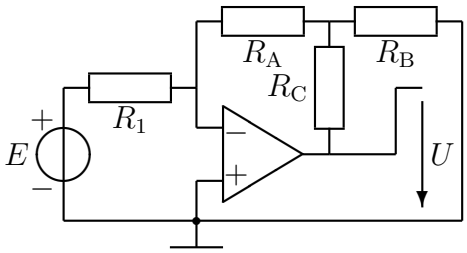
S-55.1100 SÄHKÖTEKNIIKKA JA ELEKTRONIIKKA

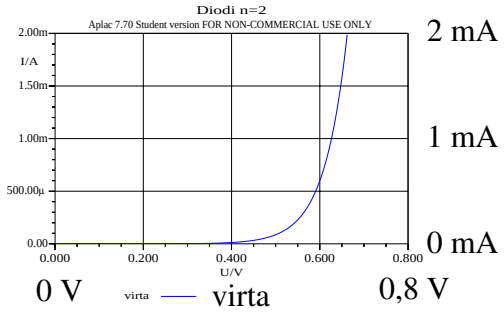
Kimmo Silvonen

2. välikoe 11.12.2012. **Saat vastata vain neljään tehtävään!**
Sallitut: Kako, [gr.] laskin, [MAOL], [sanakirjan käytöstä sovittava valvojan kanssa!]

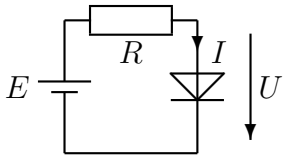
1. Laske jännite U.
$E = 1$ V, $R_1 = 2\ \Omega$, $R_\mathrm{A} = 4\ \Omega$,
$R_\mathrm{B} = 4\ \Omega$, $R_\mathrm{C} = 4\ \Omega$.



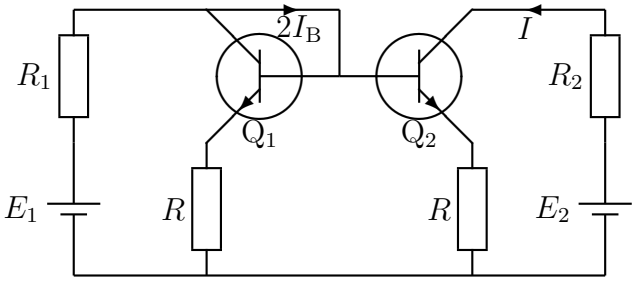
2. Diodin jännite $U = 0{,}65$ V. Laske vastus R ja saturaatiovirta I_S. $E = 5{,}6$ V, $nU_T = 50$ mV.



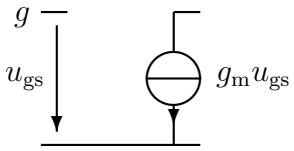
2 mA
1 mA
0 mA
0 V
0,8 V

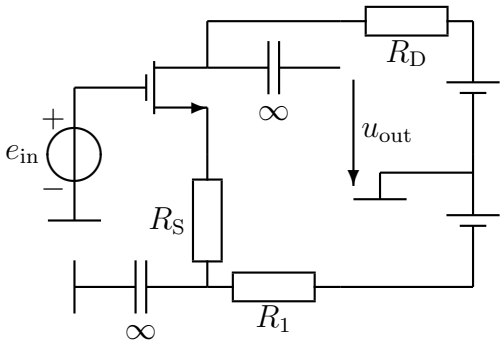


3. Laske virta I. $R_1 = 1$ kΩ, $R_2 = 0{,}5$ kΩ, $R = 100\ \Omega$, $E_1 = E_2 = 4$ V, $\beta_1 = \beta_2 = 100$, $U_\mathrm{BE1} = U_\mathrm{BE2} = 0{,}7$ V.

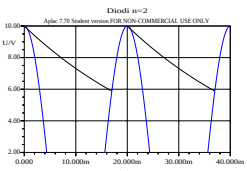


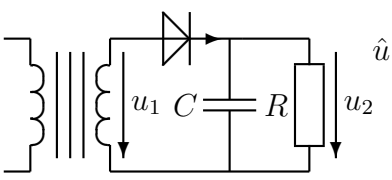
4. Laske signaalijännite u_out.
$e_\mathrm{in} = 100$ mV, $R_\mathrm{D} = 10$ kΩ, $R_1 = R_\mathrm{S} = 1$ kΩ,
$g_\mathrm{m} = 1$ mS, $U_\mathrm{t} = 2$ V.

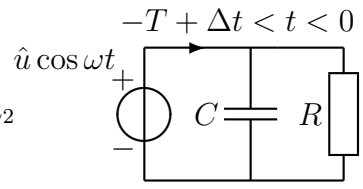


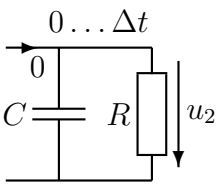


5. Jos lasket tämän tehtävän, jätä yksi tehtävistä 1-4 pois! Oleta, että $u_1 = \hat{u}\cos\omega t$ ja $u_2 = \hat{u}\,\mathrm{e}^{-t/\tau}$, missä $\tau = RC$. Hetkellä $t = \Delta t > 0$ u_2 on pienentynyt minimiarvoonsa $U_\mathrm{MIN} = u_1(\Delta t) = u_2(\Delta t)$. **Laske** jännitteen aaltoilu $\Delta u = \hat{u} - U_\mathrm{MIN}$. $\hat{u} = 10$ V, $R = 32\ \Omega$, $C = 1000$ µF, $\omega = 100\pi\ \frac{\mathrm{rad}}{\mathrm{s}}$.









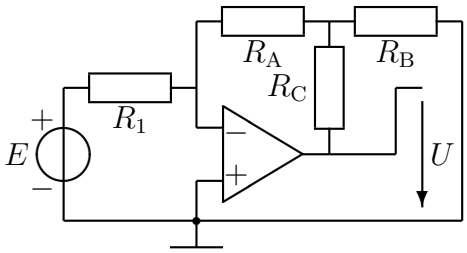
Välikokeet **voi uusia** to 20.12.2012. Tulokset tulevat **Noppaan** ylihuomenna. Anna anonyymiä **kurssipalautetta** Oodissa! Autat kehittämään opetusta. Jos palautteita tulee yli 113 kpl (50 %), kaikki saavat yhden lisäpisteen!

S-55.1100 SÄHKÖTEKNIIKKA JA ELEKTRONIIKKA

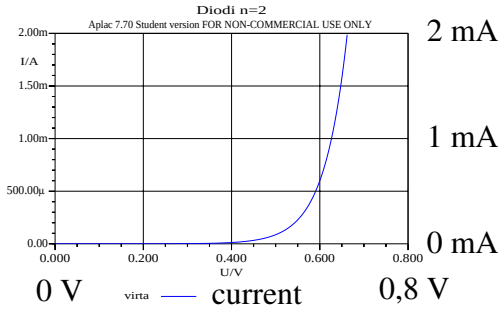
Kimmo Silvonen

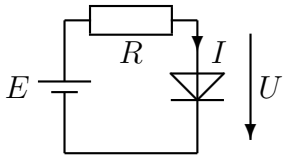
2. mid-term 11.12.2012. **You may choose only four problems!**
Allowed: Kako, [gr.] calculator, [MAOL], [dictionary, please show it to the personel!]

1. Find voltage U.
$E = 1$ V, $R_1 = 2\ \Omega$, $R_\mathrm{A} = 4\ \Omega$,
$R_\mathrm{B} = 4\ \Omega$, $R_\mathrm{C} = 4\ \Omega$.

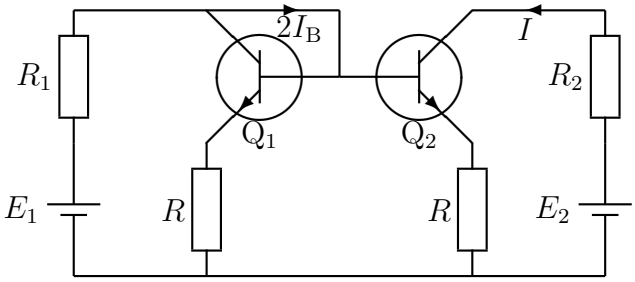


2. Voltage $U = 0.65$ V. Find resistance R and saturation current I_S. $E = 5.6$ V, $nU_T = 50$ mV.

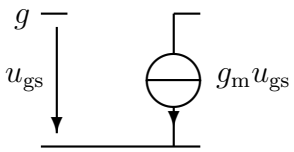


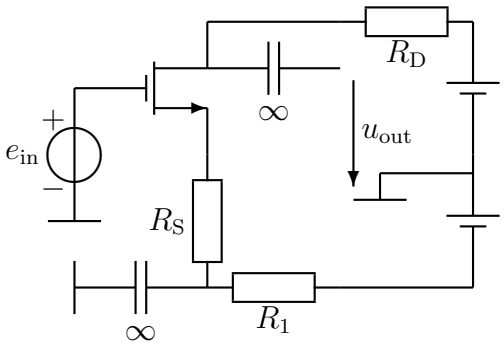


3. Find current I. $R_1 = 1$ kΩ, $R_2 = 0.5$ kΩ, $R = 100\ \Omega$, $E_1 = E_2 = 4$ V, $\beta_1 = \beta_2 = 100$, $U_\mathrm{BE1} = U_\mathrm{BE2} = 0.7$ V.

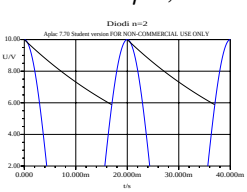


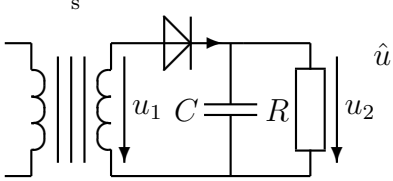
4. Find signal voltage u_out.
$e_\mathrm{in} = 100$ mV, $R_\mathrm{D} = 10$ kΩ, $R_1 = R_\mathrm{S} = 1$ kΩ,
$g_\mathrm{m} = 1$ mS, $U_\mathrm{t} = 2$ V.

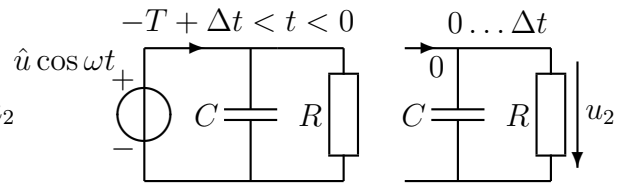




5. If you choose to do this problem skip or delete one of the problems 1-4! Assume $u_1 = \hat{u}\cos\omega t$ and $u_2 = \hat{u}\,\mathrm{e}^{-t/\tau}$, where $\tau = RC$. At $t = \Delta t > 0$ u_2 has reached its minimum value $U_\mathrm{MIN} = u_1(\Delta t) = u_2(\Delta t)$. **Calculate** voltage ripple $\Delta u = \hat{u} - U_\mathrm{MIN}$. $\hat{u} = 10$ V, $R = 32\ \Omega$, $C = 1000\ \mu$F, $\omega = 100\pi\ \frac{\mathrm{rad}}{\mathrm{s}}$.







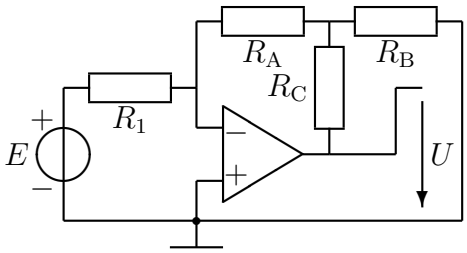
The mid-terms **can be renewed** on Thu 20.12.2012. The solutions and results will be found in **Noppa** on Thu. The anonymous **feedback** system of the course is open in Oodi! An extra point will be given if 113 students or more fill the feedback form!

S-55.1100 SÄHKÖTEKNIIKKA JA ELEKTRONIIKKA

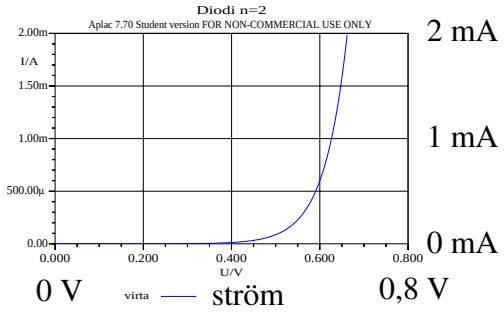
Kimmo Silvonen

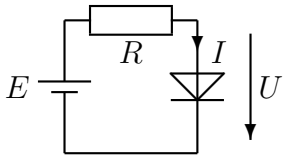
2. mellanförhör 11.12.2012. **Du får endast svara på fyra frågor!**
Tillåtna: Kako, [gr.] räknaren, [MAOL], [ordboken]

1. Beräkna spänningen U.
$E = 1$ V, $R_1 = 2\ \Omega$, $R_\mathrm{A} = 4\ \Omega$,
$R_\mathrm{B} = 4\ \Omega$, $R_\mathrm{C} = 4\ \Omega$.

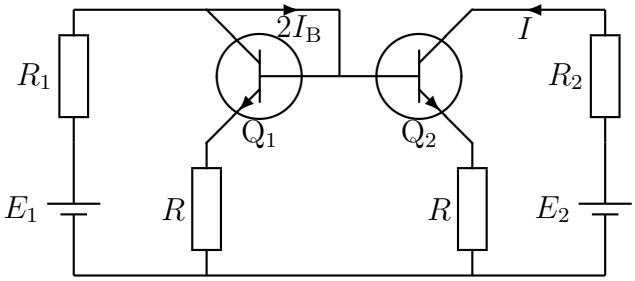


2. Spänningen är $U = 0{,}65$ V. Hur stora är R och läckströmmen I_S. $E = 5{,}6$ V, $nU_T = 50$ mV.

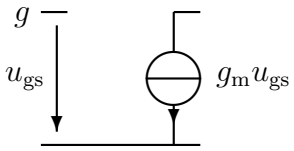


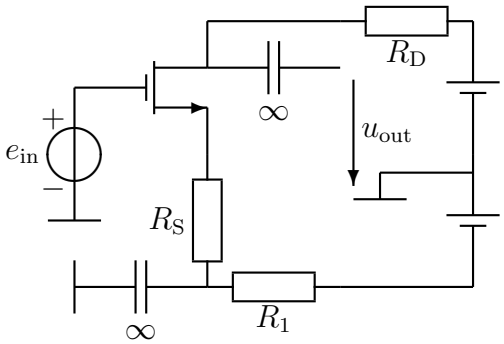


3. Beräkna strömmen I. $R_1 = 1$ kΩ, $R_2 = 0{,}5$ kΩ, $R = 100\ \Omega$, $E_1 = E_2 = 4$ V, $\beta_1 = \beta_2 = 100$, $U_\mathrm{BE1} = U_\mathrm{BE2} = 0{,}7$ V.

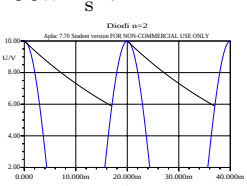


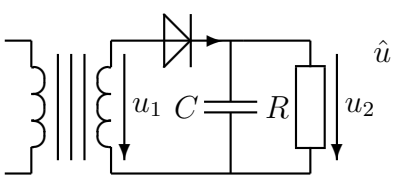
4. Beräkna signalspänningen u_out.
$e_\mathrm{in} = 100$ mV, $R_\mathrm{D} = 10$ kΩ, $R_1 = R_\mathrm{S} = 1$ kΩ,
$g_\mathrm{m} = 1$ mS, $U_\mathrm{t} = 2$ V.

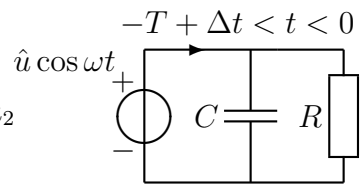


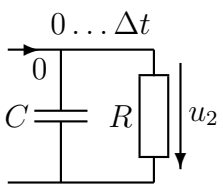


5. Om du svarar på den 5., lämna en av 1-4 bort! Man kan anta, att $u_1 = \hat{u}\cos\omega t$ och $u_2 = \hat{u}\,\mathrm{e}^{-t/\tau}$ ($\tau = RC$). När $t = \Delta t > 0$, är u_2 i sitt minimumvärde $U_\mathrm{MIN} = u_1(\Delta t) = u_2(\Delta t)$. **Beräkna** spänningsvariationen $\Delta u = \hat{u} - U_\mathrm{MIN}$. $\hat{u} = 10$ V, $R = 32\ \Omega$, $C = 1000\ \mu$F, $\omega = 100\pi\ \frac{\mathrm{rad}}{\mathrm{s}}$.









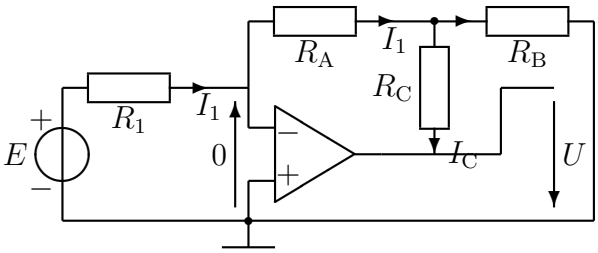
Provet kan **förnyas** to den 20.12.2012. Resultat och svar kommer till **Noppa** i övermorgon, tror jag. Ge gärna anonym **feedback** i Oodi; man ska få en ekstra pääng, om mer än 50 % av studenter (113) svarar!

S-55.1100 SÄHKÖTEKNIIKKA JA ELEKTRONIIKKA

Kimmo Silvonen

2. välikoe 11.12.2012. **Saat vastata vain neljään tehtävään!**
Sallitut: Kako, [gr.] laskin, [MAOL], [sanakirjan käytöstä sovittava valvojan kanssa!]

1. Laske jännite U.
$E = 1$ V, $R_1 = 2\ \Omega$, $R_\mathrm{A} = 4\ \Omega$,
$R_\mathrm{B} = 4\ \Omega$, $R_\mathrm{C} = 4\ \Omega$.



$$-E + R_1 I_1 - 0 = 0 \Rightarrow I_1 = \frac{E+0}{R_1} \tag{1}$$

$$+0 + R_\mathrm{A} I_1 + R_\mathrm{C} I_\mathrm{C} + U = 0 \Rightarrow I_\mathrm{C} = -\frac{R_\mathrm{A} I_1 + U}{R_\mathrm{C}} \tag{2}$$

$$+0 + R_\mathrm{A} I_1 + R_\mathrm{B}(I_1 - I_\mathrm{C}) = 0 \Rightarrow I_\mathrm{C} = \frac{R_\mathrm{A} I_1 + R_\mathrm{B} I_1}{R_\mathrm{B}} \tag{3}$$

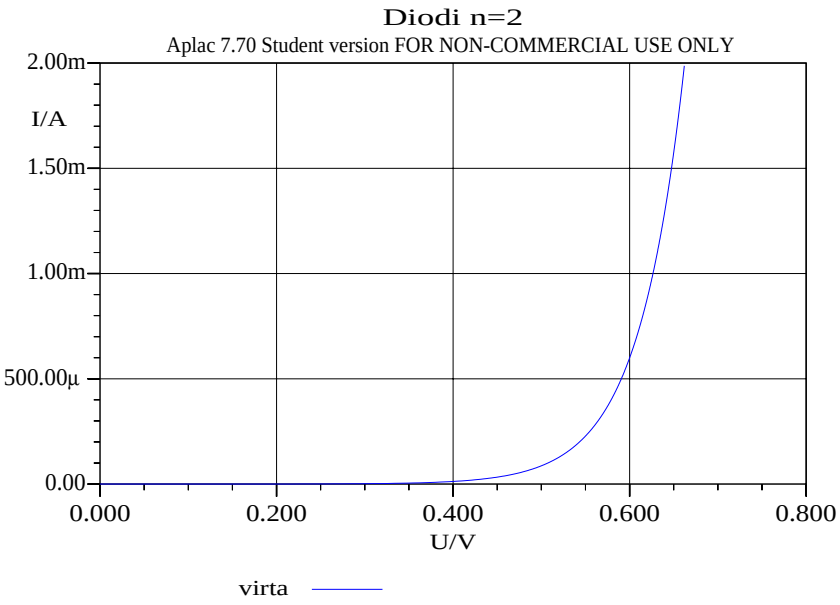
$$-\frac{R_\mathrm{A} I_1 + U}{R_\mathrm{C}} = \frac{R_\mathrm{A} I_1 + R_\mathrm{B} I_1}{R_\mathrm{B}} \Rightarrow U = -R_\mathrm{C}\,\frac{R_\mathrm{A} I_1 + R_\mathrm{B} I_1}{R_\mathrm{B}} - R_\mathrm{A} I_1 \tag{4}$$

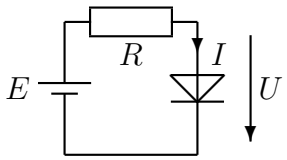
$$U = -\left(R_\mathrm{C}\,\frac{R_\mathrm{A}+R_\mathrm{B}}{R_\mathrm{B}} + R_\mathrm{A}\right) I_1 = -\frac{R_\mathrm{A}}{R_1}\left(R_\mathrm{C}\,\frac{R_\mathrm{A}+R_\mathrm{B}}{R_\mathrm{A} R_\mathrm{B}} + 1\right) E \tag{5}$$

$$U = -\frac{R_\mathrm{A}}{R_1}\left(1 + \frac{R_\mathrm{C}}{R_\mathrm{AB}}\right) E = -6\ \mathrm{V} \tag{6}$$

Tulos on ikään kuin invertoivan ja ei-invertoivan vahvistuksen tulo.

2. Diodin jännite $U = 0{,}65$ V. Laske vastus R ja saturaatiovirta I_S. $E = 5{,}6$ V, $nU_T = 50$ mV.



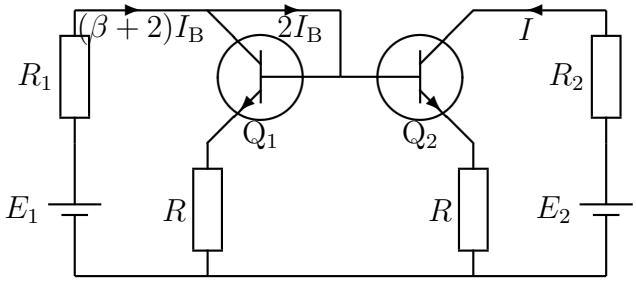


Käyrältä luettuna: $I \approx 1{,}5$ mA.

$$I = I_\mathrm{S}\left(\mathrm{e}^{U/U_T} - 1\right) = I_\mathrm{S}\,\mathrm{e}^{20U} \Rightarrow I_\mathrm{S} = \frac{I}{\mathrm{e}^{20U}} = 3{,}34\ \mathrm{nA} \tag{7}$$

$$-E + RI + U = 0 \Rightarrow R = \frac{E-U}{I} = 3{,}3\ \mathrm{k\Omega} \tag{8}$$

3. Laske virta I. $R_1 = 1$ kΩ, $R_2 = 0{,}5$ kΩ, $R = 100$ Ω, $E_1 = E_2 = 4$ V, $\beta_1 = \beta_2 = 100$, $U_{\mathrm{BE1}} = U_{\mathrm{BE2}} = 0{,}7$ V.



$$-E_1 + R_1(\beta+2)I_\mathrm{B} + U_\mathrm{BE} + R(\beta+1)I_\mathrm{B} \tag{9}$$

$$\Rightarrow I_\mathrm{B} = \frac{E_1 - U_\mathrm{BE}}{R_1(\beta+2) + R(\beta+1)} = 29{,}44\ \mu\mathrm{A} \tag{10}$$

$$I_\mathrm{B2} = I_\mathrm{B1} \Rightarrow I = \beta I_\mathrm{B} = \frac{E_1 - U_\mathrm{BE}}{R_1 \frac{\beta+2}{\beta} + R \frac{\beta+1}{\beta}} \approx \frac{E_1 - U_\mathrm{BE}}{R_1 + R} = 3\ \mathrm{mA} \tag{11}$$

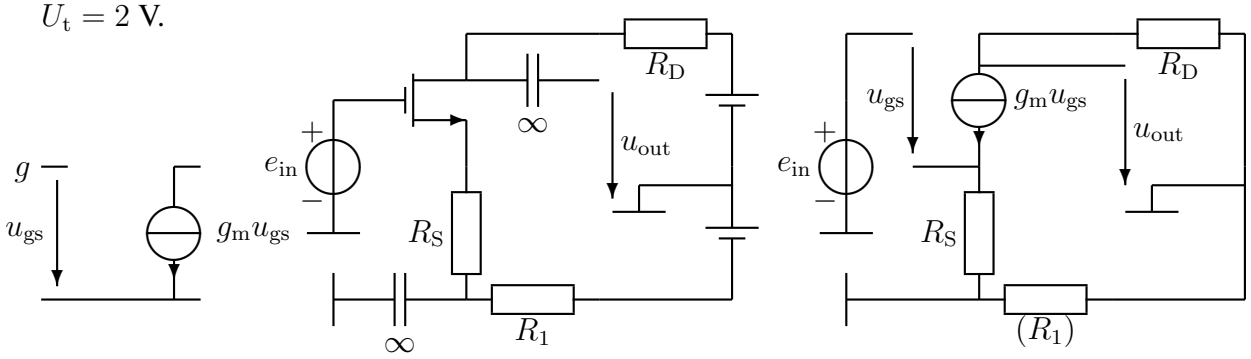
Tarkistus:

$$U_\mathrm{CE1} = E_1 - R_1(\beta+2)I_\mathrm{B} - R(\beta+1)I_\mathrm{B} = 0{,}7\ \mathrm{V} \geq 0{,}3\ \mathrm{V} \tag{12}$$

$$U_\mathrm{CE2} = E_2 - R_2\beta I_\mathrm{B} - R(\beta+1)I_\mathrm{B} = 0{,}7\ \mathrm{V} \geq 0{,}3\ \mathrm{V} \tag{13}$$

OK!

4. Laske signaalijännite u_out. $e_\mathrm{in} = 100$ mV, $R_\mathrm{D} = 10$ kΩ, $R_1 = R_\mathrm{S} = 1$ kΩ, $g_\mathrm{m} = 1$ mS, $U_\mathrm{t} = 2$ V.

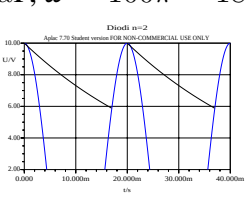


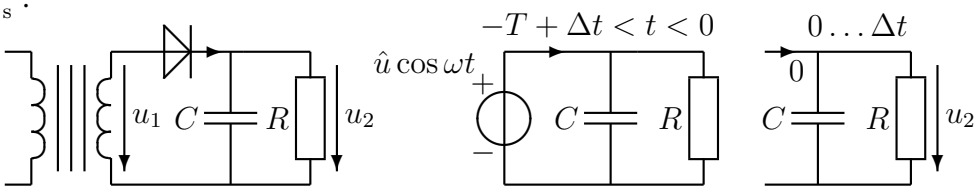
$$e = u_\mathrm{gs} + R_\mathrm{S}g_\mathrm{m}u_\mathrm{gs} \Rightarrow u_\mathrm{gs} = \frac{1}{1 + R_\mathrm{S}g_\mathrm{m}}\, e \tag{14}$$

$$u_\mathrm{out} = -R_\mathrm{D}g_\mathrm{m}u_\mathrm{gs} = -R_\mathrm{D}g_\mathrm{m}\,\frac{1}{1 + R_\mathrm{S}g_\mathrm{m}}\, e \tag{15}$$

$$A_\mathrm{u} = -R_\mathrm{D}g_\mathrm{m}\,\frac{1}{1 + R_\mathrm{S}g_\mathrm{m}} = -5 \tag{16}$$

5. Jos lasket tämän tehtävän, jätä yksi tehtävistä 1-4 pois! Oleta, että $u_1 = \hat{u}\cos\omega t$ ja $u_2 = \hat{u}\,\mathrm{e}^{-t/\tau}$, missä $\tau = RC$. Hetkellä $t = \Delta t > 0$ u_2 on pienentynyt minimiarvoonsa $U_{\mathrm{MIN}} = u_1(\Delta t) = u_2(\Delta t)$. **Laske** jännitteen aaltoilu $\Delta u = \hat{u} - U_{\mathrm{MIN}}$. $\hat{u} = 10$ V, $R = 32\ \Omega$, $C = 1000$ μF, $\omega = 100\pi = 18\ \frac{\mathrm{k}^\circ}{\mathrm{s}}$.





$$U_{\mathrm{MIN}} = u_1 = \hat{u}\,\cos\omega\Delta t = \hat{u}\,\mathrm{e}^{-\frac{\Delta t}{RC}} = u_2 \tag{17}$$

Haetaan ratkaisu kokeilemalla:

Δt/ms	$\cos(100\pi t)$	$\mathrm{e}^{-t/\tau}$
13	-0,587785	0,666071
14	-0,309017	0,645573
15	0	0,625705
16	0,309017	0,606449
17	0,587785	0,587786
18	0,809017	0,569697
19	0,951057	0,552164
20	1.000	0,535172

Taulukosta nähdään, että $\Delta t \approx 17$ ms.

$$U_{\mathrm{MIN}} = u_1(\Delta t) = u_2(\Delta t) = \hat{u}\,0{,}58779 \tag{18}$$

$$\mathbf{\Delta u} = \hat{u} - U_{\mathrm{MIN}} = \hat{u}\,(1 - 0{,}58779) = \mathbf{4{,}12}\ \mathrm{V} \tag{19}$$

Vastaus edellä! Karkea likiarvo (puoliaaltotasasuuntauksen takia täys-T eikä puolikas):

$$I = C\,\frac{\Delta u}{\Delta t} \Rightarrow \Delta u = \frac{I}{C}\Delta t \approx \frac{\frac{\hat{u}}{R}}{C}\,T = 6{,}25\ \mathrm{V} \tag{20}$$

Lasketaan keskimääräisen virran likiarvo tarkemmin:

$$\Delta u \approx \frac{\frac{\hat{u}-\frac{\Delta u}{2}}{R}}{C}\,T \Rightarrow \Delta u \approx \frac{\hat{u}}{\frac{\tau}{T} + \frac{1}{2}} = 4{,}76\ \mathrm{V} \tag{21}$$

Suurilla rippelin arvoilla ja puoliaaltotasasuuntauksessa yleisemminkin yllä oleva likiarvokaava toimii huonosti, kuten tuloksestakin näkyy. Entäpä vanaha kunnon elektroniikan työhevonen, Taylorin sarja? Sarja suppenee sitä nopeammin, mitä pienempi on x; siksi äksäksi kannattaa valita pieni luku. Valitaan $x = T - \Delta t$ loogisemman Δt:n sijaan:

$$\cos\omega(T - \Delta t) = \mathrm{e}^{-\frac{\Delta t}{RC}} = \mathrm{e}^{\frac{-T+(T-\Delta t)}{RC}} \tag{22}$$

$$\cos\omega x = \mathrm{e}^{-\frac{T}{\tau}}\,\mathrm{e}^{\frac{x}{\tau}} \tag{23}$$

$$1 - \frac{1}{2!}\,(\omega x)^2 = \mathrm{e}^{-\frac{T}{\tau}}\,\left(1 + \frac{x}{\tau} + \frac{1}{2!}\,\left(\frac{x}{\tau}\right)^2\right) \tag{24}$$

$$\frac{1 + \tau^2\,\omega^2\,\mathrm{e}^{\frac{T}{\tau}}}{2\tau}\,x^2 + x + \tau(1 - \mathrm{e}^{\frac{T}{\tau}}) = 0 \Rightarrow x \approx 2{,}897\ \mathrm{ms} \tag{25}$$

Eli $\Delta t \approx 17{,}1$ ms ja $\Delta u = 4{,}14$ V. Aika hyvä! Kannattaa ehkä johtaa likiarvokaava mahdollista myöhempää käyttöä varten (käsitellään kokoaaltotasasuuntaus myöhemmin):

$$x = \frac{-1 + \sqrt{1 + 2\,(1 + \tau^2\,\omega^2\,\mathrm{e}^{\frac{T}{\tau}})\,(\mathrm{e}^{\frac{T}{\tau}} - 1)}}{1 + \tau^2\,\omega^2\,\mathrm{e}^{\frac{T}{\tau}}}\,\tau \approx \frac{\sqrt{2\,\mathrm{e}^{\frac{T}{\tau}}\,(\mathrm{e}^{\frac{T}{\tau}} - 1)} - \frac{1}{\tau\omega}}{2\pi\,\mathrm{e}^{\frac{T}{\tau}}}\,T \tag{26}$$

$$\approx \frac{\sqrt{1 - \mathrm{e}^{-\frac{T}{\tau}}}}{\sqrt{2}\,\pi}\,T = 3{,}07\ \mathrm{ms} \tag{27}$$