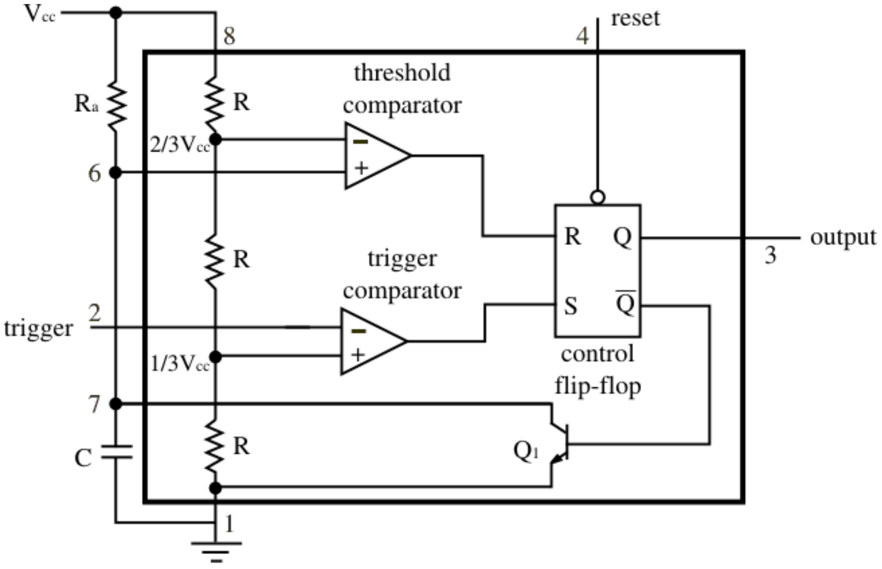
EE 322 Analog Electronics, Spring 2011
Exam 2 April 5, 2011

Rules: This is a closed book test. You may use a single page of Letter size paper which you have prepared ahead of the exam. The exam will last 50 minutes and each numbered question counts equally toward your grade.

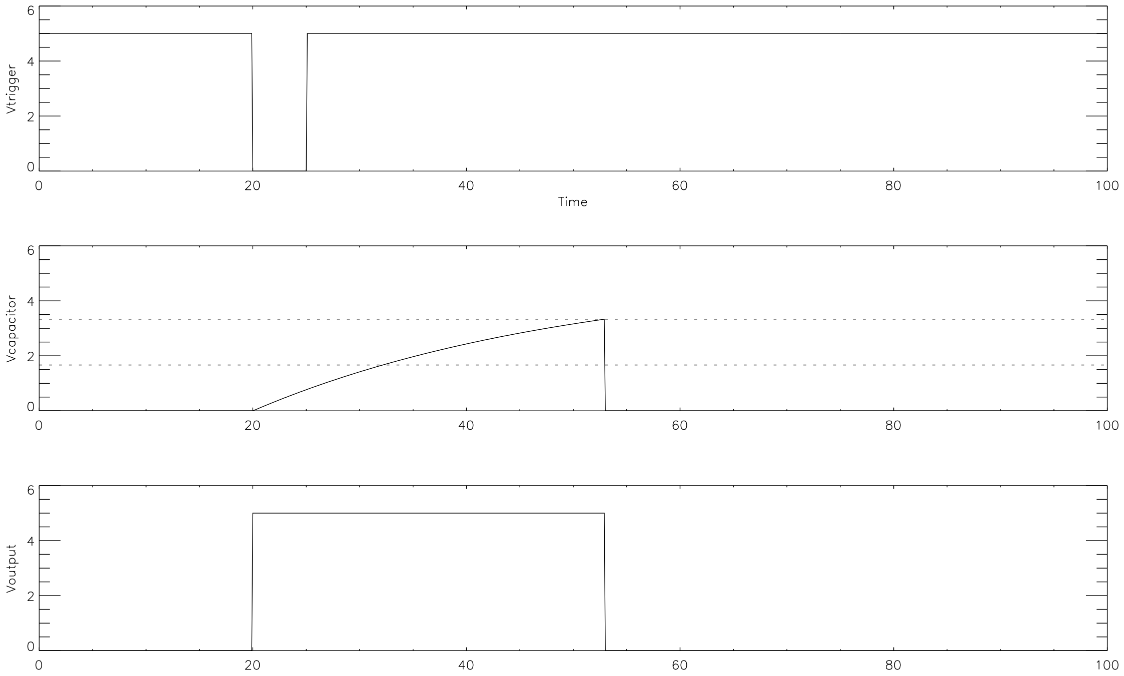
Monostable Multivibrator
Consider the following monostable multivibrator constructed from a 555 timer.



1. **Explain in words how it functions. Where is the input, where is the output, and what is the sequence of events to create a pulse?**

   When the capacitor voltage exceeds $\frac{2}{3}V_{CC}$ the output goes low and the transistor discharges the capacitor rapidly. When the capacitor is discharged the system is in a stable state assuming that the trigger line voltage is greater than $\frac{1}{3}V_{CC}$. When the trigger line is pulled below that voltage the output goes high and the transistor switches off. As the capacitor charges the trigger line is brought back to high. The capacitor charges until it reaches $\frac{2}{3}V_{CC}$ at which time the output goes low and the capacitor discharges rapidly. It stays in that state until the next trigger pulse.

2. **Plot the voltages at points 2, 7, and 3 on the same axis when a pulse is created (plot the whole cycle before, during, and after the pulse). Use $V_{CC} = 5\,\mathrm{V}$.**



3. **If $R_a = 1\,\mathbf{k}\Omega$ and $C = 1\,\mu\mathbf{F}$, what is the duration of the pulse (assuming the triggering pulse is of even shorter duration)?**

   This is computed as the time it takes an exponential decay with time constant $\tau = R_a C$ to reach $\frac{1}{3}$ of its starting value.

$$\exp\left(-\frac{t}{RC}\right) = \frac{1}{3}$$

$$t = RC\log\left(3\right) = 1\times 10^{3}\times 1\times 10^{-6}\log\left(3\right) = 1.1\,\mathrm{ms}$$

Butterworth Filter

4. **Write the expressions for the poles of a 5th order Low-Pass Butterworth filter with knee frequency $\omega_0 = 10^4\,\mathbf{s}^{-1}$. Also plot the location of the poles in the s-plane.**

   The poles are located on a circle or radius ω_0 and are separated by the angle $180°/5 = 36°$, and, of course, symmetrically located around the negative real axis. Thus they are located at $180°$, $180° \pm 36°$, and $180° \pm 2\times 36°$. In general we have $p = \omega_0\left(cos(\theta_0) + j\sin(\theta_0)\right)$. So

$$
\begin{aligned}
p_1 &= -10^4 \\
p_2 &= 10^4\left(\cos\left(180^\circ - 36^\circ\right) + j\sin\left(180^\circ - 36^\circ\right)\right) = -8.09\times 10^3 + j5.9\times 10^3 \\
p_3 &= 10^4\left(\cos\left(180^\circ + 36^\circ\right) + j\sin\left(180^\circ + 36^\circ\right)\right) = -8.09\times 10^3 - j5.9\times 10^3 \\
p_4 &= 10^4\left(\cos\left(180^\circ - 72^\circ\right) + j\sin\left(180^\circ - 72^\circ\right)\right) = 3.09\times 10^3 + j9.5\times 10^3 \\
p_5 &= 10^4\left(\cos\left(180^\circ + 72^\circ\right) + j\sin\left(180^\circ + 72^\circ\right)\right) = 3.09\times 10^3 - j9.5\times 10^3
\end{aligned}
$$

5. **What is the value of Q for each of the second order filters used to make the filter?**

   If we write $p = x + jy$ then we have $x = -\frac{\omega_0}{2Q}$, or

   $$Q = -\frac{\omega_0}{2x}$$

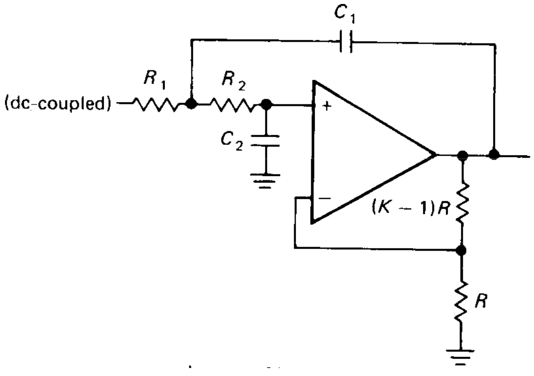
   For the second order filter formed from p_2 and p_3 we have

   $$Q_1 = \frac{10^4}{2\times 8.09\times 10^3} = 0.62$$

   For the second order filter formed from p_4 and p_5 we have

   $$Q_2 = \frac{10^4}{2\times 3.09\times 10^3} = 1.62$$

6. **Using the table and VCVS circuit below, and any other circuit element you may need, give a detailed design of the 5th order filter, specifying the values of all components. Use $R_1 = R_2 = R = 1\,\mathrm{k}\Omega$. Either remember (hopefully) what gives you ω_0, or derive an expression (time consuming).**



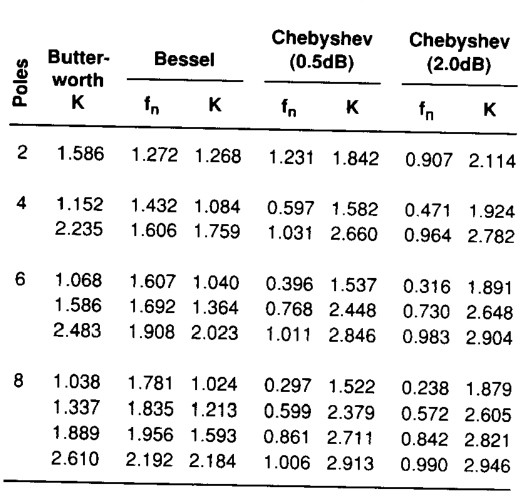


TABLE 5.2. VCVS LOW-PASS FILTERS

Poles	Butter-worth K	Bessel f_n	Bessel K	Chebyshev (0.5dB) f_n	Chebyshev (0.5dB) K	Chebyshev (2.0dB) f_n	Chebyshev (2.0dB) K
2	1.586	1.272	1.268	1.231	1.842	0.907	2.114
4	1.152	1.432	1.084	0.597	1.582	0.471	1.924
	2.235	1.606	1.759	1.031	2.660	0.964	2.782
6	1.068	1.607	1.040	0.396	1.537	0.316	1.891
	1.586	1.692	1.364	0.768	2.448	0.730	2.648
	2.483	1.908	2.023	1.011	2.846	0.983	2.904
8	1.038	1.781	1.024	0.297	1.522	0.238	1.879
	1.337	1.835	1.213	0.599	2.379	0.572	2.605
	1.889	1.956	1.593	0.861	2.711	0.842	2.821
	2.610	2.192	2.184	1.006	2.913	0.990	2.946

   Here is where the mistake happened. We are going to assume that we can use a 4th order filter cascaded with a first order filter. This is not correct, but it is somewhat close. For the VCVS filter $\omega_0 = \frac{1}{RC}$, or

$$C = \frac{1}{R\omega_0} = \frac{1}{1 \times 10^3 \times 10^4} = 1 \times 10^{-7} = 100\,\mathrm{nF}$$

These are the values for R and C for both second-order filters as well as for the first-order filter in the cascade. The only remaining taks to decide on the two resistors providing the non-inverting gain of the amplifier. For the first stage we have $K = 1.152$. Since the lower resistors is still $1\,\mathrm{k}\Omega$, the upper resistor should be $(K-1)\,R = 0.152 \times 1 \times 10^3 = 152\,\Omega$. For the second stage we get similarly that $(K-1)\,R = 1235\,\Omega$.

7. **What is one important advantage, and one important disadvantage of the Chebyshev filter compared to the Butterworth filter?**

   One advantage is a steeper initial drop-off for the Chebyshev filter than for the Butterworth filter. One disadvantage is the bandpass ripple for the Chebyshev filter which is not present in the Butterworth filter.