1. **(30 points) Count Flapula**[1]

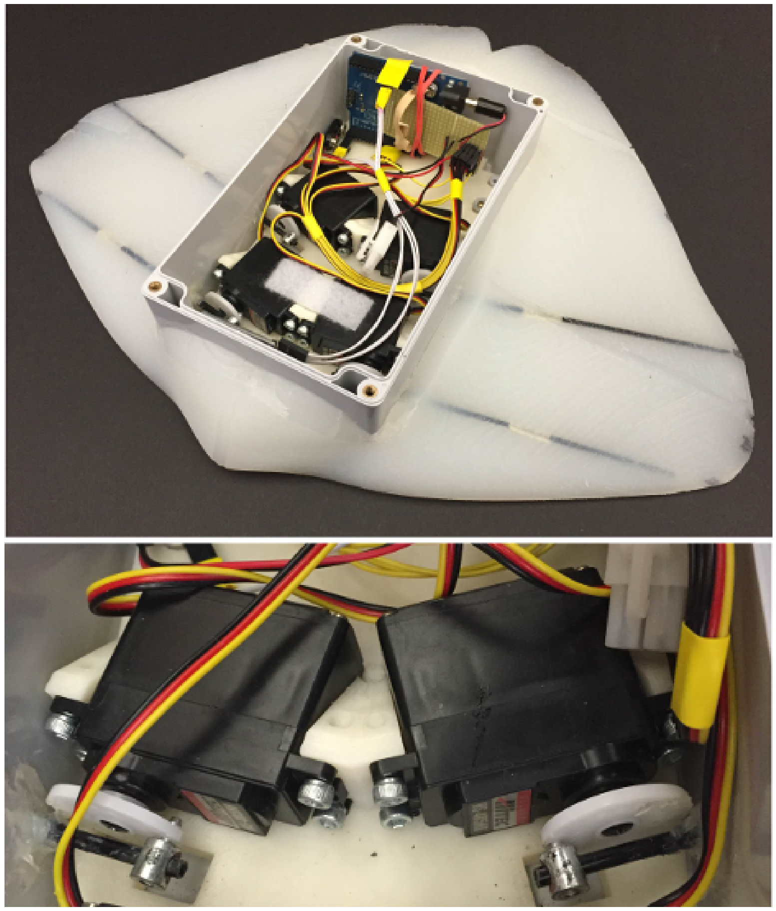

Figure 1: Count Flapula stingray-inspired robot. Top panel: The Count in all its glory, less the waterproof lid to show the actuation mechanism consisting of 4 motors that rotate carbon fiber rods. Bottom panel: Close up of the 2 rear motors showing electrical wiring. Battery power is connected via red and black wires.

Meet Count Flapula, the stingray-inspired underwater robot. This robot was designed by a student group during the winter 2015 offering of the Bioinspired Design course[2]. Full credit for the design goes to Lincoln Neely, Jack Gaiennie, and Nick Noble.

The main idea behind Count Flapula is that it propels itself like an actual stingray. Flapping of the fins is controlled by four total motors—two on each side. Check out Figure 1. The top panel shows the actuation mechanism. Each of 4 motors rotates a carbon fiber rod embedded in the fin made of cured silicone. The Nickel Metal Hydride (NiMH) battery pack used to power the power-hungry motors is not shown for clarity (It is normally seated on the strip of Velcro spanning the 2 motors toward the nose). An Arduino microcontroller mounted toward the tail-end of the waterproof chamber controls the rotational amplitude and speed of the motors to make the fins of Count Flapula flap like an actual stingray[3]. The Arduino

[1] Recommended sound track *Song of the Count* by Sesame Street: `https://www.youtube.com/watch?v=ZIniljT5lJI`

[2] This isn't a shameless plug for ENGN/BIOl 267, I swear :)

[3] Take Electronics (Engn/Phys 208) if you want to learn all about microcontrollers.

is powered by a completely separate 9V battery.

The bottom panel of Figure 1 shows a close up of the motors' electrical wiring. Three wires run to each motor: red and black are power wires connecting to the NiMH battery pack; and the yellow wire is the control signal wire (connected to the Arduino). The Count Flapula design team chose a 6V, 1600 mAh charge capacity rechargeable battery pack to power the motors[4]. The battery back is known to have an internal resistance $R_{in} = 0.32\ \Omega$. This means the battery is modeled as an ideal voltage source in series with R_{in}. The Count Flapula design team also smartly selected a motor[5] that properly functions when powered in a range between 4.8 - 6 V. All 4 motors need to be powered in this voltage range. The current draw for a single motor running at full speed and powered by a 6 V battery pack has previously been measured to be $i_{max} = 960$ mA.

(a) Draw a circuit diagram showing the battery pack connected to a *single* motor. Label battery pack's 6 V source V_b, and label its internal resistance R_{in}. Label the motor R_1.

(b) Compute the resistance of a motor running at full speed.

(c) Now draw another circuit diagram showing the battery pack connected to all 4 motors properly powered by the battery pack. As before, label battery pack's 6 V source V_b, and label its internal resistance R_{in}. Each of 4 motors should be labeled with subscripts R_1, R_2, R_3, and R_4, respectively.

(d) Compute the total equivalent resistance taking into account all 5 resistors in the circuit.

(e) Compute the voltage drop across each resistor, and compute the amount of current flow through each of them.

(f) For how long can Count Flapula swim with the motors running at the maximum speed? Assume the NiMH battery pack starts fully charged.

(g) Compute the ratio of total power consumed by the 4 motors to the amount of power lost due to internal resistance of the battery. Assume the motors are running at maximum speed—full speed ahead for Count Flapula (see Figure 2).

(h) At one point during development of the robot, Count Flapula's fins weren't flapping. A quick diagnostic was to measure the voltage across each motor, which turned out to be $\approx$1.5 V. Suggest a likely scenario for how the system was wired incorrectly. Draw any circuit diagrams and show relevant calculations to support your claim.

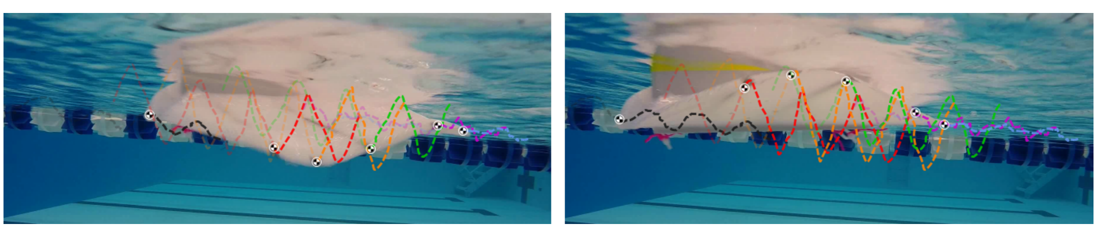

Figure 2: Count Flapula swimming in the W&L pool. The fin deformation profile is tracked over time. Left and right panels show fin at end of successive upstroke and downstroke, respectively. A maximum forward velocity of 10 cm/s flapping at 2 fin beats/sec was achieved.

[4]NiMH battery: `http://www.robotshop.com/en/6v-1600mah-rechargeable-nimh-battery.html`
[5]Hi-Tec motor: `http://www.robotshop.com/en/hitec-hs-485hb-servo-motor.html`

2. **(30 points) Pump up the Jam—Volume Control**[6] One of your friends has a broken stereo system. Bummer. On the upside, your friend knows that you are in Circuits this term, so they have a sneaking suspicion you can help them fix the broken stereo...and pump up the jam once again. After poking around a bit with your handy-dandy multimeter, you discover the issue is a malfunctioning volume knob. Upon further inspection of the volume control circuitry, you are able to jot down the following circuit diagram revealing the inner workings of the volume setting (see Figure 3). R_2 is a 100 kΩ pot that is controlled by turning the volume knob. The position of the pot's middle contact (aka "wiper") is described by α, which can be varied continuously as the volume knob is turned. As indicated on the diagram, $\alpha = 1$ if the pot's wiper is "at the top" of R_2, and $\alpha = 0$ if it is "at the bottom."

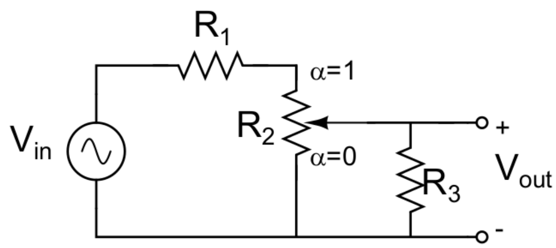

Figure 3: Volume control for stereo amplifier. $R_1 = 4.7$ kΩ. $R_3 = 15$ kΩ. $R_2 = 100$ kΩ pot.

(a) Provide an intuitive explanation which way the pot should be turned for maximum volume. You can safely assume that higher output voltage equates with higher volume.

(b) Generate an expression for V_{out}/V_{in} in terms of α, R_1, R_2, and R_3.

(c) Plot your result for $\log_{10}(V_{out}/V_{in})$ vs α for values of α = 0, 0.2, 0.4, 0.6, 0,8, and 1.0. Preferably, use a software package such as Excel. The reason for plotting the log: Our ears and brains actually function on a logarithmic scale. Every power of 10 increase in sound pressure corresponds to equal increments in perceived loudness. Sound pressure output from the speakers linearly related to the voltage driving the audio amp/speakers. Hence, you should hopefully see a quasi-linear plot, indicating that equal rotation increments on the knob correspond to equal increments in sound level, a very nice user feature.

(d) You think you've got the stereo ready to go, but make a few more careful measurements to make sure everything is working as planned. So you fire up the oscilloscope down in lab and want to measure $V_{out} = V_+ - V_-$. On which terminal would you place the oscilloscope's ground lead?

(e) Extra credit! (3 points). All this talk of audio...help your instructor get current with new songs on the Circuits morning play list. List up to 3 songs and describe their (tangential) relevance to Circuits.

[6] Recommended sound track: *Pump Up The Jam* by Techtronic: `https://www.youtube.com/watch?v=9EcjWd-O4jI`

3. **(40 points) Blame it on the Rain–Design Problem**[7]

All of us have driven through a rain storm and had to utilize the wind-shield wipers (at least I'd bet big a big bag of chocolates on that!). And we've probably all had the luxury of using wipers with an adjustable speed setting—if it is drizzling, you want them on low; if it is pouring buckets, you want them on high.

Imagine you are driving in a rainstorm up I-81 when all of the sudden your windshield wipers suddenly cease to function. That's a real drag because you've got to make it to lunch with a friend in an hour, and the rain is forecast to keep coming all day. (And don't pin your hopes on AAA road side assistance showing up anytime soon.) So, you've got to fix those wipers ASAP.

Figure 4: Driving in a driving rain: A good pair of windshield wipers is invaluable.

Luckily, you just happen to have a grab-bag of electrical components in the back seat.[8] You rummage through the bag and find a huge quantity of resistors of all values and power ratings. Similarly, there is a great selection of potentiometers of all values and power ratings. In the bag you also find a couple of small motors that can be used to rotate the blades. *A single motor can only turn a single wiper blade.*

OK, so here's the design problem: You need to rig up a circuit that uses the motors (which act like 200 Ω resistors) to turn the wiper blades. Both blades must run simultaneously, and at the same speed. You also need to be able to control the speed of the motors to run anywhere between 0.2–2 cycles/second. These are the lowest and highest settings, respectively, but you need to be able to *achieve any arbitrary value within this range.* You see printed on the side of the motors that 0.2 cycles/second requires a current flow of 5 mA; and 2 cycles/second requires a current flow of 50 mA.

To power the motors, you have access to your car's 18 V battery. Note that the battery is connected in series with a 50 Ω fuse. So, the two terminals of the car's power supply to which you have access are the (-) terminal of the battery and the side of the fuse not connected directly to the battery.

[7] Recommended sound track: *Blame it on the Ran* by Milli Vanilli: `https://www.youtube.com/watch?v=BI5IA8assfk`

[8] I mean, who doesn't have that in a random bag of electrical goodies in the back seat...not to mention some food wrappers, a few empty water bottles, maybe some old socks, melted crayons....I've said too much...back to the main event.

Devise a circuit to operate the wind shield wipers using the parts available in the car. A minimal number of components is highly preferable because the circuit will take a shorter amount of time to construct. Specify the value for all components used. Also, specify the necessary minimum power rating to make sure you don't accidentally start an electrical fire.

For your solution to receive full credit, please be sure to:

- Clearly diagram your circuit, clearly indicating the motors, battery, fuse, and any other components.
- Clearly show all relevant calculations you used to determine component values and power ratings.
- Write a brief description of your design rationale and theory of operation (about 5 sentences should be sufficient).