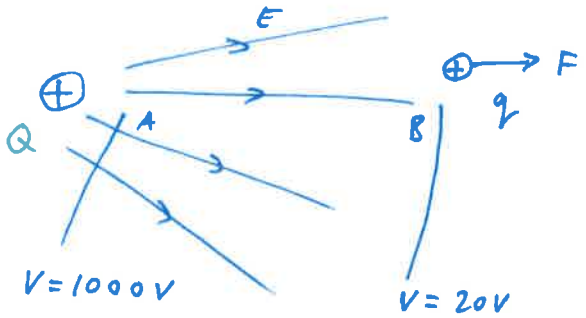
SUHTEELLINEN PERMITTIIVISYYS $\varepsilon_r > 1$

HEIKENTÄÄ VOIMAA, SÄHKÖKENTTÄÄ JA POTENTIAALIA



$U_{AB} = 1000 - 20$
$= 980\ V$

$$F = \frac{1}{4\pi\varepsilon_0}\,\frac{1}{\varepsilon_r}\,\frac{Qq}{r^2}$$

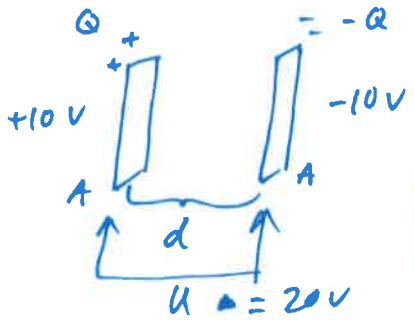
$$E = \frac{1}{4\pi\varepsilon_0}\,\frac{1}{\varepsilon_r}\,\frac{Q}{r^2}$$

$$V = \frac{1}{4\pi\varepsilon_0}\,\frac{1}{\varepsilon_r}\,\frac{Q}{r}$$

$F = Eq$

$U \leftrightarrow \frac{1}{\varepsilon_r}$

ε_r KASVATTAA KONDENSAATTORIN KAPASITANSSIA (EIKÄ SITÄ VARASTA)



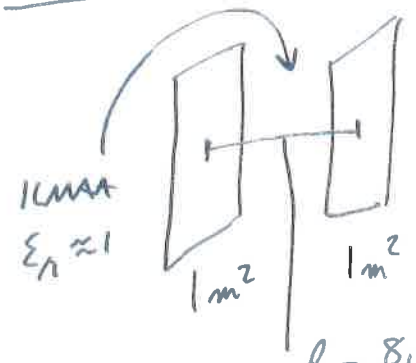
$C = \frac{Q}{U}$

$C = \varepsilon_r \varepsilon_0 \frac{A}{d}$

$\frac{1}{U} \leftrightarrow \varepsilon_r$

nF

ESIM.



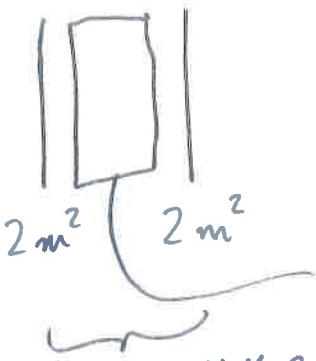
$C = \varepsilon_r \varepsilon_0 \frac{A}{d}$

$= 1 \cdot 8{,}85 \cdot 10^{-12} \cdot \frac{1}{8{,}85 \cdot 10^{-2}}$

$= 10^{-10}\ F$

$= 0{,}1 \cdot 10^{-9}\ F$

$= \underline{0{,}1\ nF}$



$$C = 7 \cdot 8{,}85 \cdot 10^{-12} \cdot \frac{2}{\frac{8{,}85}{2} \cdot 0{,}01}$$

$= 7 \cdot 2 \cdot 2 \cdot 10^{-10}\ F$

$= \underline{2{,}8\ nF}$

Suhteellisia permittiivisyyksiä

Material	Dielectric Constant - ε_r -
Acetaldehyde (41° F)	21.8
Acetic Acid (68° F)	6.2
Acetic Acid (36° F)	4.1
Acetone (77° F)	20.7
Acetone (127° F)	17.7
Acetone (32° F)	1.0159
Acetyl Acetone (68° F)	23.1
Acetyl Bromide (68° F)	16.5
Acetyl Chloride (68° F)	15.8
Acetyle Acetone (68° F)	25.0
Acetylene (32° F)	1.0217
Air (Dry) (68° F)	1.000536 ≈ 1
Air, Liquid (-191°C)	1.4
Alcohol, Industrial	16-31
Alumina	9.3-11.5
Aluminum Bromide (212° F)	3.4
Aluminum Fluoride	2.2
Amber	2.8-2.9
Ammonia (-74° F)	25
Ammonia (-30° F)	22.0
Ammonia (40° F)	18.9
Ammonia (69° F)	16.5
Aniline (32° F)	7.8
Aniline (68° F)	7.3
Aniline (212° F)	5.5
Araldite	3.6
Argon (68° F)	1.000513
Bakelite	3.5-5.0
Benzene (68° F)	2.3
Butane (30° F)	1.4
Carbondioxide (68° F)	1.000921
Calcium	3.0
Casting compound	2.5
Caster oil	4.7
Ceramic, $MgNb_2O_6$	21
Ceramic, $ZnNb_2O_6$	25
Ceramic, $MgTa_2O_6$	28
Ceramic, $ZnTa_2O_6$	38
Chlorine (32° F)	2.0
Chloroform (68° F)	4.8
Ebonite	2.5-2.9
Epoxy Resin (Cast)	3.6
Ethanol (77° F)	24.3
Ethyl Acetate (77° F)	6.0
Ethyl Alcohol (77° F)	24.3
R12 Dichlorodifluoromethane (70° F)	2.4
Glass	3.7 - 10
Glycerin, Liquid	47-68
Glycerol (77° F)	42.5
Granite	7 - 9
Guttapercha	4
Hard paper, laminated	4.5
Ice (-2°C)	3.2
Isoprene (77° F)	2.1
Insulation of high voltage cables	4.2
Insulation of telephone cables	1.5
Marble	8
Mica	2.5 - 7
Mineral Oil (80° F)	2.1
Nitrogen (68° F)	1.000580
Nylon	4.0 - 5.0
Oil paper	4
Olive oil	3
Paper	2.3
Paper, impregnated	5
Paper, waxed	2.5
Paraffin oil	2.2
Paraffin Wax	2.1-2.5
Petroleum	2.2
Phenolic resin	8
Plexiglass	3.2
Polyester Resin	2.8 - 4.5
Polyethylene	2.2-2.4
Polyamide	2.8
Polypropylene	2.2
Polystyrene	3
Porcelain	5.0-7.0
Pressed board	4
Pyrex Glass	4.3 - 5.0
Quartz	4.5
Rubber	3.0
Salt	3.0 - 15.0
Shellac	3.5
Silica Sand	2.5-3.5
Silicon	11.0 - 12.0
Slate	4
Water	4 - 88
Wood, Dry	2-6

ESIM.

$\varepsilon_0 = 8,85 \cdot 10^{-12}$

$$C = \varepsilon_r \varepsilon_0 \frac{A}{d}$$

$$= 3,2 \cdot 8,85 \cdot 10^{-12} \cdot \frac{1}{8,85 \cdot 10^{-3}}$$

$$= 3,2 \cdot 10^{-9} = \underline{3,2\ nF}$$

LASKE C

$d = 2 \cdot 10^{-3}\ m$

$A = 0.04 m^2$

$$C = \varepsilon_r \varepsilon_0 \frac{A}{d} = 4.5 \cdot 8.85 \cdot 10^{-12} \frac{0.04}{2 \cdot 10^{-3}}$$

$$= 7.965 \cdot 10^{-10} = 0.7965 \cdot 10^{-9} \approx 0.8 nF$$

LASKE C

$d = 5 \cdot 10^{-3}\ m$

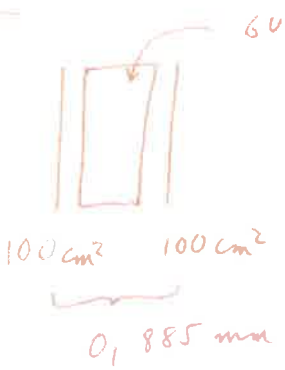
$A = 0.1 m^2$

$$C = \varepsilon_r \varepsilon_0 \frac{A}{d} = 42.5 \cdot 8.85 \cdot 10^{-12} \frac{0.1}{0.005}$$

$$= 7.5225 \cdot 10^{-9}\ F$$

$$= 7.5\ nF$$

LASKE C



$\varepsilon_0 = 8.85 \cdot 10^{-12}$

$d = 0.000885\ m = 0.885 \cdot 10^{-3}\ m$

$A = 0.01 m^2$

$$C = \varepsilon_r \varepsilon_0 \frac{A}{d} = 4 \cdot 8.85 \cdot 10^{-12} \frac{0.01}{0.000885}$$

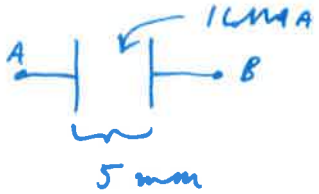
$$= 4 \cdot 10^{-10}\ F = 0.4 \cdot 10^{-9}$$

$$= 0.4 nF$$

ILMAN DIELEKTRINEN LUJUUS ELI
LÄPILYÖNTIKESTÄVYYS ON

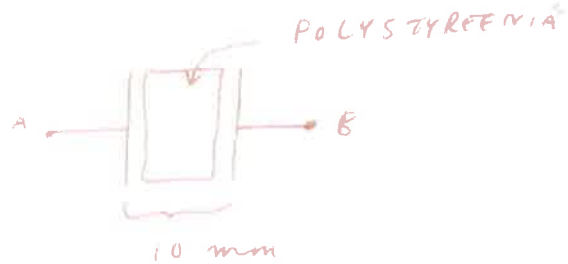
$3\ MV/m = 3 \cdot 10^6 \frac{V}{m} = 3000 \frac{V}{mm}$

ESIM.



$U_{MAX} = 5\ mm \cdot \frac{3000\ V}{mm} = 15000\ V = 15\ kV$

LÄPILYÖNTI TAPAHTUU, KUN $U_{AB} > 15\ kV$



$U_{MAX} = 10mm \cdot \frac{19700\ V}{mm} = 197\,000\ V$

$= 197\ kV$

$19.7\ MV/m = 19.7 \cdot 10^6 \frac{V}{m} = 19.7 \cdot 10^3$

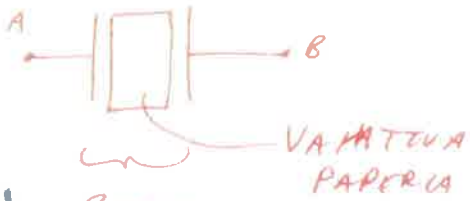
$= 19\,700\ V/mm$

Läpilyöntikestävyyksiä

Dielectric strength (in MV/m, or 10^6 Volt/meter) of various common materials

Substance	Dielectric Strength (MV/m)
Helium (relative to nitrogen)[5]	0.15
Air[6]	3.0
Alumina[5]	13.4
Window glass[5]	9.8 - 13.8
Borosilicate glass[5]	20 - 40
Silicone oil, mineral oil[5][7]	10 - 15
Benzene[5]	163
Polystyrene[5]	19.7
Polyethylene[8]	19 - 160
Neoprene rubber[5]	15.7 - 26.7
Distilled water[5]	65 - 70
High vacuum (field emission limited)[9]	20 - 40 (depends on electrode shape)
Fused silica[10]	25–40 at 20 °C
Waxed paper[11]	40 - 60
PTFE (Teflon, extruded)[5]	19.7
PTFE (Teflon, insulating film)[5][12]	60 - 173
Mica[5]	118
Diamond[13]	2000
PZT	10–25[14][15]
Vacuum	10^{12}

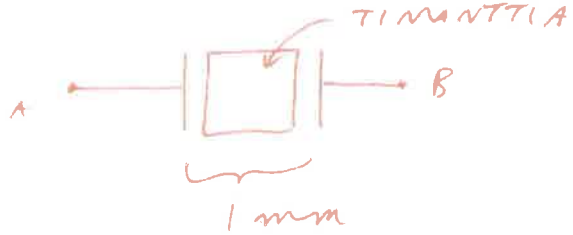
LASKE U_{max}



$50\,MV/m = 50 \cdot 10^6 \frac{V}{m} = 50 \cdot 10^3 \frac{V}{mm}$

$U_{max} = 3mm \cdot \frac{50\,000V}{mm} = 150kV$

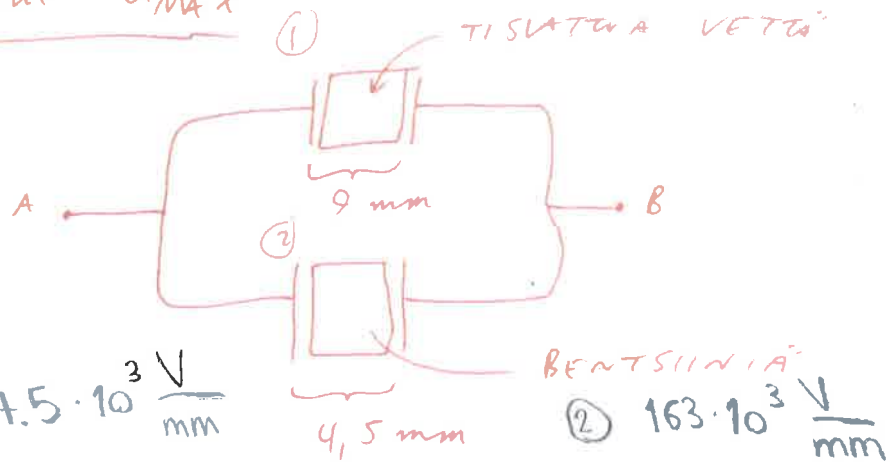
LASKE U_{max}



$2000MV/m = 2000 \cdot 10^3 \frac{V}{mm}$

$U_{max} = 1mm \cdot 2000 \cdot 10^3 \frac{V}{mm} = 2000kV$

LASKE U_{max}



① $67.5 \cdot 10^3 \frac{V}{mm}$

② $163 \cdot 10^3 \frac{V}{mm}$

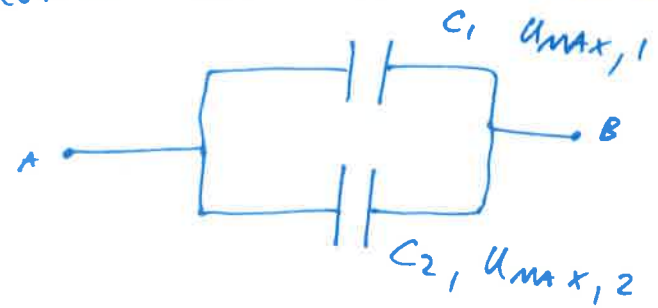
$U_{max,1} = 9 \cdot 67.5 \cdot 10^3 = 607\,500V = 607.5kV$

$U_{max,2} = 4.5 \cdot 163 \cdot 10^3 = 733\,500V$

$= 733.5kV$

$U_{max} = 607.5kV$

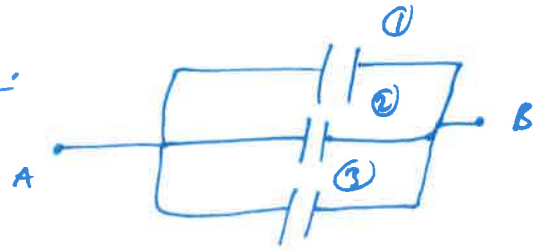
KONDENSAATTORIT RINNAN



$$C = C_1 + C_2$$

$$U_{MAX} = MIN\{U_{max,1}, U_{max,2}\}$$

ESIM.



$C_1 = 4\,nF$ $\quad U_{max\,1} = 10\,V$

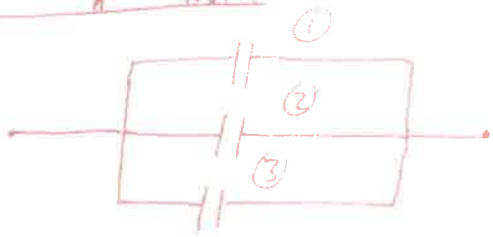
$C_2 = 5\,nF$ $\quad U_{max\,2} = 15\,V$

$C_3 = 10\,nF$ $\quad U_{max\,3} = 8\,V$

$$C_{KOK} = 4 + 5 + 10 = \underline{19\,nF}$$

$$U_{MAX} = MIN\{10, 15, 8\} = \underline{8\,V}$$

LASKE C_k & U_{MAX}



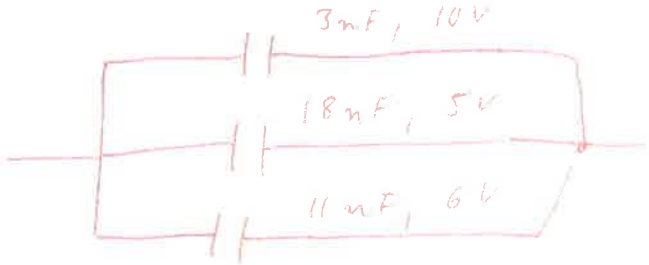
$C_1 = 31\,nF$ $\quad U_{max\,1} = 5\,V$

$C_2 = 17\,nF$ $\quad U_{max\,2} = 3{,}4\,V$

$C_3 = 18\,nF$ $\quad U_{max\,3} = 4{,}3\,V$

$C_k = 66\,nF$ $\quad U_{max} = 3.4\,V$

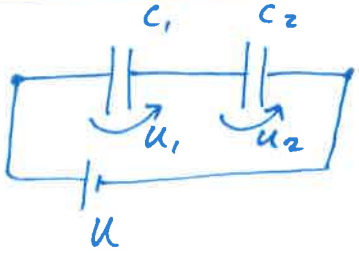
LASKE C & U_{MAX}



$C_{KOK} = 32\,nF$

$U_{MAX} = 5V$

KONDENSAATTEORIT SARJASSA



LATAUTUMINEN → SAMA VARAUS Q

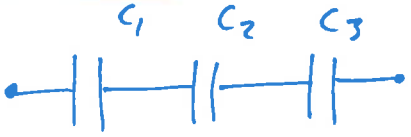
$$C = \frac{Q}{U} \rightarrow U = \frac{Q}{C}$$

$$U = U_1 + U_2 = \frac{Q}{C_1} + \frac{Q}{C_2} = Q\left(\frac{1}{C_1} + \frac{1}{C_2}\right)$$

TOISAALTA $U = \frac{Q}{C_{KOK}}$

$$\Rightarrow \boxed{\frac{1}{C_{KOK}} = \frac{1}{C_1} + \frac{1}{C_2}} + \frac{1}{C_3} + \frac{1}{C_4} + \ldots$$

ESIM.



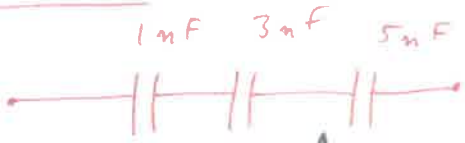
$C_1 = 3\ nF$
$C_2 = 2\ nF$
$C_3 = 17\ nF$

$$\frac{1}{C_{KOK}} = \frac{1}{3} + \frac{1}{2} + \frac{1}{17} =$$

$$C_{KOK} = \left(\frac{1}{3} + \frac{1}{2} + \frac{1}{17}\right)^{-1}$$

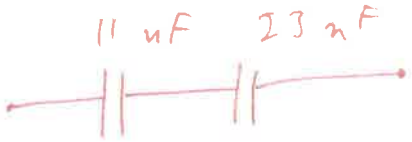
$$= \frac{102}{91} = 1.1208\ldots\ nF$$

LASKE C_{KOK}



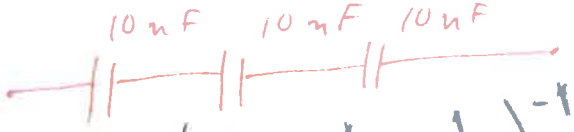
$$C_{kok} = \left(\frac{1}{1} + \frac{1}{3} + \frac{1}{5}\right)^{-1} = \frac{15}{23} = 0.6521\ldots nF$$

$$C_{kok} = \left(\frac{1}{5} + \frac{1}{10} + \frac{1}{8}\right)^{-1} = \frac{40}{17} = 2.3529\ldots nF$$



$$C_{kok} = \left(\frac{1}{11} + \frac{1}{23}\right)^{-1}$$

$$= \frac{253}{34} = 7.4411\ldots$$



$$C_{kok} = \left(\frac{1}{10} + \frac{1}{10} + \frac{1}{10}\right)^{-1} = \left(\frac{3}{10}\right)^{-1} = \frac{10}{3}\ nF$$

$$= 3.3333\ldots nF$$

$$C_{kok} = \left(\sum_{k=1}^{n} \frac{1}{C_k}\right)^{-1}$$

KONDENSAATTORIT SARJASSA

SIIS C_1, U_{max}

KOSKA $C = \frac{Q}{U} \rightarrow Q = CU$

KONDENSAATTORICIN ON MAKSIMIVARAUS $Q_{max} = C U_{max}$

[SUUREMPI VARAUS → LÄPILYÖNTI]

ESIM.

$C_1 = 3\,nF$, $U_{max\,1} = 10\,V$

$C_2 = 5\,nF$, $U_{max} = 8\,V$

$Q_{max\,1} = 3\,nF \cdot 10\,V = 30\,nC$

$Q_{max\,2} = 5\,nF \cdot 8\,V = 40\,nC$

→ $Q_{max} = MIN(30\,nC, 40\,nC)$

$= 30\,nC$

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

→ $U = \frac{Q}{C} \rightarrow U_{max} = \frac{Q_{max}}{C_{kok}}$

$= 30\,nC \cdot \frac{1}{0{,}53\,nF}$

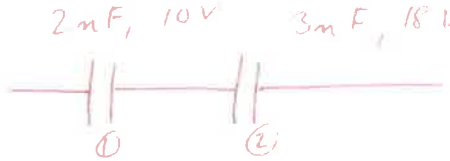
$= 15{,}9\,V$

$\frac{1}{C_{kok}} = \frac{1}{3} + \frac{1}{5}$

$= 0{,}33 + 0{,}2$

$= 0{,}53$

$C_{kok} = \frac{1}{0{,}53}$



$Q = CU$

$Q_{max\,1} = 2\,nF \cdot 10\,V = 20\,nC$

$Q_{max\,2} = 3\,nF \cdot 18\,V = 54\,nC$

$Q_{max} = 20\,nC$

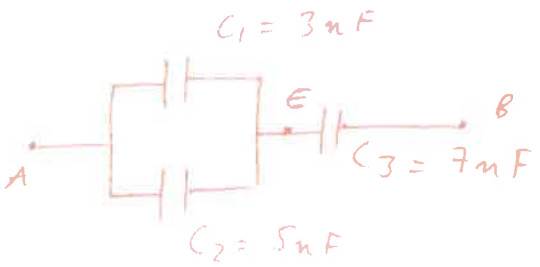
$\frac{1}{C_{kok}} = \frac{1}{2} + \frac{1}{3} = \frac{3}{6} + \frac{2}{6} = \frac{5}{6}$

$C_{kok} = \left(\frac{5}{6}\right)^{-1} = \frac{6}{5} = 1.2\,nF = \frac{1}{\frac{5}{6}}$

$U_{max} = \frac{Q_{max}}{C_{kok}} = \frac{20\,nC}{\frac{6}{5}\,nF} = \frac{50}{3}\,V$

$= 16.6666\ldots\,V$

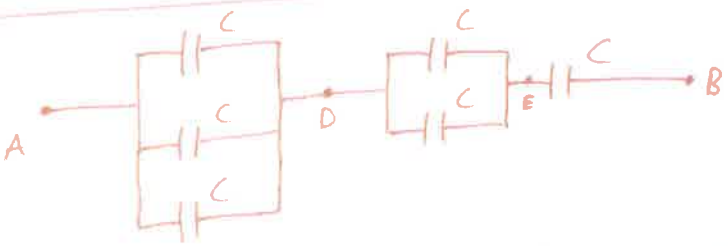
$\frac{1}{\frac{1}{x}} = x$



$C_{AE} = 3nF + 5nF = 8nF$

$\frac{1}{C_{AB}} \overset{7)}{=} \frac{1}{8} + \frac{1}{7} \overset{8)}{=} \frac{7}{56} + \frac{8}{56} = \frac{15}{56}$

$C_{AB} = \left(\frac{15}{56}\right)^{-1} = \frac{56}{15} = 3.7333\ldots nF$



KAIKILLA KONDENSAATTOREILLA ON SAMA KAPASITANSSI $C = 4nF$.
LASKE KOKONAISKAPASITANSSI

$C_{AD} = 3 \cdot 4nF = 12nF$

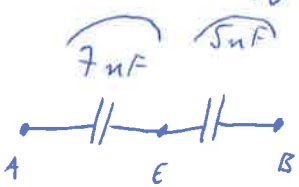
$C_{DE} = 4nF \cdot 2 = 8nF$

$C_{AB} = \left(\frac{1}{12} + \frac{1}{8} + \frac{1}{4}\right)^{-1} = \frac{24}{11} = 2.1818\ldots nF$

$= \left(\frac{11}{24}\right)^{-1}$

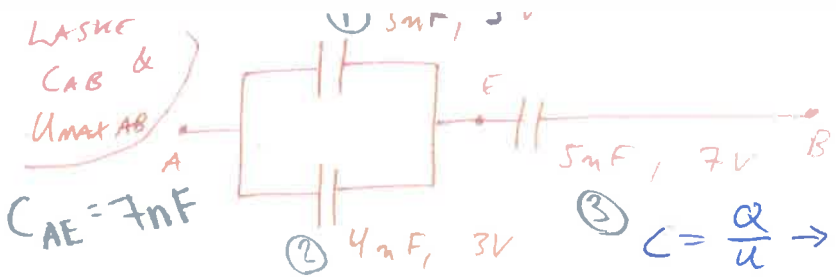
$U_{max} = 3V = U_{max}$

$7V$



$Q_{AE,max} = 7 \cdot 3 = 21nC$

LASKE C_{AB} & $U_{max\,AB}$



$C_{AE} = 7nF$

③ $C = \frac{Q}{U} \rightarrow Q = CU$

$C_{AE} = 3nF + 4nF = 7nF$

$U_{max\,AE} = 3V$

$C_{AB} = \left(\frac{1}{C_{AE}} + \frac{1}{5}\right)^{-1} = \left(\frac{1}{7} + \frac{1}{5}\right)^{-1} = \left(\frac{12}{35}\right)^{-1}$

$= \frac{35}{12} = 2.9166\ldots$

$U_{max} = \frac{Q_{max}}{C_{kok}} = \frac{21nC}{\frac{35}{12}} = 7.2V$

$Q_{max,AE} = C_{AE} \cdot U_{AE} = 7nF \cdot 3V = 21nC$

$Q_{max,1} = 3nF \cdot 5V = 15nC$

$Q_{max,2} = 4nF \cdot 3V = 12nC$

$Q_{max,3} = 5nF \cdot 7V = 35nC$

$Q_{max} = \min(35nC, 21nC) = 21nC$