SinkrOn
JURNAL & PENELITIAN TEKNIK INFORMATIKA
Sinkron : Jurnal dan Penelitian Teknik Informatika
Volume 6, Number 3, July 2022
DOI : https://doi.org/10.33395/sinkron.v7i3.11456
e-ISSN : 2541-2019
p-ISSN : 2541-044X

Arduino Implementation for Development Digital Capacitance Meters as Laboratory Measurement Devices

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Submitted : June 6, 2022 | **Accepted** : June 25, 2022 | **Published** : July 2, 2022

Abstract: Electronics Practicum in the Laboratory is a routine activity carried out to support student skills. Capacitors are one of the components that are often used in practice. Capacitors are one of the passive electronic components that have a magnitude value in the form of capacitance in Farad units. The capacitance value indicates the capacitor's ability to store electric charge. However, the value contained on the capacitor label is not necessarily the actual value because the capacitor has a tolerance range. Of course, this is very influential in the measurement and performance of electronic circuits that use capacitors. In addition, another factor that supports this research is that the available measuring instruments, such as the multimeter, are not yet equipped with capacitance measurements. Capacitance meters available in the market are still analog. The purpose of this study is to design a device that can measure the capacitance value of capacitors as a measurement device in a digital laboratory, namely the Digital Capacitance Meter. This device is made using Arduino Uno as a microprocessor for data processing. The method used is to apply the process of charging and discharging the capacitor. In this case, Arduino Uno activates a timer to measure the time required to charge and discharge the capacitor so that the Time Constant value is obtained. By using the formula T = 0.693RC, the capacitance value can be obtained. In testing using 3 different capacitors and 10 times testing on each capacitor, the accuracy of the device is 97.76% and a relative error of 2.24%.

Keywords: Arduino, Capacitance, Capacitor, Digital capacitance Meter, measurement

INTRODUCTION

The learning process, especially in electronics practicums in SMK, SMA and colleges, often uses electronic components such as resistors, inductors, capacitors and so on. These components are passive electronic components that are used with active components to be designed as a single electronic device system. Capacitors are one of the passive electronic components that have a magnitude value in the form of capacitance in Farad units. The capacitance value indicates the capacitor's ability to store electric charge. The types of capacitors include ceramic capacitors, polyester capacitors, paper capacitors, electrolytic capacitors and variable capacitors (Sendari, 2019). Capacitors are widely used in electrical devices. The application of capacitor components can be exemplified as in the Power Bank circuit. Of course, we all know the use of Power Banks as chargers for cell phones or other electronic equipment.

The size of the capacitor can be seen from the label of the capacitor packaging itself. But usually, the capacitance value listed on the package is not the actual value. This is because the capacitor has a tolerance, which means the value on the package is in the working area of the capacitor. On the other hand, sometimes there are capacitors whose packaging is old, causing the numbers on the packaging to become invisible. This of course affects the performance of a circuit that uses capacitors (Samosir et al., 2016). To overcome this, it is necessary to design a device capable of measuring the capacitance of the capacitor.

In the electronics laboratory, of course you need a lot of measuring devices, such as multimeters, wattmeter, cos phi meters and other measuring devices (Asfe et al., 2020). Multimeter is one of the measuring devices that must be in the electronics laboratory. Multimeters are used to measure many electrical quantities such as

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resistance, current, and voltage. But sometimes we encounter multimeters, there is no facility to measure capacitance for capacitors. And usually, the measuring instruments in schools are still analog. Therefore, in this study, researchers want to design a capacitor meter measuring instrument that is displayed digitally.

LITERATURE REVIEW

The value of a capacitor depends on the permittivity value of the capacitor -making material, the cross - sectional area and the distance between the two capacitor -assembling pieces. Mathematically the value of the capacitance of a capacitor is shown in equation (1).

$$C = \varepsilon \frac{A}{d} \qquad (1)$$

where C is the capacitance of the capacitor (in farads), ε is the permittivity, A is the cross-sectional area of the material/plate making up the capacitor, and d is the distance between the two dielectric plates. According to Halliday Resnick, the capacitance can be formulated $C = 0.0885\ A/d$ in picofarads (Halliday et al., 1997). If the capacitor is passed by current then at both ends of the capacitor will appear voltage. The amount of electric charge that can be stored by a capacitor can be mathematically expressed by equation (2)

$$Q = C.V \qquad (2)$$

Where Q is the electric charge (coulomb), C is the capacitance of the capacitor (farads) and V is the voltage (volts). If the capacitor is connected to a direct current source, in a few seconds electric current will flow to the capacitor, this condition is called the capacitor charging process. And if the electric charge in the capacitor is full, then the flow of electric current will stop. The process of charging the capacitor is shown in Figure 1 with a red arrow. On the other hand, if the capacitor is full, the capacitor will discharge, which is indicated by the blue arrow.

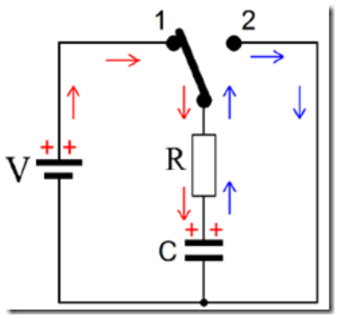

Fig. 1 Capacitor Charging and Discharging Process (Taufiqullah, 2022)

The previous research related to capacitance meter research is the implementation of microcontroller-based capacitance meter implementation research by (Samosir et al., 2016). The results showed that the difference in the value of the device made with the LCR meter was 1.127%. Further research on the design of the LCR Meter measuring instrument using Arduino uno by (Asfe et al., 2020). The LCR meter is capable of measuring resistor, capacitor and inductor components. The result shows this device has an effective measuring distance of 27.5 - 4630 ohms with an accuracy of 5.57%, for capacitance sensors having an effective measuring distance of 0.059 - 2200 micro-Farad with an accuracy of 7.87%, and for inductance sensor has an effective measuring distance above 0.35 millihenry with an accuracy of 5.14%. (Seniari et al., 2020) conducted research on RLC Meter based on Arduino Mega. The design results show that the Arduino Mega based RLC meter measuring instrument is simpler because it is able to measure the R, L and C components with one measuring instrument. The percentage error in the average measurement results decreased, when compared to measuring with the Dekko 63LCR, namely from 3.58 to 1.99; from 7.64 to 5.31 and from 9.13 to 5.15 in the calculation of R, C and L. Research conducted by (Putra et al., 2019) dan (Wijayono & Putra, 2020) on the Capacitance Measurement Method using Arduino uno. In his research, he compares the suitability of the results between experiment and theory, namely the value of R^2 in the charging and discharging process is greater than 0.95. Another study by (Tran et al., 2020) which presents a method of increasing capacitance for the determination of the measurement error of a capacitance measuring device. In this method, it takes a few capacitors without calibration to be connected in parallel in various combinations. The result of this method is the determination of the meter error and the calibration of all basic capacitors so that this method can also be called the capacitance scaling method. Research conducted by (Arunkumar et al., 2013) about capacitance meter using flow sensor. Continuous and precise

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measurement required for a two-phase flow sensor is obtained using the PC connected via RS-232 interface. The instrument covers a range of 0.0125 pF to 1000uF with a resolution of 0.0125 pF. The system is successful in the measurement of capacitance with an accuracy of 0.5% (Suzuki, 2009). As for other studies related to the capacitance meter used as a reference for this study, such as (Zulfy et al., 2017), (Andiani Putra, Heni Puspita, 2014) and (Djatmiko, 2017).

METHOD

To calculate the capacitance value of a capacitor, the capacitor is connected to the two probes of a digital capacitance meter. The two probes are connected to the analog input lines of the Arduino Uno. Then the capacitor is connected to a 5 V voltage source through the Arduino voltage source to charge the capacitor. During the charging process, Arduino will activate a timer to calculate the charging and discharging time in micro seconds. From this timer, the Time Constant (T) value of the capacitor charging process is obtained. As we know, the Arduino Uno uses 10 bits of ADC which means the value ranges from 0 – 1024. 0-volt voltage can be converted to an ADC value of 0, while 5-volt voltage can be converted to a maximum value of 1024. This capacitance calculation uses a charging and discharging process capacitor. By installing a resistor (R) of which we know the value, the capacitance value can be determined by equations (3) and (4).

$$T = 0.693RC \tag{3}$$

$$C \text{ (capacitance)} = \frac{T}{0.693R} \tag{4}$$

Where T is the Time Constant (microseconds), R is the resistor (ohms), and C is the capacitance (Farad). Figure 2 shows the design scheme of the Digital Capacitance Meter. Arduino Uno is used as a data processing microprocessor from this measuring instrument. Arduino can be said to be a practical microcontroller used for experiments in making electronic devices. Arduino has advantages in the form of easy access, many features provided and is open-source. Arduino can be loaded with Arduino IDE-based programs. In Figure 2, the capacitor whose capacitance value is to be measured is connected to probe 1 (red wire) and probe 2 (black wire). Probe 1 which is connected to the (+) pole of the capacitor, is also connected to a resistor (R) and a switch with a 5 V voltage source for the process of charging and discharging the capacitor. Probe 1 is also connected to the Arduino analog input for data recording and processing. While probe 2 is connected to ground. Then the result in the form of a capacitance value is displayed through a 16x2 LCD.

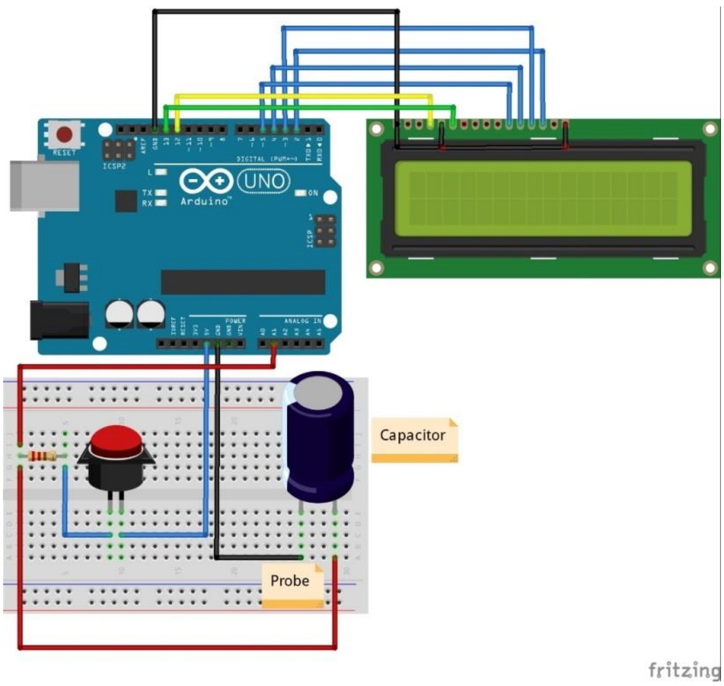

Fig. 2 Schematic of Digital Capacitance Meter

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For the initial step of testing the device, by pressing the power button (on), then wait for 2 seconds. Connect the capacitor component to probes 1 and 2, then the two probes are plugged into pin 1 and pin 3 on the device. Then press the test button. This test button is used to calibrate the instrument. If there is a capacitor connected to the probe, the display on the LCD will change according to the capacitor value being measured. The whole process is shown in Figure 3. Then the measured value is compared with the standardized ESR Meter value or sold in the market. This comparison aims to determine the measurement error of the device. ESR Meter is a measuring instrument for electrical resistance (ohm meter) for capacitors and of course can also measure the capacitance of capacitors. ESR Meter is an abbreviation of Equivalent Series Resistance. The difference between an ESR meter and an ohm meter is that the ohm meter is used for DC currents while the ESR meter is used for AC currents (Teknisi, 2019). This ESR Meter is used to compare the measurement results shown by the Digital Capacitance Meter that has been made, so that researchers know the accuracy and error of the Digital Capacitance Meter device.

Fig. 3 Flowchart system of Digital Capacitance Meter

The results of the design carried out are shown in Figure 4. The results of the overall system test are discussed in Chapter 4.

RESULT

In this research, a media product has been successfully designed to measure the value of capacitor capacitance, namely the Digital Capacitor Meter. The research references used refer to previous studies as described in chapter 2. The results of making a digital capacitance meter are shown in Figure 4. The dimensions of this device are 12 cm long, 8 cm wide, and 7 cm high, equipped with two probes for measurement. Probe 1 for

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pin (+) and probe 2 for pin (-)/ground. In addition, there is a power button to turn on the device and a test button to calibrate the device the first time it is used.

Fig. 4 Real product of Digital Capacitance Meter

The results of testing the Digital Capacitance Meter device using 3 capacitors with 10 tests for each capacitor. These results are compared with the standardized ESR Meter, so that the error value and accuracy of the device are obtained.

Table 1
100 μF Electrolytic Capacitor Measurement Results

No	Capacitance on Label (μF)	ESR Meter Measurement Results (μF)	Digital Capacitance Meter Measurement Results (μF)	Relative Error (%)	Accuracy (%)
1	100 μF	101 μF	96 μF	4	96
2	100 μF	101 μF	96 μF	4	96
3	100 μF	101 μF	97 μF	3	97
4	100 μF	101 μF	97 μF	3	97
5	100 μF	101 μF	96 μF	4	96
6	100 μF	101 μF	96 μF	4	96
7	100 μF	101 μF	96 μF	4	96
8	100 μF	101 μF	96 μF	4	96
9	100 μF	101 μF	96 μF	4	96
10	100 μF	101 μF	97 μF	3	97
Average				**3.7 %**	**96.3 %**

Table 1 shows that the test of the capacitance value of the 100 μF electrolytic capacitor has an average relative error of 3.7%, and an accuracy value of 96.3%. When compared with the measurement results of the ESR meter, the ESR meter produces a measurement value that is closer to the actual capacitance value. This is caused by the influence of the quality of the capacitor components that are not good and the tolerance of the Digital Capacitance Meter measuring instrument.

Table 2
22 μF Electrolytic Capacitor Measurement Results

No	Capacitance on Label (μF)	ESR Meter Measurement Results (μF)	Digital Capacitance Meter Measurement Results (μF)	Relative Error (%)	Accuracy (%)
1	22 μF	22 μF	23 μF	1	99
2	22 μF	22 μF	23 μF	1	99
3	22 μF	22 μF	23 μF	1	99
4	22 μF	22 μF	23 μF	1	99
5	22 μF	22 μF	23 μF	1	99

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6	22 μF	22 μF	23 μF	1	99
7	22 μF	22 μF	23 μF	1	99
8	22 μF	22 μF	23 μF	1	99
9	22 μF	22 μF	23 μF	1	99
10	22 μF	22 μF	23 μF	1	99
Average				**1 %**	**99 %**

Table 2 shows that testing the capacitance value of a 22 μF capacitor has an average relative error of 1%, and an accuracy value of 99%. This shows that the Digital Capacitance Meter device that has been made provides very good performance in measurements, because it has a very small error value and almost perfect accuracy.

Table 3
40 nF (403) Millar Capacitor Measurement Results

No	Capacitance on Label (nF)	ESR Meter Measurement Results (nF)	Digital Capacitance Meter Measurement Results (nF)	Relative Error (%)	Accuracy (%)
1	40	43.3	41.94	1.94	98.06
2	40	44.6	42.01	2.01	97.99
3	40	45.6	41.94	1.94	98.06
4	40	44.5	42.00	2.00	98.00
5	40	43.3	42.03	2.03	97.97
6	40	43.0	41.95	1.95	98.05
7	40	42.8	42.02	2.02	97.97
8	40	43.7	42.15	2.15	97.98
9	40	44	42.08	2.08	97.92
10	40	44	42.00	2.00	98.00
Average				**2.01 %**	**97.98 %**

In the measurement of this Millar type capacitor which has an actual size of 40 nF, the results obtained an average relative error of 2.01% and an accuracy of 97.98%. With this figure we can conclude that the device that has been made is able to accurately detect the value of the capacitor component and can be used for the needs of electronic measuring instruments. The measurement error is caused by various factors, including the quality of the capacitor components, and the tolerance of the measuring instrument. From the test of the three capacitors, the Digital Capacitance Meter is able to measure capacitance with an average accuracy of 97.76% and a relative error of 2.24%.

DISCUSSIONS

In the research and manufacture of this device, the researcher highlighted the difficulty of calibrating the device. Calibration is the process of equating measurement results with other standardized devices. In this case, the researcher conducted an experiment to equalize the measured value using Arduino IDE coding. Experiments continue to be carried out until a constant number is found so that measurement results are obtained that are close to the original capacitance value of the capacitor. In addition, this value is also compared with the ESR Meters sold in the market. The final result of the test, it is found that the Capacitance Meter device that has been made has a measurement accuracy of 97.76% and a relative error of 2.24%.

CONCLUSION

The conclusion obtained in this study is that a Digital Capacitance Meter has been successfully designed using Arduino Uno as a measuring device in the school laboratory. This device can be used as an electronics practicum media in measuring the capacitance value of a capacitor and can increase the learning efficiency of students.

In this testing using 3 different capacitors and 10 times testing on each capacitor, the accuracy of the device is 97.76% and a relative error of 2.24%.

ACKNOWLEDGMENT

The researcher would like to thank the Electrical Engineering Education Study Program, FKIP, Universitas PGRI Madiun for facilitating this research. In addition, to all Electrical Engineering Education lecturers who have fully supported in completing the manufacture of this Digital Capacitance Meter.

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