Electrical Science: 2021-22
Lecture 8
Capacitors

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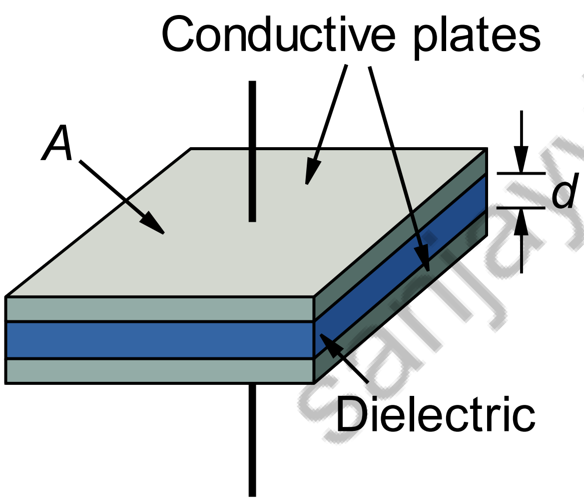
Capacitors

- A capacitor is a device which can store electrical charge.
- Capacitor consists of a pair of conducting plates separated by an insulator. The insulator is called a dielectric and is often air, paper or oil.

$$C = \frac{Q}{V}$$

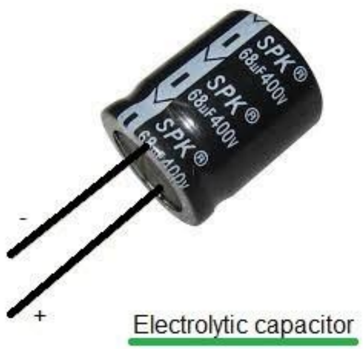


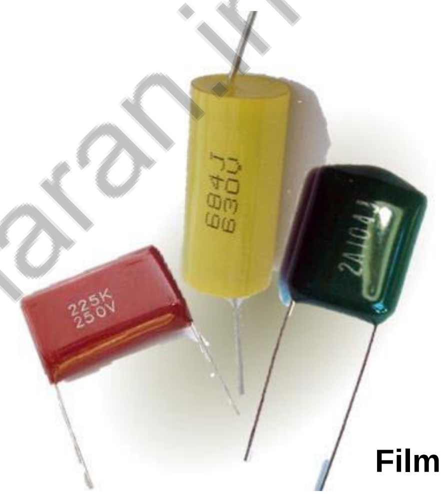
C= capacitance (unit farad (F))

Q = the magnitude of the charge on one plate (unit coulombs (C))

V = the p.d. between the plates (unit volts (V))

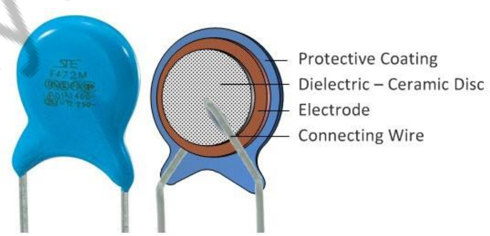
Types of Capacitors





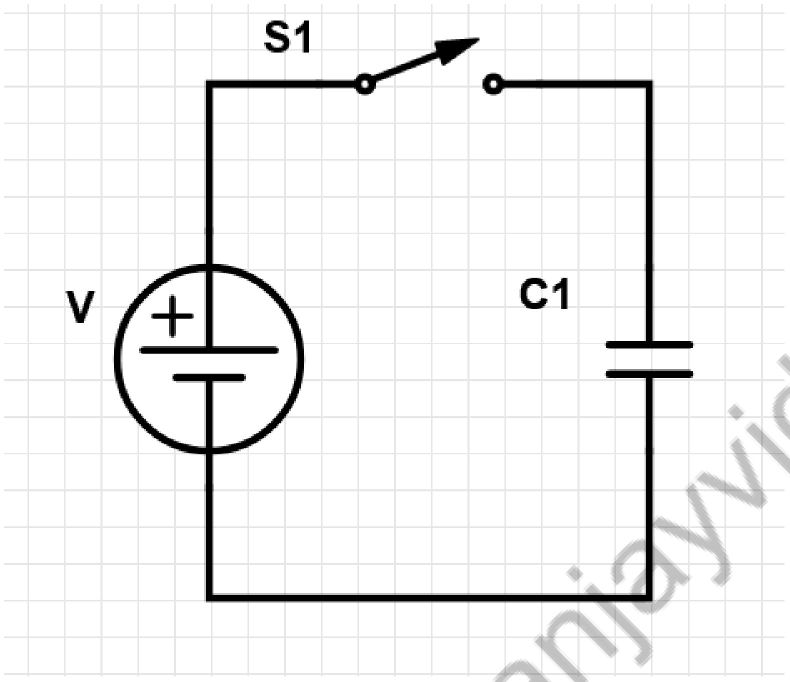
Film Capacitor

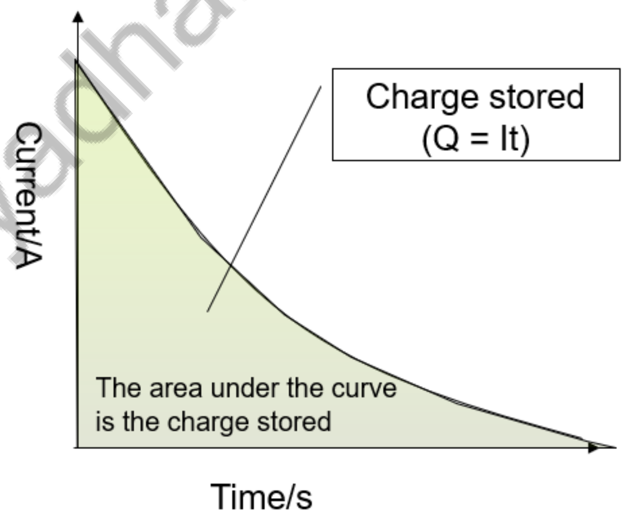
Ceramic capacitors



The multilayer ceramic capacitors are prepared by using the surface mounted (SMD) technology and they are smaller in size, therefore, it is used widely. The values of the ceramic capacitors are typically between the 1nF and 1µF and the values are up to 100µF are possible.

Charge Stored in a Capacitor





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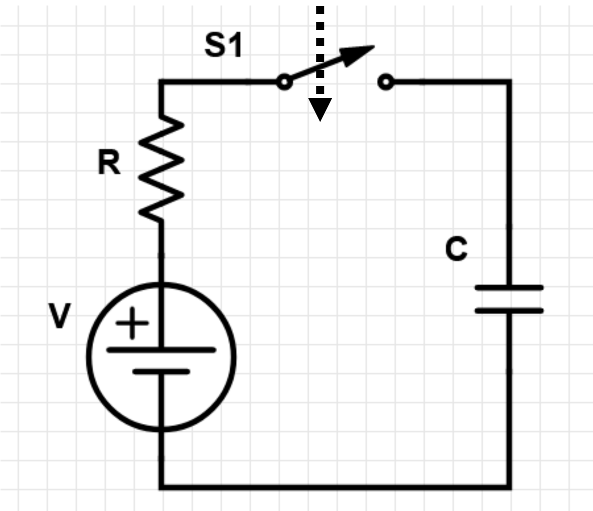
Charging a Capacitor



V - iR - q/C = 0

$$\frac{dq}{dt} = \frac{V}{R} - \frac{q}{RC}$$

$$\frac{dq}{q - CV} = -\frac{dt}{RC}$$

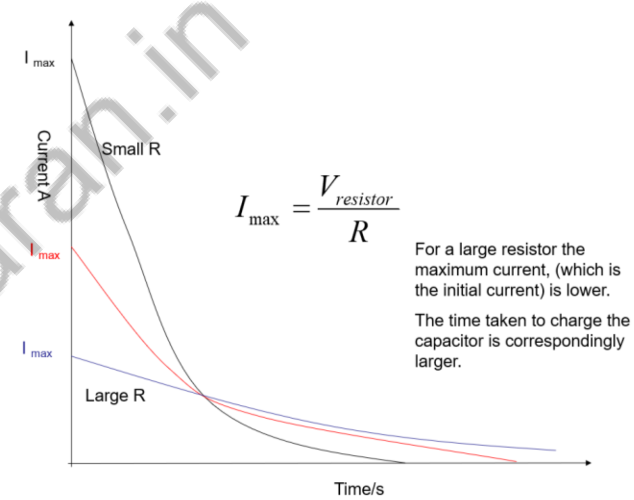
$$\int_0^q \frac{dq}{q - CV} = -\int_0^t \frac{dt}{RC}$$

$$\ln\left(\frac{q-CV}{-CV}\right) = -\frac{t}{RC}$$

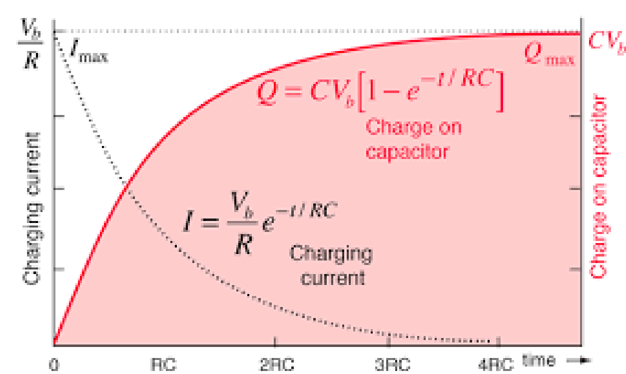
$$q = CV(1 - e^{-t/RC})$$

$$i = \frac{V}{R} e^{-t/RC}$$

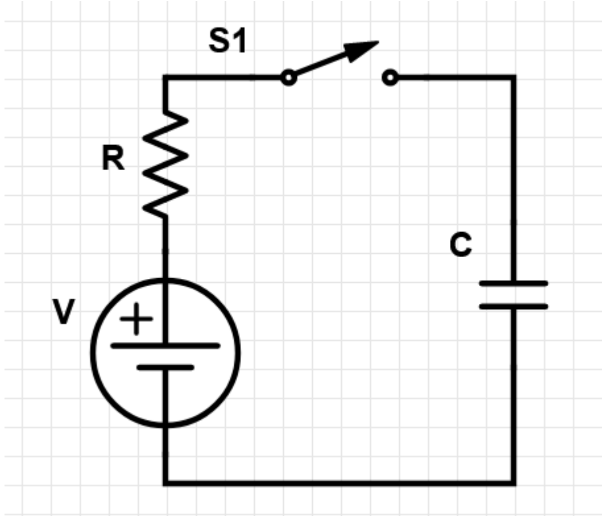
$$i = I_0 e^{-t/RC}$$



$$V_c = \frac{q}{C} = V(1 - e^{-t/RC})$$

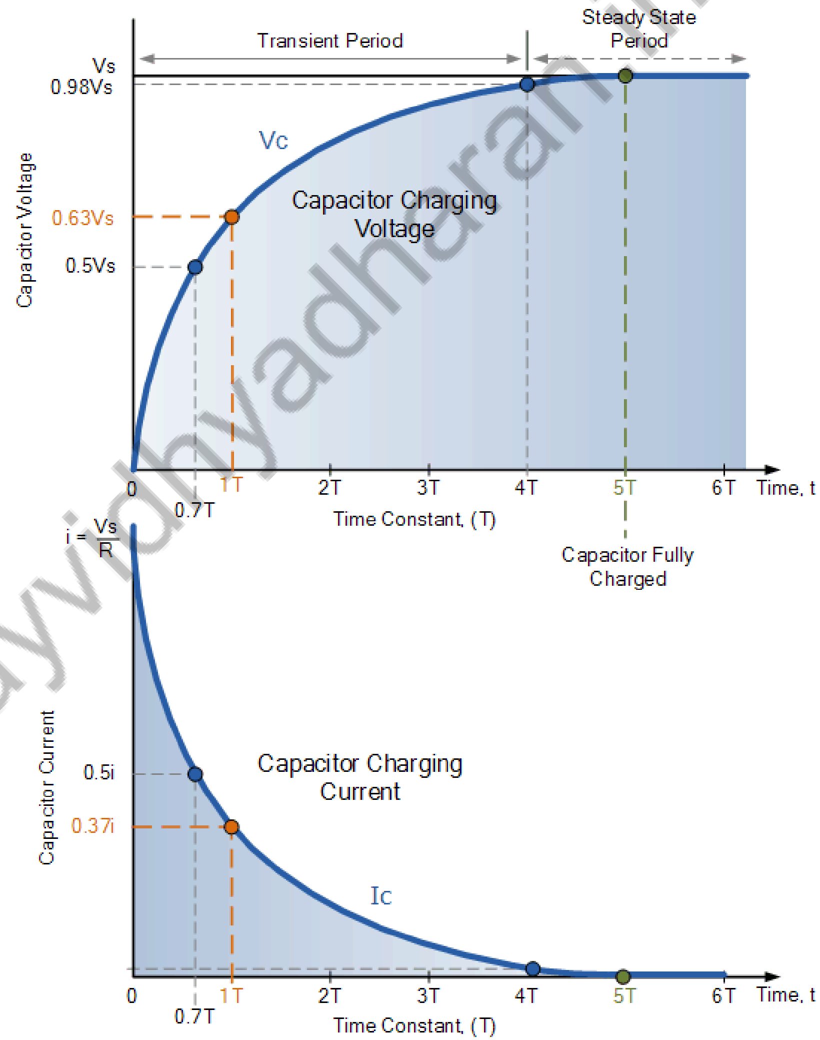


Charging a Capacitor

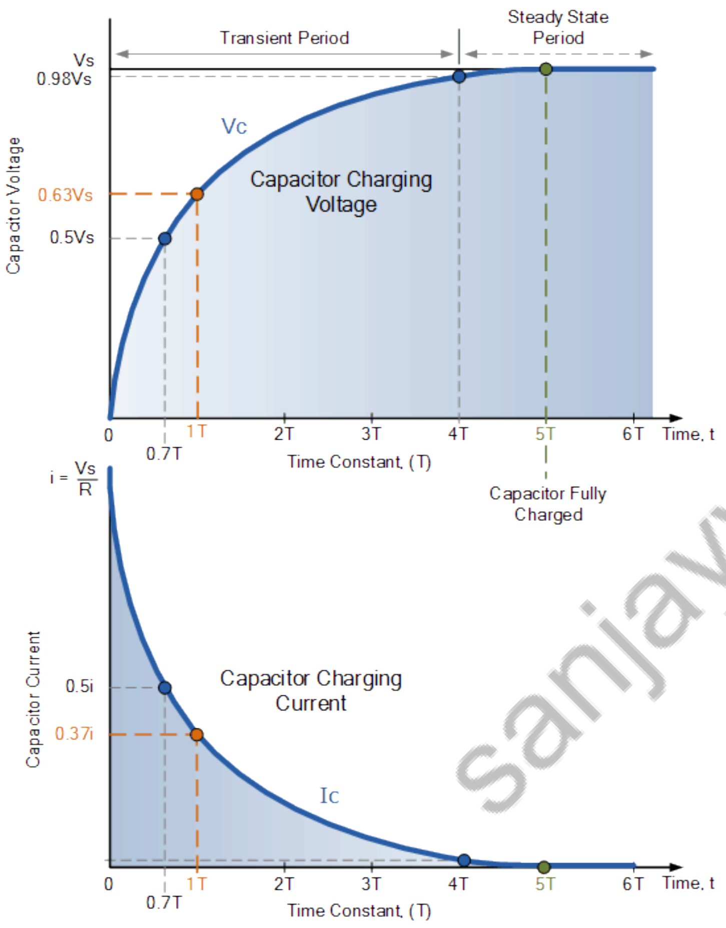


$$V_c = V\,(1 - e^{-t/RC})$$

Time Constant T = RC



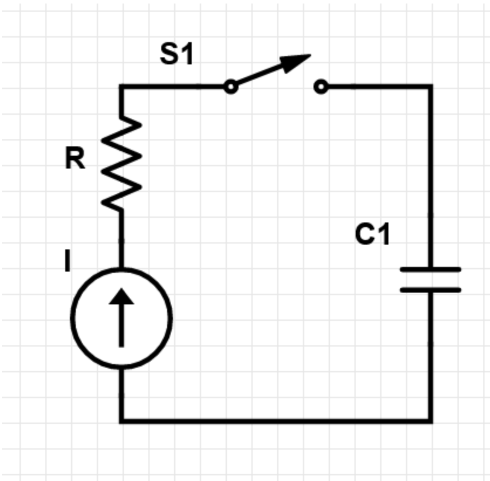
Charging a Capacitor



$$V_c = V\left(1 - e^{-t/RC}\right)$$

Time Constant	RC Value	Percentage of Maximum	
		Voltage	Current
0.5 time constant	0.5T = 0.5RC	39.3%	60.7%
0.7 time constant	0.7T = 0.7RC	50.3%	49.7%
1.0 time constant	1T = 1RC	63.2%	36.8%
2.0 time constants	2T = 2RC	86.5%	13.5%
3.0 time constants	3T = 3RC	95.0%	5.0%
4.0 time constants	4T = 4RC	98.2%	1.8%
5.0 time constants	5T = 5RC	99.3%	0.7%

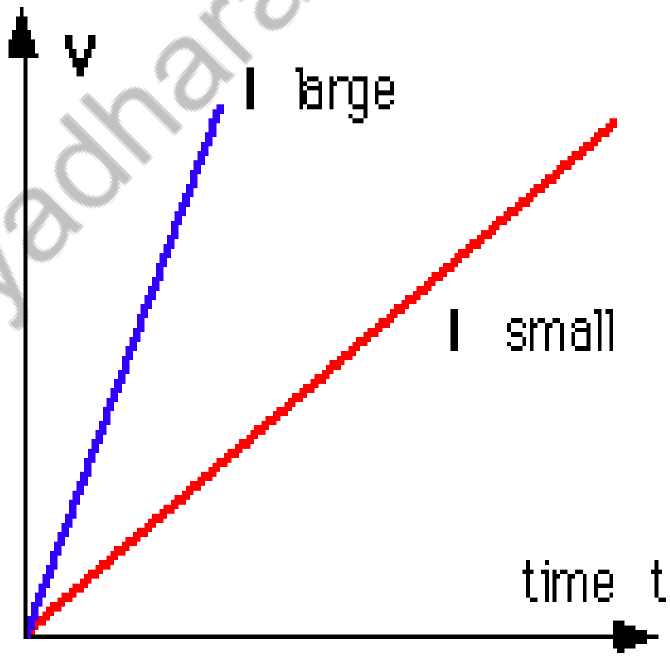
Charging a Capacitor



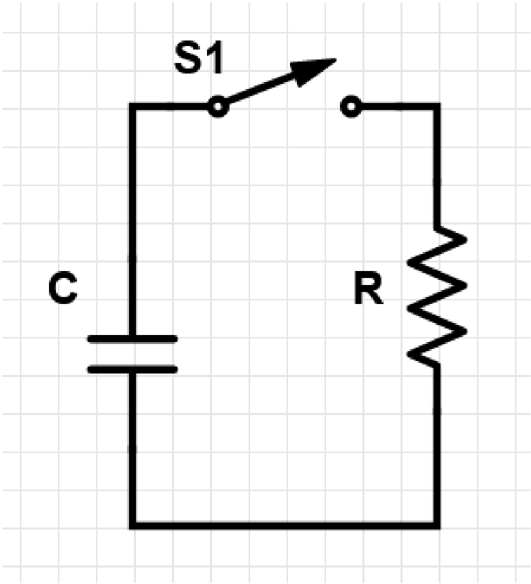
I= $\frac{dq}{dt} = C\,\frac{dV_c}{dt}$

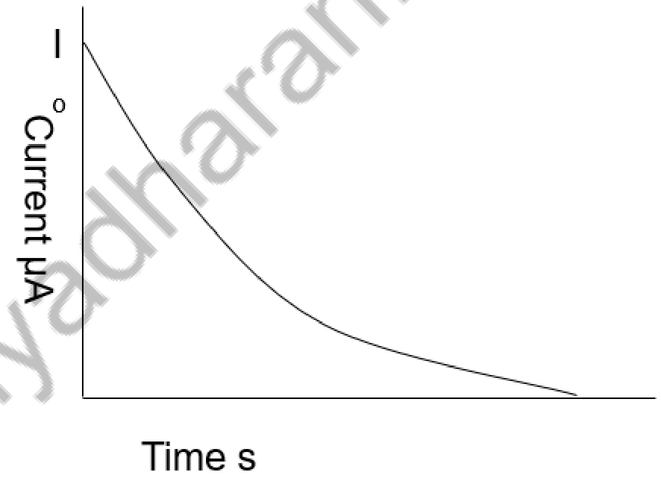
$$dV_c = \frac{I}{C}dt$$

$$V_c = \frac{I}{C}t$$



Discharging a Capacitor





$$I = I_o e^{\frac{-t}{CR}}$$

$$I_0 = \frac{V_o}{R}$$

$$V_c = \text{V} \ e^{-t/RC}$$

Note that the only variable on the right is t.

When t=CR

e = 2.718 so 1/e = 0.368

$$I = 0.368 I_o$$

Series Capacitors

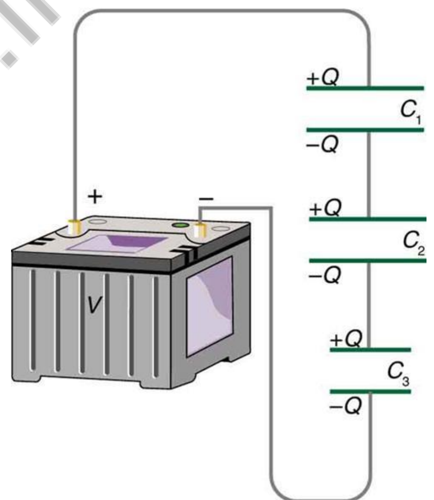
$V_1 = \frac{Q}{C_1}$ $V_2 = \frac{Q}{C_2}$ $V_3 = \frac{Q}{C_3}$

$$V_1 + V_2 + V_3 = Q\left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right)$$

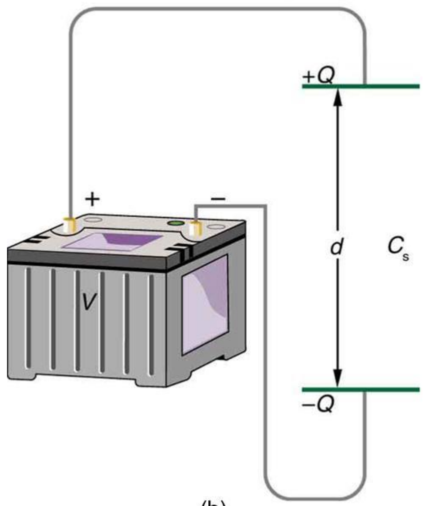
$$V = Q\left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right)$$

A single capacitor which has the same effect is: $V = \frac{Q}{C}$

So: $$\frac{1}{C} = \left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right)$$

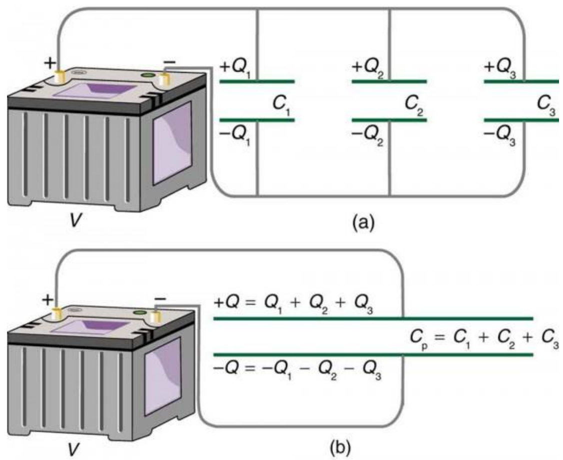


(a)



(b)

Parallel Capacitors



$Q_1 = C_1V \quad Q_2 = C_2V \quad Q_3 = C_3V$

$$Q_1 + Q_2 + Q_3 = C_1V + C_2V + C_3V$$

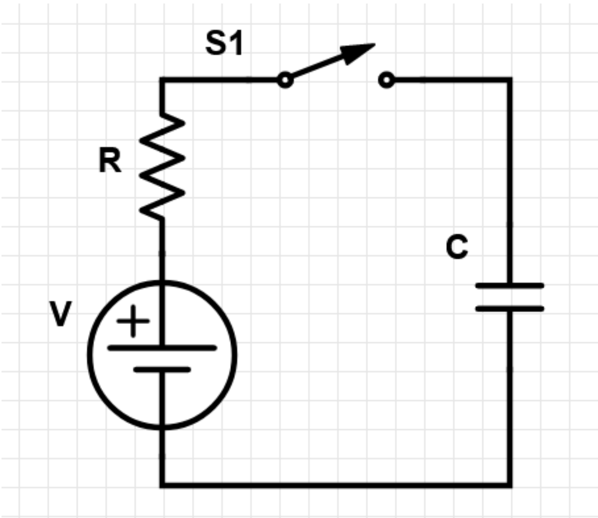
$$Q_1 + Q_2 + Q_3 = (C_1 + C_2 + C_3)V$$

$$Q = CV$$

So $C = C_1 + C_2 + C_3$

	capacitors	resistors
Series connection	$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$	$R = R_1 + R_2 + R_3$
Parallel connection	$C = C_1 + C_2 + C_3$	$R = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$

Energy Stored in Capacitor

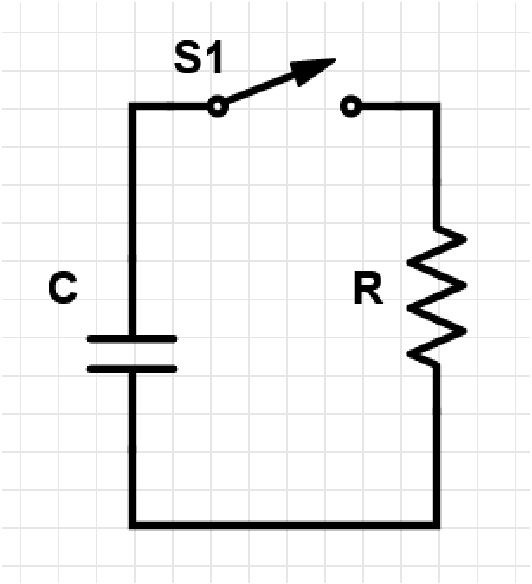


Energy **stored** in C= $\int_0^V V_C \, . C dV_c = \frac{1}{2} V^2 * C$

Energy **consumed** from power supply = $V_{DD} \int_0^T i(t)dt \; = \; V_{DD} . Q_{CL} = V_{DD}^2 . C_L$

Energy **dissipated** in Resistor during charging = $\frac{1}{2} . V_{DD}^2 \, . C_L$

Energy Stored in Capacitor



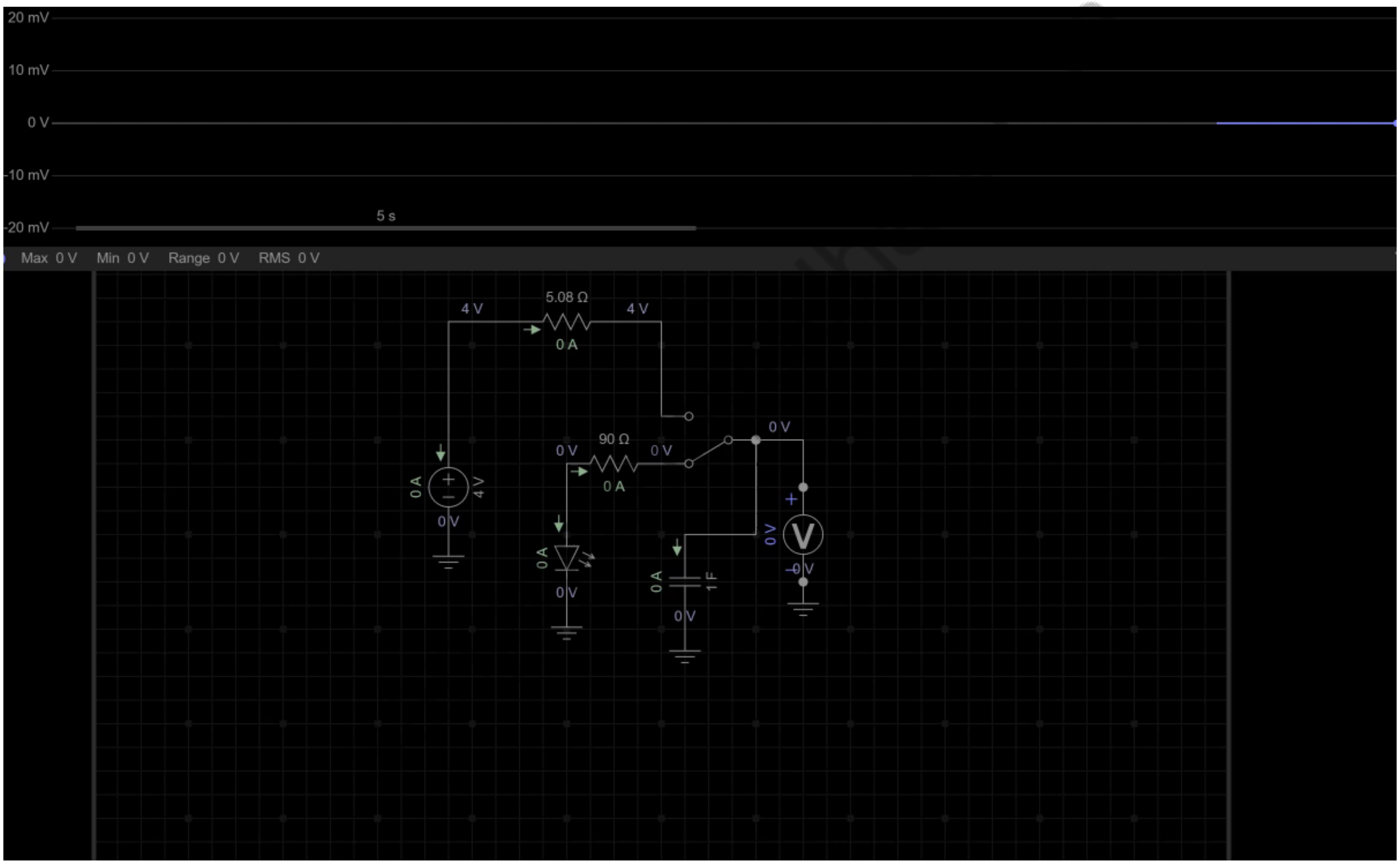
Energy **stored** in C during charging= $\int_0^V V_C \, . \, C dV_c = \frac{1}{2} V^2 * C$

Energy **dissipated** in Resistor during discharging = $\frac{1}{2} V^2 * C$

Applications of Capacitors

1. Energy storage
2. Power conditioning
3. RF coupling and decoupling applications
4. LPF, HPF. BPF Filters
5. Oscillators
6. Noise Filters

Energy Stored in Capacitor



Thank you