**Circuits Engn/Phys 207: Exam 2 Style Problems 12 weeks boiled down to a set quick problems** December 7, 2022Below are some 'quick' no tricks, no frills problems that emphasize big concepts over heavy computations. The prompts highlight the real-world importance and implementation of Circuits; these relatively long preludes perhaps belie the simplicity of the underlying problems. Without further ado, let's get solving!

1. **Resistance is Futile**: Which of the following resistor networks (top or bottom) in Figure 1 has a lower equivalent resistance? Briefly justify answer with 1 sentence.

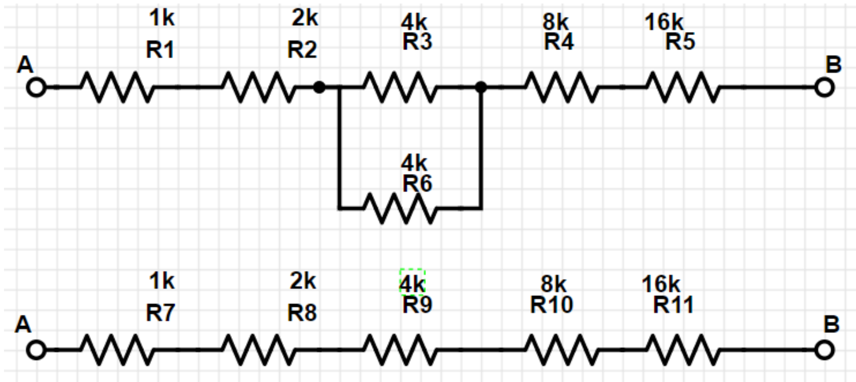


Figure 1: Two resistor networks for your consideration.

2. **Pic-n-Choose**: You're in lab working on a final project. To test the behavior of your circuit, you are sweeping through frequencies ranging from 1 Hz to 10 kHz. Let's assume your wave generator is set to output a wave that is 100 mV amplitude and a frequency of 10 Hz. In order to clearly see multiple oscillation cycles of the input wave on the picoscope display, what would be a suitable settings (values selected) for the voltage and time axes (e.g. see Figure 2)? Order of magnitude answer are plenty fine here.

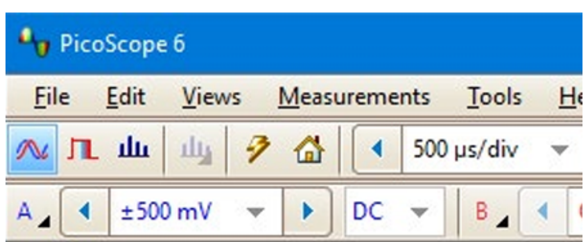


Figure 2: Picoscope Settings for vertical and horizontal display scales

3. **Up, Over, and Down**:Figure 3 shows the magnitude response of the Intan RHD2000 amplifier. They write in their product sheet: "Innovative circuit architecture combines amplifiers, analog and digital filters, a multiplexed 16-bit analog-to-digital converter (ADC)."

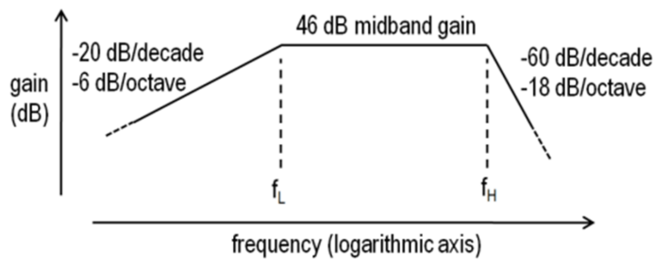


Figure 3: Intan RHD 2000 series amplifier specification.

(a) What is the ratio expected ratio of $|\frac{Vout}{Vin}|$ in the passband?

(b) What type of filters must they use, given the slopes of the cutoff regions illustrated.

(c) How many different discrete levels (values) can the ADC output?

4. **R-2R Ladder**: A digital to analog converter (DAC) turns bits and bytes back into analog-like waveforms. For example, when you play back an digital music file, the computer takes successive chunk of 0s and 1s (bytes) and very quickly turns them into an analog looking waveform that is literally music to our ears. Featured below (Figure 4) is the classic R-2R ladder configuration which is commonly found in DACs. (A 4 bit example is illustrated for simplicity; real world systems typically use in 8, 16, or 24 bits). For now, were just going to use this as motivation to look at equivalent resistance.

   Given that R = 8 kΩ, what is the equivalent resistance between node b and ground?

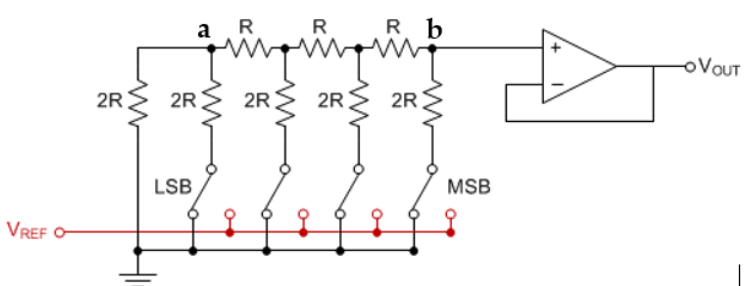


Figure 4: R-2R ladder in a 4-bit DAC. All bits are set to digital 0 = ground. Image credit: Texas Instruments

5. **Better Living Through Chemistry**

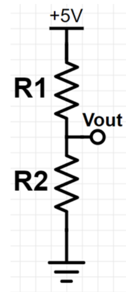


Figure 5: The simplest sensing circuit.

A new chemical sensor has been developed for environmental monitoring applications of volatile organic compounds (VOCs). $R1$ is a plain old resistor (5 kΩ), and $R2$ represents the new chemical sensor whose baseline resistance is 5.0 kΩ. (VOC concentration of 0). Based on R&D testing the new chemical sensor will increase in resistance up to a maximum value of 5.1 kΩ.

(a) For remote deployment a battery must be used. The battery must power the circuit for at least 3 months (90 days) continuously. Compute the minimum charge capacity of the battery that would meet this requirement?

(b) A microcontroller will be used to make analog readings as follows: `int myReading = analogRead(A0);` What value do you expect this to return in baseline conditions? Assume the microcontroller has a 10-bit ADC on board.

(c) What is the expected dynamic range of the circuit above (no VOC vs maximum concentration)?

(d) Is there any addition or modification you would suggest? If so, sketch your proposed circuit and briefly justify in 1-2 sentences.

6. **Ear Worm**: Figure 6 shows a (partial) circuit diagram of a novel system to monitor vital signs, including the ECG (heartbeat waveform) using an outer ear implant.

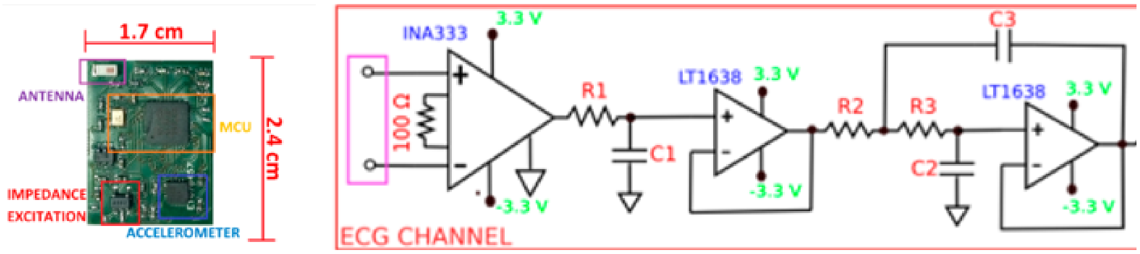


Figure 6: ECG measurement circuitry. Image adapted from: Gil et al, Sensors, 2019: `https://www.mdpi.com/1424-8220/19/7/1616/htm`

(a) What is the voltage gain of the INA333 set for? The datasheet is found by googling it or clicking hereto get it from TI's website. The voltage gain formula may look very familiar to you!

(b) The authors write $R_1 C_1$ forms a low pass filter set for a cutoff frequency of 20 Hz. By imposing dimensioning on the power line, the capacitor value C1 was chosen to be 4.7 $\mu$F. Therefore, what is the value of $R_1$ they should choose?

7. **Home town favorite**: The world-famous WLUR broadcasts at 91.5 MHz on the FM dial. Which of the LC resonators shown in Figure 7 would be suitable for tuning into WLUR? If neither seems suitable, suggest a value for the inductor $L$ which would set the resonance frequency to 91.5 MHz. Briefly justify answer with one equation or sentence.

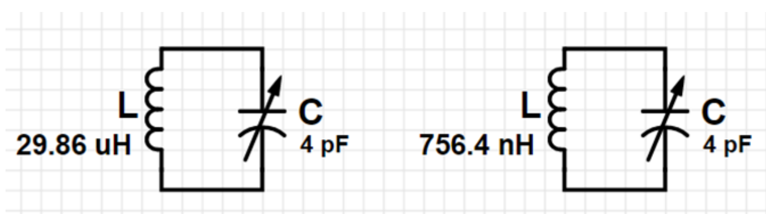


Figure 7: LC resonators

8. **Cell Plan** Figure 8 shows a simple circuit model of a biological cell. The capacitors $Cm$ model the membrane lipid bilayer. The resistor $Rs$ models the resistance of saline inside of the (very small volume) cellular compartment. Such circuit models are commonly used to analyze nerve stimulation, cancer cell dynamics, and more.

   With that background, imagine you connect a wave generator between nodes $a$ and $b$ and input a sine wave $v_{in}(t) = A\sin(2\pi ft)$. At what frequency $f$ (units of Hz) will the amplitude of the voltage drop be equal across all 3 components, i.e., $|\tilde{V}_{Cm}| = |\tilde{V}_{Rs}|$?

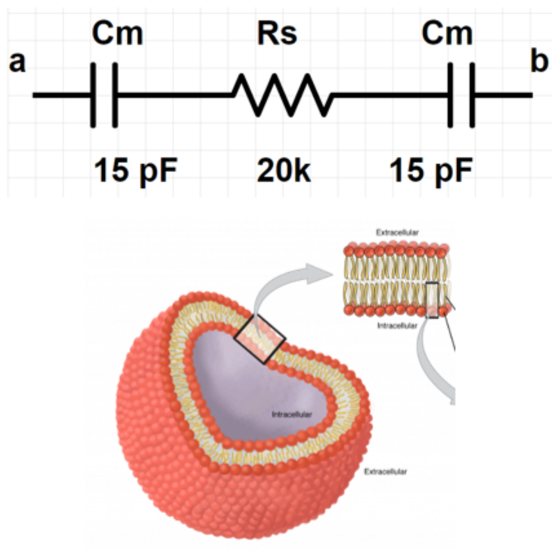


Figure 8: Circuit model of a biological cell.