IE1206 Embedded Electronics

Le1 → Le2 PIC-block Documentation, Seriecom Pulse sensors

Le3 → Ex1 → KC1 LAB1 *I*, *U*, *R*, *P*, serial and parallel

Pulse sensors, Menu program

- ***Start of programing task***

Le4 → Ex2 Kirchhoffs laws Node analysis Two-terminals R2R AD

Le5 → Ex3 → KC2 LAB2 ***Two-terminals, AD, Comparator/Schmitt***

Le6 → Ex4 → Le7 → KC3 LAB3 Transients PWM

Step-up, RC-oscillator

Le8 → Ex5 → Le9 Phasor jω PWM CCP CAP/IND-sensor

Ex6 → Le10 → Le11 → KC4 LAB4 ***LC-osc, DC-motor, CCP PWM***

Le12 → Ex7 → Display LP-filter Trafo

- ***Display of programing task***

Le13 → Written exam Trafo, Ethernet contact

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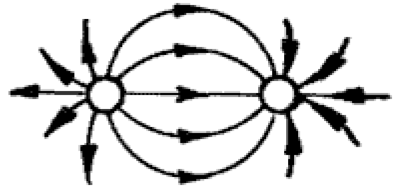
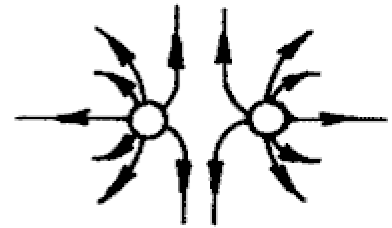
electric fields

The force between charges can be calculated using Coulomb's Law. The force between like charges is repulsive, between different charges atractive.

The electric field E at a point charge Q_1 can be seen as the force on a "test charge", a "unit charge“ (Q_2 =+1).
The electric lines of force are starting from a positive charge and end on a negative charge.

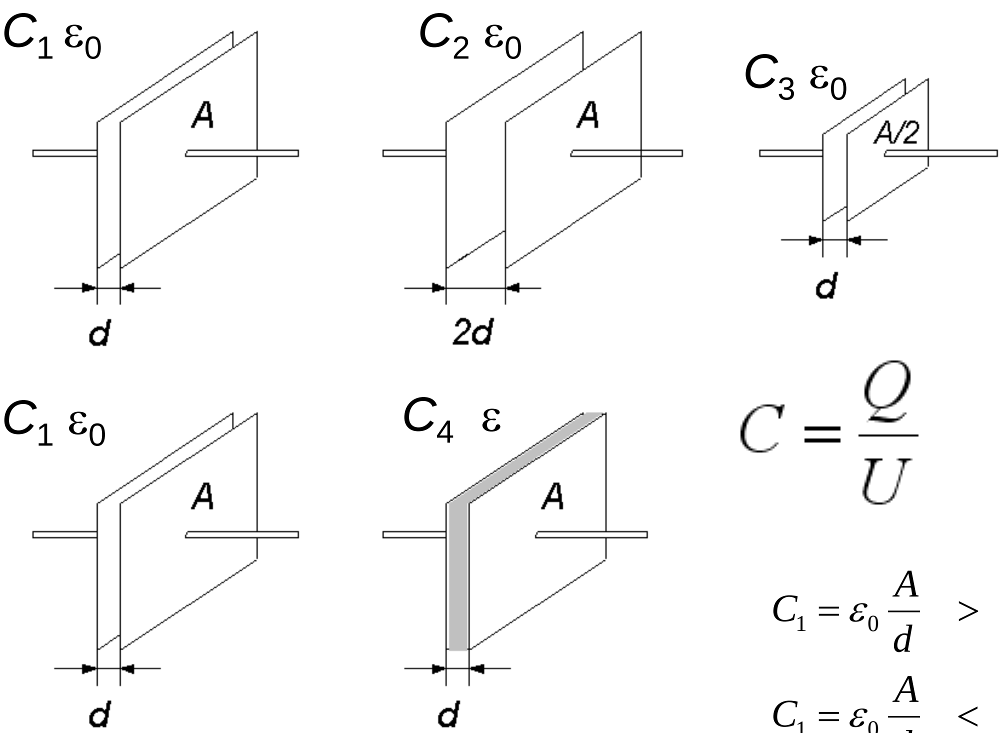
The force lines may not cross each other.

$$F = \mathrm{k} \cdot \frac{Q_1 \cdot Q_2}{r^2} \qquad \overline{E} = \mathrm{k} \cdot \frac{Q_1 \cdot 1}{r^2} \qquad \mathrm{k} = \frac{1}{4\pi \cdot \varepsilon_0} = 9 \cdot 10^9 \ \mathrm{Nm^2/C^2}$$

The constant k has a very big value, **the electical forces are strong**.

Plate capacitor

$$C = \frac{Q}{U} \qquad C = \varepsilon \frac{A}{d}$$



A capacitor capacitance C is proportional to the area A and inversely proportional to flat distance d.

If the insulation material between the plates is polarizable (ε) the capacitance is increased.

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

$$C_1 = \varepsilon_0 \frac{A}{d} \quad > \quad C_2 = \varepsilon_0 \frac{A}{2d} \quad = \quad C_3 = \varepsilon_0 \frac{A/2}{d}$$

$$C_1 = \varepsilon_0 \frac{A}{d} \quad < \quad C_4 = \varepsilon \frac{A}{d} \qquad \varepsilon = \varepsilon_r \cdot \varepsilon_0 \quad \varepsilon_0 = 8{,}85\ \mathrm{pF/m}$$

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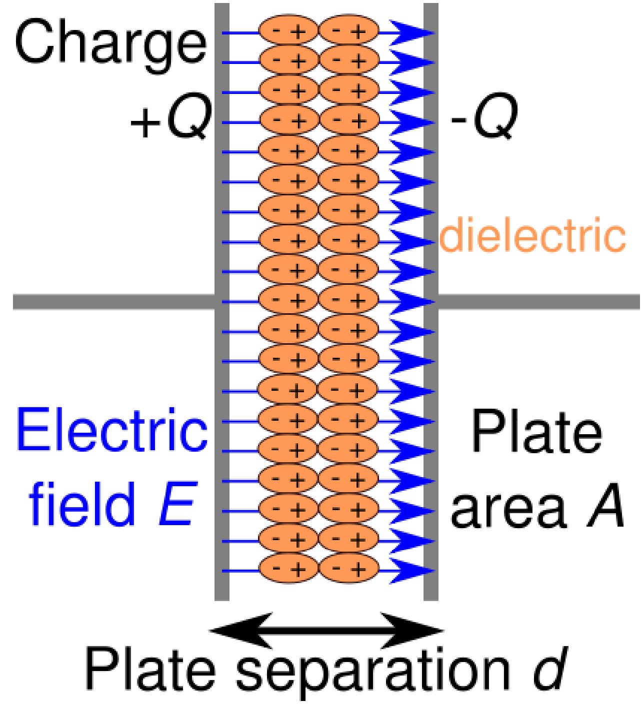
Dielectric

Most materials are polarizable, and will then increase the electric field, and the capacitance of the capacitor if placed between the plates.



Titanite used in ceramic capacitors, the increases the capacitance 7500 times in comparison to vacuum or air.

$\varepsilon_r = 7500$

ε_r is playing the same role for the electric field as μ_r does for the magnetic field.

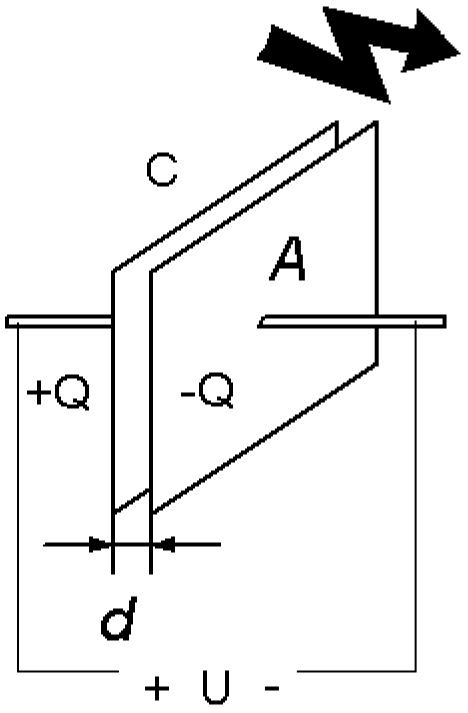
$$\varepsilon = \varepsilon_r \cdot \varepsilon_0 \qquad \varepsilon_0 = 8{,}85\ \mathrm{pF/m}$$

Short *d*, Voltage rating

High capacitance value could be obtained with a small flat distance *d*.

The drawback is that the risk increases for arcing between the plates. Each capacitor then has a maximum rated voltage which must not be exceeded.

A capacitor for higher rated voltage are necessarily larger than a lower rated voltage if the capacitance is the same.

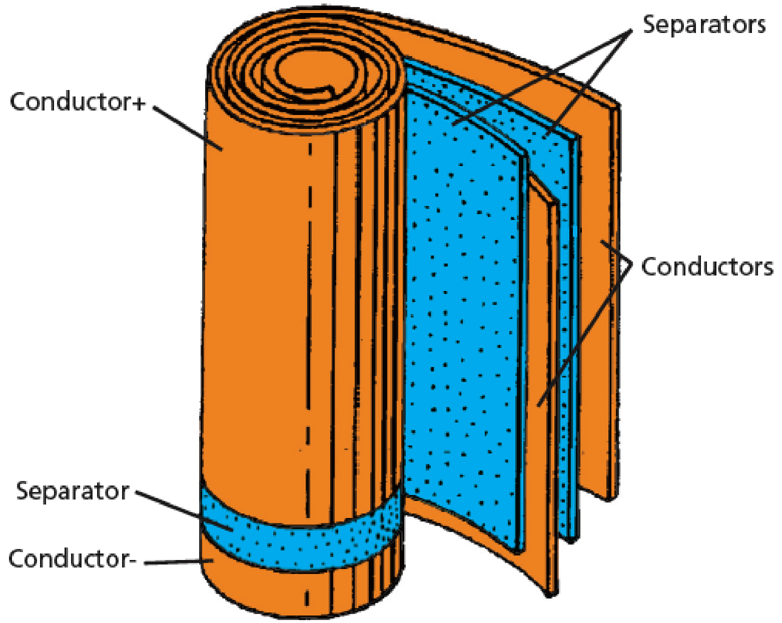


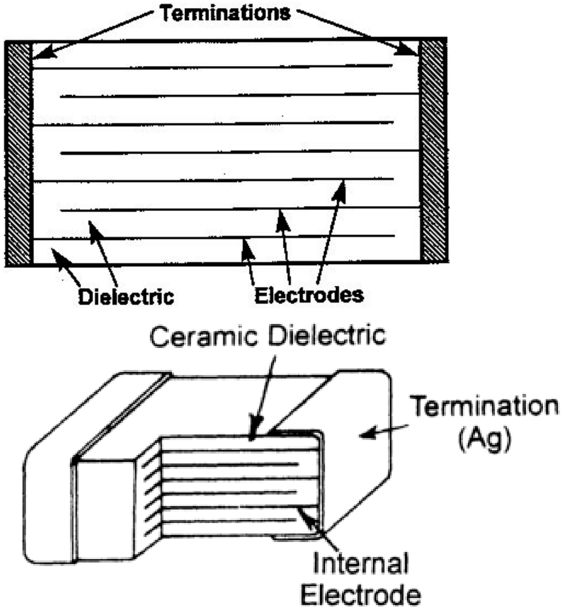
$$C = \frac{Q}{U} \qquad E = \frac{U}{d}$$

The electric field *E* of the capacitor is *E*=*U*/*d*. The air can withstand 2.5 kV/mm before arcing!

Big area *A*

High capacitance one can get with large area *A*. The capacitor can then be rolled, or type by multilayer type, so that "the component surface" is minimized despite the large inner surface.





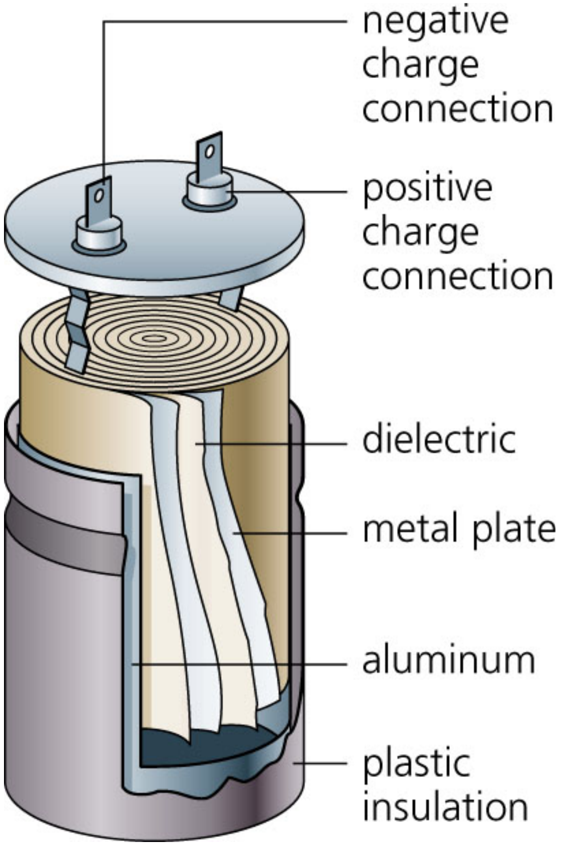
Multilayer Capacitor with ceramic dielectrics (= high ε_r).

Very short distance *d*

The **electrolytic capacitor** is based on extremely small distance *d* between the electrodes. One electrode is an aluminum foil, and the dielectric is a thin insulating oxide layer on the foil. The other electrode is the electrolyte itself which of course is in close contact with the surface of the foil.

The capacitor must be polarized correctly, with the same polarity as when the oxide layer was formed. Otherwise the oxide layer is destructed and the capacitor is shorted!

The capacitor is also destroyed if the rated voltage is exceeded.



Big area *A* and very short distance *d*

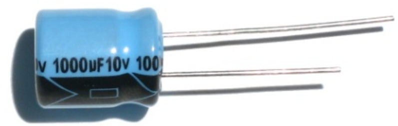
Tantal electrolytic capacitor have a "sponge formed" electrode.

The total inner surface *A* becomes extremely large. The insulation consists of an oxide layer so even *d* is small.

A 3.5 mm×2.5 mm× 5.5 mm, 4.7µF **tantal electrolytic capacitor** has the equivalent inner area of 40 cm^2 !

Capacitors


221J


1000µF10V


WIMA
MP 3-Y2
0.01
250~
40/110/56/C
WIMA
MP 3-X2
0.22
250~
40/110/56/C


NEC
FS
NEC

Supercap (9.2)

$$C = \frac{Q}{U} \qquad I = Q \cdot t$$

The backup capacitors of the type "Supercap" can be used as a power backup for memories - if one for example needs to move the phone from one room to another without the phone forgetting its settings.

Make a rough estimate of how long the charge in the capacitor will last?

Assume that C = 1 F and U is initially 5V. The equipment draws I = 10 mA and operates down to 2.5V.

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$$\Delta Q = C \cdot \Delta U = 1 \cdot (5 - 2{,}5) = 2{,}5 \text{ As} \qquad t = \frac{\Delta Q}{I} = \frac{2.5}{10 \cdot 10^{-3}} = 250 \text{ s} = 4 \text{ min}$$

School’s ”biggest” supercap?

3000 F × 16
Research is going on for energy storage for routers in places where batteries woud have 'inappropriate' temperatures.

For example, in the desert or in the arctic.

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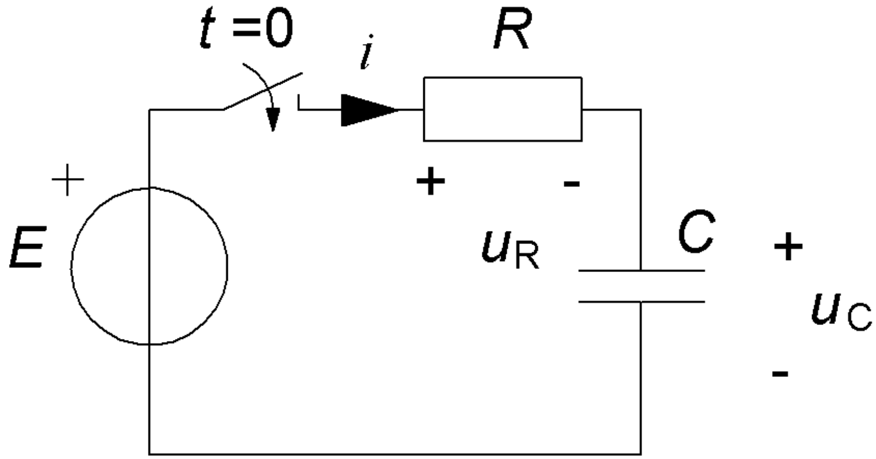
Capacitor transients

$\tau = R \cdot C$



The voltage across the capacitor orginates from the collected charge.

$$u_C(t) = \frac{q(t)}{C} = \frac{\int_0^t i(z)\,\mathrm{d}z}{C}$$

$$E = u_R + u_C \quad \Leftrightarrow \quad E = i(t) \cdot R + \frac{1}{C}\int_0^t i(z)\,\mathrm{d}z$$

$$\frac{\mathrm{d}}{\mathrm{d}t}E = \frac{\mathrm{d}}{\mathrm{d}t}i(t) \cdot R + \frac{\mathrm{d}}{\mathrm{d}t}\frac{1}{C}\int_0^t i(z)\,\mathrm{d}z \quad \Rightarrow \quad 0 = R\frac{\mathrm{d}i(t)}{\mathrm{d}t} + \frac{1}{C}i(t) \quad \Leftrightarrow \quad 0 = R \cdot C\frac{\mathrm{d}i(t)}{\mathrm{d}t} + i(t)$$

$$i(t) = \frac{E}{R} \cdot e^{-\frac{t}{\tau}} \qquad \tau = R \cdot C$$

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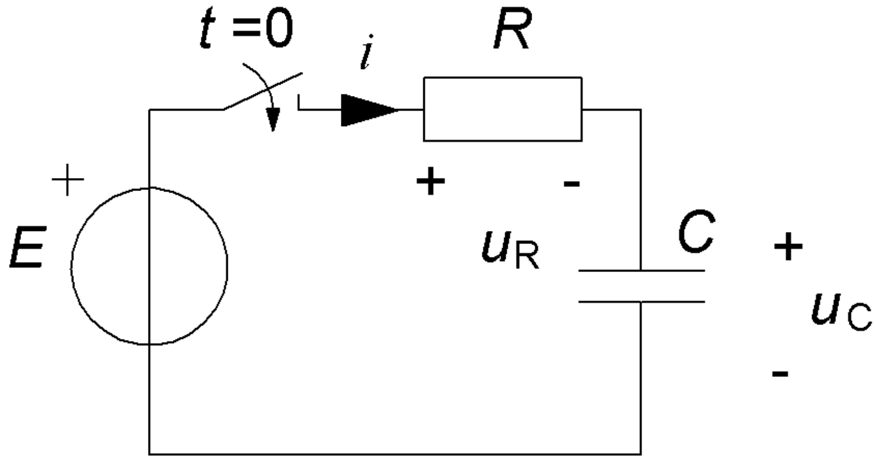

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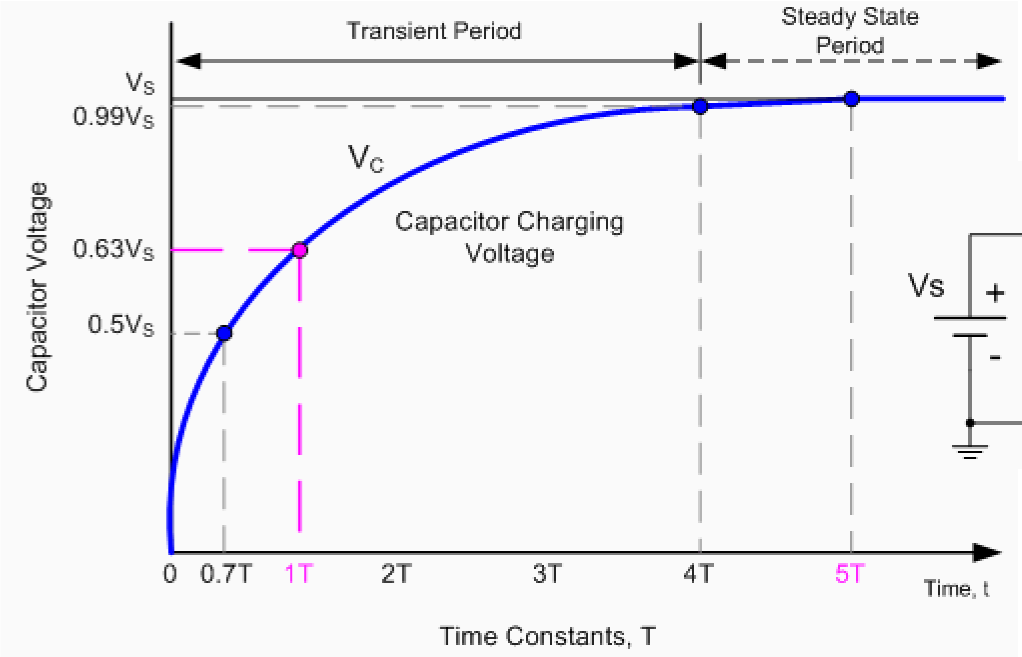
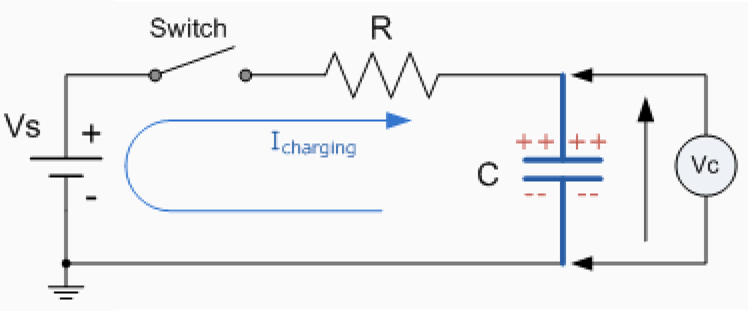
The differential equation has the solution:

$$\boxed{i(t) = \frac{E}{R} \cdot e^{-\frac{t}{\tau}} \qquad \tau = R \cdot C}$$

Charging a capacitor





Time constant

$$T = R \cdot C$$

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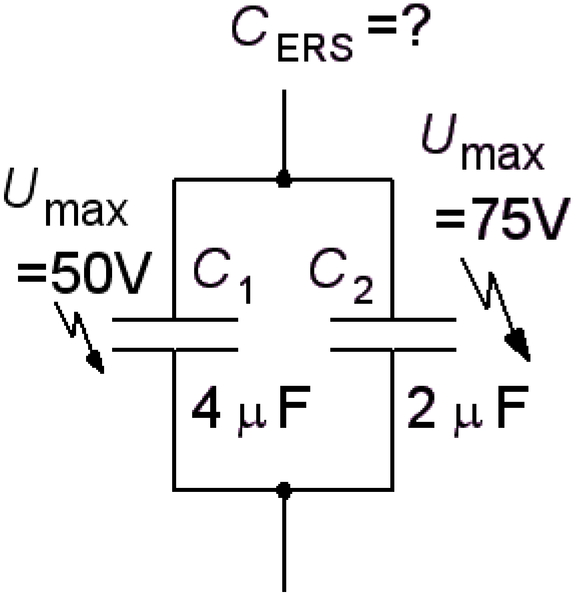
Parallel connected capacitors

(Ex. 9.3) Two capacitors parallel-connected. What about the equivalent capacitance and its rated voltage?

$C_1 = 4\ \mu F\ 50V$

$C_2 = 2\ \mu F\ 75V$



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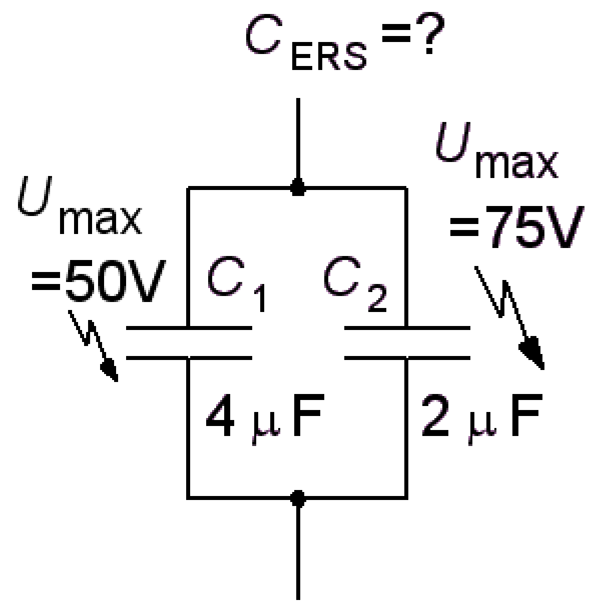

Capacitance is added, the parallel connection is the same as if plate surfaces were added. The capacitor with the worst withstanding voltage determines the equivalent capacitor rated voltage. It is in this capacitor the impact would occur.

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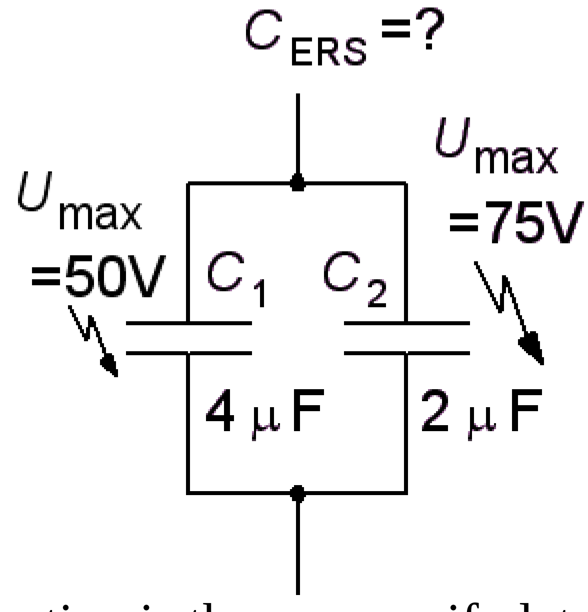

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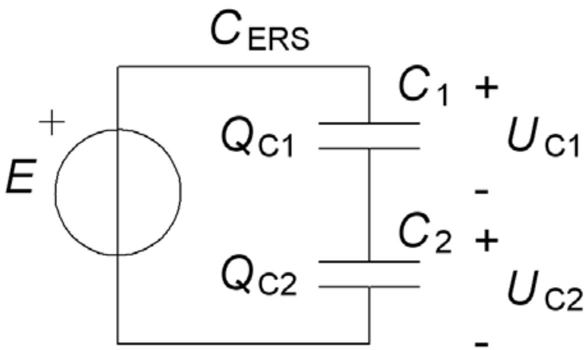
$C_{ERS} = C_1 + C_2 = 4 + 2 = 6$ μF 50V

Series connected capacitors

$$E = U_{C1} + U_{C2} \quad U = \frac{Q}{C} \quad \Rightarrow \quad E = \frac{Q}{C_{\mathrm{ERS}}} = \frac{Q_{\mathrm{C1}}}{C_{\mathrm{C1}}} + \frac{Q_{\mathrm{C2}}}{C_{\mathrm{C2}}} \quad Q = Q_{\mathrm{C1}} = Q_{\mathrm{C2}}$$

$$\Rightarrow \quad \frac{1}{C_{\mathrm{ERS}}} = \frac{1}{C_{\mathrm{C1}}} + \frac{1}{C_{\mathrm{C2}}}$$



$$C_{\mathrm{ERS}} = \frac{C_1 \cdot C_2}{C_1 + C_2}$$

Parallel coupling formula for resistors is comparable to series coupling capacitors formula!

In a capacitive voltage divider the voltages are divided inversely with the capacitor capacitances. The smallest capacitor will have the highest voltage – will it withstand it?

Example. Series connected capacitors

(Ex. 9.4) Two capacitors are connected in series. Calculate the equivalent capacitance and specify how the voltage is divided between the capacitors.

E = 10 V

C_1 = 6 μF

C_2 = 12 μF

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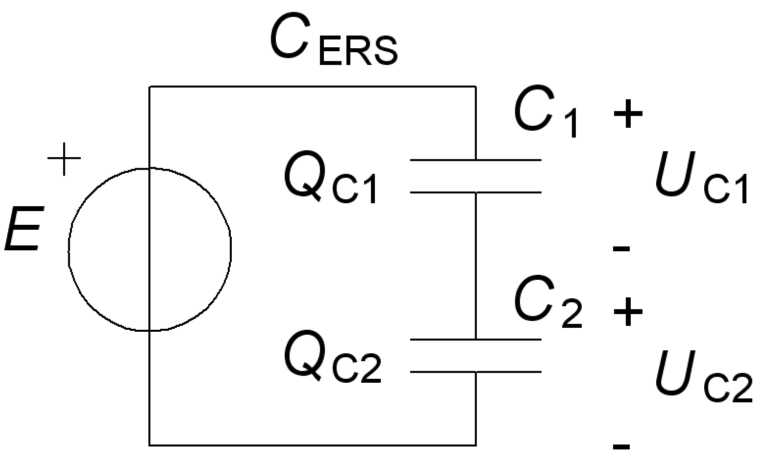

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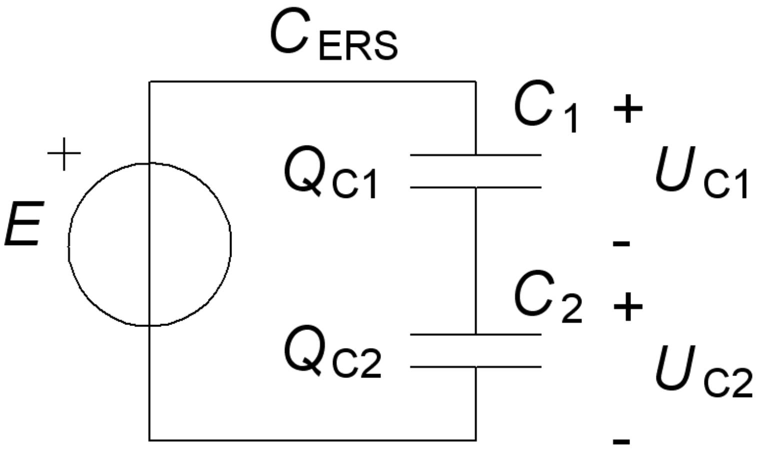

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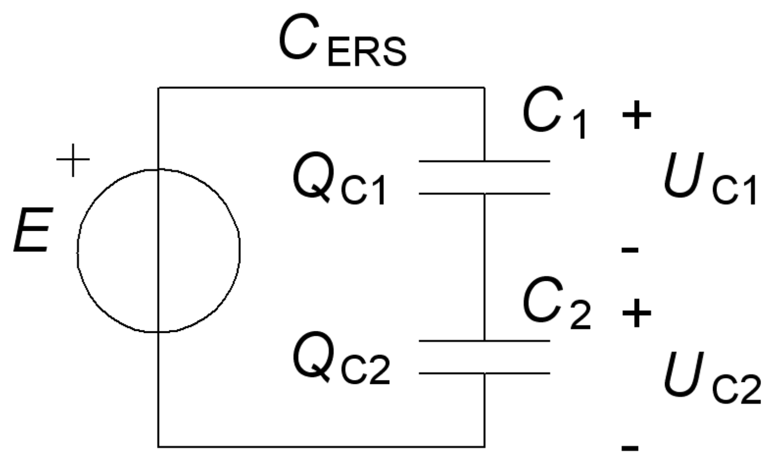

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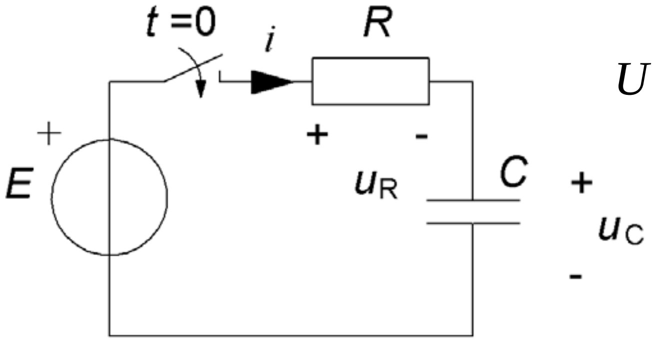
$$Q_{C1} = Q_{C2} = Q \quad = \quad C_{\text{ERS}} \cdot E \quad = \quad C_1 \cdot U_{\text{C1}} \quad = \quad C_2 \cdot U_{\text{C2}}$$

$$C_{\text{ERS}} = \frac{6 \cdot 12}{6 + 12} = 4\ \mu\text{F} \quad Q = 4 \cdot 10^{-6} \cdot 10 = 40\ \mu\text{C}$$

$$U_{\text{C1}} = \frac{Q}{C_1} = \frac{40 \cdot 10^{-6}}{6 \cdot 10^{-6}} = 6{,}66\ \text{V} \qquad U_{\text{C2}} = E - U_{\text{C1}} = 10 - 6{,}66 = 3{,}33\ \text{V}$$

Energy in capacitor



$$U=\frac{Q}{C}\quad\Rightarrow\quad\frac{\mathrm{d}u_C}{\mathrm{d}t}=\frac{1}{C}\cdot\frac{\mathrm{d}q}{\mathrm{d}t}\quad\Rightarrow\quad\frac{\mathrm{d}q}{\mathrm{d}t}=i=C\frac{\mathrm{d}u_C}{\mathrm{d}t}$$

Instantaneous power:

$$p=i\cdot u_\mathrm{C}=C\frac{\mathrm{d}u_\mathrm{C}}{\mathrm{d}t}\cdot u_\mathrm{C}\quad\Rightarrow$$

Energy:

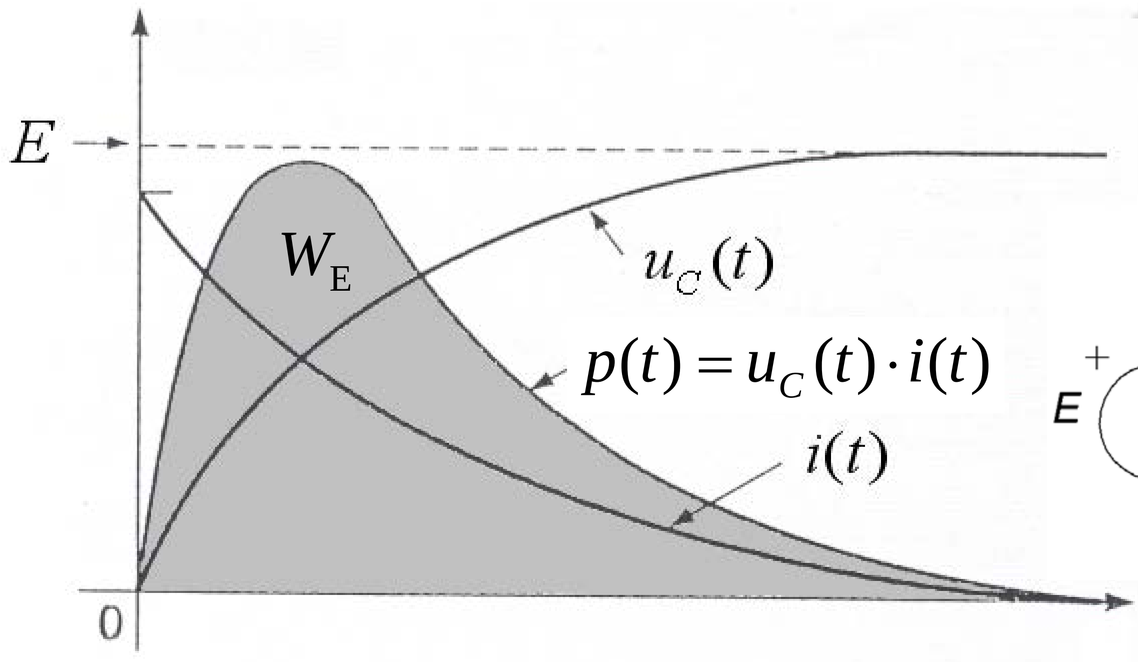
$$W=\int_{t=0}^{t=\infty}p\,\mathrm{d}t=\int_{t=0}^{t=\infty}C\cdot u_\mathrm{C}\cdot\frac{\mathrm{d}u_\mathrm{C}}{\cancel{\mathrm{d}t}}\,\cancel{\mathrm{d}t}=\int_{u=0}^{u=E}C\cdot u_\mathrm{C}\;\mathrm{d}u_\mathrm{C}=\frac{1}{2}\cdot C\cdot E^2$$

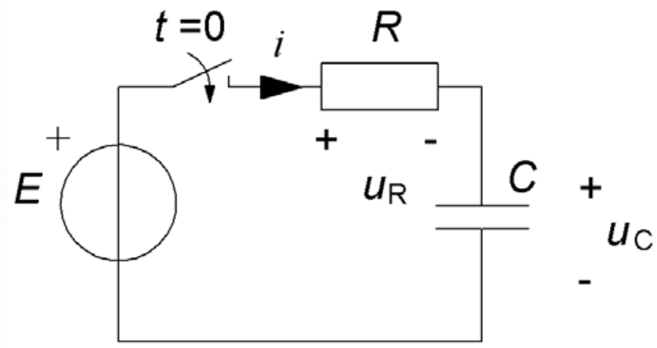
Stored energy in the electrical field:

$$W_\mathrm{E}=\frac{1}{2}C\cdot U^2$$

Remember the formula, but its allowed to skip the derivation …

Energy in capacitor





$$W_E = \frac{1}{2} C \cdot E^2$$

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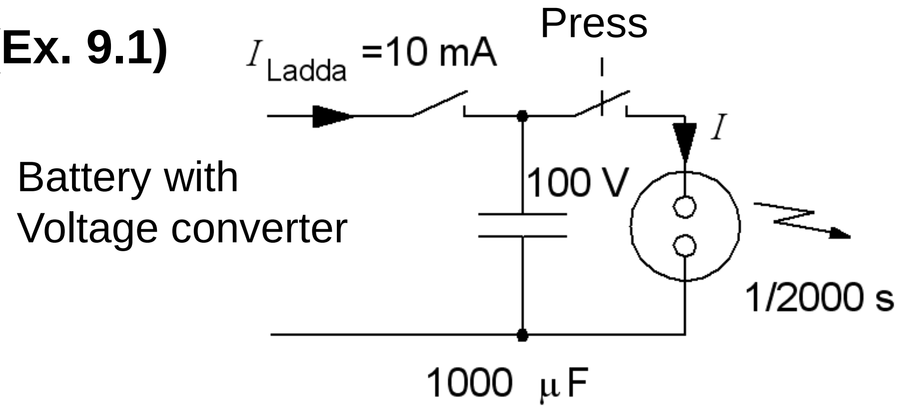
Camera Flash

(Ex. 9.1)



$$W = \tfrac{1}{2} \cdot C \cdot U^2$$

$$Q = C \cdot U$$

$$I = \frac{Q}{t}$$

$$P = \frac{W}{t}$$

Electric energy in capacitor W ?

$$W = \tfrac{1}{2} \cdot C \cdot U^2 = \tfrac{1}{2} \cdot 1000 \cdot 10^{-6} \cdot 100^2 = 5 \text{ J, Ws}$$

Capacitor charge Q ?

$$Q = C \cdot U = 1000 \cdot 10^{-6} \cdot 100 = 0{,}1 \text{ C, As}$$

The lightning current (mean value) I?

$$I = \frac{Q}{t} = \frac{0{,}1}{1/2000} = 200 \text{ A}$$

Power during flash discharge P ?

$$P = \frac{W}{t} = \frac{5}{1/2000} = 10 \text{ kW}$$

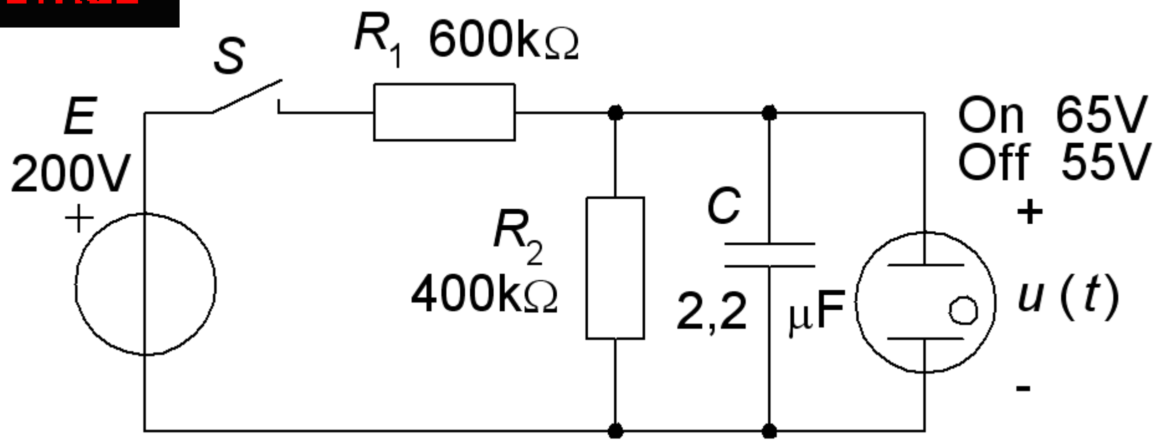
How long to wait for next flash t_{Ladda} ?

$$U = \frac{Q}{C} = \frac{I_{\text{Ladda}} \cdot t_{\text{Ladda}}}{C} \quad \Rightarrow \quad t_{\text{Ladda}} = \frac{C \cdot U}{I_{\text{Ladda}}} = \frac{1000 \cdot 10^{-6} \cdot 100}{10 \cdot 10^{-3}} = 10 \text{ s}$$

Nowdays LED Flash?

(Ex. 10.9)

Neon lamp



Blink-circuit with Neon-lamp
at exercise …

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Simulate Neon lamp