ECE 203

Circuits I

Capacitors

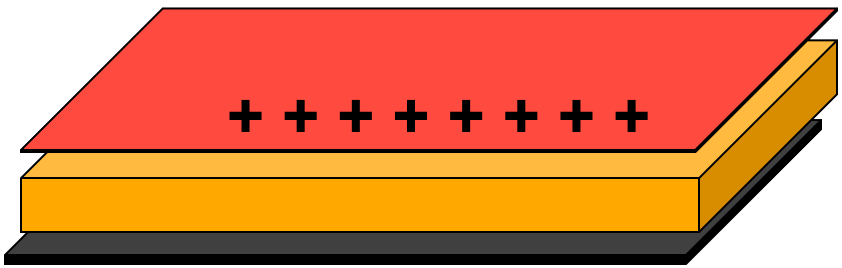
Lecture 9-1

Energy Storage Elements

- **Capacitors** store energy in an electric field
- **Inductors** store energy in a magnetic field
- Capacitors and inductors are passive elements:
  - Can store energy supplied by circuit
  - Can return stored energy to circuit
  - Cannot supply more energy to circuit than is stored
- For our purposes, capacitors and inductors are linear devices

Capacitance

- Capacitance occurs when two conductors (plates) are separated by a dielectric (insulator)
- Charge on the two conductors creates an electric field that stores energy



Capacitance

- The voltage difference between the two conductors is proportional to the charge:

$$q = C\,V$$

Since $i = dq/dt$; then also

$$i = C\,dv/dt$$

- The proportionality constant C is called capacitance.
  - Units of Farads (F) = Coulomb/Volt
  - For two parallel plates: $C = \varepsilon A / d$

Current in a Capacitor

Since $i = C\,dv/dt$

then current only flows when the voltage across the capacitor is changing.

So, no current flow in a capacitor for DC.

Dielectric Constant

$\varepsilon = \varepsilon_r \varepsilon_o$

ε_o is the dielectric constant of free space

$\varepsilon_o = 8.85 \times 10^{-12}$ F/cm

ε_r is the relative dielectric constant

Dielectric constant of common capacitor insulators:

- Air- 1.0006
- Glass- 4 to 7
- Barium titanate- 1200
- Mica- 5.4
- Oil- 2 to 5

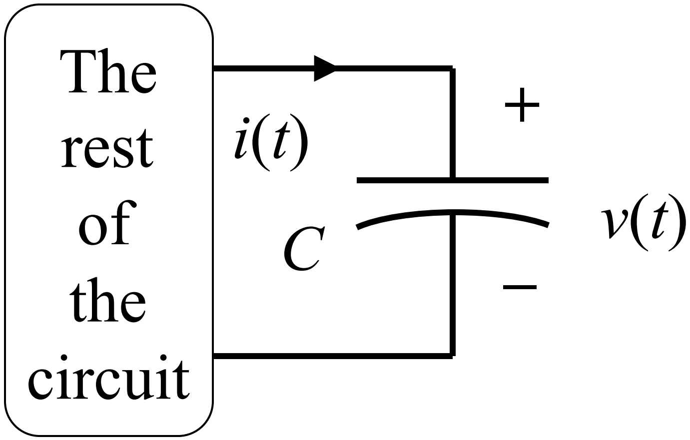
Michael Faraday

The English chemist and physicist Michael Faraday, b. Sept. 22, 1791, d. Aug. 25, 1867, is known for his pioneering experiments in electricity and magnetism. Many consider him the greatest experimentalist who ever lived. Several concepts that he derived directly from experiments, such as lines of magnetic force, have become common ideas in modern physics. Faraday was born at Newington, Surrey, near London. He received little more than a primary education, and at the age of 14 he was apprenticed to a bookbinder. There he became interested in the physical and chemical works of the time. After hearing a lecture by the famous chemist Humphry Davy, he sent Davy the notes he had made of his lectures. As a result Faraday was appointed, at the age of 21, assistant to Davy in the laboratory of the Royal Institution in London.

Perhaps the greatest experimentalist to ever live!

Michael Faraday
(1791-1867)

Capacitor



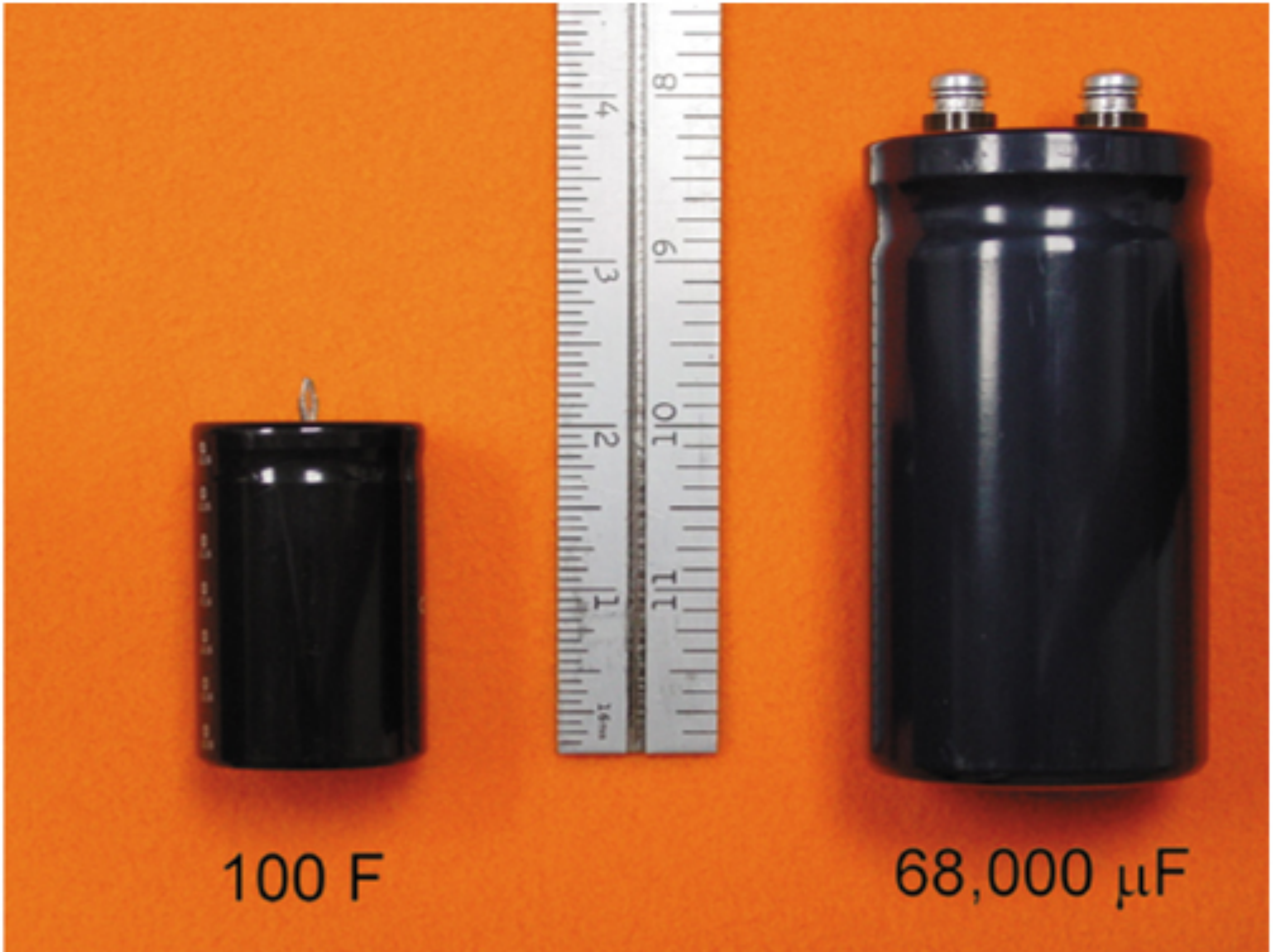
$$\boxed{i(t) = C\frac{dv(t)}{dt}}$$

$$\boxed{v(t) = \frac{1}{C}\int_{-\infty}^{t} i(x)\,dx}$$

Energy Stored in Capacitor

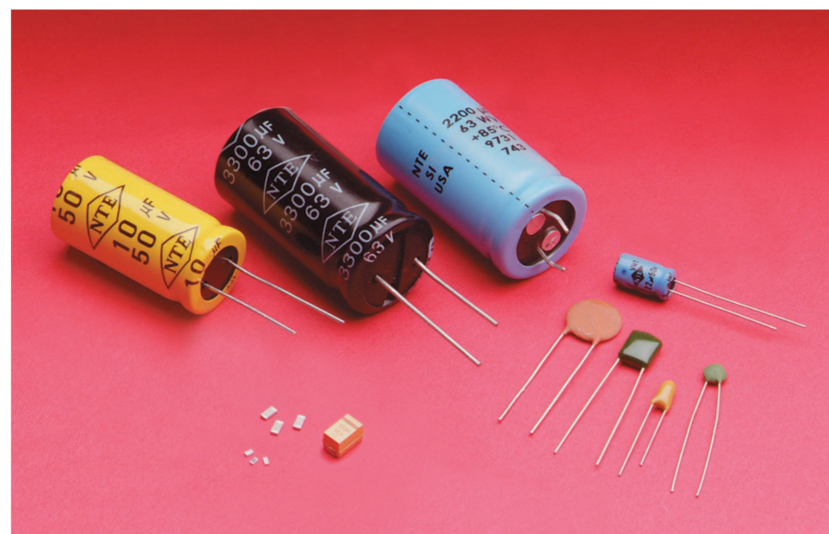
$W_C = \frac{1}{2} CV^2$

Example of Capacitors



AC & Capacitors

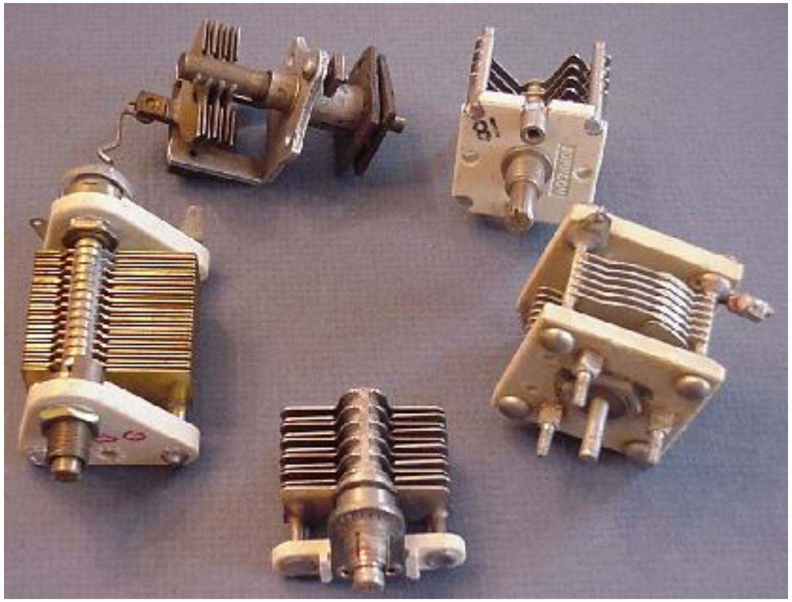
- Capacitors are charge storage devices, but don't allow DC to flow.
- AC can flow because a little charge is stored each cycle and returned.
- The current flow increases with frequency.

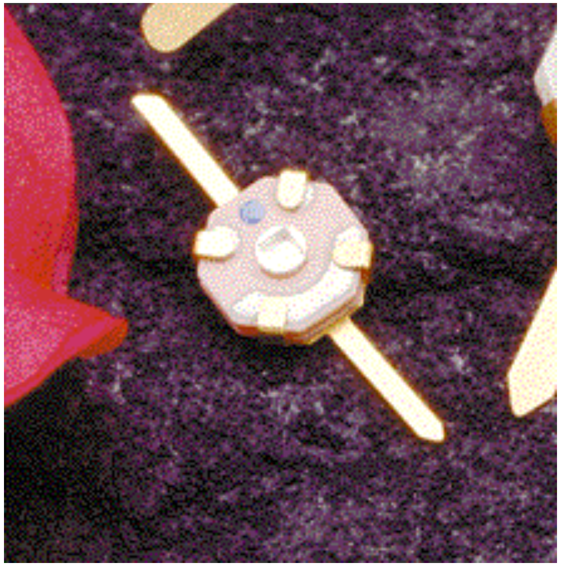


Variable Capacitors

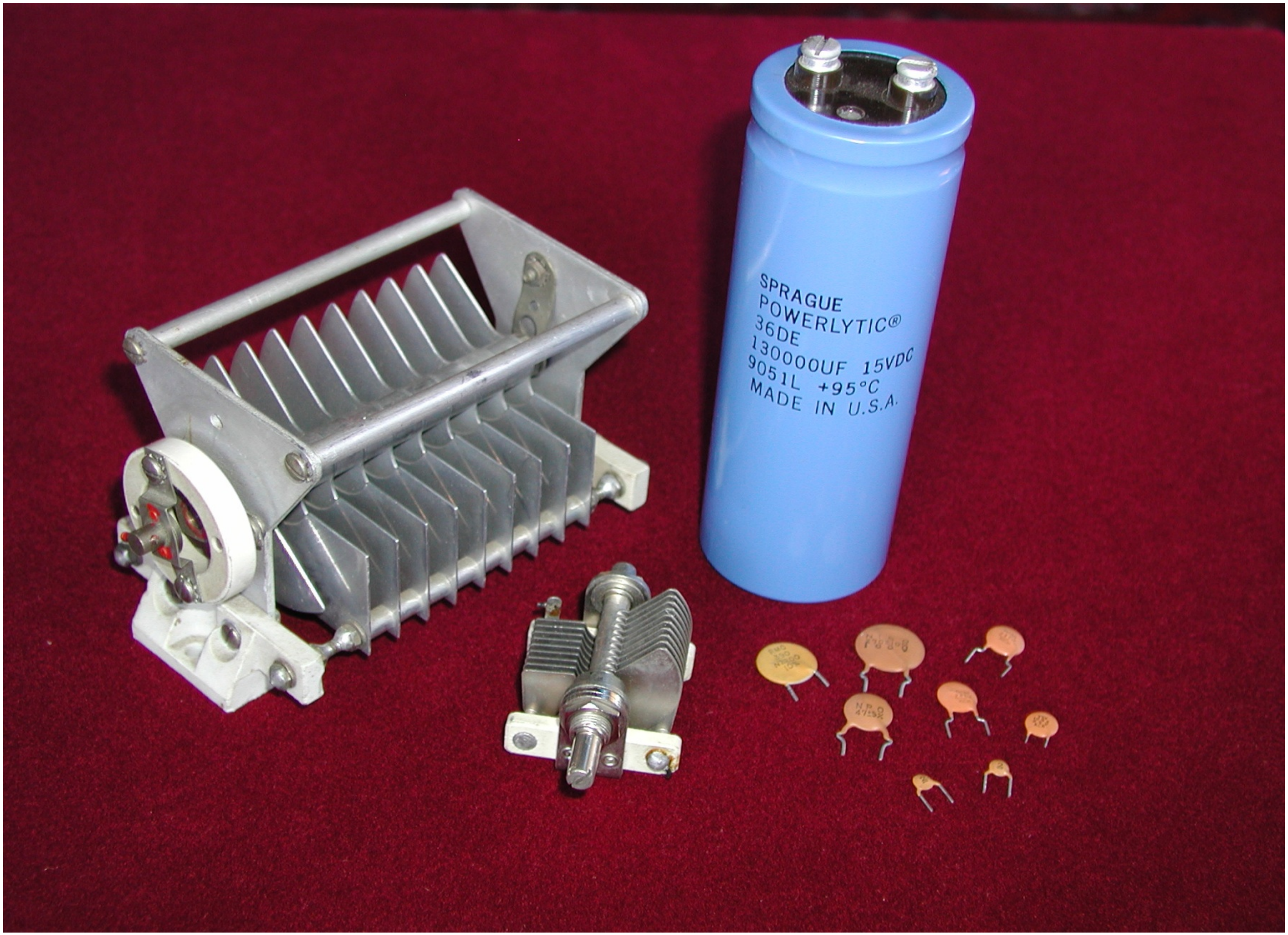
- Capacitors can be variable. Used for tuning:

    Radios, antennas, crystal oscillators (to drive computers).



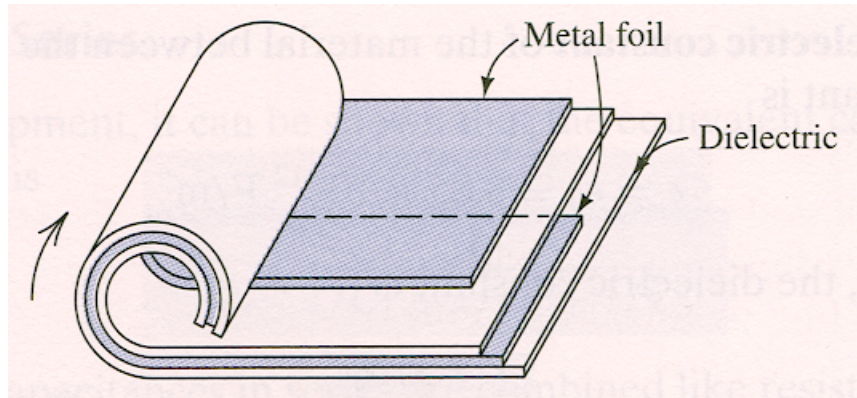


Capacitors


SPRAGUE
POWERLYTIC®
36DE
130000UF 15VDC
9051L +95°C
MADE IN U.S.A.

Practical Capacitors

- A capacitor can be constructed by interleaving the plates with two dielectric layers and rolling them up, to achieve a compact size.



- To achieve a small volume, a very thin dielectric with a high dielectric constant is desirable. However, dielectric materials break down and become conductors when the electric field (units: V/cm) is too high.
  - Real capacitors have maximum voltage ratings
  - An engineering trade-off exists between compact size and high voltage rating

TABLE 6.1 Standard capacitor values

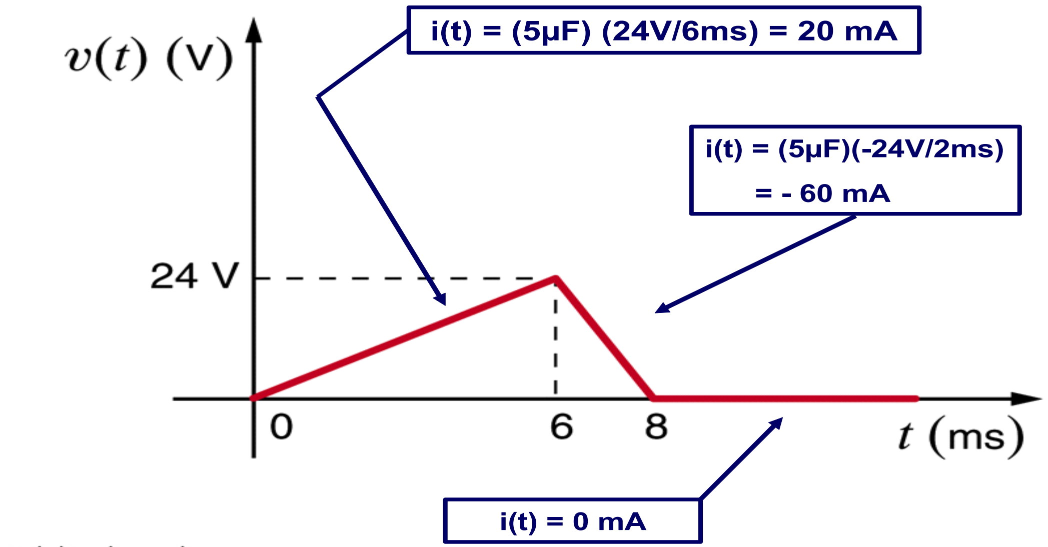
pF	pF	pF	pF	µF	µF	µF	µF	µF	µF	µF
1	10	100	1000	0.010	0.10	1.0	10	100	1000	10,000
	12	120	1200	0.012	0.12	1.2	12	120	1200	12,000
1.5	15	150	1500	0.015	0.15	1.5	15	150	1500	15,000
	18	180	1800	0.018	0.18	1.8	18	180	1800	18,000
2	20	200	2000	0.020	0.20	2.0	20	200	2000	20,000
	22	220	2200	0.022	0.22	2.2	22	220	2200	22,000
	27	270	2700	0.027	0.27	2.7	27	270	2700	27,000
3	33	330	3300	0.033	0.33	3.3	33	330	3300	33,000
4	39	390	3900	0.039	0.39	3.9	39	390	3900	39,000
5	47	470	4700	0.047	0.47	4.7	47	470	4700	47,000
6	51	510	5100	0.051	0.51	5.1	51	510	5100	51,000
7	56	560	5600	0.056	0.56	5.6	56	560	5600	56,000
8	68	680	6800	0.068	0.68	6.8	68	680	6800	68,000
9	82	820	8200	0.082	0.82	8.2	82	820	8200	82,000

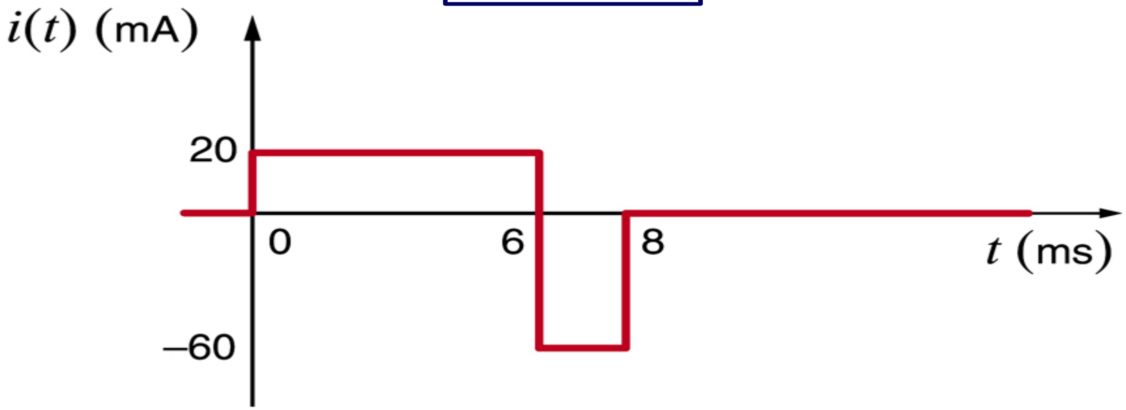
Capacitor Uses

- Store Energy for camera flash
- Filtering of electrical signals- selectively remove certain frequencies
- Tune radios or oscillators

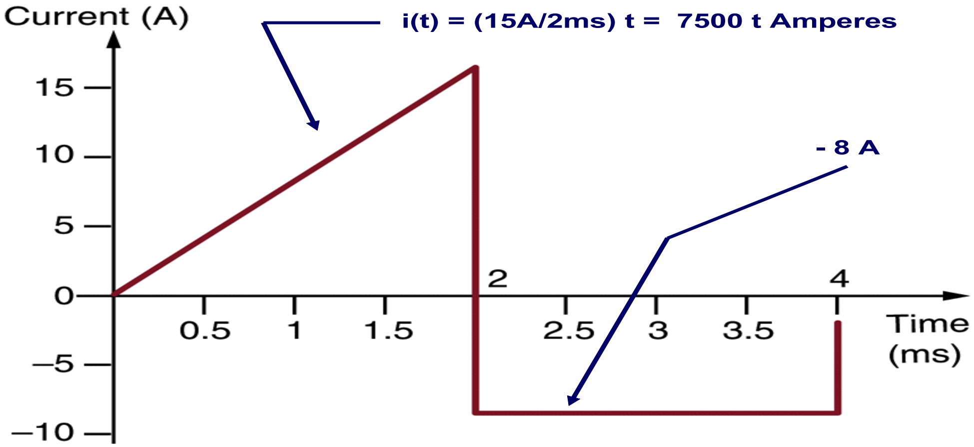
Capacitance also appears as an undesired “parasitic” element in circuits; this can degrade circuit performance, for example in printed circuit boards or integrated circuits.

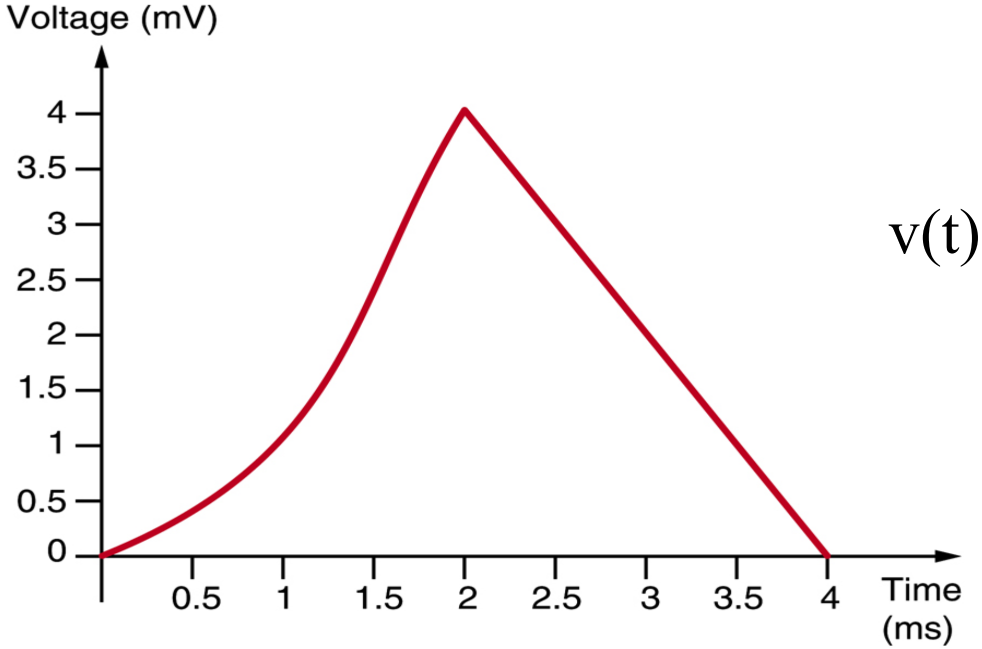
C = 5 μF ? ? Determine the Current $i(t) = C\,dv(t)/dt$



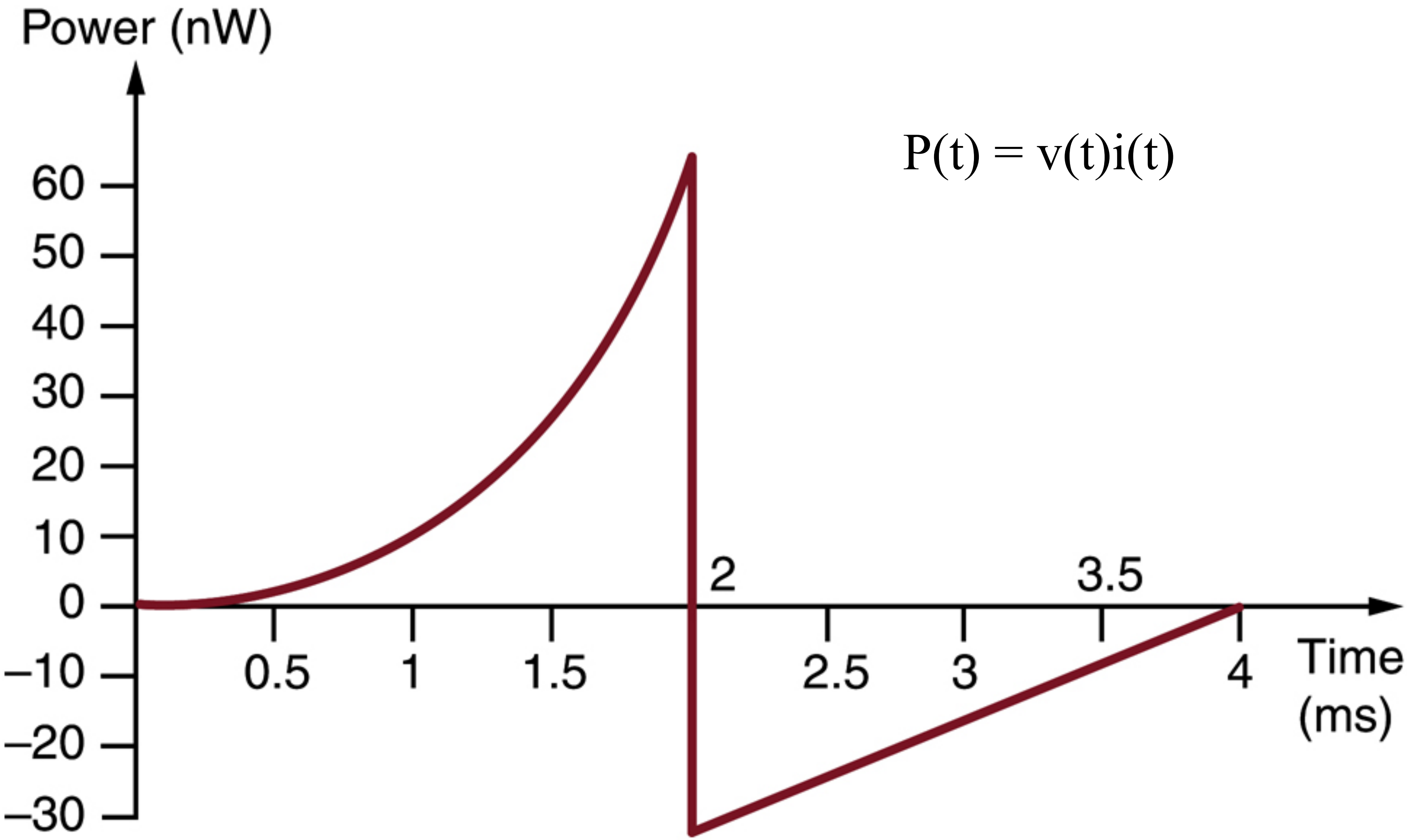


C = 4 μF ? ? Determine the Voltage $i(t) = C\, dv(t)/dt$

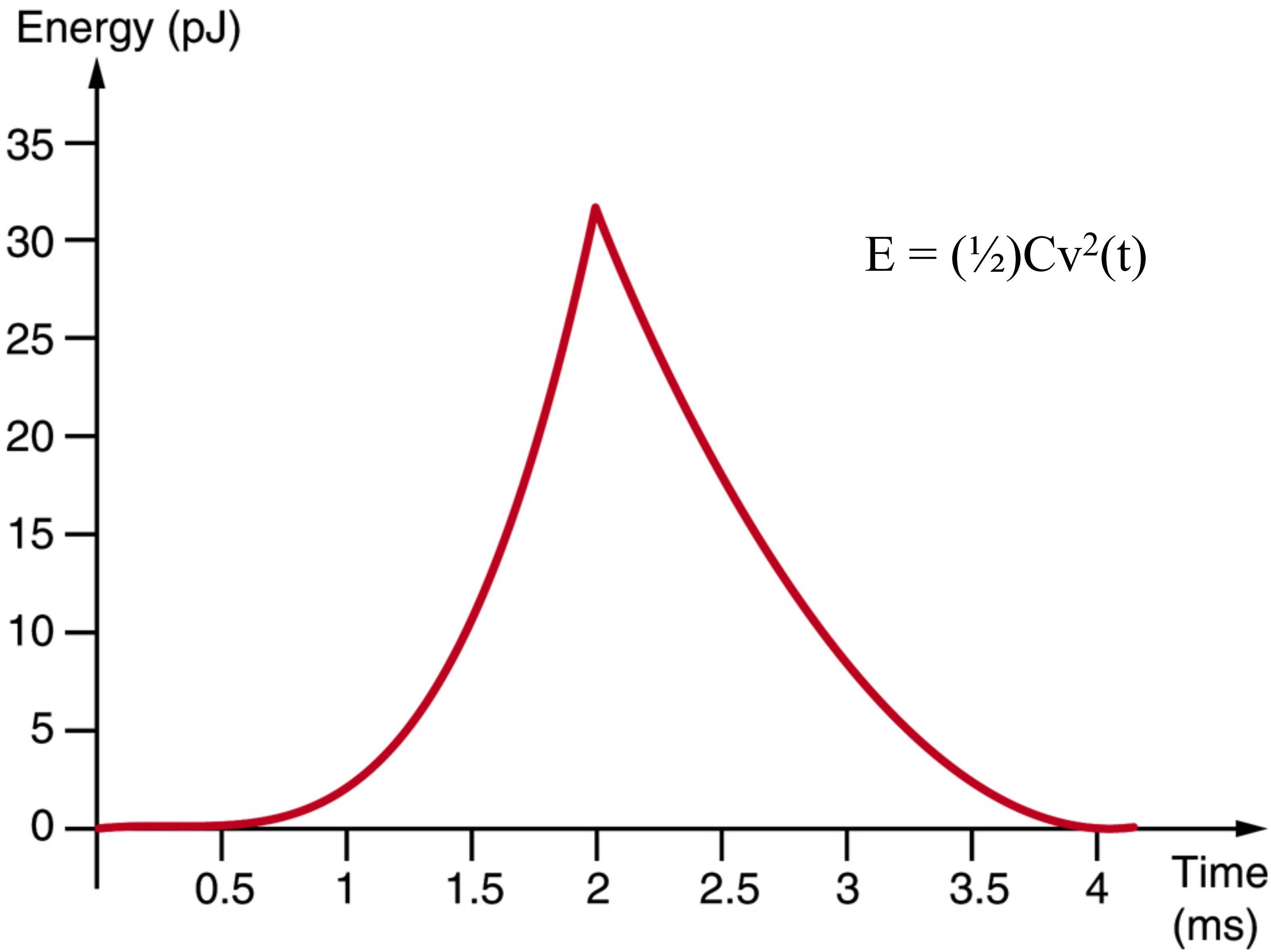




$$v(t) = v(t_o) + (1/C) \int_{to}^{t} i(x)\, dx$$



Power (nW)
P(t) = v(t)i(t)
60
50
40
30
20
10
0
−10
−20
−30
0.5
1
1.5
2
2.5
3
3.5
4
Time (ms)



Energy (pJ)
35
30
25
20
15
10
5
0
0.5
1
1.5
2
2.5
3
3.5
4
Time
(ms)
$E = (½)Cv^2(t)$

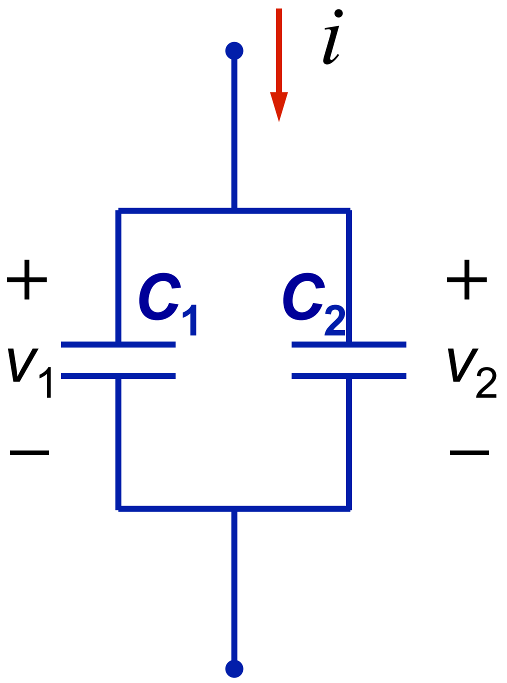
Adding Capacitors in Series

$1/C_{tot} = 1/C_1 + 1/C_2$

So, capacitors in series add like resistors in parallel.

Capacitors in Parallel:

$$C_{Total} = C_1 + C_2$$



Capacitors in parallel add like resistors in series.

Go to Example 9-1.1

Capacitive voltage and current dividers

These work a bit differently than you might expect because of how capacitance adds in series and parallel

Some examples: Go to example 9-1.2