MASSACHVSETTS INSTITVTE OF TECHNOLOGY
**Department of Electrical Engineering and Computer Science**

**6.002x – Circuits and Electronics**
**Spring 2004**

**Problem Set 3**
**Readings and exercises for the week of Feb. 17–23**

Issued: 17 February 2004

**Reading:** Be sure to do the required readings *before class* as indicated.

- Read chapter 4 of Agarwal and Lang before lecture on Feb. 23, but don't obsess over it.
- Read the handout *BJT's Without Tears* before lecture on Feb. 25. This handout was distributed in lecture on Feb. 17, and is also available on the class web site.

## Part 1: To do on line before recitation on Friday, February 20

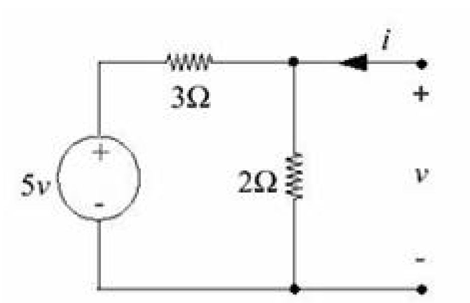


Figure 1: Find the Thévenin and Norton equivalents (problem 1.1)

### 1.1: Quick question on Thevénin and Norton equivalents

Find the Thevénin equivalent and the Norton equivalent at the indicated terminals for the network shown in figure 1.

## Part 2: To do on line before lecture on Monday, Feb 23

### 2.1: Thevénin Equivalent (Agarwal and Lang, Chapter3 ex. 22a)

Find the Thévenin equivalent at the terminals for the circuit shown in figure 2.

### 2.2: Computing weighted sums

The circuit shown in figure 3 can be used for computing weighted sums:

$$v_{\text{OUT}} = av_1 - bv_2 - cv_3$$

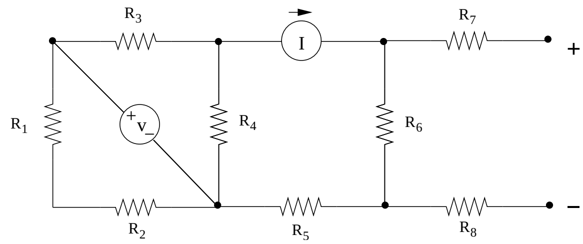


Figure 2: Find the Thévenin equivalent (problem 2.1)

where $a$, $b$, and $c$ are positive numbers. Here $v_{\mathrm{OUT}}$ is the op-amp output voltage, $v_1$ through $v_3$ are node voltages measured with respect to a common ground, and the values of the resistors are suitably chosen.[1] Demonstrate that you understand how the circuit works by showing how to choose resistors to produce the appropriate $v_{\mathrm{OUT}}$, given values for $a$, $b$, and $c$. Note that this scheme can be extended to arbitrary numbers of terms by including more inputs to the op-amp. (Hint: Think about superposition: consider the response to each input separately.)

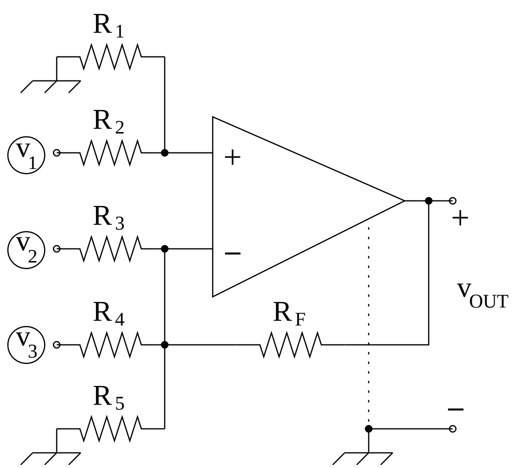


Figure 3: Circuit for computing weighted sums

[1]We drew circles around the $v_i$ in the figure because these are node voltages measured with respect to the ground. You may assume that these potentials are determined by voltage sources.

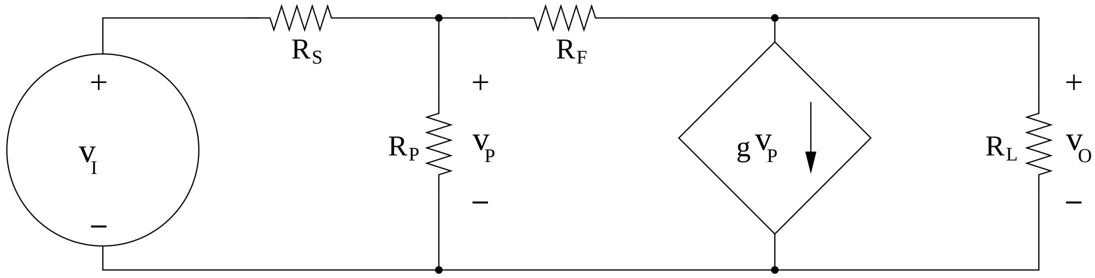


Figure 4: Circuit with dependent source

**2.3: Dependent sources**

Find the Thévenin equivalent and the Norton equivalent of the circuit shown in Figure 4, as seen by the load $R_L$.

Note: This circuit is a model of a one-stage transistor amplifier with negative feedback, as we'll see later. Typical values for the parameters might be $g \approx .038\ \Omega^{-1}$, $R_\mathrm{P} \approx 2500\ \Omega$, $R_\mathrm{S} = 1\ \mathrm{k}\Omega$, $R_\mathrm{F} = 11\ \mathrm{k}\Omega$ to produce a gain $V_\mathrm{O}/V_\mathrm{I}$ of about 10 for a load $R_\mathrm{L} = 10\ \mathrm{k}\Omega$.

**2.4: X-10 power**

An X-10 receivers are generally specified to reliably detect and act on a signal of 0.1 Volt. The input resistance of the X-10 receiver is very high. Suppose that a certain X-10 transmitter is specified to put out 0.5 Watt into a 5 $\Omega$ load and 0.2 Watt into a 20 $\Omega$ load.

1. What is the equivalent source resistance of the transmitter?
2. For what load resistance does the X-10 transmitter put a maximum power into the load? How much power is the maximum?
3. As we add loads to a branch circuit (by turning on lights and appliances) does the load resistance seen by the transmitter increase, decrease, or remain the same?
4. We have an X-10 transmitter and an X-10 receiver, both as specified above, attached to the same 120 V house current branch circuit. Assume that the equivalent resistance of the power line feeding this branch circuit is 20 $\Omega$ at 120 kHz. We increase the load by turning on incandescent lighting and heating until the receiver fails to decode the signal. Approximately how many watts of load are required to cause the X-10 system to fail because of loading? Is this possible in a residential dwelling?

   Note: The heating and incandescent lighting loads, unlike the power line or electric motors or fluorescent lighting, have approximately the same resistance as 120 kHz as at 60 Hz.

   Hint: This problem is not very difficult conceptually, but some of the parts—the last part in particular—can produce equations that are an awful mess to solve by hand. One reason is that the values in this problem are realistic ones for X-10, rather than values chosen to make the algebra come out easy. If you run across an equation that is messy to solve, see if you can make approximations that simplify the required algebra. And note that the algebra will be often simpler if you substitute in numerical values sooner rather than later in solving the equations. It's also fine for you to use computer programs to solve the equations numerically.