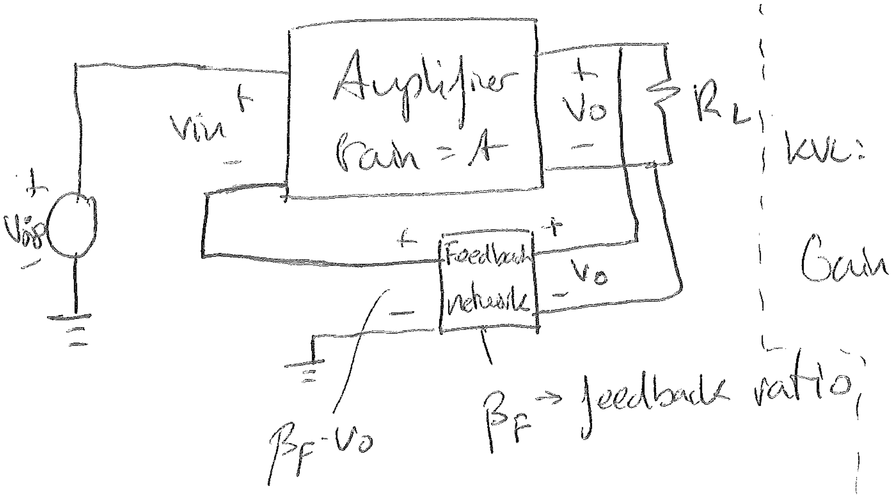
Stability of aplifiers

11/11/2016
Madhu

- → Feedback to avoid oscillations.
- → opamps are ~~ate~~ are type of feedback aplifiers.



$\frac{V_o}{V_{in}} = A$

KVL: $V_{in} + \beta_F V_o = V_{sig}$

Gain w/ feedback $A_F = \frac{V_o}{V_{sig}}$

$$\frac{V_o}{A} + \beta_F V_o = V_{sig}$$

$$V_o\left(\frac{1}{A} + \beta_F\right) = V_{sig}$$

$$\frac{V_o}{V_{sig}} = \boxed{A_F = \frac{A}{1 + A\beta_F}}$$

→ If $A\beta_F >> 1$

$A_F \approx \frac{1}{\beta_F}$

→ Gain depends only in β_F, gain is independent of aplifiers and depends only on feedback network.

→ Avoids variation between aplifiers and between mosfets and changes in Vcm, Voffset, ...

→ Also avoid oscillations.

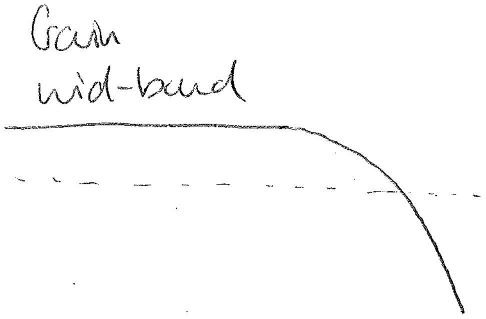
→ Oscillator has a finite output voltage and no input voltage with an infinite gain (DC supplies on with an ac. output)

oscillations due to small variations) noise.

→ Oscillation occurs if $A_F \to \infty$
or $(1+A\beta_F)=0$

→ Condition for oscillation $A\beta_F=-1$ or
$A\beta_F = 1\underline{\angle \pm 180°}$

↳ proposed by Barkhausen
∴ Barkhausen criterion.



Gain when phase angle is ±180°
→ if this gain is still large
→ possible stability problem.

→ Condition for stability.

→ Therefore gain should be lower than 0 dB at a frequency when the phase angle = -180°

→ Now we need to look at phase of Bode plots. Bode phase plots

② 11/11/2016
Madhu

Bode phase plots:

① Single pole function:

$A(s)$ $\frac{1}{s+\alpha} \longrightarrow \frac{1}{\alpha+j\omega}$ ↗ numerator ↗ denominator

$$\text{Phase } \theta = 0^\circ - \tan^{-1}\left(\frac{\omega}{\alpha}\right)$$

$$\theta = -\tan^{-1}\left(\frac{\omega}{\alpha}\right)$$

→ what this looks like using asymptotic approach:

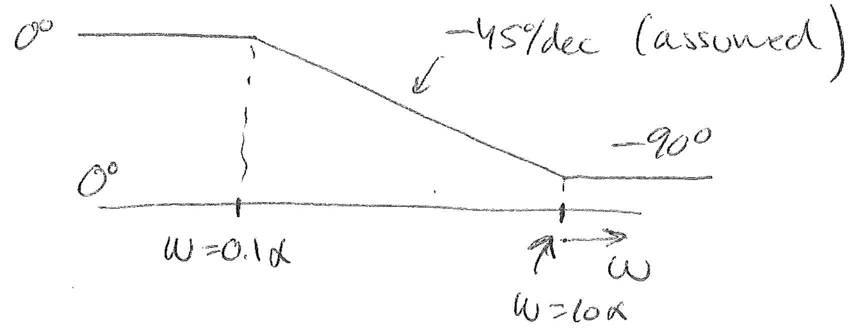
Asymptotic plot:

$\omega << \alpha$: $\tan^{-1}$(small angle in radians) = angle in radians.

$$\tan^{-1}\left(\frac{\omega}{\alpha}\right) = \frac{\omega}{\alpha}$$

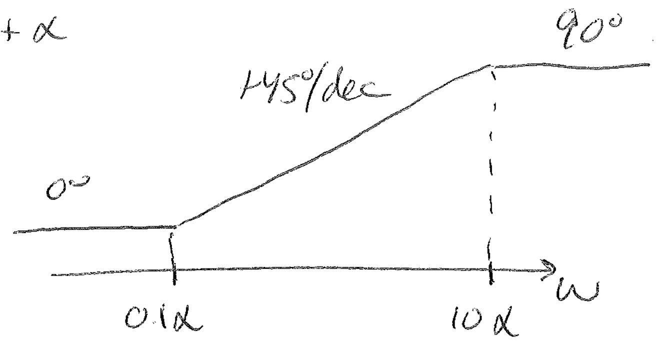
$\omega >> \alpha$: $\tan^{-1}\left(\frac{\omega}{\alpha}\right) \approx \tan^{-1}(\infty) = 90^\circ$

$\left(\frac{1}{(s+\alpha)}\right) \rightarrow$



② Single zero function:

$A(s) = s + \alpha$



Phase plots (how to draw them)

1 → List of poles and zeros in ascending order.

2 → List when $\omega = 0.1x$ and $\omega = 10x$ for each pole and zero.

3 → Combine information.

→ ex $\dfrac{s+100}{s+2000}$ zero $s=-100$ pole $s=-2000$

Zero at $\omega=100$	Pole at $\omega=2000$
$\omega=(0,10)$: 0° level	$\omega(0,200)$: 0° level
$\omega=(10,1000)$: +45°/dec	$\omega(200 \to 20000)$: -45°/dec
$\omega=(1000,\infty)$: 90° level	$\omega(20000 \to \infty)$: -90° level

→ overall plot:

$(0 \to 10)$: 0° level

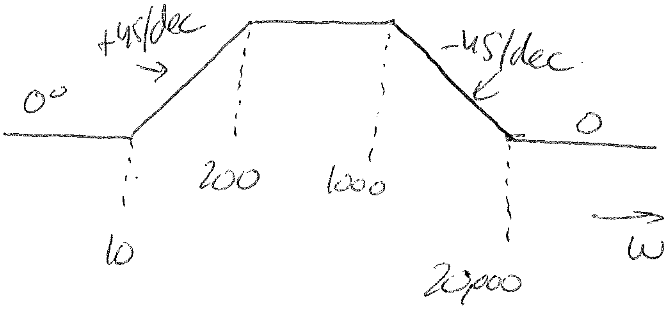
$(10 \to 200)$: +45°/dec

$(200 \to 1000)$: level

$(1000 \to 20{,}000)$: -45°/dec

$(20{,}000 \to \infty)$: 0° level

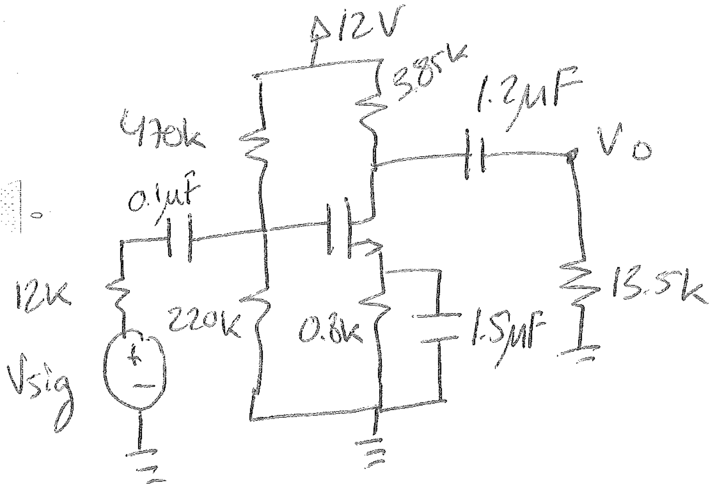
$\Delta\phi = ?$



11/14/2016

Madhu

1.



$K = 1.5mA/V^2$

$V_T = 0.75V$

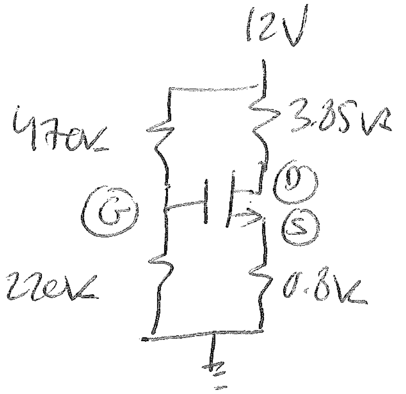
$C_{gs} = 5pF$

$C_{gd} = 3pF$

$C_{ds} = 25pF$

- DC
- small-signal mid-band gain
- ω_{Lo}
- ω_{Hi}

DC Analysis



→ $V_G = 12V \cdot \frac{220k}{220k+470k} = 3.826V$

→ $V_G - \overset{k\Omega}{0.8} I_D = V_{GS}$

→ $V_{GS} = 3.826V - \overset{k\Omega}{0.8} \cdot \frac{1}{2} 1.5mA/V^2 (\overset{V_{GS}}{\cancel{3.826}} - 0.75)^2$

$3.826 - 0.6V_{GS}^2 + 0.9V_{GS} - 0.3375 = V_{GS}$

$V_{GS} = 2.329V$

→ and $I_D = 1.87mA$

→ Also $V_D = 12 - (1.87mA)(3.85k\Omega) = 4.801V$

$V_{DS} > V_{GS} - V_T$

$V_{GD} = -0.975 < V_T$

∴ sat. ac.

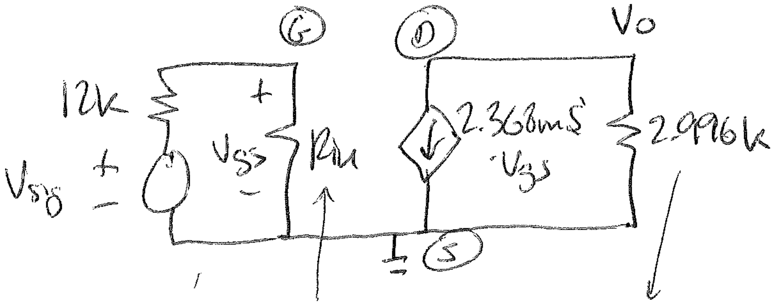
~~ac small signal~~

→ $g_m = 1.5mA/V^2(2.329 - 0.75) = 2.368\ mS$

Mid-band gain

Small capacitances are opens. Large caps are shorts.

Small-signal eq. circuit:



$R_{in} = (470 || 220) = 149.8k$ $\quad R_{eq} = R_D || R_L = 13.5k || 3.85k = 2.996k$

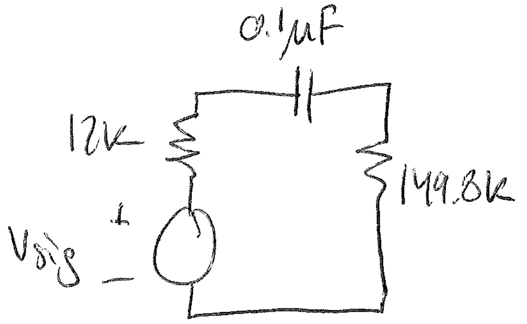
$$\rightarrow \frac{V_o}{V_{gs}} = -g_m \cdot R_{eq} = (-2.368mS)(2.996k) = -7.094 \text{ V/V}$$

$$\rightarrow \frac{V_{gs}}{V_{sig}} = \frac{R_{in}}{R_{in}+12k} = \frac{149.8k}{149.8+12k} = \frac{149.8}{161.8} = 0.9258.$$

$$\rightarrow \boxed{A_{mid} = \frac{V_{gs}}{V_{sig}} \cdot \frac{V_o}{V_{gs}} = (0.9258)(-7.094) \text{ V/V} = -6.568 \text{ V/V}}$$

Lower-freq. response.

① C_1 acting alone.



$$\omega_{C_1} = \frac{1}{\tau} = \frac{1}{(\underset{\times 10^{-6}F}{0.1\mu F})(\underset{\times 10^3}{12k + 149.8k})} = 61.8 \text{ r/s}$$

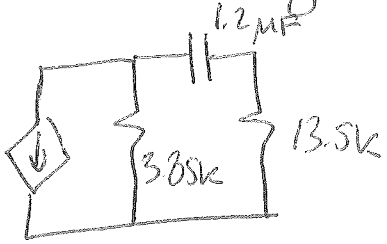
$\tau = R_{TH} \cdot C$

↳ cont's

7 Cont'd

② 11/14/2016
Madhu

② C_2 acting alone:

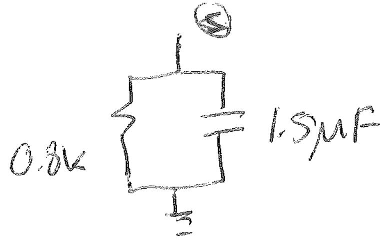


$$\omega_{C2} = \frac{1}{\tau} = \frac{1}{(1.2\times10^{-6}F)(3.85k+13.5k)}$$

$$\omega_{C_2} = 48.03 \ r/s$$

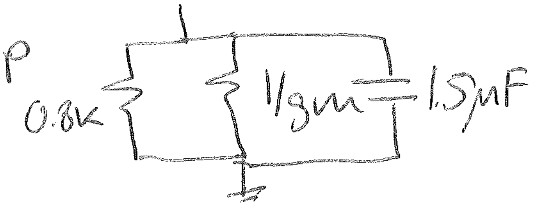
③ Bypass C_S acting alone:

ω_z



$$\omega_z = \frac{1}{(1.5\times10^{-6}F)(0.8\times10^{3}\Omega)} = 833.3 \ r/s$$

ω_p



$$\omega_p = \frac{1}{(1.5\times10^{-6}F)(276.4\Omega)} = 2412 \ r/s$$

gm = 2.368 mS

$\rightarrow \frac{1}{gm} = 0.4223k$

$\rightarrow (0.8k \| 0.4223k) = 0.2764 k\Omega$

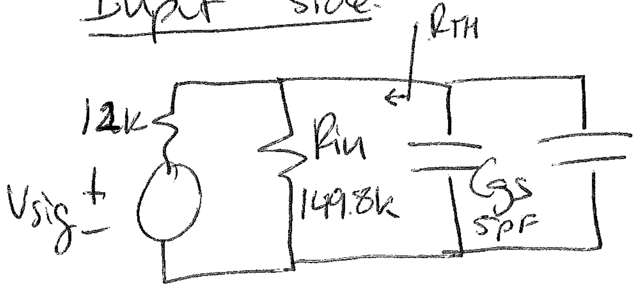
→ Take 2412 r/s as dominant frequency ω_{Low}

↑ completes low frequency analysis.

4/14/2016

High frequency analysis

Input side



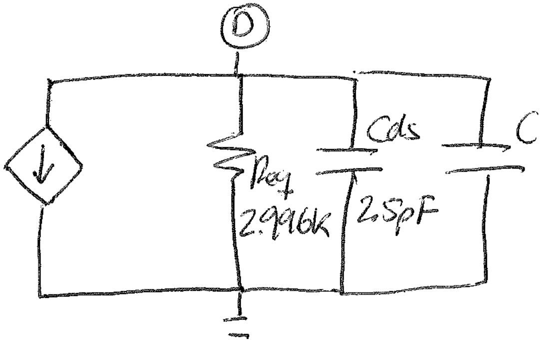
$C_M = C_{gd}(1 + g_m R_{eq})$
$= 24.28pF$

$\{ C_{gd} = 3pF$
$g_m = 2.368mS$
$R_{eq} = 2.996k \}$

$$\omega_{hi(in)} = \frac{1}{RC} = \frac{1}{(11.11k\Omega)(29.28 \times 10^{-12}F)} = 3.074 \times 10^6 \; r/s$$

$R_{TH} = [(149.8k)//(12k)] = 11.11k\Omega$
$C = 29.28pF$

Output side:



$C'_M = C_{gd}\left(1 + \frac{1}{g_m R_{eq}}\right) = 3.423pF$

$$\omega_{hi(out)} = \frac{1}{RC} = \frac{1}{(2.996k\Omega)(5.923 \times 10^{-12}F)} = 5.635 \times 10^7 \; r/s$$

$R = 2.996k$
$C = 5.923pF$

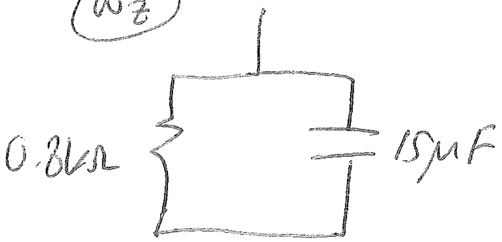
$\therefore \boxed{\omega_{hi} = 3.074 \times 10^6 \; r/s}$

↑ completes analysis.

③ 11/14/2016
Madhu

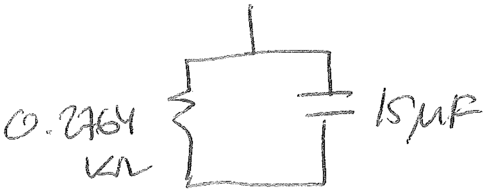
↳ Now changing bypass capacitor to 15 μF.

(ω_z)



$$\omega_z = \frac{1}{(15\times10^{-6}F)(0.8k\Omega)} = 83.33 \text{ r/s}$$

(ω_p)



$$\omega_p = \frac{1}{(0.2764k\Omega)(15\times10^{-6}F)} = 241.2 \text{ r/s}$$

↑ Take this as a non-dominant situation.

→ Then find ω = ? when gain is 0.707·Avid by making Avid = 1 (normalized)

$$\therefore \text{Gain} = \frac{s^2(s+\omega_z)}{(s+\omega_{c1})(s+\omega_{c2})(s+\omega_p)}$$

$s = j\omega$

$$\left|\frac{-\omega^2(83.33+j\omega)}{(61.8+j\omega)(48.0+j\omega)(241.2+j\omega)}\right| = 0.707$$

$$\therefore \boxed{\omega_{low} = 238.6 \text{ r/s}}$$

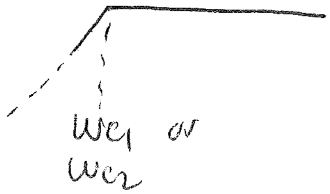
⇒ New lecture:

No dominant pole situations

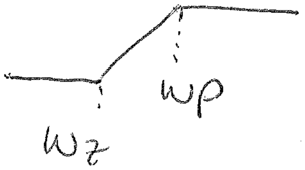
→ lower freq. cutoff.

$$\left.\begin{cases} C_1 \text{ acting alone: DC gain} = 0, \text{ pole at } \omega_{c1} \\ C_2 \text{ acting alone: DC gain} = 0, \text{ pole at } \omega_{c2} \end{cases}\right\}$$

$$\frac{s}{s+\omega_{c1}} \qquad \frac{s}{s+\omega_{c2}}$$



$$\left.\begin{cases} C_s \text{ (bypass cap.) DC gain} \neq 0 \\ \text{zero at } \omega_z \\ \text{pole at } \omega_p \end{cases}\right\} \qquad \frac{s+\omega_z}{s+\omega_p}$$



$$\therefore \left\{\begin{matrix}\text{low freq} \\ \text{gain}\end{matrix}\right\} = \frac{s^2(s+\omega_z)}{(s+\omega_{c1})(s+\omega_{c2})(s+\omega_p)} = 1 \text{ (normalized)}$$

$s \to j\omega$

$$\left| \frac{-\omega^2(j\omega+\omega_z)}{(j\omega+\omega_{c1})(j\omega+\omega_{c2})(j\omega+\omega_p)} \right| = 0.707 \Leftarrow \begin{cases} 3\text{dB drop} \\ \frac{1}{2} \text{ power} \\ \sqrt{0.5} \end{cases}$$

11/16/2016
Madhu

No dominant pole in

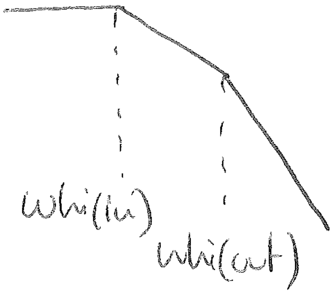
→ High frequency cutoff.

$$\left.\begin{array}{l}\omega_{hi(in)}\\ \omega_{hi(out)}\end{array}\right\}$$

$$\frac{K_1}{s+\omega_{hi(in)}}$$

$$\frac{K_2}{s+\omega_{hi(out)}}$$

overall gain $= \dfrac{K_1K_2}{(s+\omega_{hi(in)})(s+\omega_{hi(out)})} \Rightarrow$



Make mid-band gain 0dB or 1.

$\therefore$ by making $K_1K_2 = \omega_{hi(in)}\,\omega_{hi(out)}$

↳ $\dfrac{\omega_{hi(in)}\,\omega_{hi(out)}}{(s+\omega_{hi(in)})(s+\omega_{hi(out)})}$ = normalized gain.

With no dominant pole: find magnitude = 0.707

$$\left|\frac{\omega_{hi(in)}+\omega_{hi(out)}}{(j\omega+\omega_{hi(in)})(j\omega+\omega_{hi(out)})}\right| = 0.707 = \sqrt{1/2}$$

Amplifier example (from before).

Change C_{gs} to 2.5pF
Change C_{gd} to 2pF
Change C_{ds} to 10pF

Input side

$C_M = 16.19pF$

$C_{in} = 18.68pF$

$$\omega_{hi(in)} = \frac{1}{(18.68\times10^{-12}F)(11.11\times10^{3})} = 4.816\times10^{6} \text{ r/s}$$

Output side

$C'_M = 2.282\,pF$

$C_{out} = 12.282pF$

$$\omega_{hi(out)} = \frac{1}{(12.282\times10^{-12}F)(2996)} = 2.718\times10^{7} \text{ r/s}$$

↑ Take this as a non-dominant pole situation.
(only ~4x between them).

High freq. gain $\left\} \left| \frac{(2.718\times10^{7})(4.816\times10^{6})}{(j\omega+2.718\times10^{7})(j\omega+4.816\times10^{6})} \right| = 0.707 = \sqrt{1/2}\right.$

and $\boxed{\omega_{hi} = 4.677\times10^{6} \text{ r/s}}$

② 11/16/2016
Madhu

Back to stability of amplifiers.

If gain magnitude ≥ 0 dB ~~then~~ when the gain has a phase angle of −180°, then amplifier is potentially unstable.

→ Need Phase plots to analyze this situation:

→ For any Pole frequency ω_x

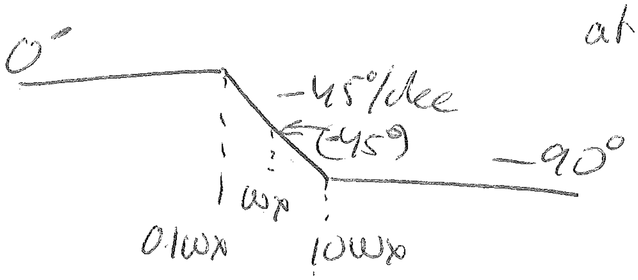
~~$\omega = 0.1\omega_x \rightarrow \omega = 10\,\omega_x$: $\theta = 0^\circ$~~

$\omega = 0 \rightarrow \omega = 0.1\,\omega_x$: $\theta = 0^\circ$ (level)

$\omega = 0.1\omega_x \rightarrow \omega = 10\omega_x$: slope of $-45^\circ/\text{dec}$

$\omega > 10\cdot\omega_x$: $\theta = -90^\circ$ (level)

at $\omega_x = -45^\circ$



Finding θ at ω_y (any ω_y that falls between $0.1\omega_x$ and $10\omega_x$.

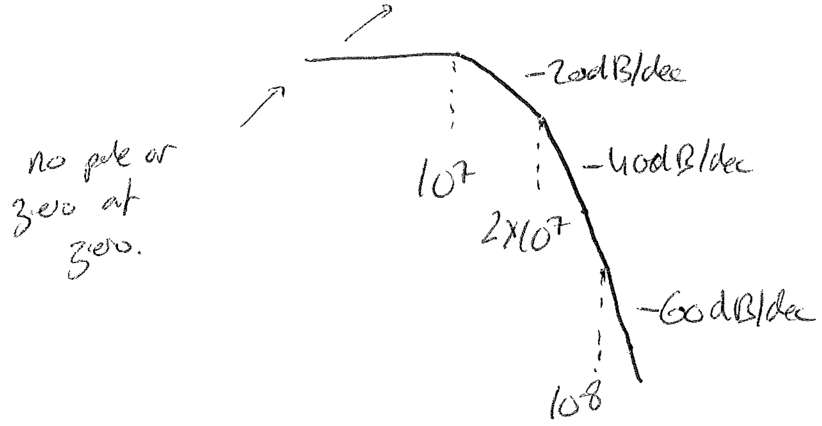
$$\theta_{\omega_y} = -45 \log\left(\frac{\omega_y}{0.1\omega_x}\right)$$

Example:: $A(s) = 10^{26} \frac{1}{(s+10^7)(s+2\times10^7)(s+10^8)}$

Mag. plot

20 log(5000) = 73.95dB

DC gain $A(s\to 0) = \frac{10^6}{10^7+2\times10^7+10^8} = 5000$



Phase plot

Pole at 10^7: $(0, 10^6)$ level at 0°
$(10^6 \to 10^8)$ −45°/dec slope
$(10^8 \to \infty)$ level at −90°

Pole at 2×10^7: $(0, 2\times10^6)$ level at 0°
$(2\times10^6 \to 2\times10^8)$ −45°/dec slope
$(2\times10^8 \to \infty)$ level at −90°

Pole at 10^8: $(0 \to 10^7)$ level at 0°
$(10^7 \to 10^9)$ −45°/dec slope
$(10^9 \to \infty)$ level at −90°

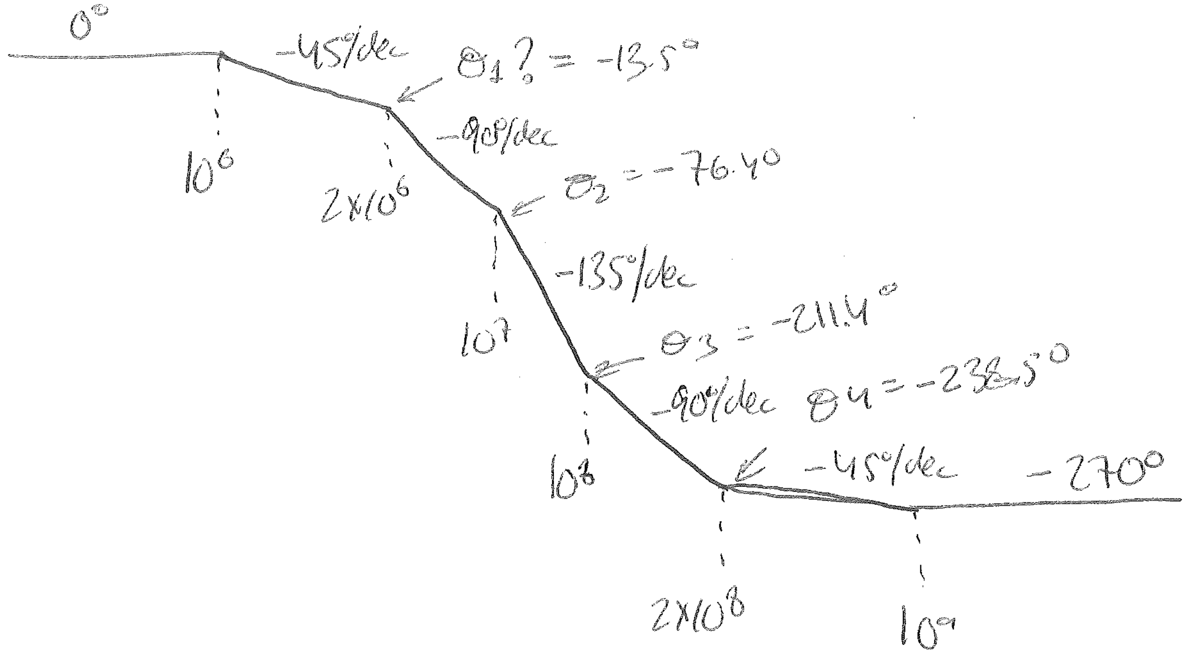
Overall plot: $(0 \to 10^6)$ level at 0°
$(10^6 \to 2\times10^6)$ −45°/dec
$(2\times10^6 \to 10^7)$ −90°/dec
$(10^7 \to 10^8)$ −135°/dec
$(10^8 \to 2\times10^8)$ −90°/dec
$(2\times10^8 \to 10^9)$ −45°/dec
$(10^9 \to \infty)$ level at −270°

↓ cont'd

↳ cont'd

③ 11/16/2016
Madhu

Drawing <u>phase plot</u>



→ What is ω when θ = 180° ?

$$\theta_1 = \overset{0}{-45}\log\left(\frac{2\times10^{6}}{0.\cancel{1}\cdot10^{6}}\right) = -13.5^\circ$$

$$\theta_2 = \overset{\theta_1}{-90}\cdot\log\left(\frac{10^{7}}{\cancel{0.1}(2\times10^{6})}\right) = -76.4^\circ$$

$$\theta_3 = \overset{\theta_2}{-135}\cdot\log\left(\frac{10^{8}}{10^{7}}\right) = -211.4$$

$$\theta_4 = \overset{\theta_3}{-90}\cdot\log\left(\frac{2\times10^{8}}{10^{8}}\right) = -238.5^\circ$$

$$\theta_5 = \overset{\theta_4}{-45}\cdot\log\left(\frac{\overset{10^9}{\cancel{10^{9}}}}{\underset{2\times10^{8}}{\cancel{2\times10^{8}}}}\right) = -270^\circ$$

$$\Delta\theta = (-76.4)-(-180^\circ) = -135\log\left(\frac{\omega_{180}}{10^{7}}\right) = -103.6$$

$$\cancel{\left(\frac{-135}{-103.6}\right) = \left(\log\left(\frac{\omega_{180}}{10^{7}}\right)\right)}$$
10 $\cancel{10}$

$$\boxed{\omega_{180} = 5.853\times10^{7}\ r/s}$$

↳ Check what gain is at this ω !
If > 0dB → unstable.

$$\left(\cancel{\log}\right)_{\cancel{10}}$$

$$\frac{\omega_{180}}{10^{7}} = 10^{\left(\frac{-103.6}{135}\right)}$$

$$\omega_{18} = (10^{7})(5.85)$$

7 cont'd

11/18/2016

Madhu

→ Check for stability:

Gain$_{dB}$ at ω where θ = −180°

→ From previous. $\omega = 5.853 \times 10^7$ r/s at θ = −180°

→ Gain at $\omega = 5.853 \times 10^7$ r/s:

$$67.96 - 40 \log\left(\frac{5.853 \times 10^7 \text{ r/s}}{2 \times 10^7 \text{ r/s}}\right) = 49.31 \text{dB}.$$

∴ Amplifier is potentially unstable.

① → Fix by reducing gain (to what level?)

② → Fix by controlling phase angle.

① Gain margin:

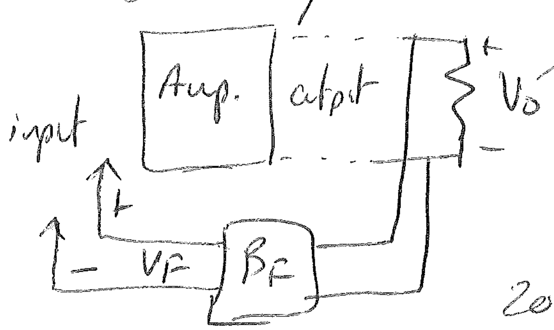
- No. of dB below 0dB at ω where θ = −180° } 15 to 30 dB.

- Suppose we choose 15dB as the gain margin. then need to go ~~down~~ reduce the gain to −15 dB at ω_{180}.

∴ Reduction of gain by 64.31 dB in previous example.

How do we do this?

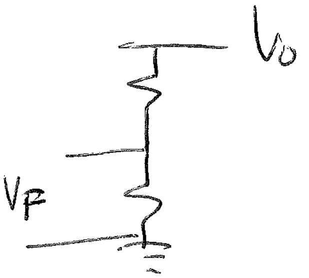
→ Introduce negative feedback:



need β_F to reduce gain by 64.31dB.

$20 \log \beta_F = -64.31$

β_F is typically a voltage divider:



$20 \log \beta_F = -64.31$

$\beta_F = 6.088 \times 10^{-4}$

(not a very good way to fix it because it reduces overall gain significantly).

② Another way: stability ~~$\omega_{180} =$~~

→ Phase angle at ω where gain = 0dB

→ should be above −180° line. (by how much?)

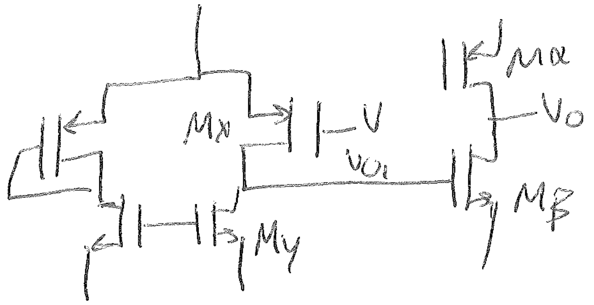
→ <u>Phase margin</u>:

No of degrees above −180° line at ω where $\theta = -180°$ → typically 30° to 45°.

② 11/18/2016

Madhu

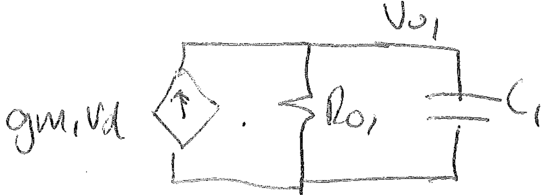
→ Example: 2-stage CMOS diff. amp:



→ Has generally two poles:
one from 1st stage and
another in 2nd stage.

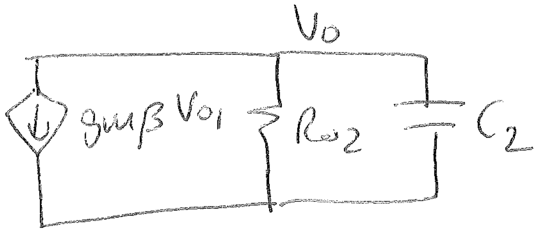
→ C_1, C_2 → from MOSFET capacitances

1st-stage.



$R_{o1} = \left(r_{o(Mx)} || r_{o(My)}\right)$

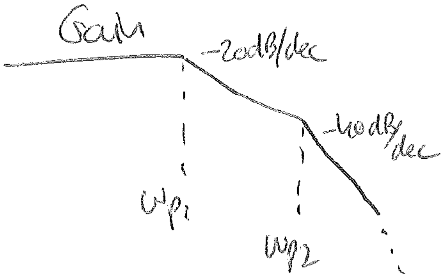
2nd stage

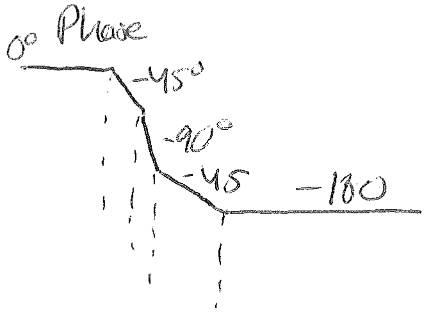


$R_{o2} = (r_{o\alpha}) || (r_{o\beta})$

Two poles:

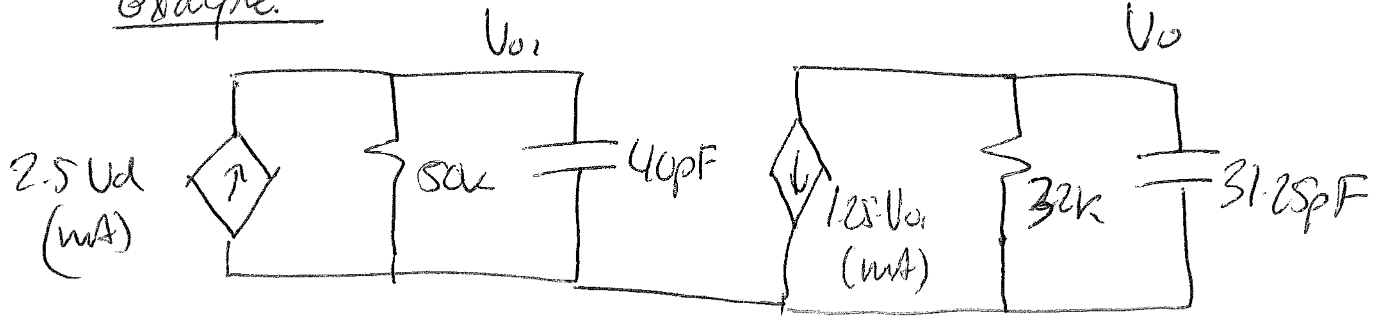
$$\omega_{p1} = \frac{1}{R_{o1}C_1} \qquad \omega_{p2} = \frac{1}{R_{o2}C_2}$$





→ For 2-stage CMOS op:
Determine ω at 0dB and → from gain bode plot
then look at phase plot to
see how far away from −180° we are.
→ Phase margin.

Example.



→ |Midband gain| $= (2.5)(50)\times(1.25)(32) = 5000$
→ 73.98dB

→ Poles: $\frac{1}{(40\times10^{-12})(50\times10^{3})} = 5\times10^{5}$ r/s

$\frac{1}{(31.25\times10^{-12})(32\times10^{3})} = 10^{6}$ r/s

→ $A(s) = \frac{K}{(s+5\times10^{5})(s+10^{6})}$

→ find k for DC gain of 5000

$\therefore \frac{k}{\cancel{s(}(5\times10^{5})(10^{6})} = 5000$

$k = (5000)(5\times10^{5})(10^{6})$

$k = 2.5\times10^{15}$

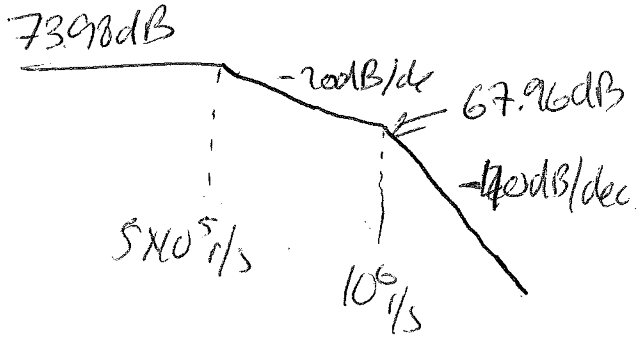
$A(s) = \frac{2.5\times10^{15}}{(s+5\times10^{5})(s+10^{6})}$

→ |Gain| plot

→ ~~Phase plot (next page)~~

Gain at $\overset{1\times10^{6}}{\cancel{5\times10^{5}}}$ r/s

$= 73.98\text{dB} - 20\cdot\log\left(\frac{1\times10^{6}}{5\times10^{5}}\right) = 67.96$ dB



→ 0dB gain at 5×10^{7} r/s.

$-67.96\text{dB} = -40\cdot\log\left(\frac{W_{0dB}}{10^{6}}\right)$

need to drop 67.96dB at -40dB/dec slope.

$10^{\left(\frac{67.96}{40}\right)} = 10^{\left(\log\frac{W_{0dB}}{10^{6}}\right)} \rightarrow W_{0dB} = 50\times10^{6}$

③ 11/18/2016
Madhu

→ Phase plot:

Pole at 5×10^5:
$(0 \to 5\times10^4)$ level at 0°
$(5\times10^4 \to 5\times10^6)$ −45°/dec
$(5\times10^6 \to \infty)$ level at −90°

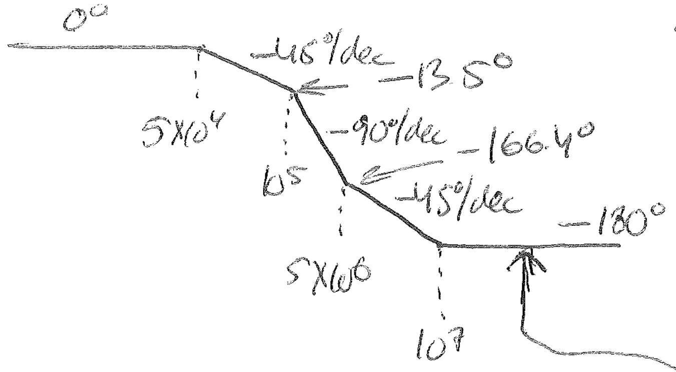
Pole at 10^6:
$(0 \to 10^5)$ level at 0°
$(10^5 \to 10^7)$ −45°/dec
$(10^7 \to \infty)$ level at −90°

Overall

$$\theta_1 = 0 - 45 \cdot \log\left(\frac{10^5}{4\times10^4}\right) = -13.5^\circ$$

$$\theta_2 = \theta_1 - 90 \cdot \log\left(\frac{5\times10^6}{10^5}\right) = -166.4^\circ$$

$$\theta_3 = \theta_2 - 45 \cdot \log\left(\frac{10^7}{5\times10^6}\right) = -180^\circ$$



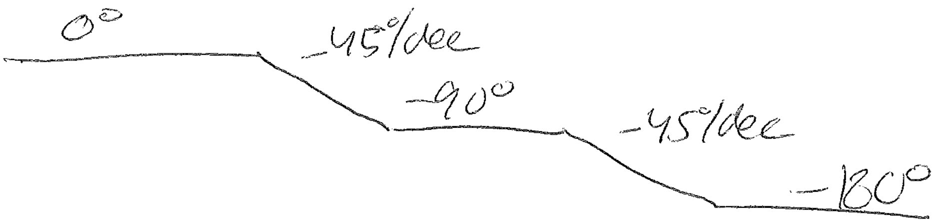
→ Now, find 0dB gain $\omega_{0dB} = 5\times10^7$ r/s (from previous page).
θ at

∴ θ = −180° at ω of 0dB.
→ unstable.

~~→ Fix by shifting phase plot to higher frequencies~~

→ Fix by shaping phase plot by pulling poles away from each other. → Pole-splitting.

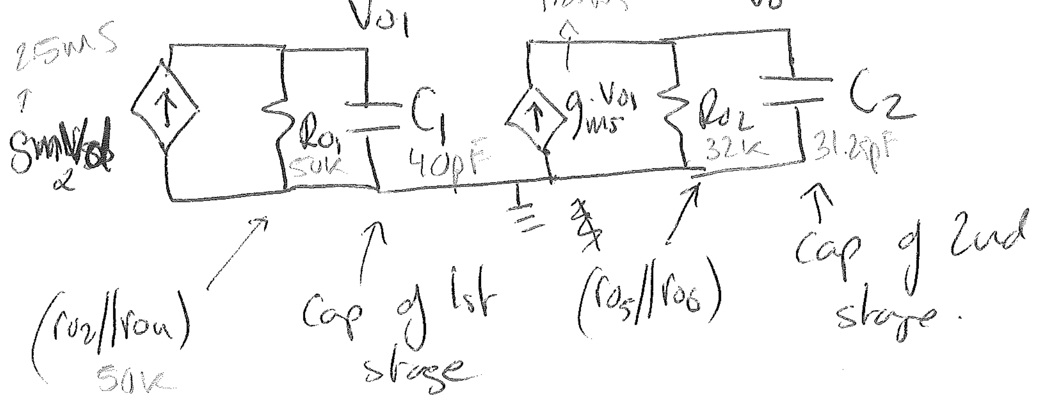
→ Introduce a low freq. pole << high freq. pole.



→ stability

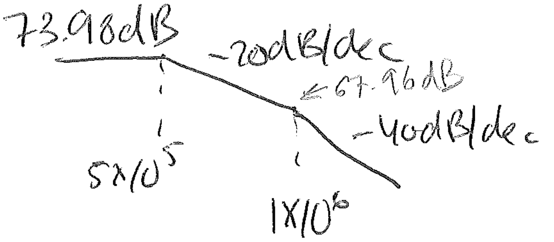
11/28/2016
Madhu

→ 2-stage CMOS Diff Amp - example

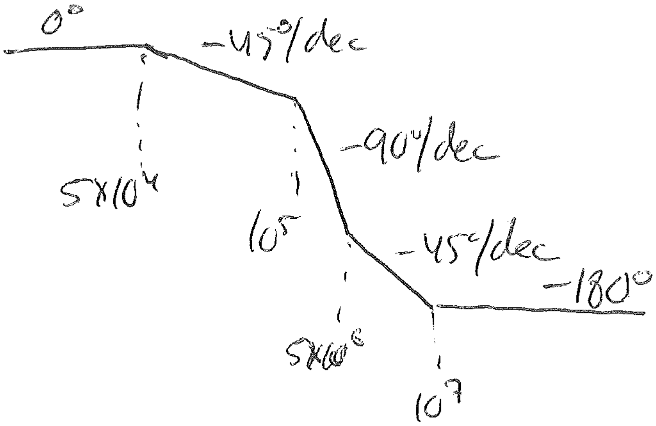


$$A(s) = \frac{2.5\times10^{5}}{(s+5\times10^{5})(s+10^{6})}$$

Mag bode plot



Phase plot



→ Use phase margin instead of ~~ph~~ magnitude margin.

→ Phase margin

$\omega_{0dB} =$ $\qquad 40\log\left(\frac{\omega_{0dB}}{10^{6}}\right) = 67.9$

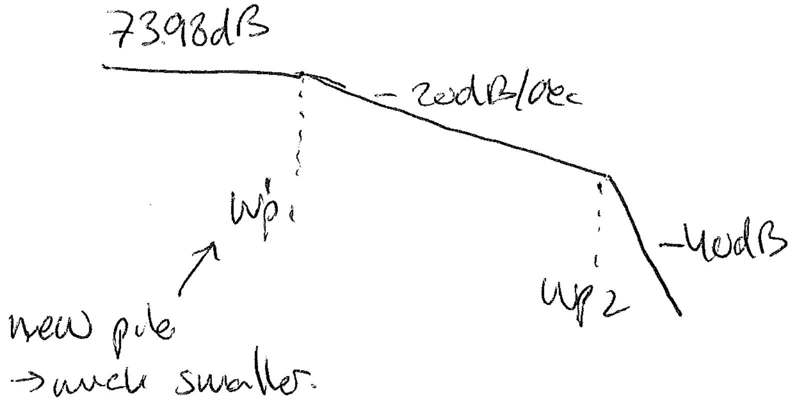
$\omega_{0dB} = 5\times10^{7}$ r/s

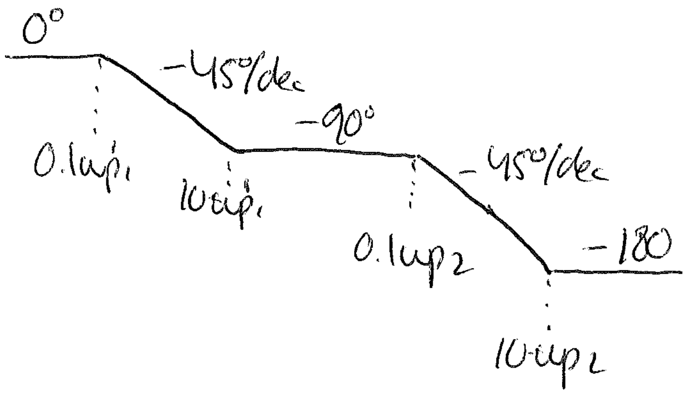
$\theta = -180°$

Phase margin = 0 → potentially unstable

→ Pole splitting:

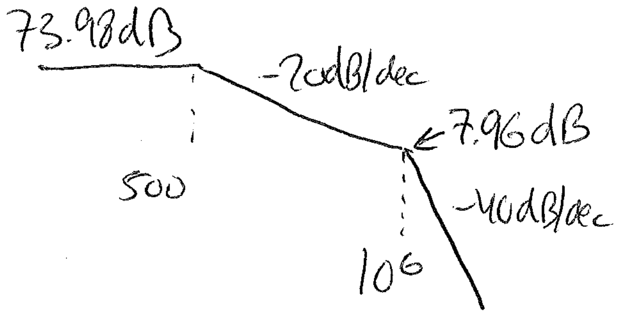
→ Fix by moving lower pole to a much smaller value.

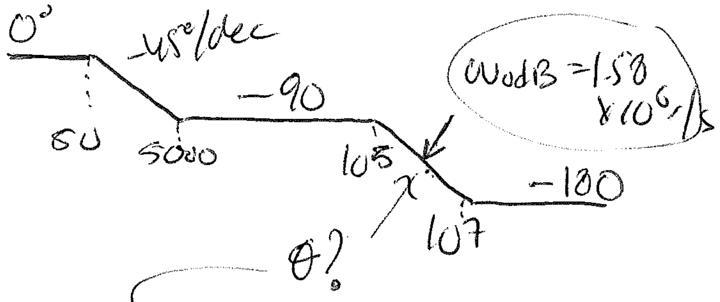




As example:

→ Suppose we picked new pole $\omega p_1 = 500$ r/s (arbitrary choice)





$$7.96\text{dB} = 40 \log \left(\frac{\omega_{0dB}}{10^6}\right)$$

$$\omega_{0dB} = 1.58 \times 10^6 \text{ r/s}$$

$$\omega_{0dB} = 10^6 \times 10^{\left(\frac{7.96}{40}\right)} = 1.58 \times 10^6 \text{ r/s}$$

θ at 1.58×10^6 r/s

$$= -90 - 45 \log \left(\frac{\overset{1.58 \times 10^6 \text{ r/s}}{\cancel{\omega_{0dB}}}}{10^5}\right)$$

$$\theta = -144°$$

≠ −180° (no oscillation)

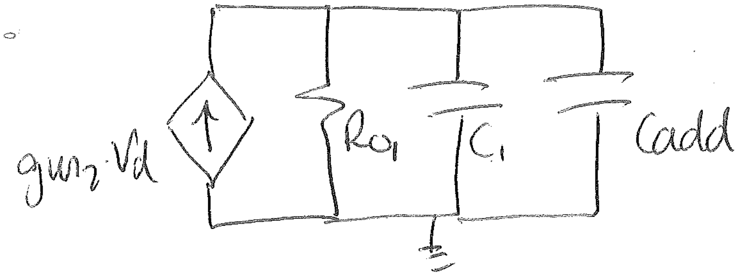
Also 36° above 180° line.

Phase margin is 36° (amplifier is stable).

→ DC gain stays the same (high), but low cut freq.

② 11/28/2016
Madhu

Back to amplifier:



Add capacitance to make new pole = 500 r/s.

→ Before it was 5×10^5 r/s

$R_{o1} = 50k$ $C_1 = 40pF$

new pole:

$$500 = \frac{1}{R_{o1}(C_1 + C_{add})}$$

$$C_{add} = \frac{1}{(500 \cdot 50k)} - C_1 = 40nF - 40pF = 39.96nF$$

↗

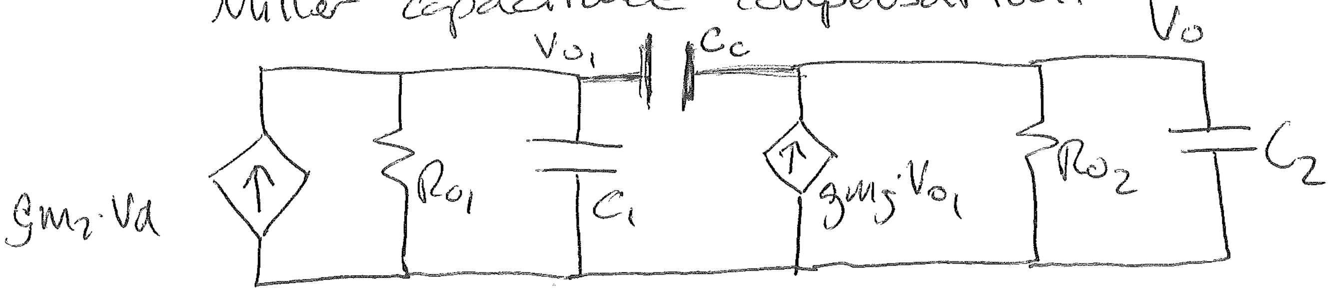
→ Too large.

→ Not a good solution

→ Good approach.

→ How it's actually done:

Miller capacitance compensation.



→ Add a capacitor between two stages.

→ C_c will appear as large parallel capacitance to C_1.

→ C_c – miller capacitance compensation:

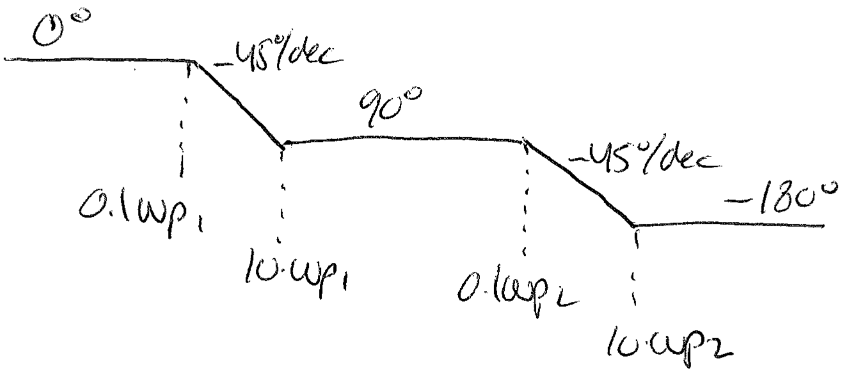
→ It will result in two-poles.

$$\omega_{p1} = \frac{1}{g_{m5} R_{o1} R_{o2} C_c}$$ ← dominant pole.

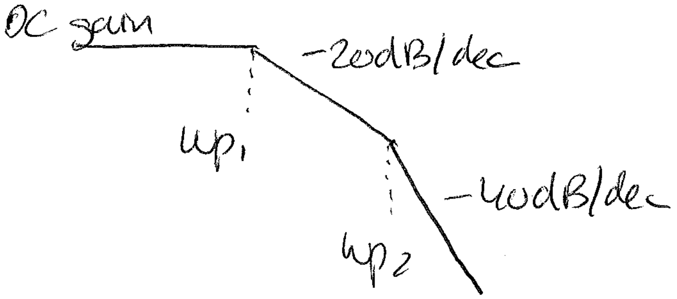
$$\omega_{p2} = \frac{g_{m5}}{C_1 + C_2}$$

→ We know g_{m5}, C_1, C_2 → find ω_{p2}

→ Phase plot: → Need to find ω_{p1}



→ Mag. plot:



~~→ To find ω_{p1} → pick a first margin. typically (−30 → −45dB).~~

Procedure:

① Find ω_{p2}

② Choose phase margin θ_{pm}

③ Find ω at which angle: $(-180° + \theta_{pm})$

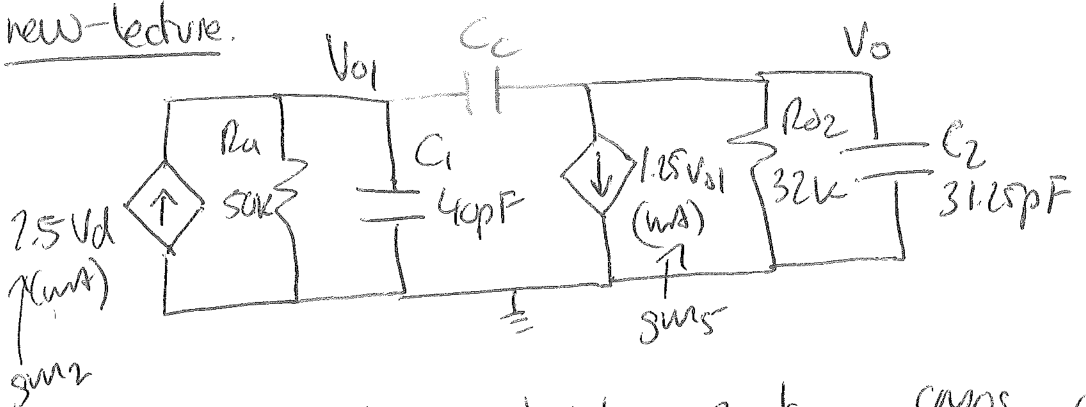
④ Go to magnitude plot and make gain = 0dB at freq of ③

⑤ Find ω_{p1}

⑥ Calculate C_c.

new-lecture.

11/30/2016
Madhu

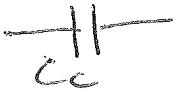


→ Potentially unstable 2-stage CMOS amplifier.

→ Move poles apart from each other → stability.

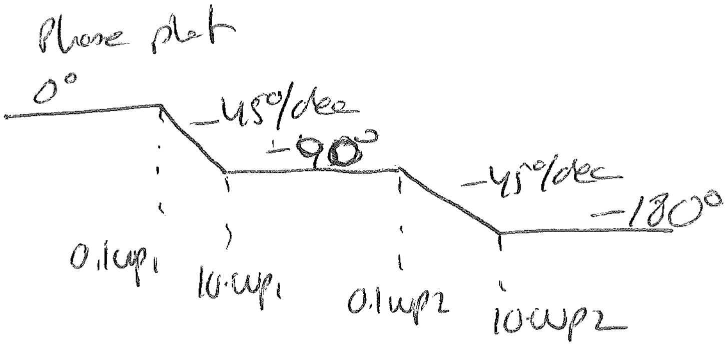
→ Adding a capacitor to C_1 results in too large of capacitor

→ Add a compensation capacitor → miller capacitance



☆ Adding C_c:

2-poles



$$\omega_{p1} = \frac{1}{g_{m5} R_{o1} R_{o2} C_c}$$

$$\omega_{p2} = \frac{g_{m5}}{C_1 + C_2}$$

Procedure:

① Find ω_{p2}

② Pick phase margin (30° → 45°)

③ Find ω_{p1} value.

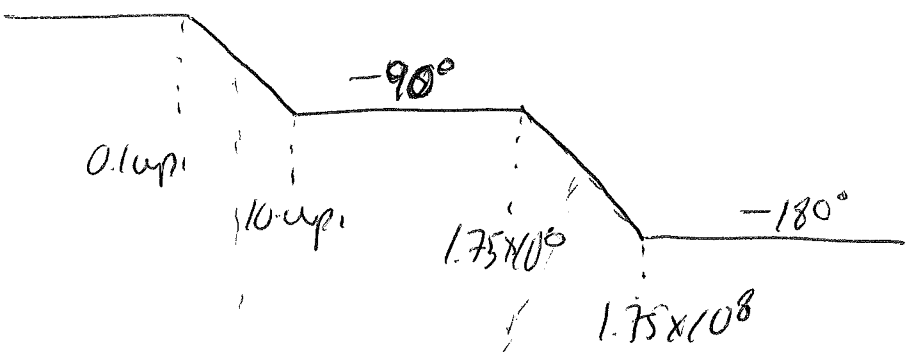
④ Find C_c value

For this example:

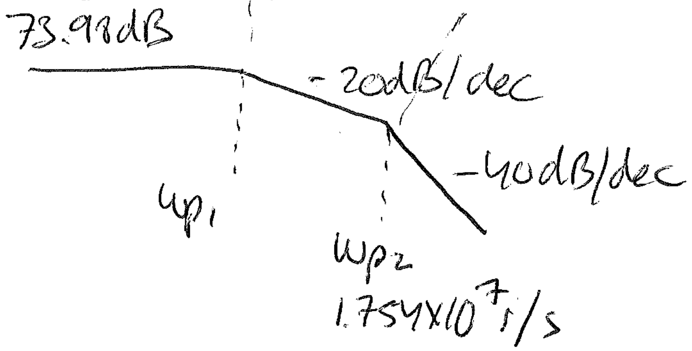
☆ → $\omega_{p2} = \dfrac{1.25\times10^{-3}\ S}{(40+31.25)\times10^{-2}\ F} = 1.754\times10^{7}$ r/s

☆ → Picking phase margin:

→ Phase plot:



→ Magnitude plot:



→ Choose 30° phase margin:

∴ ω for 0dB gain is where $\theta = -180+30 = -150°$

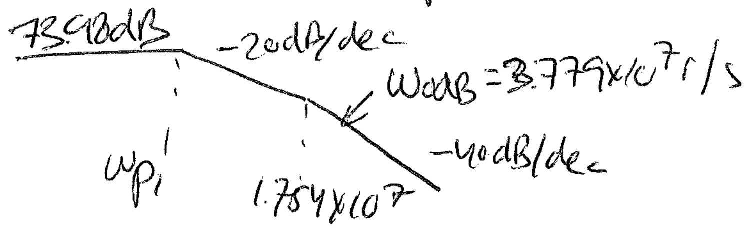
→ From phase plot:

→ loose −60° starting at 1.754×10^{6} at −45°/dec.

$$-60 = -45°/\text{dec}\cdot\log\left(\frac{\omega_{0dB}}{1.754\times10^{6}}\right)$$

$$\omega_{0dB} = \left(10^{60/45}\right)\left(1.754\times10^{6}\right) = 3.779\times10^{7}\ \text{r/s}.$$

→ From magnitude plot:

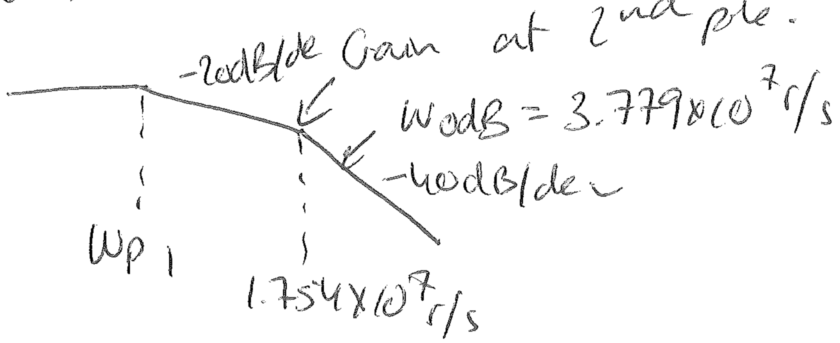


contd

② 11/30/2016
Madhu

Lp cont's

→



→ Gain at 2nd pole = $40\log\left(\frac{\overset{W_{0dB}.}{3.779\times10^7}}{1.754\times10^7}\right) = 13.33\text{dB}.$

→ Finding w_{p1}: need to go from 73.98dB to 13.33dB at a slope of -20dB/dec from w_{p1} to w_{p2}.
w_{p2} = 1.754×10^7 r/s.

$$73.98-13.33 = 20\log\left(\frac{1.754\times10^7\text{ r/s}}{w_{p1}}\right)$$

$$10^{\left(\frac{73.98-13.33}{20}\right)} = 10^{\left(\log\left(\frac{1.754\times10^7}{w_{p1}}\right)\right)}$$

~~$w_{p1} = \left(10^{\frac{(73.98-13.33)}{20}}\right)(1.754\times10^7) =$~~

~~$w_{p1} = 10^{\left(\frac{73.98-13.33}{20}\right)}$~~

$$w_{p1} = \frac{1.754\times10^7}{10^{\left(\frac{73.98-13.33}{20}\right)}} = 1.627\times10^4 \text{ r/s}$$

→ Find C_c from w_{p1}

$$C_c = \frac{1}{g_{m5}\cdot R_{o1}\cdot R_{o2}\cdot w_{p1}} = \frac{1}{(1.25\text{mS})(50k)(32k)(1.627\times10^4\text{ r/s})}$$

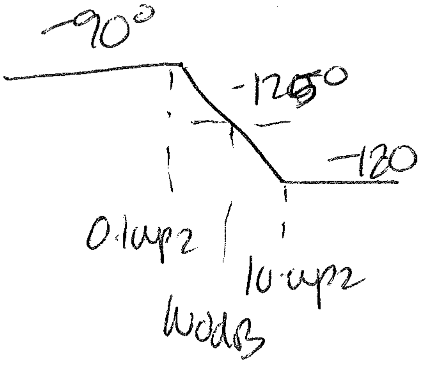
$$\boxed{C_c = 30.73\text{pF}}$$

→ Now choose a phase margin of ~~45°~~ 55°.

ω for 0 dB gain is where $\theta = -180 + 55° = -125°$ ~~-90~~

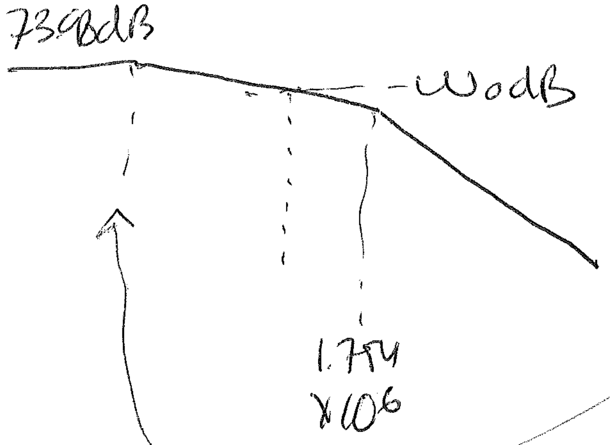
→ loose ~~45°~~ 35° starting at 1.754×10^6 at -45°/dec.

∴ ~~one decade 1.754×10^7 r/s = ω_{0dB}~~



$$35° = 45\log\left(\frac{\omega_{0dB}}{1.754\times10^6}\right)$$

$$\omega_{0dB} = 10.51\times10^6 \text{ r/s}$$



~~10.51×10^6 r/s~~ → 10.51×10^6 r/s

$$73.98 = 20\log\left(\frac{\omega_{0dB}}{\omega_{p1}}\right)$$

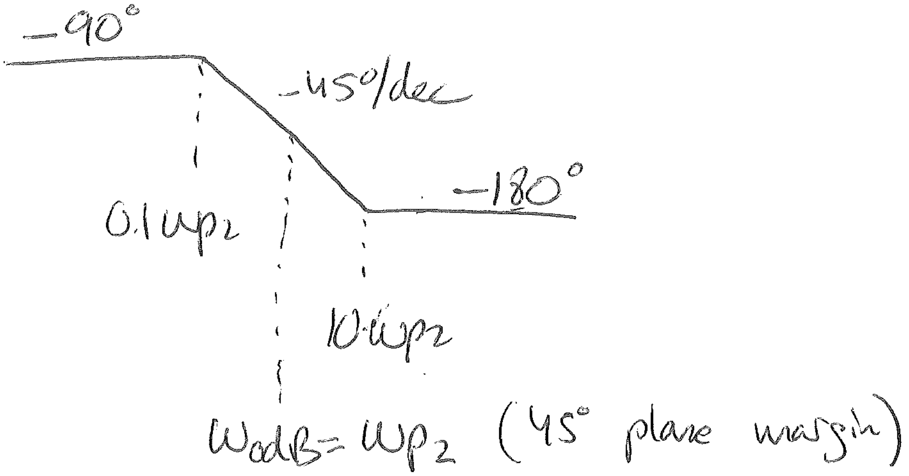
$$\omega_{p1} = 2102 \text{ r/s}$$

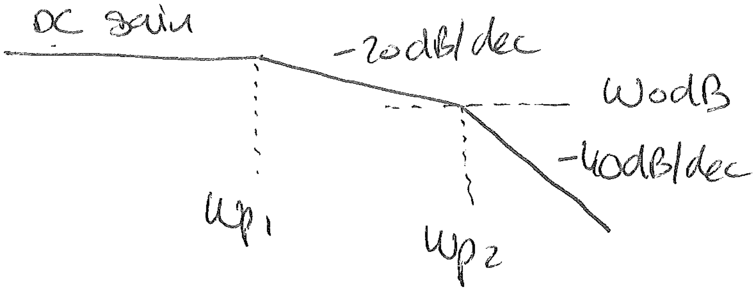
And $C_c = \dfrac{1}{(1.25\times10^{-3})(\cancel{50k})(32k)(2102)}$

$$C_c = 237.9 \text{ pF}$$

③ 11/30/2016
Madhu

→ special case when phase margin = 45°





$$\therefore \quad \text{DC gain} = 20\log\left(\frac{\omega_{p2}}{\omega_{p1}}\right)$$

$$\text{and} \quad \omega_{p1} = \frac{\omega_{p2}}{10^{\frac{\text{dc gain}}{20}}}$$