COMPSYS/ELECTENG 209 – Progress Review Preparation

Analogue Design

You are expected to deliver an LTspice simulation model of your team's final analogue design, which should have the functionalities listed below,

1. Voltage and current sensing circuit design (Lab 1 Q3 & Q4)
2. Level-shifting and amplification circuit design for both voltage and current sensors (Lab 2 Q2 & Q3)
3. Filter circuit designs for both voltage and current sensors (Lab 2 Q4)
4. 5V regulator circuit design (Lab 2 Q5)
5. Circuitry to generate the offset voltage supplied to the Op-Amp (Lab 2 Q5)
6. Voltage zero crossing detector circuit design

The model should be in a single LTspice file, neatly drawn with text comments to help us understand your design (you may copy-paste LTspice model given for Lab 2 and use it as a template - remove unwanted parts, rearrange to make it tidy and add extra parts as needed). Read LTspice Simulations to understand how we will assess and test your model.

Part 1: Voltage and current sensing circuit design (Lab 1 Q3 & Q4)

Instructions from Lab 1 Part 3

Part 3: Sensing AC Load Current Your analogue circuitry should sense the current through the AC load as well as the voltage supplied by the AC source.

Current sensor: can be measured using a shunt resistor, which produces a voltage drop that is proportional to the current flowing through it. Because the microcontroller ADC can only read analogue voltages and convert them to digital numbers. Therefore, we must convert the current to a corresponding voltage before it can be fed to an ADC channel through a signal conditioning circuit.

CURRENT SENSOR

Selected Shunt Resistor (R_S): 0.565 Ohms

Working for Q2.1 (Calculating maximum and minimum current)

$$S = I^2 Z$$

$$S = \frac{V^2}{Z}$$

$$7.5 = \frac{12.6^2}{Z}$$

$$Z = 21.168$$

$$I^2 = \frac{S}{Z} = \frac{7.5}{21.168}$$

$$I_{max} = 0.595\ A$$

$$S = I^2 Z$$

$$S = \frac{V^2}{Z}$$

$$2.5 = \frac{15.4^2}{Z}$$

$$Z = 94.864$$

$$I^2 = \frac{S}{Z} = \frac{2.5}{94.864}$$

$$I_{min} = 0.16234\ A$$

Shunt resistor Calculations at $P = 200\ mW$:

$$P = I^2 R_s$$
$$At\ I_{\text{minimum}} = 0.162\ A, \qquad R_s = 5.589\ \Omega$$
$$At\ I_{maximum} = 0.595\ A, \qquad R_s = 0.5649\ \Omega$$

Lab 1 Q 3.2 Sensing the load current

Source VA	Vac(rms)	RL	IL(rms)	Vis(pk) Theo	Vis(pk) Sim	Pis Theo	Pis Sim
7.5VA	12.6V	17	0.595 A	463.8 mV	451.71 mV	190.36 mW	183.08 mW
7.5VA	15.4V	29	0.487 A	382.5 mV	375.25 mV	129.47 mW	124.38 mW
2.5VA	15.4V	94	0.162 A	129.0 mV	128.2 mV	14.72 mW	14.20 mW

Calculation of first row: @ 7.5 VA and 12.6 V

Finding R(load)

$$S = \frac{V^2}{Z} = \frac{V^2}{\sqrt{R^2 + Z^2}}$$

$$\sqrt{R^2 + Z^2} = \frac{V^2}{S}$$

$$R^2 = \left(\frac{V^2}{S}\right)^2 - Z^2 = \left(\frac{12.6^2}{7.5}\right)^2 - (4\pi)^2$$

$$R = 17.034\ \Omega$$

And at **7.5 VA and 12.6 V** we know this gives the **maximum current**, therefore $I = 0.595\ A$

$$I = \sqrt{\frac{S}{Z}} = \sqrt{\frac{7.5}{\sqrt{17^2 + (4\pi)^2}}} = \sqrt{\frac{7.5}{21.168}} = 0.595\ A$$

$V_{is}(pk)$ is the peak of the observed amplitude of sensed voltage:

$$V_{is}(pk) = \frac{R_s}{R_s + Z}(V)(\sqrt{2})$$

$$V_{is}(pk) = \frac{0.565}{0.565 + 21.14}(12.6)(\sqrt{2})$$

$$V_{is}(pk) = 0.4638\ V$$

P_{is} is the power dissipated across the shunt resistor:

$$P_{is} = \frac{V^2}{R} = \frac{\left(\frac{0.4638}{\sqrt{2}}\right)^2}{0.565} = 0.19036\ W = 190.36\ mW$$

Additional comments: Since the power dissipated at the highest current is below 200 mW, we will use the smaller shunt resistor value in our current sensor.

VOLTAGE SENSOR Lab 1 Q4: Sensing AC Source Voltage

- Since the ADC of your microcontroller can only measure voltages in the range from 0V to 5V
- Voltage sensor should step-down to be within this range.
- Achieved by using a **voltage divider** circuit.
- The voltage divider will translate the high voltage AC input to a lower and safer voltage before feeding it into an ADC channel through its own signal conditioning circuit.
- Maximum load voltage to about 2Vpk-pk

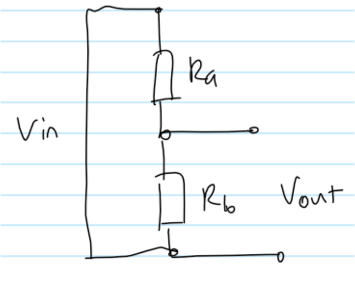
$$2\ V_{pk-pk} \text{ is equivalent to } 1\ V_{pk}$$

$$V_{out} = \frac{R_b}{R_b + R_a}(V_{in})$$

$$1\ V_{pk} = \frac{R_b}{R_b + 56\ k}(15.6)(\sqrt{2})$$

$$R_b = 2.7\ k\Omega\ (E12\ value)$$

Note: $R_a = 56\ k\Omega$ was a random high E12 resistor value, other combinations can work with different R_a values



Q 4.2 Verify voltage divider and check power dissipated

Source VA	Vac(rms)	RL	IL(rms)	Vvs(pk) Theo	Vvs(pk) Sim	Pvs Theo	Pvs Sim
7.5VA	12.6V	17	0.595 A	0.820 V	0.817 V	0.124 mW	0.120 mW
7.5VA	15.4V	29	0.487 A	1.001 V	1.000 V	0.186 mW	0.180 mW
2.5VA	15.4V	94	0.162 A	1.001 V	1.000 V	0.186 mW	0.180 mW

Calculation of first row: @ 7.5 VA & 12.6 V

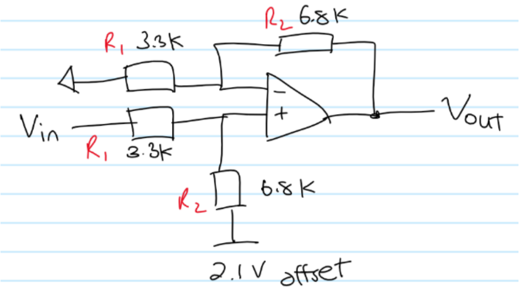
$$R_L = 17\ \Omega, \qquad I_{L(RMS)} = 0.595\ A$$

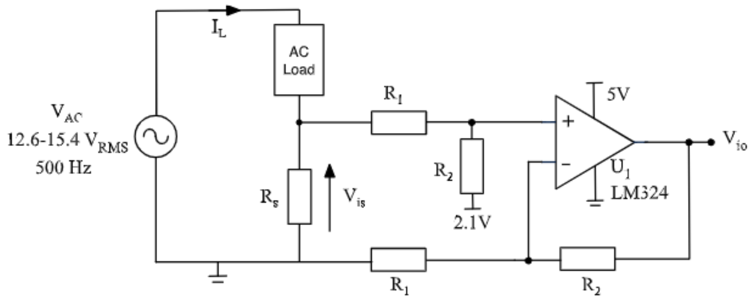
$$V_{vs(pk)} = \frac{2.7k}{2.7k + 56k}(12.6)(\sqrt{2}) = 0.8196\ V$$

$$P_{vs} = \frac{V_{rms}^2}{R} = \frac{\left(\frac{0.8196}{\sqrt{2}}\right)^2}{3920} = 0.1244\ mW$$

Add notes on SNR, Dissipations (Pis), Sensitivity

Part 2: Level-shifting and amplification circuit design for both voltage and current sensors (Lab 2 Q2 & Q3)





To determine the resistor values R1 and R2 that is required to produce output that has 2 Vpk-pk and 2.1V offset, we can find the ratio between amplitude (1 V) and maximum input Vis

$$V_{out} = \left(\frac{R_2}{R_1}\right) V_{in}$$

$$1\ V_{pk} = \left(\frac{R_2}{R_1}\right)(0.4638)$$

$$\frac{R_2}{R_1} = 2.156$$

Let $R_2 = 7\ k\Omega$, then $R_1 = 3.246\ k\Omega$

Converting to E12 resistor values, we will get $R_2 = 6.8\ k\Omega$ and $R_1 = 3.3\ k\Omega$

Lab 2 Q 2.2 Table

Source VA	Vac(rms)	RL	IL	Vis,pk Theo	Vis,pk Sim	Vio,pk Theo	Vio,pk Sim
7.5VA	12.6V	17	0.595 A	463.8 mV	452 mV	3.056 V	3.02 V
7.5VA	15.4V	29	0.487 A	382.5 mV	374 mV	2.888 V	2.87 V
2.5VA	15.4V	94	0.162 A	129.0 mV	128 mV	2.366 V	2.36 V

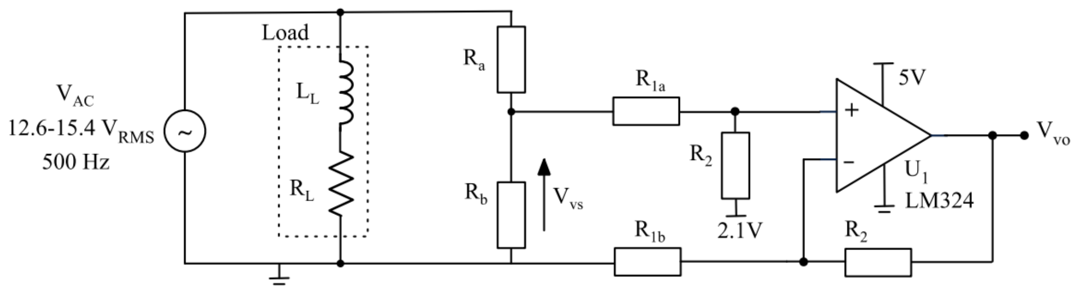
<u>Calculation of first row: @ 7.5 VA and 12.6 V</u>

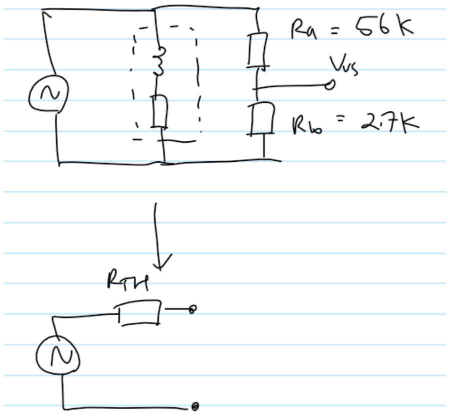
$$V_{is(pk)} = \frac{R_s}{R_s + Z_L}\left(V_{ac(pk)}\right) = \frac{0.565}{0.565 + \sqrt{17^2 + (4\pi)^2}}(12.6)\left(\sqrt{2}\right) = 0.46384\ V$$

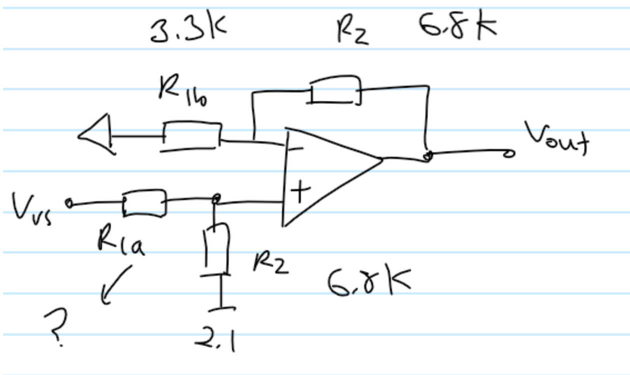
$$V_{io(pk)} = V_{ref} + V_{is(pk)}\left(\frac{R_2}{R_1}\right)$$

$$V_{io(pk)} = 2.1 + (0.4638)\left(\frac{6.8\ k}{3.3\ k}\right) = 3.055709\ V$$

Conditioning Voltage Measurement







Calculating the **Thevenin Resistance**:

$$R_{TH} = \frac{R_a \times R_b}{R_a + R_b} = \frac{56\ k\ \times 2.7\ k}{56\ k + 2.7\ k} = 2.5758\ k\Omega$$

Using $R_{1b} = 3.3\ k\Omega$ we can work out R_{1a}

$$R_{1a} = R_{1b} - R_{TH} = 3.3\ k - 2.5758\ k = 724.2\ \Omega$$

And using E12 resistors, we can use 680 Ω

Some clipping is observed on V_{vsOUT} output from the LTspice simulation. In order to reduce clipping, we will increase the value of resistor R_{1b} from 3.3 $k\Omega$ to 3.9 $k\Omega$. This will mean we need to change out R_{1a} value too.

$$R_{1a} = 3.9\ k - 2.5758\ k = 1.324\ k\Omega$$

$$R_{1a} = 1.2\ k\Omega \text{ (E12 value)}$$

Lab 2 Q 3.2

Source VA	Vac(rms)	RL	IL	Vvo,pk Theo	Vvo,pk Sim
7.5VA	12.6V	17	0.595 A	3.53 V	3.45 V
7.5VA	15.4V	29	0.487 A	3.84 V	3.49 V
2.5VA	15.4V	94	0.162 A	3.84 V	3.49 V

<u>Calculation of first row: @ 7.5 VA and 12.6 V</u>

$$V_{vs(pk)} = \frac{2.7\ k}{2.7\ k + 56\ k}(12.6)(\sqrt{2}) = 0.8196\ V$$

$$V_{vo(pk)} = V_{ref} + V_{vs}\left(\frac{R_2}{R_1}\right) = 2.1 + (0.8196)\left(\frac{6.8\ k}{3.9\ k}\right) = 3.529\ V$$

Part 3: Filter circuit designs for both voltage and current sensors (Lab 2 Q4)

- Signals from op amp contain lots of high-frequency electrical noise
- Due to aliasing the noise will introduce error in digital values obtained by C program

$$Transfer\ function\ of\ \frac{V_{filter}}{V_{OpAmp}}$$

$$\frac{V_{filter}}{V_{OpAmp}} = \frac{X_c}{Z} = \frac{X_c}{\sqrt{R^2 + X_c^2}}$$

Cut-off frequency at $10\ kHz$

$$f_c = \frac{1}{2\pi RC}$$

$$Let\ R = 1\ k\Omega$$

$$10\ kHz = \frac{1}{2\pi(1\ k\Omega)C}$$

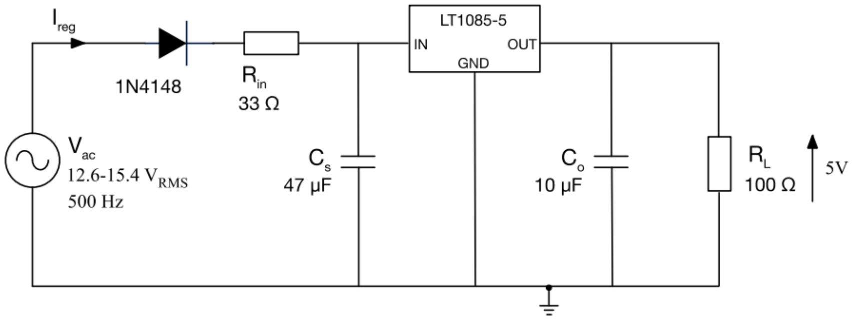
$$C = 15.915\ nF$$

Bode Magnitude and phase plots:

Magnitude → the modulus of the transfer function.

Phase → this only matters if there are more components e.g. voltage and current, they could be out of phase which could introduce inaccuracies in calculations

Part 4: 5V regulator circuit design (Lab 2 Q5)



$$C_{in} = \frac{I_{in}T_g}{\Delta V_{in}}$$

$$\Delta V_{in} = \frac{(50\ mA)\left(\frac{1}{500\ Hz}\right)}{47\ nF}$$

$$\Delta V_{in} = 2.12765\ V$$

Part 5: Circuitry to generate the offset voltage supplied to the Op-Amp (Lab 2 Q5)

Buffer is used in addition to a voltage divider to derive 2.1 V offset.

- Advantages of buffers: zero resistance and constant voltage
- Disadvantages: limited output current