$\boxed{\text{Examples}}$ from Ch. 5 & 6. (mai am examples la st. notițele of Ch. 6.).

Example 5.6

Reminder: input offset voltage V_{OS} can be written as in the general expression, in terms of different operating changes affecting it:

$$\boxed{V_{OS} = V_{OS\phi} + TC(V_{OS})\cdot\Delta T + \frac{\Delta v_{CM}}{CMRR} + \frac{\Delta V_S}{PSRR} + \frac{\Delta v_O}{a}}$$

$\Delta v_{CM} \cong v_P$

- $V_{OS\phi}$: initial input offset voltage (due to mismatches in the input stage)
- $TC(V_{OS})\cdot\Delta T$: because V_{OS} varies w/ temperature. All characteristics of transistors vary with T!
- $\frac{\Delta v_{CM}}{CMRR}$: models the variation of v_O as a consequence of the change in v_{CM} (which alters the mismatches)
- $\frac{\Delta V_S}{PSRR}$: similar to the prev. one but due to changes in power supply voltage.
- $\frac{\Delta v_O}{a}$: related to changes in $v_P - v_N = v_D$ due to changes in v_O because a of the OpAmp is finite.

An OpAmp has the ratings:

$$\begin{cases} a = 10^5\ V/V \quad a_{min} = 10^4\ V/V \\ TC(V_{OS})_{avg} = 3\ \mu V/^\circ C \\ CMRR = PSRR = \begin{cases} 100\ dB & \text{typical} \\ 80\ dB & \text{minimum.} \end{cases} \end{cases}$$

Find worst case and most probable change of V_{OS} over the following operating ranges:

$$\begin{cases} 0^\circ C \le T \le 70^\circ C \\ V_S = \pm 15V \pm 5\% \\ -1 \le v_P \le 1\ V \\ -5 \le v_O \le 5\ V \end{cases}$$

Thermal change from room temperature:

(1) $\Delta V_{OS1} = 3\ \mu V/^\circ C \cdot \underbrace{(70-25)^\circ C}_{=\Delta T} = 135\ \mu V$

$$\frac{1}{CMRR} = \frac{1}{PSRR} = \begin{cases} 10^{-100/20} = 10\ \mu V/V & \text{typical} \\ 10^{-80/20} = 100\ \mu V/V & \text{maxim} \end{cases} \Rightarrow$$

Note: here we used definition of decibels:

$CMRR_{dB} = 20\log_{10} CMRR \Rightarrow$

$\Rightarrow CMRR = 10^{\frac{CMRR_{dB}}{20}} \Rightarrow \frac{1}{CMRR} = 10^{-\frac{CMRR_{dB}}{10}}$

(2) $\Rightarrow \Delta V_{OS2} = \frac{\Delta v_P}{CMRR} = \frac{\pm 1V}{CMRR} = \begin{cases} \pm 10\ \mu V & \text{typical} \\ \pm 100\ \mu V & \text{maxim} \end{cases}$

(3) $\Delta V_{OS3} = \frac{\Delta V_S}{PSRR} = \frac{2\times(\pm 0.75)}{PSRR} = \begin{cases} \pm 15\ \mu V & \text{typical} \\ \pm 150\ \mu V & \text{maxim.} \end{cases}$

(4) $\Delta V_{OS4} = \frac{\pm 5V}{a} = \begin{cases} \pm 5\ \mu V & \text{typical} \\ \pm 500\ \mu V & \text{maxim} \end{cases}$

Hence:

(a) Worst case V_{os} change is:

$$\Delta V_{OS} = \pm(135+100+150+500)\mu V = \pm 885\,\mu V = \pm 0.885\,mV$$

(b) Most probable V_{os} change is given by the root-mean-square (RMS):

$$\Delta V_{OS} = \pm(135^2+10^2+15^2+50^2)^{\frac{1}{2}} = \pm 145\,\mu V = \pm 0.145\,mV$$

Example 6.2 page 265

(a) Design an audio amplifier using μA741 opamps with a gain of 60 dB.
(b) Sketch its magnitude plot
(c) Find actual bandwidth.

(a) $A_o^{dB} = 60\,dB = 20\log_{10} A_o \Rightarrow A_o = 10^{\frac{A_o^{dB}}{20}} = 10^{\frac{60}{20}} = 10^3$ V/V required!

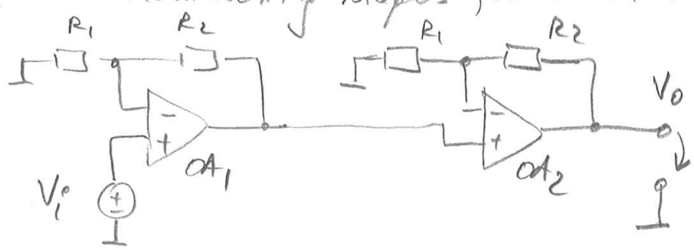
Bandwidth is $f_B \geq 20\,kHz$ (audio) required!

By equation (6.14), page 265,
the gain-bandwidth product of the non-inverting OpAmp based amplifier is:

$$GBP = A_o f_B = f_t = 1\,MHz \text{ for μA741 OpAmp.}$$

$$\Rightarrow f_B = \frac{f_t}{A_o} = \frac{10^6}{10^3} = 10^3\,Hz = 1\,kHz < 20\,kHz \text{ that is required!}$$

⇒ Cascade two noninverting stages, each with smaller gain but wider bandwidth!



Gain $A_1 = 1+\frac{R_2}{R_1}$ Gain $A_2 = 1+\frac{R_2}{R_1}$: make them equal for maximum bandwidth!!!

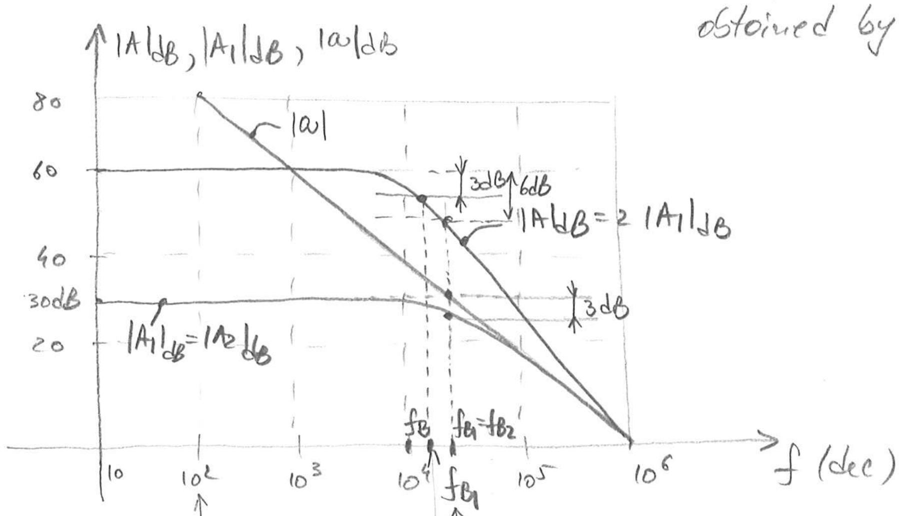
Total gain $A = A_1 \cdot A_2 \underset{A_1=A_2}{=} A_1\,A_2 = A_1^2 = 10^3$ V/V required!

$\Rightarrow A_1 \quad A_2 = \sqrt{1000} = 31.62$ V/V or 30 dB.

Therefore: $f_{B1} = f_{B2} = 10^6/31.62 = 31.62\,kHz > 20\,kHz$! which is good!

(b)

$A = A_1^2 \Rightarrow |A|_{dB} = 2 \cdot |A_1|_{dB} \Rightarrow$ magnitude plot of A can be obtained by x2 that of A_1!



$f_{B_1} = f_{B_2} = 31.62$ kHz

see page 261 that for $f = 10^2$, μA741 has $|a| = f_t/f = 10^6/10^2 = 10000$ V/V $= 80$ dB

(c)

$f_B < f_{B_1} = f_{B_2} = 31.62$ kHz.

but by definition, bandwidth is f_B for which gain decreases with 3dB!

$|A(j f_B)| = \frac{10^3}{\sqrt{2}}$ must be equal to:

$$|A_1(jf)|\Big|_{f=f_B} = \frac{31.62^2}{1+\left(\frac{f_B}{f_{B_1}}\right)^2} = \boxed{\frac{31.62^2}{1+\frac{f_B^2}{(31.62\times 10^3)^2}} = \frac{10^3}{\sqrt{2}}} \Rightarrow f_B = 31.62\sqrt{\sqrt{2}-1} = 20.35 \text{ kHz}.$$

$\boxed{f_B = 20.35 \text{ kHz}} > 20$ kHz that we needed! nice!

Example 6.3

→ Vezi simulation with LTSpice!