Digital Meter for measuring Capacitance of an Ultra Capacitor

Ms. Jayassre Ramakrishnan [1], Dr. P P Vaidya[2],
[1]Assistant Professor, Department of Instrumentation Engineering, [2]Professor & HOD, Department of Instrumentation Engineering,
Vivekanand Education Society's Institute of Technology,
Mumbai, jayashree.ramakrishnan@ves.ac.in, 9920103927

ABSTRACT— Ultra Capacitors(UC) have large energy density, high power density, high capacitance in the order of farads coupled with low equivalent series resistance (ESR) and low rated voltages. Standard measurement devices like LCR meters, etc., are not suitable for measurement of capacitance of Ultra capacitors as the measurement ranges of these devices are much narrower. This paper proposes a Digital meter for measuring Capacitance of Ultra Capacitor using Charge-discharge method.

KEYWORDS— Ultracapacitors, Charge-Discharge Method, Capacitance Measurement, Operational Amplifier, Window Comparator, Inverting mode, digital meter

INTRODUCTION

Energy storage capability is constrained while using a single energy storage device in terms of size, cost and maintenance for meeting the electrical power requirements of applications. The more effective approach for supplying the electrical power requirements, is to arrive at the requirements from two perspectives viz., average power requirements and peak power requirements[1].

While batteries and fuel cells are widely used to provide the average power requirements of applications, capacitors with higher power capability, are commonly used for meeting the peak power requirements. With the trend of Increasing Pulse duration of peak power requirements, conventional capacitors are found to have limitations in energy density[2],[6]. Therefore, there is a need for a device that can deliver high power and as well as store large amount of energy. Ultra capacitors have been useful for such applications.

ULTRACAPACITORS

Ultra Capacitors (UC), also known as Super Capacitors or Electric Double Layer Capacitors (EDLC), are electrochemical capacitors having very large energy density and higher power density as compared to common capacitors[3], [4]. In Ultra Capacitors, the large energy density is achieved through enormous surface area created by porous carbon electrodes and also through small charge separation created by the dielectric separator[7]. These capacitors offer higher specific power density, higher efficiency, longer shelf and increased cycle-life than normal batteries.

An UC is a special type of capacitor with high capacitance, low equivalent series resistance (ESR), and low rated voltage values. The most attractive property of UCs is their high capacitance value which is expressed in a scale thousands of farads as against milli farads/micro farads of the conventional capacitors. These advantages have made UC attractive for varieties of potential applications such as consumer electronics, electric/hybrid vehicles, and industrial power management.[5]

NEED FOR NEW METHOD OF MEASURING CAPACITANCE OF ULTRACAPACITOR

Standard measurement devices like LCR meters are not sufficient for measuring the characteristics of an Ultracapacitor. For example, the measurement range of standard LCR meters for capacitance measurement is much narrower than the capacitance value of UCs. Furthermore, these measurement devices have limited energy[8],[9]. Most of them are battery powered. Therefore, these devices cannot change the stored energy levels in a UC with their limited energies, making them not suitable for measuring characteristics of UC. Hence, there is need for exploring a new method of measuring capacitance of an UC.

While developing a meter for measuring Capacitance of an UC, it is essential that the method is capable of applying large DC current signals at low rated voltage. Charging/Discharging method is apt and meets these requirements greatly. However, there is a need for Data acquisition, measurement and display system in Digital platform. Accordingly, the following method was evolved after studying the General Characteristics of Ultracapacitors and the requirements of a user.

DIGITAL METER FOR ULTRACAPACITOR

The proposed method is basis charging / discharging of UC. An UC is charged and time taken while charging from Set Voltage point V_1 to V_2, is converted into a pulse using a window Comparator. Pulse generated, is fed into a micro controller, with the help of which, the Capacitance of the UC is arrived and displayed.

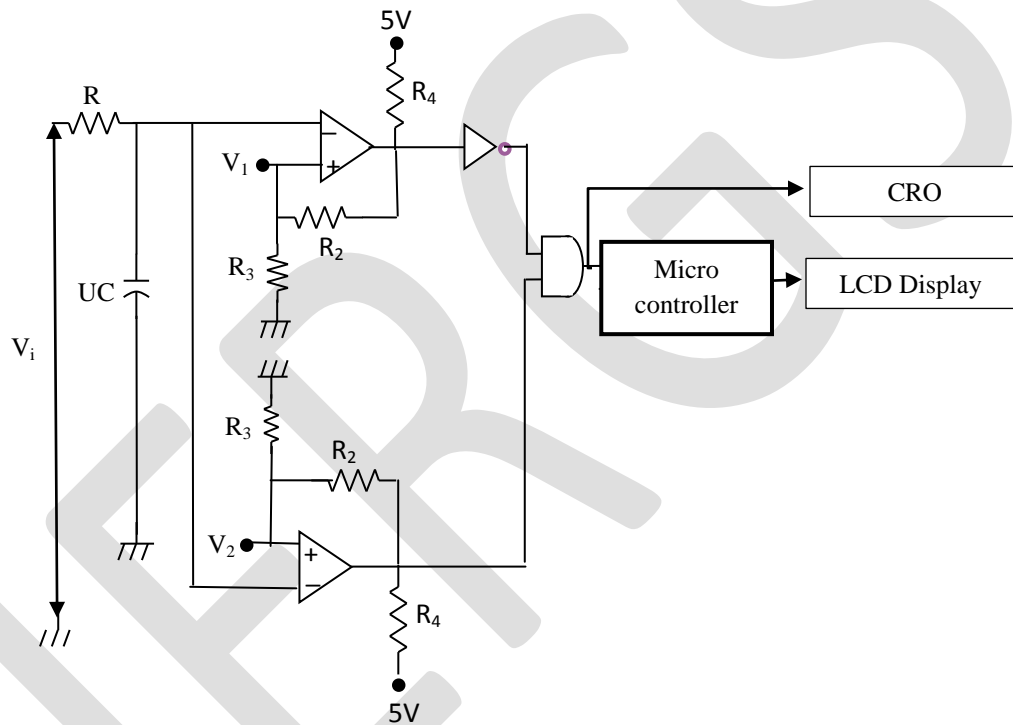The circuit deployed in this method is given below in Fig 1.

Fig. 1 Circuit of digital meter

$R = 10\Omega$, $R_2 = 100K\Omega$, $R_3 = 4.7K\Omega$, $R_4 = 470\Omega$, $V_i = 2V$. V_1, V_2 are Set voltage points

A potential divider is used for setting the values of V_1 and V_2 using V_{CC} which is 5V. V_i of 2 V has been selected considering the low rated voltage of Ultra capacitors.

In the window comparator used in the circuit, both the comparators are working in inverting mode. Reference voltage is applied to the non-inverting input and Voltage across the capacitor is applied to the inverting input. Whenever, the voltage across the capacitor goes above set voltage (V_1 or V_2), the output of the comparator becomes low[10], [11]. Using NOT and AND gates, pulse is obtained from V_1 to V_2. Pulse can be observed in CRO and the same is fed to a microcontroller for evaluating capacitance value.

The calculations for arriving at Capacitance of UC is given below:

$$V_1 = V_i (1 - e^{-t_1/RC}) \dotfill 1$$

$$V_2 = V_i\left(1 - e^{-t_2/RC}\right) \quad\text{..2}$$

$$\frac{t_1}{RC} = -\ln\left(1 - \frac{V_1}{V_i}\right) \quad\text{..3}$$

$$\frac{t_2}{RC} = -\ln\left(1 - \frac{V_2}{V_i}\right) \quad\text{..4}$$

From the above equations, the value of C can be arrived by the following formula.

$$C = \frac{t_2 - t_1}{R\left[\ln\left(1 - \frac{V_1}{V_i}\right) - \ln\left(1 - \frac{V_2}{V_i}\right)\right]} \quad\text{..5}$$

In the above equation, $t_2 - t_1$ is the pulse width measured in seconds through the circuit. All other values, V_2, V_1 and R are known and hence, C can be arrived at using the above equation.
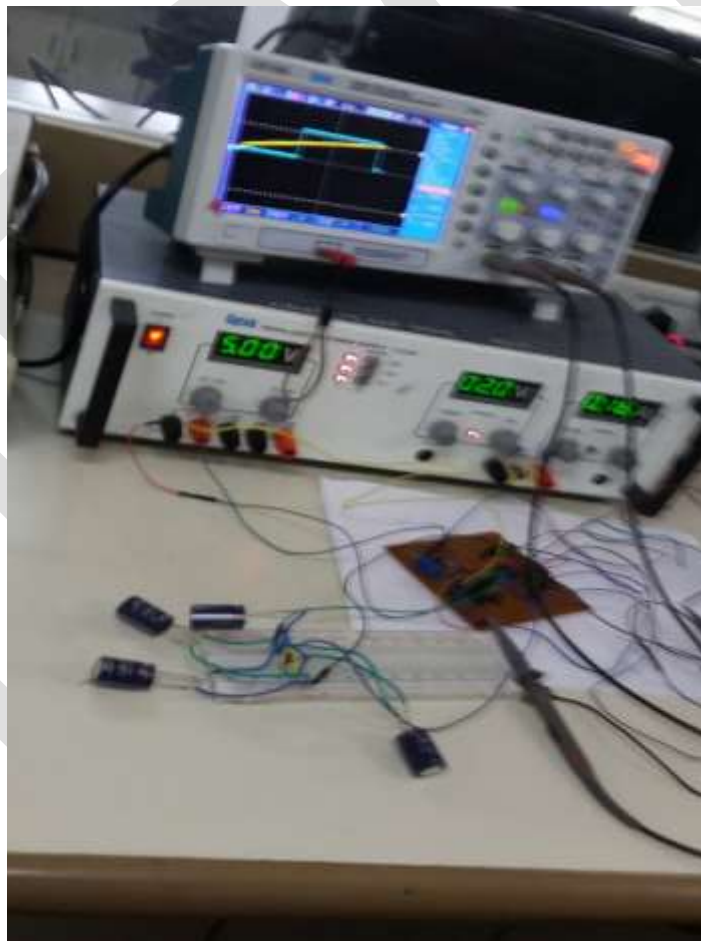
HARDWARE IMPLEMENTATION

Fig 2 PCB Circuit and pulse display in CRO

Readings were taken for many values of capacitance of UC viz., 3, 25, 50, 75, 100 & 350 farads. The RMS value of errors, i.e. between Measured Value and Real Value were analyzed and the same are given below in Table 1.

Table 1

V1 (V)	V2 (V)	Pulse Width (Seconds)	Measured Value of C (Farads)	Real Value of C (Farads)	Error (Farads)	RMS Value of Error %
0.52	1.12	16.7	3.212	3	0.212	
0.54	0.94	10	3.123	3	0.123	
0.58	0.98	10.2	3.0834	3	0.0834	
0.58	0.98	10.4	3.1439	3	0.1439	4.8%
0.58	0.98	9.6	2.909	3	-0.091	
0.58	0.98	10.6	3.204	3	0.204	
0.42	0.98	12.8	2.925	3	-0.075	
0.58	0.98	88	26.602	25	1.602	
0.58	0.98	84	25.39	25	0.39	
0.62	1.00	88	27.33	25	2.33	
0.50	1.14	154	27.68	25	2.68	7.2%
0.54	0.94	85	26.545	25	1.545	
0.54	0.96	90	26.53	25	1.53	
0.56	0.96	88	27.044	25	2.044	
0.56	0.96	86	26.429	25	1.429	
0.58	0.98	180	54.41	50	4.41	
0.48	0.9	184	56.89	50	6.89	12.4%
0.46	0.9	184	54.7	50	4.7	
0.58	0.98	192	58.04	50	8.04	
0.58	0.98	272	82.225	75	7.225	
0.46	0.9	288	85.61	75	10.61	12.8%
0.46	0.9	288	85.61	75	10.61	
0.58	0.98	368	111.25	100	11.25	
0.58	0.98	380	114.8	100	14.8	14.1%
0.38	0.8	348	115.96	100	15.96	
0.58	0.98	1288	389.36	350	39.36	
0.58	0.98	1352	408.7	350	58.7	14.4%
0.58	0.98	1328	401.47	350	51.47	

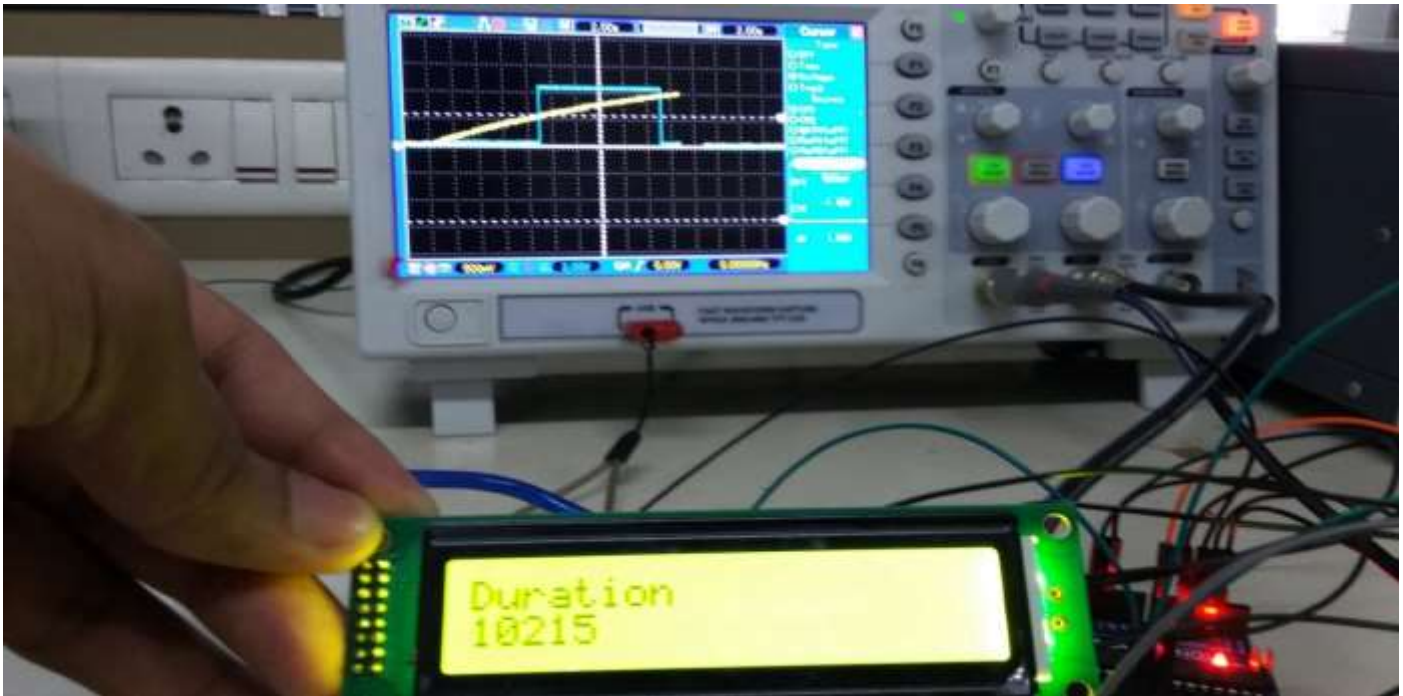**Capacitance of Ultracapacitor - Measured Vs Real Value**

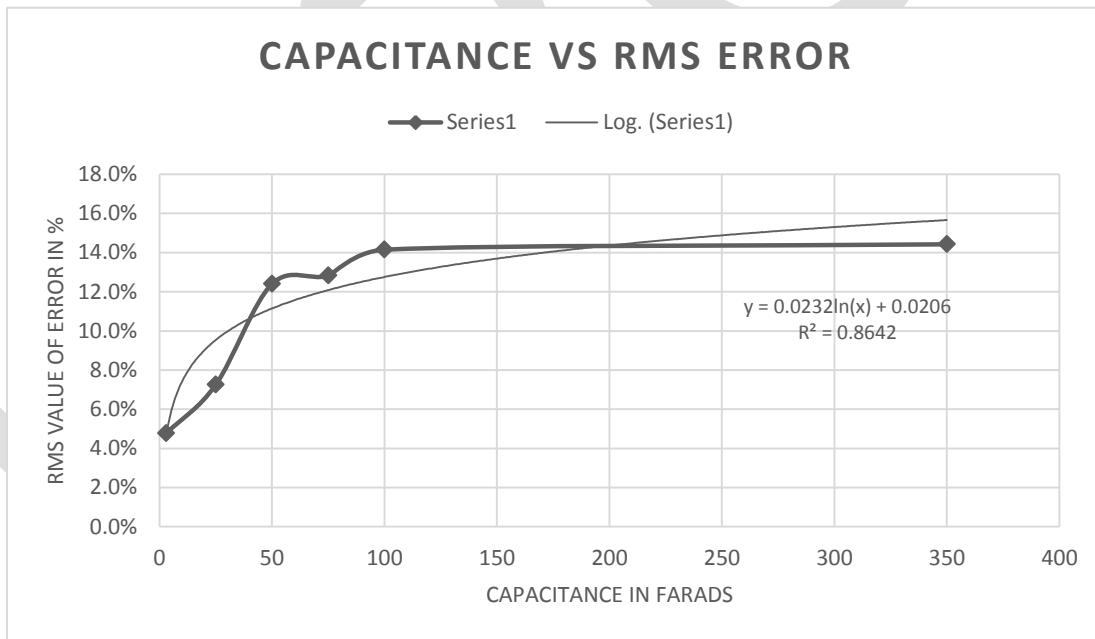Fig 3. Output in CRO and LCD Display

Fig. 4. Chart Capacitance Vs RMS Error

The points were plotted in the graph in Fig 4. Logarithmic function was found to be best fit for these values with R^2 as high as 0.8642. The errors were more or less saturated in the range of 12% to 14% for Capacitance Value range of 50 Farads to 350 Farads. For Capacitance Values below 50 Farads, the errors are further less and follows Logarithmic path.

ACKNOWLEDGEMENT

CONCLUSION

Measurement of Capacitance of Ultracapacitor has been a challenge in view of higher order of Capacitance values. Developing the digital meter which is simple to use will go a long way in deployment of Ultracapacitor in day-to-day applications mainly in Automobile and other high energy applications.

REFERENCES:

[1] Hasan Huseyin Eroglu, Ahmet M Hava, Gulhane Medical Military Academy, Middle East Technical University *"Design and Implementation of an Ultra capacitor Test System"* 978-1-4244-9312-8/11/$26 @ 2011 IEEE.

[2] R P Deshpande, *"Ultracapacitors, Future of Energy Storage",* ISBN-13: 978-9339214050.

[3] Maxwell Technologies, *"Gateway to a new thinking in energy management-Ultracapacitors",* San Diego, 2005

[4] J.R.Miller, A.F Burke, *"Electric vehicle capacitor test procedures manual, Revision 0,* Idaho National Engineering Laboratory, Report No. DOE/ID-10941, 1994.

[5] Chia-Jui Chiang, Jing-Long Yang, and Wen-Chin Cheng, *"Dynamic Modeling of the Electrical and Thermal Behavior of Ultracapacitors",*2013, 10th IEEE International Conference on Control and Automation (ICCA), Hangzhou, China, 978-1-4673-4708-2/13/$31.00 ©2013 IEEE

[6] A. Burke, *"Ultracapacitors: why, how, and where is the technology,"* Journal of Power Sources, vol. 91, pp. 37–50, 2000.

[7] R. Gallay, *"Properties and State of Art of High Power Ultracapacitors,"* 16 Seminario Interattivo, Bressanone Marzo, Italy, 2005.

[8] V.A. Shah, J.A. Joshi, R. Maheshwari and R. Roy, "Review of Ultracapacitor Technology and its Applications," In Fifteenth National Power Systems Conference (NPSC) Conf. Records, pp. 142-147, IIT Bombay, 2008.

[9] Y. Kim, *"Ultracapacitor Technology Powers Electronic Circuits,"* Power Electronics Technology, October 2003.

[10] Ramakant A. Gayakwad, *Op-Amps and Linear Integrated Circuits*, 3RD edition, Prentice-Hall India, 2011

[11] D.Roy Choudhury, Shail B. Jain, *Linear Integrated Circuits*, 4th edition, New age International Publishers, 2010.

[12] Fairchild Semiconductor, *LM311 single comparator, datasheet, Rev 1.0.1,* www.fairchildsemi.com