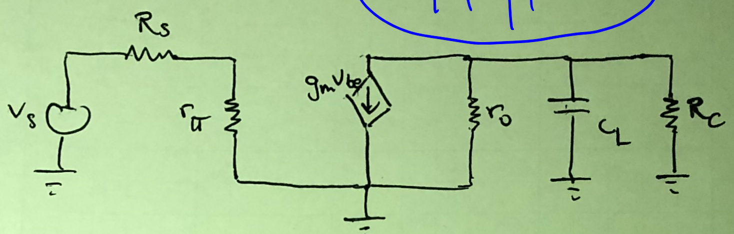
Problem 1

91/100

$\beta = 100$

$V_T = 25\,mV$

1. a)



$V_A \gg V_{CE} \rightarrow I_c \approx I_{co}$

$R_{in} = r_\pi = \frac{\beta}{g_m} = \frac{\beta V_T}{I_{co}} \approx \frac{\beta V_T}{I_c}$, $\quad I_c = I_s e^{V_{BE}/V_T}$

$I_c = I\,bias$

$I_c \approx I_E$ ~~= 100 μA~~ $= 100\,\mu A$

$R_{in} = \frac{100 \cdot 25 \times 10^{-3}}{100 \cdot 10^{-6}} = 25 \cdot 10^3 = \boxed{25\,k\Omega}$ $\quad I_c = \beta I_B =$ ~~100 μA~~

b.) $\frac{V_{out}}{V_s} = \frac{V_{out}}{V_b} \cdot \frac{V_b}{V_s}$ $\qquad V_{out} = V_{out,DC} + \underbrace{A_V V_{in}}_{V_{out}}$

$\frac{V_b}{V_s} = \frac{Z_{in}}{R_s + Z_{in}}$ $\qquad \underbrace{\cancel{V_{be} = V_b - 0.6}}_{\text{large signal}} \rightarrow V_{be} = V_T \ln\left(\frac{I_c}{I_s}\right) = \cancel{0.69}$ 0.69 ~~0.81~~

Find $\frac{V_{out}}{V_{in}}$ (small signal)

$0 = g_m V_{be} + \frac{V_{out}}{r_o} + \frac{V_{out}}{Z_c} + \frac{V_{out}}{R_c}$

$0 = g_m V_{be} + V_{out}(r_o // Z_c // R_c)^{-1} \rightarrow g_m V_{be} + V_{out}\left[\underbrace{\frac{r_o R_c}{r_o + R_c}}_{\alpha} // Z_c\right]^{-1}$

$-g_m V_{be} = V_{out}\left[\frac{\alpha}{1 + s\alpha C}\right]^{-1}$

$\frac{V_{out}}{V_b} = -g_m\left[\frac{\alpha}{1 + s\alpha C}\right]$, $\qquad \alpha = \frac{r_o R_c}{r_o + R_c}$ $\qquad r_o \approx \frac{V_A}{I_c} = \frac{100\,V}{100\,\mu A} = 10^8\,\Omega$

$\rightarrow \frac{V_{out}}{V_s} = -g_m\left[\frac{Z_{in}}{R_s + Z_{in}}\right]\left[\frac{\alpha}{1 + s\alpha C}\right]$

~~$V_{out,DC} =$~~

$\frac{V_{out,DC}}{V_{in}} = -g_m(R_c // r_o) \approx -g_m R_c$

c.) $g_m = \frac{I_c}{V_T} = 0.004$

DC $\frac{V_{out}}{V_{in}} = -g_m R_c = (0.004)(10{,}000) = -40\,V/V$

c) continued...

$$f_T = |s_o| = \frac{1}{\alpha C} = \frac{1}{\left(\frac{10^3 \cdot 10^8}{10^3 + 10^8}\right) 10\,pF} = 1 \times 10^8 \text{ Hz} = \boxed{100 \text{ MHz}}$$

this is f_{3dB}, but looking for f_T

-5

Problem 2

a.) non-inverting

$$V_{out, err} = \boxed{V_{os}\left(1+\frac{R_f}{R_i}\right) + I_B R_f - \left(1+\frac{R_f}{R_i}\right) I_B R_s}$$

$$V_{out, err} = V_{os}(11) + 10R_i I_B - 11 I_B R_s$$

$$V_{out, err} = (10^{-3})(11) + 10(-1nA)R_i - 11(-1nA)R_s$$

$$V_{out, err} = 11\cdot10^{-3} - 10\cdot10^{-9}R_i + 11\cdot10^{-9}R_s$$

b.) Given $R_s = 0$,

$$V_{out, err} = 11\cdot10^{-3} - 10\cdot10^{-9}R_i$$

$$R_i = 1.1\cdot10^{6}\,\Omega = 1.1\,M\Omega$$

$$R_f = 11 M\Omega$$

c.) Given $R_s = 1k$, $V_{os} = 0$

$$V_{out, err} = -10\cdot10^{-9}R_i + 11\cdot10^{-9}R_s \Big|_{R_s = 1k}$$

$$+10\cdot10^{-9}R_i = 11\cdot10^{-6}$$

$$R_i = \cancel{0.0009\,\Omega = 0.9\,m\Omega}\ \ 1100\,\Omega$$

$$R_f = \cancel{9\,m\Omega}\ \ \cancel{110,000\,\Omega}\ \ 11,000\,\Omega$$

Problem 3

a.) non-inverting

$$\frac{V_{out}}{V_{in}} = \left[1 + \frac{R_2}{R_1}\right]\left[\frac{A\beta}{1+A\beta}\right]$$

$$A_0 = 120\ dB = 10^6\ \frac{V}{V}$$

$$\frac{1}{\beta} = 1 + \frac{R_f}{R_i} = 11$$

$$\frac{V_{out}}{V_{in}} = 11\left[\frac{10^6/11}{1 + 10^6/11}\right]$$

$$\beta = \frac{1}{11}$$

$$= 10.9999$$

$$f_T = 10^7$$

$$f_{3dB} = \beta f_T = \frac{10^7}{11} = 909\ kHz$$

b.) $V_{out} = 100 \times 10^{-3}\left[u(t_{\frac{nT}{2}}) - u(t_{nT})\Big|_{n=0,1,2\ldots\infty}\right]\left[1 + \frac{R_f}{R_i}\right]$ X

$\cancel{V_{out}}$ $A_{CL} = \dfrac{A_0}{1 + s\tau + \beta A_0}$

$$f_{3dB} = \frac{1+\beta A_0}{\tau} \approx \frac{\beta A_0}{\tau}$$

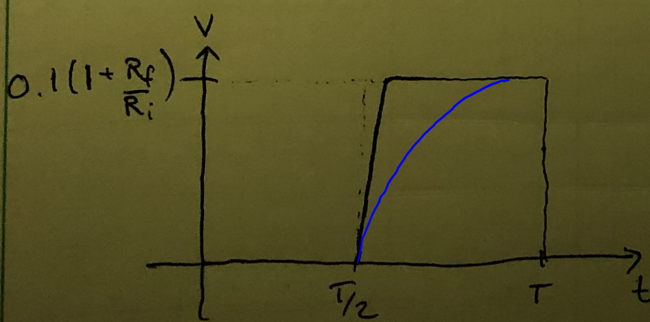
$$\tau = \frac{A_0}{f_T} = 0.1$$

$$A_{CL} = \frac{A_0}{1 + 0.1s + \frac{A_0}{11}}$$

$$\tau_{CL} = \frac{\tau}{\beta A_0} = 9.09 \times 10^{-9}$$

$$= \frac{A_0}{1 + \frac{s}{10} + \frac{A_0}{11}}$$

$$V_{out} = 0.1\left[u(t_{\frac{nT}{2}}) - u(t_{nT})\Big|_{n=0,1,2\ldots\infty}\right](1 - e^{-t/\tau_{cl}})\left(1 + \frac{R_f}{R_i}\right)$$



$\leftarrow$ $0.1\left(1 + \frac{10R_i}{R_i}\right) = \boxed{1.1\ V}$

Problem 3

c) 0.1% settling → $6.9\tau = 6.9 \cdot 9.09 \times 10^{-9} = 6.27 \times 10^{-8}$

$t_{settle} = \frac{1}{2f_{clk}}$ $\qquad T = \frac{1}{f}$

$f_{clk} = \frac{1}{2 \cdot 6.27 \times 10^{-8}} = 7.97 \times 10^{6}$ Hz

$T = \frac{1}{7.97 \times 10^{6} \text{ Hz}} = 1.254 \times 10^{-7}$ s $\times 2$

-1

d) ideal gain = $0.1(11) = 1.1$ V/V

we gain = $0.1\left(1 + \frac{R_f(0.999)}{R_i(1.001)}\right)$ $\qquad R_f = 10R_i$

$= 1.098$ V/V

$\frac{\text{ideal} - \text{actual}}{\text{ideal}} = \frac{1.1 - 1.098}{1.1} = 0.18\%$ error

settling error ? $\quad -3$