Physics S123: Homework 1, Passive Devices I

Total points: 30

1 Power Transmission (1 point)

If the power utility in Cambridge sent power about the city at 100V rather than at 20,000V, by what factor would power losses grow? Think of the power lines as long resistors.

If an electric stove were powered at 120V rather than at 240V, by what factor would power losses in its house wiring grow?

'What are we asking?', you ask Students sometimes complain that they’re not sure what we’re asking, on some problem-set questions. If you find yourself puzzled in this way, don’t suffer in silence: send an email.

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2 Dividers & Their Thevenin Models (12 points, total of points shown below)

Suppose you have a +100V (DC) power supply, and you need two output voltages, 50V and 10V, subject to the specifications shown below, without wasting excessive power.

<table>
<thead>
<tr>
<th>Output</th>
<th>Specification</th>
<th>Current Limitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>50V</td>
<td>should droop no more than 10% when 100µA is drawn from the output into a “load” returned to ground. (As you increase the current out of the circuit to 100µA, the output shouldn’t fall below 40V.)</td>
<td></td>
</tr>
<tr>
<td>10V</td>
<td>should droop no more than 10% when loaded by a 100k resistor to ground.</td>
<td></td>
</tr>
</tbody>
</table>

Figure 1: The two outputs you are to produce

2.1 Thevenin Models (4 points)

Show Thevenin models for the voltage sources described in the box. Show numbers for $V_{Thev}$ and $R_{Thev}$. You may use exact values, even these would not be practical to implement in a circuit. (We hope you’ll discover that this model provides the best way to solve the problem posed in problem 3, below. We’re promoting Thevenin, here. For one, it means you don’t have to worry about the 100V supply yet.)

2.2 Complete Circuits (8 points)

Design the two circuits, minimizing power dissipation, given the constraints stated above.

2.3 Power dissipation (2 points)

How much power is dissipated by the divider you designed to drive the 100k load? (With no load attached.)

How much power would that divider dissipate (no load attached), if it had been designed so that it “should droop no more than 10% when loaded by a 1k resistor to ground.”
3 Effect of Loading by Instruments (4 points)

What happens to $V_{out}$ for each of the two circuits of problem 1, when that circuit drives each of the following instruments (give answers to roughly 1%, this time)–DVM (digital meter), VOM (analog meter), and your home-made voltmeter of Lab 1. (Labor-saving HINT: use your Thevenin models. Doing this should keep the arithmetic easy; don’t overwork yourself by calculating performance of the actual circuits you designed, with their non-ideal resistors.)

3.1 A DVM with (constant-) $R_{in}$ of 10MΩ? (2 points)

- Figure 2: 50V
- Figure 3: 10V

3.2 A VOM whose front panel shows the specification, “20,000 Ω/V” (2 points)

(This is a little harder¹). Assume that the meter can be switched to any of the following full-scale ranges: 1V, 10V, 50V, 1000V. Choose the single most appropriate range.

- Figure 4: 50V
- Figure 5: 10V

¹If you’re not yet clear on what “20,000 Ω/V” means, see the Manual’s worked example at pp. 22-23 for help. Basically, if you set the meter to the “10V-maximum” setting, its resistance is $10V \cdot 20,000Ω = 200kΩ$. 

4 Divider and Shifter (5 points, total)

Suppose you are given the following signal source:

- voltage range: ±5V
- $R_{OUT} \leq 100\Omega$
- frequency: DC to 10kHz

You are to modify this signal so as to feed it to an analog-to-digital converter (ADC), with the following specifications:

- full-scale voltage range: 0V to +5V
- resolution to about 1% (so you should not let your circuit load or alter the original signal by more than 1%)

You are given a +5V DC supply, and any resistors you want. Flip to the next page...

![Figure 6: Divide and shift, drawing of inputs and outputs](image)

4.1 Design the Divider-Shifter (2 points)

4.2 $R_{OUT}$ for your circuit (1 point)

What is $R_{OUT}$ for your circuit?

4.3 Max $C_{IN}$ for ADC? (2 points)

Given the $R_{OUT}$ that you found for your circuit—a circuit that is to feed the ADC—what is the maximum $C_{IN}$ that you can tolerate, if the voltage into the ADC must settle to within about 1% within 1 $\mu$s?
5 Thevenin & C (4 points)

5.1 Simplify: Draw the model

Start by simplifying the circuits shown below, into a single Thevenin model driving a single $C$, after the switch is closed. (The trickiest part of this question is to realize that it doesn’t matter whether one terminal of a capacitor is held at ground or some other DC voltage.)

![Circuit Diagram 1](image1)

![Circuit Diagram 2](image2)

Figure 7: Thevenin and RC: circuits to be simplified

5.2 Complete the plot

Then complete the plot, showing voltages and the $RC$ time-constant, with its value indicated.
6 Accidental Filters (4 points)

6.1 Which is which? (2 pts)

Which is the low-pass, which the high-pass? Which might work as differentiator, which might work as integrator? (Explain your answer, briefly.)

6.2 ... How Would you Test to find the answer ’which is which?’ (2 pts)

If you suspect you’ve got one of these accidental filters, what’s the quickest way to check whether in fact you do? (Use your instruments, not just your eyeballs!)

7 X100 Probe (1 point)

Show a design for a X100 probe: a device that increases a scope’s input impedance by a factor of 100. Assume that the scope’s $R_{IN} = 1M$, scope’s stray $C_{IN} = 30pF$, and cable stray capacitance = 100pF. The goal, of course, is to achieve “flat” frequency response.