Experiment # 6

Wheatstone's Bridge
Capacitors

Principles

The underlying principles of a Wheatstone Bridge are described in Experiment #5 and need not be repeated here. As stated, the bridge was developed for determining the values of unknown resistances accurately. It works on the principle of ratio-proportion and does not use meters.

In this experiment we investigate the possibility of using a Wheatstone bridge for determining the values of unknown capacitors accurately. A circuit containing capacitors is of little use when fed by DC electricity, simply because no current will flow. If fed by AC electricity, on the other hand, pseudo current will be present in the system. It should be pointed out that pseudo current is capable of performing all the chores of a real current.

In an AC circuit a capacitor may be represented by its reactance χ_C, where:

$$\chi_C = \frac{1}{2\pi f C} \qquad \text{..........(1)}$$

Consider the Wheatstone Bridge circuit shown in Fig. (1a). Resistors R_S and R_X of a conventional Wheatstone bridge have been replaced by capacitors C_S and C_X. Additionally, the bridge is connected to an AC source of frequency f and the balance point is monitored by a headphone.

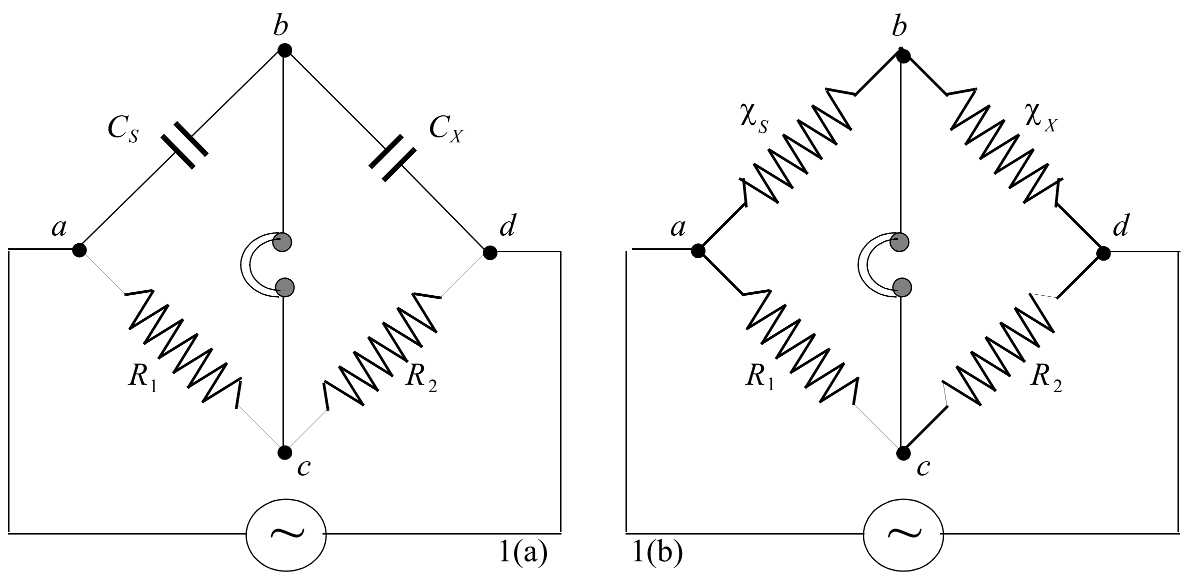


Fig (1) A Wheatstone Bridge For Use with Capacitors.

We next replace the capacitors by their reactances. This is shown in Fig (1b). According to the theory developed in Experiment 5, the bridge will be balanced when:

$$\frac{\chi_S}{\chi_X} = \frac{R_1}{R_2} \qquad \text{..........(2)}$$

Writing:

$$\chi_S = \frac{1}{2\pi f C_S} \qquad \& \qquad \chi_X = \frac{1}{2\pi f C_X}$$

we get:

$$\frac{\chi_S}{\chi_X} = \frac{\frac{1}{2\pi f C_S}}{\frac{1}{2\pi f C_X}} = \frac{C_X}{C_S}$$

The condition for balancing the bridge takes the form:

$$\frac{C_X}{C_S} = \frac{R_1}{R_2}$$

Rearranging, we get:

$$C_S = C_X\left(\frac{R_2}{R_1}\right) \qquad \text{..........(3)}$$

This equation can be used for determining the values of unknown capacitors experimentally, in a laboratory.

Objectives of the Experiment

(a) To determine the value of an unknown capacitor, using a Wheatstone's Bridge

(b) To find the equivalent capacitance of two capacitors when connected (i) in series (ii) in parallel.

Setting Up

Determining the value of an un-known capacitor

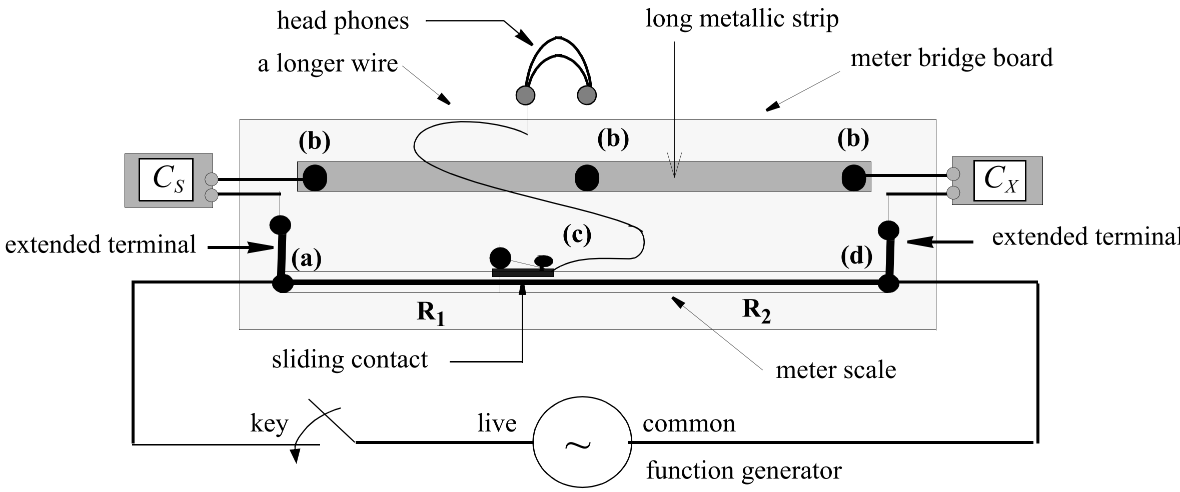
The meter bridge of Experiment 5 and the mathematical analysis may be used for this experiment as well. It was established that:

$$\frac{R_1}{R_2} = \frac{l_1}{l_2} \qquad \text{or} \qquad \frac{R_2}{R_1} = \frac{l_2}{l_1}$$

Inserting this value of R_2/R_1 in Eqn (3) above, we get:

$$C_S = C_X\left(\frac{l_2}{l_1}\right) \qquad \text{..........(4)}$$

This equation is in the form of the equation of a straight line and can be used to determine the value of an unknown capacitor by plotting a graph.



Note: Some models do not have the extended terminals, on the two sides of the meter stick.

Fig (2) A Complete Wheatstone's Bridge Circuit

Series and Parallel Combination of Capacitors

Following are the formulae for calculating the equivalent capacitance C_{eq}, of a set of two capacitors combined in series and in parallel.

Series combination of two capacitors:

$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} \qquad \text{..........(5)}$$

Adding fractions, we get:

$$C_{eq} = \frac{1}{(1/C_1 + 1/C_2)} = \frac{C_1 C_2}{C_1 + C_2} \qquad \text{..........(6)}$$

Parallel combination of two capacitors:

$$C_{eq} = C_1 + C_2 \qquad \text{..........(7)}$$

Formulae (5) and (7) may be extended to accommodate any number of capacitors. Eqn (6), however, is used only when two capacitors are connected together in series.

Procedure

(A) Determining the Value of the Given (Unknown) Capacitor C_X.

(1) Set up the circuit given in Fig (2). We shall use capacitance substitution boxes, one each for the "standard" and the "un-known" capacitors. A special function generator, that incorporates a power amplifier and a digital display, will be used for this experiment. The instrument, however, takes few minutes to warm up. It is recommended that it should be switched on now, allowing enough time for it to produce a steady output. We shall use an external key to connect and disconnect the voltage supply to the circuit. When you are ready to take a trial, close the key and explore the balance point. The key should be returned to the "open" position immediately after the null point has been located.

(2) Set the frequency of function generator to 1.0 kHz. This is the standard test frequency. The frequency is displayed digitally on the LCD screen. Set the volume to a level that is pleasant for your ears. It should not be unnecessarily high. Many of us are used to listening to our favorite music at very high sound levels. Please do not treat this sound as your favorite music. If the level is kept high, the meter bridge wire will become hot.

The connection to the headphone set is made via a special adapter. You will find the adapter on the table. Please use it carefully.

(3) Set a value of 1.0 μF (or the value assigned by the Instructor) on the C_X capacitance box and check its exact value using the LCR-meter. Enter this value (with correct units) in the Data sheet. While using the LCR meter, the *Capacitance box should be removed* from the circuit.

(4) Select following values of C_S on the *standard capacitance,* capacitance box, one at a time: 0.40 μF, 0.50 μF, 0.60 μF,.......1.0 μF, 1.10 μF.......1.50 μF. These will be the twelve trials for this part of the experiment.

(5) For each trial, close the key, move the sliding contact till the sound (in your ears) disappears completely. This is the *galvanometer null* and the bridge is now balanced. You may experience a small region of the length of the wire for which you do not hear any sound. To counter this situation, it is recommended that you move the sliding contact in one direction only, say in the direction of increasing length on the meter stick. The first convincing position of no-sound should be accepted as the null point. Open the key to disconnect the voltage supply. Depress the sliding contact again and carefully read and record the length l_1.

Note (1): While balancing the bridge, *do not drag* the sliding contact over the meter bridge wire. This will eventually deform the wire and its resistance per unit length will become erratic, and so will be the results of the experiment. The best way of moving the sliding contact is to release it before moving; one would go: depress-release-move, depress-release-move...

Note (2): As stated in step (1) above, the circuit should be kept on for as short a time as possible. The meter bridge wire may become hot; its resistance will then increase. This will affect your result unfavorably.

(5) When all 12 trials have been completed, switch off the circuit.

(B) Determining the Equivalent Capacitance of Two Capacitors, Connected in Series.

(1) Use the third capacitance box on your table together with the one used as C_X, as the two given capacitors and connect them in series. Select values 4.0 μF and 6.0 μF for the two capacitors (or as instructed by the Instructor). Find the actual value of this combination using the LCR-meter. While using the LCR-meter, make sure that the two capacitance boxes have been disconnected from the circuit.

(2) Select the following values of C_S: 1.80 μF, 1.90 μF,.......2.80 μF, and, finally, 2.90 μF for the 12 trials.

(3) Repeat step (5) of part (A) of this experiment.

(C) Determining the Equivalent Capacitance of Two Capacitors, Connected in Parallel.

(1) Connect the two capacitances in parallel and select values 0.50 μF and 0.70 μF for them (or as instructed by the Instructor). Find the actual value of this combination using the LCR-meter. While using the LCR-meter, make sure that the two capacitance boxes have been disconnected from the circuit.

(2) Select the following values for C_S: 0.50 μF, 0.60 μF,.......1.0 μF, 1.10 μF,.......1.60 μF for the 12 trials.

(3) Repeat step (5) of part (A) of this experiment

Calculations and Graphs.

(1) For each part and for each trial find (i) l_2 as (100 - l_1), and (ii) l_2 / l_1

(2) For each part, plot C_S on y-axis and l_2 / l_1 on the x-axis; using the computer. There will be three graphs altogether. Record values of slope in each case and compare with their expected (those found using LCR-meter) values. Find percent errors.

(3) Complete the report with "Results",

Conclusions and Discussions

Write your conclusions from the experiment and discuss them.

What Did You Learn in this Experiment?.

A hearty and thoughtful account of what you learned in this experiment by way of the principle and the techniques of experimentation, should be given

Data & Data Tables

Name.................................... **Date**..............................

Instructor.............................. **Lab Section**....................

Partner.......................... **Table #**..........................

(A) Determining the value of the given (un-known) capacitor.

(a) Value of C_X set on the capacitance box; (nominal value): (μF)

(b) Actual value as found by using the LCR-meter: (μF)

Table 1: Determining the Value of an Unknown Capacitance

Serial #	C_S (μF)	l_1 (cm)	$l_2 = 100 - l_1$ (cm)	Serial #	C_S (μF)	l_1 (cm)	$l_2 = 100 - l_1$ (cm)
1				7			
2				8			
3				9			
4				10			
5				11			
6				12			

(B) Determining the effective capacitance of two capacitors, connected in series.

(a) Values of C_X set on the two capacitance boxes (nominal values):

(i) μF (ii) μF

(b) Actual value of the combination, as found by using the LCR-meter: μF

Table 2: Determining the Equivalent Capacitance of Two Capacitors Connected in Series

Serial #	C_S (μF)	l_1 (cm)	$l_2 = 100 - l_1$ (cm)	Serial #	C_S (μF)	l_1 (cm)	$l_2 = 100 - l_1$ (cm)
1				7			
2				8			
3				9			
4				10			
5				11			
6				12			

(C) Determining the effective capacitance of two capacitors, connected in parallel.

(a) Values of C_X set on the two resistance boxes (nominal values):
(i) μF (ii) μF

(b) Actual value of the combination, as found by using the LCR-meter: μF

Table 3: Determining the Equivalent Capacitance of Two Capacitors Connected in Parallel

Serial #	C_S (μF)	l_1 (cm)	$l_2 = 100 - l_1$ (cm)	Serial #	C_S (μF)	l_1 (cm)	$l_2 = 100 - l_1$ (cm)
1				7			
2				8			
3				9			
4				10			
5				11			
6				12			

Additional Data or Information (if any)