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Capacitance Measurements System Using RC Circuit

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Abstract

This article reports the technique of measuring capacitance using the concept of charging capacitors in the RC-series circuit. The proposed capacitance measuring system is built using 3 sub-systems: (1) Arduino M0 board (with 12-bit internal ADC) to control the process of discharging and charging capacitor voltages using the digitalWrite() function; (2) ERM20004FB-2 LCD with $I2C$-serial module to display measurement data; and (3) $R_{\text{CHARGE}}C_X$-series circuit (R_{CHARGE} is a carbon-film 89. 7Mohm resistor and C_X is the capacitor to be measured). The charging time ofthe capacitor voltage from $0V_S$ to $0.5V_S(\Delta t)$ is calculated using the analogRead() and micros() functions. The C_X value is calculated using the equation $C_X = \frac{\Delta t}{(693.1471 \times R)} nF$ and with the value Δt displayed on the LCD module. The capacitance measuring system has been tested to measure capacitance of 14 ceramic-disk capacitors from $1nF$ to $100nF$ with an error rate< ±0.7% (compared to LCR-821 . The results of the study concluded that the error rate was influenced by changes in the resistance value of R_{CHARGE}.

Keywords: capacitance measurement, RC circuits, Arduino M0 application

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1. Introduction

Microcontroller systems can be implemented to measure capacitance by using 3 ways: (1) using an RC or LC relaxation oscillator (R and L values are known), measuring the output frequency, and calculating capacitance using resonance frequency equations $[1-3]_;$ (2) using RC Monostable-MV (R value known), measure T_{ON} pulse width, and calculating capacitance using pulse width equation $[4-5]_;$ and (3) using a capacitor charging system in RC-series circuit with a stable DC voltage source, measuring the charging time until the capacitor voltage reaches a certain value, and calculating capacitance using the charging equation of the capacitor [6-9]. The accuracy of the capacitance measurement by measuring the charging time can be increased using Arduino M0 which has a 12-bit ADC [10].

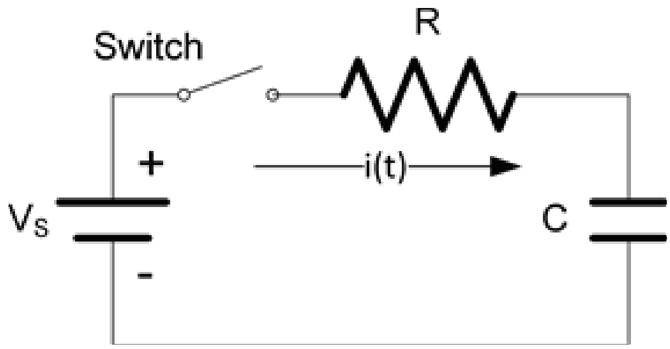

Figure 1: RC circuit with DC voltage source.

2. Methods and Equipment

2.1. Methods

2.1.1. RC charging circuit

The RC charging circuit is realized using a DC voltage source, resistor, and capacitor connected in series as shown in Figure 1 [11]. When the switch is closed, current $i(t)$ flows from the voltage source through resistors and capacitors so that equations (1) to (3).

$$V_S = V_R + V_C \tag{1}$$

$$V_S = i(t)R + \frac{1}{c}\int_{t=0}^{t=\sim} i dt \tag{2}$$

$$i(t) = \frac{V_S}{R}e^{-\frac{t}{RC}} \tag{3}$$

The capacitor voltage can be calculated using equation (4). If the values of R, VS, and Δt (the charging time of VC(t) = $0.5V_S$ to V_S) is known, then capacitance can be calculated using equations (5) to (7) [11].

$$V_c(r) = V_s\left(1 - e^{-\frac{t}{RC}}\right) \tag{4}$$

$$e^{-\frac{r}{RC}} = \frac{V_S - V_C(t)}{V_S} \tag{5}$$

$$-t = RC\ln\left(\frac{V_S - 0,5V_S}{V_S}\right) \tag{6}$$

$$C_X = \frac{\Delta t}{0,6931471 \times R_{CHG}} Farad \tag{7}$$

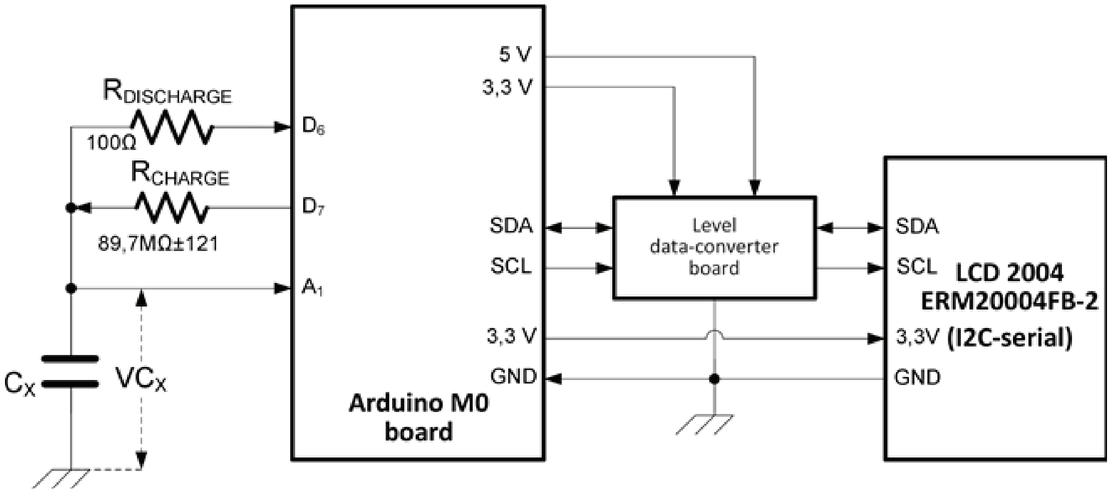

Figure 2: Capacitance measurement system circuit.

2.1.2. Description of the capacitance measurement system

The capacitance measuring system (Figure 2) was built using the concept of charging a capacitor C_X in an RC-series circuit that is controlled by Arduino M0 using pinMode() and digitalWrite Before the charging cycle, the C_X voltage is emptied through $R_{DISCHARGE}$ which is connected to the ground through a digital pin 6. C_X charging cycle is done through R_{CHARGE} which is connected to a voltage of 3.3 Volts via digital pin 7. C_X charging time from $0V_S$ to $0.5V_S(\Delta t)$ is calculated using the micros() function and then the capacitance can be calculated (equation 7) and displayed to the ERM20004FB-2 LCD with $I2C$-serial module. The pseudo-code of the Arduino M0-based capacitance measuring system uses the concept of charging capacitors in the RC-series circuit as described below:

1. discharging C_X until $VC_X = 0$ Volts,
2. charging C_X and save time (t1),
3. stop charging when the ADC $= 2048(VC_X = 0.5V_S)$,
4. save time (t2),
5. calculate Δt and C_X using equation 7,
6. show C_X and Δt values to LCD, and
7. repeat step 1.

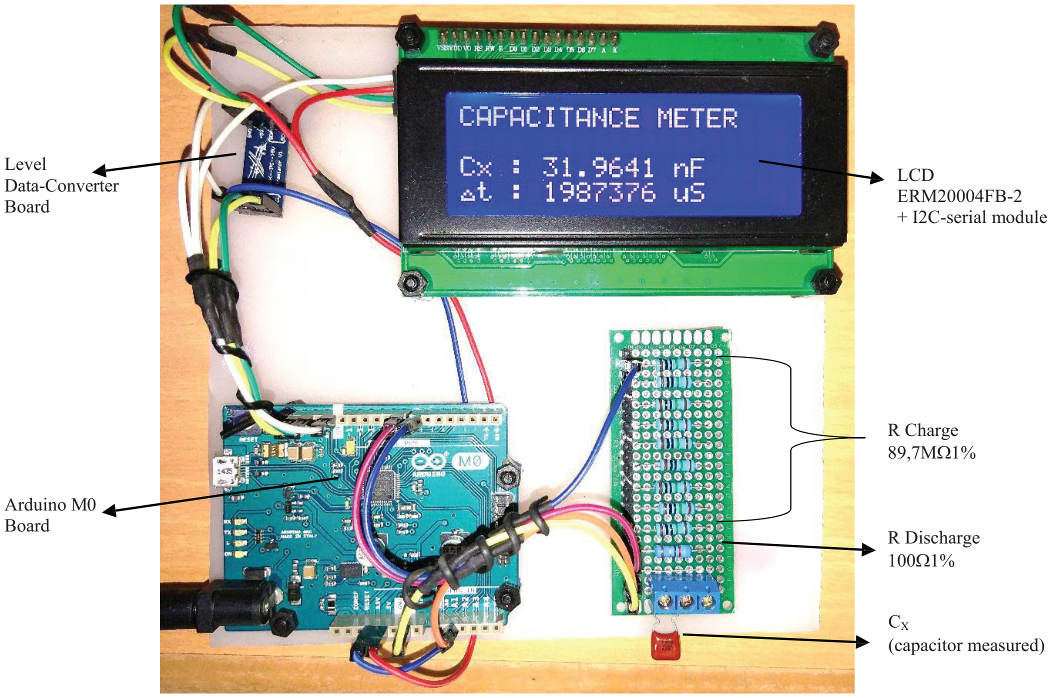

Figure 3: Capacitance measuring system when measuring C_X(323K or 32nF±5%.

3. Results

$R_{\text{DISCHARGΓNG}}$ is set at 100Ohm1% to get a fast discharge time (t_{6RC} = $120\mu Sec$) when connected with C_X maximum $(100nF)$ and R_{CHARGING} determined at 89. 7MOhm (9 resistors in series) to get Δt minimum > $50000\mu S$ when connected to C_X minimum $(1nF)$. Level data converter module (3.3Volt to 5Volt) is used to connect SDA and SCL signals from Arduino M0 to 4×20char LCD boards (with $I2C$-serial module). Capacitor measurement system has been successfully created (Figure 3 , not calibrated, and has been tested to measure the capacitance of 14 ceramis-disks capacitors alternately using GWinstek LCR-821 (5 times each) and the results are shown in Table 1. Sketch ofthe system is created using Arduino IDE ver. 1.9.0-Beta and written in the following paragraph:

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```
#include <LiquidCrystal_I2C.h>
LiquidCrystal_I2C lcd(0x27,20,4);
byte delta[]=
{ B00000,B00000,B00000,B00100,B01010, B10001, B11111,B00000 };
unsigned long t1, t2, dt; float R, nanoF;
void setup()
{ lcd.begin(); lcd.clear();
  lcd.setCursor(0, 0); lcd.print("CAPACITANCE METER");
  lcd.setCursor(0, 2); lcd.print("Cx : ");
  lcd.createChar(0, delta); lcd.setCursor(0, 3); lcd.write(0);
  lcd.setCursor(1, 3); lcd.print("t : ");
  pinMode(7, OUTPUT); digitalWrite(7, LOW);
  pinMode(8, OUTPUT); digitalWrite(8, LOW);
  delay(5000);
  analogReadResolution(12);
  R = 89.7;
}

void loop()
{ do { pinMode(8, OUTPUT);
       digitalWrite(8, LOW);
       delay(2000);
     } while(analogRead(0) < 1);
  pinMode(8, INPUT);
  digitalWrite(7,HIGH);
  t1 = micros();
  while(analogRead(1) < 2048){}//ADC=2048 equal to 0,5VS
  t2 = micros();
  digitalWrite(7,LOW);
  dt = t2 - t1;
  nanoF = dt/(693.1471*R);
  lcd.setCursor(5, 2); lcd.print(nanoF,4);lcd.print(" nF    ");
  lcd.setCursor(5, 3); lcd.print(dt); lcd.print(" uS    ");
}
```

C_X measurement results (columns 2 and 4 in Table 1) are the average of 5 measurements using LCR- 821 and using capacitance measuring system. The % error (column 8) value is calculated using equation (8).

$$\%error = \frac{C_X system\ value - C_X LCR\text{-}821}{C_X LCR\text{-}821} \times 100 \tag{8}$$

4. Discussion

Referring to equation (7), there are 2 variables that affect the measurement results of capacitance: (1) stability of the Δt; and (2) stability of the R_{CHARGE}. Because Δt is generated from the function of micros() which has a $4\mu S$ resolution [12] so that it is assumed that it does not affect the measurement results, the change in the R_{CHG} value will cause a change in the value of the C_X measurement. If the R_{CHARGE} value rises, then the C_X measurement value will decrease and vice versa. The average

Table 1: Data from measurement of 14 capacitors.

No.	capasitor (ceramics disk) value	measurement results					
		LCR-821		capacitance measuring system			% measurement error
		C_X (nF)	SD	C_X (nF)	SD	$\Delta t(\mu S)$	
1	2	3	4	5	6	7	8
1	102K (10nF 10%)	0,9208	0,0091	0,9271	0,0110	68,732	0,68
2	302M (3nF 20%)	3,1005	0,0143	3,0948	0,0509	219,994	-0,18
3	472K (4n7F 10%)	4.4351	0,0016	4.4334	0,0859	229,528	-0.04
4	103G (10nF 2%)	9,4243	0,0018	9,4108	0,0058	567,639	-0,14
5	103K (10nF 10%)	9,7432	0,0068	9,7289	0,0109	586,508	-0,15
6	153J (15nF 5%)	15,4270	0,0083	15,4217	0,0377	899,649	-0,03
7	223K (22nF 10%)	20.7686	0,0103	20.6276	0,0392	1,266,618	-0.68
8	273K (27nF 10%)	25.9722	0,0181	25.7965	0,0241	1,590,332	-0.68
9	333K (33nF 10%)	31.9410	0,0113	31.9659	0,0796	1,984,776	0.08
10	473J (47nF 5%)	41.9192	0,0274	41.8124	0,1494	2,598,063	-0.25
11	563K (56nF 10%)	52.7006	0,0576	52.6150	0,0948	3,255,986	-0.16
12	633J (63nF 5%)	69.0542	0,1407	68.8577	0,0623	4,272,470	-0.28
13	104K(100nF 10%)	94,3276	0,1942	94,4634	0,1975	5,891,775	0,14
14	104J(100nF 5%)	98.5234	0,0575	98.5654	0,2419	6,128,104	0.04

R_{CHARGE} value is $89.7M\Omega$ with standard deviation 121 (measured 5 times using LCR-821 , so it can be concluded that there is a correlation between the % error value of the measurement ofthe capacitance measuring system and the instability of the R_{CHARGE} value.

5. Conclusion

An Arduino-based capacitance measuring system uses the technique of calculating the charging time of the capacitor voltage in the RC-series circuit has been successfully made to measure the capacitance of 14 ceramic-disk capacitors with a measurement error rate< ±0.7% (compared to LCR- 821 .

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Conflict of Interest

The researcher does not have a conflict of interest related to the completion ofthis article.

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