Conference Paper

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 (\( R_{\text{CHARGE}} \) is a carbon-film 89.7Mohm resistor and \( C_X \) is the capacitor to be measured). The charging time of the capacitor voltage from 0\( V_S \) to 0.5\( V_S \) (\( \Delta t \)) is calculated using the analogRead() and micros() functions. The \( C_X \) value is calculated using the equation
\[
C_X = \frac{\Delta t}{(693.1471R)nF}
\]
and with the value \( \Delta t \) 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 \( R_{\text{CHARGE}} \).

Keywords: capacitance measurement, RC circuits, Arduino M0 application

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 \( T_{\text{ON}} \) 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].
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).

\[ V_S = V_R + V_C \]  
\[ V_S = i(t)R + \frac{1}{C} \int_{t=0}^{t=\infty} i(t) \, dt \]  
\[ i(t) = \frac{V_S}{R} e^{-\frac{t}{RC}} \]  

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

\[ V_c(t) = V_s \left(1 - e^{-\frac{t}{RC}}\right) \]  
\[ e^{-\frac{t}{RC}} = \frac{V_S - V_C(t)}{V_S} \]  
\[ -t = RC \ln \left(\frac{V_S - 0.5V_S}{V_S}\right) \]  
\[ C_X = \frac{\Delta t}{0.6931471 \times R_{CHG}} \text{ Farad} \]
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 $R_{\text{DISCHARGE}}$ which is connected to the ground through a digital pin 6. $C_X$ charging cycle is done through $R_{\text{CHARGE}}$ 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 $\Delta t$ and $C_X$ using equation 7,
6. show $C_X$ and $\Delta t$ values to LCD, and
7. repeat step 1.
3. Results

$R_{\text{DISCHARGING}}$ is set at 100Ohm1% to get a fast discharge time ($t_{6RC} = 120\mu\text{Sec}$) when connected with $C_x$ maximum (100\,nF) and $R_{\text{CHARGING}}$ determined at 89. 7MOhm (9 resistors in series) to get $\Delta t$ minimum $> 50000\mu\text{S}$ when connected to $C_x$ minimum (1\,nF). 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 of the system is created using Arduino IDE ver. 1.9.0-Beta and written in the following paragraph:
```c
#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);
    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 0,5V S
    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).

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

4. Discussion

Referring to equation (7), there are 2 variables that affect the measurement results of capacitance: (1) stability of the $\Delta t$; and (2) stability of the $R_{	ext{CHARGE}}$. Because $\Delta t$ 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 $R_{	ext{CHARGE}}$ value will cause a change in the value of the $C_X$ measurement. If the $R_{	ext{CHARGE}}$ value rises, then the $C_X$ measurement value will decrease and vice versa. The average
<table>
<thead>
<tr>
<th>No.</th>
<th>capacitor (ceramics disk) value</th>
<th>measurement results</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>LCR-821</td>
<td>capacitance measuring system</td>
<td>Δt(μS)</td>
<td>% measurement error</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cx (nF)</td>
<td>SD</td>
<td>Cx (nF)</td>
<td>SD</td>
</tr>
<tr>
<td>1</td>
<td>102K (10nF 10%)</td>
<td>0.9208</td>
<td>0.0091</td>
<td>0.9271</td>
<td>0.0110</td>
</tr>
<tr>
<td>2</td>
<td>302M (3nF 20%)</td>
<td>3.1005</td>
<td>0.0143</td>
<td>3.0948</td>
<td>0.0509</td>
</tr>
<tr>
<td>3</td>
<td>472K (4n7F 10%)</td>
<td>4.4351</td>
<td>0.0016</td>
<td>4.4334</td>
<td>0.0859</td>
</tr>
<tr>
<td>4</td>
<td>103G (10nF 2%)</td>
<td>9.4243</td>
<td>0.0018</td>
<td>9.4108</td>
<td>0.0058</td>
</tr>
<tr>
<td>5</td>
<td>103K (10nF 10%)</td>
<td>9.7432</td>
<td>0.0068</td>
<td>9.7289</td>
<td>0.0109</td>
</tr>
<tr>
<td>6</td>
<td>153J (15nF 5%)</td>
<td>15.4270</td>
<td>0.0083</td>
<td>15.4217</td>
<td>0.0377</td>
</tr>
<tr>
<td>7</td>
<td>223K (22nF 10%)</td>
<td>20.7686</td>
<td>0.0103</td>
<td>20.6276</td>
<td>0.0392</td>
</tr>
<tr>
<td>8</td>
<td>273K (27nF 10%)</td>
<td>25.9722</td>
<td>0.0181</td>
<td>25.7965</td>
<td>0.0241</td>
</tr>
<tr>
<td>9</td>
<td>333K (33nF 10%)</td>
<td>31.9410</td>
<td>0.0113</td>
<td>31.9659</td>
<td>0.0796</td>
</tr>
<tr>
<td>10</td>
<td>473J (47nF 5%)</td>
<td>41.9192</td>
<td>0.0274</td>
<td>41.8124</td>
<td>0.1494</td>
</tr>
<tr>
<td>11</td>
<td>563K (56nF 10%)</td>
<td>52.7006</td>
<td>0.0576</td>
<td>52.6150</td>
<td>0.0948</td>
</tr>
<tr>
<td>12</td>
<td>633J (63nF 5%)</td>
<td>69.0542</td>
<td>0.1407</td>
<td>68.8577</td>
<td>0.0623</td>
</tr>
<tr>
<td>13</td>
<td>104K (100nF 10%)</td>
<td>94.3276</td>
<td>0.1942</td>
<td>94.4634</td>
<td>0.1975</td>
</tr>
<tr>
<td>14</td>
<td>104J (100nF 5%)</td>
<td>98.5234</td>
<td>0.0575</td>
<td>98.5659</td>
<td>0.2419</td>
</tr>
</tbody>
</table>

The measurement error value of RCHARGE is 89.7 MΩ 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 of the capacitance measuring system and the instability of the RCHARGE 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 of this article.

References


