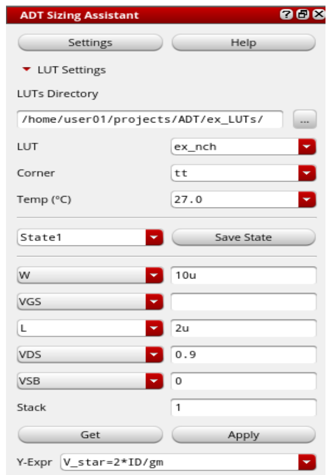
Analog IC Design

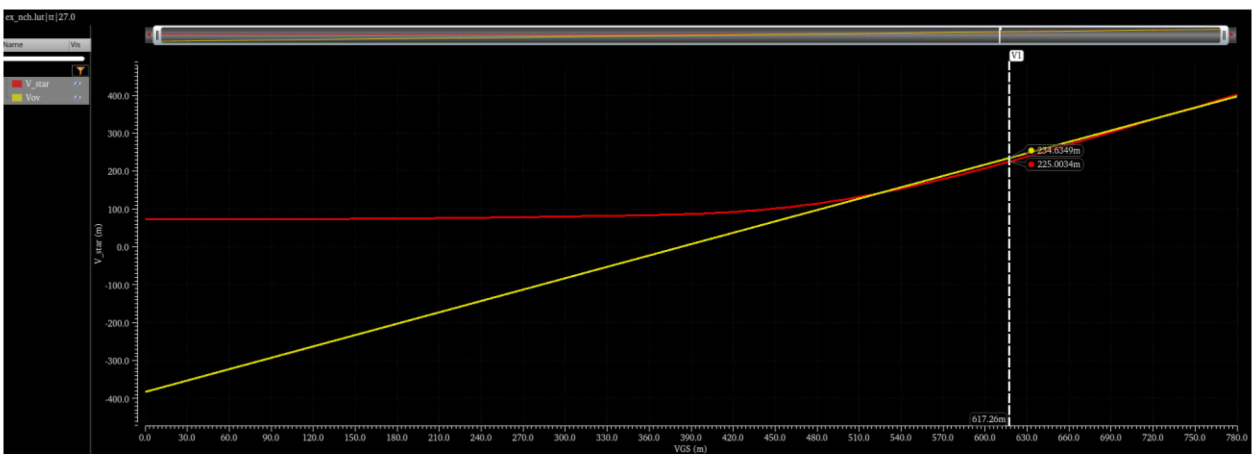
Lab 2

Part 1: Sizing Chart

Sizing Assistant



V* & Vov vs VGS

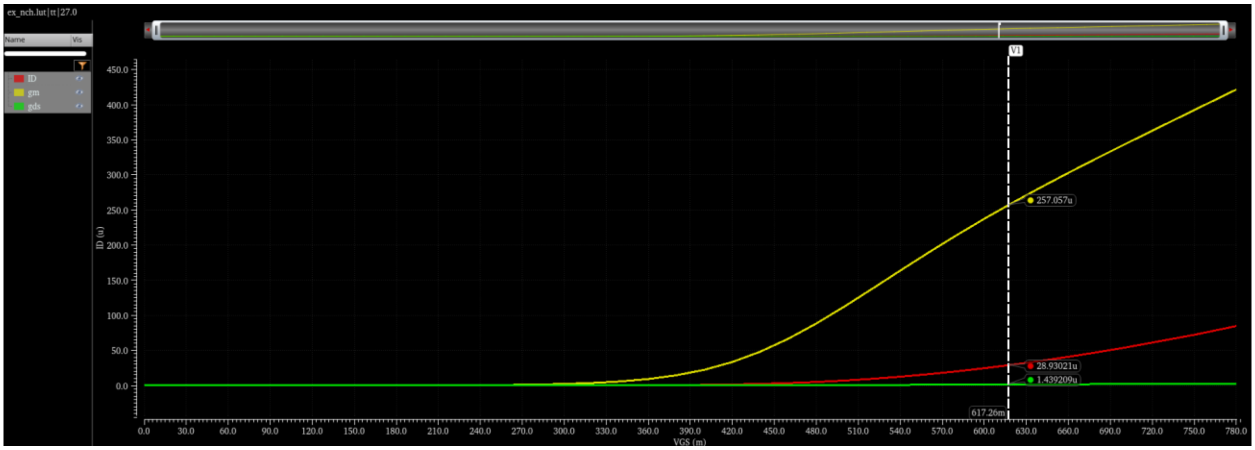


Mag (A_v) = $2V_{RD}/V_Q^*$ → 8 = (2(1.8/2))/V* → V_Q^* = 0.225 V

RD = V_{RD}/ID = (1.8/2)/100µ = 9 kΩ

From Graph: VGS_Q = 617.26 mV, Vov_Q = 234.6 mV

ID, gm & gds vs VGS



From Graph: ID_X = 28.93 μA, gm_X = 257.057 μS, gds_X = 1.439 μS

Width Sizing

W = $\frac{(100\mu)(10\mu)}{28.93\mu}$ = 34.566 ≈ 34.6 μm

gm_Q = $\frac{(257.057\mu)(34.6\mu)}{10\mu}$ = 889.4 μS

gds_Q = $\frac{(1.439\mu)(34.6\mu)}{10\mu}$ = 4.979 μS

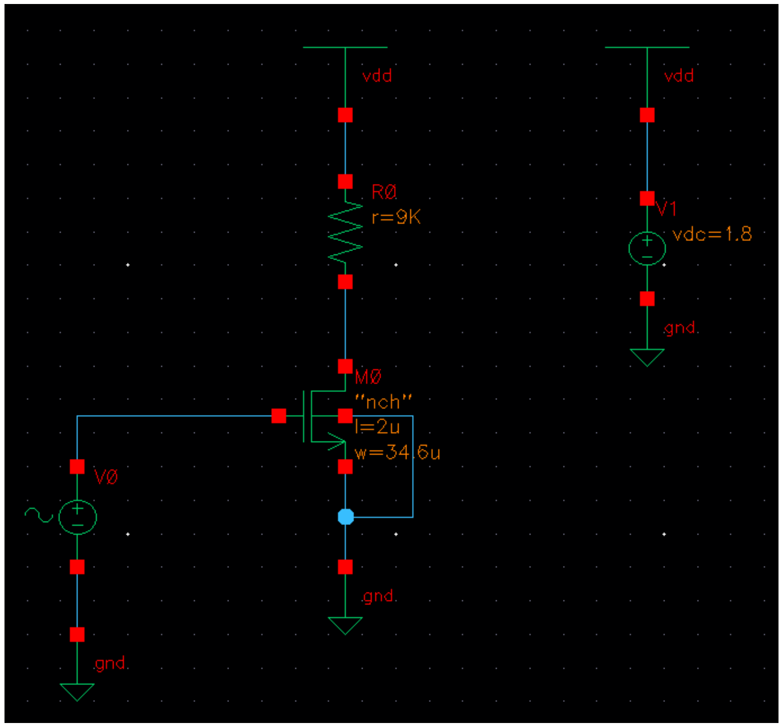
r_o = 1/gds_Q = $\frac{1}{(4.979\mu)}$ = 200.8 kΩ

Gain = |Av| = gm_Q (RD || r_o) = $\frac{889.4\mu}{\frac{1}{9k}+\frac{1}{200.8k}}$ = 7.66 ≈ 8

Part 2: CS Amplifier

1) OP & AC Analysis

Schematic



DC OP (Q-point)

M0:vgs M0:id M0:gm M0:gds M0:vd...

	Name	Value
1	M0:vgs	617.3E-3
2	M0:id	100.4E-6
3	M0:gm	893.0E-6
4	M0:gds	4.997E-6
5	M0:vds	896.6E-3
6	M0:region	2.000
7	M0:rout	200.1E3

	ID (μA)	gm (μS)	gds (μS)	VDS (mV)	r_o (kΩ)	Region
Part 1	100.0	889.4	4.98	900.0	200.8	Sat.
Part 2	100.4	893.0	4.997	896.6	200.1	Sat.

RD & r_o

- We notice that RD (9 kΩ) << r_o (200 kΩ), and gain = -gm (RD|| r_o). Therefore, we can justify ignoring r_o since that the smaller resistance is more dominant in parallel connection.
- If min. L is used, r_o decreases, as $r_o = \frac{v_A}{I_{DS}}$ & Early voltage is directly proportional with L ($V_A \propto L$). Moreover, smaller L causes short channel effects which lead to lower drain current.

Intrinsic Gain

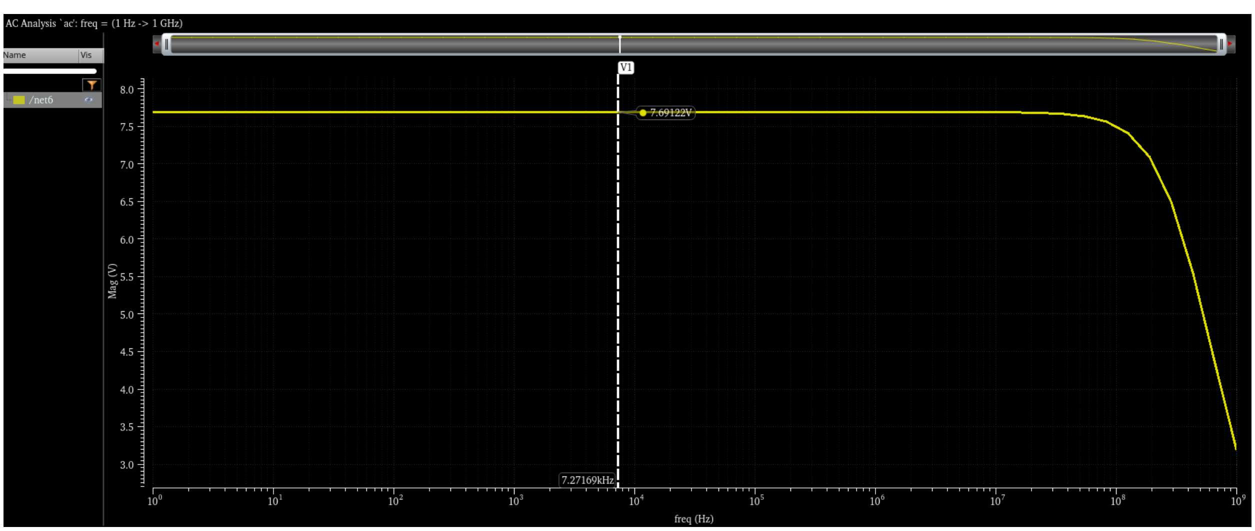
Intrinsic gain = -gm (r_o) = -(896.6μ)(200.1k) = -179.4 $\approx$ -179

Analytical Amplifier Gain

- Av = -gm (RD|| r_o) = = $\frac{-896.6\mu}{\frac{1}{9k}+\frac{1}{200.1k}}$ = -7.72 ≈ -8 (per Part 2)
- Av = -7.66 (per Part 1)
- |Amplifier gain| << |Intrinsic Gain|

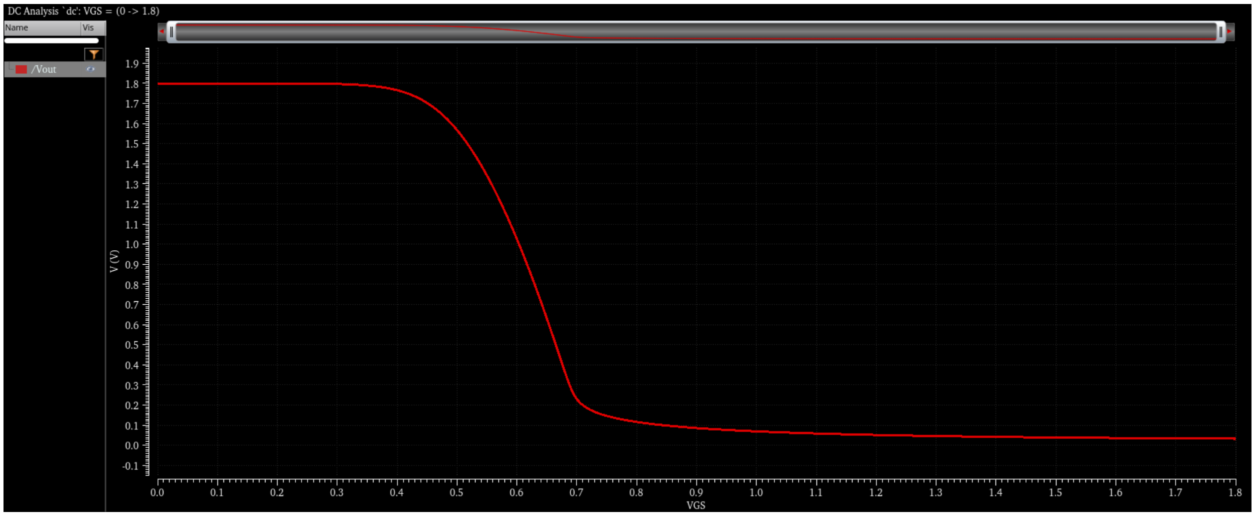
AC Analysis

Magnitude = 7.69



2) Gain Non-Linearity

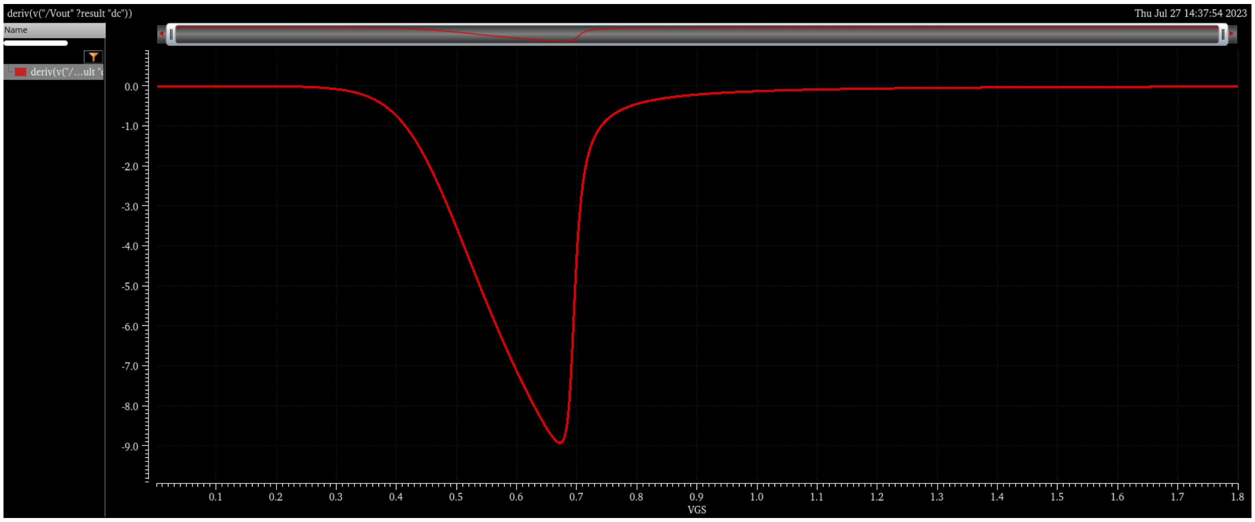
Vout vs Vin (DC)



Comment:

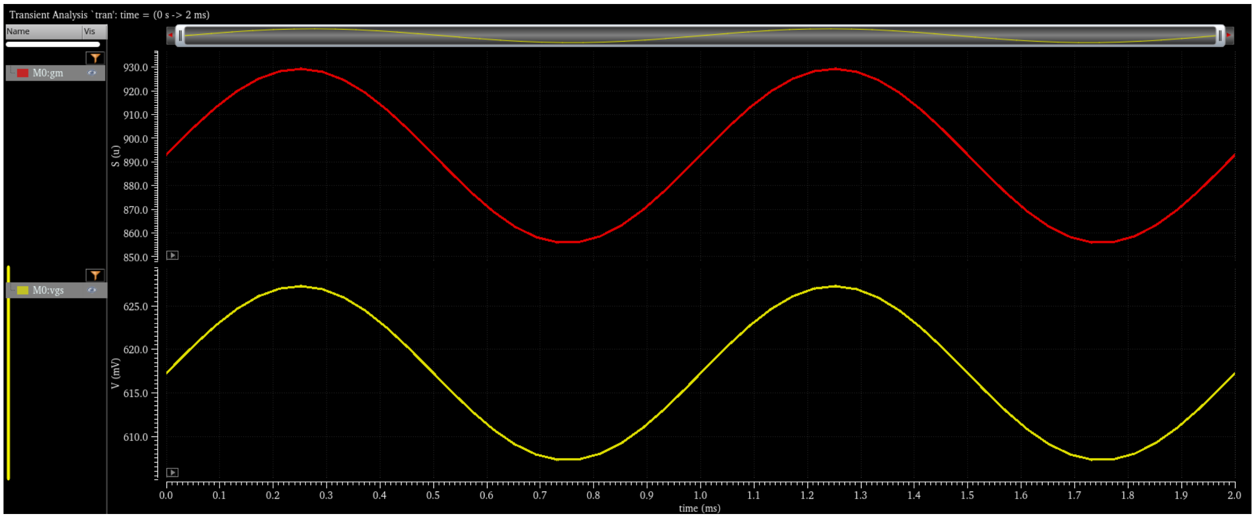
- It is a non-linear relation.
- Gain = -gm (RD) & gm = f(Vin), which means that any change in input voltage would change gm, thus changing the Q-point on the quadratic ID vs VGS curve.

Small Signal Gain



Comment: It is a non-linear relation due to dependence of gm on the input voltage, thus changing the Q-point on the quadratic ID vs VGS curve. The absence of source resistance increases the non-linearity.

gm vs Time

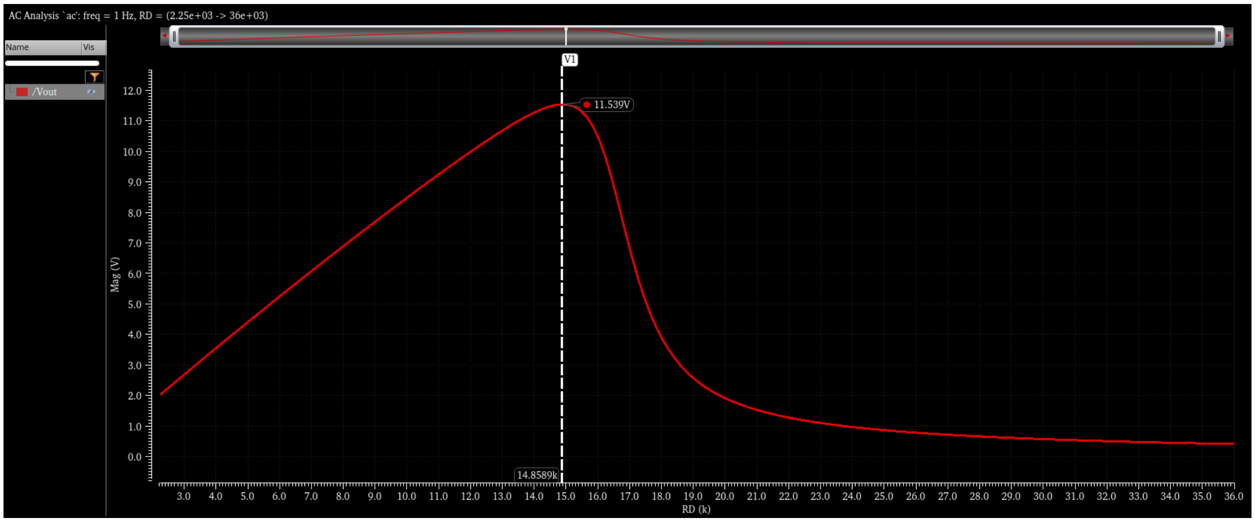


Comments:

- gm has the same waveform as Vin, so gm = f(Vin)
- The amplifier is non-linear as it is function of gm and gm varies with Vin

3) Maximum Gain

Gain vs RD



Behavior Justification

At the beginning, the relation is linear since Av = (2*VRD)/Vov per square-law. This relation holds until the voltage drop on RD incredibly increases making the transistor go out from saturation region, so this relation is not valid anymore.

Highest Gain

RD = 14.86 kΩ and Av = 11.539

Analytical Analysis

Maximum gain happens when Vout = Vov = VGS – Vth = 0.617-0.38 = 0.24

$$(VDD - Vov)/ID = \frac{1.8-0.24}{100.4\mu} = 15.54\ k\Omega$$

$$|A_V| = 889.4m * \frac{200.8\times15.54}{200.8+15.54} \approx 12.8$$

	RD (kΩ)	Av
Simulation	14.86	15.54
Analytical	11.54	12.8

Signal Swing at Maximum Gain

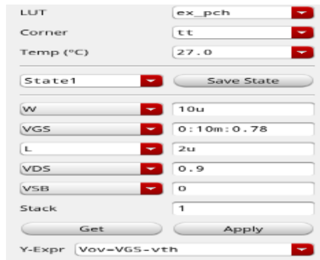
Available swing zero since output is set to Vov. Any swing would lead to driving the transistor out of saturation.

Supply Voltage Scaling Down

From this equation Av = (2*VRD)/Vov, decreasing VDD would lead to a lower voltage drop on drain resistance leading to a smaller gain.

4) Gain Linearization (Feedback)

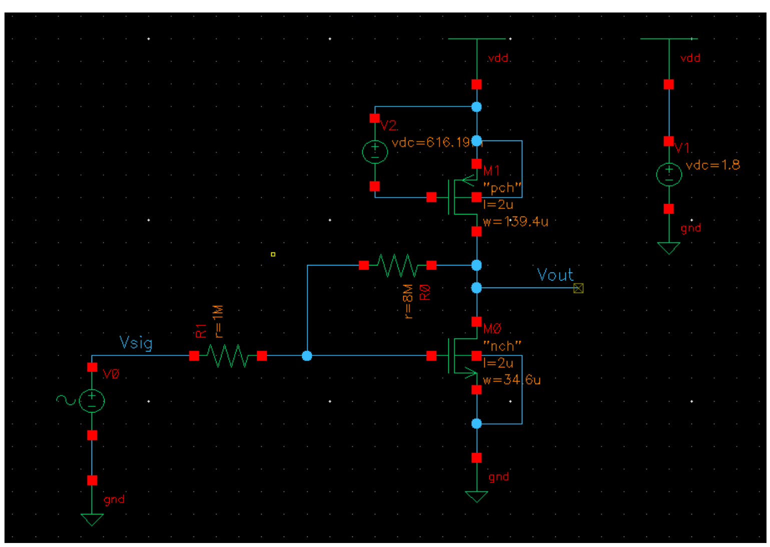
Sizing



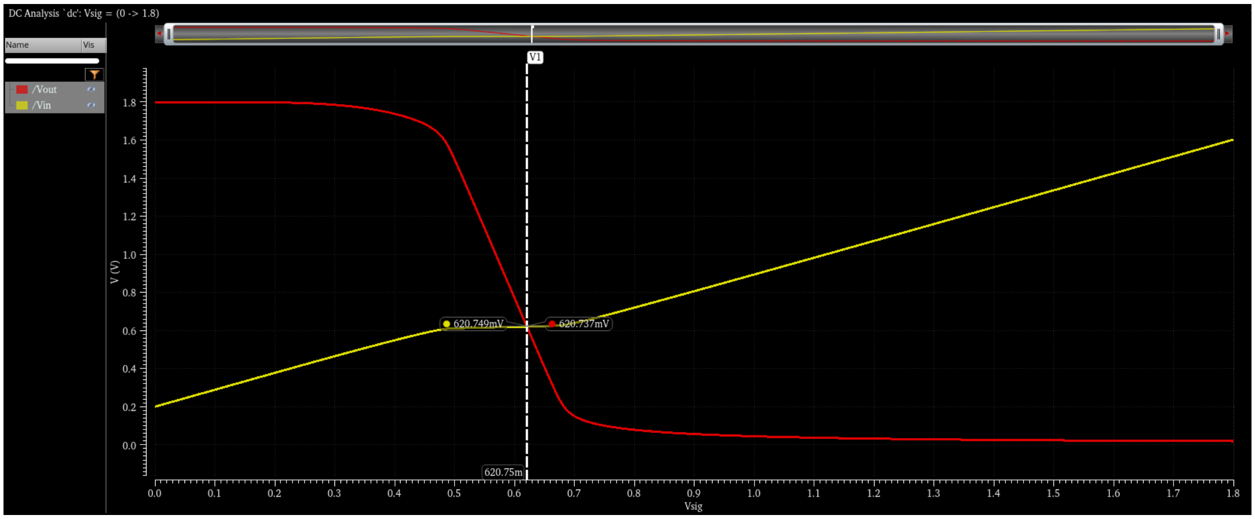
From Graph: $VGS_Q = 616.19$ mV, $Vov_Q = 222.84$ mV, $ID_X = 7.175$ μA

$$W = \frac{(100\mu)(10\mu)}{7.175\mu} = 139.37 \approx 139.4 \ \mu m$$

Schematic

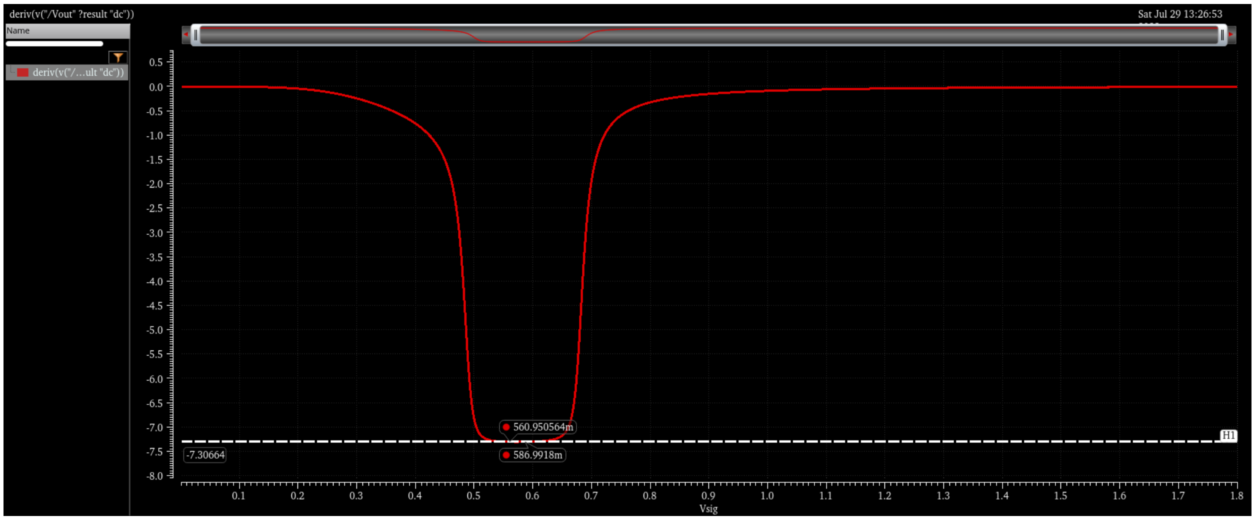


Vin and Vout vs Vsig



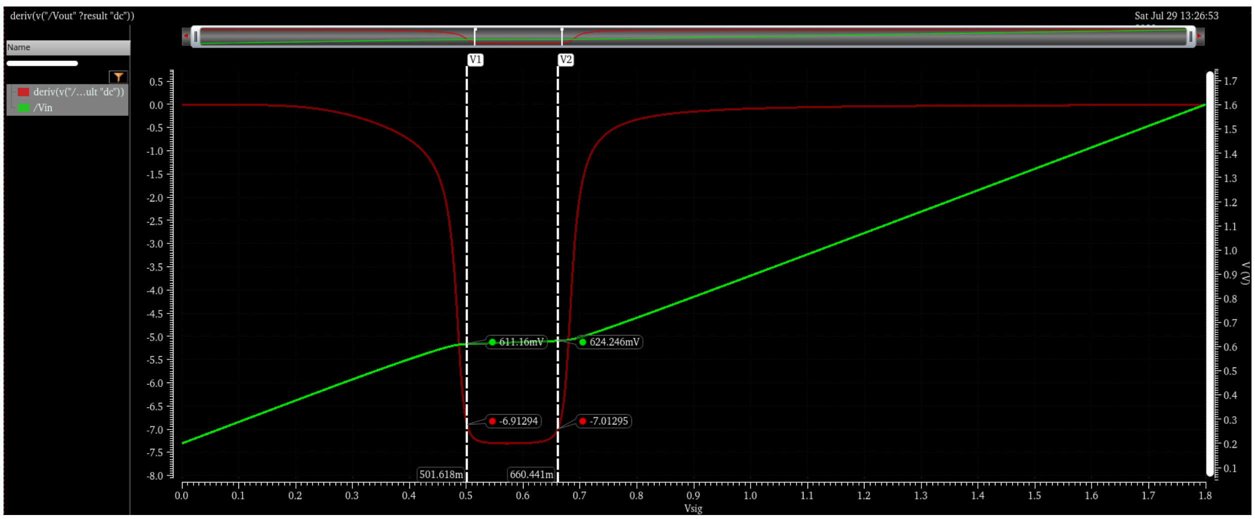
- V = 620.75 mV is the voltage where the two curves cross. Note that this voltage is approximately equal to VGS_{M1}. At this point Vout is also equal to Vin because no current flows in the two resistors.
- Vout vs Vsig is non-linear per square law as gm is non-linear and function in input voltage.

Small Signal Gain



- Small signal gain = -7.3
- The gain is approximately **linear** only in the part where the derivative is constant (saturation region). Despite the non-linearity in large signal, we linearize the curve around the operating point making a linear relation in small signal. The gain is non-linear in triode and cutoff regions.

Simulation Input Range



Vin ≈ 610 mV – 625 mV

Analytical Input Range

Input range = (1.8 – 2* 0.225)/8 = 168 mV

From graph: Vsig range = 660 - 500 = 160 mV

	Input Range (mV)
Analytic	168
Simulation	160