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ECE 118

13 April 2024

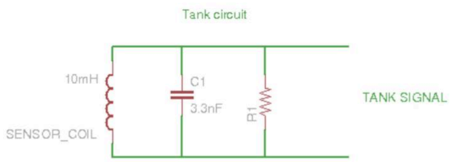
Lab 1 - Signal Conditioning and Filtering

1. Resistor color codes
    a. red red red: 2.2 kΩ
    b. brown black red: 1 kΩ
    c. yellow violet orange: 47 kΩ
    d. brown black green: 1 MΩ
    e. brown black black: 10 Ω
    f. green black yellow: 500 kΩ
2. You should never insert the o'scope probe tips into the proto-board holes.

Part 1 - Circuit Module Basics

1. Tank Circuit

   The resonant frequency of the oscillator should be close to 25 kHz and based on calculations it would be 27.7 kHz. The quality factor would depend on R_1 and would be $R(0.574 * 10^{-3})$. If R_1 is 1kΩ, the quality factor is 0.574 and if R_1 is 10kΩ then the quality factor would be 5.74.



Admittance $Y = \frac{1}{Z} = \sqrt{G^2 + B^2}$

Conductance $G = \frac{1}{R}$

Inductive Susc. $B_L = 1/(2\pi f L)$

Capacative Susc. $B_c = 2\pi f C$

$= X_c \rightarrow V_L = -V_c$

$X_L = X_c \rightarrow 2\pi f_0 L = \frac{1}{2\pi f_0 C}$

$2\pi f_0 = j\omega_0 \qquad j\omega_0 L = \frac{1}{j\omega C}$

$= G + B_L + B_c$

$= \frac{1}{R} + \frac{1}{2\pi f_0 L} + 2\pi f_0 C$

$4\pi^2 f_0^2 LC = 1$

$f_0^2 = \frac{1}{4\pi^2 LC}$

$f_0 = \sqrt{\frac{1}{4\pi^2 LC}} = \boxed{\frac{1}{2\pi\sqrt{LC}} \text{ Hz}}$

$\omega_0 = \boxed{\frac{1}{\sqrt{LC}} \text{ rad}}$

if $L = 10\text{mH}$, $C = 3.3\text{nF}$

$f = \frac{1}{2\pi\sqrt{(10\text{mH})(3.3\text{nF})}} = 27.7 \text{ KHz}$

$Q = \frac{R}{2\pi f L} = 2\pi f C R = R\sqrt{\frac{C}{L}} = R(5.7\text{m})$

for $1\text{K}\Omega$ $Q = 10^3(0.57 \times 10^{-3}) = 0.5744$

for $10\text{K}\Omega$ $Q = 10^4(0.57 \times 10^{-3}) = 5.744$

2. Split Rail Buffer

The expected output of the buffered rail is 1.65 V. We can assume that we can draw around 30 mA of current although in an ideal op-amp we could draw infinite current.. This is based on the lab documentation for the MCP6004 where the output short-circuit current is about ± 30mA. The output would need to be injected into the negative input of the op-amp and to the next portion of the circuit which would be the non-inverting amplifier in the positive terminal.

3. Non-inverting Amplifier

With a required gain of 2, the resistor values can be calculated. Based on the equation, the resistors have to be of the same value. A good option could be 1kΩ or 10kΩ. The input expected input trace would be an amplified signal as shown below.

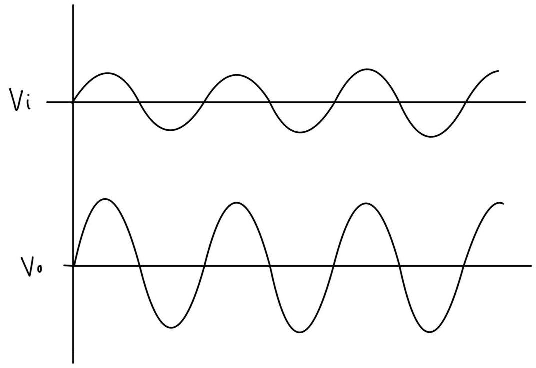
$$\text{Gain} = 2$$

$$\frac{V_{out}}{V_{in}} = 1 + \frac{R_2}{R_1}$$

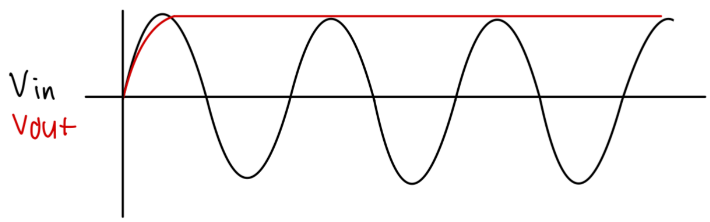
$$2 = 1 + \frac{R_2}{R_1}$$

$$1 = \frac{R_2}{R_1}$$

$$R_2 = R_1$$



4. Peak Detector



The RC time constant can be chosen based on this period assuming that the frequency remains at the desired 25 kHz. This would make $\tau = RC > 36\mu s$. Based on availability of resistors and capacitors we could use are $R = 47k\Omega$, and $C = 1nF$ to achieve this which would result in $\tau = RC = (47kHz)(1nF) = 47\mu s$ which is greater than our target.

5. Comparator with Hysteresis

Based on Appendix A, two resistors are given, $R_4 = 3.9k\Omega$ and $R_3 = 1M\Omega$. If the low threshold is 1.0V and the high threshold is 1.8V, then the calculated resistors are as follows:

$$\Delta V = V_{a1} - V_{a2} = 1.8V - 1.0V = 0.8V$$

$$n = \Delta V/V_{a2} = 0.8V/1.0V = 0.8$$

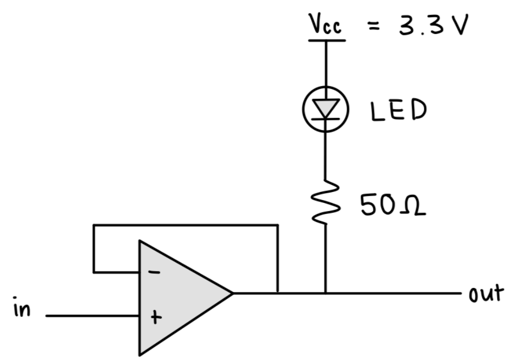
$$R_1 = n \times R_3 = 0.8 \times 1M\Omega = 800\ k\Omega$$

$$R_2 = (R_1||R_3)/(V_{cc}/V_{a1} - 1) = (\frac{1}{\frac{1}{R_1}+\frac{1}{R_3}})/(V_{cc}/V_{a1} - 1) = (\frac{1}{\frac{1}{800k\Omega}+\frac{1}{1M\Omega}})/(3.3V/1.8V - 1)$$

$$R_2 = (444.4k\Omega)/(0.83) = 533.3k\Omega$$

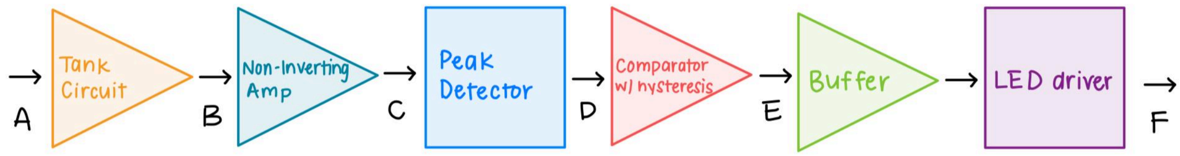
The resulting values for the resistors are $R_1 = 800\ k\Omega$, $R_2 = 533.3\ k\Omega$, $R_3 = 1\ M\Omega$ and $R_4 = 3.9\ k\Omega$.

6. LED and Buffer



Since the circuit is set up to have the LED active low, at 0V the LED will turn on and at 3.3V the LED will be off. Based on the circuit configuration and Ohm's Law, the current drawn by the LED will be $i_{LED} = \frac{3.3V}{(50\Omega+R_{LED})}$. The circuit above does not have a buffer capacitor on the op-amp which should be added and would be around 0.1µF.

Part 2 - Track Wire Detection



The diagram above illustrates the input and output of each stage.

For the <u>tank circuit</u> the input (Stage A) would be the oscillating electromagnetic field from the track wire . The expected output (Stage B) would be an oscillating sinusoidal wave with a frequency of 25 kHz.

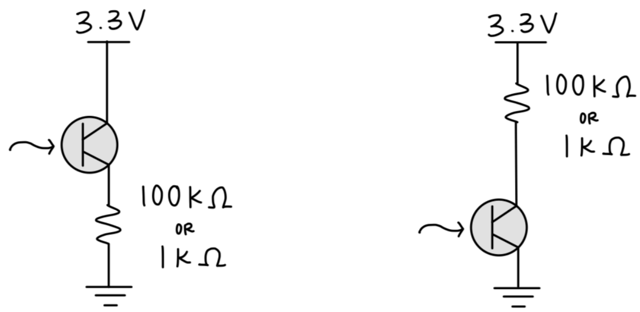
The input of the <u>non-inverting amplifier</u> (Stage B) would come from the tank circuit as an oscillating signal. The expected (Stage C) output would be an amplified oscillating sinusoidal wave within a useful voltage range.

The input of the <u>peak detector</u> (Stage C) will come from the non-inverting amplifier and the output (Stage D) should be something with DC content. When the track wire is sensed it should be high and low in its absence.

The input of the <u>comparator</u> (Stage D) will be the output of the peak detector. The output (Stage E) will be an improved high/low snap and with the hysteresis it will improve the noise in the signal.

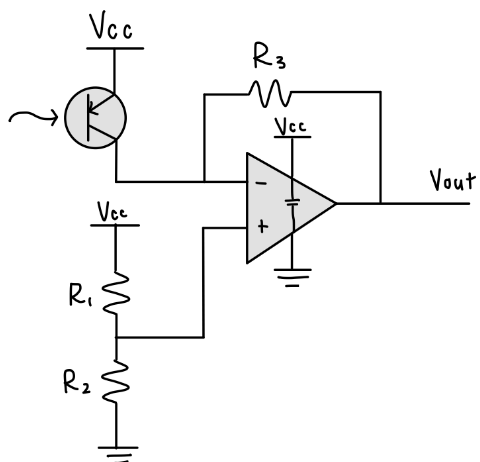
The input of the <u>buffer/LED driver</u> (Stage E) will be the output of the comparator. The output (Stage F) will be the same as the previous stage, the comparator, but can be fed into the microcontroller as a digital signal. In this stage the LED can also be used to visualize the high and low of the signal.

Part 3 - PhotoTransistor and TransResistive Amplification



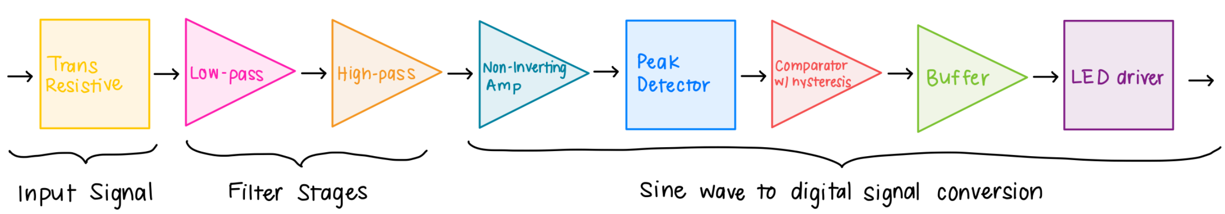
(a) Sourcing Configuration (b) Sinking Configuration

For this part, we will use a phototransistor in a sinking and sourcing configuration.

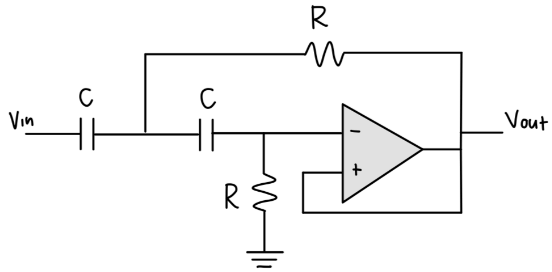


We will also need a transresistive op-amp. With a gain of 1V/mA we can determine the resistor, R_3 to be $\frac{1V}{1mA} = 1k\Omega$. There would also be a capacitor across the op-amp of 0.1µF. The other resistors from the voltage divider can serve as a voltage reference.

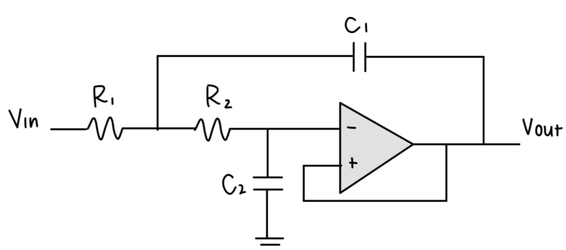
Part 4 - Beacon Detector



The block diagram for the circuit beacon detector is illustrated above with all the components that would be included.



For the high pass filter we could use a second order Sallen-Key high pass filter with equal resistors and equal capacitors. The cutoff frequency for this filter is modeled by $f_0 = \frac{1}{2\pi\sqrt{R_1C_1R_2C_2}}$. The closest cutoff frequency for this would be using resistors of 11kΩ and capacitors of 0.01μF. This would result in a cutoff frequency of 1446.86 Hz or 1.45 kHz which is close to our desired frequency. Unfortunately, the resistors are not a common value found in the lab, therefore using 10kΩ resistors would be more feasible. This would result in a cutoff frequency of 1591.54 Hz or 1.59 kHz. Another ideal choice would be using 6.8 kΩ resistors which are available in our kits. This would result in a cutoff frequency of 2340.51 Hz or 2.34 kHz.



For the low pass filter we could use a second order Sallen-Key low pass filter. The cutoff frequency is modeled by $f_0 = \frac{1}{2\pi\sqrt{R_1C_1R_2C_2}}$. The closest cutoff frequency using the available resistors and capacitors is 2579.12 Hz or 2.58 kHz which is slightly higher than our desired frequency. This would be using R_1 = 6.8 kHz, R_2 = 5.6 kHz, C_1 = C_2 = 0.01μF. Since this cutoff frequency is higher than our desired, changing the resistor R_2 to 6.8 kHz just as R_1 would lower the cutoff frequency to 2340.51 Hz or 2.34 kHz.

The full schematic of the circuit we intend to build to do the actual filtering to detect the beacon is shown below. Each part has a different color corresponding to the block diagram and is also labeled. Some values are already known but are not displayed for clarity.