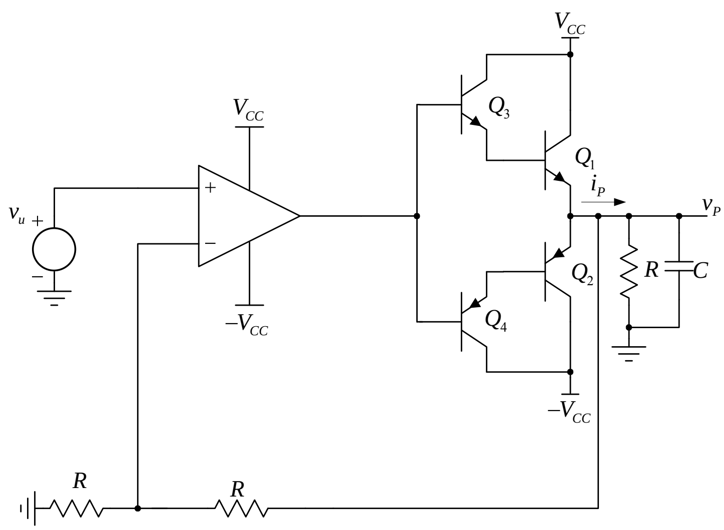
1. U kolu sa slike 1 operacioni pojačavač se može smatrati idealnim, osim što ima strujno ograničenje $i_{OP\max} = 5\text{mA}$. Parametri tranzistora su $\beta_{FN} = 100$, $\beta_{FP} = 30$, $|V_{BE}| = 0.7\text{V}$, dok je $V_{CC} = 15\text{V}$, $R = 20\Omega$, $C = 1\mu\text{F}$. Napon na ulazu kola je oblika $v_u = V_u \sin \omega t$.

a) [10] Ako je $V_u = 5\text{V}$ i $\omega = 50\dfrac{\text{krad}}{\text{s}}$, nacrtati i označiti dijagrame v_U, v_P, i_R, i_C, i_P, i_{C1}, i_{C2} i v_{IOP} tokom jedne periode ulaznog napona.

b) [4] Ako je $V_u = 5\text{V}$ i $\omega = 50\dfrac{\text{krad}}{\text{s}}$, odrediti srednju snagu disipacije tranzistora Q_1

c) [4] Odrediti zavisnost maksimalne amplitude ulaznog napona V_u od ω.

d) [2] Ukoliko $C \to 0$, dimenzionisati tranzistore Q_1 i Q_2 po snazi.



Slika 1

Rešenje:

a)

$v_u = 5\text{V}\sin\omega\text{t}$

$v_P = 2v_U = 10\text{V}\sin\omega t$

$i_R = \dfrac{v_P}{R} = 0.5\text{A}\sin\omega t$

$i_C = C\dfrac{dv_P}{dt} = \omega C v_P \cos\omega t = 0.5\text{A}\cos\omega t$

$i_P = i_R + i_L = 0.5\text{A}\sin\omega t + 0.5\text{A}\cos\omega t = 0.71\text{A}\sin\left(\omega t + \dfrac{\pi}{4}\right)$

Tranzistor Q_1 se uključuje kada postaje $i_P > 0$, odnosno

$i_P(t_1) = 0.71\text{A}\sin\left(\omega t_1 + \dfrac{\pi}{4}\right) = 0$

$t_1 = \dfrac{-\dfrac{\pi}{4} + 2k\pi}{\omega}$

Tranzistor Q_1 vodi dok je $i_P > 0$, tj. gasi se u trenutku t_2:

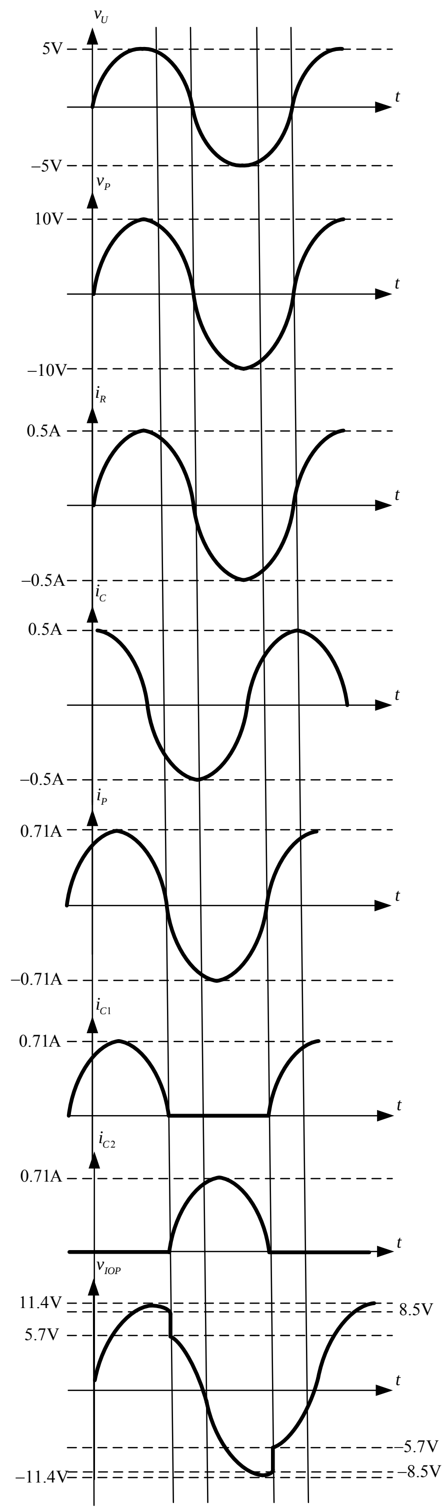
$t_2 = \dfrac{\dfrac{3\pi}{4} + 2k\pi}{\omega}$

Kada vodi tranzistor Q_1 napon na izlazu operacionog pojačavača je

$$v_{IOP} = v_P + 2V_{BE} = 10\text{V}\sin\omega t + 2V_{BE}, \frac{-\frac{\pi}{4} + 2k\pi}{\omega} \le t \le \frac{\frac{3\pi}{4} + 2k\pi}{\omega}$$

Kada vodi tranzistor Q_2 napon na izlazu operacionog pojačavača je

$$v_{IOP} = v_P - 2V_{BE} = 10\text{V}\sin\omega t - 2V_{BE}, \frac{\frac{3\pi}{4} + 2k\pi}{\omega} \le t \le \frac{\frac{7\pi}{4} + 2k\pi}{\omega}$$



b)

$$p_{D1} = v_{CE1} i_{C1} = \begin{cases} (V_{CC} - v_P) i_P, & i_P > 0 \\ 0, & i_P \le 0 \end{cases}$$

$$P_{D1} = \frac{1}{T}\int_{t_1}^{t_2} (V_{CC} - v_P) i_P dt = \frac{\omega}{2\pi}\int_{-\frac{\pi}{4\omega}}^{\frac{3\pi}{4\omega}} (V_{CC} - v_P) i_P dt$$

$$P_{D1} = \frac{\omega}{2\pi}\int_{-\frac{\pi}{4\omega}}^{\frac{3\pi}{4\omega}} (15 - 10\sin\omega t) 0.71 \sin\left(\omega t + \frac{\pi}{4}\right) dt = \frac{1}{2\pi}\int_{-\frac{\pi}{4}}^{\frac{3\pi}{4}} (15 - 10\sin x) 0.71 \sin\left(x + \frac{\pi}{4}\right) dx = \ldots = 2.13\text{W}$$

c)

naponsko ograničenje: $V_{u\max} = \frac{V_{CC} - 2V_{BE}}{2} = 6.8\text{V}$

strujno ograničenje se javlja kada je $i_{P\max} = (1+\beta_{FP})^2 i_{OP\max} = 4.805\text{A}$ (gledamo i_{C2}, zbog manjeg strujnog pojačanja pnp tranzistora)

$$i_{p\max} = 2V_{u\max}\sqrt{\frac{1}{R^2} + \omega^2 C^2}$$

$$V_{u\max} = \frac{i_{p\max}}{2\sqrt{\frac{1}{R^2} + \omega^2 C^2}}$$

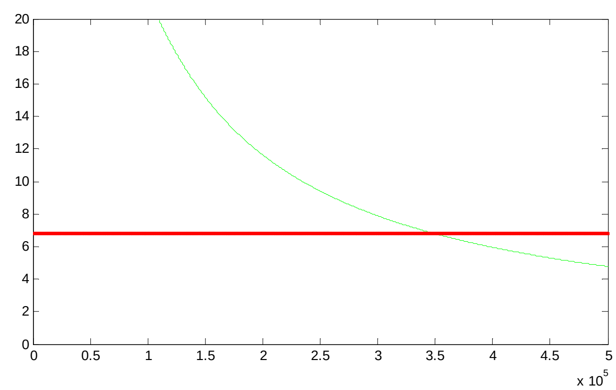
Uzima se stroži od dva uslova. Za male vrednosti ω to je naponsko, za velike strujno, granična vrednost učestanosti se određuje na osnovu jednačine

$$\frac{i_{p\max}}{\sqrt{\frac{1}{R^2} + \omega^2 C^2}} = V_{CC} - 2V_{BE}$$

$$\omega_{gr} = \frac{1}{C}\sqrt{\left(\frac{i_{p\max}}{V_{CC} - 2V_{BE}}\right)^2 - \frac{1}{R^2}} = 350\frac{\text{krad}}{\text{s}}$$

$$V_{u\max} = \begin{cases} 6.8\text{V}, & \omega < \omega_{gr} \\ \frac{i_{p\max}}{2\sqrt{\frac{1}{R^2} + \omega^2 C^2}}, & \omega > \omega_{gr} \end{cases}$$

$$V_{u\max} = \begin{cases} 6.8\text{V}, & \omega < \omega_{gr} \\ \frac{4.805}{2\sqrt{0.0025 + 10^{-12}\omega^2}}, & \omega > \omega_{gr} \end{cases}$$



d)

$$P_{D1}=\frac{1}{T}\int_0^{T/2}\left(V_{CC}-v_P\right)i_R dt=\frac{\omega}{2\pi}\int_0^{T/2}\left(V_{CC}-2V_u\sin\omega t\right)\frac{2V_u}{R}\sin\omega t dt$$

Može direktno, ali može i... Zakon o održanju energije:

$$P_{D1}=\frac{2P_{CC}-P_{OUT}}{2}$$

$$P_{CC}=V_{CC}I_{C1}=V_{CC}\frac{2V_u}{\pi R}$$

$$P_{OUT}=\frac{\left(2V_u\right)^2}{2R}$$

$$P_{D1}=\frac{2V_{CC}\frac{2V_u}{\pi R}-\frac{2V_u^{\ 2}}{R}}{2}=\frac{2V_{CC}}{\pi R}V_u-\frac{V_u^{\ 2}}{R}=\frac{V_u}{R}\left[\frac{2V_{CC}}{\pi}-V_u\right]$$

Maksimum ove funkcije...

$$\frac{dP_{D1}}{dV_u}=0, V_u=\frac{V_{CC}}{\pi}=4.77\text{V}$$

$$P_{D1\max}=1.14\text{W}$$

$P_{D2\max}=P_{D1\max}=1.14\text{W}$ (zbog simetrije)