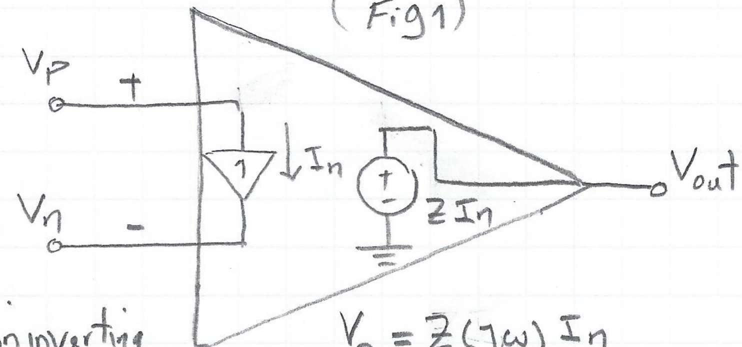
Monolithic Silicon Power F. Moraveji

Op-Amp White Paper 1 CFA 3/12/2021

⇒ Current Feedback Amplifier Analysis

- In Current Feedback Amplifiers, Forward gain is Transimpedance $Z(jw)$
- The input Voltage v_i is imposed on inverting input Via 1X Buffer
- The closed-loop bandwidth does not depend on closed-loop gain!
- Feedback node is low-impedance and Feedback quantity is current

(Fig1)



⇒ V_i is imposed on noninverting node Via 1x buffer

$V_o = Z(jw)\,I_n$

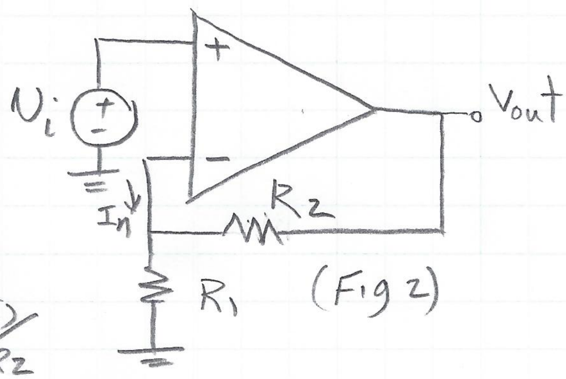
$Z(jw)$ = Transimpedance Gain

⇒ By applying Superposition

$$I_n = \underset{(V_{out}=0)}{\frac{v_i}{R_1 \| R_2}} - \underset{(V_i=0)}{\frac{V_o}{R_2}}$$

$$V_o = I_n Z(jw)$$

$$\frac{V_o}{v_i} = \left(1 + \frac{R_2}{R_1}\right) \cdot \frac{1}{R_2} \cdot \frac{Z(jw)}{1 + \frac{Z(jw)}{R_2}}$$



(Fig 2)

$1 + \frac{R_2}{R_1}$ = Closed-loop Gain $\qquad \frac{Z(jw)}{R_2}$ = Loop Gain

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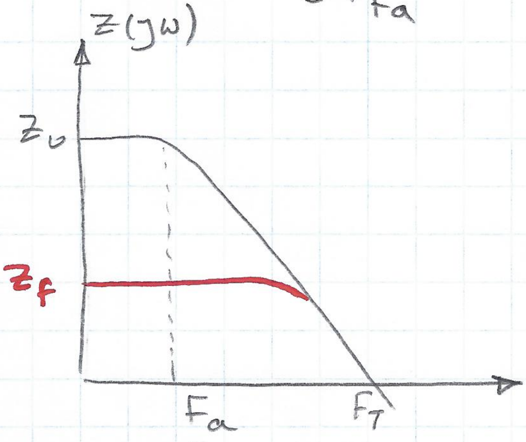
For the current-feedback amplifier depicted in Fig 2 the closed-loop gain can be written as

$$\frac{V_o}{V_i} = \left(1+\frac{R_2}{R_1}\right)\frac{1}{R_2}\frac{Z(j\omega)}{1+Z(j\omega)/R_2} \quad \text{where} \quad \frac{Z(j\omega)}{R_2} = \text{loop-Gain}$$

The closed-loop transimpedance gain is equal to

$$\frac{v_o}{i_i} = \frac{Z}{1+ZY} = Z_f(j\omega) \quad \text{if } ZY \gg 1 \quad Z_f(j\omega) = 1/Y$$

$$Z(j\omega) = \text{open-loop Transimpedance Gain} = \frac{Z_0}{1+j\,f/f_a}$$



$$\frac{V_o}{V_i}(j\omega) = \left(1+\frac{R_2}{R_1}\right)\frac{1}{R_2}\frac{Z(j\omega)}{1+Z(j\omega)/R_2}$$

For $f \gg f_a$ $\quad Z(j\omega) = \frac{Z_0 f_a}{jf}$

$$\frac{V_o}{V_i}(j\omega) = \left(1+\frac{R_2}{R_1}\right)\frac{Z_0 f_a/jf}{R_2 + Z_0 f_a/jf}$$

$f_T = Z_0 f_a$

$F_A = \frac{f_T}{R_2}$

$$\boxed{\frac{V_o}{V_i}(j\omega) = \left(1+\frac{R_2}{R_1}\right)\frac{1}{1+j\,f/f_A}}$$

where $f_A = \frac{Z_0 f_a}{R_2}$ $\Rightarrow$ As it can be seen, the closed loop bandwidth of current-feedback amplifier is independent of noise gain $1+\frac{R_2}{R_1}$. It is inversely proportional to R_2 (feedback resistor) and directly proportional to corner frequency f_a of transimpedance

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⇒ Basic Current Feedback Topology

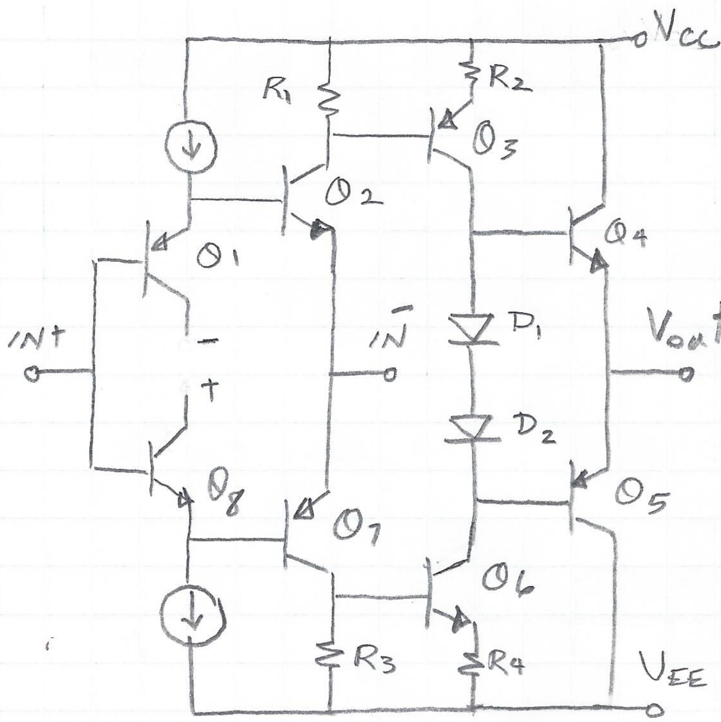


Fig 1

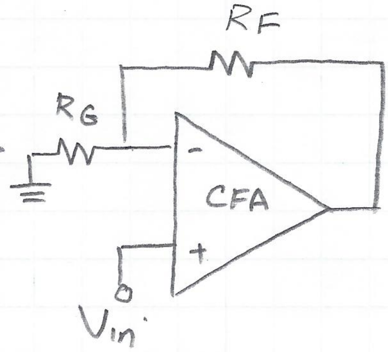
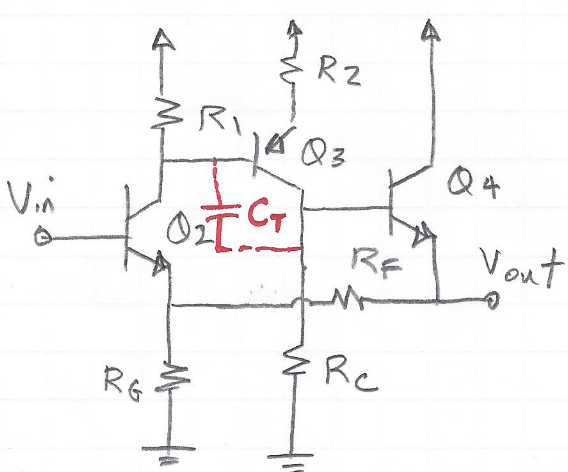


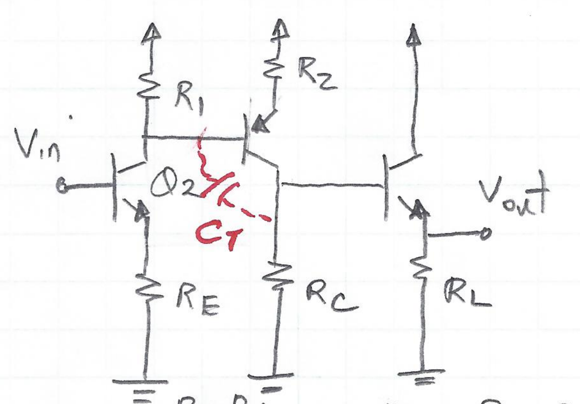
Fig 2

⇒ In order to analyze above circuit, a simplified half circuit can be used



Series-shunt Feedback

Fig 3



$$R_E = \frac{R_F R_G}{R_F + R_G} \qquad R_L = R_G + R_F$$

open-loop Circuit

Fig 4

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⇒ Half Circuits of Fig_3 and Fig_4 Can be used to better understand Current Feedback Amplifiers

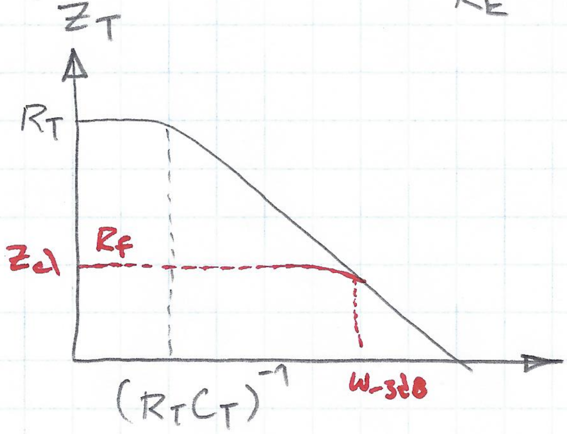
Fig4 is the open-loop circuit for Fig3 which takes into account the loading effect of feedback resistors R_F & R_G

From Fig4, the open-loop DC gain is:

$$A_{DC} = \frac{R_1}{R_E} \cdot \frac{R_C}{R_2} \qquad \omega_p = \frac{1}{R_1\left(\frac{R_C}{R_2} C_T\right)}$$

$\longleftrightarrow$ Miller effect

Now define Transresistance $R_T = \frac{R_1 R_C}{R_2}$ then we can write $A_{DC} = \frac{R_T}{R_E}$ $\quad \omega_p = \frac{1}{R_T C_T}$



$$A(j\omega) = \frac{R_T}{R_E} \frac{1}{1+j\,\omega/\omega_p} = \frac{R_T}{R_E} \frac{1}{1+j\omega R_T C_T} = \frac{V_o}{V_{in}}$$

$$\frac{V_o}{V_{in}} \cdot R_E = \frac{R_T}{1+j\omega R_T C_T} \Rightarrow i_{in} = \frac{V_{in}}{R_E}$$

$$\frac{V_o}{i_{in}} = Z_T(j\omega) = \boxed{\frac{R_T}{1+j\omega R_T C_T}} \qquad \text{Eq. 1}$$

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⇒ How To Calculate closed-loop Transimpedance in Current-Feedback Amplifiers

In order to find the closed-loop Transimpedance $Z_{cl}(j\omega)$ which is set by resistors R_F & R_G in Fig3, we can use the general closed-loop equation for series-shunt Feedback

$$Z_{cl} = \frac{v_o}{i_i} = \frac{Z_T(j\omega)}{1 + Z_T(j\omega)Y(j\omega)} \quad Eq_2$$

$$Z_T(j\omega) = \frac{R_T}{1 + j\omega R_T C_T} \quad \& \quad Y(j\omega) = R_F$$

After substituting for $Z_T(j\omega)$ & $Y(j\omega)$ in Eq_2 and assuming $R_T / R_F \gg 1$

$$\boxed{Z_{cl}(j\omega) = \frac{R_F}{1 + j\omega R_F C_T}} \qquad \boxed{\omega_{-3dB} = \frac{1}{R_F C_T}}$$

⇒ It can be seen from these two key equations that in current-feedback amplifiers, the closed-loop -3dB bandwidth is set by feedback resistor R_F and total internal capacitor C_T