# ENGR-2300

# Electronic Instrumentation

# Quiz 1

# Fall 2018

**Name _____SOLUTIONS____________**

**Section ___**

Question I (20 points) ___________

Question II (20 points) ___________

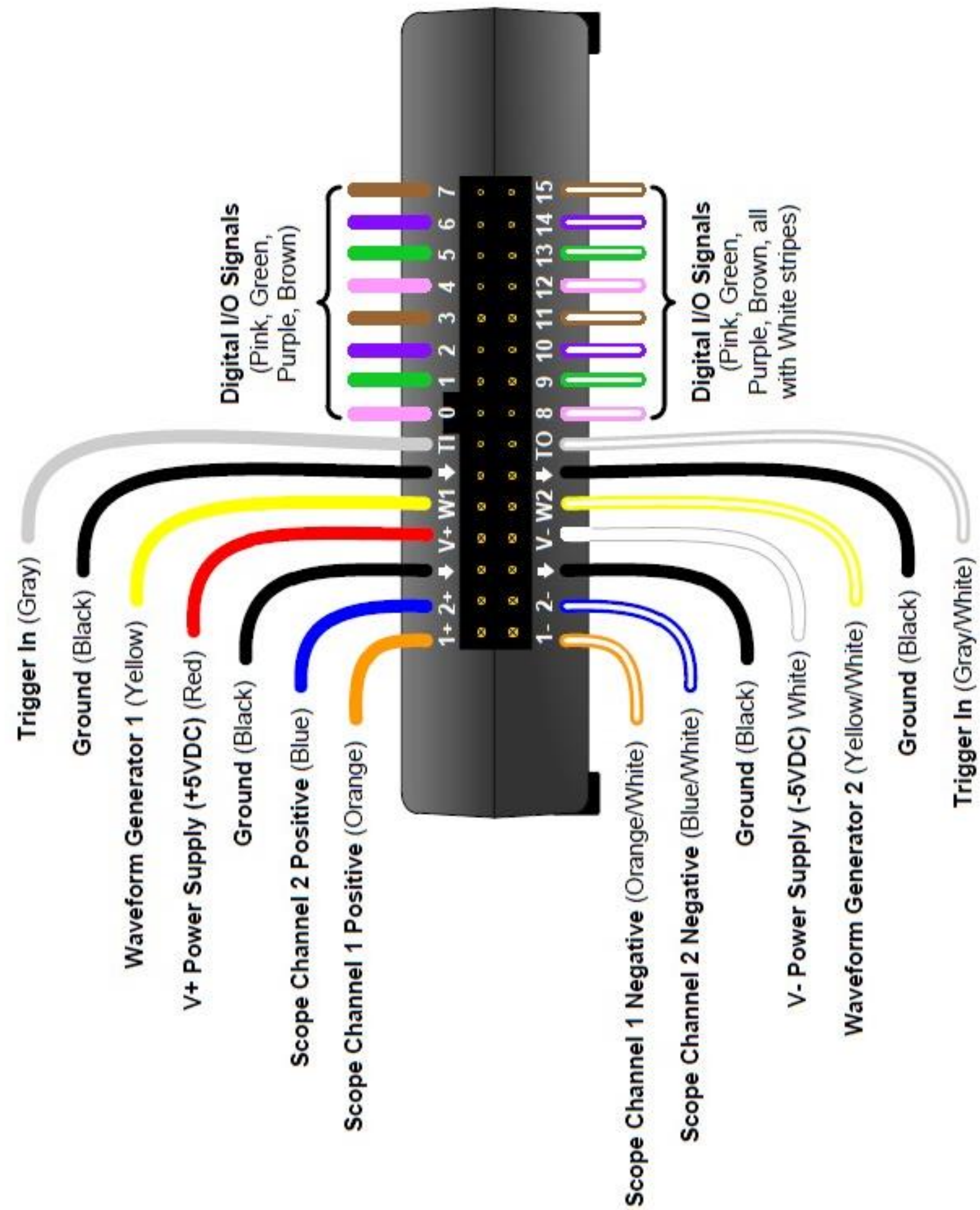
Question III (20 points) ___________

Question IV (20 points) ___________

LMS Question (20 points) (graded on LMS)

Total (80 points) ______________

On all questions: SHOW ALL WORK. BEGIN WITH FORMULAS, THEN SUBSTITUTE VALUES AND UNITS. No credit will be given for numbers that appear without justification. Unless otherwise stated in a problem, provide 3 significant digits in answers. Read the entire quiz before answering any questions. Also it may be easier to answer parts of questions out of order.




| Type | $R_{int}$ (Ω) | $V_{oc}$ (V) | Capacity[a] continuous, to 1V/cell (mAh) | @ (mA) | (mAh) | @ (mA) | Size (in) | Weight (gm) | Connec[b] | Comments |
|---|---|---|---|---|---|---|---|---|---|---|
| *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-$MnO_2$ |

**Analog Discovery 2 partial set of Specifications -**
**Analog Inputs**

- Channels: 2
- Channel type: differential
- Resolution: 14-bit
- Input impedance: 1MΩ||24pF
- Scope scales: 500uV to 5V/div
- Analog bandwidth with included flywires: 9 MHz @ 3dB, 2.9 MHz @ 0.5dB, 0.8 MHz @ 0.1dB
- Input range: ±25V (±50V diff)
- Input protected to: ±50V
- Cursors with advanced data measurements
- Captured data files can be exported in standard formats
- Scope configurations can be saved, exported, and imported

**Arbitrary Waveform Generator**

- Channels: 2
- Channel type: single ended
- Resolution: 14-bit
- AC amplitude (max): ±5 V
- DC Offset (max): ±5 V
- Analog bandwidth with included flywires: 9 MHz @ 3dB, 2.9 MHz @ 0.5dB, 0.8 MHz @ 0.1dB
- Slew rate (10V step): 400V/μs
- Standard waveforms: sine, triangle, sawtooth, etc.
- Advanced waveforms: Sweeps, AM, FM.
- User-defined arbitrary waveforms: defined within WaveForms software user interface or using standard tools (e.g. Excel)

**Power Supplies**

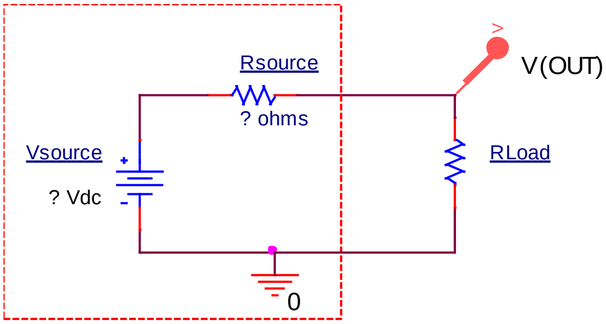
- Voltage range: 0.5V…5V and -0.5V…-5V
- Pmax (USB powered): 500mW total
- Imax (USB powered): 700mA for each supply
- Pmax (AUX powered): 2.1W for each supply
- Imax (AUX powered): 700mA for each supply
- Accuracy (no load): ±10mV
- Output impedance: 50mΩ (typical)

**Voltmeters**

- Channels (shared with scope): 2
- Channel type: differential
- Measurements: DC, AC, True RMS
- Resolution: 14-bit
- Accuracy (scale ≤0.5V/div): ±5mV
- Accuracy (scale ≥1V/div): ±50mV
- Input impedance: 1MΩ || 24pF
- Input range: ±25V (±50V div)
- Input protected to: ±50V

**I. Voltage Dividers (20 points) As stated on the cover page: Round answers to 3 significant digits. Show formulas first and show your work. *No credit will be given for numbers that appear without justification.*** *Note: Pages 2 and 3 of this quiz have background information.*

Batteries and other voltage sources can generally be modeled by combining an ideal voltage source and a resistor. The circuit below is set up to characterize the voltage source shown in the red dashed box. Six different load resistors are connected and the voltage V(OUT) is measured. The results of the six trials are listed in the table below. *Note that there is more information than you need to find the source voltage and resistance.*




| Trial | Rload | V(OUT) |
|---|---|---|
| 1 | 1MΩ | 12V |
| 2 | 100kΩ | 11.99V |
| 3 | 10kΩ | 11.94V |
| 4 | 1kΩ | 11.43V |
| 5 | 100Ω | 8V |
| 6 | 10Ω | 2V |

a) Find the source voltage **Vsource**. (4pts)

Since Rload>>Rsource during trial 1, we can approximate V(OUT) as Vsource.

Vsource =___12V___

b) Find the source resistance **Rsource**. (4pts)

Consider trial 5. Current through RLoad (same as current supplied by source, and going through Rsource) is 8V/100Ω = 80mA.

Using voltage division, voltage across Rsource=4V (Vsource – Vout)
Rsource=4V/80mA=50 Ω.

Rsource =___50 Ω__

c) Given RLoad=100Ω, find the **power dissipated** by each resistor Rsource and Rload. (4pts)

$P_{Rsource}$ = VI = (4V)(80mA) = 320mW = 0.32W
$P_{RLoad}$ = (8V)(80mA) = 640mW = 0.64W

$P_{Rsource}$ = __0.32W__

$P_{RLoad}$ = _0.64W____

d) **Verify** that power dissipated by both resistors is equal to the power supplied by Vsource. Use the same RLoad as in part c. (4pts)

Power supplied by Vsource= VI = (12V)(80mA) = 0.96W

$P_{RLoad}$ + $P_{Rsource}$ = __0.96W___(from previous part) $P_{Vsource}$ = ___0.96W_______

e) Which of the following type of resistors will work for RLoad in these six trials? Assume all six resistors are the same type, and then circle all possible answers. (4pts)

$P_{max} = max\left(\frac{VOUT^2}{RLoad}\right) = \frac{8\times8}{100}$ = 640 mW

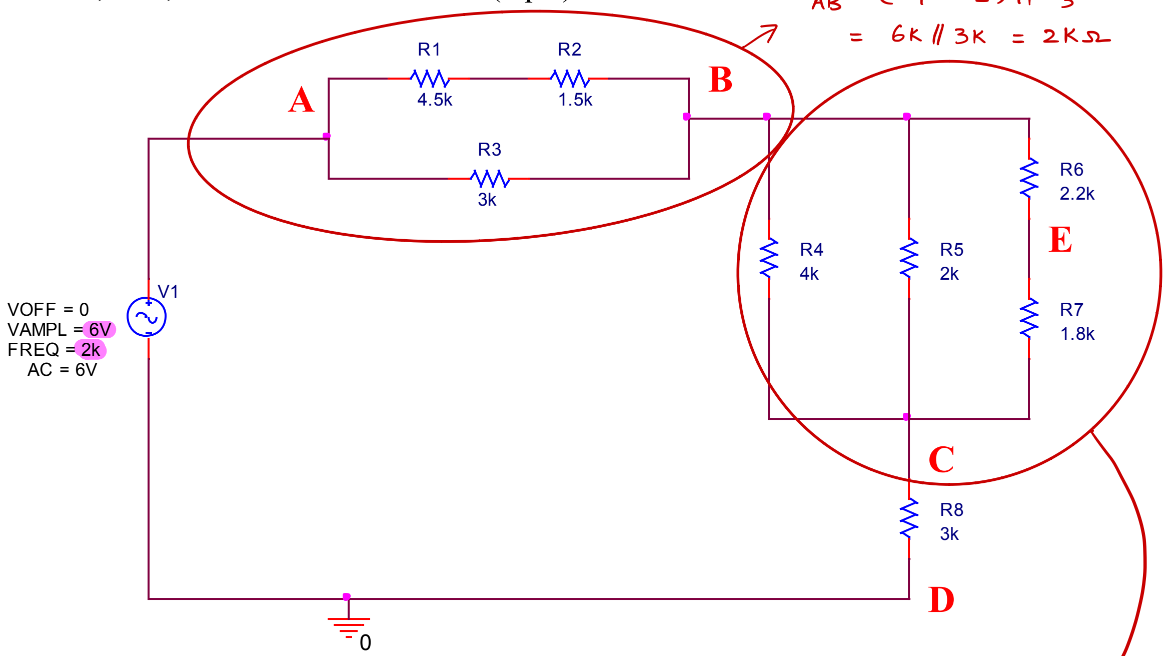
1W and 2W resistors will work!

¼ W ½ W 1W (circled) 2W (circled)

**II. Resistor Combinations, concepts and miscellaneous (20 points)** *Please note that pages 2 and 3 of this quiz have background info.*

a) Find the resistance between node A and node B, $\mathbf{R_{AB}}$, and resistance between node B and node C, $\mathbf{R_{BC}}$, shown in circuit below. (2 pts)

$R_{AB} = (R_1 + R_2) \| R_3$
$= 6K \| 3K = 2K\Omega$




$R_{BC} = R_4 \| R_5 \| (R_6 + R_7)$
$= 4K \| 2K \| 4K$
$= 1K\Omega$

$R_{AB}$ = 2KΩ $R_{BC}$ = 1KΩ

b) Find the peak voltages at points A, B, C, and D (4pts)

Peak source voltage = 6V

Peak voltage at A, $V_A = 6V$

Peak voltage at B, $V_B = 6\left(\frac{4K}{6K}\right) = 4V$

Peak voltage at C, $V_C = 6\left(\frac{3K}{6K}\right) = 3V$

Peak voltage at D, $V_D = 0V$ (GND)

$V_A$ = 6V

$V_B$ = 4V

$V_C$ = 3V

$V_D$ = 0V

c) Find the peak current through resistor R6, i.e. 2.2k ohm (3pts)

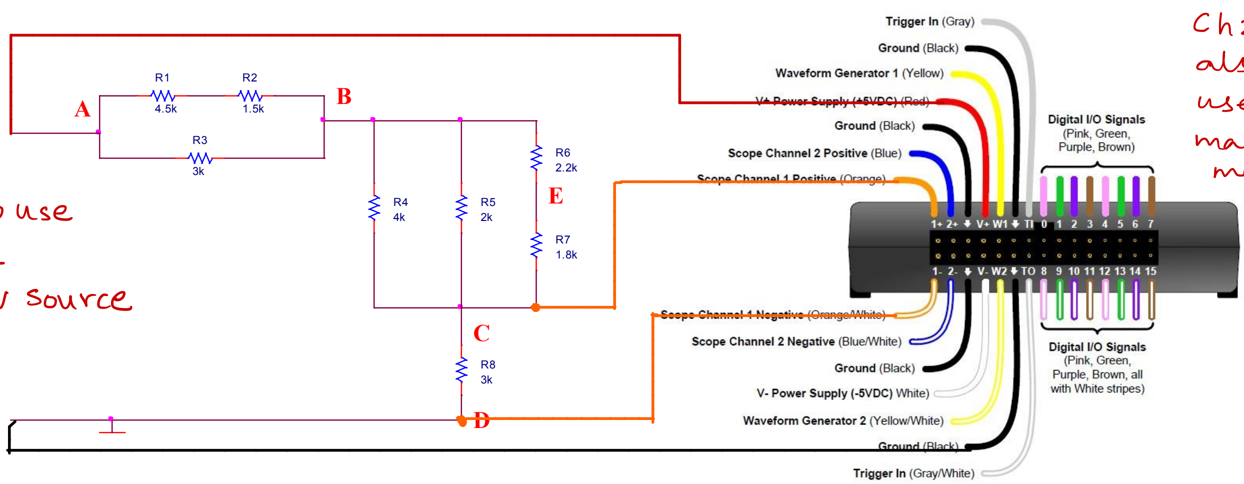
$$I_{R6} = I_{R7} = \frac{V_{BC}}{R_6 + R_7} = \frac{4V - 3V}{4K} = 0.25\,mA = 250\,\mu A$$

$I_{R6}$ = 250 μA

d) Current through resistor R6 is a periodic waveform. Find its time period. (1 pt)

Voltages and currents at any point in circuit $= \frac{1}{f} = \frac{1}{2KHz} =$ 0.5 ms

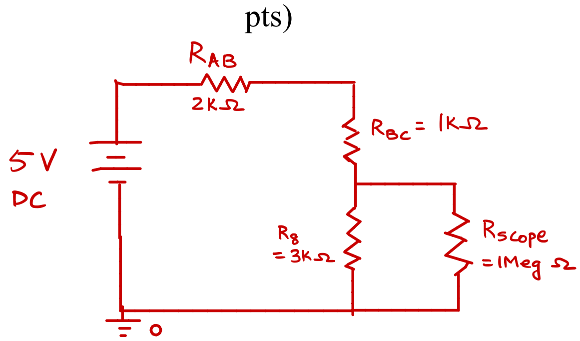
e) In the figure below, the same resistive network has been redrawn without the voltage source. Draw lines to represent the wires you need to connect to determine the voltage across $R_8$ i.e. voltage between nodes C and D, when input voltage is 5V DC using only the Analog Discovery (no additional instrumentation). (3pts)




Can also use W1 or W2 as DC 5V source

Ch2 can also be used to make measurement

f) What voltage will be measured in part e, i.e. across $R_8$ using the Analog Discovery? Give your answer in Volts. Hint: Add the input resistance of Analog Discovery channel. (3 pts)




$$V_{CD(meas.)} = 5V\left(\frac{R_8 \parallel R_{scope}}{R_{AB} + R_{BC} + R_8 \parallel R_{scope}}\right)$$

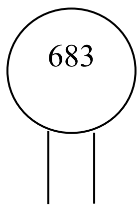
$$= 5V\left(\frac{2991.03}{5991.03}\right)$$

$V_{CD(meas.)}$ = 2.496 V

g) Give a short explanation of the procedure you would follow to plot the current through resistor $R_8$ using Analog discovery board and Waveforms Software? You did something similar to limit the current to about 25mA through the current-limiting resistor in Experiment 3. (1 pt)

Analog Discovery cannot make direct current measurements. You would need to measure voltage across $R_8$ using scope Ch1 or Ch2 and then create a Math channel which does Ch1/3000 A or Ch2/3000 A respectively.

h) What is the capacitance of the capacitor shown below? 0.068 μF (1 pt)




$C = 68 \times 10^{3}$ pF

$= 68$ nF

$= 0.068$ μF

i) What is the resistance of a resistor with the following color code? 6.3KΩ ± 5% (1 pt)

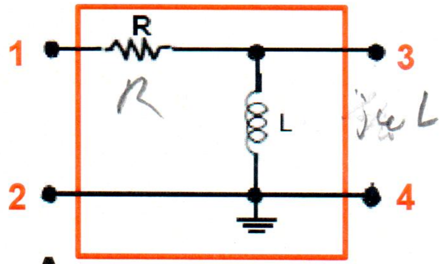

j) When defining the VSIN component (sinusoidal voltage source), indicate any two (of the four) parameters that are available when you place the part. (1 pt)

Amplitude Frequency

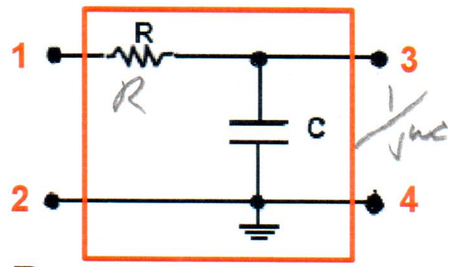
offset AC

Soln

### III. Filters & Transfer Functions (20 points)




A




B

a) Shown above are basic, two-element, passive filter configurations made with RL and RC combinations. Determine the general complex transfer function for each circuit in terms of R, L, C and frequency ω, by modeling each as a voltage divider. This is an AC steady state problem. (2 pts)

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

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

b) For both circuits, what are the magnitude and phase for low frequency, but not zero frequency? (2pts)

Circuit A Mag $\left|\frac{j\omega L}{R}\right| = \frac{\omega L}{R}$ Phase $\angle(j\omega L) - \angle R = 90 - 0 = 90^\circ$

Circuit B Mag $\frac{1}{1} = 1$ Phase $\angle 1 - \angle 1 = 0 - 0 = 0$

c) What type of filter is each? Choices are as shown on the Crib Sheet: low pass, high pass, band pass or band reject. (2pts)

Circuit A High Pass

Circuit B Low Pass

d) Given: L=5mH, R=1kΩ, and C=1uF. Find the corner frequency for each circuit. Give the value of both $\omega_C$ and $f_C$. (4pts)

Circuit A $|R| = |j\omega L|$

$\omega_A = \frac{R}{L} = \frac{1000}{5\times10^{-3}} = 2\times10^5$ rad/sec

$f_A = \frac{\omega_A}{2\pi} = 3.18\times10^4$ Hz

Circuit B $|R| = \left|\frac{1}{j\omega C}\right|$

$\omega = \frac{1}{RC} = \frac{1}{(10^3)(10^{-6})}$

$\omega = 1000$ rad/sec

$f = 159$ Hz

e) Given the three transfer functions phase plots below, pick the corresponding function from the ones provided. Write the letter of the transfer function in the space provided.(6pts)

a) $H(j\omega) = \dfrac{\frac{1}{j\omega C}}{\frac{1}{j\omega C} + R + j\omega L}$

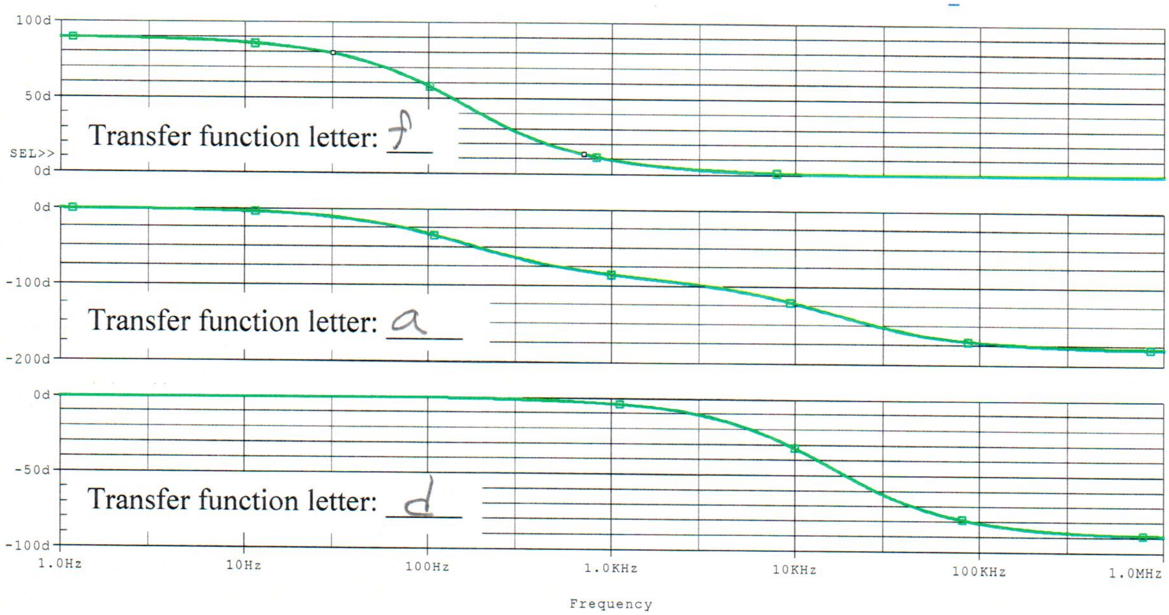
d) $H(j\omega) = \dfrac{\frac{1}{j\omega C} + R}{\frac{1}{j\omega C} + R + j\omega L}$

b) $H(j\omega) = \dfrac{j\omega L}{\frac{1}{j\omega C} + R + j\omega L}$

e) $H(j\omega) = \dfrac{\frac{1}{j\omega C} + j\omega L}{\frac{1}{j\omega C} + R + j\omega L}$

c) $H(j\omega) = \dfrac{R}{\frac{1}{j\omega C} + R + j\omega L}$

f) $H(j\omega) = \dfrac{R + j\omega L}{\frac{1}{j\omega C} + R + j\omega L}$

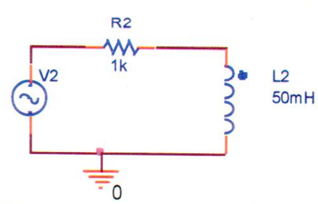



Transfer function letter: f

Transfer function letter: a

Transfer function letter: d

f) For the circuit shown determine the magnitude and phase angle of the voltage across L2 given that V2 has a magnitude of 1V, a phase angle of 0 degrees and f=2kHz. (2pts)




$\underline{V}_2 = H(j\omega)\underline{V}_1 \qquad \underline{V}_1 = 1\angle 0^\circ$

$f = 2000 \quad \omega = 1.26\times10^4 \text{ rad/sec}$

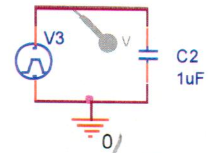
$H(j\omega) = \dfrac{j\omega L}{R + j\omega L} = \dfrac{(j)(1.26\times10^4)(5\times10^{-2})}{1000 + j(1.26\times10^4)(5\times10^{-2})} = \dfrac{j\,628}{1000 + j\,628}$

$|H(j\omega_1)| = \dfrac{628}{\sqrt{1000^2 + 628^2}} = 0.869 \qquad \angle H(j\omega_1) = 0 - \tan^{-1}\dfrac{628}{1000} = -31.8^\circ$

$|V_2| = 0.869 \quad \angle V_2 = -31.8^\circ$ OR $-0.55$ rad

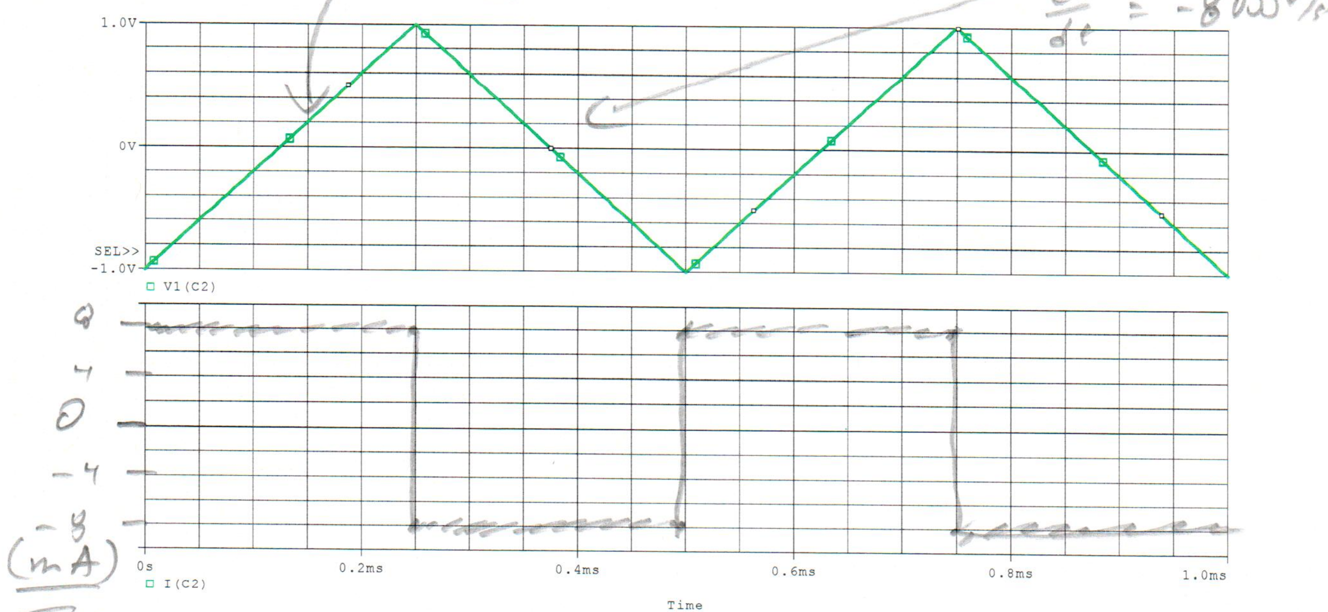
Soln

g) The plot below shows the voltage applied to a 1uF capacitor (C2 in the figure.) On the blank plot, sketch the current flowing through C2. You must assign values to the vertical axis and label key values. (2pts)




$\frac{dv}{dt} = \frac{2}{0.25ms} = 8000\ V/sec$

$\frac{dv}{dt} = -8000\ V/s$

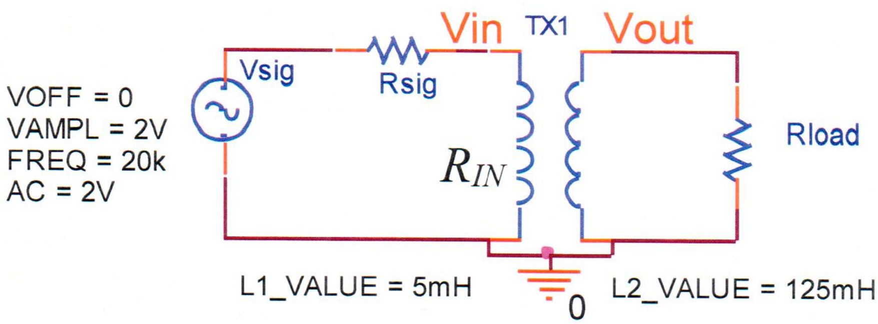



From Crib sheet $I_c = C \frac{dv_c}{dt}$

$I_c = (10^{-6})(8 \times 10^{3}) = 8 \times 10^{-3}\ A$

$= 8\ mA$

**IV – Signals, Transformers and Inductors (20 points)**




Given the circuit above with **Rsig=100Ω, and Rload=5kΩ**, assume an ideal transformer with full coupling.

a) For the given information, determine the turns ratio, a. And determine the ratios Vout/Vin, Iout/Iin and the transformer input impedance Rin. (Rin is Vin/Iin) (6 pts)

$a = \frac{N_2}{N_1} = \sqrt{\frac{L_2}{L_1}} = \sqrt{\frac{125mH}{5mH}} = 5$

$V_{out} = a \cdot V_{in} \quad \frac{V_{out}}{V_{in}} = a, \quad \frac{I_{out}}{I_{in}} = \frac{1}{a}$

$R_{in} = \frac{R_{load}}{a^2} = \frac{5000}{25} = 200$ ohms

a= 5 (2)

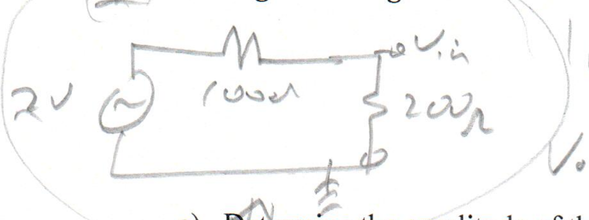
Vout/Vin= 5 (1)

Iout/Iin= 0.2 (1)

Rin= 200Ω (2)

b) Draw the circuit diagram for the voltage divider consisting of the signal source resistance, Rsig, and transformer input impedance Rin from part a). Then ***solve for Vin*** (voltage across the input terminals of the ideal transformer) ***and Vout,*** the voltage across the output terminals and the of the ideal transformer. **Assume the phase of Vsig is zero degrees and give the answer in the form of v(t)=V₁Cos(ωt+θ₁)** (4 pts)

(2)




$|V_{in}| = (2)\frac{200}{300} = 1.33$

$V_{out} = a V_{in}$

Vin(t)= 1.33 cos ωt (1)

Vout(t)= 6.67 cos ωt (1)

c) Determine the amplitude of the primary and secondary currents (Iin and Iout). This is just the magnitude not the time domain form (2 pts)

I from $V_{sig} = I_{in} = \frac{2}{100+200} = 6.67mA$

$I_{out} = \frac{1}{a} I_{in} = 1.33mA$

Iin= 6.67mA

Iout= 1.33mA

Soln

d) The experiment was repeated with different number of turns for L1, the primary windings. Complete the chart below given the different values of a, the turns ratio. Keep other values of part a) (6pts)

| a | $R_{IN}$ | Vin | Vout |
|---|---|---|---|
| 10 | 50 Ω | 0.667V | 6.67V |
| 7 | 102 Ω | 1.01V | 7.07V |
| 4 | 312 Ω | 1.51 V | 6.06 V |

$R_{in} = \frac{R_{load}}{a^2}$


$V_{out} = a V_{in}$

e) Of the different values of a, the turns ratio, in part d), which will deliver the most power to the load, Rload? (2pts) Power to load $= V_2^2 / R_{load}$

Max $V_2$ ⇒ max power

$a = 7$ is max for the value of in in part d)

Comment: Maximum power to the load is desired when detecting signals, such as with the detector for a satellite dish or cell tower receiver. The load is the sensor. The signal source and the signal resistance is the antenna. Transformers are often used to match the source signal to the detector. The power grid is very different. For power distribution it is more important to maximize the efficiency than to maximize the power to the load.