# Examples

**6.3.** (problem 6.3 from textbook, page 303)
Constant GBP opamp has ... of freq. less than $f_b$.

~~Example 1~~: (data to ex.1. in 2011)

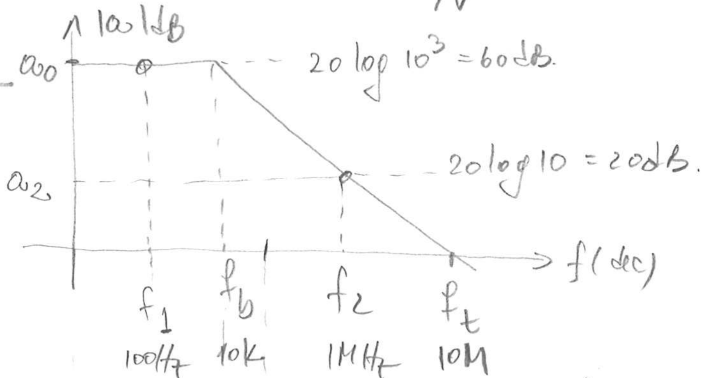
$|a(j\,100\,Hz)| = 1\,V/mV = 1000\,V/V$ ($f_1$)

$|a(j\,1\,MHz)| = 10\,V/V$ ($f_2$)

a) $f_x = ?$ at which $\measuredangle a = -60^\circ = \angle a(jf_x)$

b) $f_x = ?$ at which $|a| = 2\,V/V$

**Solution:**




$$GBP = f_t = a_f \cdot f = a_2 \cdot f_2 = 10 \cdot 1\,MHz = \boxed{10\,MHz = f_t}$$

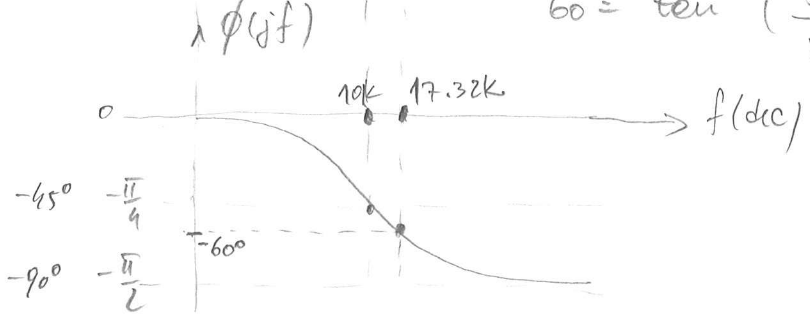
Also: $$f_b = \frac{f_t}{a_0} = \frac{10\,MHz}{10^3} = \boxed{10\,kHz = f_b}$$

(a) $$a(jf) = \frac{a_0}{1 + j\,f/f_b} \Rightarrow \measuredangle a = \angle a(jf) = -\arctan(f/f_b) = -\tan^{-1}\left(\frac{f}{f_b}\right)$$

$$-60 = -\tan^{-1}\left(\frac{f_x}{f_b}\right)$$

$$60 = \tan^{-1}\left(\frac{f_x}{10^4}\right) \Rightarrow \boxed{f_x = 17.32\,kHz}$$

expected!

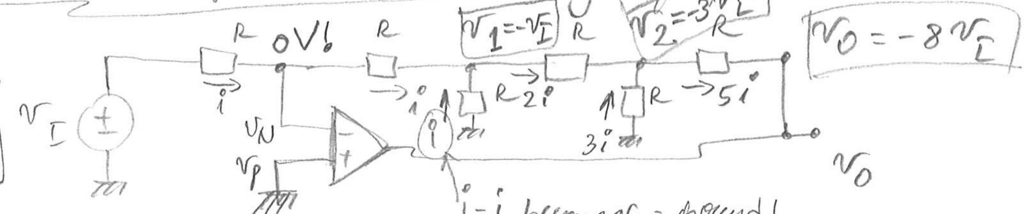



(b) $$|a(jf)| = \left.\frac{a_0}{\sqrt{1 + \left(\frac{f}{f_b}\right)^2}}\right|_{f=f_x} = 2\,\frac{V}{V} \Rightarrow \left(\frac{a_0}{2}\right)^2 = 1 + \left(\frac{f_x}{f_b}\right)^2$$

$$\frac{10^6}{4} = 1 + \frac{f_x^2}{(10^4)^2} \Rightarrow \boxed{f_x = 5\,MHz}$$

## 6.8. Example 2

(a) Find the closed-loop GBP of the inverting amplifier:




$i = i$ because $v_N$ = ground!

$GBP = |A_0| \cdot f_B = ?$ (eq. 6.16)

Assume $\{ r_d >> R, \; r_o << R$

$f_t = 4\,MHz$ ← Given!

(I) $A_0 = ? = A_{ideal}$

$i = \frac{v_I}{R}$

$v_1 = -v_I$ , $v_2 = v_1 - R \cdot 2i = -3v_I$ , $v_O = v_2 - R\,5i = -8v_I$

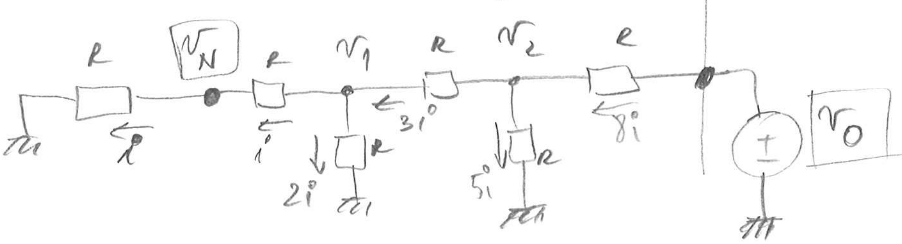
$\Rightarrow \boxed{A_{ideal} = -8\ V/V} = A_0$

(II) $f_B = ?$ $\Rightarrow f_B = \beta \cdot f_t$ (see eq. 6.15(b)).

$\beta = ?$ $f_t = 4\,MHz$.

Negative feedback taken separately to study $\boxed{\beta} \triangleq \frac{v_N}{v_O}$

$\beta = ?$ :




nu discuto așa cum e folosit ca IV amplifier! → neg. feedback network.
~~shunt out ⇒ sample voltage~~
~~shunt in ⇒ compare current~~
} DO NOT mention îi confuzionezi! This is used as voltage amplifier!

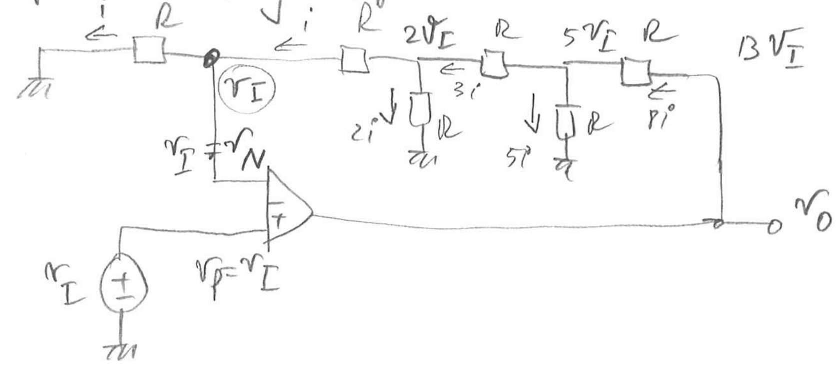
$i = \frac{v_N}{R}$ , $v_1 = 2v_N$ ; $v_2 = v_1 + R \times 3i = 5v_N$ ; $v_O = v_2 + 8i \times R = 13v_N$

$\Rightarrow \beta_v = \frac{v_N}{v_O} = \frac{v_N}{13v_N} = \frac{1}{13}\ \frac{V}{V}$

$\Rightarrow f_B = \frac{4\,MHz}{13} \cdot \frac{V}{V} \Rightarrow \boxed{GBP = |A_0| \cdot f_B = |-8| \cdot \frac{4\,MHz}{13} = \frac{32}{13}\,MHz.}$

(b) Repeat for non-inverting configuration:



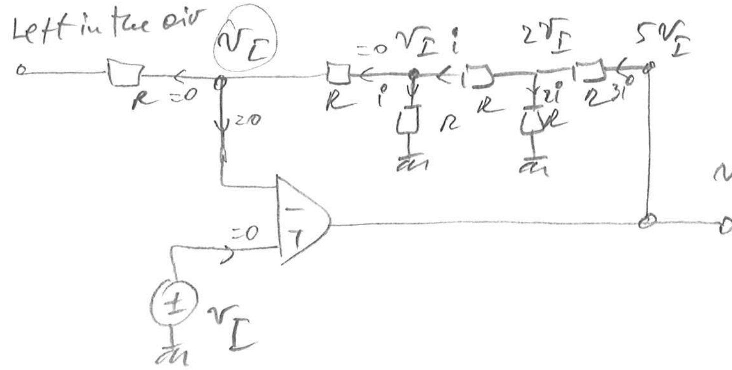



: same current ratios as in part II from a).

Left as exercise!

$$\Rightarrow \boxed{A_0 = 13\ V/V} \quad \beta = \frac{1}{13}\ V/V \Rightarrow \boxed{GBP = A_0 \cdot \underbrace{\beta f_t}_{= f_B} = 13 \cdot \frac{1}{13} \cdot 4\,MHz = 4\,MHz.}$$

(c)




$$v_O = 5 v_I \Rightarrow \boxed{A_0 = 5\ \frac{V}{V}}$$

$$A_0 = 5\ V/V \qquad \beta = \frac{1}{5} \qquad \Rightarrow \boxed{GBP = 4\,MHz}$$

(Exam 1; Spring '11)

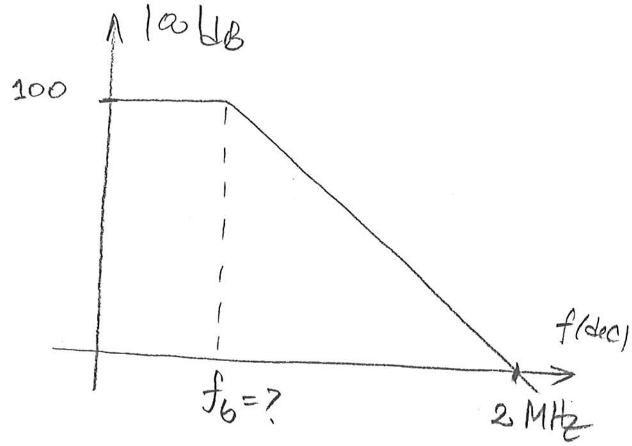
**PROBLEM 5**

The open-loop frequency characteristic of an OpAmp, using the dominant pole model, is shown in the figure below. The OpAmp has $r_d = 1M\Omega$ and $r_0 = 100\Omega$.

a) Find the value of $f_b$ for the OpAmp.

Important!

b) If the OpAmp is used to build a non-inverting amplifier with a gain of 10, calculate the bandwidth of the amplifier. Calculate the input impedance for an input frequency of 500kHz.




(a) $a_0 = 10^{100/20} = 10^5$

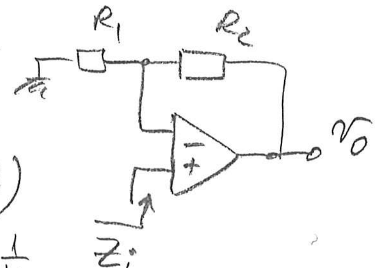
$f_t = 2\,MHz = f_b \cdot a_0 \Rightarrow$

$\Rightarrow f_b = \frac{f_t}{a_0} = 20\,Hz$

(b) $A_0 = 10$, $f_t = A_0 \cdot f_B \Rightarrow f_B = \frac{f_t}{A_0} = 200\,kHz.$

Bandwidth!

The input impedance of a "series input" negative feedback configuration is:




$$Z_i = R_{id}\,\frac{1+j\,f/f_B}{1+j\,f/f_b},\ \text{where: } R_{id} = r_d(1+a_0\beta)$$

and $\beta = \frac{R_1}{R_1+R_2} = \frac{1}{10}$

$\Rightarrow R_{id} = 1M(1+10^5\cdot\frac{1}{10}) \cong 10^4 \cdot 1M\Omega$
$= 10\,G\Omega$

$$f = 500\,kHz \Rightarrow |Z_i| = R_{id}\cdot\left|\frac{1+j\,f/f_B}{1+j\,f/f_b}\right|$$

$$= 10\,G\Omega \cdot \frac{\sqrt{1+\left(\frac{500k}{200k}\right)^2}}{\sqrt{1+\left(\frac{500k}{20}\right)^2}}$$

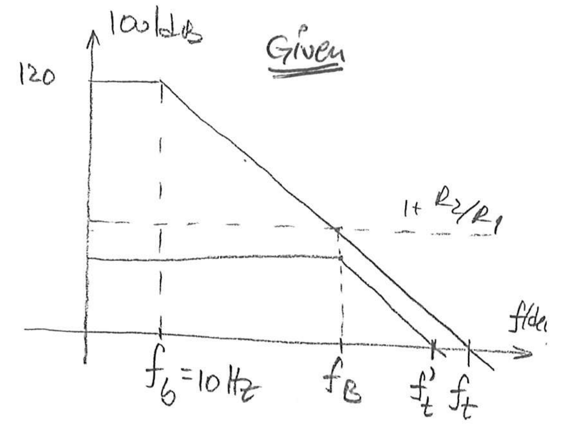
**EXAM 2- ECE 723 - SPRING 2009**
**Open Book, Closed Notes, 50 minutes**

## PROBLEM 1

The open-loop frequency characteristic of an OpAmp, using the dominant pole model, is shown in the figure below. The OpAmp has $r_d = 1M\Omega$ and $r_O = 100\Omega$, $C_c = 30pF$.

a) Find the value of $f_t$ for the OpAmp.
b) If the OpAmp is used to build an **inverting** amplifier with $R_1$=10k and $R_2$=40k, sketch its frequency response and calculate:
   - the 3dB bandwidth (that is $f_B$)
   - the unity gain bandwidth of the amplifier (that is $f'_t$)

c) If the OpAmp is used to build an **inverting** amplifier with a gain of 10, derive the formula calculate the frequency $f_x$ at which the input impedance is $1.2R_1$. Assume that such frequency $f_b << f_x << f_t$.

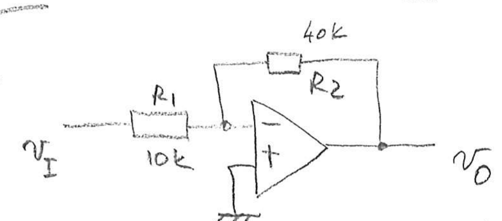



(a) $|a_o|_{dB} = 120 \iff 120 = 20 \cdot \log a_o$

$$\Rightarrow \boxed{a_o = 10^6}$$

$$\boxed{f_t = a_o \cdot f_b = 10^6 \cdot 10\ Hz = 10\ MHz}$$

(b)

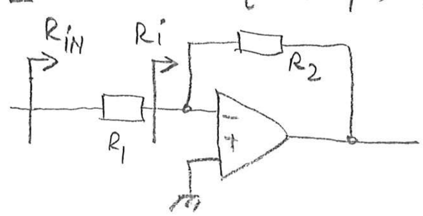



$$\boxed{A(jf) = A_o \cdot \frac{1}{1 + j\ f/f_B}} \quad \text{Eq. 6.15.a}$$

$|A_o| \cong \left| -\frac{R_2}{R_1} \right| = 4$ $\qquad f_B \cong \beta \cdot f_t = \frac{R_1}{R_1 + R_2} \cdot f_t = \frac{1}{5} \cdot 10\ MHz = 2\ MHz.$ $\qquad \boxed{f_B = 2\ MHz}$

Use Eq. 6.16 $\Rightarrow f'_t = (1-\beta) f_t = \frac{4}{5} \cdot 10\ MHz = 8\ MHz$ $\qquad \boxed{f'_t = 8\ MHz}$

(c)




Use Eq. 6.23 $\Rightarrow R_{IN} = R_1 + R_i = R_1 + \frac{R_2}{1+a_o} \cdot \frac{1 + j\ f/f_b}{1 + j\ f/f_t} \Rightarrow$

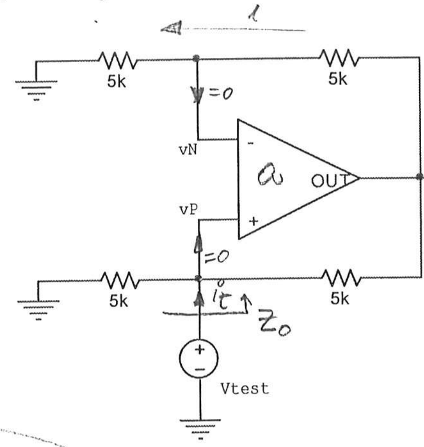
$$\Rightarrow 1.2 \cdot R_1 = \left| R_1 + \frac{R_2}{1+a_o} \cdot \frac{1 + j\ f_x/f_b}{1 + j\ f_x/f_t} \right| \cong \left| R_1 + \frac{R_2}{1+a_o} \cdot \left(j \cdot \frac{f_x}{f_b}\right) \right| \Rightarrow$$

$$\Rightarrow 1.2^2 = 1^2 + \left(\frac{R_2}{R_1} \cdot \frac{1}{1+a_o}\right)^2 \cdot \left(\frac{f_x}{f_b}\right)^2 \Rightarrow \boxed{f_x = \ldots}$$

(This is similar to last problem of Exam #1)

(Exam 2; spring 11) P. 6.24 ?

**PROBLEM 2**
In the given circuit, all resistances are equal to 5kΩ. The Op Amp has $a_0 = 10^5$ V/V, $f_t = 10$ MHz, $r_d = \infty$, $r_0 = 0$. Sketch the magnitude plot of the impedance $Z_0$ seen by the load.




$v_{test} = v_P$

$$\left\{\begin{array}{l} v_0 = a\cdot(v_P - v_N) = a\cdot(v_{test} - v_N) \\ v_0 = 2\cdot v_N \end{array}\right\} \Rightarrow$$

$$\Rightarrow \boxed{v_N = \frac{a}{2+a}\cdot v_{test}}$$

$$i_t = \frac{v_{test}}{R} + \frac{v_{test} - v_0}{R} = \frac{v_{test} + v_{test} - 2v_N}{R} = \frac{2}{\left(1+\frac{a}{2}\right)R}\cdot v_{test} \Rightarrow$$

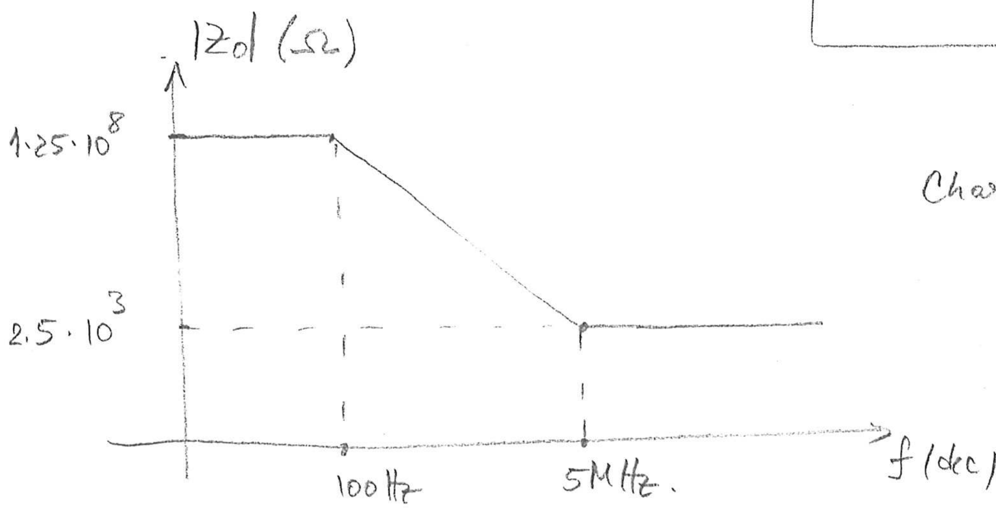
$$\Rightarrow \boxed{Z_o = \frac{v_{test}}{i_t} = \frac{R}{2}\left(1+\frac{a}{2}\right)}$$

We know: $\boxed{a = \dfrac{a_0}{1+j\,f/f_b}}$

where $f_b = f_t/a_0 = 100$ Hz

$$\Rightarrow Z_o = (2.5\,k\Omega)\cdot\left(1+\frac{10^5/2}{1+j\,f/100\,Hz}\right)$$

$$\cong \boxed{1.25\cdot 10^8\cdot\frac{1+j\,f/5\,MHz}{1+j\,f/100\,Hz} = Z_o}$$




Character capacitive!

(This is similar to a problem from HW #5 !)