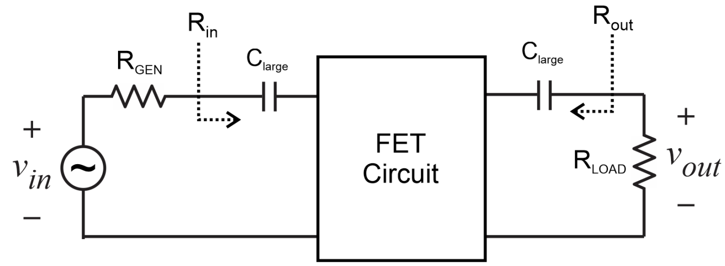
1) **Small Signal Parameters:** For the following FET amplifiers, you are going to obtain the small signal parameters, $\boldsymbol{A_V}$ (voltage gain), $\boldsymbol{R_{in}}$ and $\boldsymbol{R_{out}}$ using the circuits from homework assignment #3. The circuits from assignment #4 fit into the box shown here. The sinusoidal generator, v_{in}, has an internal resistance R_{GEN}. The amplifier output drives a resistive load, R_{LOAD}.



The FET parameters are $\boldsymbol{V_{TN} = 2.6V}$, $\boldsymbol{k_N = 0.12\ A/V^2}$, $\boldsymbol{V_A = large}$. For each circuit, the bias point (Q-point) is the same as found in homework assignment #5 with $\boldsymbol{V_{GS} = 3.0\ V, I_{DQ} = 9.6\ mA}$ ***and*** $\boldsymbol{V_{DS} = 10.4\ V}$. For this assignment you do not need to repeat the calculations of the DC parameters (Step 1). In this case, the FET is "saturated" and we will assume that the FET is operating under the small signal condition having a magnitude of v_{in} that places $v_{gs} \ll k_n\left(V_{GS} - V_{TN}\right)$ $(requirement\ for\ small\ signal)$.

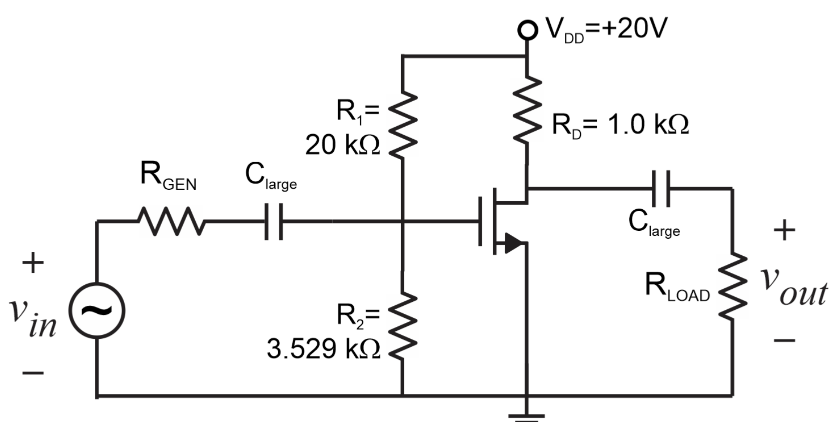
For the following circuits, use a generator resistance and load resistance of

$$\boldsymbol{R_{GEN} = 1\ k\Omega}$$

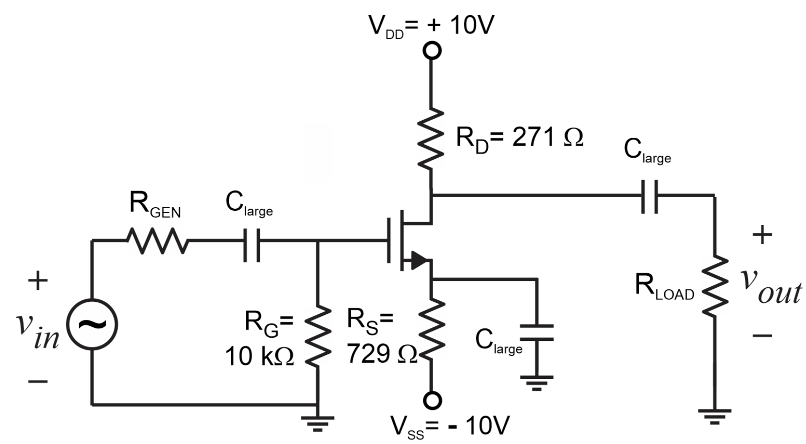
$$\boldsymbol{R_{LOAD} = 1\ k\Omega}$$

Find $\boldsymbol{A_V}$ (voltage gain), $\boldsymbol{R_{in}}$ and $\boldsymbol{R_{out}}$ for each of the following circuits (A-D).

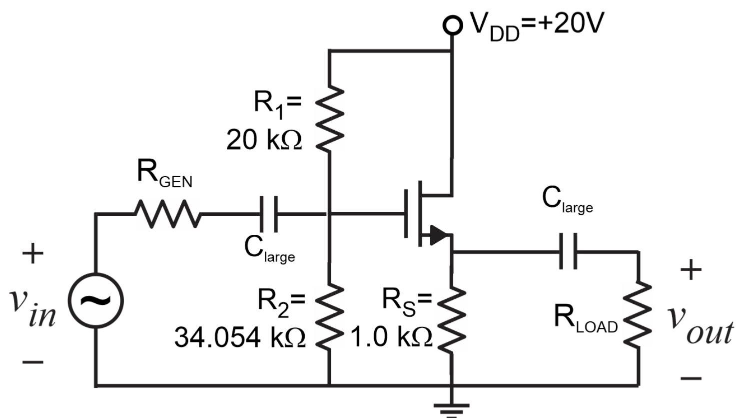
A) Common Source Amplifier



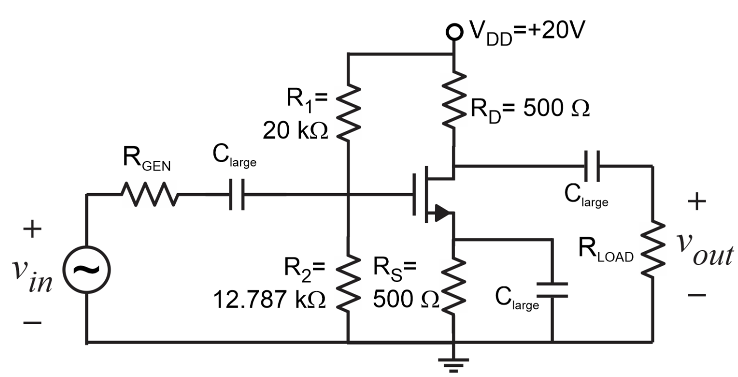
B) Common Source Amplifier with bypassed source resistor



C) Common Drain (a.k.a. Source Follower)



D) Common Source Amplifier with bypassed source resistor



2) Hand Calculation of Harmonic Distortion

Background: When the input signal to a non-linear network is a sinusoid (*cosωt*) at frequency ω (=2πf). The output from this network may contain a DC term, a fundamental frequency (ω), and a set of harmonics (2ω, 3ω, 4ω, …).

Input = *cosωt*

Output = DC + *Acosωt* + *Bcos2ωt* + *Ccos3ωt* + …

The 2nd harmonic distortion (*2HD*) at the output is defined as the ratio of the amplitude in the 2nd harmonic to the amplitude of the fundamental, namely

2HD (%) = *B/A* x 100%

Questions:

A) **Find an expression for the 2nd harmonic distortion *(2HD)* for an n-channel MOSFET** using the following expression for saturated drain current, i_D. The *2HD* will be given in terms of *A*, V_{GS} *and* V_{TN}.

Assume a sinusoidal gate-source voltage, v_{gs}, = *Acosωt*

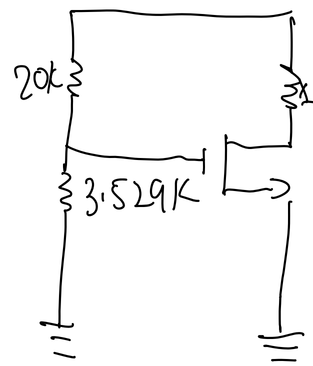
Hint: $\cos^2\Theta = ½ + ½ \cos 2\Theta$

$$i_D = \frac{k_N}{2}\left(V_{GS} - V_{TN}\right)^2 + k_N\left(V_{GS} - V_{TN}\right)v_{gs} + \frac{k_N}{2}v_{gs}^{\ 2}$$

B) What is the value of A (amplitude of v_{gs} = *Acosωt*) that produces a 1% 2HD? Assume that V_{GS} = 2.8V and V_{TN} = 2.6V. $V_{GSQ} - V_{TN}$

1

(a) $V_{TN} = 2.6V$, $K_N = 0.06 A/V$



$V_{DS} = 10.4$

$V_{GS} = 3.0$

$I_{DQ} = 9.6mA$ It's in saturation.

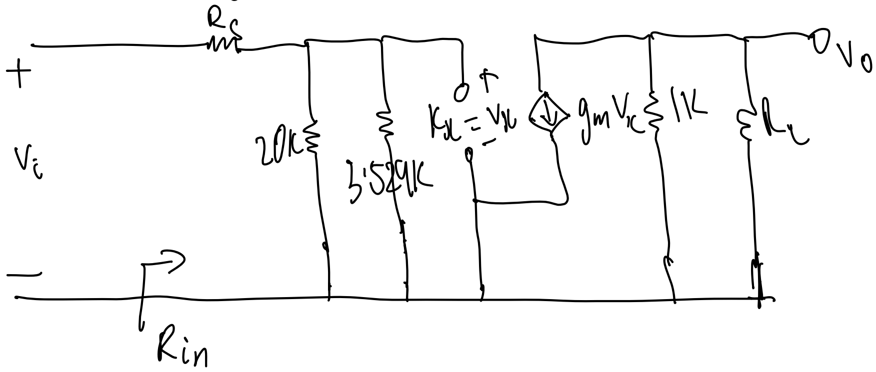
$$g_m = \frac{2 I_{DS}}{2 V_{GS}}$$

$$= \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_t)$$

$$= 2K_n (V_{GS} - V_t)$$

$$= 2(0.06)(3-2.6) = 0.048 A/V$$

AC Analysis



$$\frac{V_{out}}{V_{in}} = \frac{V_o}{V_x} = \frac{-g_m \cancel{V_{gs}}(1K)}{\cancel{V_{gs}}}$$

$$= -g_m (1K)$$

$$= -0.048(1K)$$

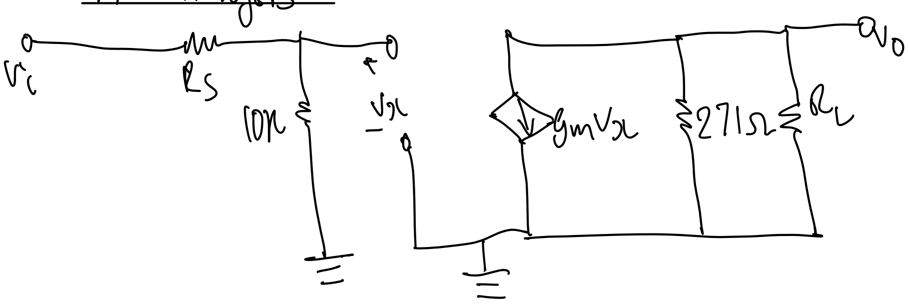
$$= -48$$

$R_{in} = (20 \| 3.529K) + R_S = 3K + R_S$

$R_{out} = 1K \| R_L$

(b) $g_m = 0.048$ A/V for this circuit

AC Analysis



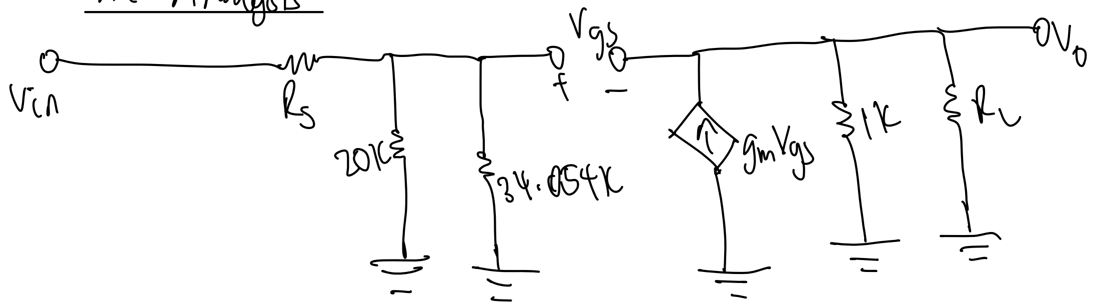
$$\frac{V_{out}}{V_{in}} = -g_m (271\Omega) = -13.008$$

$R_{in} = 10K + R_S$

$R_{out} = 271\Omega \| R_2$

(C) $g_m = 0.048\ A/V$

Ac Analysis



$$\frac{V_o}{V_{in}} = \frac{g_m \cancel{V_{gs}}(1k)}{\cancel{V_{gs}} + g_m \cancel{V_{gs}}(1k)} = g_m(1k)$$

$$= \frac{0.048(1k)}{1 + 0.048(1k)} = \frac{48}{49} \approx 0.979$$

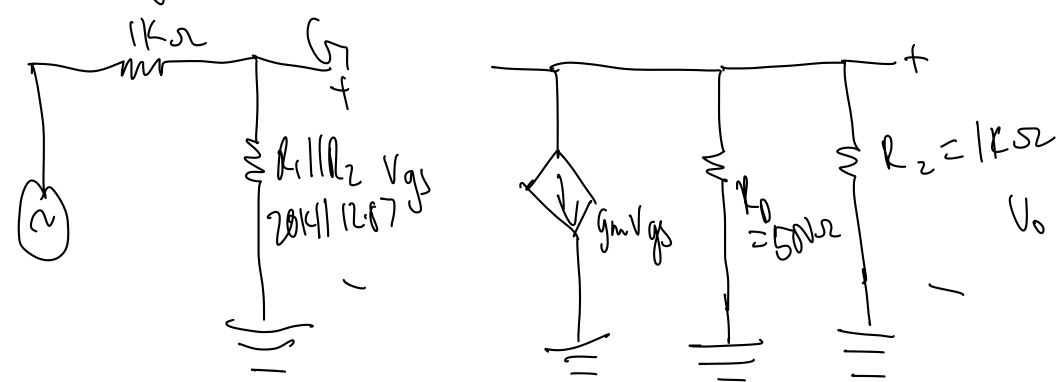
$R_{in} = (20 \| 34.05k) + R_S = 12.64 R_S$

$R_{out} = 1k \| R_L$

(D) $V_{in} = 2.6V$, $K_n = 0.06\ A/V^2$, $V_{gs} = 3V$

$I_{DQ} = 9.6mA$, $V_{DS} = 10.4V$

$$g_m = \frac{I_{DQ}}{V_{gs}} = \frac{9.6}{3} = 3.2\ mA/V$$



$V_o = -g_m V_{gs}(R_D \| R_2)$

$= -3.2(1k \| 0.5)V_{gs} = -1.0656 V_{gs}$

$$V_{gs} = \frac{V_{in}(R_1 \| R_2)}{R_1 \| R_2 + R_{sig}} = \frac{V_{in}(9.83k)}{8.83k} = V_{in}(0.886)$$

$V_o = -1.0658(0.886)V_{in}$

$$A = \frac{V_o}{V_{in}} = -1.022$$

$R_i = R_1 \| R_2 = 7.83k\Omega$

$R_o = R_D = 0.5k\Omega = 500\ \Omega$

(2)

(a) $i_D = K_n(V_{GSQ} - V_{TN})^2 + 2K_n(V_{GSQ} - V_{TN}) A\cos(\omega t) + K_n A^2 \cos^2(\omega t)$

$K_n A^2 \cos^2(\omega t) = K_n A^2 (1/2 + 1/2 \cos(2\omega t))$

$\Rightarrow$ Amplitude of 1st harmonic is $(V_{GSQ} - V_{TN})A$

$\Rightarrow$ Amplitude of 2nd harmonic is $K_n A^2/2$

$$2HD = \frac{K_n A^2/2}{2A K_n (V_{GSQ} - V_{TN})} = \frac{A}{4(V_{GSQ} - V_{TN})}$$

(B) $V_{GSQ} = 2.8V$, $V_{TN} = 2.6V$

$$2HD = \frac{A}{4(2.8-2.6)} = \frac{A}{0.8} = \frac{1}{100} \Rightarrow A = 8mV$$

So we got that the incremental voltage v_{gs}, that raids on top of quiescent voltage V_{GSQ}, need to have a amplitude less than 8mV, for the given V_{GSQ} and V_{TN}, to have 2HD less than 1%.