Analog IC Design – Cadence Tools

LPF Simulation and MOSFET Characteristics

Lab 01

Part 2: MOSFET Characteristics

1. ID vs VGS

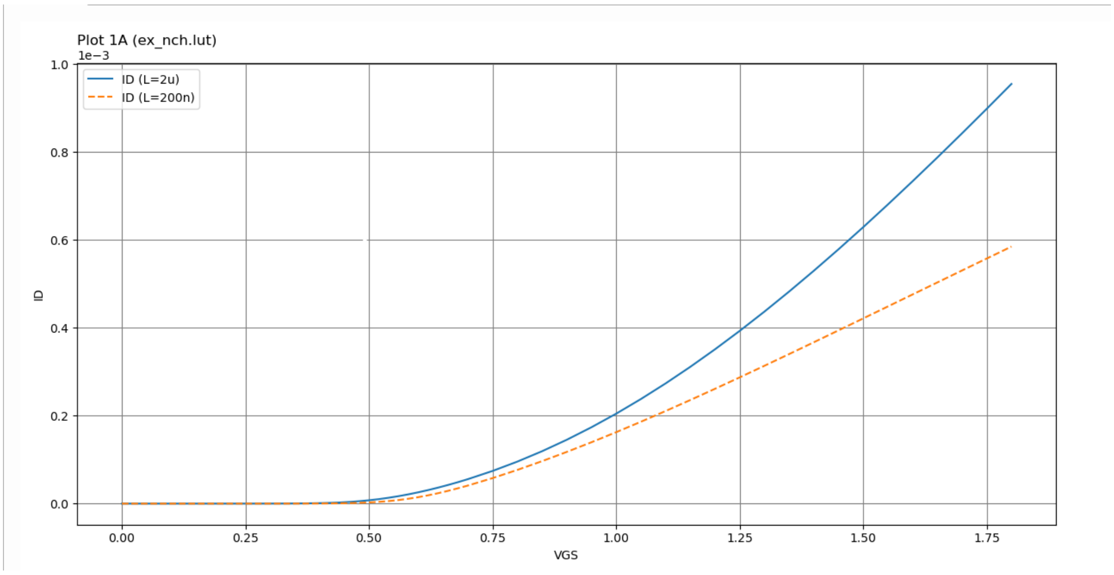


Figure 1 N_MOS ADT

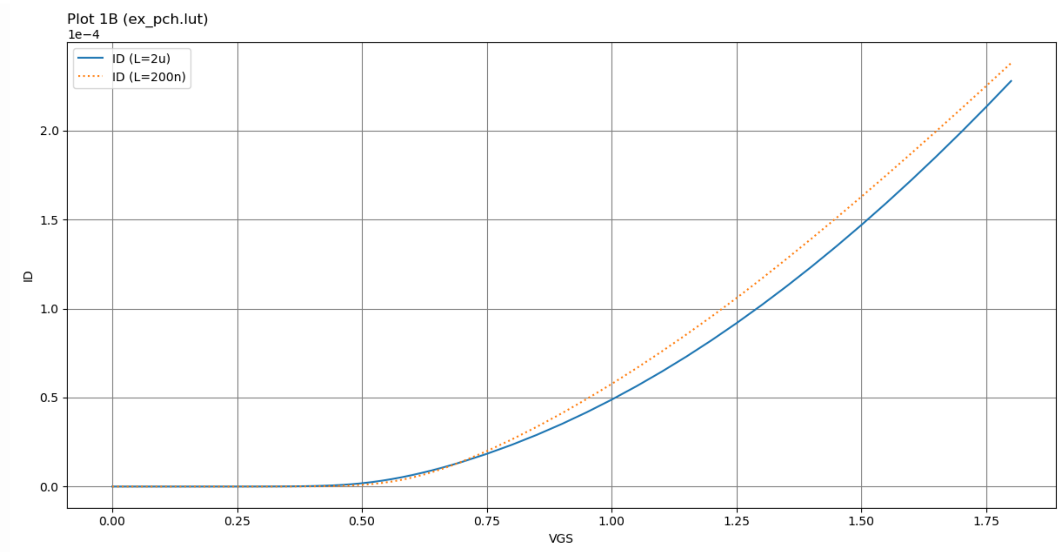


Figure 2 P_MOS ADT

the differences between short-channel and long-channel results.

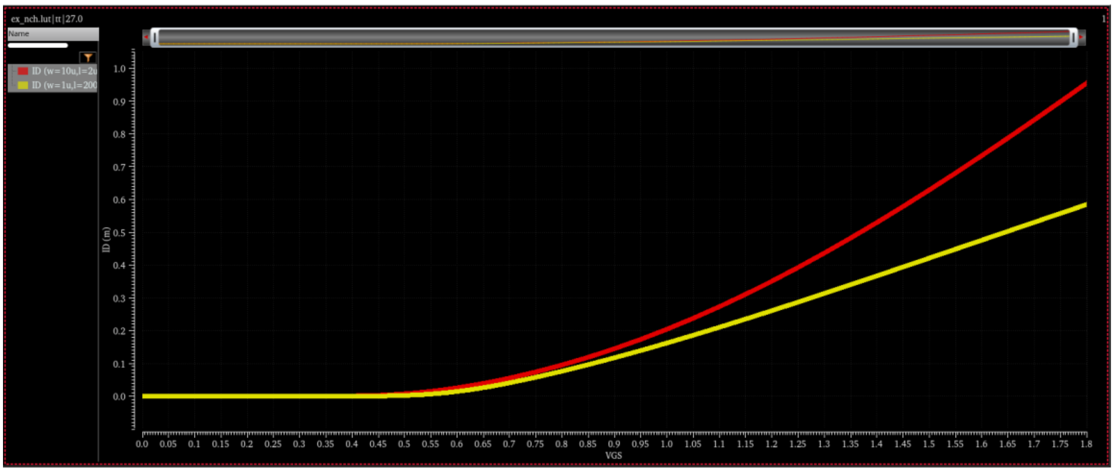


Figure 3 Id vs VGS for NMOS (Sizing Assistant)

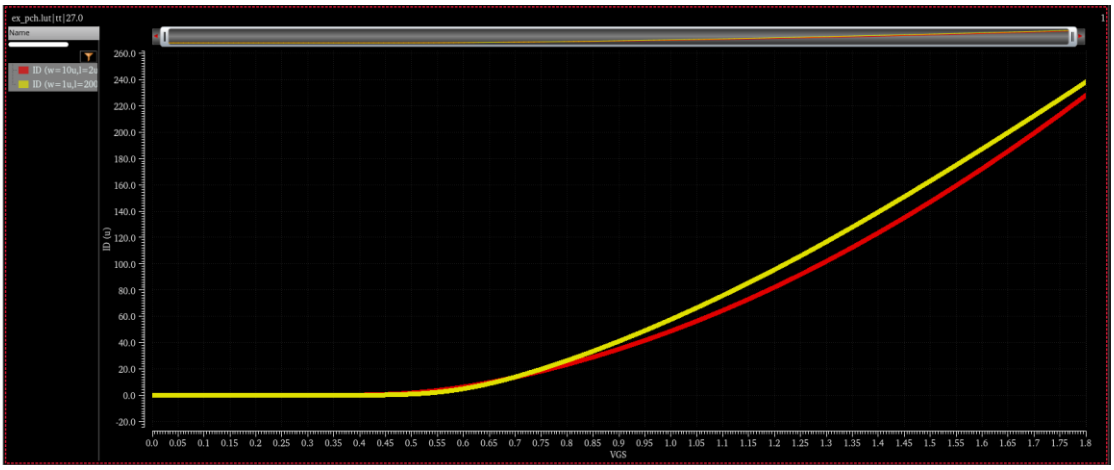


Figure 4 Id vs VGS for PMOS (Sizing Assistant)

Short Channel vs Long Channel

The long channel device has a higher current than the short channel, this is different from what we deduce from the square law that the two currents are equal if the value of the VGS is equal and the characteristics are constant. This means that the square law is not reliable in this case because of the effect of the channel length modulation, which comes from the change of the electric field, which is related to the length when the voltage is constant.

The relation for the Short Channel device is more linear than the Long Channel, because of the Velocity-Saturation, as the electrical field along the channel reaches a critical value the velocity of carriers tends to saturate and the mobility degrades, which make the curve more linear.

But the long channel device hasn't Velocity-Saturation so that it is follow the square low and the curve more quadratic not linear.

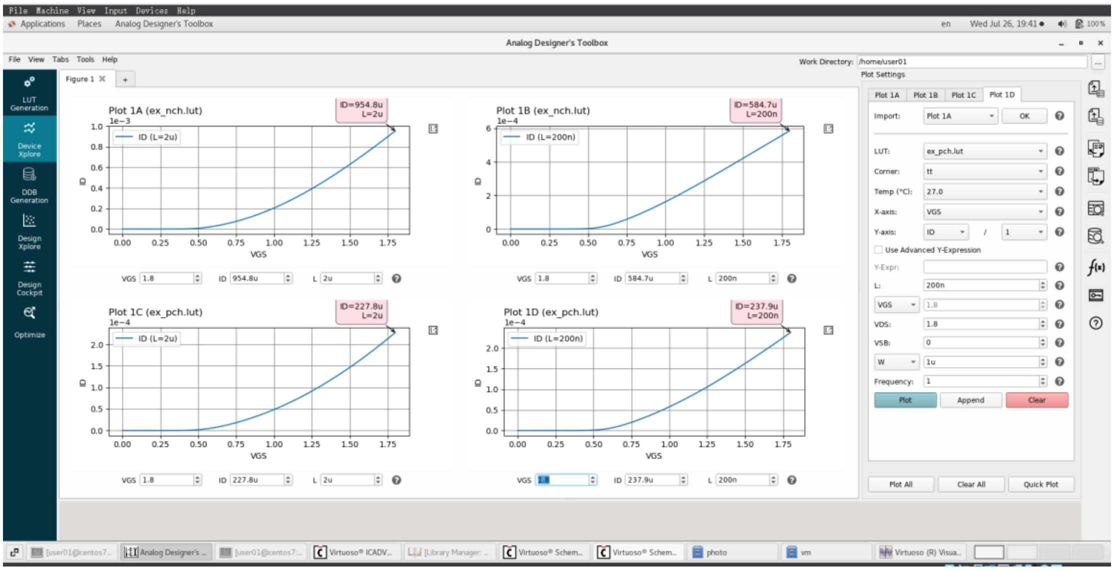
The differences between NMOS and PMOS.

NMOS has a higher current than PMOS, Because NMOS uses electrons while PMOS devices use holes, and the mobility of electrons is more than that of holes, This means that electrons can move more easily and quickly through the channel, resulting in higher current flow in NMOS devices.

The ratio between NMOS and PMOS currents at VGS = VDD is

$$\text{For Short channel} = \frac{I_{Dn}}{I_{Dp}} = \frac{584.7u}{237.9u} = \frac{\mu_n}{\mu_p} = 2.45775535939$$

$$\text{For Long channel} = \frac{I_{Dn}}{I_{Dp}} = \frac{954.8u}{227.8u} = \frac{\mu_n}{\mu_p} = 4.19139596137$$



NMOS is more affected by short-channel effects, as it changes by larger factor than PMOS.

2.gm vs VGS

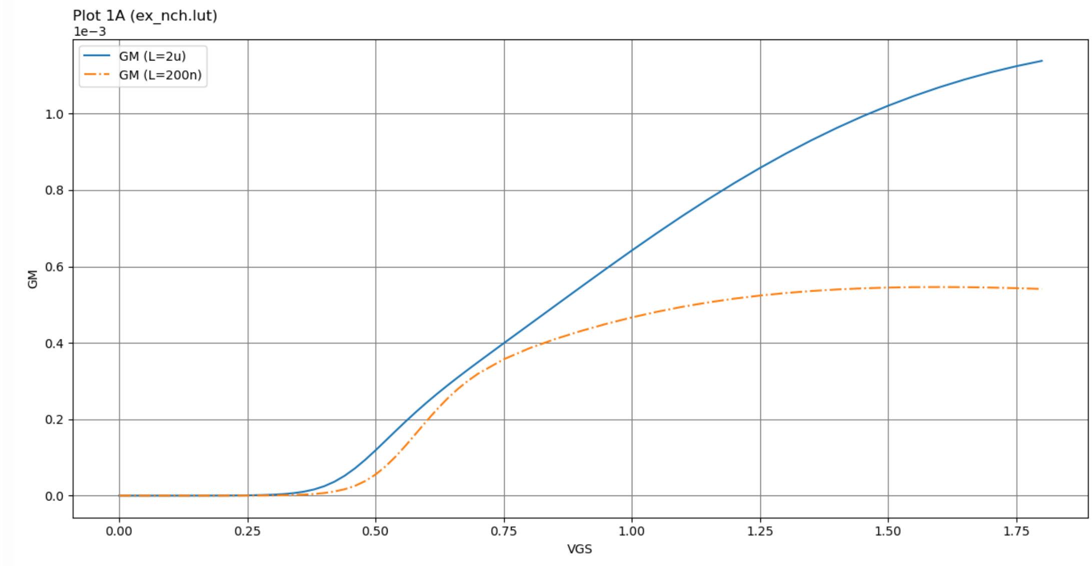


Figure 5 gm vs VGS N_MOS ADT

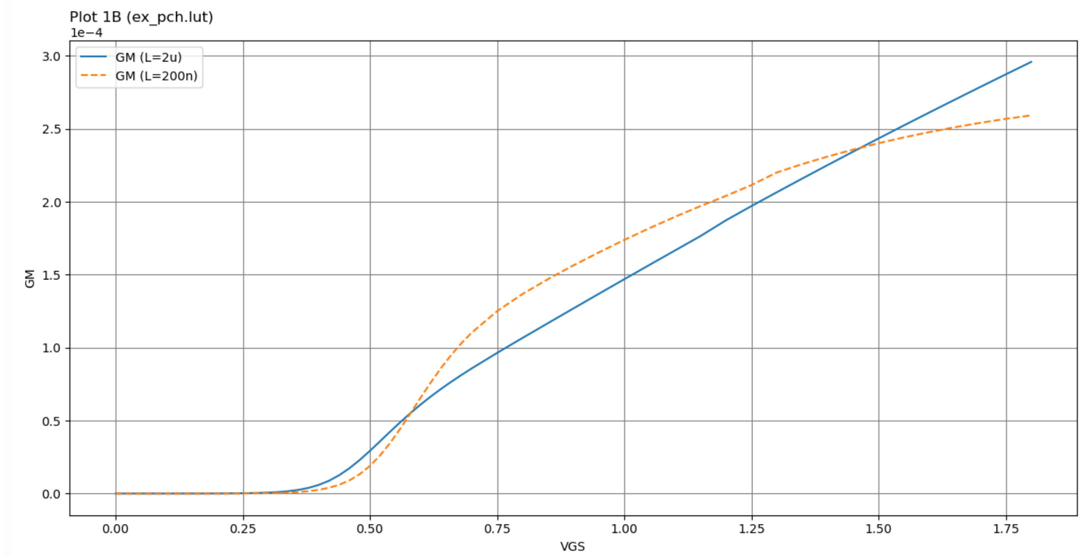


Figure 6 gm vs VGS P_MOS ADT

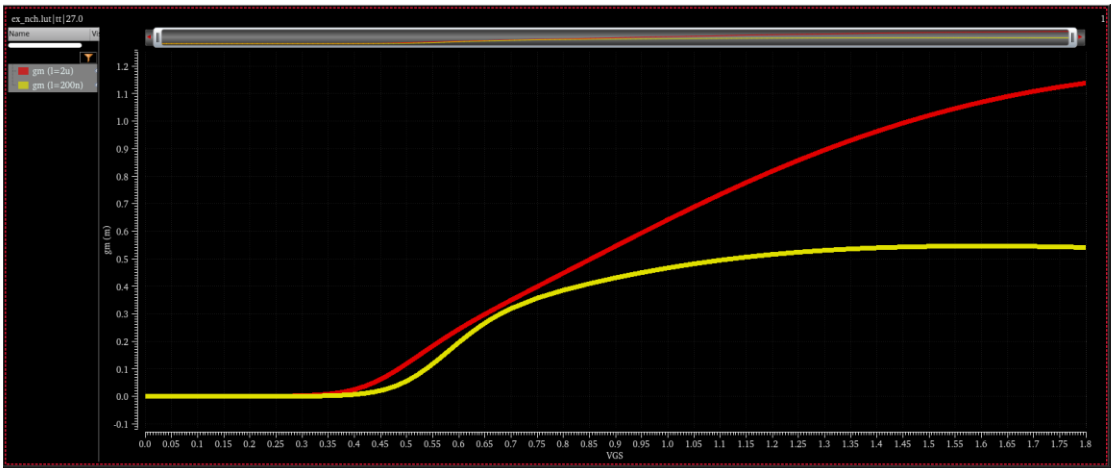


Figure 7 gm vs VGS N_MOS (Sizing Assistant)

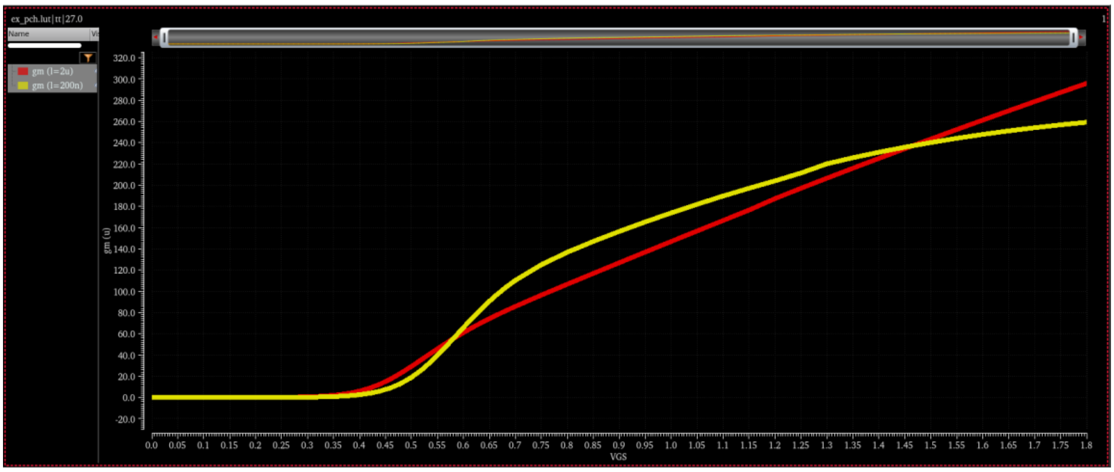


Figure 8 gm vs VGS P_MOS (Sizing Assistant)

the differences between short-channel and long-channel results:

gm saturates in Short channel & Long channel, as gm = $\frac{\partial I_D}{\partial V_{GS}}$ and the result of this relation is different due to the channel length effect.

In the long channel device gm increases linearly because of the square low, and it's following the equation:

$$g_m = \frac{\partial I_D}{\partial V_{GS}} = K_n * (V_{GS} - V_{TH})$$

But for the long channel device it is not linear because the Velocity-Saturation which have an average due to phonon scattering which mean that its derivative isn't a linear relation.

3.ID vs VDS

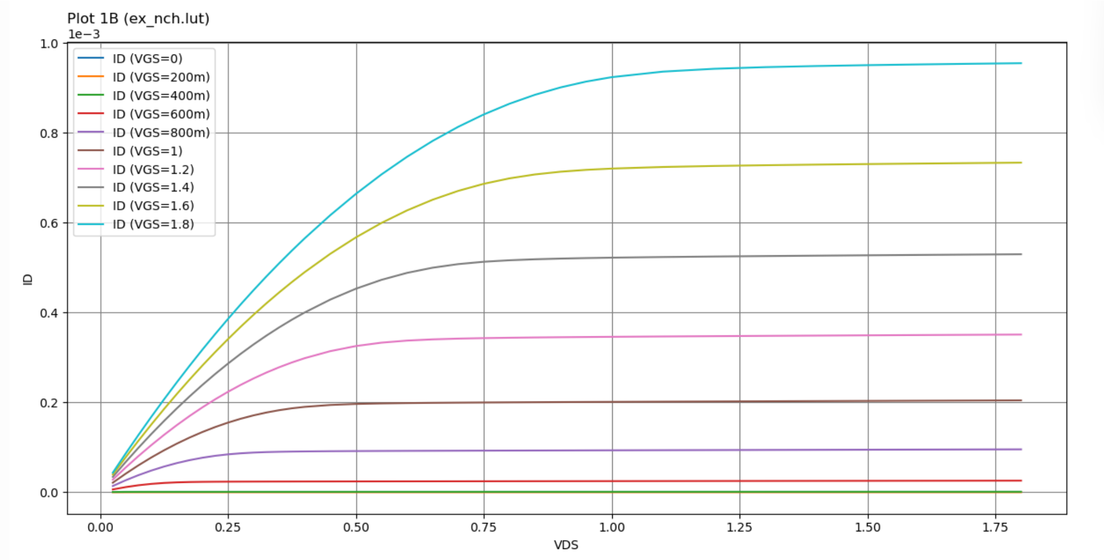


Figure 9 Id vs VDS N_MOS long channel ADT

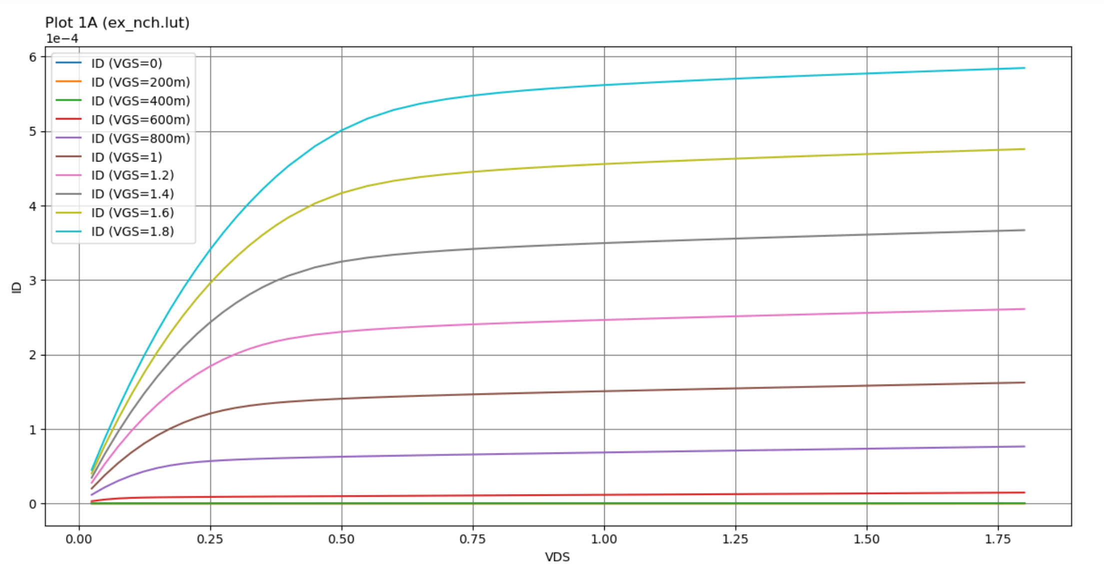


Figure 10 Id vs VDS N_MOS short channel ADT

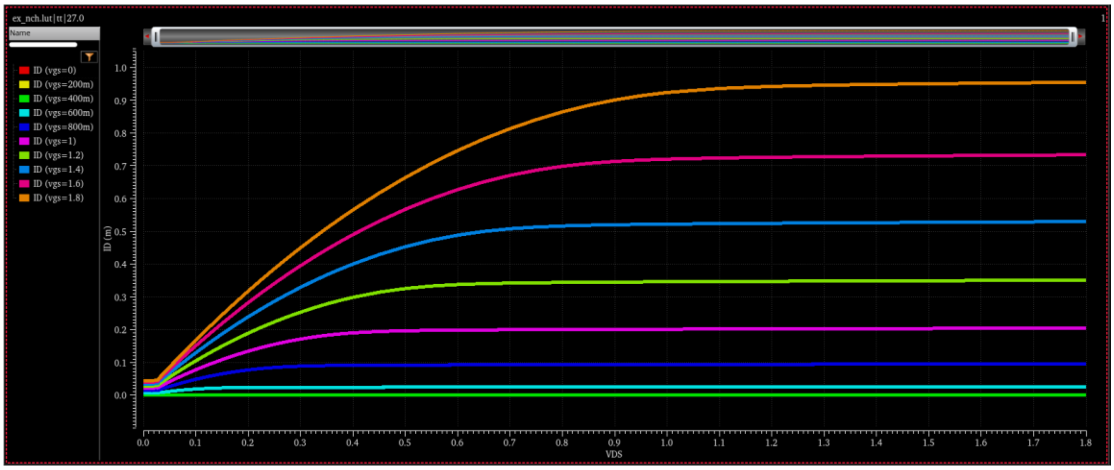


Figure 11 Id vs VDS N_MOS long channel ADT

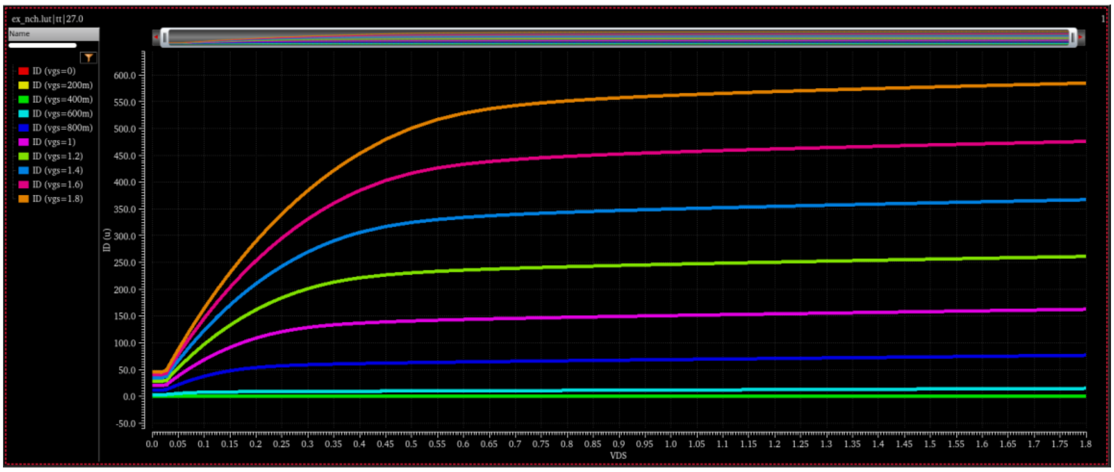


Figure 12 Id vs VDS N_MOS short channel ADT

The differences between short channel and long channel results.

Long channel has higher current, because the effect of the Velocity-Saturation in the short channel device which come because the phonon scattering.

Short channel has higher slope in the saturation region, because the channel length modulation effect as a resistance and the length of the channel is inverse proportional with the value of the resistance, and Short channel has higher resistance so it has higher slope in the saturation region.

[Optional] gm and ro in Triode and Saturation

1) Plot gm and ro vs VDS for NMOS device. Use $W = 10\mu m$ and $L = 2\mu m$, $VDS = 0\!:10m\!:VDD$, and $VGS \approx VTH + 0.5V$.

   $VTH \approx 0.4$

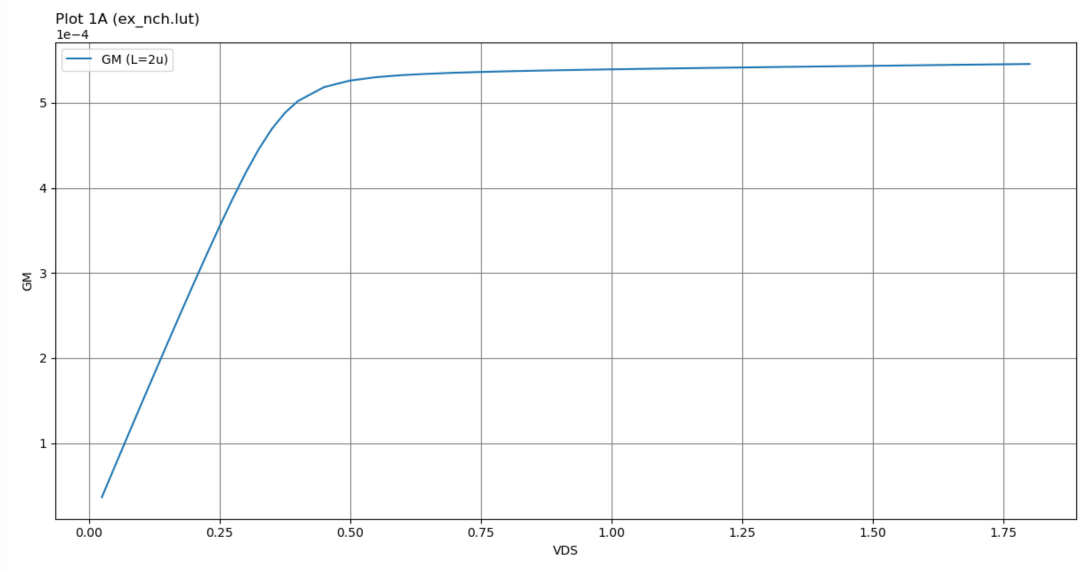


Figure 13 gm vs VDS N_MOS ADT

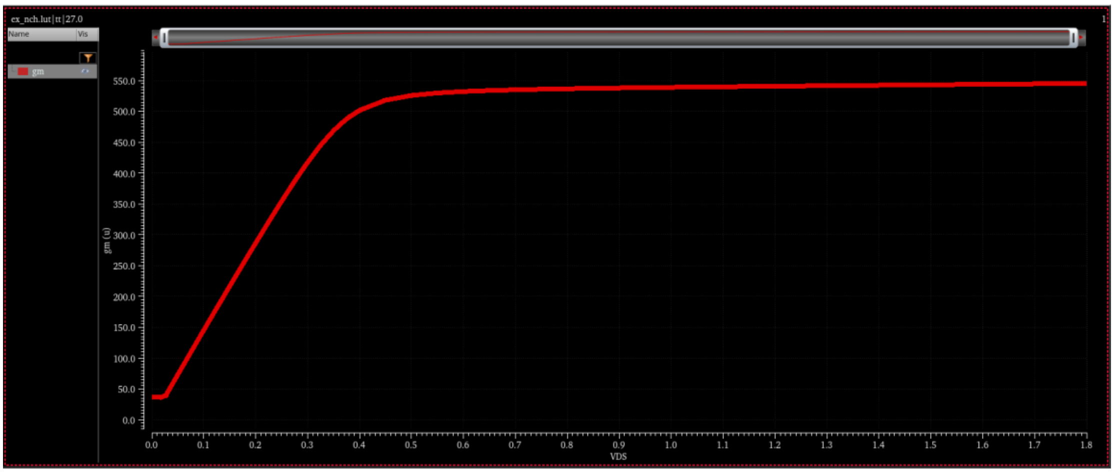


Figure 13 gm vs VDS N_MOS (Sizing Assistant)

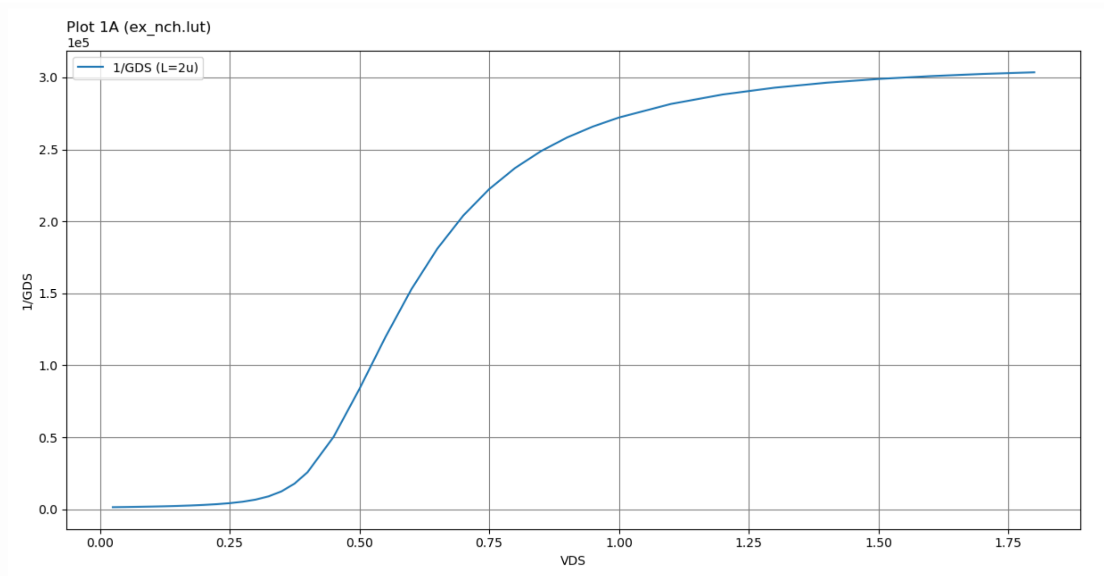


Figure 13 ro vs VDS N_MOS ADT

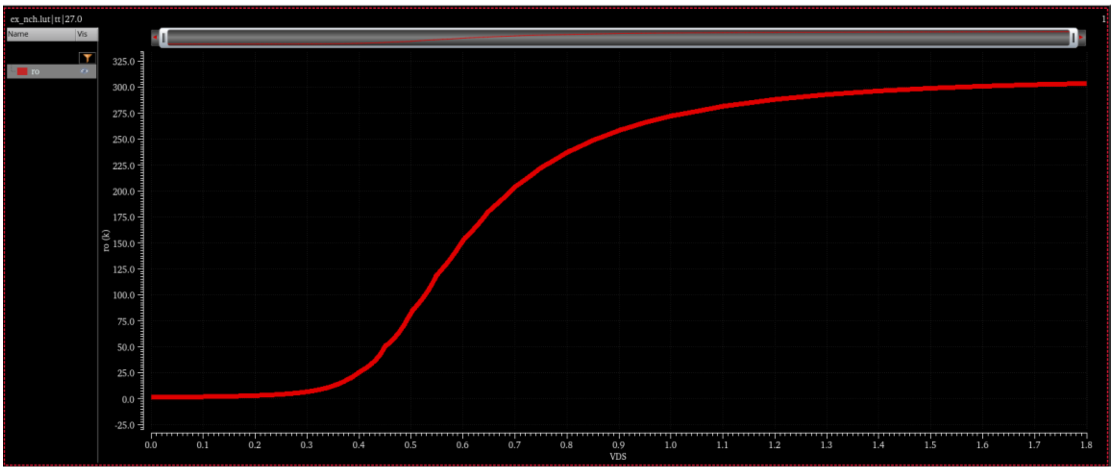


Figure 13 ro vs VDS N_MOS (Sizing Assistant)

2) Comment on the variation of gm vs VDS.

We can describe the behaviour of gm vs VDS in 3 regions :

Triode Region when (VDS < Vov) :
In this region, the NMOS operates as a voltage-controlled resistor if as (Kn$V_{ov} \gg \frac{V_{DS}}{2}$), so gm is relatively linear with respect to VDS . It is primarily determined by the overdrive voltage VOV, the NMOS operates in the linear.

$$\text{ID} = \text{Kn}(V_{ov} * V_{DS} - \frac{V_{DS}^2}{2}).$$

That's make the relation linear which with *the relation* $g_m = \frac{\partial I_D}{\partial V_{GS}}$ *make gm* relatively linear.

Saturation Region when (VDS > Vov):
As VDS increases and becomes greater than Vov, the NMOS enters the saturation region. In this region, gm starts to saturate with increasing VDS. The reason for this saturation is the square low ID $= \frac{K_n^2}{2} * V_{ov}^2\ (1 + \gamma V_{DS})$ which with *the relation* $g_m = \frac{\partial I_D}{\partial V_{GS}}$ *make gm* relatively constant.

• In the first part of the curve, is the relation linear? Why?

Yes, because in this region the system is in triode and as we shown the triode region has linear relation between gm and VDS.

• **Does gm saturate? Why?**

YES, as in saturation the square low ID $= \frac{K_n^2}{2} * V_{ov}^2\ (1 + \gamma V_{DS})$ is valid and $g_m = \frac{\partial I_D}{\partial V_{GS}}$
So gm will be relatively constant and saturate.

• **Where do you want to operate the transistor for analog amplifier applications? Why?**

For analog amplifier applications we want to operate the transistor in the saturation region, as ID depends only on VGS (it is also has a little dependent on VDS because of the channel length modulation) and gm is high which mean high gain.

3) Comment on the variation of ro vs VDS.

• **Does ro saturate just after the transistor enters saturation similar to gm? Why?**

NO, It saturates , but not similar to gm it takes more time than gm before saturation because the channel length modulation effect ,as ro increase with channel length modulation because Va depending on VDS, and its effect appears because the channel pinch-off.

• **Does ro increase if the transistor is biased more into saturation?**

YES, it will increase, because of the channel length modulation effect (Early effect).

• **Should we operate the transistor at the edge of saturation?**

NO, because it has small ro, so its gain will be small and if the input is sinusoidal then half of the signal will be amplified in the triode region and the other half will be in the saturation region that make a distortion in the output.

• **Where do you want to operate the transistor for analog amplifier applications? Why?**

For analog amplifier applications we want to operate the transistor in the saturation region, as ro is high which mean high gain. And also because of the other reasons we shown before