HF1

HIGH-FREQUENCY CUTOFF APPROXIMATION f_H

- FOR ACCURATE f_H VALUE
  CAN DO EXACT ANALYSIS OR SIMULATION

HOWEVER OPEN-CIRCUIT TIME-CONSTANT METHOD
TOGETHER WITH MILLER'S THEOREM
(FOR COUPLED CAPACITORS)
GIVES f_H ESTIMATE

PROCEDURE

1) USE MILLER'S THEOREM TO SEPARATE COUPLED CAPACITORS

2) FOR EACH HIGH FREQ (HF) CAP FIND τ_i ASSOCIATED WITH THAT CAP WHILE OTHER HF CAPS OPENED.

EACH POLE IS ESTIMATED TO BE

$$f_{P_i} = \frac{1}{2\pi \tau_i}$$

HF 1A

3) 2 METHODS TO ESTIMATE f_H

- OPEN-CIRCUIT TIME CONSTANT (OTC) ESTIMATE
- DOMINANT POLE ESTIMATE

OTC

$$f_H \approx \frac{1}{2\pi \sum \tau_i} = \left(\frac{1}{f_{P1}} + \frac{1}{f_{P2}} + \ldots\right)^{-1}$$

DOMINANT POLE

$$f_H \approx \frac{1}{2\pi \tau_{MAX}}$$

WHERE τ_{MAX} IS LARGEST τ_i

OR EQUIVALENTLY

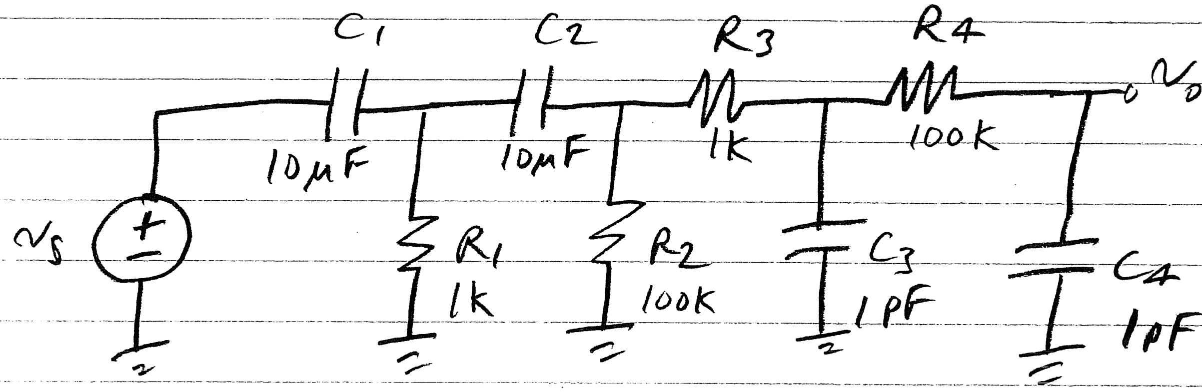
$$f_H \approx f_{P\,MIN}$$

WHERE $f_{P\,MIN}$ IS SMALLEST f_{Pi}

HF2

SHORT/OPEN CIRCUIT TIME-CONSTANT EXAMPLE

(WIDELY SPACE POLES SO USE DOMINANT ESTIMATE)

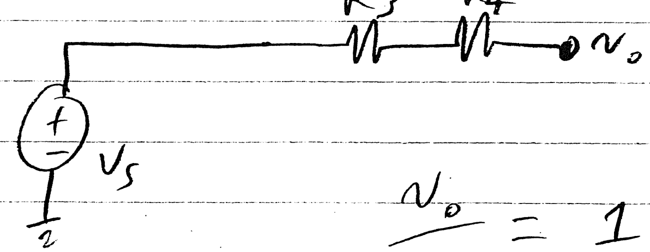


FIRST DETERMINE WHICH CAPS ARE LOW FREQ CUTOFF & WHICH HIGH FREQ CUTOFF

LF ⇒ C_1, C_2

HF ⇒ C_3, C_4

FOR MIDBAND GAIN SHORT LF CAPS
OPEN HF CAPS



$$\frac{v_o}{v_s} = 1$$

HF3

$\underline{f_L}$

FOR LF CUTOFF ⇒ OPEN HF CAPS
~~ZERO~~ INDEPENDENT SOURCE

FIND POLES DUE TO EACH LF CAP
(WHILE OTHER LF CAP SHORTED)

$$C_1 \Rightarrow \quad f_{p_1} = \frac{1}{2\pi C_1 (R_1 \| R_2)} \simeq \frac{1}{2\pi C_1 R_1}$$

$$f_{p_1} = 15.9 \text{ HZ}$$

$$C_2 \Rightarrow \quad f_{p_2} = \frac{1}{2\pi C_2 (R_2)} = 0.159 \text{ HZ}$$

LOW FREQ CUTOFF IS <u>HIGHER</u> OF f_{p_1} & f_{p_2}

$$f_L = 15.9 \text{ HZ}$$

f_H

FOR HF CUTOFF ⇒ SHORT LF CAPS
ZERO v_s

FIND POLES DUE TO EACH HF CAP
(WHILE OTHER HF CAPS OPEN)

$$C_3 \Rightarrow f_{p3} = \frac{1}{2\pi C_3 R_3} = 159 \text{ MHZ}$$

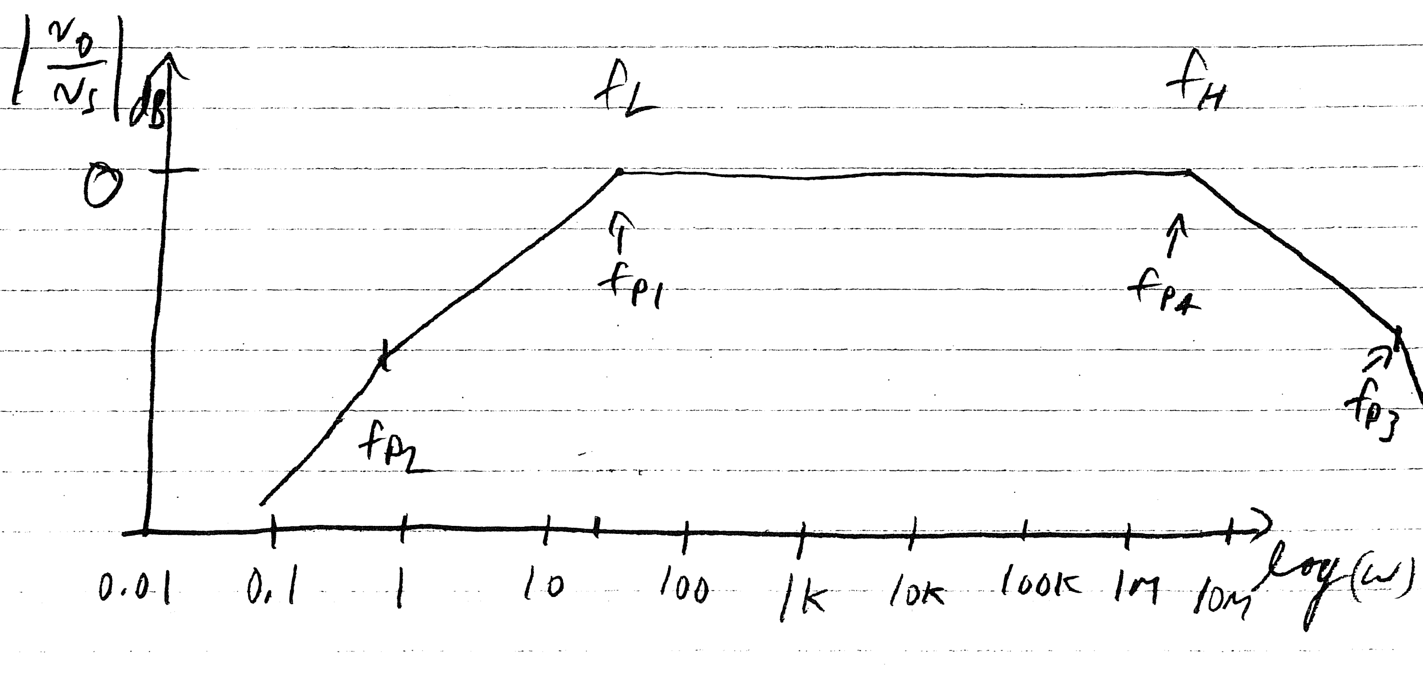
$$C_4 \Rightarrow f_{p4} = \frac{1}{2\pi C_4 (R_3 + R_4)} \approx \frac{1}{2\pi C_4 R_4}$$

$$= 1.59 \text{ MHZ}$$

HIGH FREQ CUTOFF IS LOWER OF

f_{p3} + f_{p4}

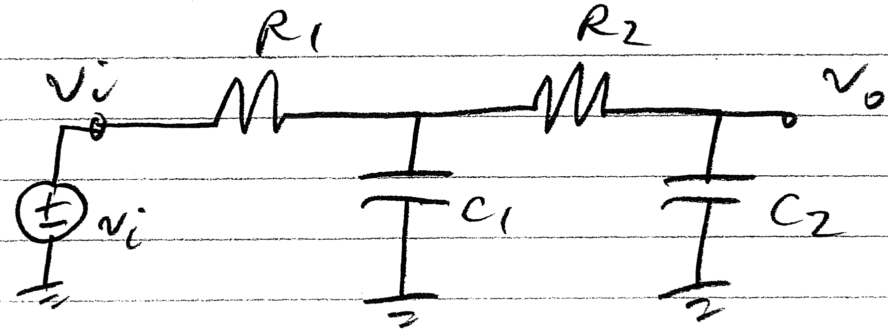
$$f_H = 1.59 \text{ MHZ}$$



HF5

HOW ACCURATE ARE POLE ESTIMATES FOR OPEN-CIRCUIT TIME CONSTANT (OTC)?

CONSIDER



CAN SHOW

$$\frac{v_o}{v_i} = \frac{1}{s^2(C_1C_2R_1R_2) + s[C_2(R_1+R_2) + C_1R_1] + 1}$$

USING OPEN-CIRCUIT TIME CONSTANT METHOD

$$\tau_1 = C_1R_1 \qquad \tau_2 = C_2(R_1+R_2)$$

NOTE $$\frac{v_o}{v_i} = \frac{1}{s^2(C_1C_2R_1R_2) + s(\tau_1+\tau_2) + 1}$$

SUM OF OPEN-CIRCUIT TIME-CONSTANTS

HF5A

NOTE

IF $T(S)$ EXPRESSED AS (REAL POLES & ZEROS)

$$T(S) = \frac{\left(1+\frac{S}{\omega_{Z1}}\right)\left(1+\frac{S}{\omega_{Z2}}\right)\cdots\left(1+\frac{S}{\omega_{Zm}}\right)}{\left(1+\frac{S}{\omega_{P1}}\right)\left(1+\frac{S}{\omega_{P2}}\right)\cdots\left(1+\frac{S}{\omega_{Pn}}\right)}$$

$$= \frac{1 + a_1 S + a_2 S^2 + \dots + a_m S^m}{1 + b_1 S + b_2 S^2 + \dots + b_n S^n}$$

THEN $b_1 = \frac{1}{\omega_{P1}} + \frac{1}{\omega_{P2}} + \cdots + \frac{1}{\omega_{Pn}}$

& IT CAN BE SHOWN THAT

$$b_1 = \sum_{i=1}^{n} C_i R_i$$

SUM OF OPEN CIRCUIT-TIME CONSTANTS

IF ZEROS NOT DOMINANT & ONE-POLE DOMINANT
THEN $b_1 \approx \frac{1}{\omega_{P1}}$

HF6

EXAMPLES

$C_1 = C_2 = 1.59\,pF$

Ex 1 $R_1 = 1k$ $R_2 = 100k$

ACTUAL $\Rightarrow$ $f_{P2} = 990\,KHZ$ $f_{P1} = 101\,MHZ$

OTC $\Rightarrow$ $f_{P2} = 990\,KHZ$ $f_{P1} = 100\,MHZ$

Ex 2 $R_1 = 10k$ $R_2 = 100K$

ACTUAL $\Rightarrow$ $f_{P2} = 901\,KHZ$ $f_{P1} = 11.1\,MHZ$

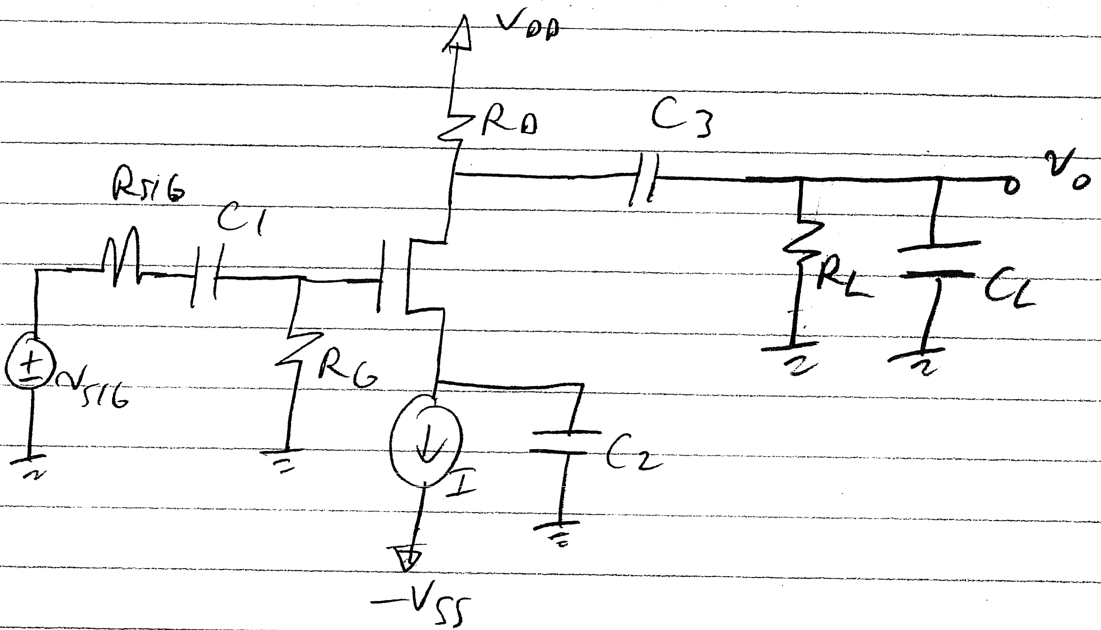
OTC $\Rightarrow$ $f_{P2} = 909\,KHZ$ $f_{P1} = 10\,MHZ$

Ex 3 $R_1 = 30k$ $R_2 = 100K$

ACTUAL $\Rightarrow$ $f_{P2} = 723\,KHZ$ $f_{P1} = 4.61\,MHZ$

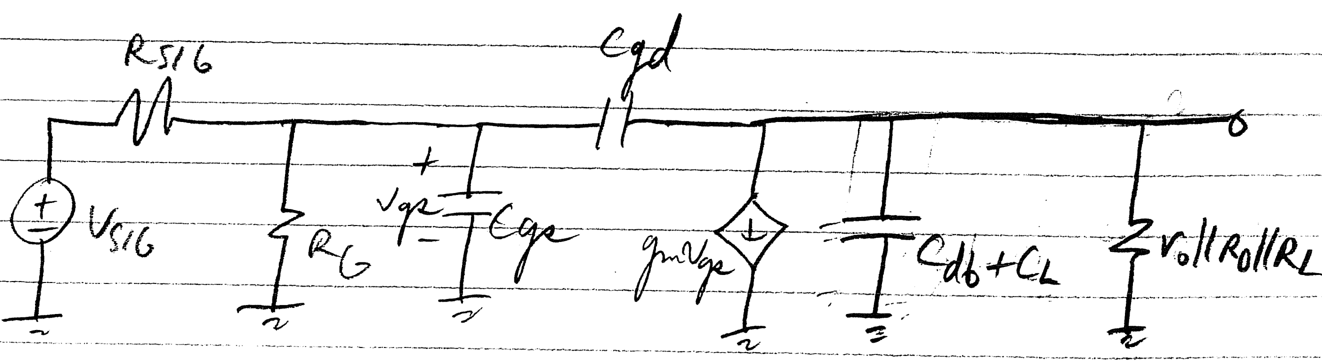
OTC $\Rightarrow$ $f_{P2} = 769\,KHZ$ $f_{P1} = 3.33\,MHZ$

COMMON SOURCE AMP



ALL C_1, C_2, C_3 ARE LOW FREQ COUPLING & BYPASS

SO SHORT THEM FOR HIGH FREQ ANALYSIS



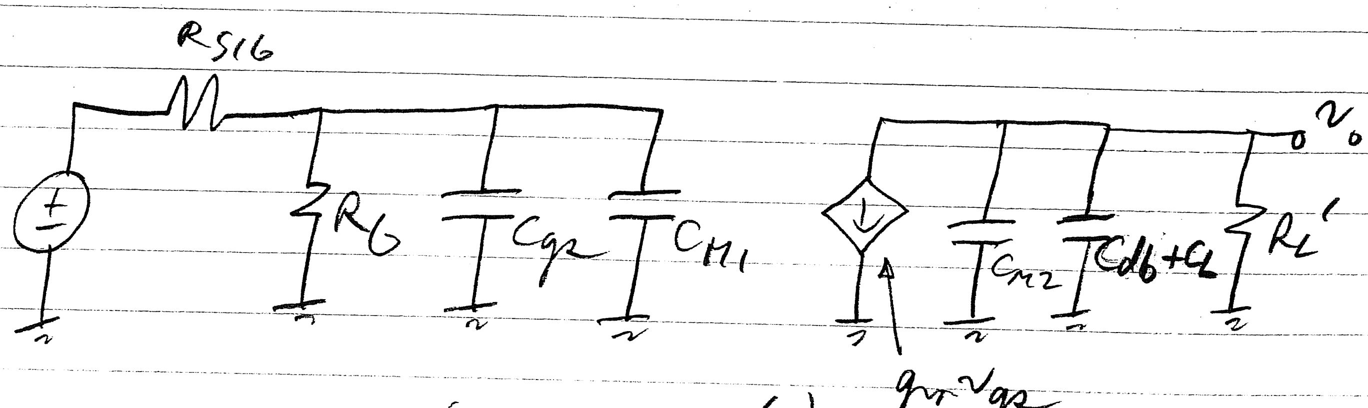
MIDBAND GAIN $\dfrac{v_o}{v_{gs}} = -g_m (r_o \| R_L \| R_D)$

$= -g_m R_L'$

LET $R_L' = r_o \| R_L \| R_D$

HF8

USING MILLER THEOREM



$$C_{M1} = C_{gd}(1 + g_m R_L')$$

$$C_{M2} = C_{gd}\left(1 + \frac{1}{g_m R_L'}\right) \simeq C_{gd} \quad \text{IF } g_m R_L' \gg 1$$

SO

$$\omega_{P1} = \left[(C_{gs} + C_{M1})(R_{SIG} \| R_G)\right]^{-1} = 2\pi f_{P1}$$

$$\omega_{P2} = \left[(C_{db} + C_L + C_{gd})\; R_L'\right]^{-1} = 2\pi f_{P2}$$

SO

$$\frac{v_o}{v_{SIG}} \simeq \frac{-g_m R_L' \times \left(\frac{R_G}{R_G + R_{SIG}}\right)}{\left(1 + \frac{s}{\omega_{P1}}\right)\left(1 + \frac{s}{\omega_{P2}}\right)}$$

DOMINANT f_H ESTIMATE

$f_H \simeq f_{P1}$ OR f_{P2} WHICH EVER IS LOWER

OTC f_H ESTIMATE

$$f_H = \left(\frac{1}{f_{P1}} + \frac{1}{f_{P2}} \right)^{-1} = f_{P1} \| f_{P2}$$

MATHEMATICAL PARALLEL

- OFTEN W_{P1} IS LOW DUE TO MILLER EFFECT ON C_{gd}
- CAN KEEP W_{P1} HIGH IF R_{SIG} IS SMALL

EX LET $R_{SIG} = 0$
FIND f_H + f_t (UNITY GAIN FREQ)
ASSUMING $g_m R_L' \gg 1$

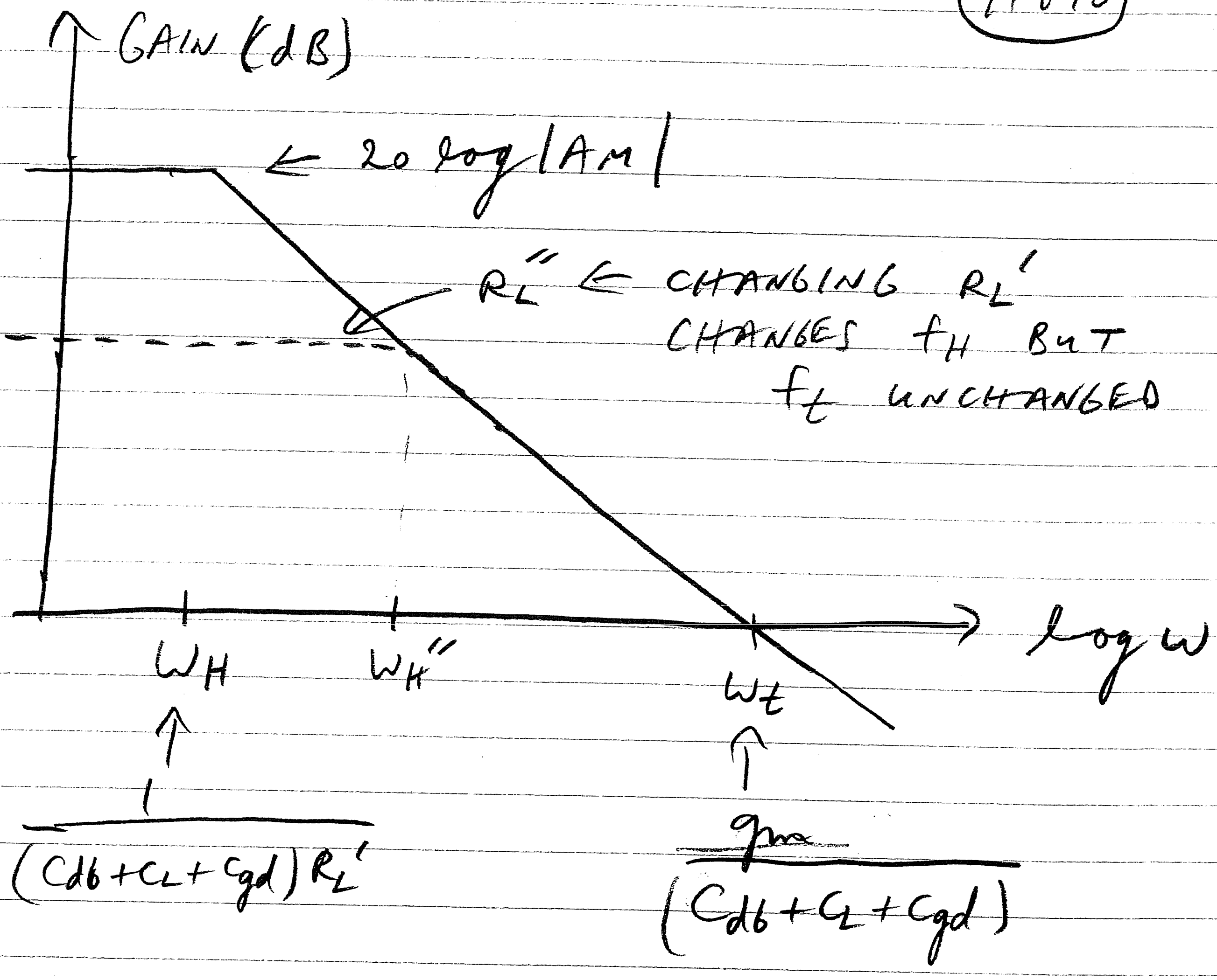
$$f_H = \frac{W_{P2}}{2\pi} = \frac{1}{2\pi (C_{db} + C_L + C_{gd}) R_L'}$$

+ LOW FREQ GAIN $A_M = -g_m R_L'$

$\Rightarrow f_t = |A_M| f_H$ [SEE SINGLE TIME CONSTANT pg 13]

$$f_t = \frac{g_m}{2\pi (C_{db} + C_L + C_{gd})}$$

HF10



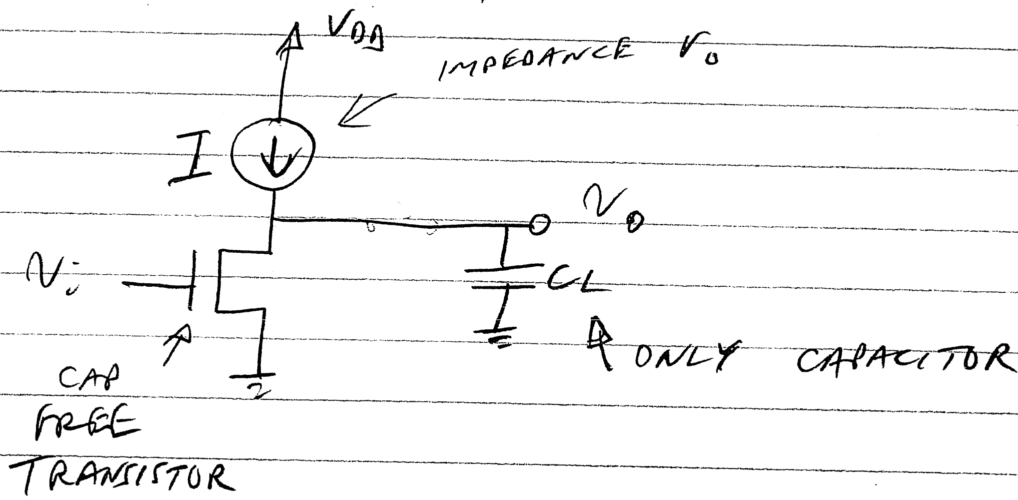
GAIN (dB)
← 20 log |AM|
R_L'' ← CHANGING R_L' CHANGES f_H BUT f_t UNCHANGED
log ω
ω_H
ω_H''
ω_t
$\frac{1}{(C_{db}+C_L+C_{gd})R_L'}$
$\frac{g_m}{(C_{db}+C_L+C_{gd})}$

HF11

CASCODE AMP

CONSIDER

COMMON SOURCE (CS)



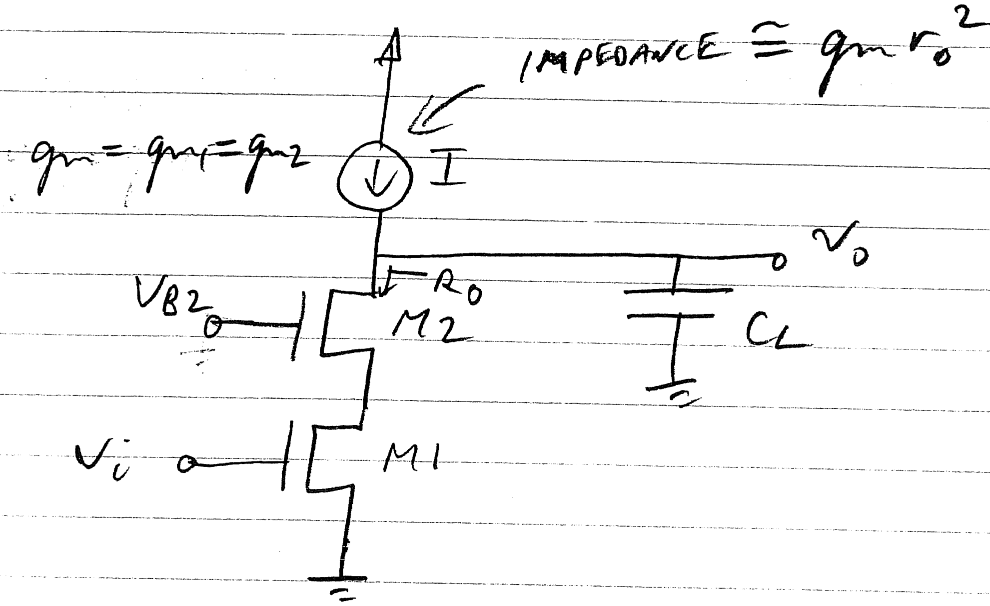
DC GAIN $\Rightarrow$ $-g_m\left(\frac{r_o}{2}\right)$

f_{3dB} $\Rightarrow$ $\dfrac{1}{2\pi C_L\left(\frac{r_o}{2}\right)}$

f_t $\Rightarrow$ $\dfrac{g_m}{2\pi C_L}$

HF12

CASCODE AMP

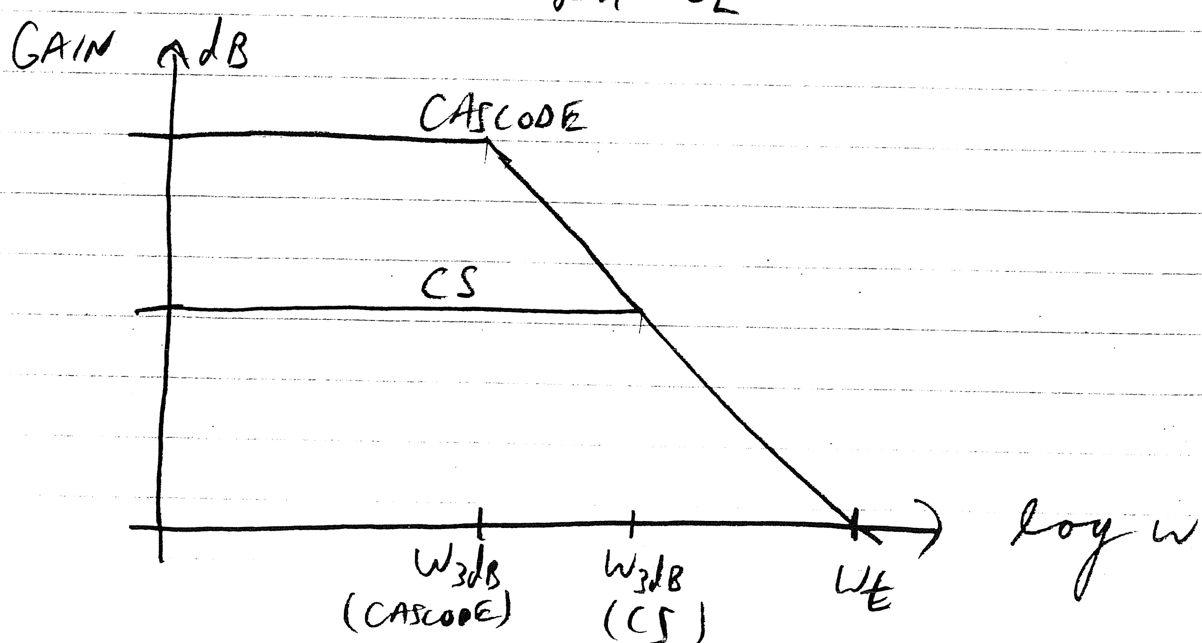


$R_o \approx g_m r_o^2$

DC GAIN $\Rightarrow$ $-\dfrac{g_m^2 r_o^2}{2}$ INCREASED BY $g_m r_o$

f_{3dB} $\Rightarrow$ $\dfrac{1}{2\pi C_L \left(\frac{r_o}{2}\right)(g_m r_o)}$ DECREASED BY $g_m r_o$

f_t $\Rightarrow$ $\dfrac{g_m}{2\pi C_L}$ (UNCHANGED)



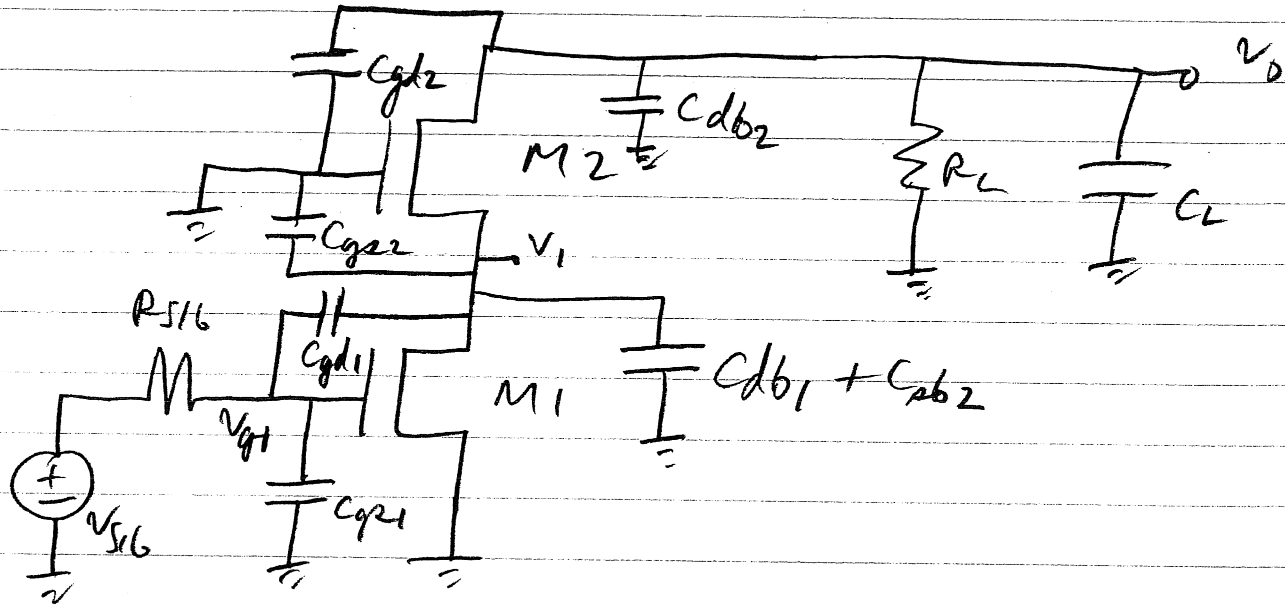
CASCODE AMP

IF OUTPUT CAPACITANCE LOAD

DETERMINES f_H THEN
CASCODE AMP HAS SAME f_t
AS COMMON-SOURCE AMP
BUT HIGHER DC GAIN
(AND LOWER f_H)

HF14

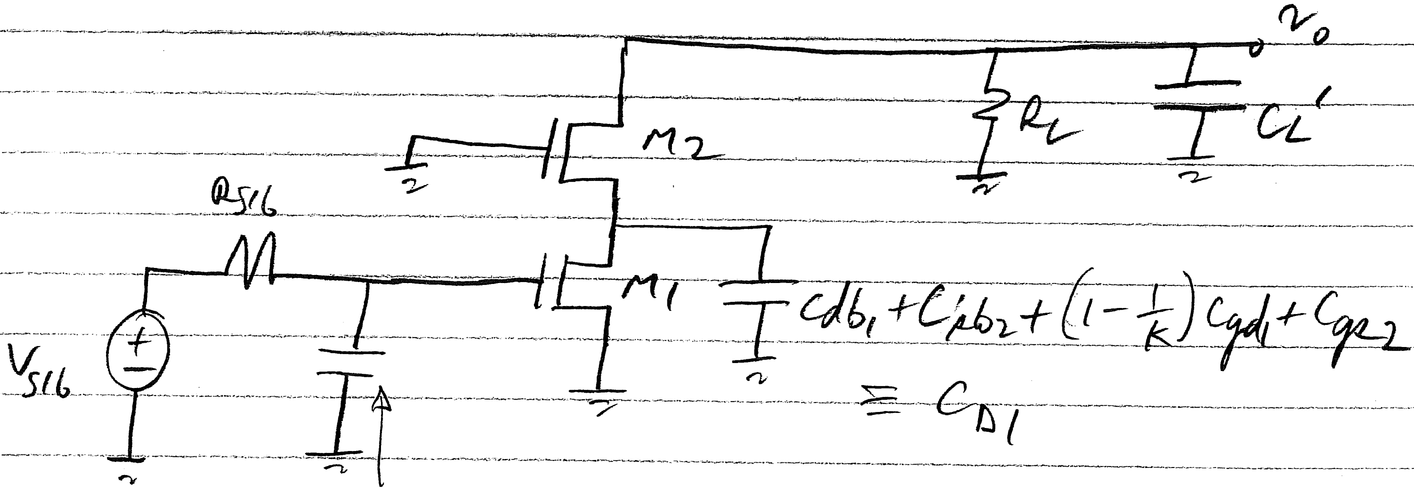
OTHER CAPS IN CASCODE AMP



- TYPICALLY GAIN $\frac{v_1}{v_{g1}}$ NOT LARGE
  SO NO LARGE MILLER EFFECT ON C_{gd1}.
- THERE IS MILLER EFFECT ON C_{gd2} BUT SINCE v_{g2} NOT IN SIGNAL PATH DOES NOT AFFECT POLES OF SYSTEM.

HF 15

SO APPROX CIRCUIT IS



$$C_{gs1} + (1-k)\,C_{gd1} \equiv C_{G1}$$

$$C_L' = C_{gd2} + C_{db2} + C_L$$

<u>REQ</u>

$C_{G1} \Rightarrow R_{SIG}$

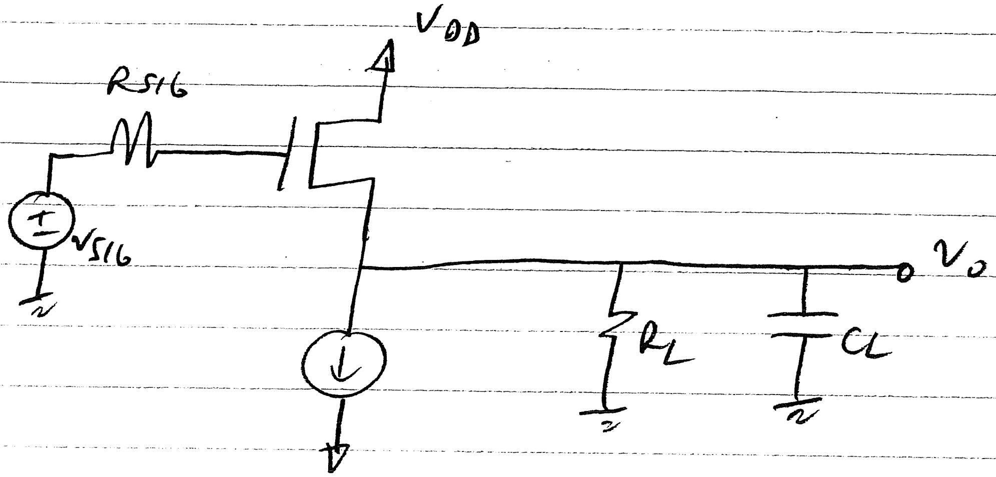
$C_{D1} \Rightarrow \simeq \dfrac{1}{g_{m2}}$ DEPENDS ON R_L

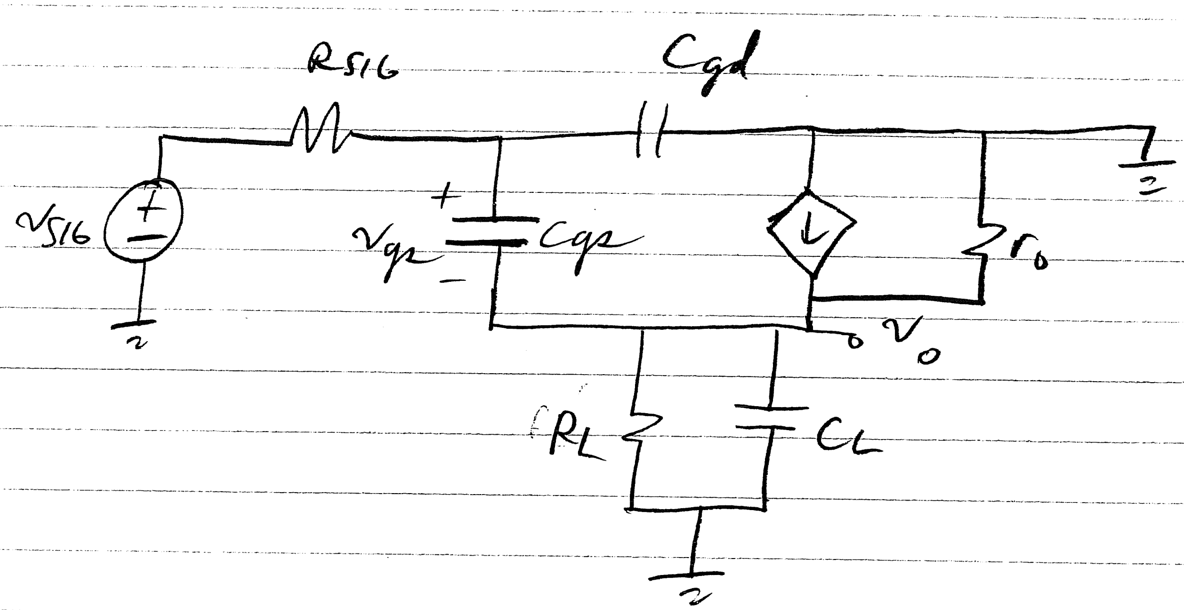
$C_L' \Rightarrow \simeq R_L \| (g_{m2} r_o^2)$

(USUALLY DOMINATES)

HF 16

SOURCE FOLLOWER





LET $R_L' = R_L \| r_o$

$r_s = \frac{1}{g_m}$

$$\frac{v_o}{v_{SIG}} = A_M = \frac{R_L'}{R_L' + r_s}$$

& $R_o = r_s \| r_o$

HF17

3 POLES C_{gd}, C_{gs}, C_L

$$f_{P_1} = \frac{1}{2\pi C_{gd} R_{SIG}}$$

$$f_{P_2} = \frac{1}{2\pi (C_L)(R_L \| r_o \| r_s)} \approx \frac{1}{2\pi (C_L)(r_s)}$$

$$f_{P_3} = \frac{1}{2\pi C_{gs}(R_{gs})}$$

WHERE $R_{gs} = \dfrac{R_{SIG} + R_L'}{1 + g_m R_L'}$

(REQUIRES ANALYSIS)

ALL 3 POLES USUALLY HIGHER THAN IN COMMON-SOURCE CASE.