 to 8 V. Save the VI as DAQ4_name.vi. Use the phototransistor circuit below:



The DAQ card will not provide enough current to power the lightbulb so you will have to use a BJT as a power/current amplifier.



Because of the voltage drop across the BJT, also record the voltage across the lamp with your VI so that an accurate intensity versus voltage curve can be obtained. Plot the intensity as a function of the voltage in an x-y graph (use the XY Graph Express VI) in your VI. Write the XY Data file out to a file. Save this project as DAQ7_name.vi.

Appendices

Appendix A: Parts List

Discrete Passive Components

- Assorted Resistors
- Decade Boxes
- Assorted Potentiometers
- Assorted Capacitors
- 0.1 mH Inductors

Discrete Active Components

- 1N914 – Small Signal Diode
- 1N4001 – Small Voltage Rectifier
- 2N4124 – Small Signal NPN Transistor
- 2N4126 – Small Signal PNP Transistor (complimentary to 2N4124)
- 2N3904 – General Purpose NPN
- 2N3906 - General Purpose PNP (complimentary to 2N3906)
- Assorted Zener Diodes

Operational Amplifiers

- 741 – General Purpose Bipolar
- 411 – General Purpose JFET
- 351 – General Purpose JFET
- 353 – Dual 351
- 356 – General Purpose JFET
- AD547 – Precision Op Amp
- OP177 – Top Shelf Precision Op Amp

Instrumentation Amplifiers

- AD524 – Precision Variable/Internal Gain Instrumentation Amplifier
- INA101 – Precision Variable Gain Instrumentation Amplifier

Comparators

- 311 – General Purpose Comparator
- 339 – Dual GP Comparator
- 711 – Quad GP Comparator

Timers/Oscillators

- 555 – Single Timer
- 556 – Dual Timer

TTL and TTL-compatible CMOS Logic

- 7400 / 74LS00 / 74HCT00 – Quad 2-Input NAND
- 7402 / 74LS02 / 74HCT02 – Quad 2-Input NOR
- 7404 / 74LS04 / 74HCT04 – Hex NOT
- 7408 / 74LS08 / 74HCT08 – Quad 2-Input AND
- 7410 / 74LS10 / 74HCT10 – Triple 3-Input AND
- 7427 / 74LS27 / 74HCT27 – Triple 3-Input NOR
- 7486 / 74LS86 / 74HCT86 – Quad 2-Input XOR
- 7447 / 74LS47 / 74HCT47 – BCD to 7-Segment Decoder
- 7474 / 74LS74 / 74HCT74 – Dual Positive Edge JKFF

Optoelectronics

- Phototransistors
- Photodiodes
- Photoresistors
- Assorted visible and IR LEDs
- 7 Segment LED Displays (MAN-72 and compatibles)
- Photoswitches (Reflective and Transmissive)
- 4N31, 4N32 Optocoupler
- 4N37 Optoisolator

Transducers

- AD590 Temperature Sensors
- LM355 Temperature Sensors
- UGN3503 Hall Sensors
- EMD-4000 Humidity Sensors

Appendix B: Resistor Codes

Color	Figure	Multiplier	Tolerance
Black	0	1	-
Brown	1	10	-
Red	2	100	-
Orange	3	1000	-
Yellow	4	10^4	-
Green	5	10^5	-
Blue	6	10^6	-
Violet	7	-	-
Grey	8	-	-
White	9	-	-
Gold	-	10^{-1}	5%
Silver	-	10^{-2}	10%

Appendix C: Operational Amplifiers

We have several kinds of operational amplifiers available to us in this course. Additionally, there are many different kinds of specialized amplifiers, instrumentation amplifiers, audio amplifiers, low power, high speed, ... the list goes on and on. Many of the amplifiers are “generic.” By generic, I mean that several manufacturers make their own version of the chips, but a common number identifies them. A summary of the specifications of several common, general purpose, generic op amps is shown in the table below. Detailed sheets are in Appendix D.

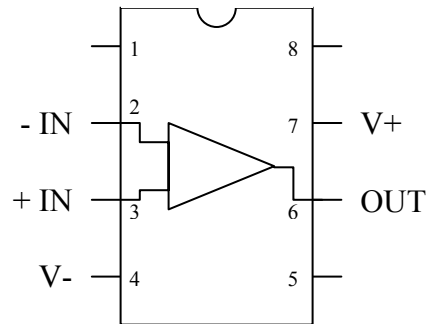
Op Amp	Type	Gain	Slew Rate (V/ μ s)	V _{os} (typ.) (mV)	Comment
741	Bipolar	2×10^4	0.5	6	An Old Classic
351	JFET	2.5×10^4	13	5	
411	JFET	2.5×10^4	15	0.8	Very good general purpose
353	JFET	2.5×10^4	13	5	Dual 351
356	JFET	5.0×10^4	12	3	Higher Gain

Additionally, we have some higher gain and precision amplifiers available. We will probably not use these until project time, if at all.

Op Amp	Type	Gain	Slew Rate (V/ μ s)	V _{os} (typ.) (mV)	Comment
AD547	JFET	2.5×10^5	3	< 0.25	Precision amp.
OP177	Bipolar	1.2×10^7	0.3	< 0.025	Top shelf precision amp.

The “pin-out” diagrams for the single unit amplifiers are all basically the same (for DIP-8 packages). The main differences between the pin-outs are the method used to compensate for the offset voltages (using the remaining pins 1, 5, and 8). Detailed pin-outs and data sheets are available for you to use.

Typically V₋ and V₊ (the supply voltages) are ± 15 V, but the op amp will usually operate over a much wider range of voltages than this. Keep in mind that the input and output voltages cannot go outside of the range defined by V₋ and V₊. Also keep in mind that in circuit diagrams, the connections for V \pm are rarely shown.



Note that the pins are numbered from the upper left corner (as indicated by the notch or a dot at the end).

Appendix D: Common Data Sheets

The following data sheets are for your use in this course. They are fairly generic data sheets and may not be for the exact manufacturer that we have in stock. In fact, most of the ICs in stock will be a mixture of brands. For more detailed information regarding each chip, you may want to visit the manufacturer's web site and download pdf files of the datasheets yourself.

In this version of this manual, the following data sheets are included:

<u>Device</u>	<u>Manufacturer</u>	<u>Document Date</u>
2N4124	Vishay Semiconductors	5/2002
2N4126	Vishay Semiconductors	5/2002
2N3958	Vishay Semiconductors	6/2001
LM741	National Semiconductor	7/2000
LF411	National Semiconductor	7/2000
LF351	National Semiconductor	12/1995
LF353	National Semiconductor	7/2000
OP177	Analog Devices	2002
AD524	Analog Devices	1999
INA101	Burr-Brown	1998
LM111/LM211/LM311	National Semiconductor	1/2001
LM555	National Semiconductor	2/2000
DM74LS00	Fairchild Semiconductor	7/1986
DM74LS02	Fairchild Semiconductor	5/1986
DM74LS04	Fairchild Semiconductor	3/2000
DM74LS47	Fairchild Semiconductor	10/1988
DM74LS74A	Fairchild Semiconductor	7/1986
AD590	Analog Devices	1997
UGN3503	Allegro Microsystems	