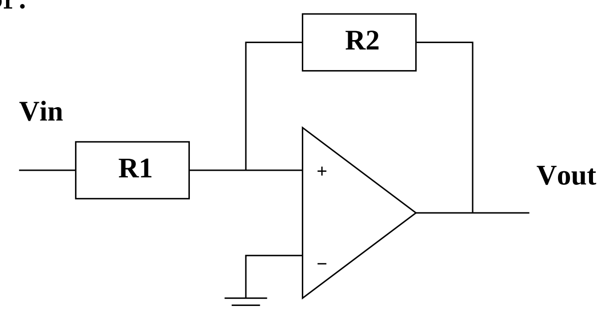
EE 322 Advanced Electronics, Spring 2012
Exam 3
solution
Wednesday April 25, 2012

Rules: This is a closed-book exam. You may use only your brain, a calculator and pen/paper. Each numbered question counts equally toward your grade.

Note: The questions are designed to test your conceptual understanding, not your ability to do many pages of math. If you find yourself doing long calculations there is a high probability that you are doing something wrong.

Bistable element

1. **Design a bistable circuit with a op-amp which has threshold levels of -5 V and $+5$ V when the op-amp saturation levels are ± 15 V. Use $1\,\mathrm{k}\Omega$ as the smallest resistor.**



We select the resistors R_2 and R_1 as follows. They voltage levels are symmetric so we need only one determination. When $V_{\text{in}} = 5\,\text{V}$ and $V_{\text{out}} = -15\,\text{V}$ then we want $V_+ = 0$. So in other words

$$\frac{V_{\text{in}}}{R_1} = -\frac{V_{\text{out}}}{R_2}$$

$$\frac{R_2}{R_1} = -\frac{V_{\text{out}}}{V_{\text{in}}} = -\frac{-15}{5} = 3$$

So pick $R_1 = 1\,\mathrm{k}\Omega$ and $R_2 = 3\,\mathrm{k}\Omega$.

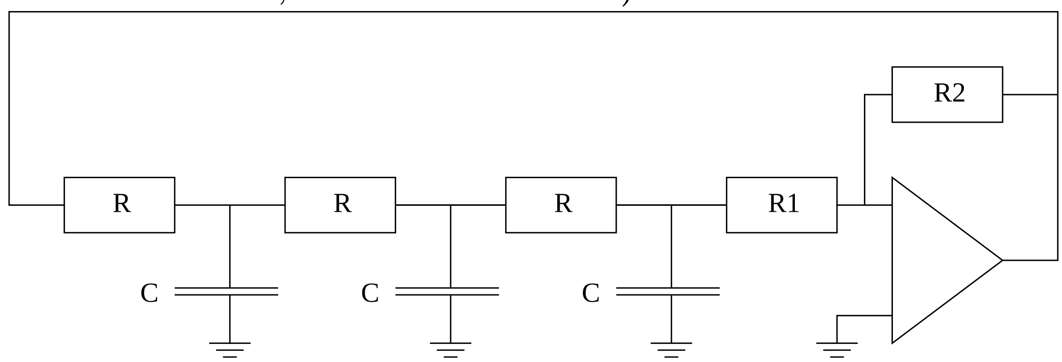
2. **One single modification makes this into a bistable circuit with threshold levels of -1 V and $+9$ V. What is that single modification?**

We can guess a voltage on the negative pin but same resistor ratio. If we guess $+3$ V, then there is 18 V down to -15 V. One third of that is 6 V, add that to 3 V and we get 9 V. Good.

Next, from 3 V up to 15 V is 12 V. Divide that by 3 and we get 4 V. Subtract that from 3 V and we get -1 V.

Linear oscillator

3. **Draw a linear oscillator consisting of 3 RC low-pass circuit in series, followed by a inverting amplifier. Include one resistor for each RC term and the two resistors that make up the inverting amplifier (it is possible to simplify as shown in the book, but let's not do that).**



4. **What should be the phase of each RC term for oscillation?**

   Each term LP filter should have a phase of $-60°$.

5. **What amplitude does that phase correspond to, and what does that imply about what the gain of the inverting amplifier should be to sustain oscillation?**

   The filter looks like this,

$$\frac{1}{1+j\omega RC}$$

   and we know that

$$\frac{\omega RC}{1} = \tan 60° = \sqrt{3}$$

   Then the amplitude is

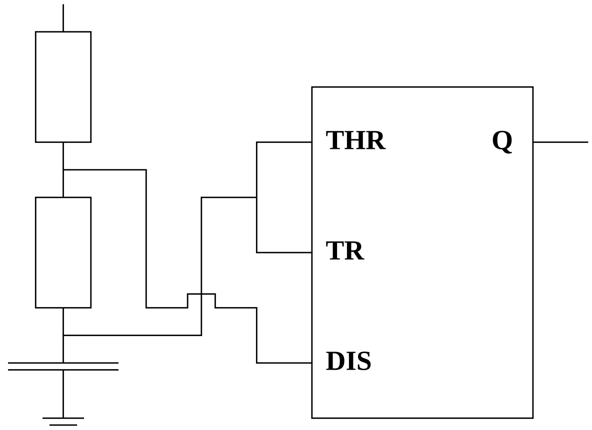
$$\frac{1}{\sqrt{1+\omega^2R^2C^2}} = \frac{1}{\sqrt{1+3}} = \frac{1}{2}$$

   The amplitude of the inverting stage must be at least the inverse of the cube of that number, so

$$\frac{R_2}{R_1} \geq \left(\frac{1}{2}\right)^{-3} = 2^3 = 8$$

Astable multivibrator

6. **Draw a astable multivibrator built from a 555 timer.**



Phase-locked loop

Consider a phase-locked loop consisting of a XOR type phase detector, a low-pass filter, a VCO, and a divide by two in the feedback path. The VCO has $f_{\text{out}} = 10\,\text{MHz/V}\,V_{\text{in}}$, and the XOR phase detector has output levels of 0 and 5 V. The input reference signal is 25 MHz.

7. **Determine the phase difference between the divided feedback signal and the reference signal.**

   The LP filter is outputing exactly its maximum voltage. That means that it is high all the time. That in turn means that there is a 180° phase shift between the reference and the feedback signal.

8. **Plot for at least two full periods of the reference all three signals (reference, output, feedback). Draw to scale and clearly label the time/phase offsets between the various signals.**