Introduction

Motivation

Lab

Part 0: Warm-up

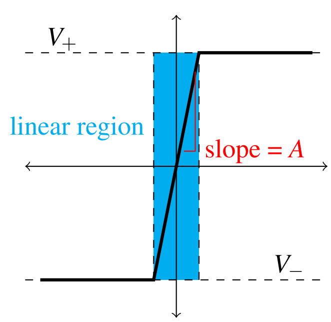
1. **Ideal op-amp review**

   Recall the characteristics of the ideal op-amp:

   - Infinite open-loop (i.e., not in feedback) voltage gain.
     This is vital for Golden Rule I. It allows the amplifier to instantly correct a voltage difference of any magnitude between the input terminals.
   - Infinite input impedance (the inputs act as ideal voltmeters)
   - Zero output impedance (the output acts like an ideal voltage source)
   - Infinite bandwidth
     This liberates the op-amp's performance from dependence on frequency.
   - Zero input offset voltage (i.e., for an input of 0V, the output will be exactly 0V)
   - **Open-loop performance:** The open-loop output voltage is given by

     $$V_o = A(V_+ - V_-),$$

     where A is the amplifier's open-loop gain.



And, recall the Golden Rules for an ideal op-amp in negative feedback:

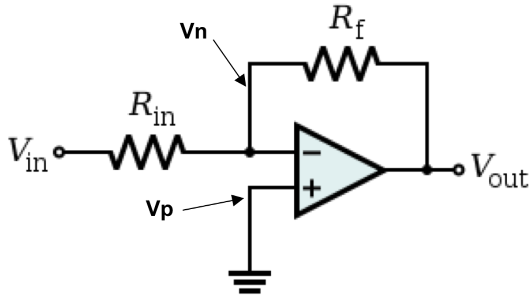
(i) $V_+ = V_-$: The output attempts to do whatever is necessary to make the voltage difference between the inputs zero.
This doesn't mean that the op-amp actually directly changes the voltage at its inputs: that would be both impossible and inconsistent with golden rule II. It simply "looks" at the inputs and moves the output so that the input voltage differential goes to zero.

(ii) $I_{in,+} = I_{in,-} = 0$: The inputs draw no current.

> Remember: the Golden Rules *only* apply when the op-amp is in negative feedback!

Negative feedback linearizes the amplifier's performance and allows the overall circuit to become less dependent on component imperfections. To investigate negative feedback further,

We can now use this model to investigate the first circuit you will build: the inverting amplifier.

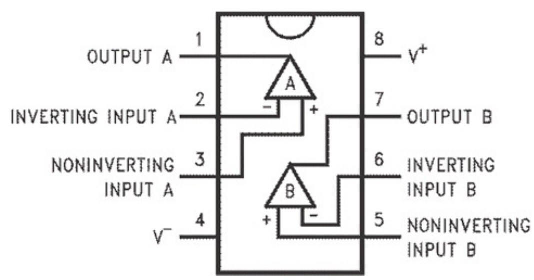


In negative feedback, $v_n = v_p$

Since v_p is grounded, $v_p = v_n = 0$

$$i_{in} = \frac{V_{in} - v_n}{R_{in}}$$
$$V_{out} = -R_f * i_{in}$$
$$V_{out} = -V_{in}\frac{R_f}{R_{in}}$$

2. **The physical op-amp**



This is a schematic for the type of op-amp chip we will be using in lab.
The most important thing to keep in mind about the physical op-amp is that **it has to be powered**, namely by a voltage through the V^+(also referred to as **VDD**) input pin, and another voltage through the V^-(also referred to as **VSS**) input pin as shown in the diagram above.
V^+ and V^- specify the range of voltages that the op-amp chip can output, where V^+ and V^- are the upper and lower bounds of that range, respectively.

Now you are ready to do the first part of the lab! Go to the jupyter notebook and complete parts 0 and 1.

Part 1: Digital Debugging

We will now investigate a 1-bit serial adder built using NAND gates and the MSP430. The NAND logic circuit is a half adder, just like the one you explored in HW0! We will use an XOR gate, built using four NAND gates, for the sum bit, and an AND gate for the carry. MSP430 will be used for the two binary inputs, and LEDs will be used for sum and carry bits. Let's get started!

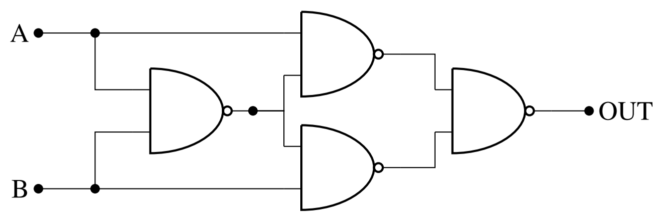
Consider this part of the lab a prelude to the work you will be doing in 61C and (if you choose to take it) 151. Note 1 and the prelab will be useful resources for you in this part of the lab.

1. **Digital logic review** To refresh what you saw in the lab homework problem/prelab problem, the logic gate summary table is reprinted here for your convenience:

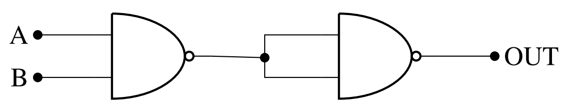
A	B	AND	OR	NAND	NOR	XOR	XNOR
0	0	0	0	1	1	0	1
0	1	0	1	1	0	1	0
1	0	0	1	1	0	1	0
1	1	1	1	0	0	0	1

2. Half adder from NAND Gates

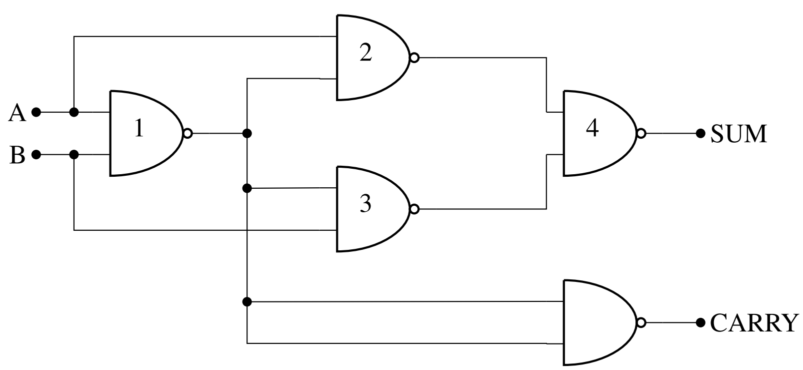
Recall from the prelab that an XOR gate can be constructed using NAND gates.



Similarly, an AND gate can be constructed using two NAND gates.



The XOR and AND gate can then be used to construct the complete half adder. The numbers on the NAND gates for XOR correspond to the schematic in the ipython notebook:



Now you are ready to do the second part of the lab! Go to the jupyter notebook and complete part 2

Part 2: Checkoff Requirements

- First take the checkoff quiz: http://tinyurl.com/debugLabQuiz
- Show your GSI both the input and output signals on your oscilloscope at the same time.
- Show your GSI your completed quiz.
- Show your GSI your order confirmation for your TI op-amps.
- Show your GSI your working, debugged half adder circuit and explain the bugs you caught.
- Return the adder circuit.
- Be prepared to answer some questions.