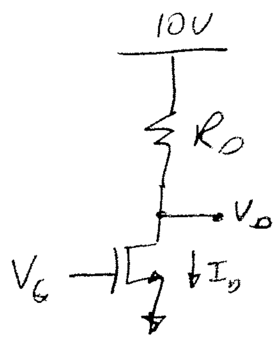
2.



$KP_N = 100\mu A/V$

$V_{TN} = 0.7V$

$W/L = 10\mu m / 1\mu m$

$$\text{Max } R_D \text{ for saturation} = \frac{10V - V_{DS_{sat}}}{I_{DSAT}}$$

where $V_{DS_{sat}} = V_{GS} - V_{TN}$

w/ $V_{GS} = 1V \Rightarrow V_{DS_{sat}} = 0.3V$

$V_{GS} = 2V \Rightarrow V_{DS_{sat}} = 1.3V$

$$I_{DSAT} = \frac{1}{2} KP_N \frac{W}{L} (V_{GS} - V_{TN})^2$$

w/ $V_{GS} = 1V \Rightarrow I_{DSAT} = 45\mu A$

w/ $V_{GS} = 2V \Rightarrow I_{DSAT} = 845\mu A$

V_{GS}	Max R_D
1V	$\frac{10V - 0.3V}{45\mu A} = 216k\Omega$
2V	$\frac{10V - 1.3V}{845\mu A} = 10.3k\Omega$

w/ $V_G = 2V$; $R_D = 5k\Omega$

$$R_D = 5k\Omega \leq R_{MAX} = 10.3k\Omega$$

∴ Transistor is saturated.

w/ $R_D = 5k\Omega$: $I_D = 845\mu A$

$$V_O = 10V - I_D R_D = 10V - 845\mu A(5k\Omega) = 5.78V$$

w/ $V_G = 2V$; $R_D = 15k\Omega$

$$R_D = 15k\Omega > R_{MAX} = 10.3k\Omega$$

∴ Transistor is in triode.

$$I_D = K_N' \frac{W}{L}\left[V_{GS} - V_{TN} - \frac{1}{2}V_{DS}\right]V_{DS}$$

$$I_D = (1m\,^{A}/_{V^2})\left[1.3V - 0.5(10V - I_D 15k\Omega)\right](10V - I_D 15k\Omega)$$

$$\Rightarrow 112.5\times10^3 I_D^2 - 129.5 I_D + 37\times10^{-3} = 0$$

$$I_D = 527\mu A \quad \underline{OR} \quad 624\mu A$$

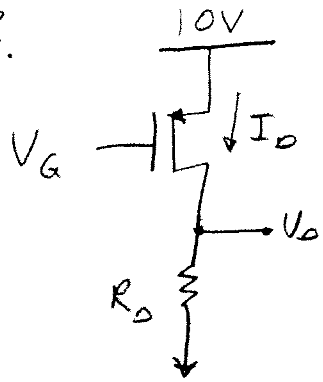
$V_O = 2.1V \Rightarrow$ still in sat. (not valid) $\qquad V_O = 0.64V \Rightarrow$ triode (valid)

w/ $R_D = 15k\Omega$:

$$I_D = 624\mu A$$

$$V_O = 0.64V$$

3.



$KP_p = 30\,\mu A/V$

$V_{TP} = -1V$

$W/L = 10$

$$\text{Max } R_D \text{ for saturation} = \frac{10V - V_{SDsat}}{I_{DSAT}}$$

where $V_{SDsat} = V_{SG} - |V_{TP}|$

w/ $V_G = 8.5V \Rightarrow V_{SDsat} = 0.5V$

w/ $V_G = 7.5V \Rightarrow V_{SDsat} = 1.5V$

$$I_{Dsat} = \frac{1}{2} KP_p \frac{W}{L} \left(V_{SG} - |V_{TP}|\right)^2$$

w/ $V_G = 8.5V \Rightarrow I_{Dsat} = 37.5\,\mu A$

w/ $V_G = 7.5V \Rightarrow I_{Dsat} = 337.5\,\mu A$

V_G	Max R_D
8.5V	$\frac{10V - 0.5V}{37.5\,\mu A} = 253\,k\Omega$
7.5V	$\frac{10V - 1.5V}{337.5\,\mu A} = 25.2\,k\Omega$

w/ $V_G = 7.5V$ & $R_D = 20k\Omega$

$R_D = 20k\Omega \leq R_{MAX} = 25.2k\Omega$

∴ Transistor is saturated

w/ $R_D = 20k\Omega$

$I_D = 337.5\mu A$

$V_D = I_D R_D = 337.5\mu A(20k\Omega) = 6.75V$

w/ $V_G = 7.5V$ & $R_D = 40k\Omega$

$R_D = 40k\Omega > R_{MAX} = 25.2k\Omega$

∴ Transistor is in triode.

$$I_D = KP_p \frac{W}{L}\left[V_{SG} - |V_{TP}| - \frac{1}{2}V_{SD}\right]V_{SD}$$

$$I_D = (0.3\,mA/V)\left[1.5V - 0.5(10V - I_D 40k\Omega)\right](10V - I_D 40k\Omega)$$

$$\Rightarrow 240\times10^3 I_D^2 - 101 I_D + 10.5\times10^{-3} = 0$$

$I_D = 187.5\mu A$ or $233.3\mu A$

$V_D = 7.5V \Rightarrow$ still in sat (not valid)

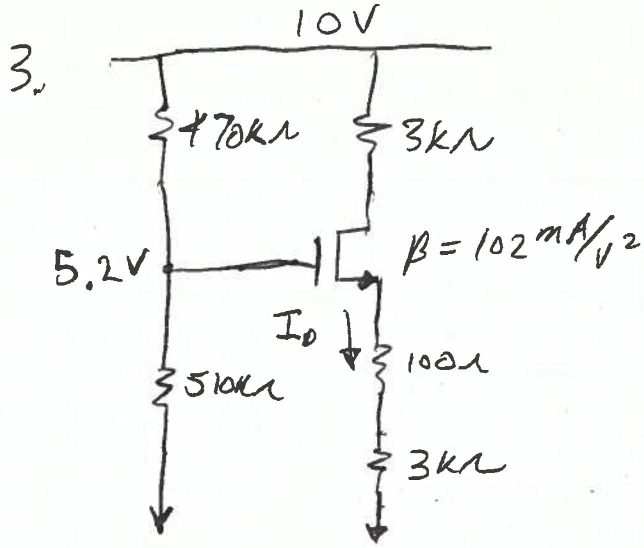
$V_D = 9.33V \Rightarrow$ triode (valid)

w/ $R_D = 40k\Omega$

$I_D = 233.3\mu A$

$V_D = 9.33V$

3.



$KP_N \frac{W}{L} = \beta = 102\ mA/V^2$

$V_{TN} = 2.0V$

$\lambda = 0.01V^{-1}$ (r_o calc only)

$$V_G = 10V\left(\frac{510K}{470k + 510k}\right) = 5.20V$$

$$I_D = \frac{1}{2} KP_N \frac{W}{L}\left[V_G - I_D R_S - V_{TN}\right]^2$$

$$I_D^2 R_S^2 - I_D\left[2(V_G - V_{TN})R_S + \frac{2}{KP_N \frac{W}{L}}\right] + (V_G - V_{TN})^2 = 0$$

$$9.61\times10^6 I_D^2 - 19.86\times10^3 I_D + 10.24 = 0$$

$$I_D = 987\ \mu A \quad \underline{OR} \quad 1.08\ mA$$

$$V_S = I_D R_S = 3.06V \quad \underline{OR} \quad 3.35V \text{ (inconsistent)}$$

(valid)

$$V_D = 10V - 3k\Omega(987\mu A) = 7.04V$$

$$g_m = KP_N \frac{W}{L}(V_{GS} - V_{TN}) = (102\ mA/V^2)(2.14 - 2.0) = 14.3\ mA/V$$

$$r_o = \frac{1}{\lambda I_D} = \frac{1}{(0.01V^{-1})(987\mu A)} = 101k\Omega$$

$V_D = 7.04V$		$g_m = 14.3\ mA/V$
$V_G = 5.2V$	$I_D = 987\mu A$	$r_o = 101k\Omega$
$V_S = 3.06V$		

April 12, 2019

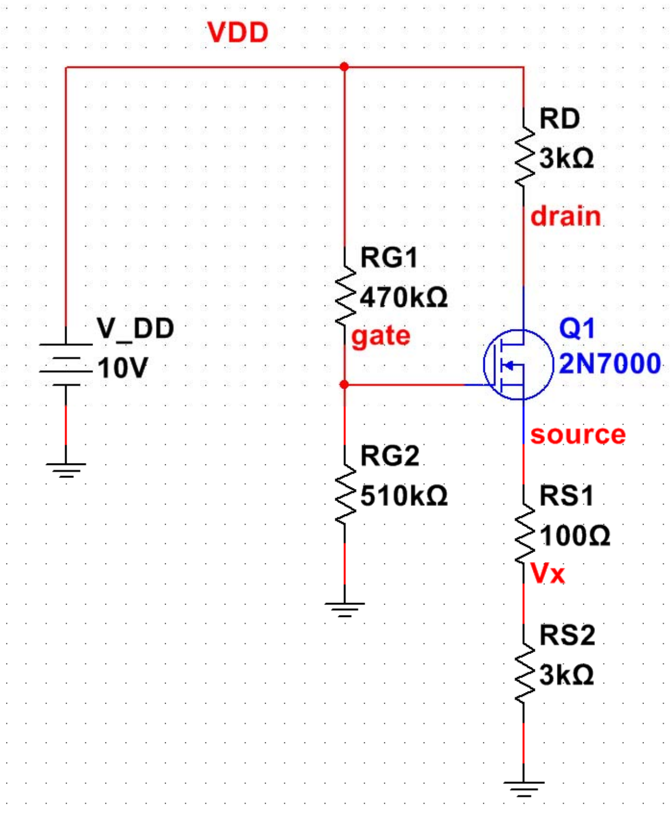
ECEN 325

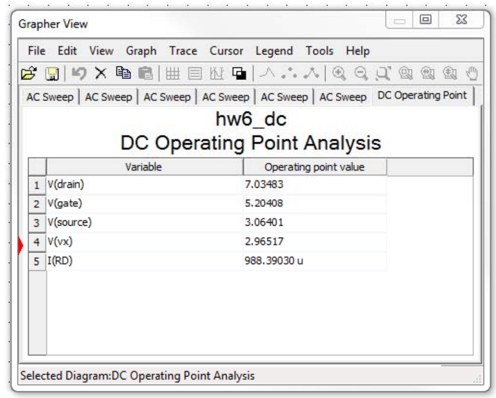
Homework #8 Multisim

Instructor: Sam Palermo

3.

DC Operating Points





	Variable	Operating point value
1	V(drain)	7.03483
2	V(gate)	5.20408
3	V(source)	3.06401
4	V(vx)	2.96517
5	I(RD)	988.39030 u

4. Common Source Amplifier

$$A_V = -\frac{g_m(R_D \| R_L)}{1 + g_m R_{S1}} = -\frac{(14.3\,\text{mA/V})(3\,\text{k}\Omega \| 20\,\text{k}\Omega)}{1 + (14.3\,\text{mA/V})(100\,\Omega)}$$

$$\boxed{A_V = -15.4\ \text{V/V} = 23.7\,\text{dB}}$$

$$R_{in} = R_G = 470\,\text{k}\Omega \| 510\,\text{k}\Omega = 245\,\text{k}\Omega$$

$$\boxed{R_{in} = 245\,\text{k}\Omega = 108\,\text{dB}\Omega}$$

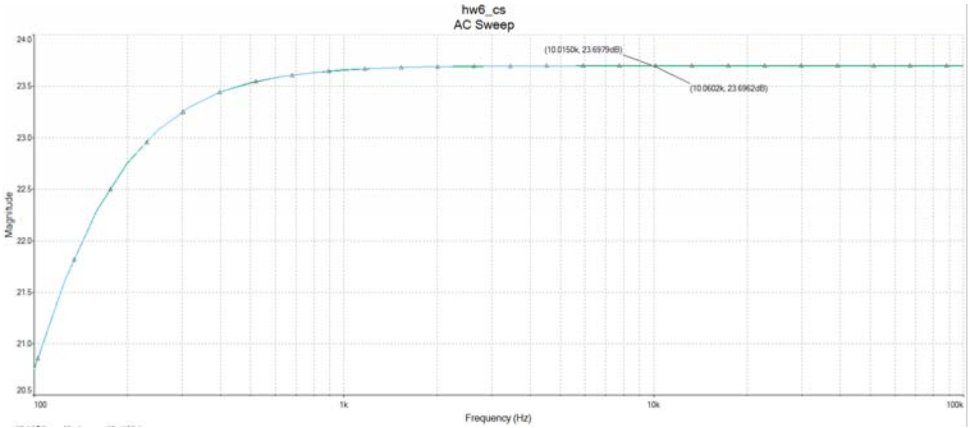
$$\boxed{R_{out} = R_D = 3\,\text{k}\Omega = 69.5\,\text{dB}\Omega}$$

$$G_V = \frac{R_{in}}{R_{in} + R_{vs}} A_V = \frac{245\,\text{k}\Omega}{245\,\text{k}\Omega + 50}(-15.4)$$

$$\boxed{G_V = -15.4\ \text{V/V} = 23.7\,\text{dB}}$$

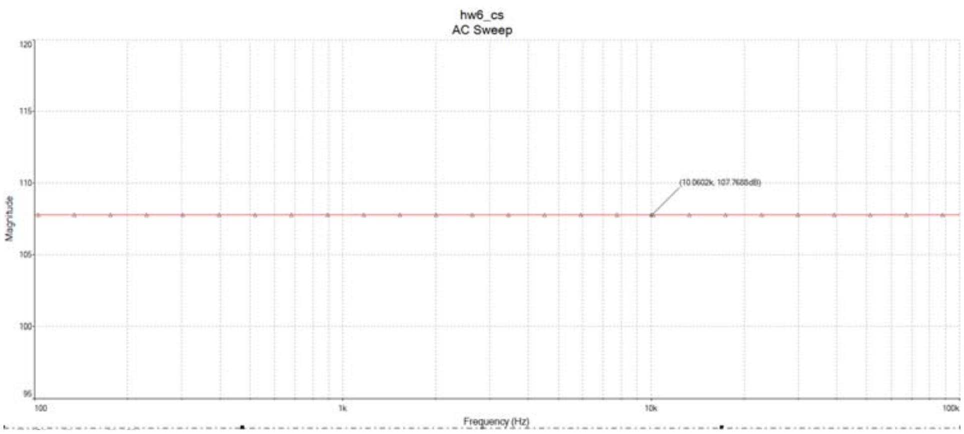
2. Common Source Amplifier

A_V and G_v



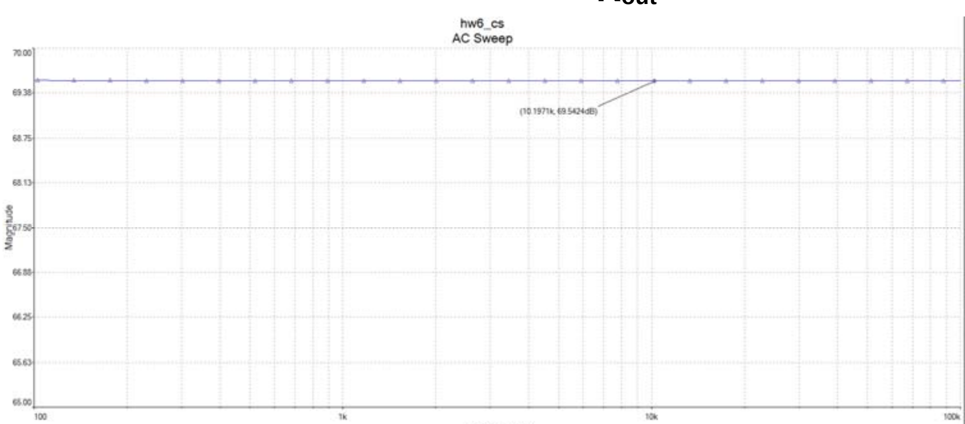
The simulated value of 23.7dB closely matches the hand calculation of 23.7dB for both A_v and G_v.

R_{in}



The simulated R_{in} value of 108dBΩ matches the hand calculation of 108dBΩ.

R_{out}



The simulated R_{out} value of 69.5dBΩ closely matches the hand calculation of 69.5dBΩ.

5. Common Drain Amplifier

$$A_v = \frac{g_m(R_S \| R_L)}{1 + g_m(R_S \| R_L)} = \frac{14.3^{mA/V}(3.1k\Omega \| 20k\Omega)}{1 + 14.3^{mA/V}(3.1k\Omega \| 20k\Omega)}$$

$$\boxed{A_v = 0.975\ V/V = -0.22\ dB}$$

$$R_{in} = R_G = 470k\Omega \| 510k\Omega = 245k\Omega$$

$$\boxed{R_{in} = 245k\Omega = 108\ dB\Omega}$$

$$R_{OUT} = R_S \| \frac{1}{g_m} = 3.1k\Omega \| \frac{1}{14.3^{mA/V}}$$

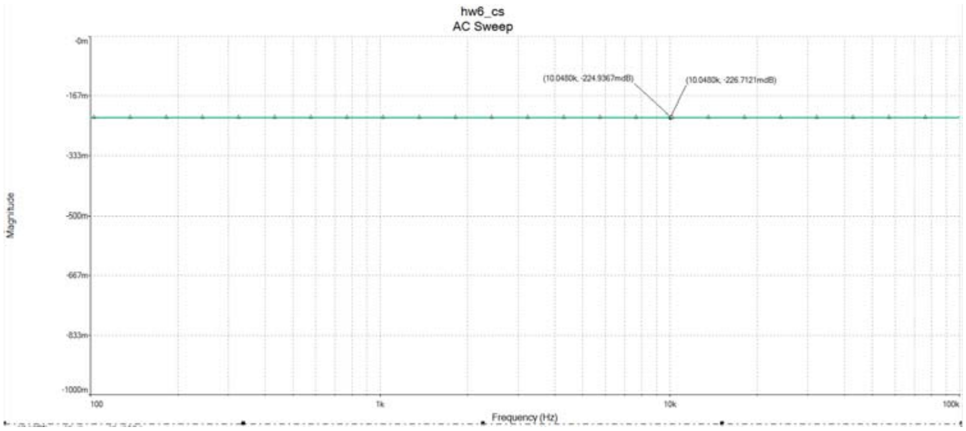
$$\boxed{R_{OUT} = 68.4\Omega = 36.7\ dB\Omega}$$

$$G_v = \frac{R_{in}}{R_{in} + R_{vs}} A_v = \frac{245k\Omega}{245k\Omega + 50}(0.975)$$

$$\boxed{G_v = 0.975\ V/V = -0.22\ dB}$$

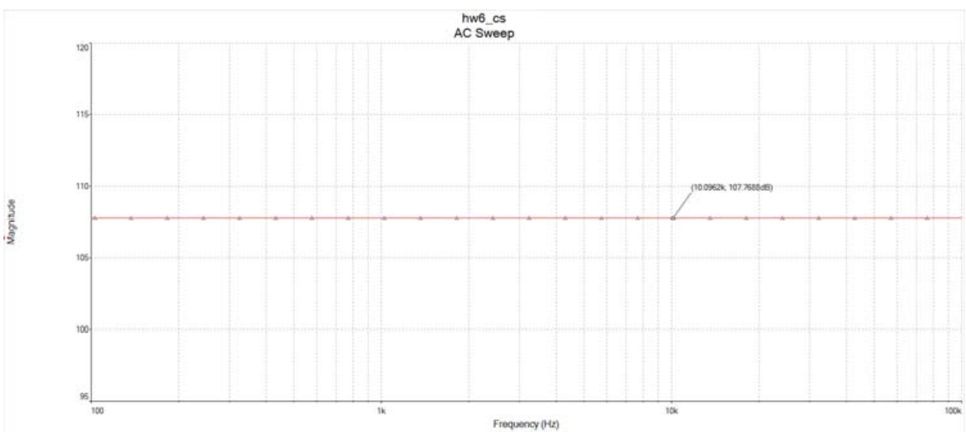
3. Common Drain Amplifier

A_V and G_v



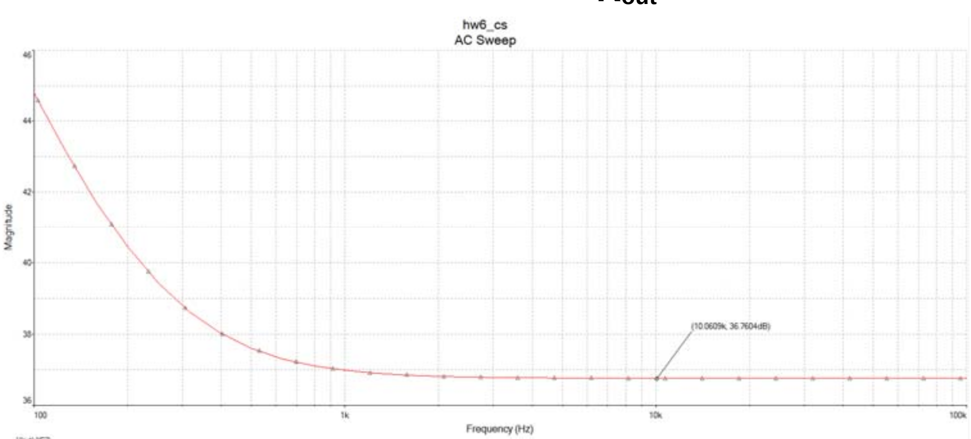
The simulated value of -0.22dB and -0.23dB closely matches the hand calculation of -0.22dB for both A_v and G_v, respectively.

R_{in}



The simulated R_{in} value of 108dBΩ matches the hand calculation of 108dBΩ.

R_{out}



The simulated R_{out} value of 36.8dBΩ closely matches the hand calculation of 36.7dBΩ.

6. Common Gate Amplifier

$A_v = g_m (R_D || R_L) = (14.3 \frac{mA}{V})(3k\Omega || 20k\Omega)$

$$\boxed{A_v = 37.3 \frac{V}{V} = 31.4 dB}$$

$R_{in} = R_S || \frac{1}{g_m} = 3.1k\Omega || \frac{1}{14.3 \frac{mA}{V}}$

$$\boxed{R_{in} = 68.4\Omega = 36.7 dB\Omega}$$

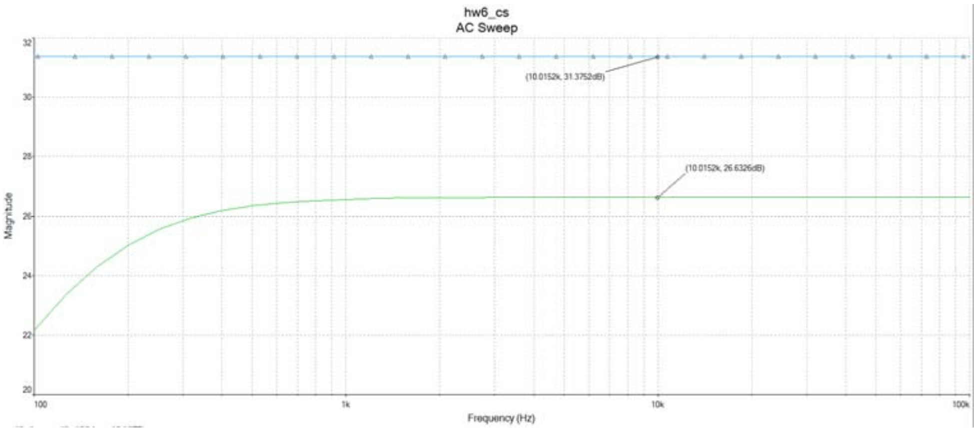
$$\boxed{R_{out} = R_D = 3k\Omega = 69.5 dB\Omega}$$

$G_v = \frac{R_{in}}{R_{in} + R_{vs}} A_v = \frac{68.4\Omega}{68.4\Omega + 50\Omega} (37.3 \frac{V}{V})$

$$\boxed{G_v = 21.5 \frac{V}{V} = 26.7 dB}$$

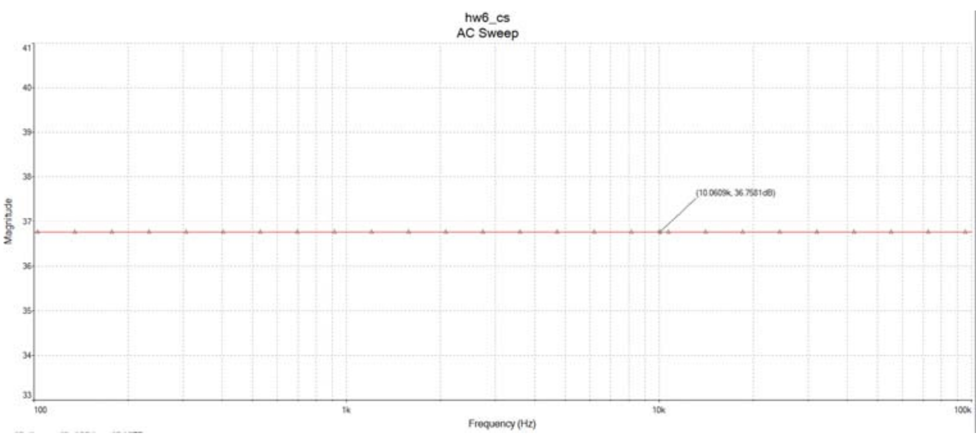
4. Common Gate Amplifier

A_V and G_v



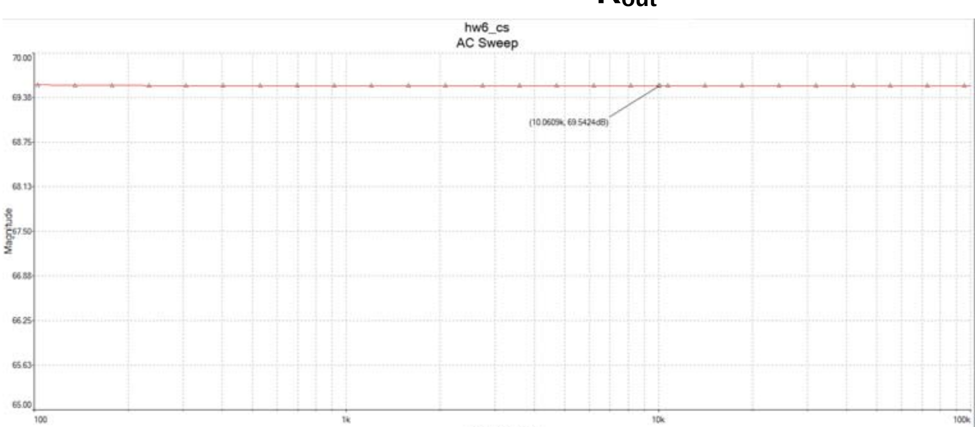
The simulated A_v value of 31.4dB matches closely the hand calculation of 31.4dB. The simulated G_v value of 26.6dB closely matches the hand calculation of 26.7dB.

R_{in}



The simulated R_{in} value of 36.8dBΩ matches the hand calculation of 36.7dBΩ.

R_{out}



The simulated R_{out} value of 69.5dBΩ closely matches the hand calculation of 69.5dBΩ.