Comparators

Objectives
1) Learn how to design using comparators
2) Learn how to breadboard circuits incorporating integrated circuits (ICs)
3) Learn how to obtain and read IC datasheets
4) Learn how to design and build a bargraph display
5) Learn how to select the correct current-limiting resistor for use with an LED

Situation

As a junior engineer in Blaupunkt's Car Audio division you have been tasked to design a four-segment light emitting diode (LED) bargraph meter that graphically displays the voltage output by the audio amplifier.

In your old EE223 notes you find information on using comparators that will be useful. A comparator looks similar to an opamp but has no negative feedback. You will recall that for an opamp, $V_{out} = A(V^+-V^-)$, where A is huge. If there is no negative feedback then whenever $V^+ > V^-$ the output will attempt to go as high as it can, which is usually a few volts less than its positive power supply. Whenever $V^+ < V^-$ the output goes as low as it can, which is usually a few volts above its lower power supply.

A comparator is similar, but has two differences:

1) The output goes <u>exactly</u> to its lower power supply (usually ground) when $V^+ < V^-$.
2) The output is disconnected (it looks like an internal open) when $V^+ > V^-$.

Here's how to think of it: the comparator does what an opamp would do, except that instead of going "high" it disconnects. This is shown schematically below:
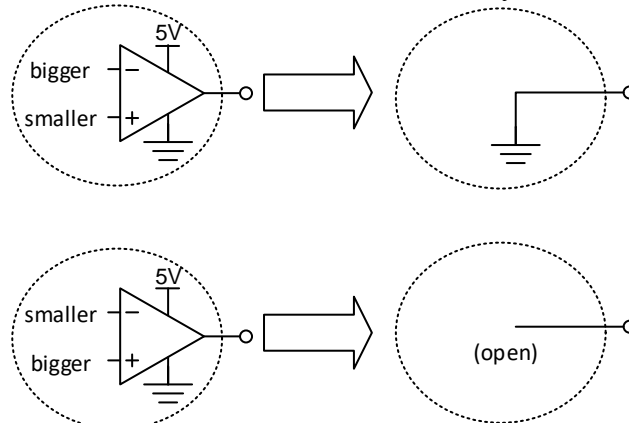

Figure 1: A model of a comparator, showing the output looks like either a short to ground or an open, depending on the relative voltages at the inputs. Note: this is a comparator, not an opamp, even though both have the same triangular shape. Opamps are used with negative feedback; comparators are used without negative feedback.

Figure 1 shows how the comparator is used in a circuit. Like an opamp, no current flows into a comparator, so the two 1kΩ resistors form a voltage divider to create 2.5V. When V_{test} is greater than 2.5V (i.e., when $V^+ < V^-$) then the comparator's output goes to ground, allowing current to flow through the LED which lights. When V_{test} is less than 2.5V (i.e., when $V^+ > V^-$) then the comparator's output disconnects, and the LED is extinguished.
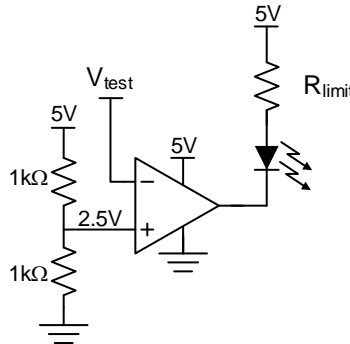

Figure 1: Example comparator circuit that turns on the LED when $V_s > 2.5V$

The name R_{limit} in Figure 1 comes from the fact that it is needed to limit the current flowing through the LED. To find R_{limit}, note that the LED drops 2V and requires about 10mA to light (less than this won't light it brightly, but more than that will burn it out). Therefore to find R_{limit},

$$R_{limit} = \frac{5V - 2V}{10mA} = 300\Omega \text{ for this design.}$$

Design Note: All normal-sized LEDs have a voltage drop of about 2V (the exact amount depends on the color of the LED), and all normal-sized LEDs work well on 10mA of current.

Confusion cleanup: When we talk about the voltage "drop" across an LED, we mean that the LED actually absorbs 2V of potential when it is lit. When less than 2V exists across it, it is unlit. If you try to put more than 2V across it, it will burn up. This is why the R_{limit} resistor is always required; the LED will absorb 2V and the remaining voltage will appear across R_{limit}.

Your engineering team supervisor informs you that the voltage coming from the car's audio amplifier varies from 0 to 5V and that you must power your circuit directly from the 12V car battery. She suggests you use the circuit shown in Figure 2 as a model for your design. Further design constraints come from the supply division who stock National Semiconductor's LM339 quad comparator IC's, and from marketing who specify for aesthetic reasons to use 3 green LEDs to display the lower voltage levels and 1 red LED to display the highest voltage level. You checked on the web under National's website (www.national.com) and did a search on LM339 to find a datasheet for the LM339 (included on the last page of this lab) that specifies the chip's pinout.
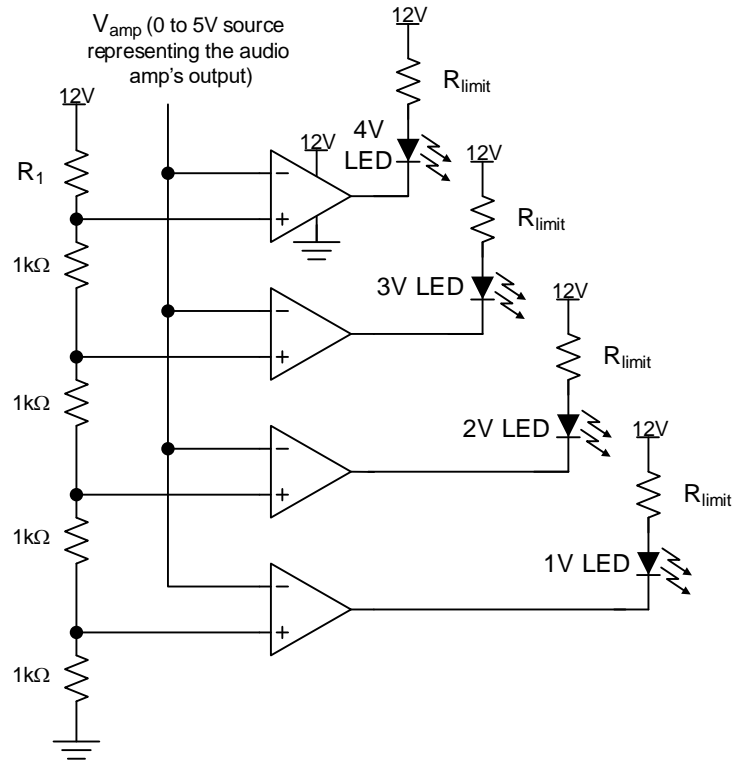
Figure 2: Generic bargraph display schematic. Notice that the power connections are only shown on the top comparator. This is because typically 4 comparators are packaged on a single chip, so all four share the same V_{cc} and ground connections. The labels next to the LEDs, for instance "4V LED", do not mean the LED drops 4V; they all drop about 2V. It means that LED will turn on when V_{amp} is equal to or greater than 4V.

Prelaboratory

1.   Select R_1 in the design shown in Figure 2 so that

| when Vamp =	
0V	no LEDs light
1V	the lowest green LED lights
2V	the lowest two green LEDs light
3V	the lowest three LEDs light
4V	all LEDs light (the lower 3 green and the topmost red)

2.   Find R_{limit} so that the LEDs light fully without burning out.

3.   Use the provided datasheet for the LM339 and write the pin numbers on Figure 2. By this, I mean write a small 3 to signify pin 3 (positive chip power) next to the wire leading to the +12V in Figure 2, and a small 5 to signify pin 5 (non-inverting input of the first comparator) next to the + input of the top comparator. Complete with all pin numbers, including the power/ground pins on the comparator. (**DO THIS!** It sounds trivial, but it will help immensely when debugging. It will be the first thing I will ask to see if you need help debugging).

Laboratory

Breadboard the circuit. Use an external digitally-controlled voltage supply to mimic the behavior of V_{amp}. Record the actual vs. designed transition voltages. To connect the voltage comparator, note that only one power and ground connection is required to power all four comparators on the IC. LEDs and ICs are unipolar, meaning unlike resistors, the direction in which you connect them matters. The longer wire for the LED is the more positive, and ICs are oriented with the arc shape on the top; see the example below.

I strongly recommend you build this by sections, rather than doing the "Hail Mary" of building it all in one shot and hoping it works perfectly. Debugging is a lot harder than building, so debug small sections at a time. E.g. build and test the voltage divider resistors first. Then build and debug the LEDs and dropping resistors. Last, connect and test a single comparator (3 wires, plus the power/ground to the comparator chip). Then connect the rest of the comparators. I know most students will ignore this advice and build it all in one shot without checking it…sooner or later students will learn that it is faster to build slowly and check each module separately than the Hail Mary option.

When completed with data gathering, get checked off by the instructor by demonstrating your circuit's operation as you vary V_{amp}.
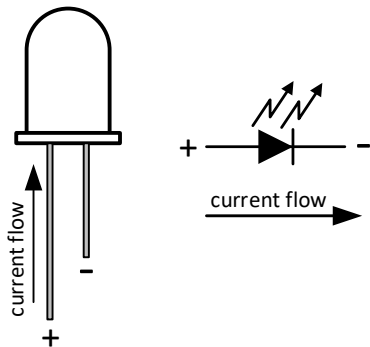
How to identify an LEDs polarity
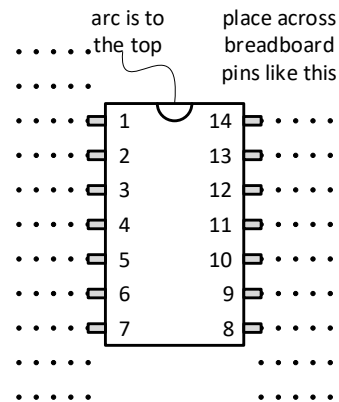
How to prototype with ICs and identify their pin numbers

LEDs and ICs require a particular orientation, unlike resistors.

Discussion Questions

1. Determine and **quantitatively** analyze potential sources of error. Qualitative analysis (e.g. "Most of the error comes from resistor tolerance") is for humanities courses. Engineering is quantitative (e.g. "Spice simulation reveals a worst-case scenario for 5% resistors (i.e., R1,3,5 at +5%, R2,4,6 at -5%) results in a +7.23% error. Moving all resistors in the same direction, i.e. +5%, results in a much smaller 0.452% error.")

(continued on next page)

2. With additional logic you could make this into an A/D converter to complement the D/A converter you built in an earlier lab. What is the name of the digital logic chip (multiplexer, demultiplexer, encoder, or decoder) you would use in place of the LEDs to make this into a 2 bit A/D converter?

3. Your lab partner accidentally hooked up the comparator inputs backwards (i.e. not the power or output leads but the inverting (-) and non-inverting (+) inputs). Describe how the circuit behaves.

4. How would you modify your design if marketing insisted that the design be changed to incorporate 12 LEDs in the display instead of 4? Use the same 12V battery as a source and assume the input voltage from the amplifier remains in the 0-4V range, and continue to use the same 1k resistors in the resistor divider (but now you will use 12 instead of 4 of them). Be **quantitative**. What values would the top resistor be (the one that used to be 8k)? What values would the LED dropping resistors be (would they change?)

N a t i o n a l   *S e m i c o n d u c t o r*

LM139/LM239/LM339/LM2901/LM3302 Low Power Low Offset Voltage Quad Comparators

General Description

The LM139 series consists of four independent precision voltage comparators with an offset voltage specification as low as 2 mV max for all four comparators. These were designed specifically to operate from a single power supply over a wide range of voltages. Operation from split power supplies is also possible and the low power supply current drain is independent of the magnitude of the power supply voltage. These comparators also have a unique characteristic in that the input common-mode voltage range includes ground, even though operated from a single power supply voltage.

Application areas include limit comparators, simple analog to digital converters; pulse, squarewave and time delay generators; wide range VCO; MOS clock timers; multivibrators and high voltage digital logic gates. The LM139 series was designed to directly interface with TTL and CMOS. When operated from both plus and minus power supplies, they will directly interface with MOS logic — where the low power drain of the LM339 is a distinct advantage over standard comparators.

Advantages

- High precision comparators
- Reduced V_{OS} drift over temperature
- Eliminates need for dual supplies
- Allows sensing near GND
- Compatible with all forms of logic
- Power drain suitable for battery operation

Features

- Wide supply voltage range
  — LM139/139A   2 to 36 VDC   or ±1 to ±18 VDC
  — LM2901:   2 to 36 VDC   or ±1 to ±18 VDC
  — LM3302:   2 to 28 VDC   or ±1 to ±14 VDC
- Very low supply current drain (0.8 mA) independent of supply voltage
- Low input biasing current: 25 nA
- Low input offset current: ±5nA
- Offset voltage: ±3mV n Input common-mode voltage range includes GND
- Differential input voltage range equal to the power
- supply voltage
- Low output saturation voltage: 250 mV at 4 mA
- Output voltage compatible with TTL, DTL, ECL, MOS and CMOS logic

Dual-In-Line Package

TOP VIEW