Increasing Energy Storage & Output of Capacitors

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***Abstract*— Efficiency of a charged capacitor is studied experimentally. The integrated luminosity over time graph of a Light emitting diode (LED) is studied as a response variable when factors capacitance, time of charging, temperature, applied voltage and resistance within the circuit are varied. The statistical results of the linear model are studied in detail to determine optimal conditions for similarly functioning devices.**

I. INTRODUCTION

Capacitors have largely been ignored as energy storage options due to their historical inability of storing large amounts of charge. But the environmental, physical, and economic costs associated with lithium-ion batteries have developed interest in using large supercapacitors as an alternative. Still supercapacitors lie between electrolytic capacitors and conventional lithium-ion batteries in terms of charge density but are steadily coming closer to conventional batteries [1]. Capacitors also do not deteriorate as fast as Batteries and can be utilized over longer lifespans thus saving resources. Supercapacitors utilizing optimized nanopore technology can beat charging times of batteries as well as reduce discharging rates [2].

In this paper we consider some of the important parameters affecting the overall energy output of capacitors and how the output can be maximized while reducing costs in the process. Electrolytic capacitors store electrical energy statically by utilizing charge within an electric field in the dielectric oxide layer between the separation of two electrodes. We observe various effects on the output delivered by aluminum oxide dielectric electrolytic capacitor to a GaAs based LED.

A key interest is to observe the effect of temperature variation on the capacitor. MOS Capacitors are observed to have low variation due to temperature changes and are ideal for automobile systems where heat fluctuations are common [3]. While electrolytic capacitors undergo electrolyte deterioration and wear out at very high temperatures, they still have low deterioration over time at operational temperatures [4].

II. EXPERIMENT

The experimental setup consisted of a Voltage source passing through a diode for safety and then via a switch connected in parallel with a resistor, capacitor, and the LED along with a small resistor for LED's protection. The LED was placed near the photodiode the voltage reading across which was measured using a probe and the entire setup was enclosed within a dark box to minimize voltage variations within the photodiode readings. The parameters used to study variation within the luminosity over time readings of the photodiode were temperature, time of charging, capacitance, resistance value, & lastly the voltage applied. To quantify the resultant photodiode output, we made measurement of the area under the voltage over time graph using the ADALM2000 voltage graphs. The voltage is proportional to the generated photocurrent because the internal resistance of the ADALM2000 is fixed at 1 Mega ohm. The switch was used to control charging time and a thermometer to confirm temperature setup. A detailed data analysis was performed.

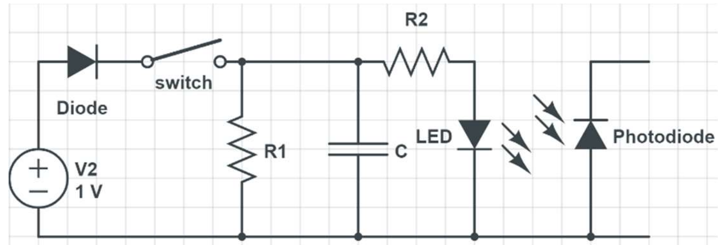


Figure 1 Experimental setup for measuring luminosity of the capacitor LED circuit

Table 1 Factors studied and their high- and low-level values.

Factor\Level	-1	1
Temperature x_1	17° C	23° C
Voltage value x_2	2.5 Volts	5 volts
Charging time x_3	5 seconds	10 seconds
Capacitance x_4	1 milli Farad	2.2 milli Farad
Resistor value x_5	470 Ohm	1000 Ohm

The results were replicated, and randomized utilizing randomly chosen multicolored LEDs. Also, by repeatedly switching out similar resistors, capacitors, and photodiodes. A linear fit was performed for the model data collected.

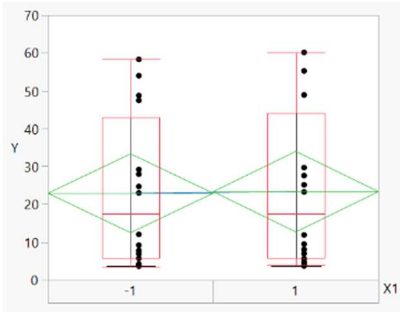
Table 2 Beta Coefficients of the linear model parameters

β_0	β_1	β_2	β_3	β_4
23.098	0.2136	16.396	7.4731	2.4666
β_5	β_{23}	β_{24}	β_{34}	β_{45}
1.0253	5.7318	0.7774	0.7212	0.5224

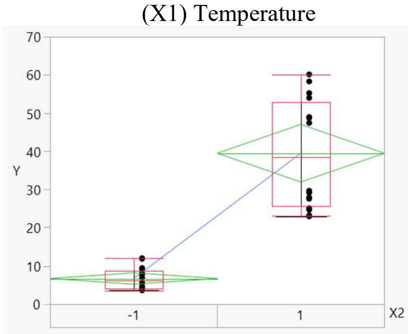
The standard form of the linear fit is written as:

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_5 x_5 + \beta_{23} x_2 x_3 + \beta_{24} x_2 x_4 + \beta_{34} x_3 x_4 + \beta_{23} x_2 x_3 + \text{experimental error.}$$

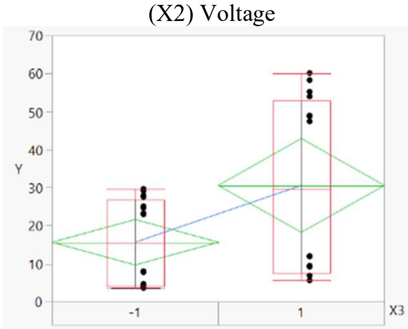
Y is the response value equivalent to photodiode output. The coefficients of interaction between certain factors like β_{12}, β_{13}, β_{14}, β_{15}, β_{25}, β_{35} were not statistically significant and thus not included in the formulation. The standard error of the beta coefficients was found to be $S_\beta = 0.1307$. We observed negligible effect due to temperature (β_1).



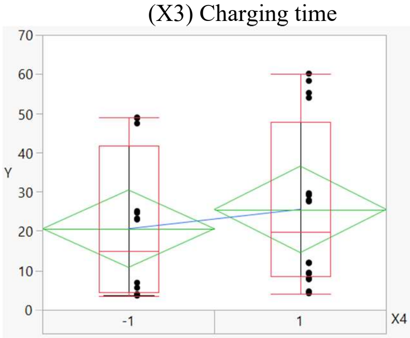
(X1) Temperature



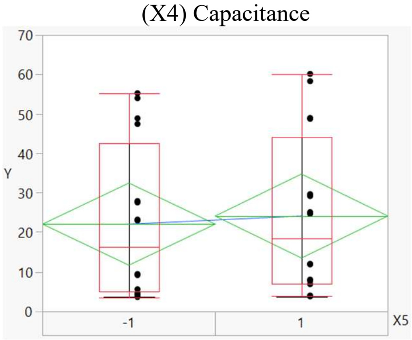
(X2) Voltage



(X3) Charging time



(X4) Capacitance



(X5) Resistance

Figure 2 Box plots of various affecting parameter showing different magnitudes of variation within response variable (Y – area of voltage time graph of photodiode, units of V-s)

III. RESULTS

After conducting a two-level full factorial experiment with 32(=2^5) possible combinations along with a randomized run order and single experiment replication we performed a detailed data analysis. The time series plot generated of the residuals shows no considerable time drift within the system and autocorrelation lag is a negligible positive value except for k=0 where it has a default value of 1. The residual versus run order plot does not show any predictable wave patterns thus no signs of systemic errors are visible. In the normal probability plot most data points are contained within the 95% confidence interval bands and there are no outliers; thus, the errors are normally distributed. In Fig. 2 the variability box plots for X1 shows that the variation for temperature is insignificant which implies the capacitor is reliable regardless of minute temperature differences. The high variation of output magnitude due to input parameters of voltage (x2) and charging time (x3) shows how more energy can be extracted if we charge the capacitors for longer times at higher potential. Resistors (x5) and capacitance (x4) values show low yet measurable variation in output magnitude implying that higher capacitance values and higher resistance provide marginally higher energy outputs in our setting. To double check, we generated a half quantile plot to ensure all statistically significant factors that deviated from the fit were included in the equation.

Thus, we have a confident fit for residuals with low errors and have a resultant statistical model that provides support to our analysis of the capacitor energy storage system.

IV. CONCLUSION

We have demonstrated the effects of variation in physical parameters on the energy functioning of a capacitor system. The optimal method for utilizing a capacitor according to our study involves high charging times at large applied voltages at room temperature to large capacitance and resistor system. Future studies would involve utilizing larger actual supercapacitors with more variable physical factors to determine whether they are suited for applications in electronic devices other than LEDs. Higher number of repeated experimentations could remove uncertainty associated with the experimental setting in our analysis.

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