ENGR-2300

Electronic Instrumentation

Quiz 1

Spring 2016

On all questions: **SHOW ALL WORK. BEGIN WITH FORMULAS, THEN SUBSTITUTE VALUES <u>AND UNITS</u>.** No credit will be given for numbers that appear without justification. Unless otherwise stated in a problem, provide 3 significant digits in your answers. Read the entire quiz before answering any questions. Also it may be easier to answer parts of questions out of order. Some questions contain reminders of these instructions, but they must be followed for the entire quiz.

24 February – Birth Date of Steve Jobs

First – two quotes from Steve Jobs:

When you're a carpenter making a beautiful chest of drawers, you're not going to use a piece of plywood on the back, even though it faces the wall and no one will see it. You'll know it's there, so you are going to use a beautiful piece of wood on the back. For you to sleep well at night, the aesthetic, the quality has to be carried all the way through.

Design is not just what it looks like and feels like. Design is how it works.

Second – a quote from Steve Wozniak:

Steve Jobs played no role at all in any of my designs of the Apple I and Apple II computer, and printer interfaces, and serial interfaces, and floppy disks and stuff that I made to enhance the computers. He did not know technology. He wanted to be important, and the important people are always the business people. So that's what he wanted to do.

Conceptual Questions

Question V in this quiz contains some conceptual questions. The following addresses how to approach such questions, provided in the unlikely event that you have not seen such questions before.

A **conceptual question** is designed to help determine whether a student has an accurate working knowledge of a specific set of concepts. For example, from the background quiz you completed on the first day of class:

A 9V battery is connected across a 2kΩ resistor. If the resistor is replaced with a 10kΩ resistor, will the current from the battery
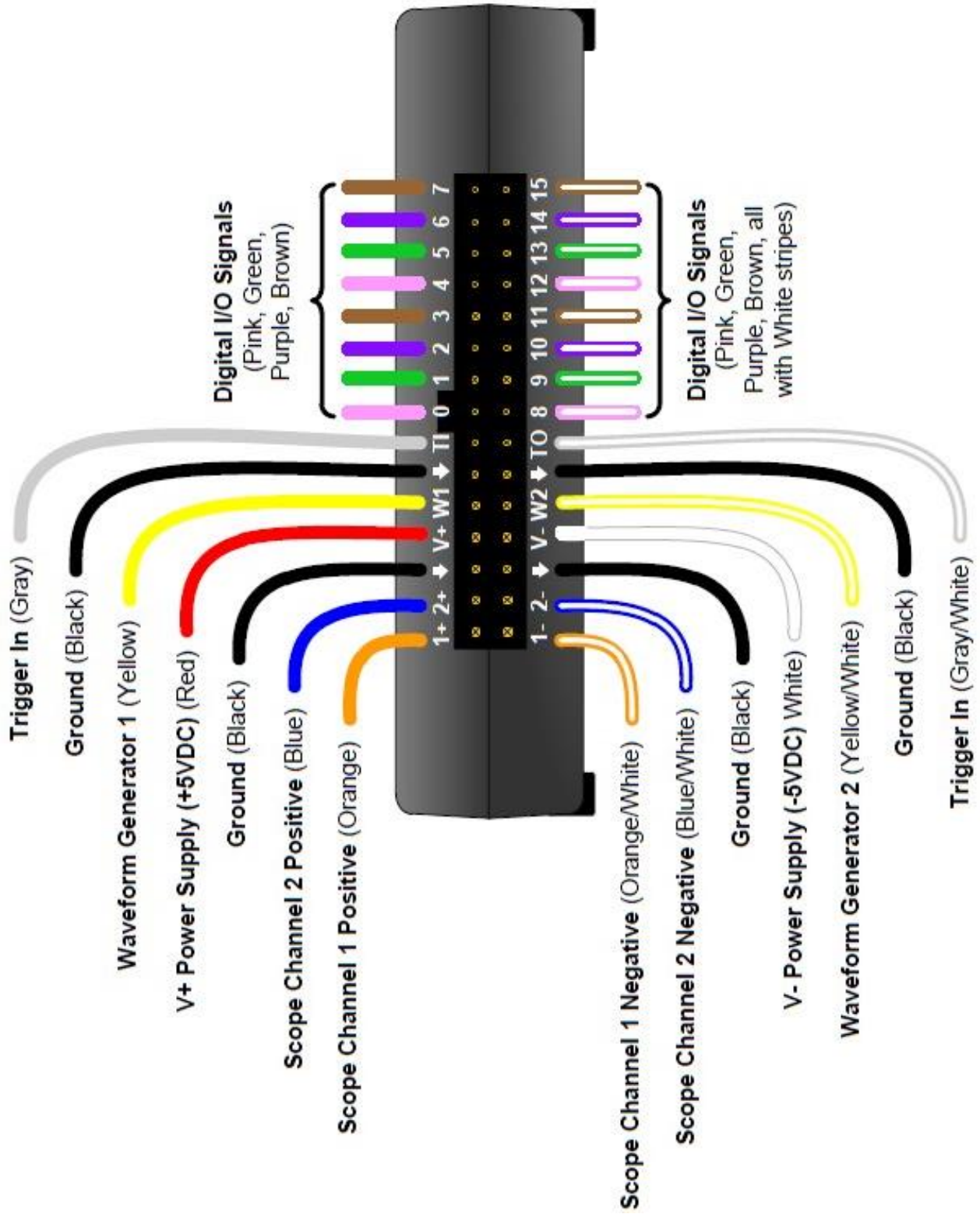
       a. Increase
       b. Decrease
       c. Stay about the same

This question tests conceptual knowledge of Ohm's Law. It can most rigorously be answered by recalling the relationship between voltage, current and resistance (the three parameters mentioned directly or indirectly in the question). $I = \dfrac{V}{R}$. From this expression a larger R will produce a smaller I for the same voltage (9V in this case). The answer does not depend on the exact values of the two resistances, only that a resistor is replaced with one that is larger. Then the current will be smaller, so the answer is b. Decrease.

Analog Discovery Connections

Digital I/O Signals
(Pink, Green,
Purple, Brown)

Digital I/O Signals
(Pink, Green,
Purple, Brown, all
with White stripes)

Trigger In (Gray)

Ground (Black)

Waveform Generator 1 (Yellow)

V+ Power Supply (+5VDC) (Red)

Ground (Black)

Scope Channel 2 Positive (Blue)

Scope Channel 1 Positive (Orange)

Scope Channel 1 Negative (Orange/White)

Scope Channel 2 Negative (Blue/White)

Ground (Black)

V- Power Supply (-5VDC) White)

Waveform Generator 2 (Yellow/White)

Ground (Black)

Trigger In (Gray/White)

Standard Resistor Values (±5%)

1.0	10	100	1.0K	10K	100K	1.0M
1.1	11	110	1.1K	11K	110K	1.1M
1.2	12	120	1.2K	12K	120K	1.2M
1.3	13	130	1.3K	13K	130K	1.3M
1.5	15	150	1.5K	15K	150K	1.5M
1.6	16	160	1.6K	16K	160K	1.6M
1.8	18	180	1.8K	18K	180K	1.8M
2.0	20	200	2.0K	20K	200K	2.0M
2.2	22	220	2.2K	22K	220K	2.2M
2.4	24	240	2.4K	24K	240K	2.4M
2.7	27	270	2.7K	27K	270K	2.7M
3.0	30	300	3.0K	30K	300K	3.0M
3.3	33	330	3.3K	33K	330K	3.3M
3.6	36	360	3.6K	36K	360K	3.6M
3.9	39	390	3.9K	39K	390K	3.9M
4.3	43	430	4.3K	43K	430K	4.3M
4.7	47	470	4.7K	47K	470K	4.7M
5.1	51	510	5.1K	51K	510K	5.1M
5.6	56	560	5.6K	56K	560K	5.6M
6.2	62	620	6.2K	62K	620K	6.2M
6.8	68	680	6.8K	68K	680K	6.8M
7.5	75	750	7.5K	75K	750K	7.5M
8.2	82	820	8.2K	82K	820K	8.2M
9.1	91	910	9.1K	91K	910K	9.1M

Type	R_{int} (Ω)	V_{oc} (V)	Capacity[a] continuous, to 1V/cell				Size (in)	Weight (gm)	Connec[b]	Comments
			(mAh)	@ (mA)	(mAh)	@ (mA)				
9V "1604"										
Le Clanche	35	9	300	1	160	10	0.65x1x1.9	35	S	
Heavy Duty	35	9	400	1	180	10	"	40	S	
Alkaline	2	9	500	1	470	10	"	55	S	280mAh@100mA
Lithium	18	9	1000	25	950	80	"	38	S	Kodak Li-MnO$_2$

I. Voltage Dividers, power, and loading (20 points) As stated on the cover page: Round answers to 3 significate digits. Show formulas first and show your work. *No credit will be given for numbers that appear without justification. And remember that additional information is provided on pages 2, 3 and 4 of this exam.*

    a) Find the voltage Vout in the circuit shown. Vin is a battery. (4 pts)

$$Vout = (12)\left(\frac{680}{680 + 280}\right) = 8.5V$$

    b) Find the current that the battery supplies. (4 pts)

$$I_{battery} = \left(\frac{8.5}{680}\right) = 12.5mA = \frac{12}{680 + 280}$$

    c) Find the power provided by the battery. (2pts)

$$P = VI = (12)(12.5)mW = 150mW$$

    d) Is R1 a standard resistor value for 5% resistors? (1pt) NO
        Is R2 a standard resistor value for 5% resistors? (1pt) YES

    e) Would 1/8W resistors be an appropriate choice to use for this circuit? You must justify your answer. (2pts)

$$P_{R1} = VI = (3.5)(12.5)mW = 44mW \quad P_{R2} = VI = (8.5)(12.5)mW = 106mW$$

  Yes for both because they are smaller than 125mW. Safety factor is not very large for R2.

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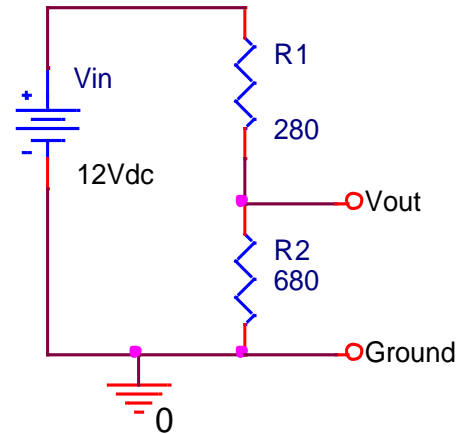
f) Now include non-ideal factors. The battery is non-ideal, it has a 10Ω internal resistance. The Analog Discovery Board was used to measure the Vout and it has a 1MegΩ input resistance. ***Redraw the schematic*** to include these real world effects ***and recalculate the Vout*** that would actually be measured using this battery and the Analog Discovery. (6pts)

$$V_{out} = \left(\frac{680}{10 + 250 + 680} \right)(12) = 8.41 \text{ V}$$
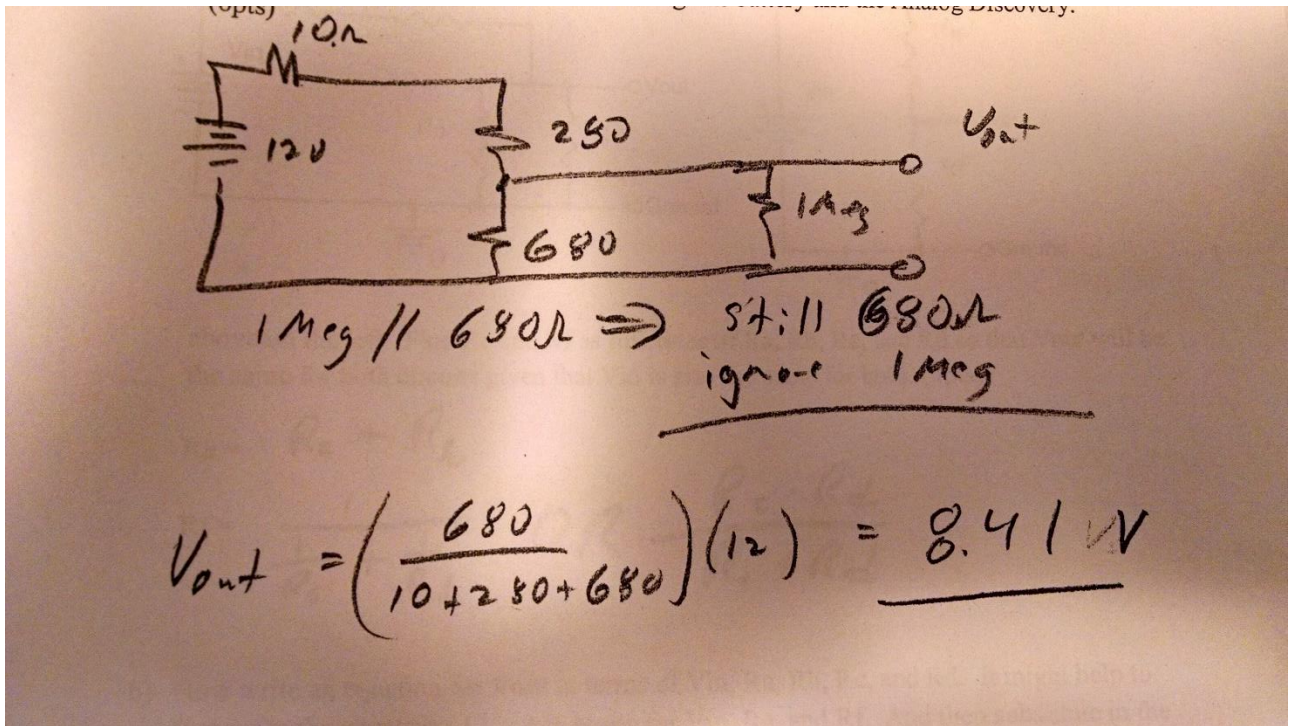
II. Resistor Combinations and more real world effects (20 points)
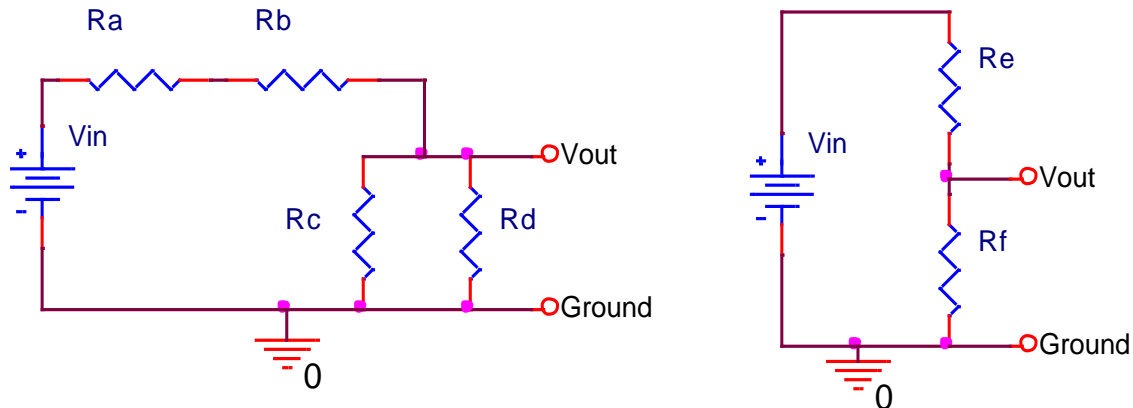
a) The circuit on the right above is intended to be a simpler equivalent version of the circuit on the left. Find Re and Rf as functions of Ra, Rb, Rc, and Rd so that Vout will be the same for both circuits given that Vin is also the same for both. (4pts)

Re =   Ra + Rb

Rf =   (Rc)(Rd)/(Rc + Rd) or $\dfrac{1}{\dfrac{1}{Rc} + \dfrac{1}{Rd}}$

b) Now write an equation for Vout in terms of Vin, Ra, Rb, Rc, and Rd. It might help to first write the equation of Vout in terms for Vin, Re, and Rf. And then substitute in the equations from part a). (4pts)

$$Vout = Vin\,\frac{Rf}{Re + Rf} = Vin\,\frac{\dfrac{RcRd}{Rc + Rd}}{Ra + Rb + \dfrac{RcRd}{Rc + Rd}} = Vin\,\frac{RcRd}{(Ra + Rb)(Rc + Rd) + RcRd}$$

Does not have to be simplified

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c) Find Vout in Volts for the circuit below. You must show your work to receive credit.
(6pts)

6k   **2k**

4k

V1

10V

4k

4k

3k

4k

6k

3k

OVout

OGround

0

2.4k
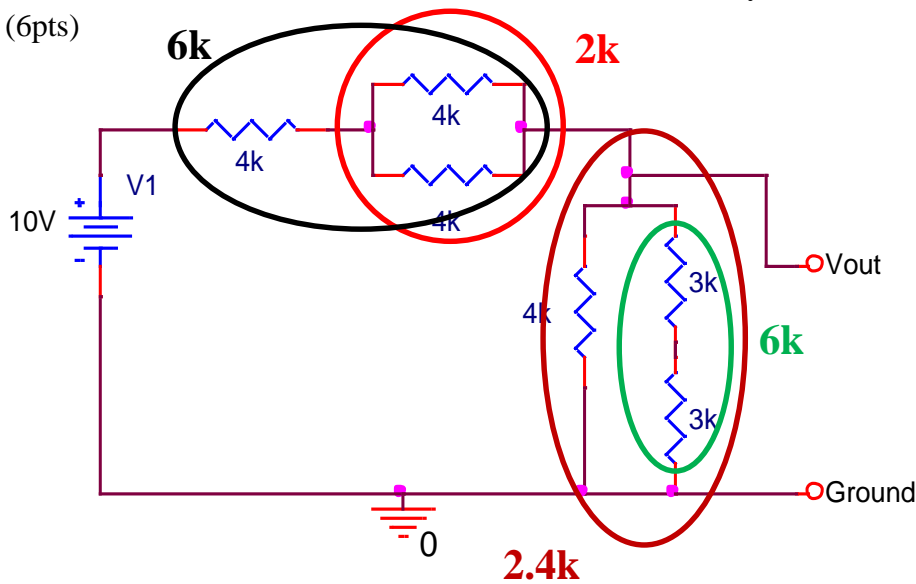
Becomes simple voltage divider with R1 = 6k and R2 = 2.4k

$$Vout = 10\frac{2.4}{2.4 + 6} = 2.86V$$

d) Another non-ideal factor is that the resistors we use in EI have a 5% tolerance. A 100k resistor could have a value between 95k and 105k, but this range includes temperature and aging effects. This site looked into this issue:

http://www.kerrywong.com/2013/02/01/100k-5-carbon-film-resistor-value-distribution/
The plot below showing measured values for 100kΩ resistors is from this site. The x axis is in kΩ, the y axis is the number of resistors that fit into bins that are 250Ω wide. Note that the distribution is much closer to 100kΩ than a 5% tolerance would imply.

Also complicating precise calculations is that for the resistors used for the plot have a temperature effect. The resistance will drop by a factor between 0 and 850pmm/°C. This may or may not explain the shift to lower values.

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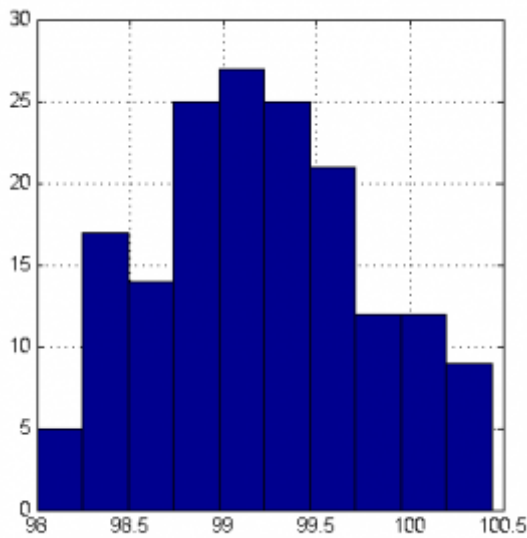
Part 1) Based on the plot, what is the approximate tolerance range for this set of resistors. It clearly isn't symmetric around 100k so your answer shouldn't be either. Express your answer as R ± X% (2pts)

Range 98 to 100.5

Answer: 99.3 ± 1.3%

Part 2) For the circuit shown below, calculate the expected Vout range using the extremes of the ±5% tolerance range. Give Vout(max) and Vout(min). (2pts)
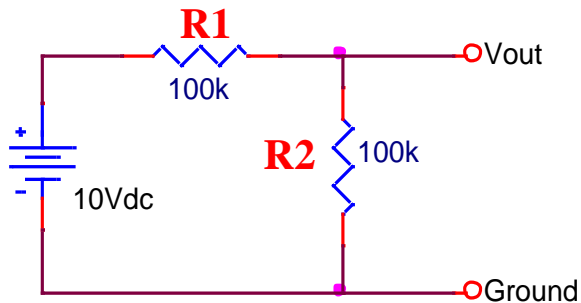
max is R1 = 95Ω and R2 = 105Ω

So 5.25V

min is R2 = 95Ω and R1 = 105Ω

So 4.75V

Part 3) Now do the same as Part 2) but use the tolerance range from Part 1). (2pts)

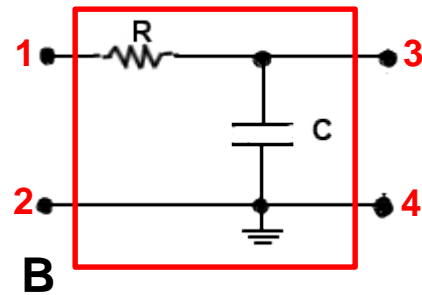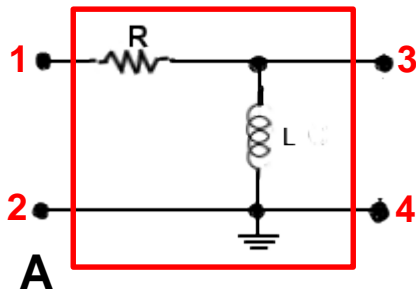max is R1 = 98Ω and R2 = 100.5Ω

So 5.06V

min is R2 = 98Ω and R1 = 100.5Ω

So 4.94V

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III. Filters & Transfer Functions (20 points)

A

B

C

D
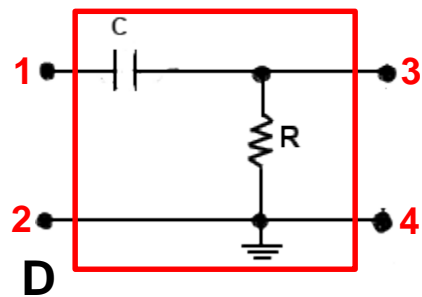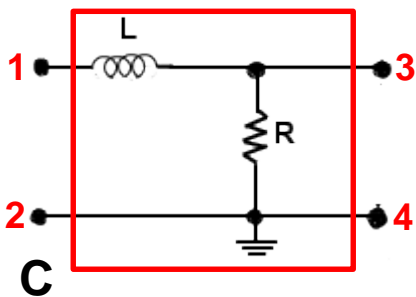
Shown above are the four basic, two-element, passive filter configurations made with RL and RC combinations. In this problem, we will consider the bottom two configurations that can be constructed by adding either an inductor or capacitor to a resistive load. Assume that the circuits are made with ideal components, unless specifically told otherwise.

a) Determine the general complex transfer function for circuits C and D in terms of R, L, C and frequency ω, by modeling each as a voltage divider. (2 pts)

C) LR:

$$\frac{V_{OUT}}{V_{IN}} = \frac{V_{34}}{V_{12}} = \frac{R}{R + j\omega L}$$

D) CR:

$$\frac{V_{OUT}}{V_{IN}} = \frac{V_{34}}{V_{12}} = \frac{R}{R + \dfrac{1}{j\omega C}} = \frac{j\omega RC}{1 + j\omega RC}$$

Either form is OK

b) Simplify the two expressions at low (not zero) frequencies. That is, assume ω is small. (2 pts)

C) LR:

$$\frac{V_{OUT}}{V_{IN}} = \frac{V_{34}}{V_{12}} \approx \frac{R}{R} = 1$$

D) CR:

$$\frac{V_{OUT}}{V_{IN}} = \frac{V_{34}}{V_{12}} \approx \frac{j\omega RC}{1} = j\omega RC$$

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c) Simplify the two expressions at high (not infinite) frequencies. That is, assume ω is large. (2 pts)

C) LR: D) CR:

$$\frac{V_{OUT}}{V_{IN}} = \frac{V_{34}}{V_{12}} \approx \frac{R}{j\omega L}$$ $$\frac{V_{OUT}}{V_{IN}} = \frac{V_{34}}{V_{12}} \approx \frac{j\omega RC}{j\xi RC} = 1$$

d) In engineering, when we say something is large or small, we make such a statement by comparing it to a specific quantity. If you have answered the previous two questions correctly, you have used an expression like either $\omega >> \omega_{REFERENCE}$ or $\omega << \omega_{REFERENCE}$ so that you can neglect terms in the general complex transfer functions. What is $\omega_{REFERENCE}$ for the two circuits? (2 pts) The reference is the corner frequency

C) LR: $\omega_{REFERENCE} = \dfrac{R}{L}$ D) CR: $\omega_{REFERENCE} = \dfrac{1}{RC}$

e) Assume the circuits are made with ideal components. Identify which are high pass filters and which are low pass filters by circling the high pass and underlining the low pass in the following list (2 pts): (CR) LR

The figure below shows what is called a crossover network for audio speakers. Since very good speakers do not work well over the entire audio frequency range, audio signals from music, speech, etc. are separated into more limited frequency bands (typically low, midrange, and high frequencies) and then directed to speakers designed for each band. High frequency speakers are called tweeters and low frequency speakers are called woofers. In the middle range of frequencies, speakers are called midranges, so it seems that audio people ran out of fun names. Of course, there are many different versions of each type, with the best known probably the subwoofer, which is designed for 20 – 60 Hz and is more felt than heard. In the crossover circuit diagram below, the speakers are modeled as 8Ω resistors for simplicity. Also, practical crossover networks have more components to balance the power to each range. However, the components shown are the most important in the design and allow us to understand how crossovers work. Note that the circuit consists of three sub-circuits a, b and c, as indicated by the subscripts on the components and nodes. Note also that you have just analyzed two types of circuits used as sub-circuits in the crossover.

VOFF = 0V

VAMPL = 25V

FREQ = 440Hz

AC = 25V
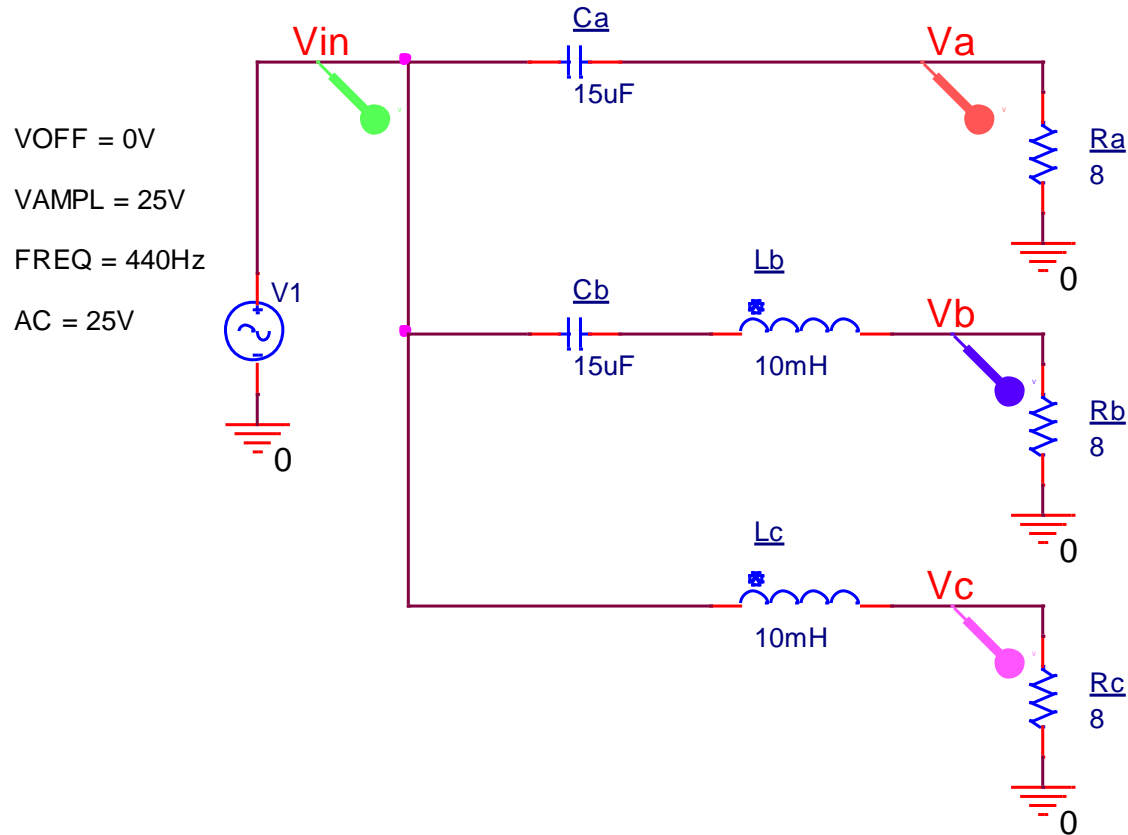
f) In this course, we address four general types of filters: low-pass, high-pass, band-pass and band-reject. Identify the type of filter for each sub-circuit. (3 pts)

    Circuit a)   HP   Circuit b: BP   Circuit c)   LP

g) Determine the corner or resonant frequency for each sub-circuit. Express your answer as an angular frequency ω, not as f. (3 pts)

    Circuit a)   Circuit b: Circuit c)

$$\frac{1}{RC} = \frac{1}{8x15x10^{-6}} = \frac{10^6}{120} = 8333.3 = 8330 \qquad \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{150x10^{-9}}} = 2581.99 = 2580$$

$$\frac{R}{L} = 800$$

h) Good speaker systems incorporate all of the individual speakers and the crossover network in the same box. Thus, when an amplifier is connected to the input to the box, it sees the combination of crossover and speakers, not individual speakers. Assume that you have a speaker system configured as shown in the circuit diagram and that you connect your multi-meter to the input to measure the DC resistance. What value resistance will be indicated on your meter? Explain your answer. (2 pts)
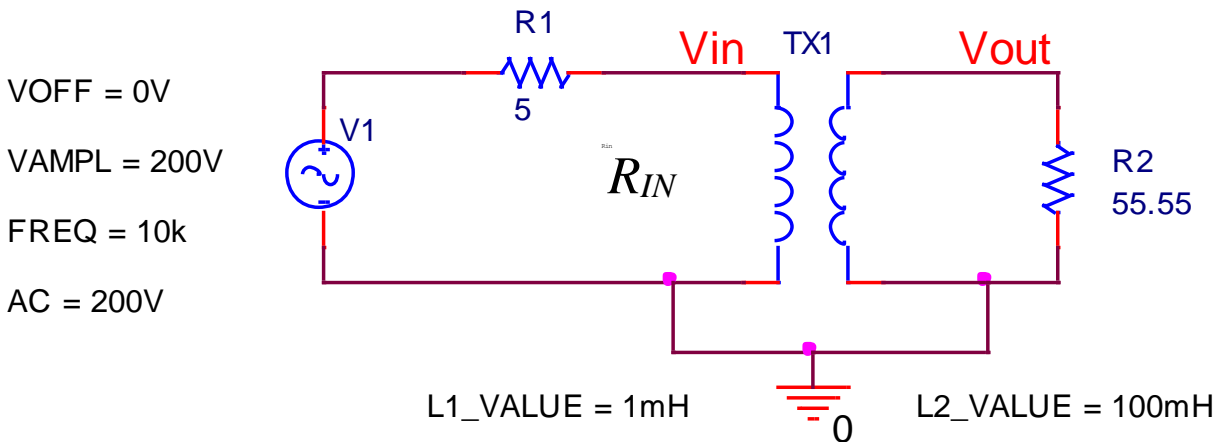
At DC, C is open circuit and L is short circuit. Thus, the measured resistance is 8Ω
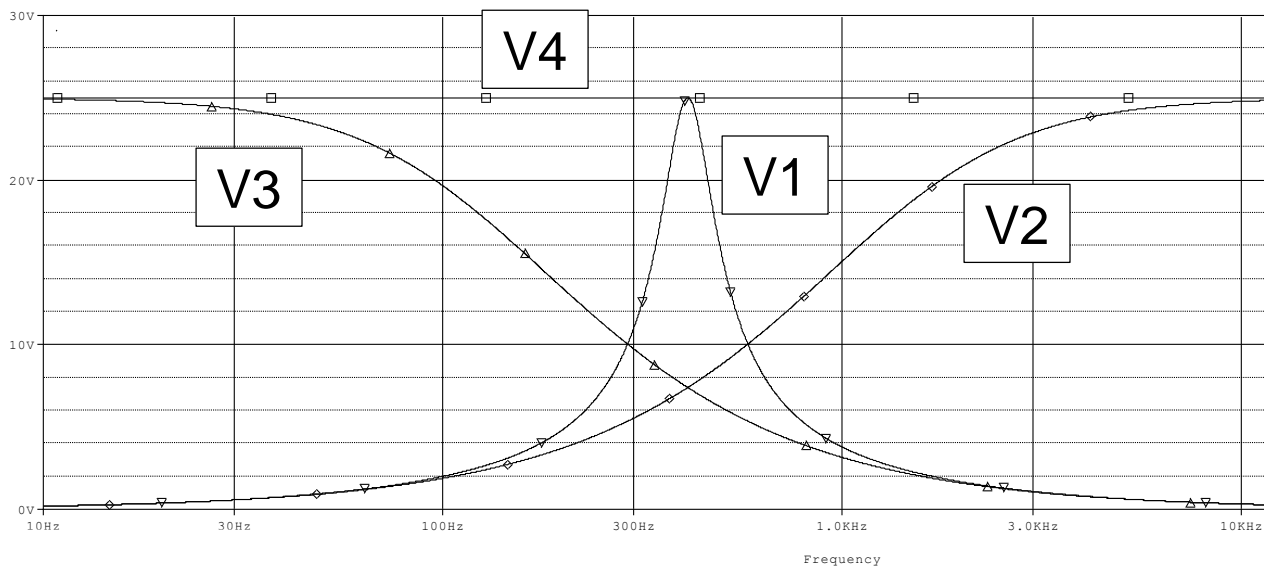
i) The figure above shows the output from PSpice simulation of the crossover. Four voltages are shown as a function of frequency. The horizontal axis is labeled at 10Hz, 30Hz, 100Hz, 1kHz, 3kHz, and 10kHz. The vertical axis is labeled at 0V, 10V, 20V and 30V. The voltages are labeled V1, V2, V3, and V4. Identify which is Vin, Va, Vb, and Vc. Identify the voltages by drawing lines between the voltages in the two columns.
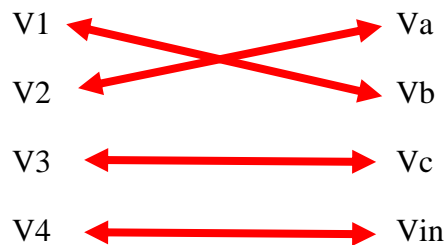
IV – Signals, Transformers and Inductors (20 points)

R1

Vin TX1

Vout

VOFF = 0V

5

V1

VAMPL = 200V

R_{IN}

R2

55.55

FREQ = 10k

AC = 200V

L1_VALUE = 1mH   0   L2_VALUE = 100mH

Given the circuit above, assume an ideal transformer with full coupling. In your answers to the following questions, *use all available and useful information*.

a) For the given information, write out the expressions for the ratios Vout/Vin, Iout/Iin and the transformer input impedance R_{IN}. (6 pts)

$$\frac{V_{OUT}}{V_{IN}} = \frac{I_{IN}}{I_{OUT}} = \sqrt{\frac{L_2}{L_1}} = 10 \qquad Z_{IN} = \frac{R_2}{L_2 / L_1} = \frac{55.55}{100} = .5555\Omega = .556\Omega$$

b) Draw the circuit diagram for the voltage divider consisting of the transformer input impedance Rin and the resistance R1. Then solve for Vin, the voltage across the input terminals of the ideal transformer. (4 pts)

$R_1=5$, $R_2=.5555$

$V_{IN}=200(.5555/5.5555)=20V$

V_{in}

R_1

V_{out}

R_2

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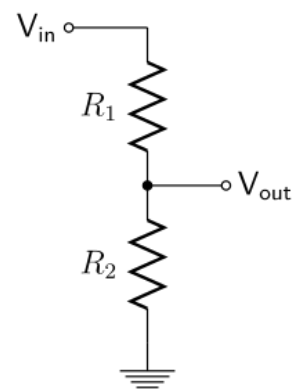
c) Find Vout from your value for Vin. (4 pts)

V_{OUT}=200V

d) Determine both the primary and secondary currents (I1 and I2). (4 pts)

$I_1 = 200/5.5555 = 36A$ $I_2 = 200/55.55 = 3.6A$

e) Determine the power delivered to the load R2. (4 pts)

200 x 3.6 = 720 W (also correct divided by 2, either answer is OK)

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V – Misc & Conceptual Questions (20 points)

The following questions all come from or are inspired by the daily videos. The answers for all

questions are worth (1 pt) each, except where noted. Remember to briefly explain your answers.

a) Is the image shown at the right

    1. a short circuit?
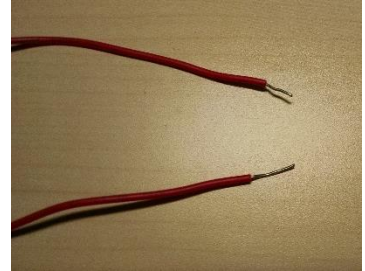
    2. an open circuit?

b) Is the image shown at the right

   1. a short circuit?

    2. an open circuit?
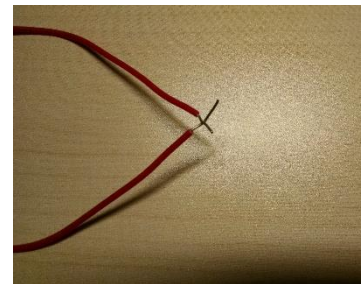
c) In the standard voltage divider configuration shown at the
right, resistor R_1 is much larger than resistor R_2. Is the power
dissipated in R_1

    1. Much greater than the power dissipated in R_2

    2. Much less than the power dissipated in R_2

    3. About the same as the power dissipated in R_2
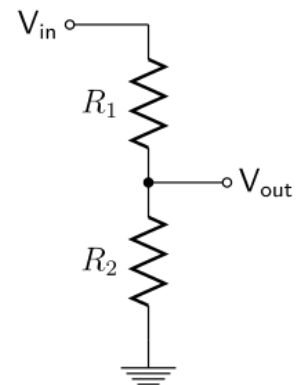
d) In the circuit at the right, two resistors (R_1 much larger
than R_2) are connected in parallel across a voltage
source V. Is the power dissipated in R_1

    1. Much greater than the power dissipated in R_2

    2. Much less than the power dissipated in R_2

    3. About the same as the power dissipated in R_2

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orchestra spectrum

singer's spectrum

Frequenz (Hz)
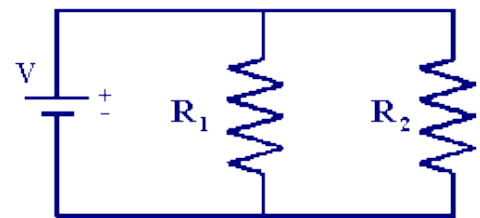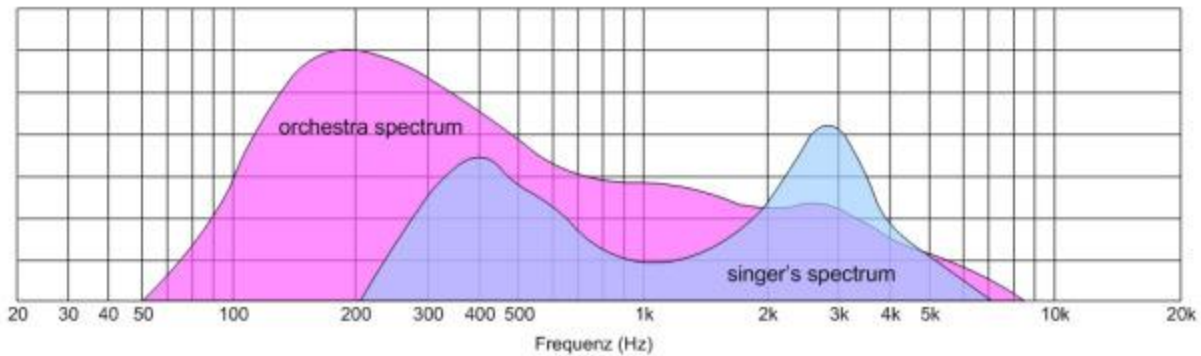
e) Assume that you have a broad-band recorded audio signal containing frequencies from 50Hz to nearly 10kHz, like the combination of a typical singer and a typical orchestra shown above. If this signal is passed through a high-pass or low pass *RC* filter, some of the signal will pass through the filter and some will not. Where does the signal go that does not make it through the filter?

1. It is stored in the capacitor *C*.

2. It is turned into heat by the resistor *R*.

3. It is reflected back to the source.

V(b)
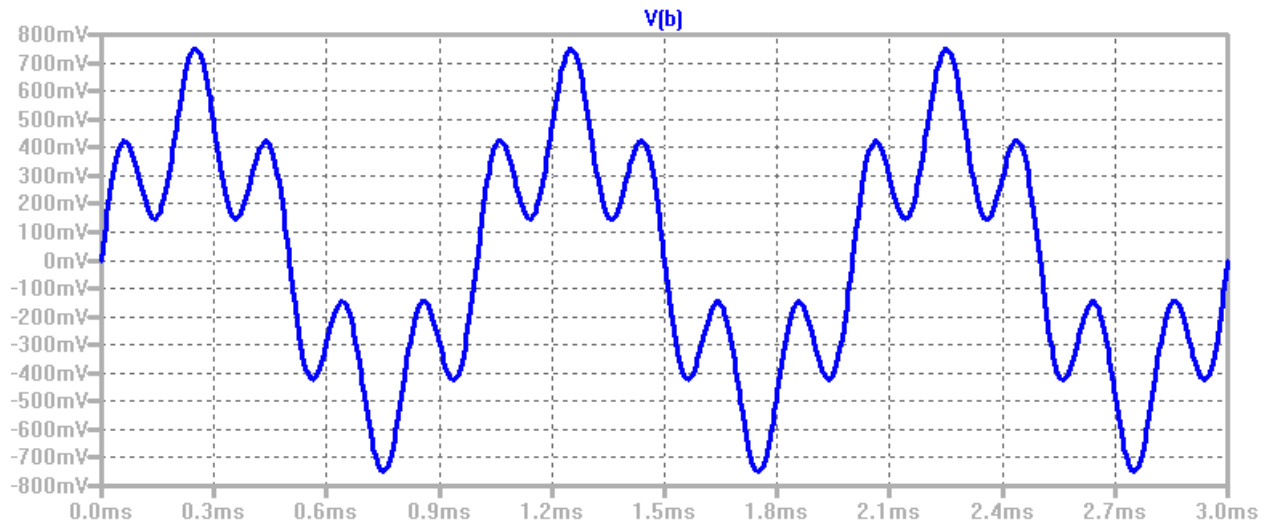
f) The signal shown above consists of two sinusoidal voltage waves with different frequencies. What are the two frequencies? The vertical scale is 100mV/Div and the horizontal scale is 3ms/Div. Circle the correct answers. (2 pts)

| 500Hz | 2kHz | 5kHz | 20kHz |
| 1kHz | 2.5kHz | 10kHz | 25kHz |

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g) A student gets into the tinkering spirit and decides to see what happens if a voltage divider is connected backwards. That is, the input voltage V_{IN} is connected where the output is usually measured and the output is measured where the input voltage is usually connected, as shown in the figure. If $V_{IN} = 4Volts$, $R_1 = 3k\Omega$ and $R_2 = 1k\Omega$, what voltage will be measured? Circle the correct answer.
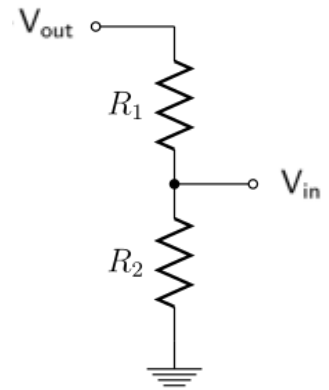
0V	6V
1V	8V
2V	12V
(4V)	16V

h) What are the colors & names of the two wires for 'Scope Ch2?

2+ and 2-   blue and blue/white

i) What are the colors & names of the two wires for Arbitrary Waveform Generator (AWG) 1?

W1 and Ground (down arrow),   Yellow and Black

j) Is it always necessary to measure both the input and output voltage or current for every circuit studied?
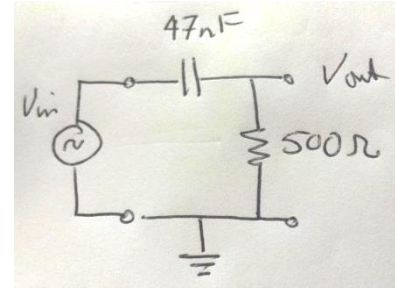
Yes!

k) What are the magnitude and phase of the transfer function for this RL circuit at high (not infinite) frequencies? (2 pts)

$$\frac{i\omega L}{R + j\omega L} \approx \frac{j\omega L}{j\omega l} = 1 \ so \ the \ phase \ is \ zero$$

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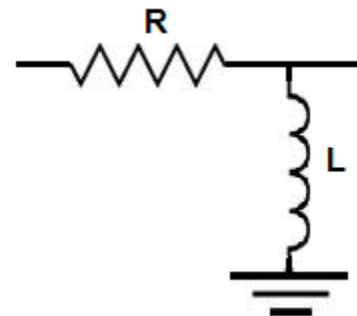
l) In the CR circuit at the right, is the current in R relatively large or small when the frequency is high?

High because the capacitor is a short circuit

m) What could you do to improve the coupling of your transformer so that it will work equally well in both step up and step down modes?
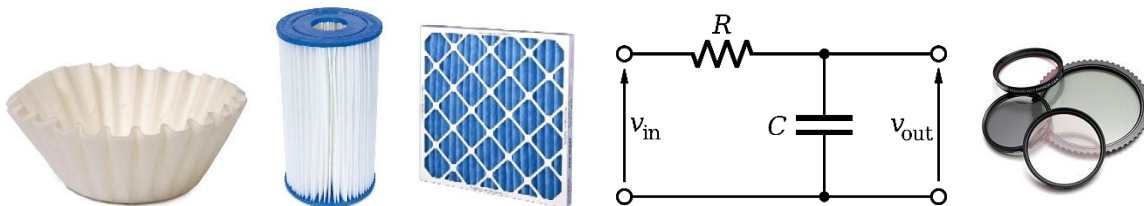
Make the primary and secondary the same length.

n) What is the color code for a 10kΩ resistor? (2 pts)

Brown   Black   Orange

o) Whose birthday is it today?

Steve Jobs

p) Which of the following images might be shown when searching online for 'filters?'

All of them

q) What is a typical internal resistance for a 9V Lithium battery?

From page 4, R_{int} is 18Ω