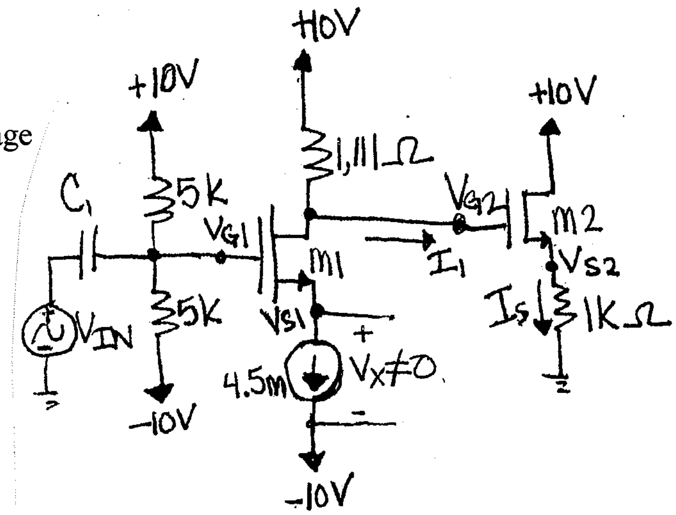
Problem 1 – (35 points)

SOLUTION

Use: V_t=2V
$k_n'(W/L)=1mA/V^2$
$\lambda=0$
$V_{IN} = 5+0.005\sin(20t)$
For DC analysis, assume that the capacitors act as an open. The current source is not ideal and has a voltage drop across it.



(a) Solve for the DC currents:
 a. $\boxed{I_1 = 0}$
 b. $\boxed{I_S = 1.35mA}$

(b) Solve for the DC voltages:
 a. $\boxed{V_{G2} = 5V}$
 b. $\boxed{V_{S2} = 1.35}$
 c. $\boxed{V_{S1} = -5V}$

(c) Verify that transistor M2 is saturated.

(d) State the DC bias point for transistor M1.

(e) Assuming that the transistor amplification is V_{S2}/V_{IN}= -4V/V. Assume the input frequency is operating within the circuits operating range. What is the **PEAK** value seen at V_{S2} using the V_{IN} value stated above.

$\boxed{V_{G1} = 0V}$

$I_{S1} = 4.5m = \frac{1}{2}(1m)[V_{GS}-2]^2$

$2 \pm \sqrt{9} = V_{GS}$

$V_{GS} = 2 \pm 3 = 5, \cancel{-1}$ Not on

$\boxed{V_{S1} = -5V}$

$V_{G2} = 10 - 1{,}111(4.5m) \cong \boxed{+5V}$

$\frac{V_{S2}}{1k} = \frac{1}{2}(1m)\cdot[\underbrace{5-V_{S2}-2}_{3-V_{S2}}]^2$

$2V_{S2} = 9 - 6\cdot V_{S2} + V_{S2}^2$

$V_{S2}^2 - 8V_{S2} + 9 = 0$

$V_{S2} = \frac{+8 \pm \sqrt{64-4(9)}}{2} = \frac{+8 \pm 5.3}{2} = 6.65, \boxed{1.35}$

$V_{GS2} = 5 - 6.65 = -1.65 \times$ off $(V_{GS} < V_t)$

$I_S = \frac{V_{S2}}{1k} = \boxed{1.35mA}$

(c) $V_{D2} = +10V$
$V_{G2} = +5V$
$V_{S2} = 1.35$
$V_{D2} = +10V > (V_{G2} = +5V) - (V_t = 2)$ ✓
$10 > 3$

(d) $V_{GS1} = +5V$, $I = 4.5mA$

(e) $\frac{V_{S2}}{V_{IN}} = -4 V/V$

$V_{S2} = 1.35 - 4(5m)\sin(20t)$

$V_{S2\,peak} = 1.35 + 20m = \boxed{1.37V}$

Problem 2 – **(35 points)**

Use: V_t=1V

$k_n'(W/L)$=10mA/V^2

V_{sig} is an AC source

Transistor 1 has DC values: V_{GS}=9V, I_D=3.2A $\rightarrow g_{m1} = K_n'\left(\frac{W}{L}\right)(V_{GS}-V_t) = 10m(9-1) = 80mA/V$

Transistor 2 has DC values: V_{GS}=1.18V, I_D=162μA $g_{m2} = 10m(1.18-1) = 1.8mA/V$

λ=0 (for all transistors) and assume all transistors are saturated

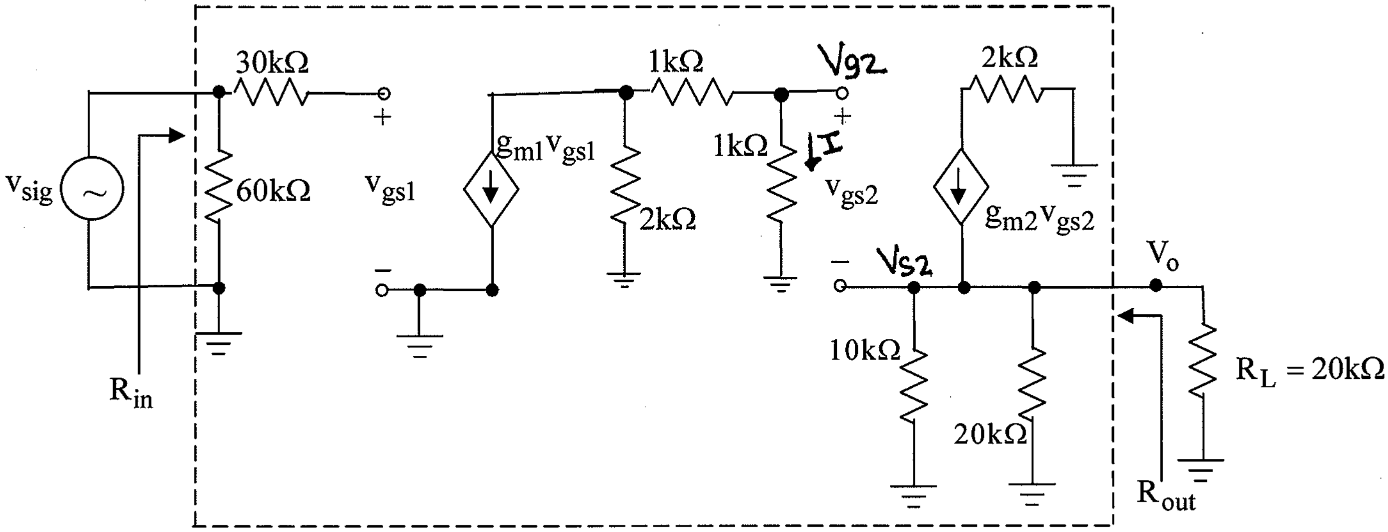
For the following hybrid-π equivalent circuit, find the following values:

(a) R_{in} (input resistance –ignore the input source, Vsig) $\boxed{R_{in} = 60K\Omega}$

(b) R_{out} (output resistance-**ignore** R_L })

(c) ideal midband gain, $\dfrac{Vo}{Vsig}$

$$R_{out} = 20k \| 10k \| \frac{1}{g_{m2}} = 6.67k \| 556 \cong \boxed{513\Omega}$$



$$V_o = g_{m2}V_{gs2} \cdot (\underbrace{10k \| 20k \| 20k}_{5k})$$

$$V_{gs2} = V_{g2} - V_{s2}$$

$$V_{g2} = \Big[\underbrace{-\frac{g_{m1}V_{gs1} \cdot 2k}{4k}}_{I}\Big] \cdot 1k = -g_{m1}V_{gs1}\frac{1}{2} \cdot 1k$$

$$V_{s2} = g_{m2} \cdot V_{gs2} \cdot 5k$$

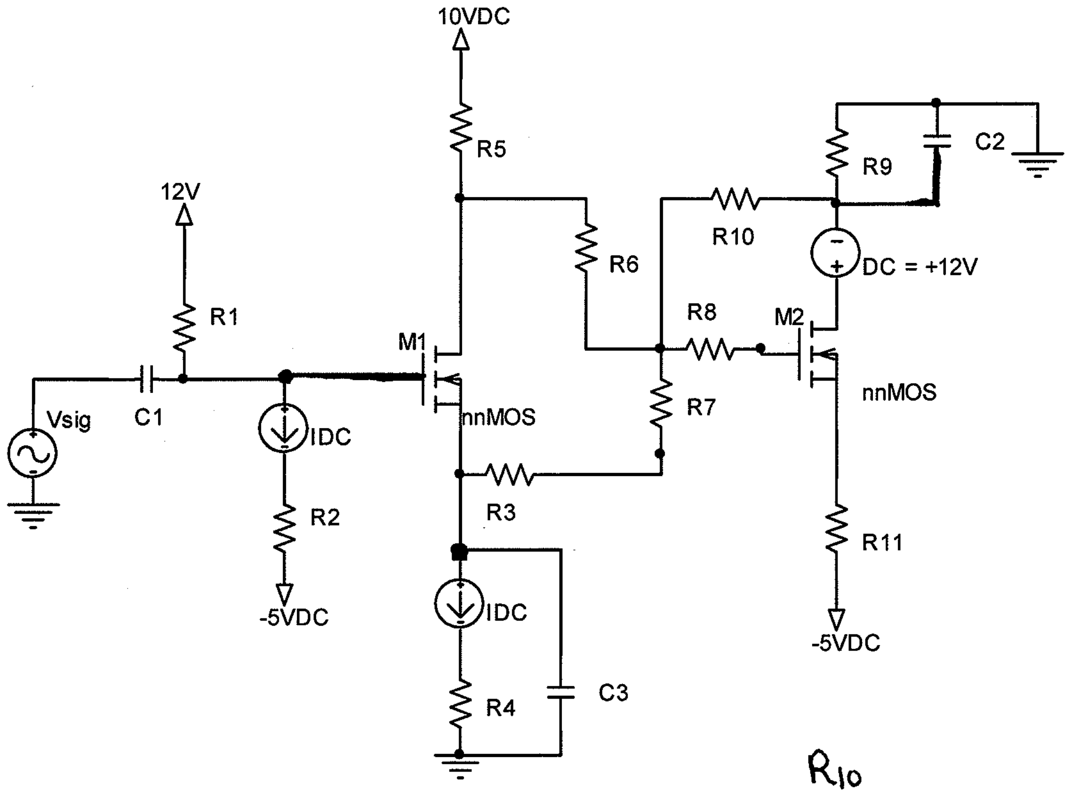
$$V_{gs2} = -\frac{1}{2}(1.8m)V_{gs1}1k - 1.8m(5k)V_{gs2} \rightarrow V_{gs2}(1+9) = -0.9\ V_{gs1}$$

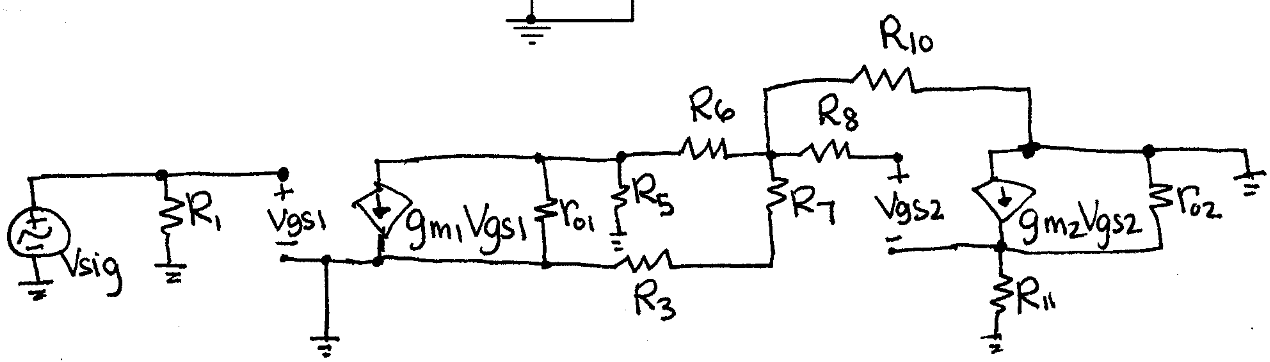
$$V_{gs1} = V_{sig}$$

$$\frac{V_o}{V_{sig}} = 9 \cdot \left(\frac{-0.9}{10}\right) = \boxed{-0.81\ V/V}$$

Problem 3 – (12 points)

For the circuit shown below, **draw** the AC small-signal equivalent circuit(use hybrid-π or model T). Make sure that everything is labeled in terms of the transistor number. (e.g. g_{m1}, v_{gs2}, r_{o1}, etc.). $\boldsymbol{\lambda \neq 0}$ for all transistors.(i.e. draw the small-signal with r_o included). v_{sig}=0.005sin(20t) AC.



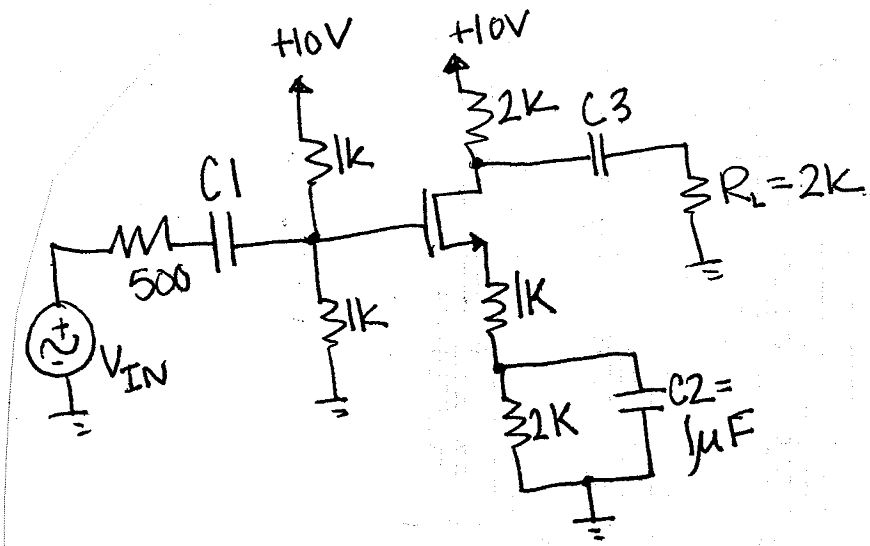


Problem 4 – **(13 points)**

Use: gm=1mA/V, λ=0, and Cgs=Cgd=5pF.

Assume that C2 yields that largest pole value for the external capacitors.

What is the operating range for the amplifier below(in Hz)?



LOW:

C2:

$$\frac{1}{C2\cdot R_{eq.}} = \frac{1}{1\mu\cdot\left(2k\,\|\,\left(\frac{1}{g_m}+1k\right)\right)} = \frac{1}{1\mu\cdot\left(\underbrace{2k\,\|\,1k+1k}\right)} = 1K\ \frac{rad}{sec}$$

High:

$$C_{eq.} = C_{gs} + C_{gd}\left(1+g_m\cdot \underset{\substack{\downarrow\\ 1k\|2k}}{R_D}\right) = 5p + 5p(1+1m\cdot 1k) = 15pF$$

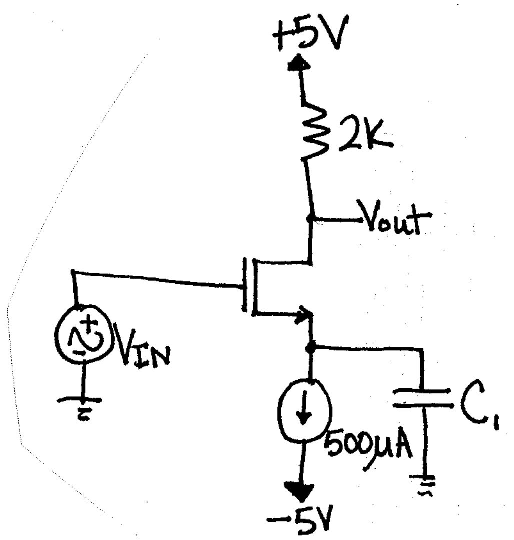
$$\omega_H = \frac{1}{C_{eq.}\cdot R'_{sig}} = \frac{1}{15p\cdot(1k\|1k\|500)} = \frac{1}{15p\cdot 250} \cong 267M\ \frac{rad}{sec}$$

$\boxed{\text{159 Hz to 43 MHz}}$

Problem 5 – (5 points)

V_t=2V, λ=0, $k_n'(W/L)$=1mA/V^2. Does this circuit operate as a **linear** AC amplifier? If so, what is the gain, $\frac{Vo}{Vsig}$, of the following circuit? If not, explain why.

V_{IN} = 5+sin(ωt).(assume that ω is in the operating range of the circuit). ~~If not, explain why.~~



$V_G = +5$ V

$500\mu = \frac{1}{2}(1m)(V_{GS}-2)^2$

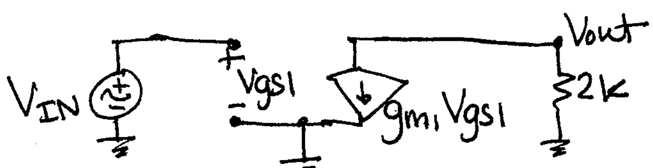
$\pm\sqrt{1} + 2 = V_{GS}$

$V_{GS} = +3, +1$ ← off

$V_D = 5 - 2k(500\mu) = 5-1 = +4V$

$V_D = +4 > (V_G - V_t) = +5-2 = +3$

∴ SATURATED



$V_{out} = -g_{m1} V_{gs1} \cdot 2k \quad , \quad V_{gs1} = V_{IN}$

$g_{m1} = 1m(3-2) = 1m$

$\frac{V_{out}}{V_{IN}} = -1m(2k) = -2 V/V$

~~$V_{IN\,total}$~~ =

$V_{out\,total} = +4 - 2\sin(\omega t)$

$V_{peak} = +6V(V_{IN}=4V) \rightarrow +6 > (V_G - V_t) = +2$ ✓

$V_{min} = +2V(V_{IN}=+6V) \rightarrow +2 < (V_G - V_t) = +4$ × NOT SATURATED

~~2~~

∴ NOT LINEAR