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Experiment 4: Capacitors

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Section 221-006
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Statement of Objectives

The objective of the lab was to compare the values of measured effective capacitance and calculated effective capacitances in series and parallel connections and to measure the time constant of various RC circuits.

Theory

Part A: Capacitors in Series and Parallel

A capacitor is a device that can store charges. It is made of two conducting surface separated by insulating dielectric. The charges on a capacitor can be written as

$$Q = CV \qquad (1)$$

Where Q is the charge,
V is the voltage across the capacitor,
C is the capacitance

The capacitance for N capacitors in series and parallel is described by the following equations.

Series: $$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + ... + \frac{1}{C_N} \qquad (2)$$

Parallel: $$C = C_1 + C_2 + C_3 + \ldots + C_N \qquad (3)$$

When a switch is closed on a circuit containing a capacitor and a resistor charges build up on the capacitor over a length of time. The potential across a capacitor in an RC circuit is dependant on a time constant τ. This constant can be defined as:

$$\tau = RC \qquad (4)$$

Part B: Measurement of a Long Time Constant &
Part C: Measurement of a Short Time Constant

The charge accumulated on a capacitor will slowly discharge if it is no longer being supplied with charge. This decay of the charge can be described by the following equation.

$$\ln V(t) = \ln V_o - \frac{t}{\tau} \tag{5}$$

The time constant can be found by observing the charging or discharging process. For the charging process, τ is equal to the time for V(t) to reach 63% of its final value. For the discharging process τ is equal to the time it takes for V(t) to fall to 37% of it's initial value.

Equipment List

- Capacimeter
- Set of capacitors
- Circuit board
- Set of resistors
- DC power supply
- Micronta Multimeter
- Timer
- Oscilloscope

Procedure

Part A: Capacitors in Series and Parallel

The capacitance of three capacitors was measured. They were then arranged in series and finally in parallel and the equivalent capacitance of each combination was measured.

Part B: Measurement of a Long Time Constant

The capacitance of another capacitor was measured. The circuit in Figure 1 was constructed. The voltmeter was set to 5V. The capacitor was charged. Once the capacitor was charged, the switch was opened and timing was started when the voltmeter read 5V. The times for each half voltage were recorded down to 0.5V.

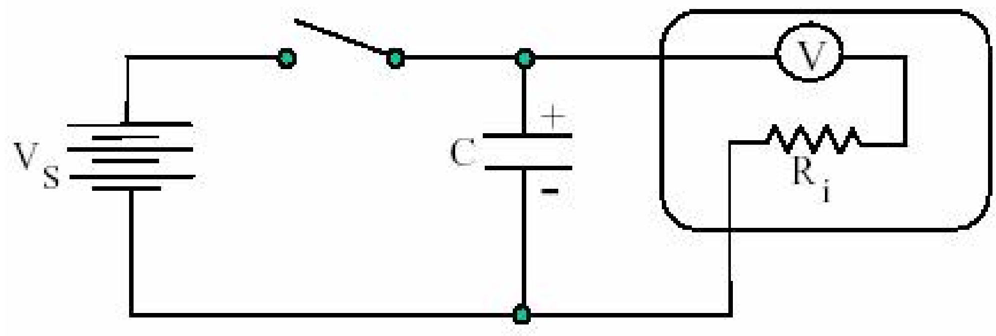


Figure 1: Circuit Containing a Micronta Multimeter

Part C: Measurement of a Short Time Constant

The capacitance of a capacitor and resistance of a resistor were found and recorded. A circuit was set up according to figure (2) and the function generator was turned on and set to 250 Hz. Adjustments were made to the oscilloscope until a charging/discharging trace in figure (3) was obtained. The value of *t* at 63% of the highest voltage and at 37% of the initial voltage was recorded as shown in figure (4).

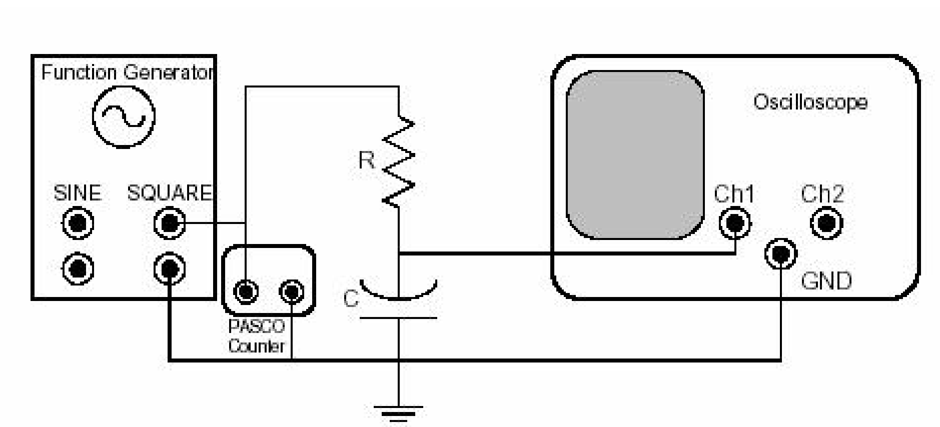


Figure 2: Circuit for Part C

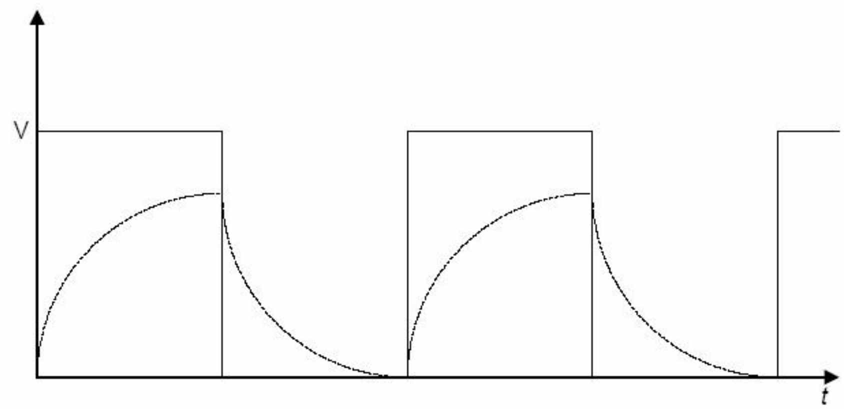


Figure 3: Square Wave Voltage Source

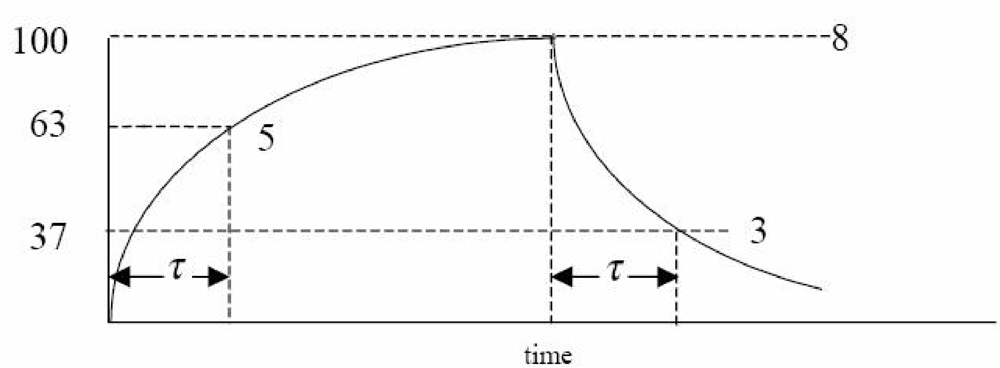


Figure 4: Square Wave with Percentage Levels at 37, 63, and 100 Marked

Data

Part A: Capacitors in Parallel and Series

Capacitor	Capacitance (nF)
1	6.11
2	5.32
3	5.53

Table 1-A

Measured Effective Capacitance (nF)	
Series	1.894
Parallel	16.9

Table 1-B

Part B: Measurement of a Long Time Constant

Discharging Capacitor

V(t)	Time (s)	V(t)	Time (s)
5	0	2.5	70.3
4.5	10.2	2	96.7
4	23	1.5	133.3
3.5	37.6	1	179.3
3	53.1	.5	267.4

Table 2-A

Resistance of Voltmeter (kΩ)	Capacitance (μF)
260	423

Table 2-B

Part C: Measurement of a Short Time Constant

Charging/Discharging Capacitor

Time for charging to 63% voltage (s)	Time for discharging to 37% voltage (s)	Average of times (s)
4.5×10^{-4}	4.0×10^{-4}	4.25×10^{-4}

Table 3-A

Resistance (kΩ)	Capacitance (nF)
46	9.92

Table 3-B

<u>Analysis</u>

Part A: Capacitors in Series and Parallel

The experimental values of the capacitances are in Tables 1-A and 1-B.

Using equations (2) and (3), the effective capacitance for N capacitors in series and parallel can be calculated:

Series:

$$\frac{1}{C} = \frac{1}{6.11} + \frac{1}{5.32} + \frac{1}{5.53} = .532$$
$$C = 1.878nF$$

Parallel: $C = 6.11 + 5.32 + 5.53 = 16.96nF$

Part B: Measurement of a Long Time Constant

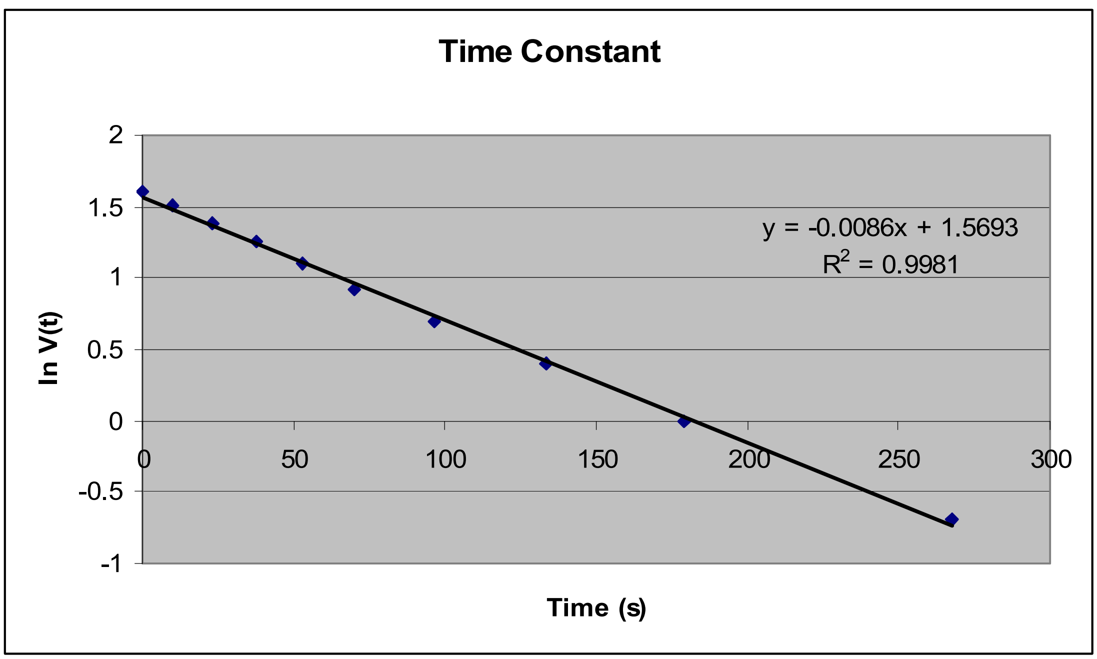
The values of V(t) were converted to ln V(t) and recorded in Table 4.

Discharging Capacitor

ln V(t)	Time (s)	ln V(t)	Time (s)
1.60944	0	0.916291	70.3
1.50408	10.2	0.693147	96.7
1.38629	23	0.405465	133.3
1.25276	37.6	0.000000	179.3
1.09861	53.1	-0.693147	267.4

Table 4

Graph 1 shows ln V(t) versus time. From equation (5), we see that the slope of the best-fit line will be $-1/\tau$.



Graph 1

The slope of the best-fit line is equal to $-0.0086s^{-1}$. Taking the negative reciprocal of that value gives us the time constant, τ, which is 116.279 s.

The theoretical time constant can be calculated directly by using equation (4)

$\tau = 284000\Omega * .000423F = 109.98s$

Part C: Measurement of a Short Time Constant

The time constant calculated by the product of RC obtained from the values of R and C in Table 3-B is 0.456 ms. The experimental value is 0.425 ms.

Discussion of Results

In part A, our measurements were very close the actual values. Our measured value of the effective capacitance in a series connection was 1.894nF. With the theoretical value being 1.878 we obtained an error of only 0.8%. The effective capacitance we obtained for parallel capacitors is 16.9, which is just slightly lower than the theoretical value of 16.96. The parallel capacitor error was 0.35%. Possible cause of this error could be slightly higher capacitance values that lie within the tolerances.

In part B, the experimental value 116.279s is larger than the theoretical value of 109.98s. The error in this measurement was 5.4%. The possible source of this error might be our in ability to accurately record time as the voltage dropped on each half volt.

In part C, the experimental value 0.425ms is slightly lower than theoretical value 0.456ms. These values give us the resulting error of 6.8%. This error could be a result of the error in calibration of the oscilloscope.

Conclusion

The results in Part A reinforce the relationship between the effective capacitance and the individual capacitances in the way which equation (2) and (3) state. In part B and C, the results, and the linearity of Graph 1, indicate that the time constant of RC circuit is, indeed, the product of R and C.