EE 322 Advanced Analog Electronics, Spring 2008
Test 2, March 19, 2008
Solutions

555 timer

1. **Draw a typical 555 timer-based oscillator circuit.**

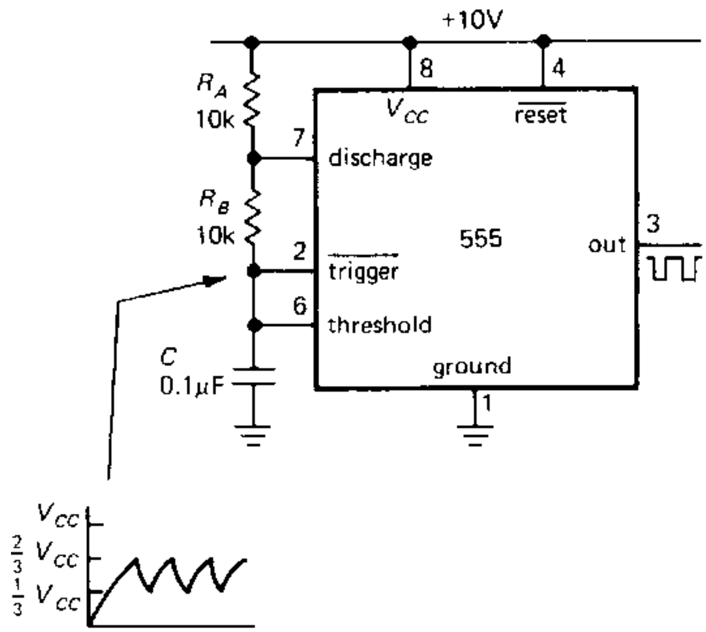


Figure 5.33. The 555 connected as an oscillator.

2. **Carefully sketch the voltages on trigger, threshold, discharge, and output pins as a function of time, for the circuit you drew, aligning the individual traces in time and indicating voltages.**

   The trigger and threshold pins always show the same thing. While the circuit is discharging, the voltage on the gate of the discharge transistor is low so the output is high. During that time the voltage on the trigger/threshold rises exponentially, and the voltage on the discharge rises also. As the trigger/threshold reaches 2/3, the output flips: the discharge transistor gate goes high and the output goes low. Trigger and threshold discharge until the reach 1/3.

3. **Using a 555 design a oscillator with a 90% duty cycle and a oscillation frequency $f = 1\,\mathrm{kHz}$.**

   I will use the design from H&H Figure 5.33 also shown above. In that case, the period is

$$T = \frac{1}{f} = 0.693\,(R_A + 2R_B)\,C$$

I will choose $C = 0.1\,\mu\text{F}$, so that

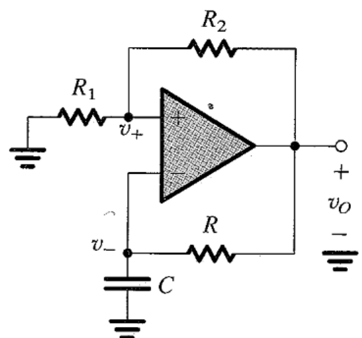
$$R_A + 2R_B = \frac{1}{0.693 f C} = \frac{1}{0.693 \times 1 \times 10^3 \times 0.1 \times 10^{-6}} = 14.4\,\text{k}\Omega$$

The duty cycle is $\frac{R_A+R_B}{R_A+2R_B} = 90\%$, or $R_A = 8R_B$. We then get

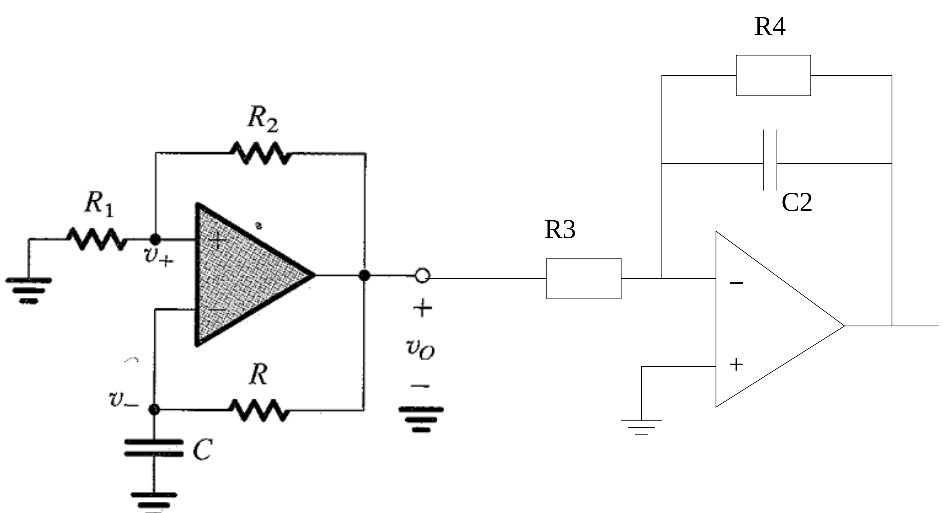
$$R_B = \frac{1}{10} \times 14.4\,\text{k}\Omega = 1.44\,\text{k}\Omega \qquad R_A = \frac{4}{5} \times 14.4\,\text{k}\Omega = 11.5\,\text{k}\Omega$$

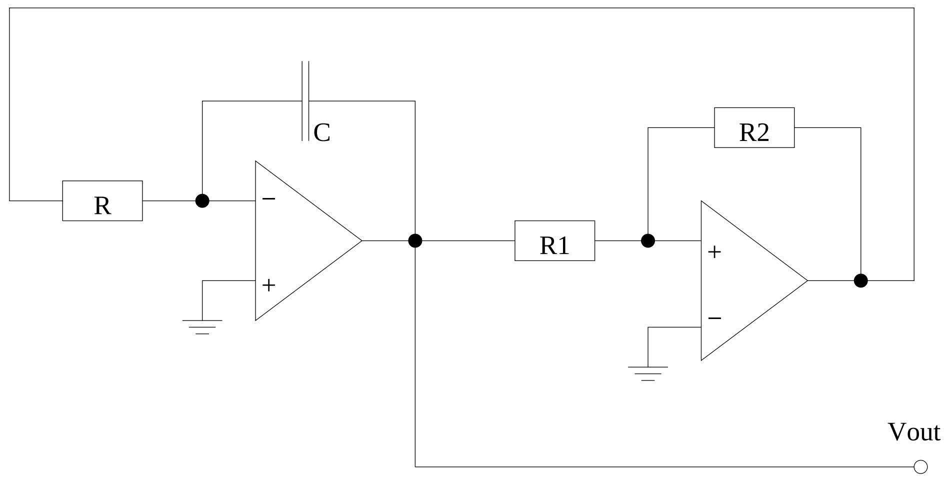
Multivibrator

4. **Draw a op-amp based multivibrator which produces a square wave.**



5. **Add to/modify the circuit to make it a triangular wave multivibrator.**





6. **Choose components and supply voltages such that the triangular wave has a frequency of 1 kHz, and amplitude of your choice. State any assumptions you make.**

First I am going to assume supply voltage of $\pm 15\,\mathrm{V}$ on both op-amps. Next I will choose $R_1 = 10\,\mathrm{k}\Omega$ and $R_2 = 20\,\mathrm{k}\Omega$. In this situation, the positive input on the second op-amp will be at zero when the output on the first op-amp is half of the output on the second op-amp. I am going to assume that the second op-amp outputs either $+15\,\mathrm{V}$ or $-15\,\mathrm{V}$. The output on the first op-amp is also given by

$$V_{\mathrm{out}} = -\frac{1}{RC}\int V_{\mathrm{in}} dt$$

Thus, when the output on the second op amp is V_{in}, the output on the first op-amp will be

$$V_{\mathrm{out}} = -\frac{V_{\mathrm{in}}}{RC}t + V_{\mathrm{out,initial}}$$

The first op-amp integrates from $-15/2\,\mathrm{V}$ to $+15/2\,\mathrm{V}$ in one half period, so

$$V_{\mathrm{out}} - V_{\mathrm{out,initial}} = 15 = \frac{15}{RC}\frac{T}{2}$$

so that

$$RC = \frac{T}{2}$$

I will choose $R = 10\,\mathrm{k}\Omega$, which makes

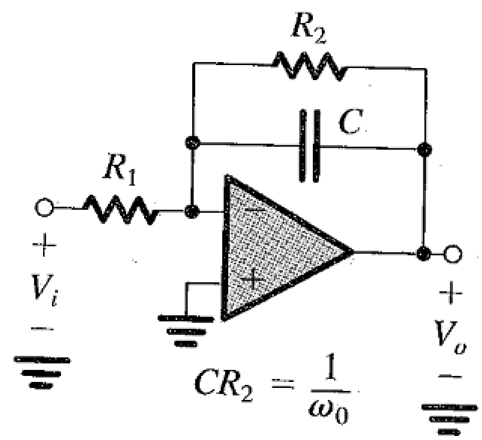
$$C = \frac{T}{2R} = \frac{0.5 \times 10^{-3}}{2 \times 10 \times 10^{3}} = 25\,\mathrm{nF}$$

Filter

In a recent homework you designed a bandpass filter by cascading a low- and a high-pass filter. We can build a band-reject filter by combining a low- and high-pass filter in parallel instead of in series.

7. **Design a op-amp based low-pass filter which has a low-frequency input impedance of $100\,\mathrm{k}\Omega$, low frequency gain of 1, and a critical frequency of $1\,$kHz.**

   The op-amp based LP filter looks like this



   We want a LF input impedance of $100\,\mathrm{k}\Omega$. Thus, $R_1 = 100\,\mathrm{k}\Omega$. We also want a LF gain of 1. Since the LF gain is $-\frac{R_2}{R_1}$, we get $R_2 = 100\,\mathrm{k}\Omega$. Finally, we want the critical frequency to $1\,$kHz. Thus

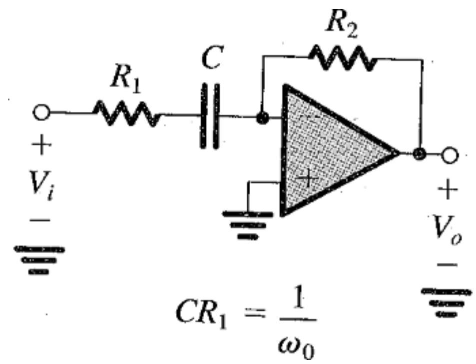
$$2\pi f_0 = \omega_0 = \frac{1}{CR_2}$$

   which gives us

$$C = \frac{1}{2\pi f_0 R_2} = \frac{1}{2\pi \times 1 \times 10^3 \times 100 \times 10^3} = 1.6\,\mathrm{nF}$$

8. **Design a op-amp based high-pass filter which has a high-frequency input impedance of $100\,\mathrm{k}\Omega$, a high-frequency gain of 1, and a critical frequency of $10\,$kHz.**

   The op-amp based HP filter looks like this

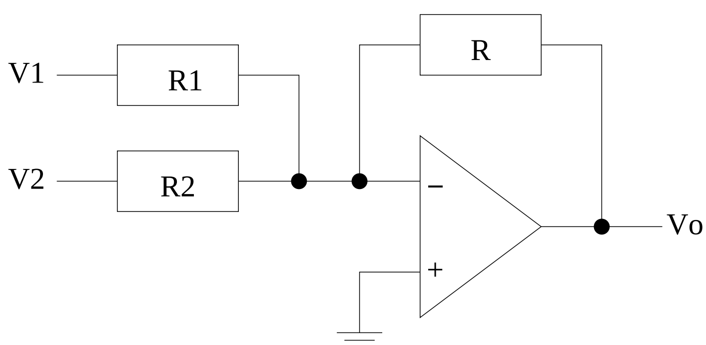


We want the HP input impedance to be 100 kΩ. Thus, $R_1 = 100\,\mathrm{k\Omega}$. We also want the HP gain to be 1. Since the HP gain is $-\frac{R_2}{R_1}$, we get $R_2 = 100\,\mathrm{k\Omega}$. We also want the critical frequency to be 10 kHz,

$$C = \frac{1}{2\pi f_0 R_1} = \frac{1}{2\pi \times 10 \times 10^3 \times 100 \times 10^3} = 159\,\mathrm{pF}$$

9. **Using these two circuits design a band-reject filter by using a summing op-amp circuit. The band-reject filter should have gain-amplitude 1 outside the band (a phase shift is OK, but it is better if you can add a little more circuitry to eliminate a phase-shift outside the band).**

   We need a inverting summing coupling. It looks like this.



Writing the node equation at the inverting input

$$\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_o}{R} = 0$$

we get

$$V_o = -R\left(\frac{V_1}{R_1} + \frac{V_2}{R_2}\right)$$

At low frequencies (where $V_2 \approx 0$) we want $V_o = -V_1$, so $R_1 = R$, and at high frequencies (where $V_1 \approx 0$) we want $V_0 = -V_2$, so we conclude that $R_1 = R_2 = R$. A reasonable value might be $100\,\mathrm{k\Omega}$.