**Mid-term – Part 1 Written Section (Closed Book) – 60-minute time limit**

**Instructions:** Complete your answers in the space below (do not use back of paper).

**Student Name** \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ **Final Score** out of 50: \_\_\_\_\_\_\_\_

1. Fill in the blanks for the following – some blanks may be multi-worded ones **(10%)**
	1. A 10-bit analog-to-digital converter results in (raw) decimal values ranging from 0 to 1023
	2. Shannon’s sampling theorem puts a limit on the minimum sampling time
	3. Motors, relays and pneumatic valves are examples of actuators
	4. Pulse-width modulation is the ratio of times when a signal is on and off
	5. I2C is a low-speed, half-duplex data transfer between integrated circuits
	6. I2C has a 2-wire interface consisting of data and clock lines
	7. Bi-directional digital lines means that the lines can be used for both input and output
	8. Like relays, transistors can act as electronic switches
	9. H-bridges are circuits that use switches to reverse the direction of current
	10. MOSFETs are voltage-driven transistors
2. Convert the following numbers. Show relevant calculations **(10%)**
	1. 67 (from base 10 to base 2)

**Answer:** 1000011

* 1. 608 (from base 10 to base 3)

**Answer:** 211112

* 1. 16 (from base 10 to base 8)

**Answer:** 20

* 1. FF (from base 16 to base 10)

 **Answer:** 255

* 1. 1101 (from base 2 to base 3)

**Answer:** 111

1. What are the 2 rules and 5 properties of an ideal op-amp? Use the 2 rules to mathematically derive the input-output relationship of the op-amp below. This op-amp circuit converts what to what? **(10%)**



**Answer:**

Rule 1: Voltage at “+” and “-” terminals are equal

Rule 2: No current at “+” and “-” terminals



* Input impedance
* Output impedance



* Open-loop gain is





* Bandwidth is



* when

From Rule 1, we have that $V^{-}=V^{+}=GND$. From Rule 2 we have current into negative input must be 0. Hence $I\_{OUT1}-\frac{V\_{OUT}-V^{-}}{R\_{FB}}≡0$. Hence $V\_{OUT}=I\_{OUT1}∙R\_{FB}$. This is a current-to-voltage converter.

1. Sketch a non-inverting op-amp and mathematically derive its input-output relationship **(10%)**

**Answer:**

**Step 1:** Add labels to help make things clearer:



**Step 2:** Recall the 2 op-amp rules:

(1)

Rule 1: Voltage at “+” and “-” terminals are equal. Hence $v\_{α}=v\_{in}$

Rule 2: No current at “+” and “-” terminals. Hence, current at $β$ must be zero. Hence$-I\_{1}+I\_{2}≡0.$

Where we see that $-I\_{1}=\frac{v\_{α}}{R\_{1}}$ and $I\_{2}=\frac{v\_{out}-v\_{α}}{R\_{2}}$. Thus we have

(2)

$$-\frac{v\_{α}}{R\_{1}}+\frac{v\_{out}-v\_{α}}{R\_{2}}≡0$$

Substituting (1) into (2) we can rewrite (2) as

$$v\_{out}=v\_{in}+\frac{v\_{in}R\_{2}}{R\_{1}}=v\_{in}\left(1+\frac{R\_{2}}{R\_{1}}\right)=v\_{in}\left(\frac{R\_{1}+R\_{2}}{R\_{1}}\right)$$

Note that $\left(\frac{R\_{1}+R\_{2}}{R\_{1}}\right)>1$ always. Hence there’s amplification (but no inversion) i.e. **Non-inverting amplifier.**

1. Consider a 4-bit Digital-to-Analog Converter (DAC) **(10 points)**
	1. What is the resolution in volts if the reference voltage is +5V

**Answer:** Recall that have $2^{4}-1=15, $this means that can resolve reference voltage (5V) into 16 discrete values ($\frac{5}{16}=0.3125 V$).

* 1. List all the possible analog voltages this DAC can deliver for +5V reference voltage

**Answer:** 0; 0.3125; 0.625; 0.9375; 1.25; 1.875; 2.1875; 2.5; 2.8175; 3.125; 3.4375; 3.75; 4.02625; 4.375; 4.6875; 5

* 1. Suppose you want an analog voltage of precisely 0.625V. What should the decimal number for a reference voltage of +5V?

**Answer:** $\frac{V\_{ref}}{16}=\frac{V}{Word}$ so $Word=\frac{16∙V}{V\_{ref}}=\frac{16∙0.625}{5}=2$

* 1. For the decimal number calculated above, suppose you want an analog voltage of precisely 0.6V. What should reference voltage be?

**Answer:** $\frac{V\_{ref}}{16}=\frac{V}{Word}$ so, $V\_{ref}=\frac{16∙0.6}{2}=4.8 V$

* 1. What is the resolution in volts if one uses an 8-bit DAC and +5V reference voltage?

**Answer:** Have$2^{8}=256$, so $\frac{5}{256}=0.0195 V$