Lecture 17

Saturday, July 15, 2023 4:32 PM

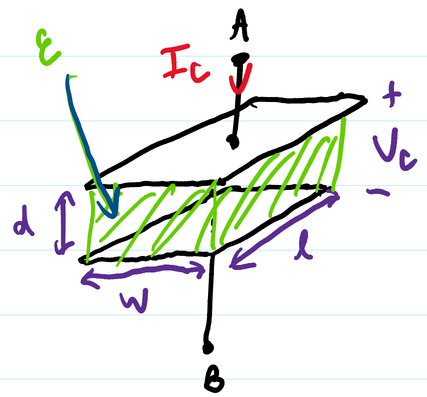
Lecture 5D: (7/20/23)

Announcements:

- Midterm on Monday!
  - 5-7pm, 145 Dwinelle
  - Don't be late!
  - Content from 3D (eigenvalues/vectors) through 5C (yesterday) + Labs: Imaging through Touch 2
- HW5 ← No slip days! Due Friday at midnight
- No lecture Monday (7/24).
  - Discussion sections will be a "review" worksheet
- Lab: Touch 2 today
  - soldering ← be careful!
- Today's Topics:
  - Physical Capacitors (Note 16) ← on the Midterm!
  - Hardware demo
  - Capacitive Touch
  - Comparators

  $\Big\}$ (Note 17)

Physical Capacitors:



Capacitance forms between overlapping parallel plates of metal.

$$C = \varepsilon \frac{A}{d} = \underbrace{\varepsilon \frac{l \cdot w}{d}}_{\text{for this example}}$$

A ← overlapping plate area

d ← plate separation distance

ε ← permittivity

$$[F] = \left[\frac{F}{m}\right] \frac{[m^2]}{[m]}$$

What is permittivity?
- Intrinsic material property
- variable "ε" (Greek letter "epsilon")
- often expressed as: $\varepsilon = \varepsilon_r \cdot \varepsilon_o$ ← "permittivity of free space"
  - ε_r: relative permittivity
  - $\varepsilon_o = 8.85 \cdot 10^{-12} \frac{F}{m}$
- Dielectric material has $\varepsilon_r > 1$

Demo with copper plates:

Two 15 x 15 cm plates held 1 cm apart in air

$$C = \varepsilon \cdot \frac{l \cdot w}{d} = \left(8.85 \cdot 10^{-12} \frac{F}{m}\right) \cdot \frac{(0.15\,m)^2}{(0.01\,m)}$$

$\varepsilon \approx \varepsilon_o$ for air

$$= 1.99 \cdot 10^{-11}\,F$$

$$= 19.9\ pF$$ ← Really small!

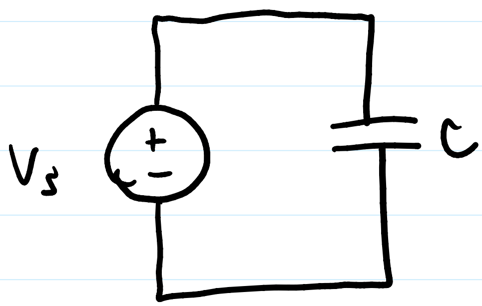
What if area is doubled? C doubles

What if separation distance doubles? C halves

* This concludes material for the Midterm. *

Class Demo:

Ex). Capacitor Limits



$C = 1\,mF$

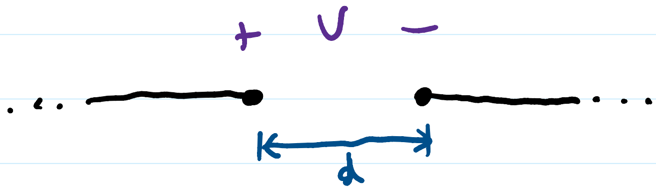
$V_r = 10V \leftarrow$ Maximum rated Voltage

$$E = \int_0^V q\,dV = \int_0^V CV\,dV = \boxed{\frac{1}{2}CV^2}$$

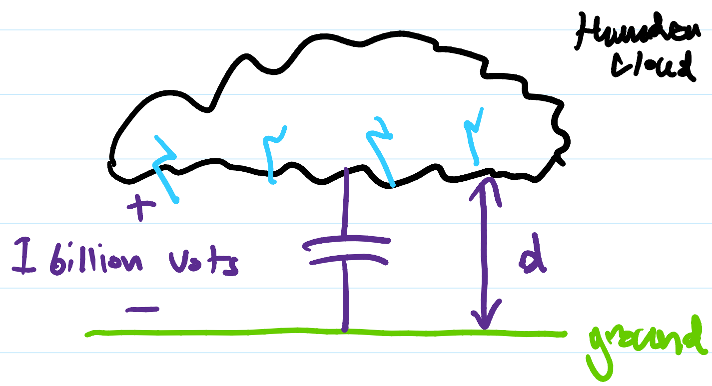
$$= \frac{1}{2}(1\,mF)\cdot(10V)^2 = 50\,mJ$$

Aside:

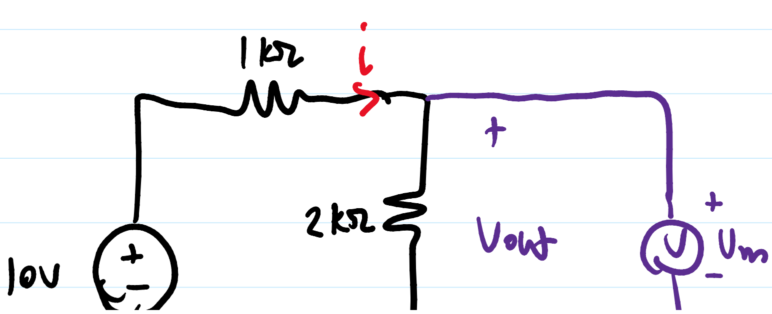
All insulating materials have a dielectric breakdown OR dielectric strength in $\frac{V}{m}$



Dielectric breakdown of air is 400 - 3000 V/mm

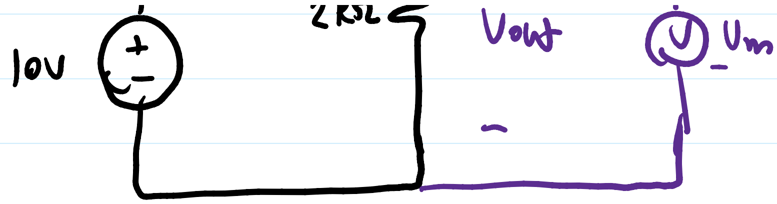


Ex). Resistive Loading

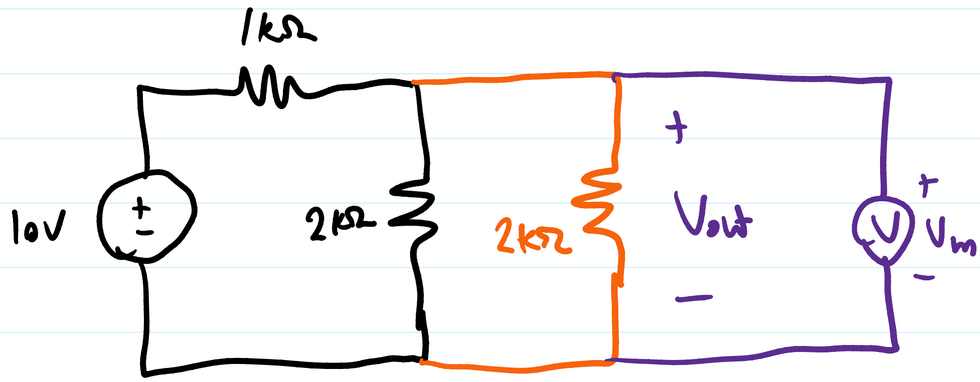


$$i = \frac{10V}{1k\Omega + 2k\Omega} = 3.33\,mA$$

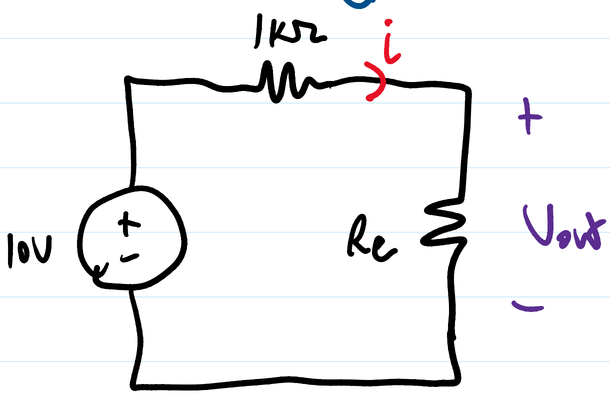
$$V_{out} = i \cdot (2k\Omega) = 6.66V$$



Add a "load" resistor. Does Vout change?



$$R_1 || R_2 = \frac{R_1 \cdot R_2}{R_1 + R_2}$$



$$R_e = 2k\Omega \,||\, 2k\Omega = \frac{(2k\Omega)\cdot(2k\Omega)}{(2k\Omega)+(2k\Omega)}$$

$$= 1k\Omega$$

$$i = \frac{10V}{1k\Omega + R_e} = \frac{10V}{2k\Omega} = 5mA$$

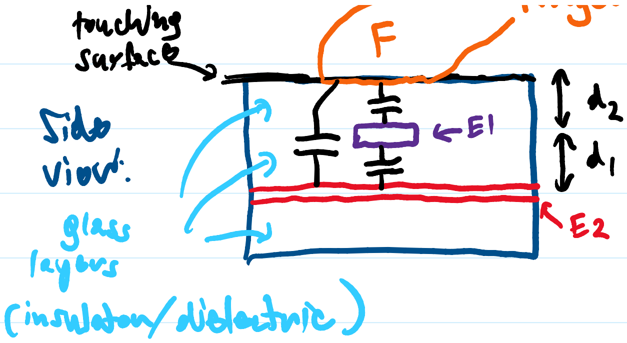
$$V_{out} = i \cdot R_e = (5mA)\cdot(1k\Omega)$$

$= 5V \Leftarrow$ less than before!

2D Capacitive Touchscreen

Capacitance forms between parallel plates of conductive material

electrons can move freely



electrons can move freely

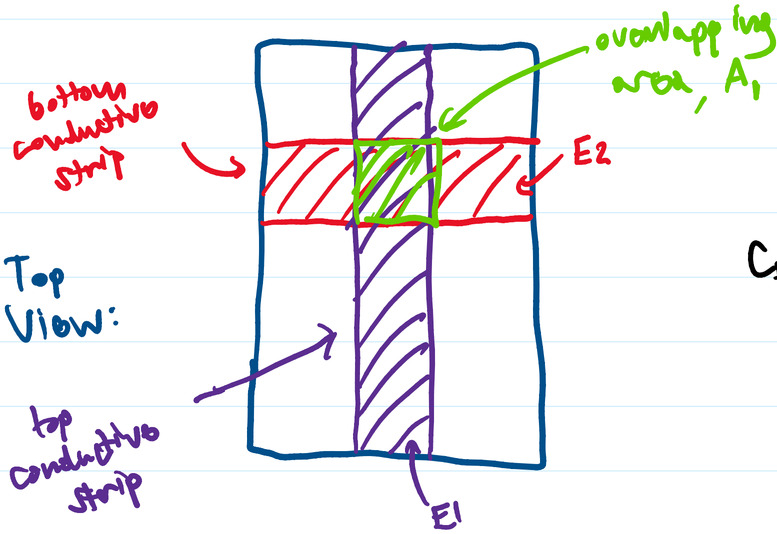
Ex). metal

copper

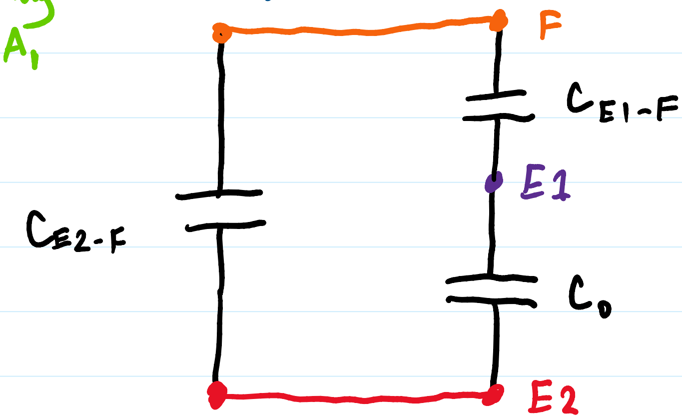
dirt/earth

thundercloud

humans?!



Equivalent Circuit:



$C_0 \rightarrow$ How much overlapping area between the top and bottom strips?

$$A_1 \rightarrow C_0 = \varepsilon \frac{A_1}{d_1}$$

permittivity of glass

$C_{E1-F} \rightarrow$ How much overlapping area between finger and top strip?

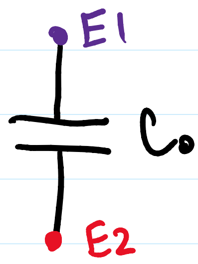
$$A_{E1-F} \rightarrow C_{E1-F} = \varepsilon \frac{A_{E1-F}}{d_2}$$

still glass

C_{E2-F}: How much overlapping area between finger and bottom strip?

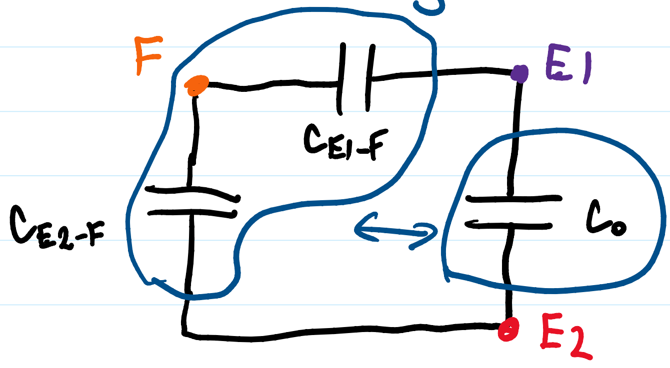
$$A_{E2-F} \rightarrow C_{E2-F} = \varepsilon \frac{A_{E2-F}}{d_1 + d_2}$$

Without finger:

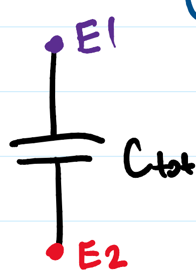


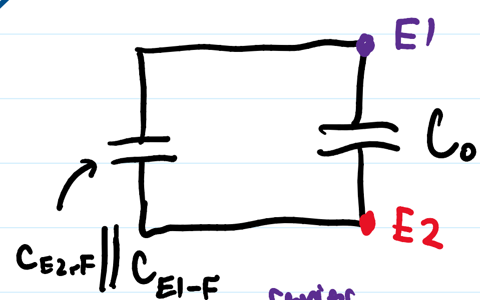
$C_{tot} = C_o$

With finger:



Equivalent capacitance between nodes E1 and E2





series capacitance

parallel

$$C_{tot} = \left(C_{E1-F} \| C_{E2-F}\right) + C_o$$
$$= C_\Delta + C_o$$

If nodes F to E2, then

$$C_{tot_{1/2}} = \left(C_{E1-F} \| C_o\right) + C_{E2-F}$$

Adding our finger increases the capacitance between nodes E1 and E2 from C_o to $C_o + C_\Delta$

If we measure this change in capacitance, then we could detect if a touch has occurred!

Capacitive touchscreen can detect multiple simultaneous touches ← unlike touchscreens