UNIVERSITY OF MIAMI
Department of Electrical and Computer Engineering
EEN 204

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EXPERIMENT 4

WHEATSTONE AND OWEN BRIDGES / PHASE MEASUREMENTS

PURPOSE: To introduce the student to two commonly used bridge circuits and to familiarize him with other impedance measuring techniques. To introduce the student to the different applications of cathode ray oscilloscopes. The *Wheatstone* and *Owen* bridges will be studied in this lab as well as phase measurements.

It is true that to measure the resistance of an element we need only measure the current flowing through it with an ammeter and the potential difference of its terminals with a voltmeter. Then, the ratio of V on I is formed and the resistance is known. However, ideal ammeters and voltmeters have to be used to measure resistances with great degree of accuracy. Ideal ammeters and voltmeters have internal resistances of zero and infinity, respectively. Practical measuring instruments don't. Since ammeters must be connected in series to measure currents, their effect is to reduce the true value of the currents they measure as a result of its finite internal resistance. Voltmeters, on the other hand, produce higher voltage readings since their finite but large resistances have the effect of reducing the circuit resistance when connected in parallel. For this reason, the ammeter-voltmeter method is not recommended for precise measurements since most meters cannot be read to more than three-digit accuracy. If this method is used, the internal resistance of the voltmeter should be much greater than R and the ammeter's resistance should be much less than R.

Bridges, on the other hand, can be used to accurately measure resistances. Different types of bridges exist and each has its own balance equations for determining unknown resistances. The principle is very simple: vary a known component until the voltmeter reading (see Fig. 4.1) drops to zero. When this condition is met, the unknown resistance is calculated by simple equations derived in terms of the bridge's known components. Bridges are not limited to applications where only resistances are measured. There are bridges designed to measure inductance's and capacitance's also, but their balancing equations are more complicated (see Figs. 4.3b-g).

Equipment

1 DC Power Supply
1 Frequency Generator
1 DVM (Multimeter)
1 Variable Resistance Box
1 Variable Capacitance Box

Preliminary Work

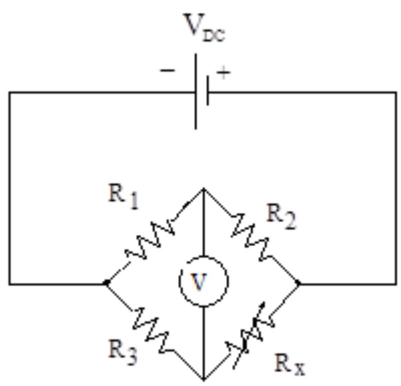
a) Derive the balancing equation for the circuit in Fig. 4.1 (*Hint:* the current across the voltmeter must be zero).

b) Derive the balancing equations for the circuit in Fig. 4.2.

Experimental Procedure

I. Wheatstone Bridge:

a) Set up the circuit of Fig. 4.1. Use a variable resistance box for R_x, let $R_2 = 470\ \Omega$, $R_1=R_3=1k\Omega$, and set the DC power supply to 5 V. The balancing equation is shown below the circuit.



$R_1 = R_x = 1k$

$$R_x = \frac{R_3R_2}{R_1}$$

Figure 4.1 Wheatstone bridge with unknown resistance R_x.

b) Balance the bridge by varying R_x.

c) Measure the values of

$R_1 =$ 1k Ω

$R_2 =$ 470 Ω

$R_3 =$ 1k Ω

d) Calculate the value of R_x from the equation $R_xR_1 = R_2R_3$.

$R_{x,\text{ calculated}} =$ 470 Ω

e) Measure the value of R_X

$R_{X,\ measured}$ = 470 Ω

f) Calculate the % error

% error R_X = 0%

II. Owen Bridge:

a) Select $C_1 = 0.01\ \mu F$, $R_2 = 560\ \Omega$, and $R_4 = 1\ k\Omega$ for the circuit of Fig. 4.2. (*Note:* when R_4 is used in the equations, we must account for the internal resistance of the inductor, r_L. That is in the calculations, R_4 is replaced by $1\ k\Omega + r_L$.). Provide the true measured values for these components.

C_1 = ________ R_2 = ________ R_4 = ________ L = ________

b) Measure the value of the internal resistance, r_L of the inductor.

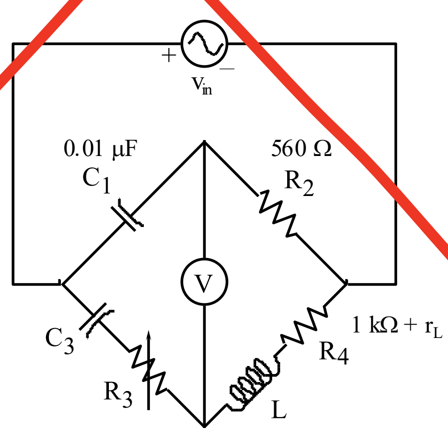
r_L = ________

c) Set the value of the capacitor C_3 by the equation

$$C_3 = \frac{C_1 R_2}{R_4} \quad \text{replace } R_4 \text{ by } r_L + 1\ k\Omega$$

C_3 = ________

d) Set up the circuit shown in Fig. 4.2



$$C_3 R_4 = C_1 R_2 \qquad L = C_1 R_3 R_2$$

Figure 4.2 Owen bridge with unknown inductor L.

e) Balance the bridge by varying R_3.

$R_{3,\ measured}$ = ____________

f) Calculate $R_3 = L/(C_1 R_2)$

$R_{3,\ calculated}$ = ____________

g) Calculate the % error in R_3.

% error R_3 = ____________

III. Phase Measurements

I. Set up the circuit shown in Fig. 8.1. Select R = 4.7 kΩ and C = 0.01 μF. List the measured values in the space provided below.

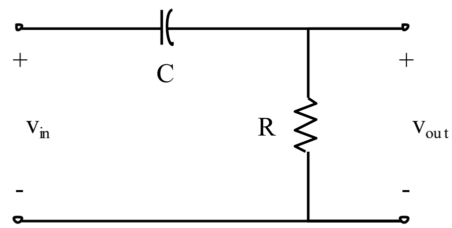


Figure 8.1 Simple *RC* circuit.

V_{in}: 1 Vrms

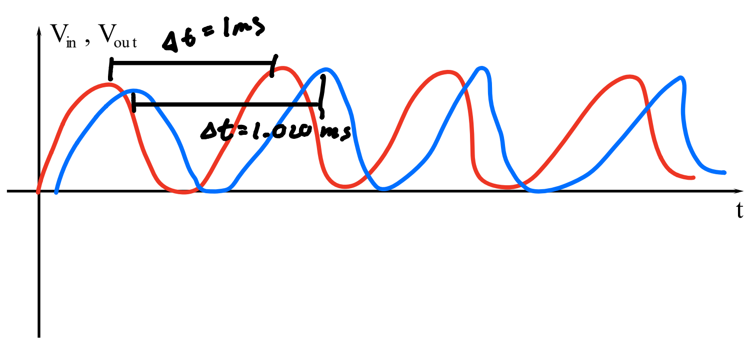
C: 0.01μf

f: 1000 Hz

R: 4.7

II. Find the phase shift between V_{in} and V_{out} by using the scope as a dual tracer. Draw the waveforms and calculate the phase shifts.

$\Delta t - \Delta t = 1 - 1.02\,ms = \frac{0.07}{1}$

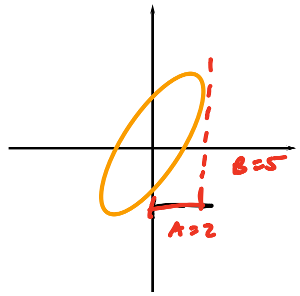


$\theta = 0.07 \times 360$

$= 25.2$

$$\theta = \frac{\text{\# of boxes of phase shift}}{\text{\# of boxes of a full cycle}} \text{ X } 360$$

III. Find the phase shift by using the Lissajous figures (draw it). **Keep the voltage scales equal.** (note: change the scope to xy mode for this)



The phase shift is calculated from the Lissajous figures using the relationship

$$\theta = \sin^{-1}\left(\frac{A}{B}\right) \qquad \sin^{-1}\left(\frac{2}{5}\right) = 23.57°$$

(See NOTES ON LISSAJOUS FIGURES.pdf for a description of A and B.)

VI. By analyzing the circuit of Fig. 8.1, find an analytic expression for the phase shift between V_{in} and V_{out}. **Compare the theoretical result with the findings of parts II and III**. Comment on the accuracy of the phase measurement techniques.

$$V_{out} = V_{in} \times \frac{R}{R - jX_c} = V_{in}\left[\frac{R(R + jX_c)}{R^2 + X_c^2}\right] \longrightarrow \frac{V_{out}}{V_{in}} = \frac{R^2}{R^2 + X_c^2} + j\,\frac{RX_c}{R^2 + X_c^2}$$

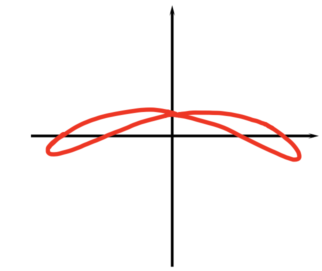
$$\frac{V_{out}}{V_{in}} = |A| \angle\theta \longrightarrow V_{out} = V_{in}|A| \angle\theta$$

$$A = \sqrt{\left(\frac{R^2}{R^2 + X_c^2}\right)^2 + \left(\frac{RX_c}{R^2 + X_c^2}\right)^2}$$

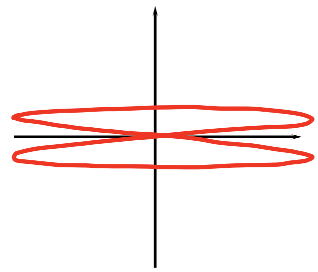
$$\theta = \tan^{-1}\left(\frac{\frac{RX_c}{R^2 + X_c^2}}{\frac{R^2}{R^2 + X_c^2}}\right) = \tan^{-1}\left(\frac{X_c}{R}\right)$$

VII. Connect two signal generators to the two inputs of the oscilloscope. Try to get different shapes of ratios of the two frequencies. Record the results and see if the picture gives the ratio of the frequencies. Use the frequencies given below. Adjust the amplitudes of V_{in1} and V_{in2} to be equal. Take care to match the frequencies of V_{in1} and V_{in2} well to stabilize the figures.

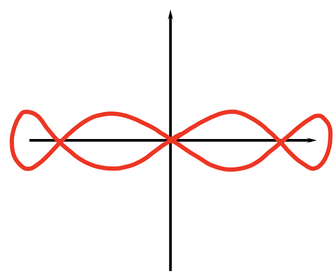
V_{in1}	V_{in2}
100 Hz	200 Hz



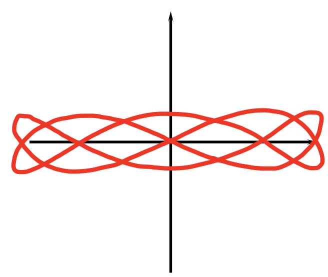
V_{in1}	V_{in2}
200 Hz	100 Hz



V_{in1}	V_{in2}
100 Hz	400 Hz



V_{in1}	V_{in2}
100 Hz	250 Hz



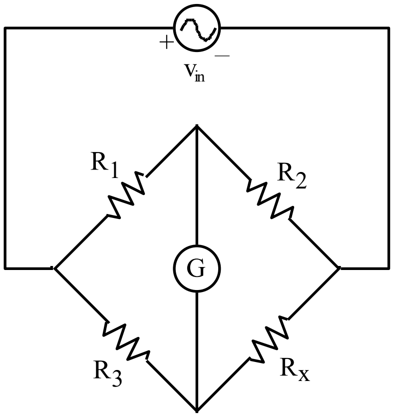
Discussion of Results

a) Prove the modified balance equations for the Owen bridge in Fig. 4.2.

i.e., $L = C_1R_2R_3$ and $r_L = \dfrac{C_1R_2}{C_3} - 1000\ \Omega.$

b) Discuss the sources of error in the experiment and ways of minimizing them.

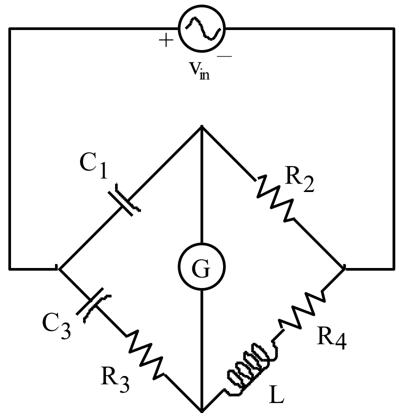
c) Figs. 4.3a-g shows some of the more frequently used bridge circuits in electrical engineering. Below each circuit are the corresponding balance equations.



$$R_xR_1 = R_2R_3$$

Wheatstone Bridge

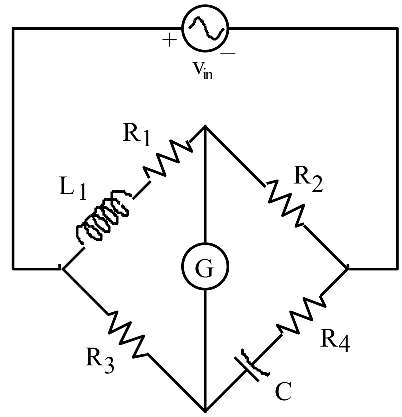
(a)



$$C_3R_4 = C_1R_2 \qquad L = C_1R_3R_2$$

Owen Bridge

(b)

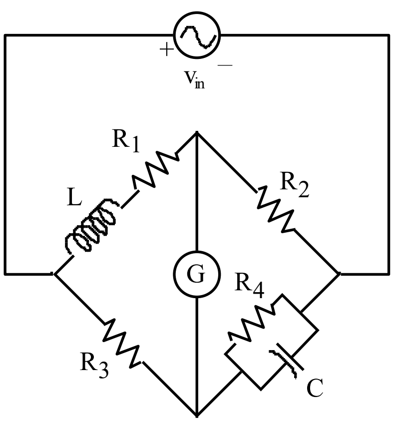


$$L_1 = R_2R_3\frac{C}{1+\omega^2C^2R_4^2}$$

$$R_1 = R_2R_3\frac{\omega^2C^2R_4}{1+\omega^2C^2R_4^2}$$

Hay Bridge

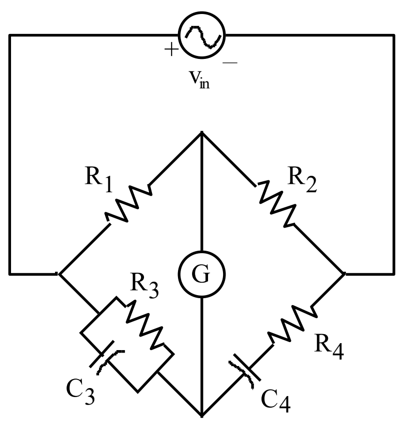
(c)



$$R_1R_4 = R_2R_3 = \frac{L}{C}$$

Maxwell Bridge

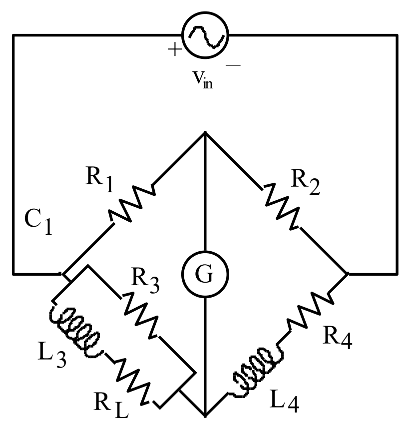
(d)



$$\frac{C_3}{C_4} = \frac{R_2}{R_1} - \frac{R_4}{R_3} \qquad C_3C_4 = \frac{1}{\omega^2R_3R_4}$$

Wien Capacitance Bridge

(e)

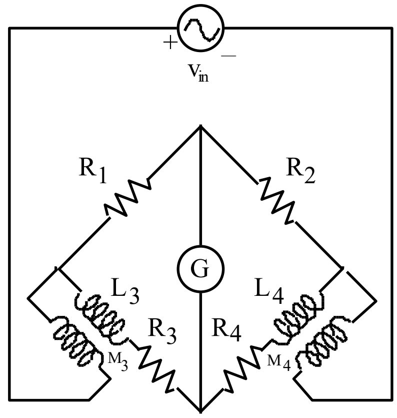


$$\frac{L_3}{L_4} = \frac{R_1(R_L+R_3)}{R_2R_3 - R_1R_4}$$

$$\omega^2L_3L_4 = R_4(R_L+R_3) - R_LR_3$$

Wien Inductance Bridge

(f)



$$R_1R_4 = R_2R_3$$

$$L_3 - L_4\left(\frac{R_1}{R_2}\right) = (M_3 - M_4)\left(1 + \frac{R_1}{R_2}\right)$$

Heaviside mutual-inductance Bridge

(g)

(i) Which quantity is being measured by each bridge?
(ii) What are the advantages or disadvantages of each bridge?

d) *Note:* In addition to their application in measurements, bridge networks find use in phase-correcting circuits. In these circuits, the phase of the input signal is altered while keeping the magnitude the same. Such circuits are employed in telephone networks.

e) Write a conclusion.

Discussion

a). $R_L = \frac{R_2 C_1}{C_1} - 1000$

$L = C_1 R_2 R_4$

b). Since we are using falstad, we should be getting precise answers. Possible errors may arise from the way we measure our variables, and how we calculated our findings.

c). **Wheatstone Bridge**
- calculate resistance R_x and balance output
- Strength → simple
  weakness → low output voltage

Oven Bridge
- inductance measure
- frequency not needed
- expensive

Hay Bridge
- Self inductance measure
- simple and cheap
- needs frequency for calculations

Maxwell Bridge
- calculate inductance or capacitance
- C and L independent of frequency but variable capacitor needed

Wien Capacitance Bridge
- measure capacitance
- can be used to determine R and L for a capacitor

Wien Inductance Bridge
- measures inductance
- stable, but is hard to design.

Heaviside mutual-inductance Bridge
- mutual inductance,
  self capacitence or inductance
- can be used for mutual or self inductance
- other easier ways to accurately measure these quantities.

e). Conclusion

We used a balanced wheatstone bridge to determine the resistance of a resistor in the circuit by balancing it with a variable resistor. This helped us learn how to measure a resistance unknown by using 2 known resistors and a variable resistor. Additionally, since we did this on falstad, we were able to familiarize ourselves with how the wheatstone bridge circuit works and how it runs. And if the wheatstone bridge is balanced $R_1 = R_x$ when voltage across the bridge is zero. And we also used the scope in x-y plot to learn about how f_1/f_2 will appear, their shapes, since we used falstad it was easier to plot and record the figures.