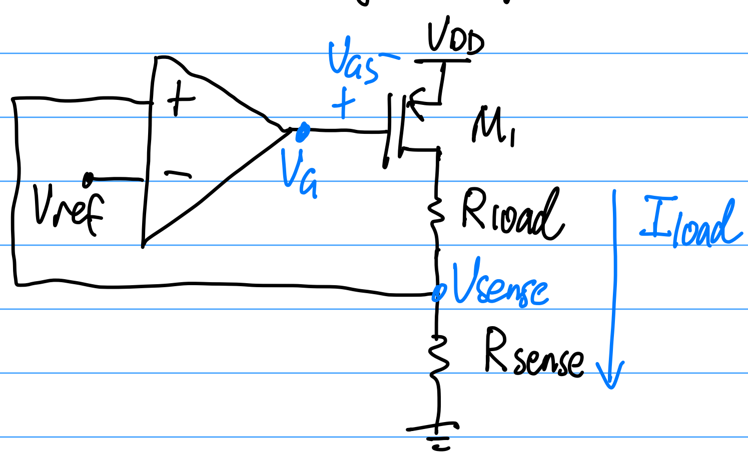
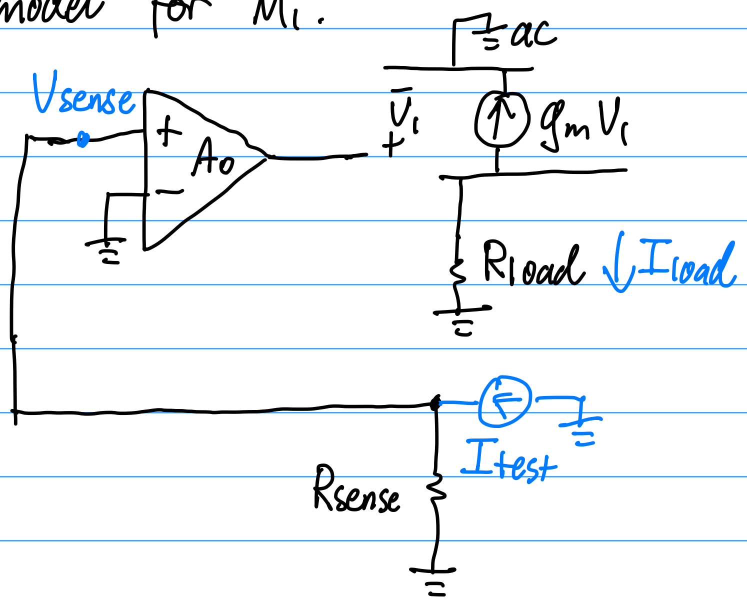
(a) Confirm negative feedback. Consider the circuit:



If $I_{load} \uparrow$ then $V_{sense} \uparrow$ then $V_G \uparrow$ then $V_{GS} \downarrow$ then $I_{load} \downarrow$. ∴ Counteracts the change
∴ Negative feedback.

Could also consider the loop gain. Break the circuit at a convenient point and use a small signal model for M_1.



$V_{sense} = I_{test} R_{sense}$

$V_1 = A_0 I_{test} R_{sense}$

$I_{load} = -g_m V_1$

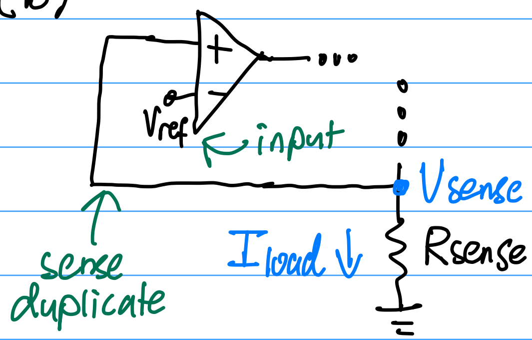
∴ Loop gain

$$= \frac{-I_{load}}{I_{test}}$$

$$= + g_m A_0 R_{sense}$$

Positive ∴ Neg. feedback.

(b)



Notice $V_{sense} = I_{load} R_{sense}$

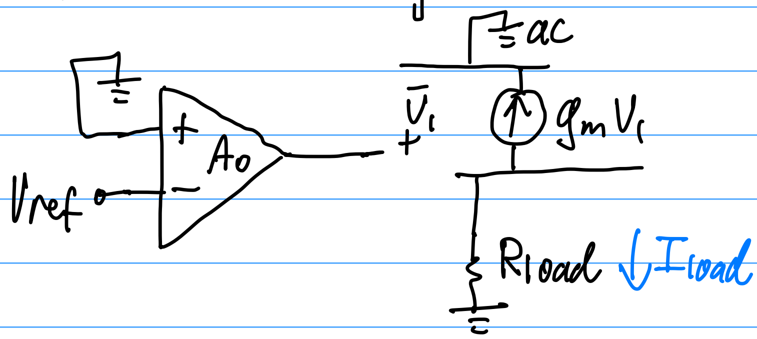
Since the sense duplicate is a good replica of the input,

$$V_{ref} \approx V_{sense}$$

$$\therefore V_{ref} = (10 \times 10^{-3}) \cdot (20)$$
$$= 0.2 \text{ V}.$$

This value is small, so for precision would need to account for the input offset of the op-amp.

(c) Draw the small signal model.



$$V_1 = -A_o V_{ref}$$
$$I_{Load} = -g_m V_1 = +g_m A_o V_{ref}$$
$$\therefore G_{OL} = g_m A_o.$$

(d) As per the answer to part (a), the loop gain is $g_m A_o R_{sense}$.

(e) The small signal transfer function is:

$$G = \frac{I_{load}}{V_{ref}} = \frac{g_m A_o}{1 + g_m A_o R_{sense}}$$

(f) $g_m = \sqrt{2 \mu_n C_{ox} \frac{W}{L} I_D}$

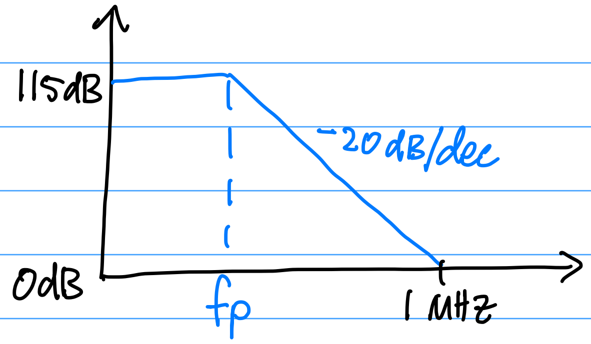
The datasheet for M_1 says $g_m = 3.1$ S at $I_D = 3$ A.

$\therefore 3.1 = \sqrt{2 \mu_n C_{ox} \frac{W}{L} \times 3}$

$\mu_n C_{ox} \frac{W}{L} = 1.602 \quad A.V^{-2}$.

At $I_D = 0.01$ A, $g_m = \sqrt{2 \times 1.602 \times 0.01} = 179$ mS.

(g).



There are $\frac{115 \text{ dB}}{20 \text{ dB/dec}} = 5.75$ decades between fp and 1 MHz.

$\therefore f_p \approx \frac{1 \text{ MHz}}{10^{5.75}} = 1.8$ Hz.

(h) Open loop bandwidth = 1.8 Hz.

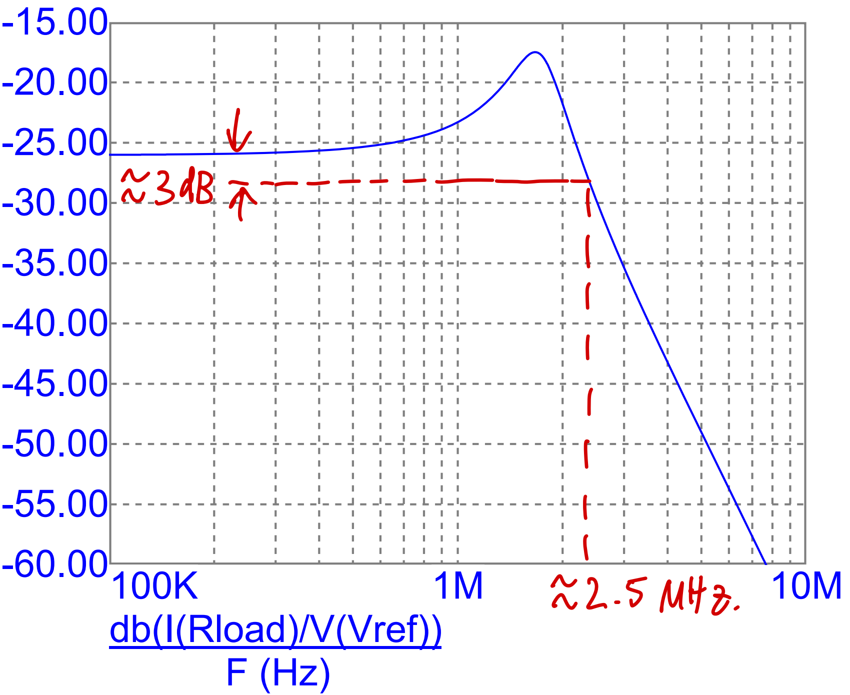
Closed loop bandwidth $= 1.8(1 + g_m A_o R_{sense})$

$= 1.8(1 + 0.179 \times 10^{115/20} \times 20)$

$= 3.6$ MHz.

(i) See next page. There must be a zero in the system response that isn't accounted for, but the bandwidth ≈ 2 MHz. Therefore the basic estimate above is reasonable.

Also the sim uses an LMV324 not LMV324A.



-15.00
-20.00
-25.00
-30.00
-35.00
-40.00
-45.00
-50.00
-55.00
-60.00
≈3dB
100K
1M
≈2.5 MHz.
10M
db(I(Rload)/V(Vref))
F (Hz)