HW-09

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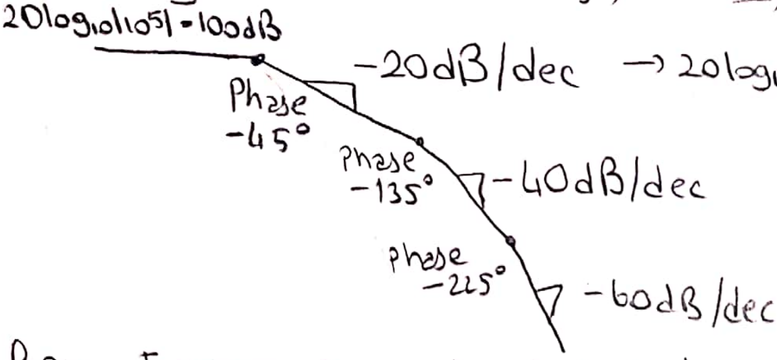
Q1. An amplifier has a dc gain of 10^5 and poles at 10^5 Hz, 3.16×10^5 Hz, and 10^6 Hz. Find the value of β, and the corresponding closed-loop gain, for which a phase margin of 45° is obtained.

Mag. Bode Plot for $A(jf)$



$\rightarrow \beta \rightarrow$ pozitif ve real olmalı.

$\rightarrow 20\log_{10}|A(jf)\beta| = 20\log_{10}|A(jf)| - 20\log_{10}\left|\frac{1}{\beta}\right|$

$A(jf) > A(jf).\beta$

Bazı 5 common terms değerleri verilmiş. $A(jf) = \dfrac{10^5}{\left(1+\frac{jf}{10^5}\right)\left(1+\frac{jf}{3.16\times10^5}\right)\cdot\left(1+\frac{jf}{10^6}\right)}$ olarak yazılabilir.

$|A(jf).\beta| = 1$ olduğu bilindiğinden β için çözersek.

$$\left|\frac{10^5.\beta}{\left(1+\frac{jf_u}{10^5}\right)\cdot\left(1+\frac{jf_u}{3.16\times10^5}\right)\cdot\left(1+\frac{jf_u}{10^6}\right)}\right| = 1$$

$\rightarrow$ closed loop gain for phase marg. 45° demiş 45° için $\underbrace{f_u = 3.16\times10^5\ Hz}_{\text{second pole}}$

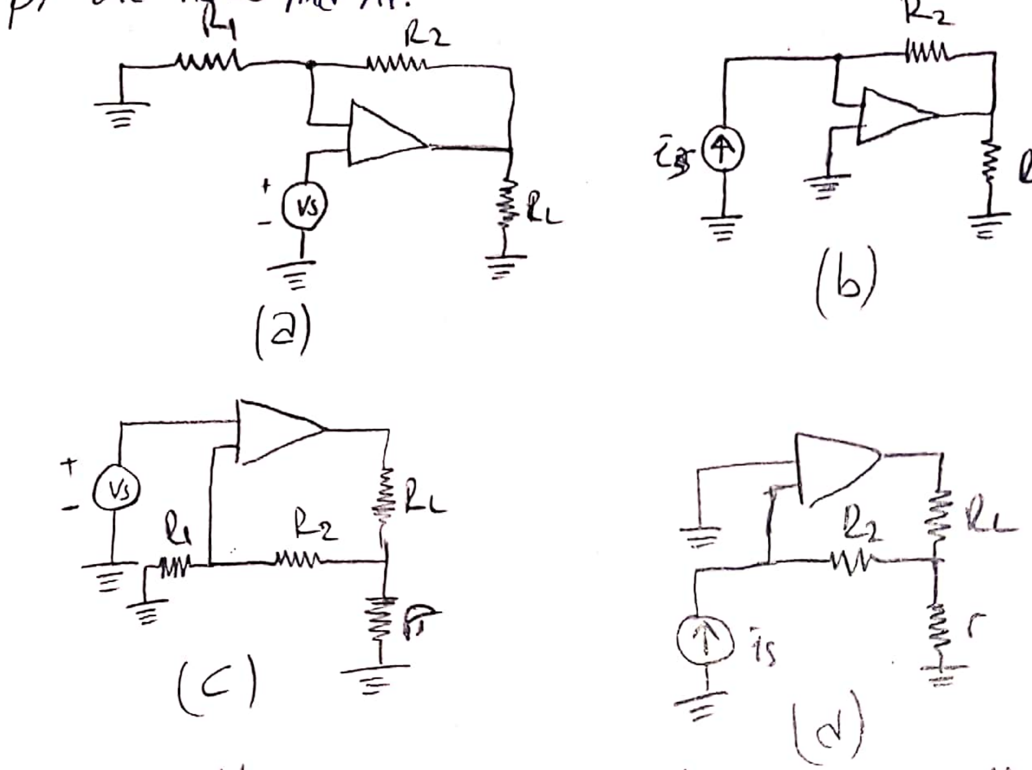
$$1 = \frac{10^5.\beta}{\underbrace{\sqrt{1+(3.16)^2}\cdot\sqrt{2}\cdot\sqrt{1+(0.316)^2}}_{4.915}} \Rightarrow 4.915 = 10^5.\beta \quad \boxed{\beta = 4.915\times10^{-5}}$$

$$\boxed{\frac{1}{\beta} = 2.0342\times10^4}$$

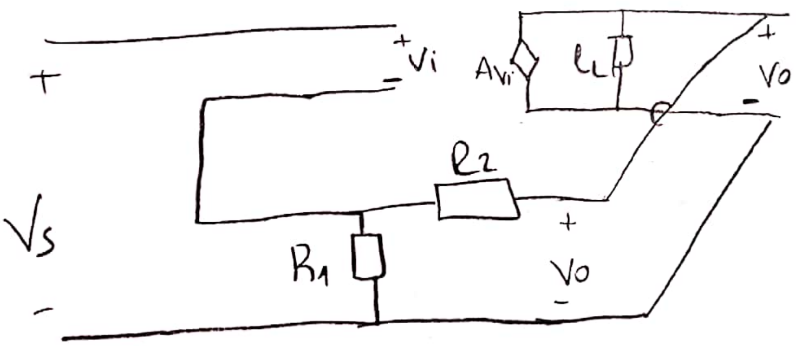
$$\boxed{20\log_{10}\left|\frac{1}{\beta}\right| = 86.168\ dB}$$

$$A_f = \frac{A}{1+A.\beta} = \frac{10^5}{1+10^5.(4.915\times10^{-5})} = \underline{\underline{1.6906\times10^4}}$$

Q2. For each of the opamp circuits shown in Fig. P.8.26, identify the feedback topology and indicate the output variable being sampled and the feedback signal. In each case, assuming the opamp to be ideal, find an expression for β, and hence find A_f.

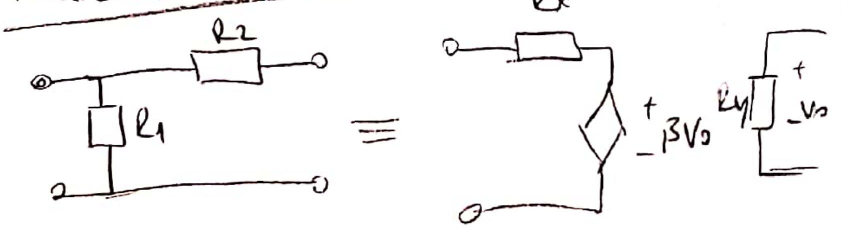


OPAMP'lar Voltage amplifier'lardır. Aslında diff. amp gibi bir davranışı var girişteki iki kolun farkını yükselterek dışarı aktarıyor. İyi bir voltage amp. olması için yüksek giriş empedansı olmalı (ss equ. empedansı) opamp'ın basit bir modellemesi aşağıdaki gibidir.



→ Burada giriş empedansı sonsuza getirilmiş. İdeale yaklaştırılmıştır. Çıkış empedansı sıfır → ideal değeri

Feedback Network



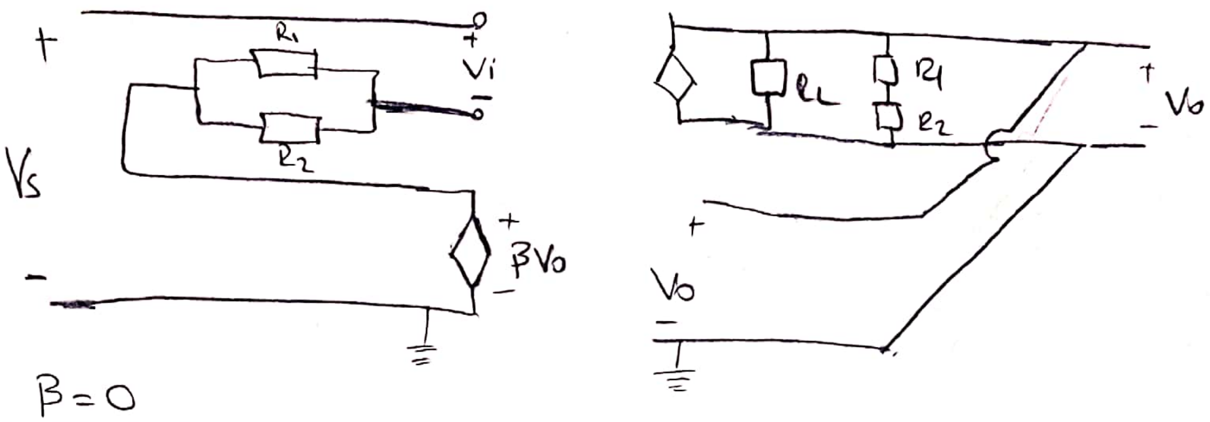
$$\beta = \frac{R_1}{R_1 + R_2}$$

$R_x = R_1 \parallel R_2$

$R_y = R_1 + R_2$

CamScanner ile tarandı

Voltage Amp. with feedback network.



$\beta = 0$

$r_{in,VA,f} = +\infty$ ($r_{in} = +\infty$ demiştik
İdeal olmayan opamp olsaydı) → $r_{in} + R_1 // R_2$ → ideale yaklaştırıyor.

$r_{out,VA,f} = 0$ ($r_{out} = 0$ demiştik
İdeal olmayan opamp olsaydı) → $r_{out} // R_L // (R_1 + R_2)$ → düşürerek ideale yaklaştırıyor.

$A_{VA,f} = A$ (ideal olmasaydı → $A_{VA,f} = \dfrac{r_{in}}{r_{in} + R_1 // R_2} \cdot A \cdot \dfrac{R_L // (R_1 + R_2)}{(R_L // (R_1 + R_2)) + r_{out}}$)

Feed back Amp. Analizi

$r_{in,f} = r_{in,VA,fl} (1 + \beta . A_{VA,fl}) = +\infty$

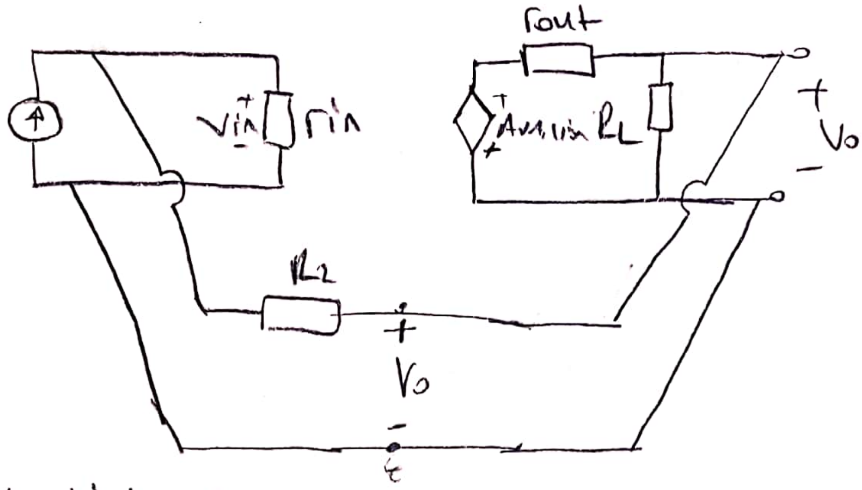
$r_{out,f} = \dfrac{r_{out,VA,fl}}{1 + \beta A_{VA,fl}} = 0$

Improving factor ile giriş empedansı yükseltiliyor çıkış empedansı düşürülüyor. Böylece Voltage amp. idealize ediliyor.

$$\boxed{A_f = \frac{A_{VA,fl}}{1 + \beta . A_{VA,fl}} = \frac{A}{1 + \frac{R_1}{R_1 + R_2} A} \simeq \frac{R_1 + R_2}{R_1}}$$

→ $A >> 1$

(b) Trans Resistance Amp. (voltage-shunt feedback.)

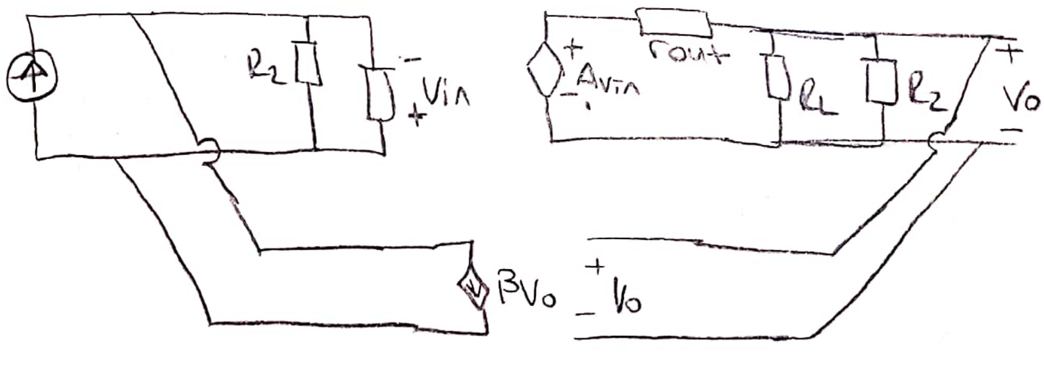


feedback Network

$$\beta = \frac{i_f}{V_o}\Big|_{V_f=0} \equiv \frac{-i_y}{V_o} = \frac{-1}{R_2} \quad \Big\{ \quad R_y = \frac{V_o}{i_y}\Big|_{V_f=0} = R_2$$

$$R_x = \frac{V_f}{i_f}\Big|_{V_o=0} = R_2$$

Transresistance Amp. with feedback network



$\beta = 0$

$r_{in,TCA,fl} = R_2 \| r_{in}$ $\quad$ $r_{in,TCA,f} < r_{in}$

$r_{out,TCA,fl} = R_2 \| R_L \| r_{out}$ $\quad$ $r_{out,TCA,f} < r_{out}$ → feedback network burada giriş ve çıkış empedanslarını

$$A_{TRA,f} = \left[-R_2 \| r_{in}\right] . A . \left[\frac{R_L \| R_2}{R_L \| R_2 + r_{out}}\right]$$

$r_{in\ TRA,f} = R_2 \leftarrow R_2 << r_{in}$

$r_{out,TRA,fl} \cong 0$

$A_{TRA,fl} = [-R_2] . A . [1] = \boxed{-A . R_2 = A_{TRA,f}}$

↳ $R_2 << R_{in}$ $\quad$ ↳ $r_{out} << R_L \| R_2$

$A \diagup \frac{1}{\quad}$ $\quad A \gg 1 \quad r+R_1+R_2$

Feedback Amp. Analysis

$$r_{in,f} = \frac{r_{in,TRA,f}}{1+\beta . A_{TRA,f}} = \frac{R_2 \| r_{in}}{1+\left(-\frac{1}{R_2}\right).\left(-R_2\|r_{in}.\right).A\left(\frac{R_L\|R_2}{R_L\|R_2+r_{out}}\right)}$$

$$\left.\begin{array}{l} r_{in} \to +\infty \\ r_{out} \to 0 \end{array}\right\} \frac{R_2}{1+\left(\frac{-1}{R_2}\right).(-R_2).A} = \frac{R_2}{1+A} \;// \quad A \gg 1 \to \frac{R_2}{A}$$

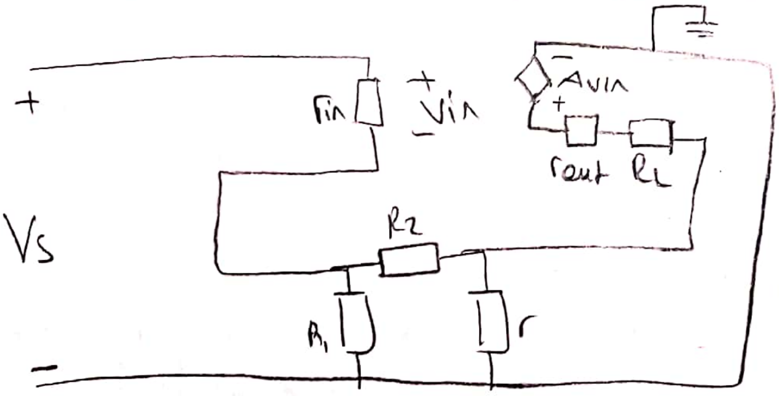
if $A \gg R_2 \to r_{in,f} = 0$

$$r_{out,f} = \frac{r_{out,TRA,fl}}{1+\beta A_{TRA,fl}} = \frac{0}{\quad} = 0 \;//$$

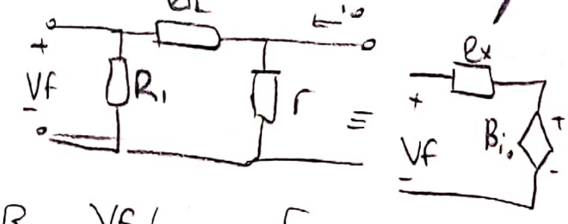
$$A_f = \frac{A_{TRA,fl}}{1+\beta A_{TRA,fl}} = \frac{\left[-R_2\|r_{in}\right].A.\left[\frac{R_L\|R_2}{R_L\|R_2+r_{out}}\right]}{1+\left(\frac{-1}{R_2}\right).\left[-R_2\|r_{in}\right]A.\left[\frac{R_L\|R_2}{R_L\|R_2+r_{out}}\right]}$$

$$A_f = \frac{-R_2.A}{1+\left(\frac{-1}{R_2}\right).(-R_2).A} = \frac{-R_2.A}{A+1} \xrightarrow{A \gg 1} -R_2 \to \begin{array}{l} r_{in} \to +\infty \\ r_{out} \to 0 \end{array} \;//$$

Transconductance amp. with current-series feedback



Feedback Network Analysis

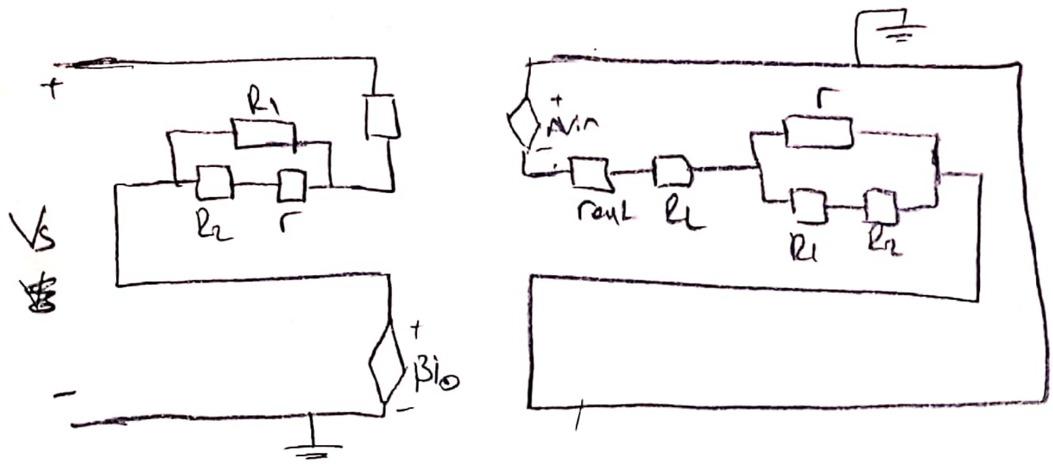


$$\beta = \frac{V_f}{i_o}\Big|_{i_f=0} = \frac{r}{r+R_1+R_2}.R_1$$

$$R_x = \frac{V_f}{i_f}\Big|_{i_o=0} = R_1 \| (R_2+r)$$

$$R_y = \frac{V_y}{i_o}\Big|_{i_f=0} = r \| (R_1+R_2)$$

CamScanner ile tarandı



$\beta = 0$

$r_{in,TCA,fl} = r_{in} + R_1 // (R_2 + r) \rightarrow r_{in,TCA,f} > r_{in}$

$r_{out,TCA,f} = r_{out} + R_L + r // (R_1 + R_2) \rightarrow r_{out,TCA,f} >> r_{out}$

Transcond. Amp. için ideal giriş çıkış portları empedansları sonsuz olduğundan current-series bağlantı tipi idealize etmiştir.

$$A_{TCA,fl} = \frac{r_{in}}{r_{in} + R_1 // (R_2 + r)} \cdot A \cdot \frac{1}{r_{out} + R_L + r // (R_1 + R_2)}$$

$r_{in} = \infty$ old. dan $\boxed{r_{in,TCA,f} = \infty}$

$r_{out,TCA,f} \cong R_L + r // (R_1 + R_2) \rightarrow r_{out} = 0$

$$A_{TCA,fl} = A \cdot \frac{1}{R_L + r // (R_1 + R_2)}$$

feedback amp. Analysis

$r_{in,f} = (1 + \beta A_{TCA,fl}) \, r_{in,TCA,fl}$

$r_{out,f} = (1 + \beta A_{TCA,f}) \, r_{out,TCA,f}$

$r_{in,f} = +\infty$,

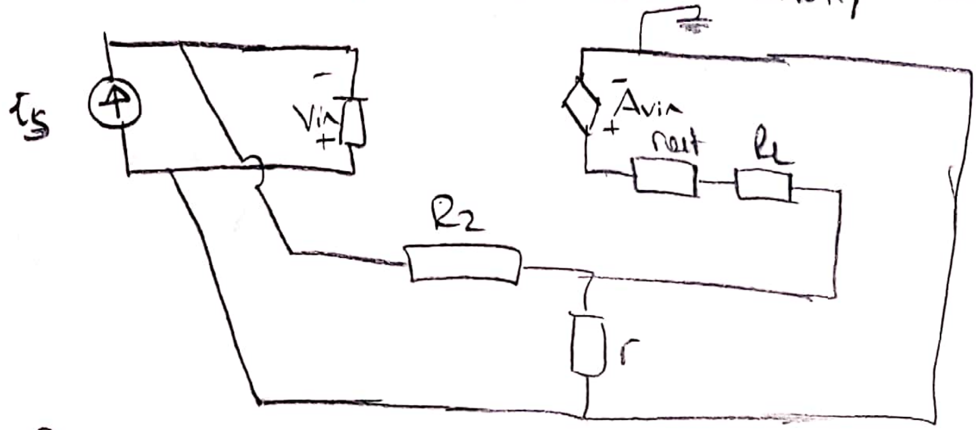
current-series bağlandı tipi giriş ve çıkış portlarını feedback faktörü oranıyla arttırır. Bu de transconductance amp.'ı idealize eder.

$$r_{out,f} = \left(1 + \frac{rR_1}{r + R_1 + R_2} \cdot A \cdot \frac{1}{R_L + r // (R_1 + R_2)}\right) \cdot \cancel{\left(R_L + r // (R_1 + R_2)\right)}$$

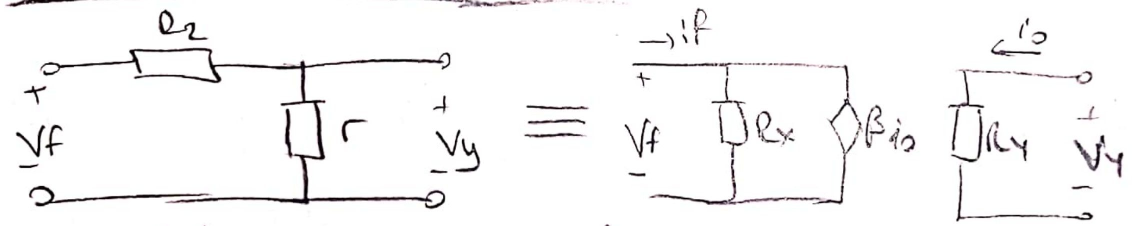
$$A >> 1 \rightarrow \boxed{r_{out,f} = \left(\frac{R_1 \cdot r \cdot A}{r + R_1 + R_2}\right)}$$

$$A_f \cong \frac{A \cdot \frac{1}{R_L + r\|(R_1+R_2)}}{1 + \frac{rR_1}{r+R_1+R_2} A \cdot \frac{1}{R_L + r\|(R_1+R_2)}} \xrightarrow{A \gg 1} = \boxed{\frac{r+R_1+R_2}{rR_1} = A_f}$$

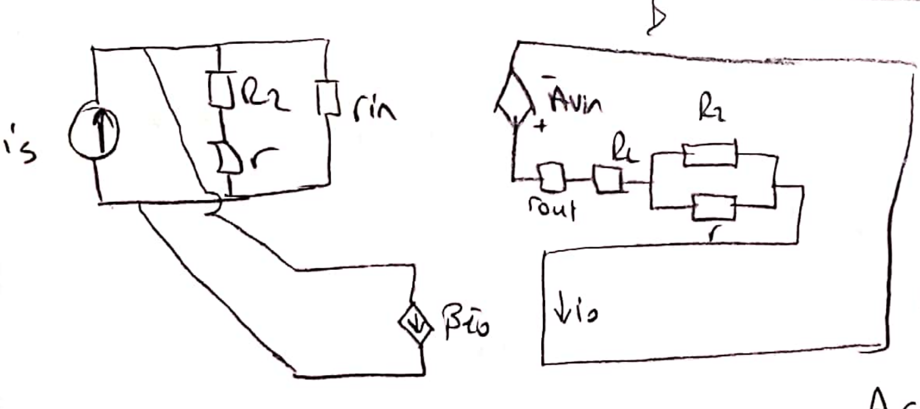
Current Amp. with current-shunt feedback



feedback network Analysis



$R_x = \frac{V_f}{i_f}\Big|_{i_o=0} = R_2 + r \qquad R_y = \frac{V_y}{i_o}\Big|_{V_f=0} = R_2\|r \qquad \beta = \frac{i_f}{i_o}\Big|_{V_f=0} = \frac{-r}{r+R_2}$



$\beta = 0$ Current Amp. with feedback

$r_{in,CA,fl} = r_{in} \| (R_2 + r)$

$r_{out,CA,fl} = r_{out} + R_L + R_2\|r$

$$A_{CA,fl} = \frac{-(R_2+r)}{R_2+r+r_{in}} A \cdot \frac{1}{r_{out}+R_L+R_2\|r}$$

$r_{in} \to +\infty \quad r_{out} \to 0$

$r_{in,CA\,fl} = (R_2 + r)$

$r_{out,CA,fl} = R_L + R_2\|r$

$$A_{CA,fl} = -A \frac{(R_2+r)}{R_L + (R_2\|r)}$$

Current Amp with feedback amp.

$$r_{in,f} = \frac{r_{in,CA,fl}}{1+\beta A_{CA,fl}} \cong \frac{R_2+r}{1+\left(\frac{-r}{r+R_2}\right)(-A)\cdot\left(\frac{R_2 \cdot r}{R_L+R_2\|r}\right)}$$

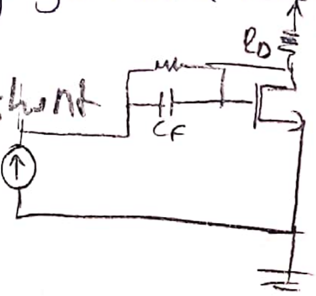
$$A \gg 1 \rightarrow \frac{R_2+r}{r.A.\frac{1}{R_L+R_2\|r}} = \frac{(R_2+r)\cdot(R_L+R_2\|r)}{r.A} = \frac{\cancel{(R_2+r)}\cdot(R_2+r)\cdot R_L}{\frac{R_2+r}{rA}}$$

$$r_{out,f} = (1+\beta A_{CA,fl})\, r_{out,CA,fl} = \frac{R_L(R_2+r)}{rA}$$

$$= \left[1+\left(\frac{-r}{r+R_2}\right)\cdot(-A)\cdot\left(\frac{R_2 \cdot r}{R_L+R_2\|r}\right)\right]\cdot(R_L+R_2\|r)$$

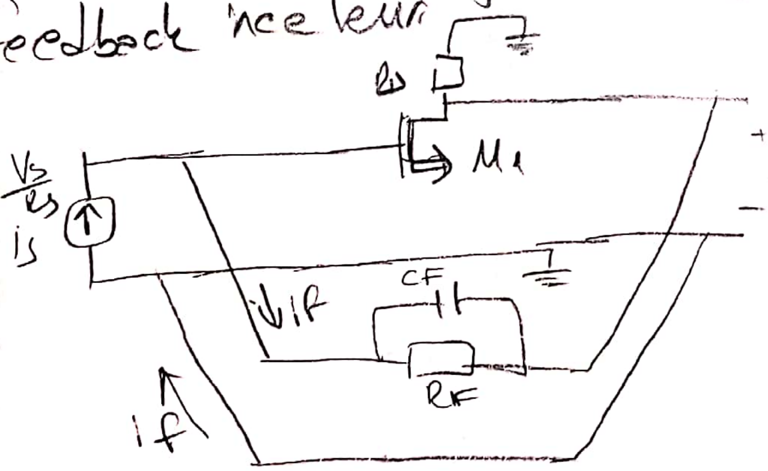
$$\left.\begin{matrix} r_{in} \rightarrow +\infty \\ r_{out} \rightarrow 0 \end{matrix}\right\} A \gg 1 \rightarrow A \cdot r, = \boxed{r_{out,f} = r.A}$$

Q3. The MOS amplifier shown in fig. P10.42 is biased to have the following small-signal MOS parameters: $g_{m1} = 1.2mA/V$ and $r_{o1} = 25k\Omega$. If $R_F = 100k\Omega$ then $R_D = 2k\Omega$ and $C_F = 10nF$. Determine (a) the voltage gain without feedback $A = v_o/i_s$. (b) the voltage gain with feedback A_f and (c) the high cutoff frequency f_H

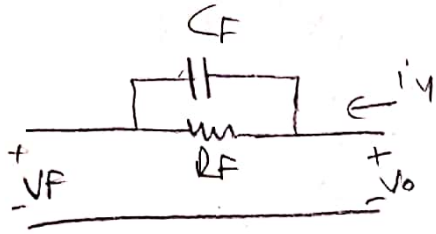


Transresistance amp. olduğundan voltage-shunt feedback'e eleur

→ transresistance amp.



CamScanner ile tarandı



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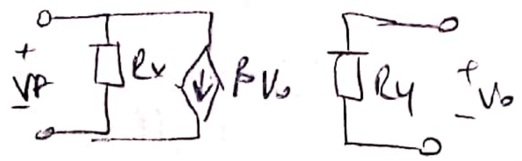
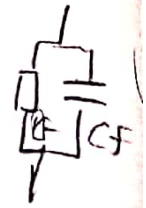
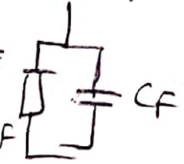


$Z_x = \frac{V_F}{i_F}\Big|_{i_y=0} =$ 

$Z_y = \frac{V_o}{i_y}\Big|_{V_F=0} =$ 

$$\beta(s) = \frac{-1}{\dfrac{R_F\cdot\frac{1}{sC_F}}{R_F+\frac{1}{sC_F}}} = -\frac{R_F+\frac{1}{sC_F}}{R_F\cdot\frac{1}{sC_F}} = -\frac{1+sC_FR_F}{R_F}$$

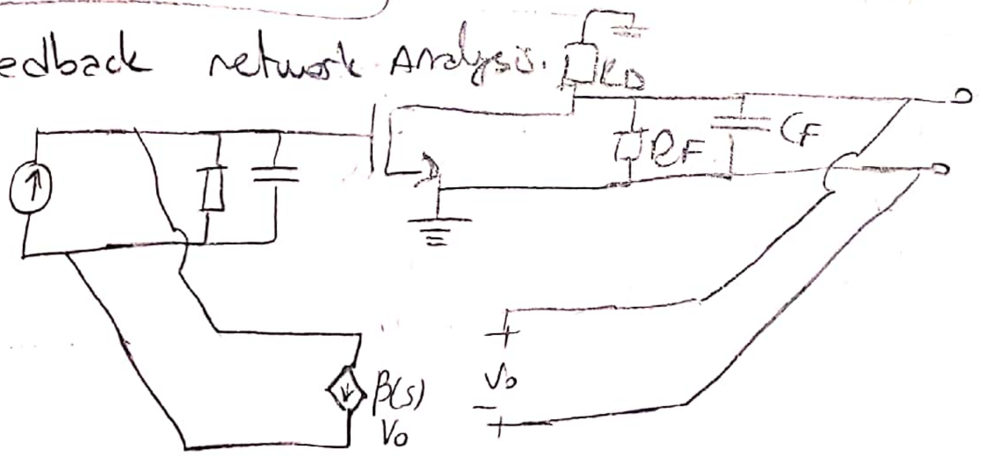
$$\beta(s) = \frac{i_F}{V_o}\Big|_{V_F=0} = \frac{-i_y}{V_o}\Big|_{V_F=0}$$

$$\beta(s) = \boxed{\frac{-1}{R_F \,||\, \frac{1}{sC_F}}}$$

$$\beta(s) = \frac{-1}{R_F}\left[1+\frac{s}{1/C_FR_F}\right] \qquad \frac{-1}{R_F}=\beta \qquad C_F\cdot R_F = \frac{1}{\omega_z}$$

$$\boxed{\beta(s) = \beta.\left[1+sW_z\right]}$$

feedback network Analysis.



$\beta=0$

$$A_{TRA,f} = \frac{V_o}{i_s} = R_F(-g_{m1})\left[R_D \,||\, R_F \,||\, r_{o1}\right] = -2.4\times10^6$$

$$r_{in,TRA,f} = R_F = 100k\Omega, \quad r_{out,TRA,f} = R_D \,||\, R_F \,||\, r_{o1} = 2k\Omega$$

$$\tau_1 = R_F.C_F \qquad \tau_2 = C_F(R_D \,||\, R_F \,||\, r_{o1})$$

$$\boxed{\tau_1 = 100k\Omega.10nF = 10^{-3}s} \qquad \tau_2 = 10.10^{-9}.(2k\Omega \,||\, 100k\Omega \,||\, 25k\Omega)$$

$$\boxed{\tau_2 = 2\times10^{-5}s}$$

$$W_{H,TRA} = \frac{1}{\tau_1+\tau_2} = \frac{1}{100\times10^{-5}+2\times10^{-5}} \approx \frac{1}{2\times10^{-5}} = \frac{100000}{2} = 5\times10^4 \text{ rad/s}$$

$$\boxed{W_{H,TRA} = 5\times10^4 \text{ rad/s}}$$

$$A_{TRA,fl}(jw) = \frac{A_{TRA,fl}}{1+\frac{jw}{w_{H,TRA,fl}}} = \frac{-2.4\times10^6}{1+\frac{jw}{5\times10^4}}$$

$$r_{in,f} = \frac{r_{in,TRA,f}}{1+\beta . A_{TRA,fl}} = \frac{100k\Omega}{1+(-10^{-5}).(-2.4\times10^6)}$$

$r_{in,TRA,f} = 100k\Omega$

$r_{out,TRA,f} = 2k\Omega$

$A_{TRA,f} = -2.4\times10^6$

$$\boxed{\beta = \frac{-1}{R_F} = \frac{-1}{100k\Omega} = -10^{-5}}$$

$$r_{in,f} = \frac{10^5}{25} = \frac{100.000}{25} = 4000 = 4k\Omega$$

$$r_{out,f} = \frac{R_D \| R_F \| r_{oA}}{1+g_m[\underbrace{R_D\|R_F\|r_{oA}}_{2k\Omega}]} = \frac{2000}{1+1.2\cancel{k}.2\cancel{k}} = \frac{2000}{2.5} = 800\Omega$$

$$A_f(jw) = \frac{A_{TRA,fl}(jw)}{1+\beta(jw).A_{TRA,fl}(jw)} = \frac{\frac{-2.4\times10^6}{1+\frac{jw}{5\times10^4}}}{1+\beta.\left[1+\frac{jw}{w_Z}\right]\frac{-2.4\times10^6}{1+\frac{jw}{5\times10^4}}}$$

$$= \frac{A_{TRA,fl}}{1+\frac{jw}{w_{H,TRA,f}}+A_{TRA,fl}.\beta+\frac{\frac{jw}{w_Z}}{A_{TRA,f}.\beta}}$$

$$= \frac{A_{TRA,f}}{1+A_{TRA,f}.\beta} . \frac{1}{1+\frac{jw}{(1+A_{TRA,f}.\beta).\left[w_{H,TRA,f} \| \frac{w_Z}{A_{TRA,f}.\beta}\right]}}$$

$$w_{H,f} = (1+A_{TRA,fl}.\beta)\left[w_{H,TRA,f} \| \frac{w_Z}{A_{TRA,f}.\beta}\right]$$

Compute the voltage gain

$$\frac{V_o}{V_s} = \frac{v_o}{R_s \frac{V_s}{R_s}} = \frac{1}{R_s}\cdot\frac{v_o}{i_s} = \frac{1}{R_s}\cdot A_f = \frac{1}{R_s}\cdot\frac{A_{TRA,fl}}{1+\beta\cdot A_{TRA,fl}}$$

$$\text{Midband} = \frac{1}{R_s}\cdot\frac{-2.4\times10^{6}}{1+24} = \frac{-9.6\times10^{4}}{R_s} \;//$$

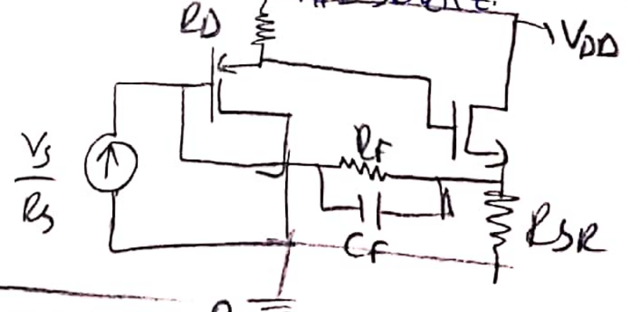
$\beta = -10^{-5}$

$A_{TRA,fl} = -2.4\times10^{6}$

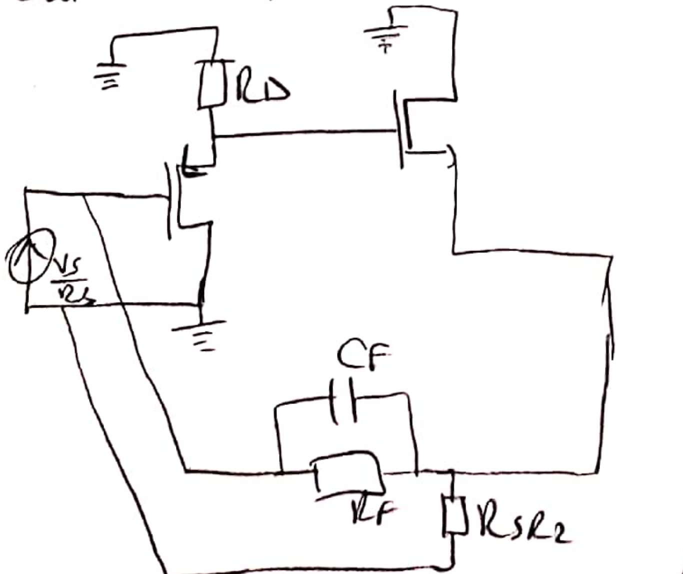
$$W_z = \frac{1}{C_F R_F} = \frac{1}{1nF\cdot100k} \doteq 1000\,rad/s$$

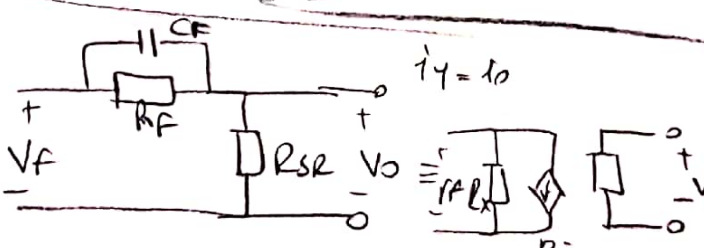
$$\frac{W_z}{A_{TRA,fl}\cdot\beta} = \frac{1000}{-2.4\times10^{6}\cdot-10^{-5}} = \frac{1000}{24} = 41.7\,rad/s$$

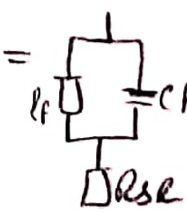
Q4. The MOS amplifier shown in fig. P10.50 is biased to have the following small signal MOS parameters: $g_{m1} = 1.2mA/V$, $r_{o1} = 25k\Omega$, $g_{m2} = 1.6mA/V$ and $r_{o2} = 25k\Omega$. If $R_D = 1.5k\Omega$ then $R_{SE1} = 500k\Omega$, $R_{SR2} = 2k\Omega$ $R_F = 8k\Omega$ ⓐ voltage gain without feedback $A = v_o/v_s$ ⓑ the voltage gain with feedback A_f; ⓒ the feedback capacitor C_F to limit the high frequency $f_H = 50kHz$.

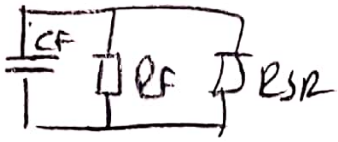


Current Amp. with Current Shunt





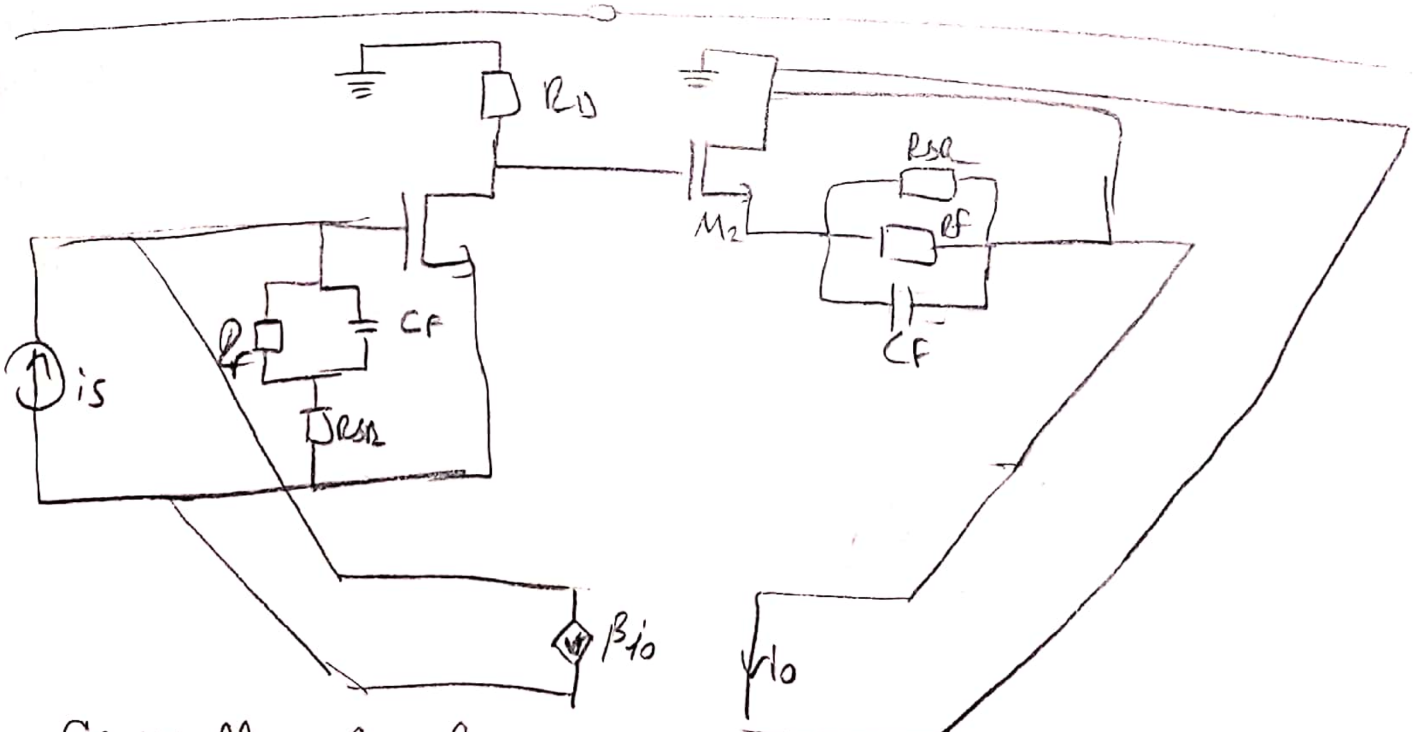
$Z_x = \frac{V_F}{i_F}\Big|_{i_Y=0} =$ 

$$Z_y = \frac{V_o}{i_y}\Big|_{v_f=0} =$$ 

$$\beta_{(s)} = \frac{i_f}{i_y}\Big|_{v_f=0} = -\frac{R_{SR}}{R_{SR} + R_F \parallel \frac{1}{sC_F}}$$

$$\beta_{(s)} = \frac{-R_{SR}}{R_{SR} + \frac{R_F \cdot \frac{1}{sC_F}}{R_F + \frac{1}{sC_F}}} = -\frac{R_{SR}}{R_{SR} + \frac{R_F}{1+sC_FR_F}} = -\frac{R_{SR}(1+sC_FR_F)}{R_{SR}+R_F+sC_FR_FR_{SR}}$$

$$= \underbrace{-\frac{R_{SR}}{R_{SR}+R_F}}_{\beta} \cdot \frac{1+\frac{s}{1/C_FR_F} \longrightarrow w_z}{1+\frac{s}{1/C_F(R_F \parallel R_{SR})} \longrightarrow w_p} \longrightarrow \beta \cdot \frac{1+\frac{s}{w_z} \rightarrow \text{zero}}{1+\frac{s}{w_p} \rightarrow \text{pole}}$$

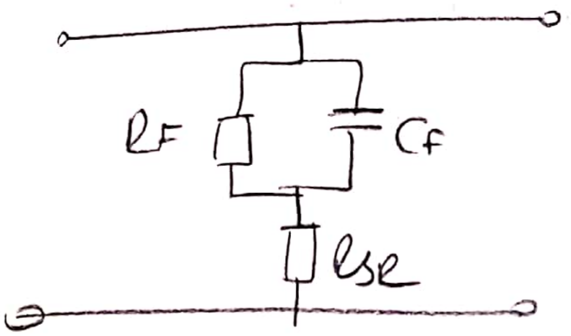


$$r_{in,CA,fl} = R_F + R_{SR}$$

$$r_{out,CA,fl} = r_{o2}\left(1 + g_{m2}(R_{SR} \parallel R_F)\right)$$

$$A_{CA,fl} \cong (-g_{m1})(R_D)\left[\frac{g_{m2}}{1+g_{m2}(R_{SR} \parallel R_F)}\right] \cdot (R_F + R_{SR})$$

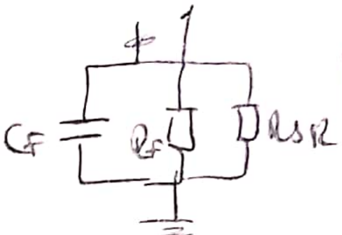
$W_{H,CA,f}$, OCTC



$\tau_1 = R_1 C_1 \quad C_1 = C_F \quad R_1 = R_F$

$\tau_1 = R_F C_F =$

$\tau_1 = 8k\Omega . C_F$



$\boxed{\tau_2 = C_2 R_2 = 625 . C_F}$

$C_2 = C_F$

$R_2 = R_F \| R_{sR} \| \frac{1}{g_{m2}}$

$8k\Omega \qquad \ll 1k\Omega$

$\boxed{R_2 \cong \frac{1}{g_{m2}} = 625\Omega}$

$\boxed{W_{H,CA,f} \cong \frac{1}{625 . C_F}}$

$$A_{CA,fl}(jw) = \frac{A_{CA,fl}}{1 + \frac{jw}{w_{H,CA,fl}}}$$

$$r_{in,f} = \frac{r_{in,CA,fl}}{1 + \beta A_{CA,fl}} \longrightarrow \text{giriş portunda yükseltici}$$

$$r_{out,f} = r_{out,CA,fl}(1 + \beta A_{CA,fl}) \longrightarrow \text{çıkış portunda azaltıcı}$$

$$A(jw) = \frac{A_{CA,fl}(jw)}{1 + \beta(jw) A_{CA,fl}(jw)} = \frac{\dfrac{A_{CA,fl}}{1 + \frac{jw}{w_{H,CA,fl}}}}{1 + \dfrac{A_{CA,fl}}{1 + \frac{jw}{w_{H,CA,fl}}} . \beta . \dfrac{1 + \frac{jw}{w_z}}{1 + \frac{jw}{w_p}}}$$

$$\cong \frac{A_{CA,fl}\left(1 + \frac{jw}{w_p}\right)}{1 + \frac{jw}{w_{H,CA,fl}} + \frac{jw}{w_p} + A_{CA,fl}\beta + \frac{jw}{\frac{w_z}{A_{CA,fl}\beta}}}$$

$$= \frac{A_{CA,fl}}{1 + \beta . A_{CA,fl}} . \frac{1 + \frac{jw}{w_p}}{1 + \frac{jw}{(1 + A_{CA,fl}\beta)\left[w_{H,CA,fl} \| w_p \| \frac{w_z}{A_{CA,fl}\beta}\right]}} //$$