

EE220 / EE223 Assignment 1 : Characterization of NMOS / PMOS Transistor

Using cadence for first time ? Well, this document is a right place to start with. This document is intended for SJSU students only. As of 2014, a student can use one of the following versions of Cadence Virtuoso :

Cadence Virtuoso 6.1.3 (For most classes – EE166, EE224 or any other VLSI classes)
Cadence Virtuoso 6.1.5.500 (Newer version , for EE223 but highly **required** for EE220)
Cadence Virtuoso 6.1.6 (For EE220 / EE230)

Although you can use any version of Virtuoso on your Unix machine , it's important that you stick to same version of Cadence Virtuoso throughout your semester.

Cadence Virtuoso 6.1.3 can be set up using Prof.Jones' set-up instructions (excerpt from Prof.Jones' famous inverter tutorial)

First, log into a computer in the lab. This can be done sitting in the lab, using VNC, or through ssh. If using ssh, use the -Y option to ensure all the X11 comes back to your computer.

Start a terminal session. (Right click, and select terminal)

[items you should type are shown in a typewriter style font the stylized ↵ indicates the carriage return or the enter key]

Create a directory for the 45nm sub-threshold work. I'll use st45 for sub-threshold forty five.

mkdir st45

↖

Change to that directory

cd st45

↖

copy the setup data to the directory (there is a period typed before the carriage return)

cp ~morris/setup45/*.

↖

Check and see the correct files were copied

ls

↖

You should get
cds.lib s45 s45.csh

start Cadence 6.1 with the following command

./s45

↙

This will set up an environment and start the cadence system

Cadence Virtuoso 6.1.5.500 / 6.1.6 can be set-up by first downloading "gpdk045_RFIC.tgz" and bashrc_eecad from Prof.Hamedi's webpage (<http://ics.sjsu.edu/EE220/>) with username and password given during his first class.

1. Simply create a new folder in your 'Home' directory and then unzip gpdk045_RFIC.tgz folder under this new folder.

2. Next, copy bashrc file to this new folder

3. Now you can simply run Cadence by :

- a. Opening Konsole
- b. Type *cd <Name of your cadence folder>*
- c. Type *source bashrc_eecad*
- d. Type *virtuoso*

```
bash-4.2$ cd st45
bash-4.2$ source bashrc_eecad
[██████████@eecad45 st45]$ virtuoso
```

4. And now you will be running your Cadence Virtuoso 6.1.5.500 / 6.1.6

FAQ : Why is the folder name st45 ? - No idea, but people have been using it to point 45nm technology

This first tutorial will be based on **Cadence 6.1.3** and we will be using **Schematics XL** and **ADE-L** as Cadence 6.1.5.500 and 6.1.6 is not yet completely configured. Make sure that you install Cadence 6.1.3 using instruction on page 1 of this tutorial. EE223 students can use Cadence 6.1.3 through their semester while EE220 students need to switch to Cadence 6.1.5.500 / 6.1.6 for all class assignments (except assignment 1, you can use Cadence 6.1.3 as well) and final project.

Again, this tutorial is using **Cadence 6.1.3**

This tutorial is created by ISAs for students of EE220 and EE223. The tutorial follows Assignment 1 common for these courses. Created for SJSU students.

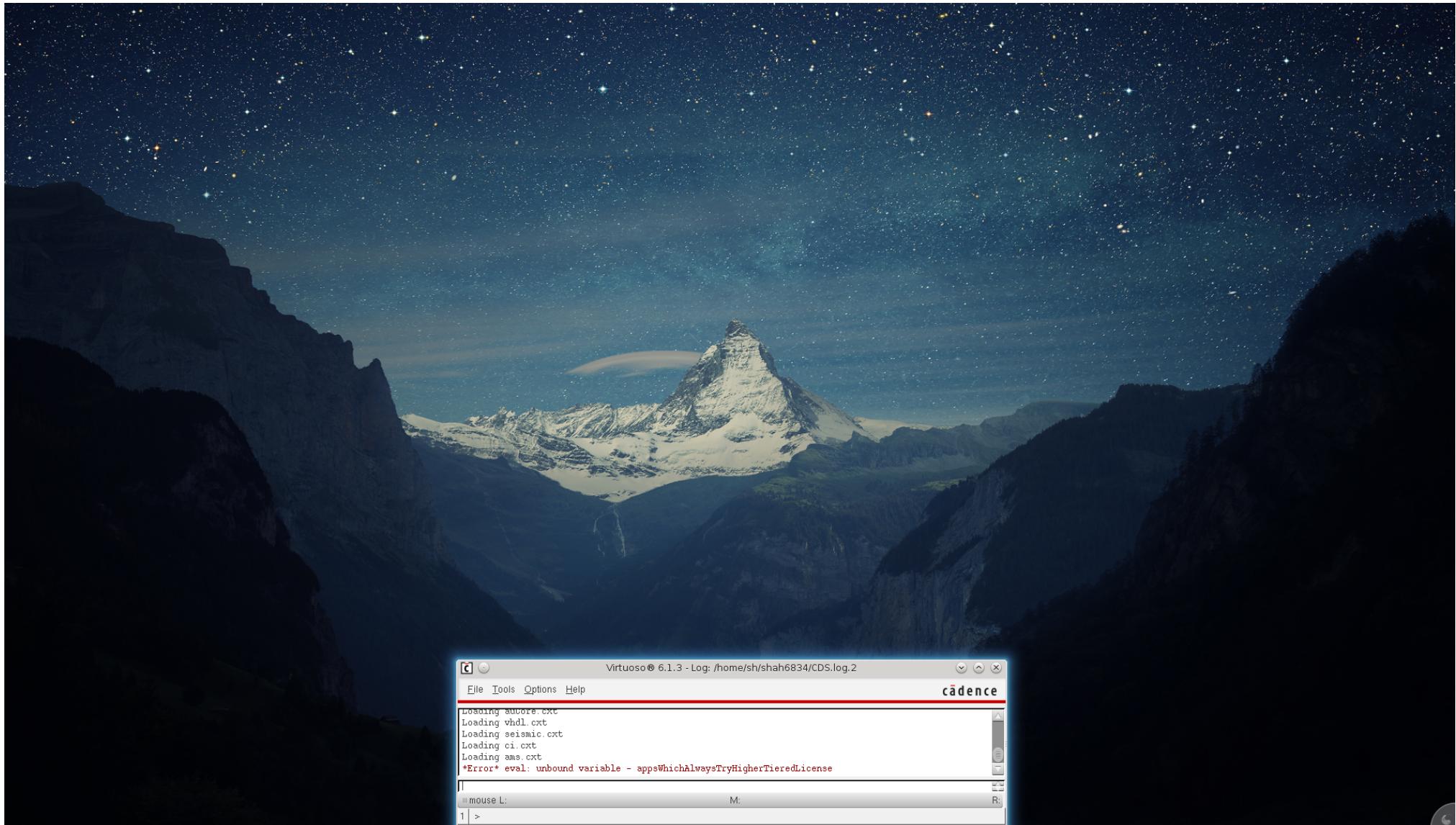
1. Go to your Home Directory using your Konsole (name for Terminal in KDE desktop environment) and then type ./s45 into your Konsole window.

OR

Simply go to your cadence folder and double click on "s45" file

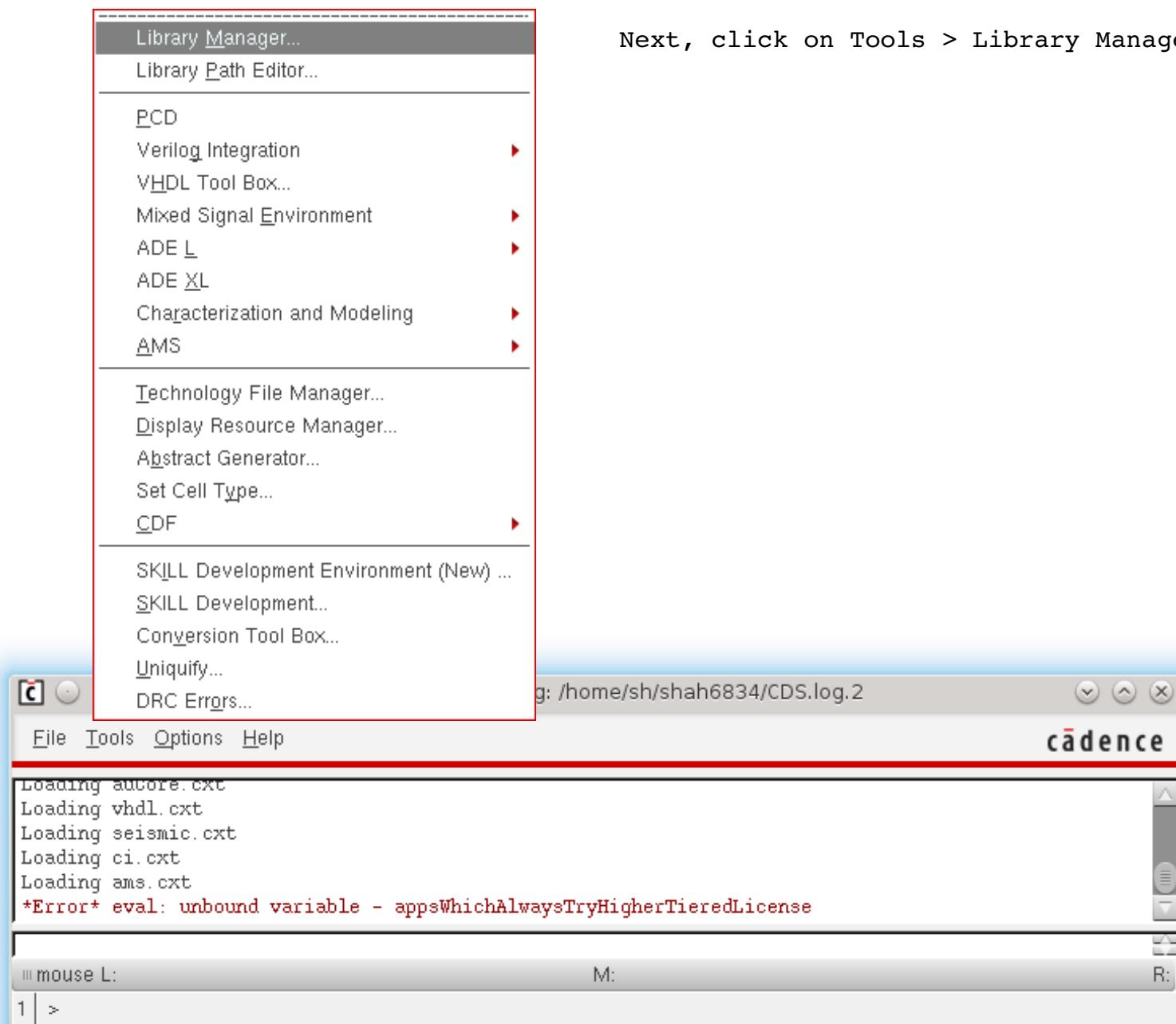


2.



This is your main window. **Remember**, if you ever close this window, it means you are quitting Cadence.

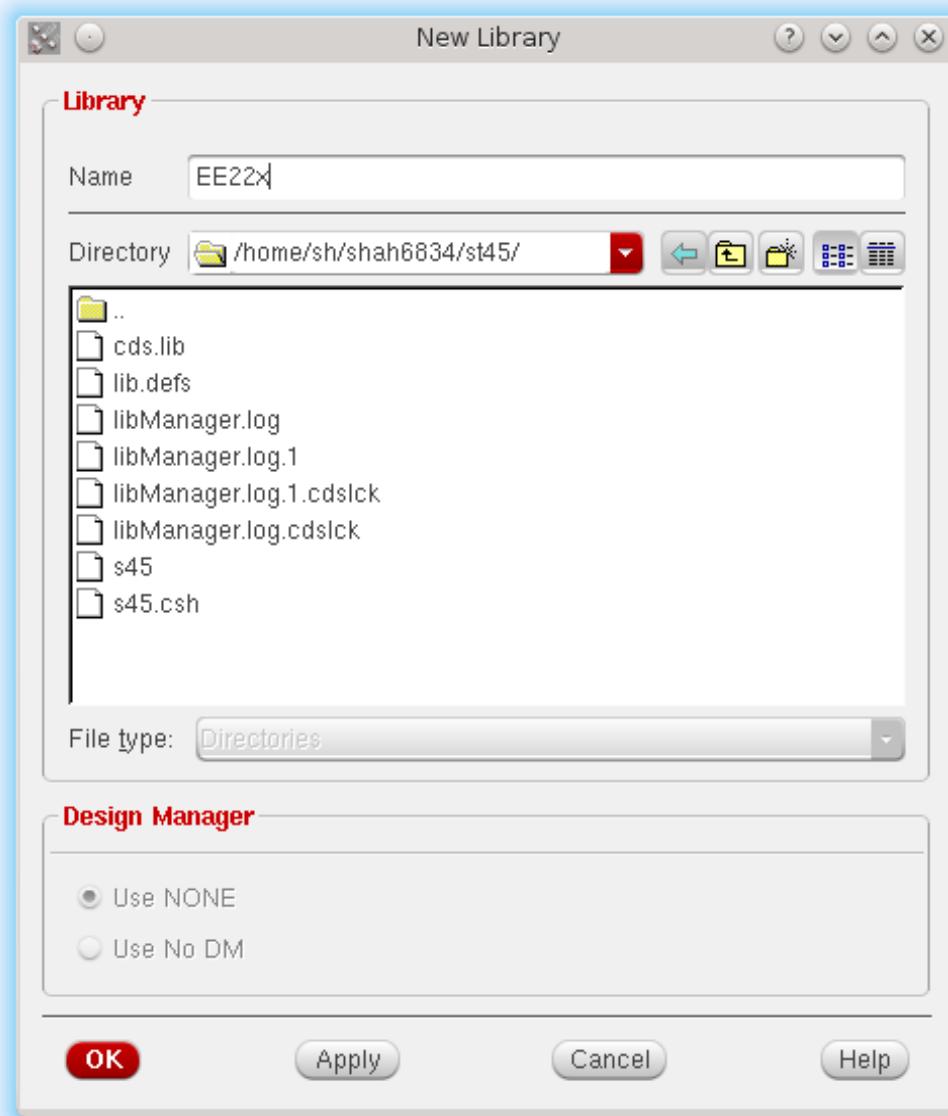
3.



Next, click on Tools > Library Manager

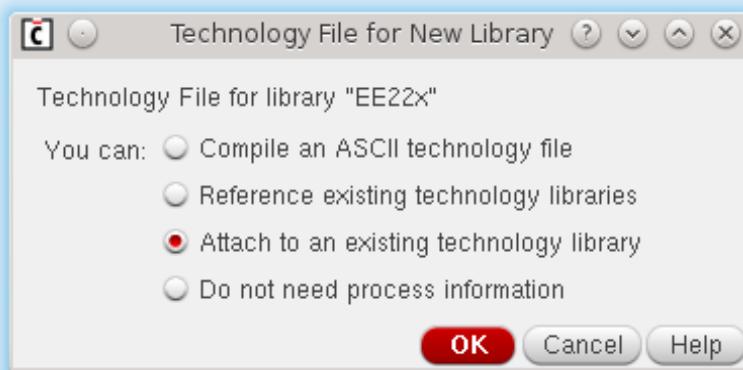
4. Next, go to File > New > Library

This window will help you create a new Library. A library is a collection of smaller circuits (called cells) and together can be used in a schematic (for example a schematic of inverter which comprises of cells [components] like nmos, pmos, vdc, gnd etc)



Here, we are creating an **empty** library called EE220x , which you will be using throughout your semester to store all your cells / schematics.

6.

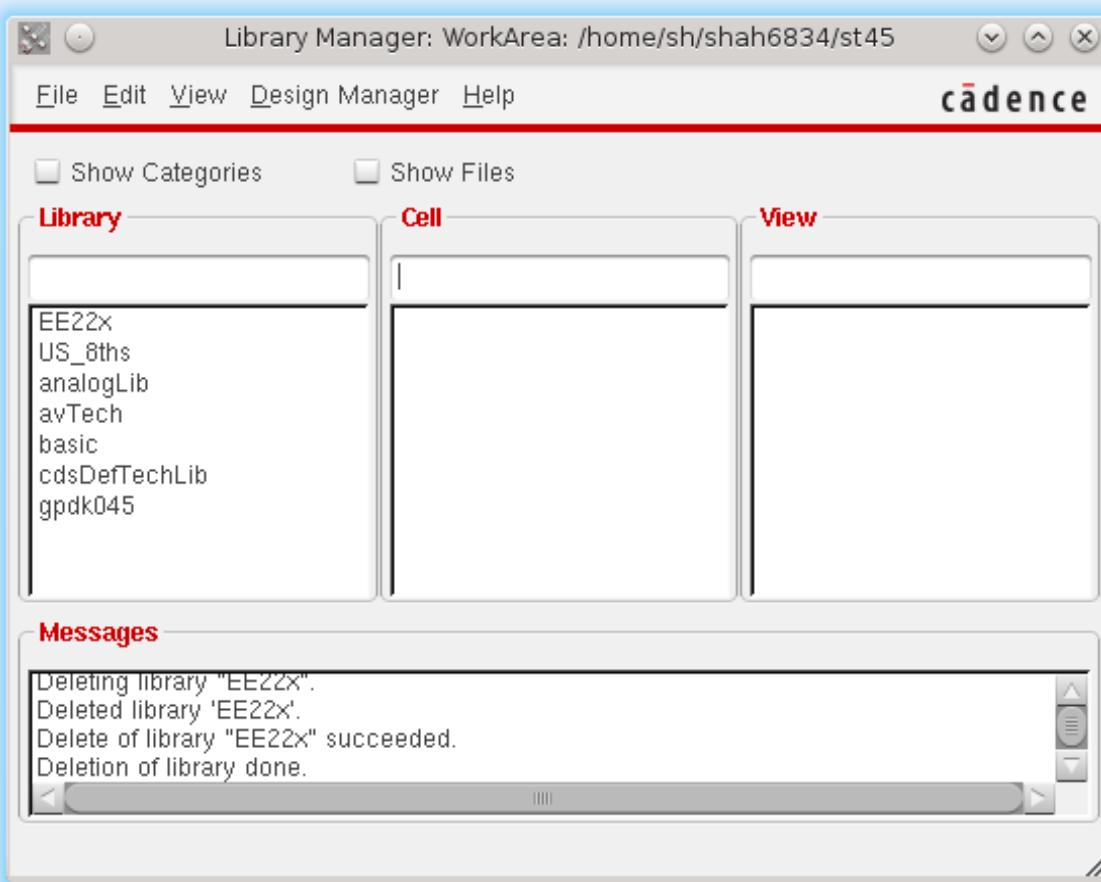


Make sure that you select this option. You don't wanna miss this one!

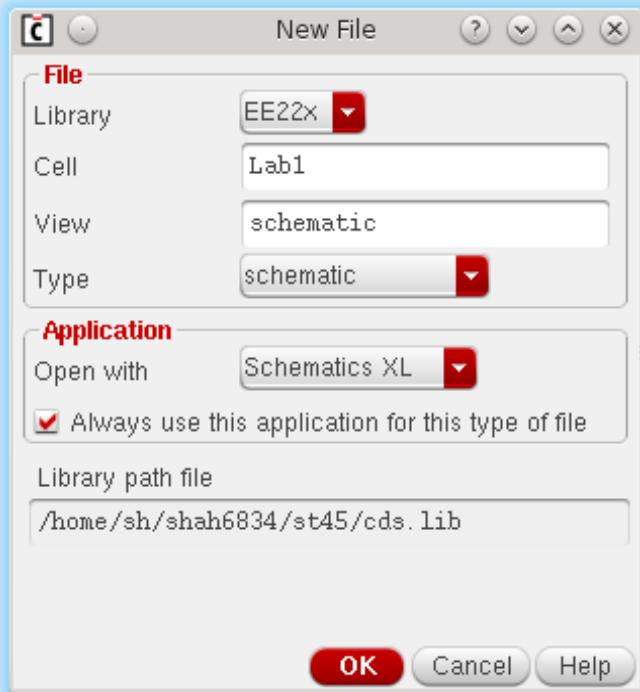
7.



When you attach your library to gdk045, it means you are assigning use of technology from 45nm models.

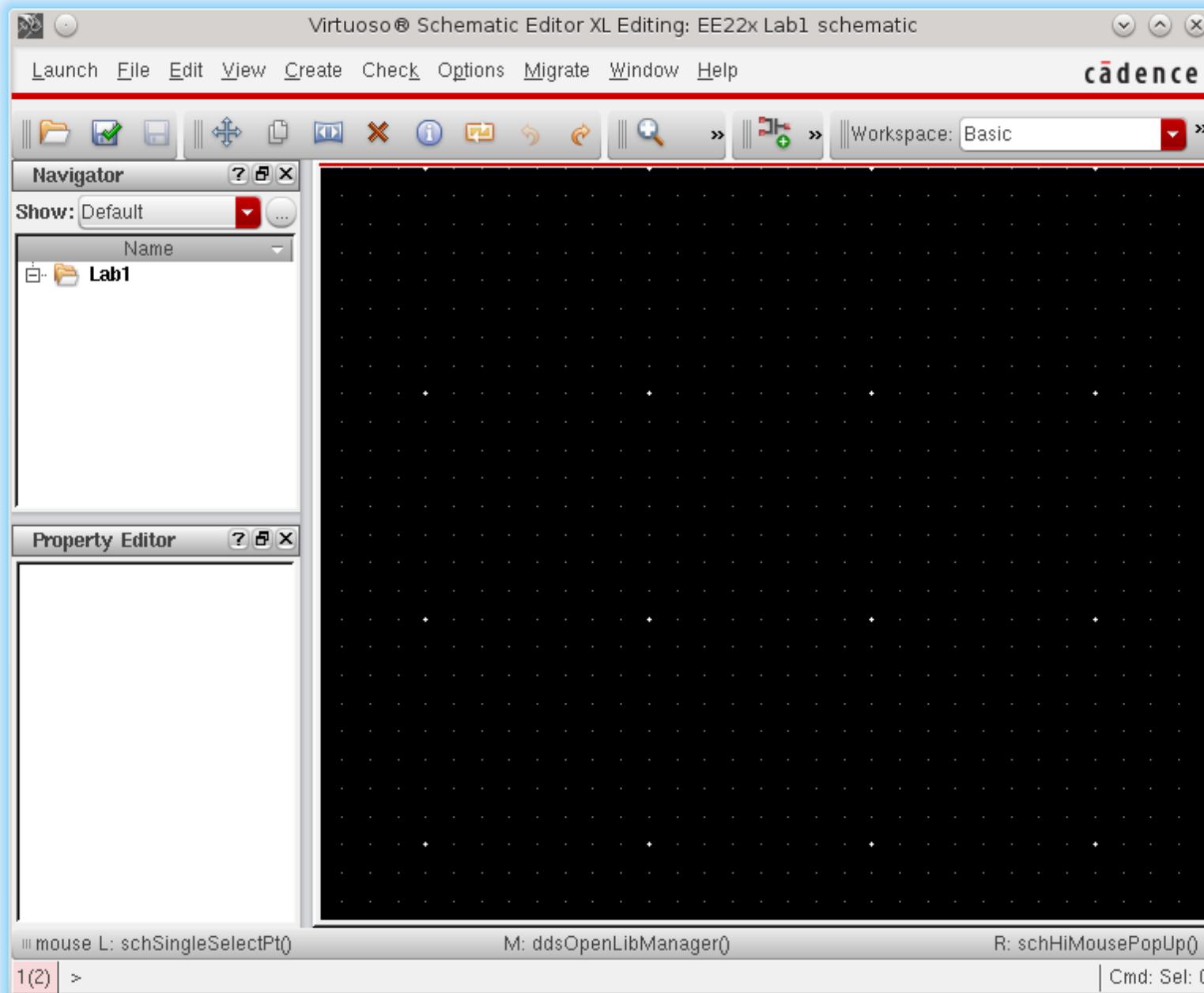


So, now you have your library (which is empty at present) and a bunch of other libraries too. Remember **analogLib** can be used to *instantiate* (fancy word to insert a component from library, you will hear this a lot from digital design students at SJSU) components like voltage sources, gnd and other basic components like resistors, capacitors etc. Always use gpdk045 to instantiate transistor (nmos1v , pmos1v) in your schematic.

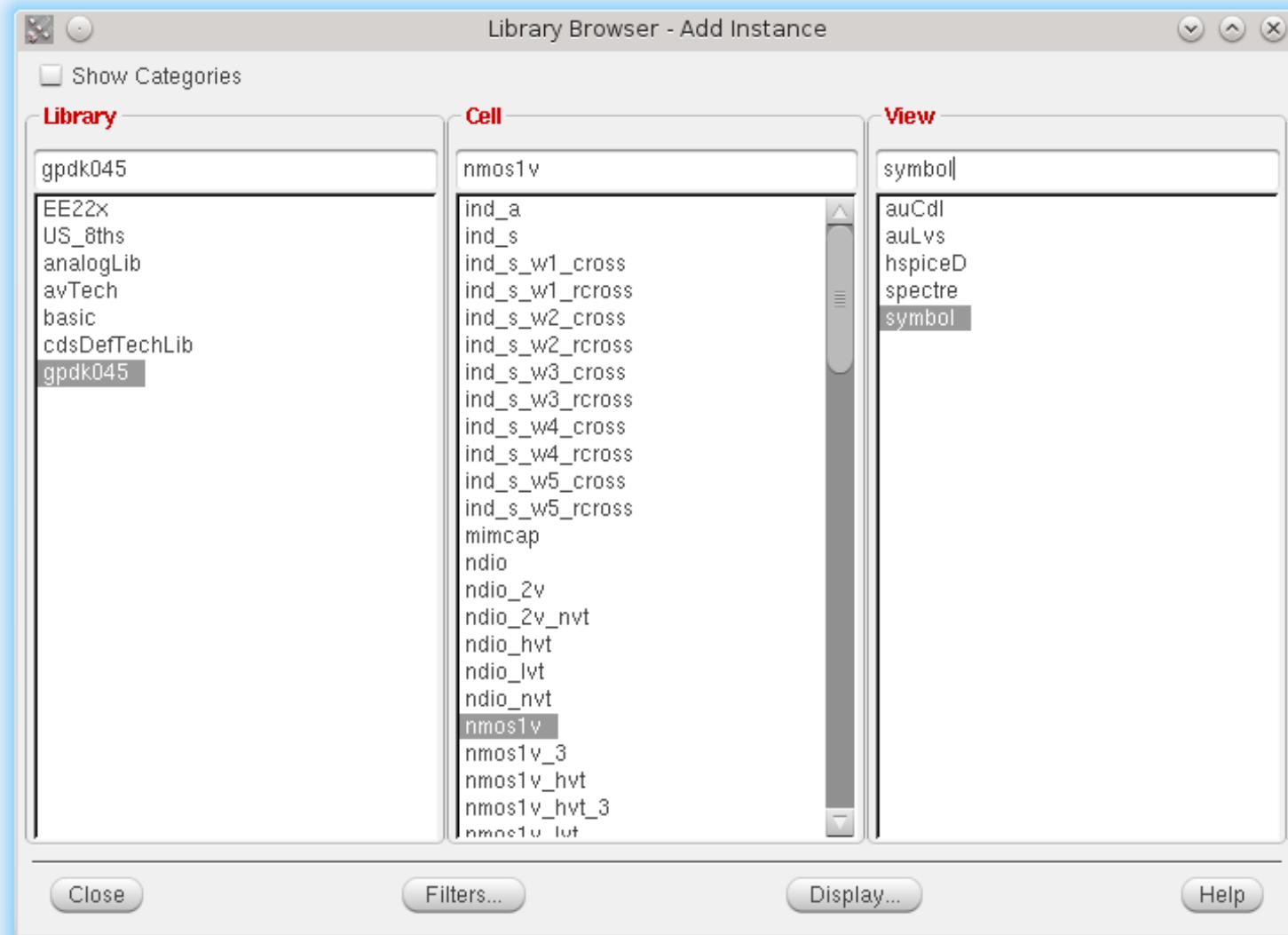


In your library manager, goto File>New>Cell View
Now let us create our first Lab1 assignment. Make sure that you select type as *schematic* and always open application with SchematicsXL (it's better than Schematic-L and in a short while we will tell you why. Make sure that you SchematicXL throughout this tutorial).

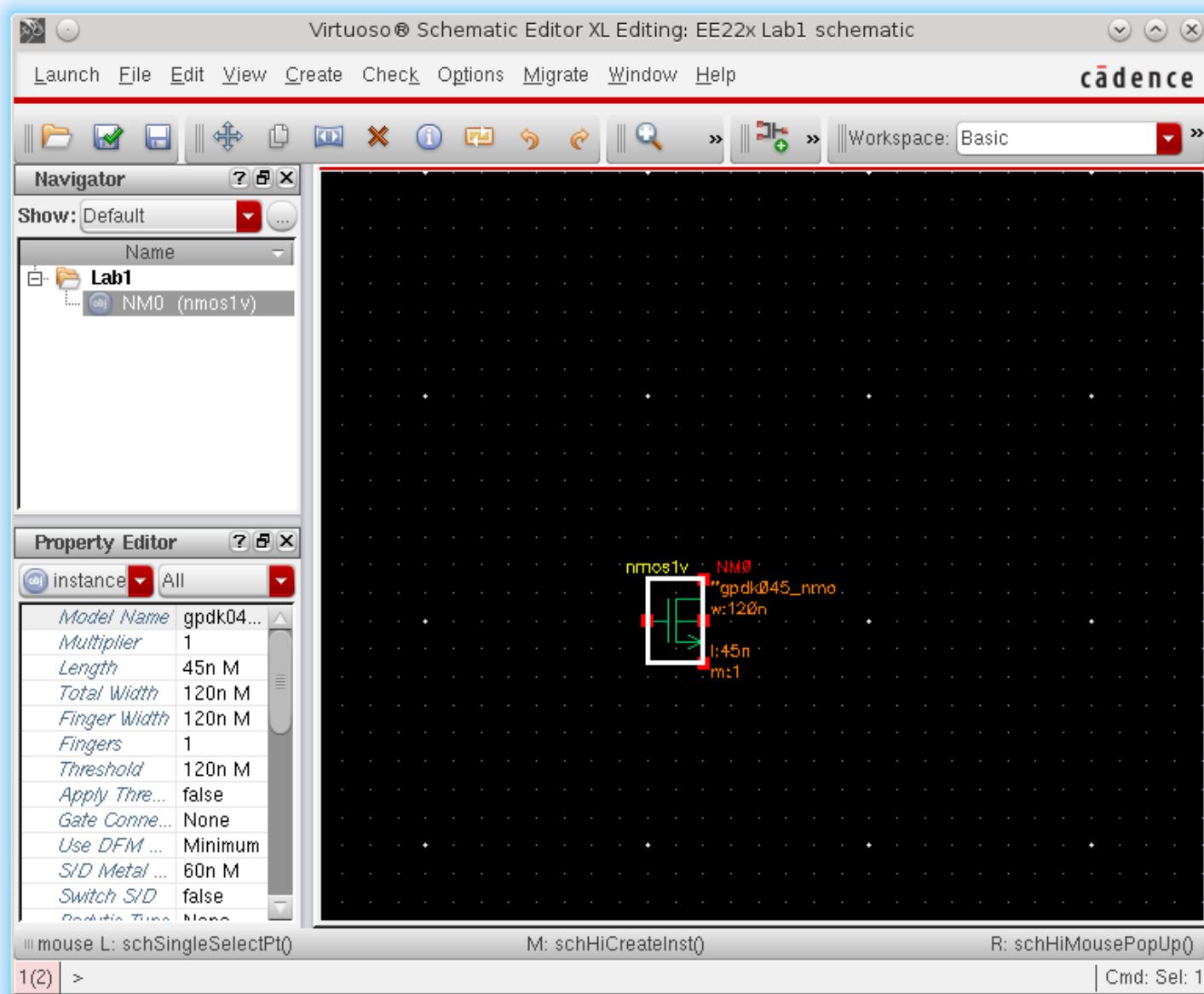
10. Once you click OK, you will come to Schematic view



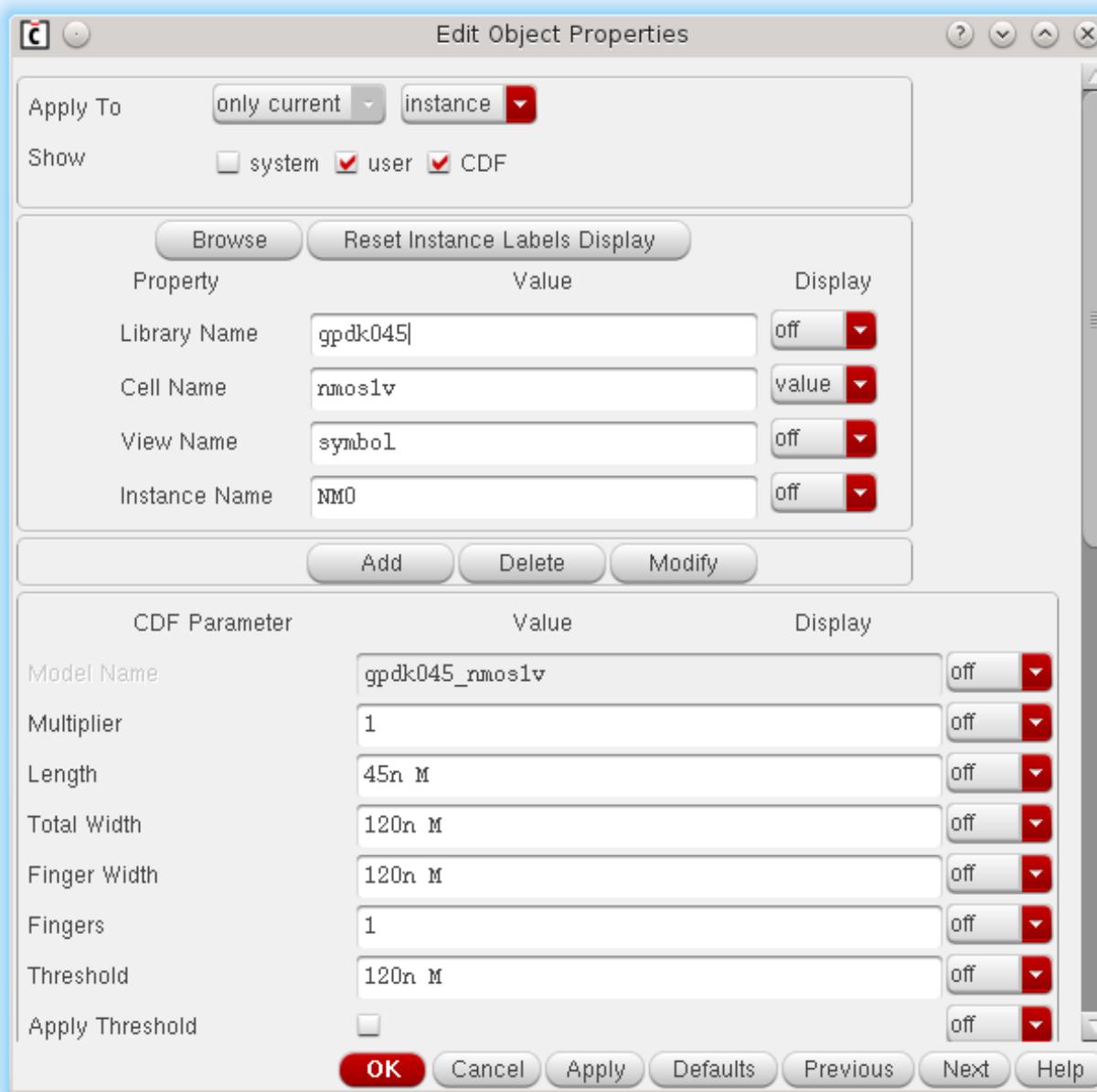
11. Press "I" (shortcut got Instance) or go to Create>Instance. Click on symbol and hit Enter.



12. So, now you have got your nmos on your schematic. If you click on it, you will come across a property editor on you bottom left corner.



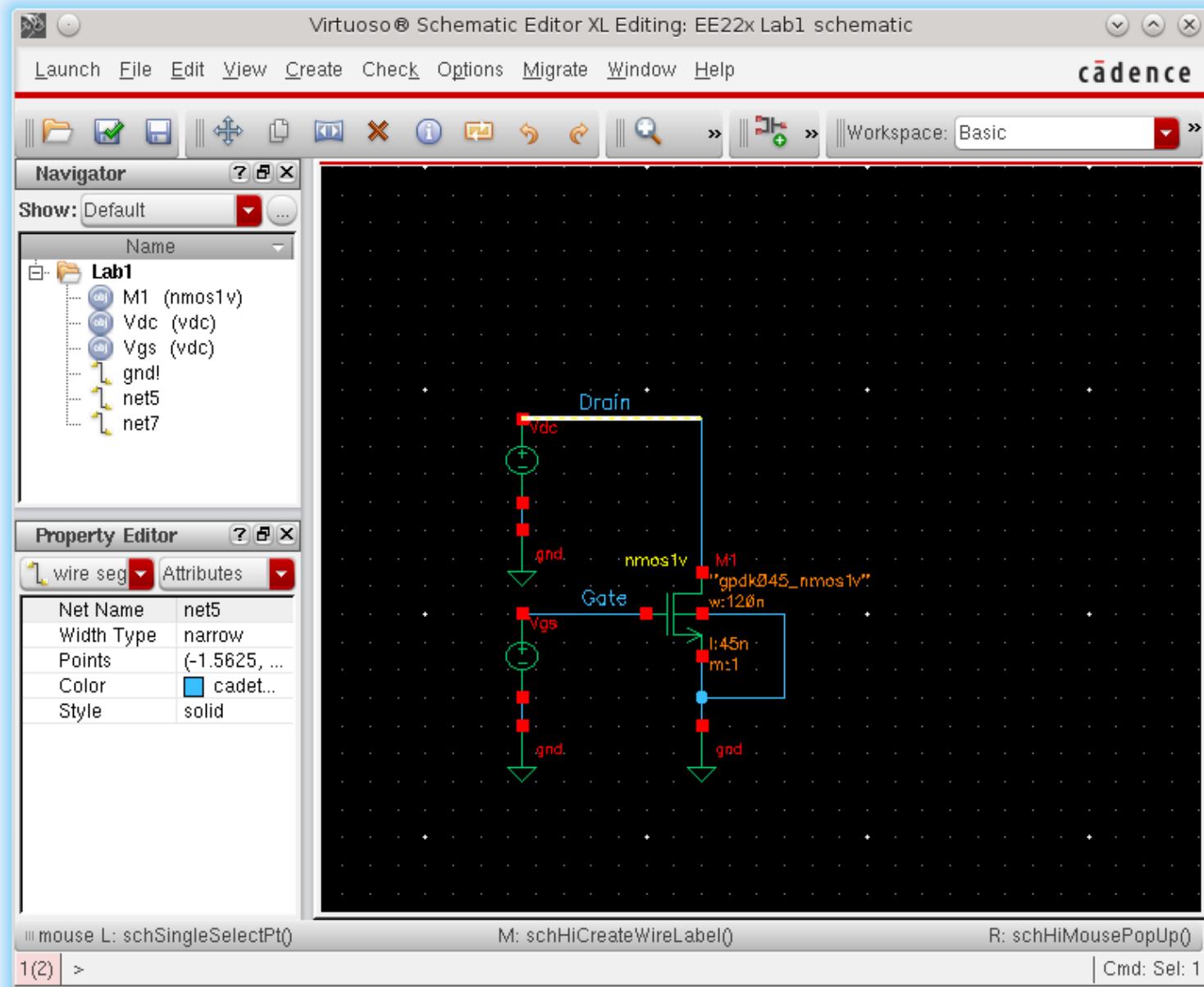
12. You can even click on your *instance* and goto property editor by pressing the key "Q".



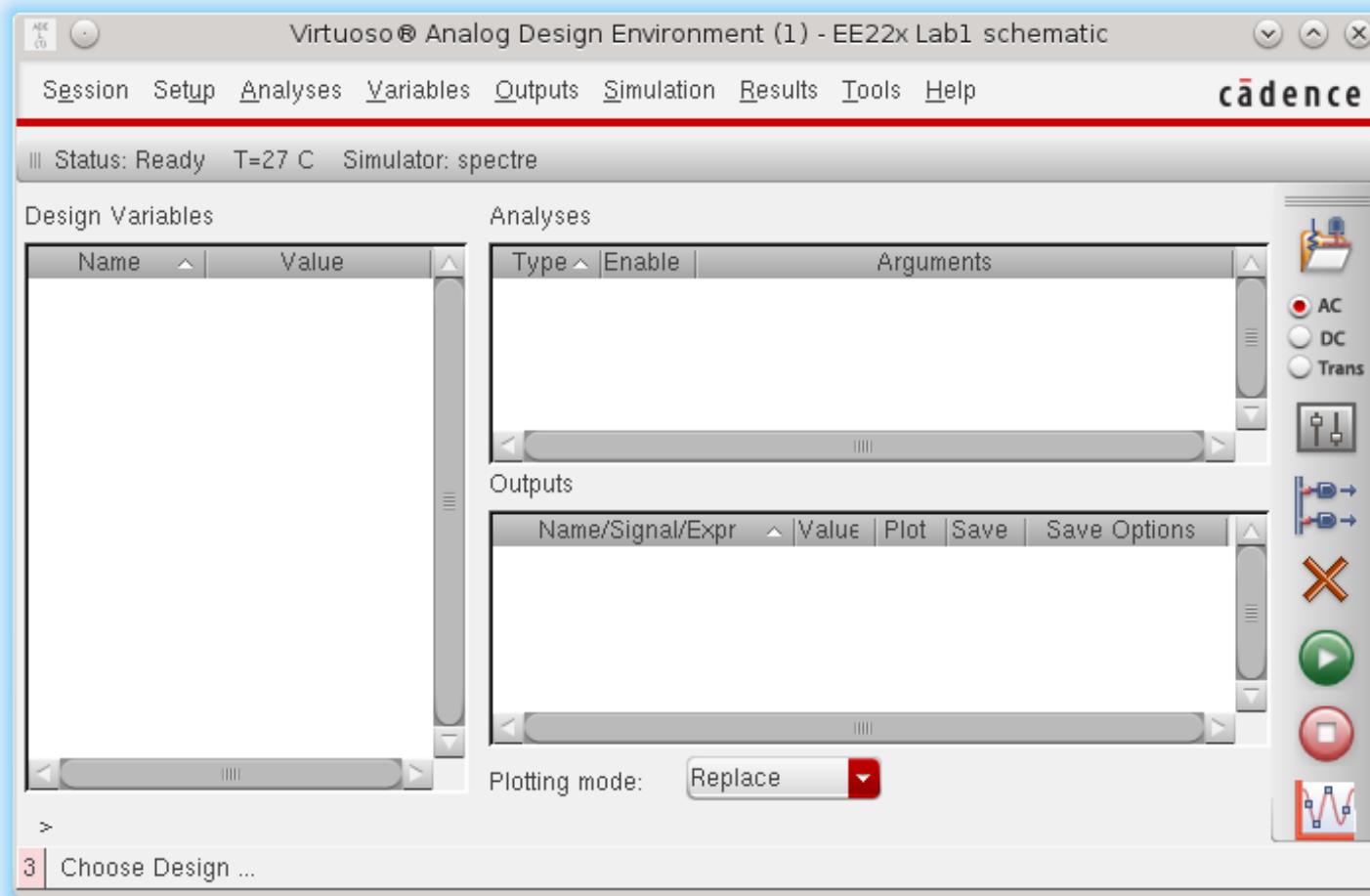
Instance name : It's always a good practice to rename your instance

This is where you can change specs for your nmos. Here the length of transistor is 45nM while the min width is 120nM (you can go all the way upto 10uM). Another useful parameter is Finger and Finger width. By increasing the numbers of fingers, you would thus be increasing resistance and thus.. (do you homework, guess how it is gonna affect your design)

13. Now we will add vdc (Vgs, Vdc), gnd connections, draw wires and **name them** (To draw wires, use shortcut key "P" and to rename them, click on wire and use shortcut key "L" and then add wire name. You can find both these options in menu as Create>Wire(narrow) to create wire and Create> WireName to name it)

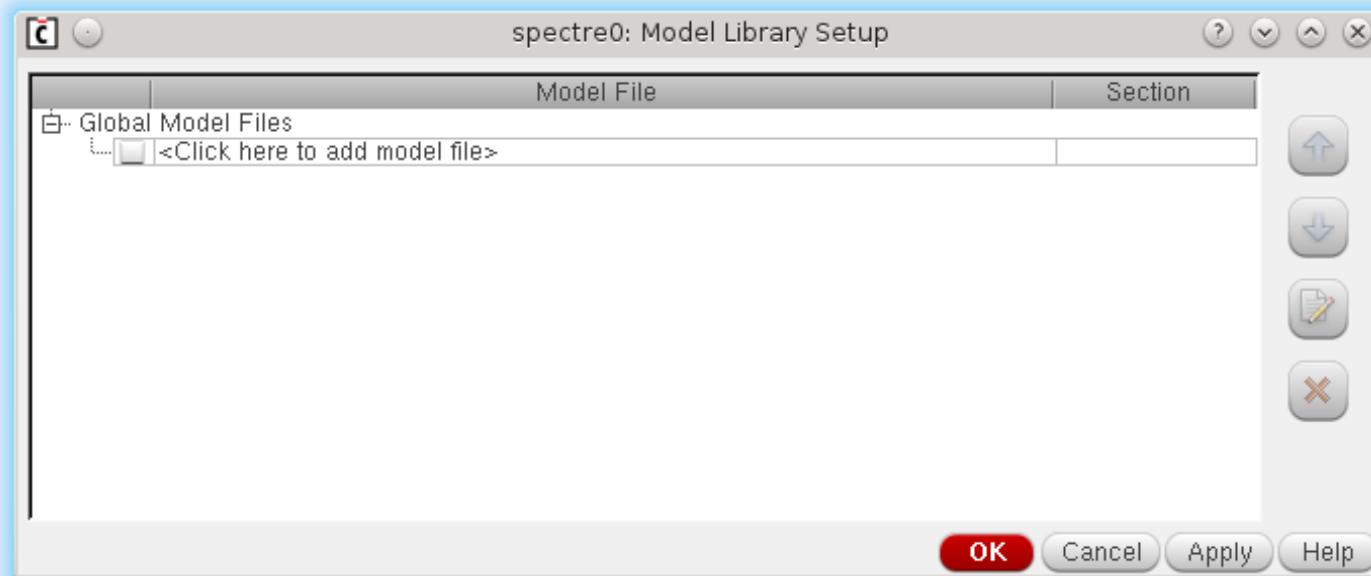


14. Now, it's time to run simulation. Remember we told you to use ADE-L ? Well, you can open ADE-L by going to menu Launch>ADE-L

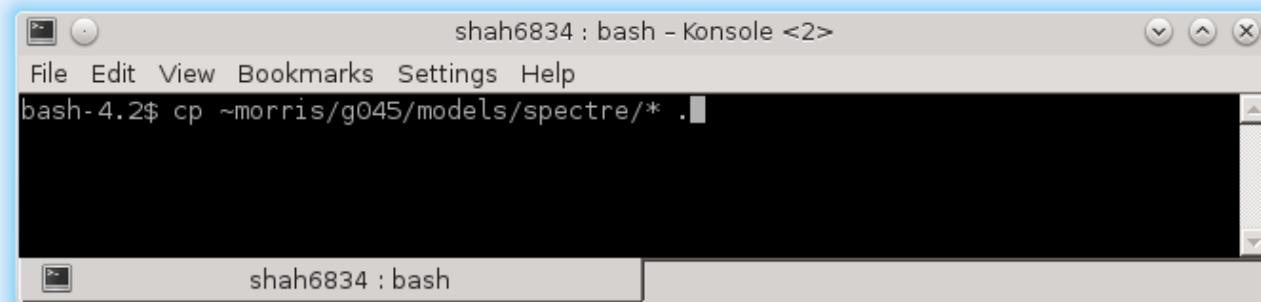


This is what it looks like. On your left are your **Design Variables**, to your right is **Analyses** window and lower right bottom is your **Outputs**. Before we go on to explain what they mean, it's always important to check and save  your schematics to check for any warnings/error (netlist).

15. Before you run or we explain you how to use ADE-L, **make sure** that you select model library. Let's not get into why we have to run TT (typical-typical, in some old versions this is equivalent to NN which is normal-normal). For this, on your ADE-L window, goto Setup>Model Libraries and you will come across this window :



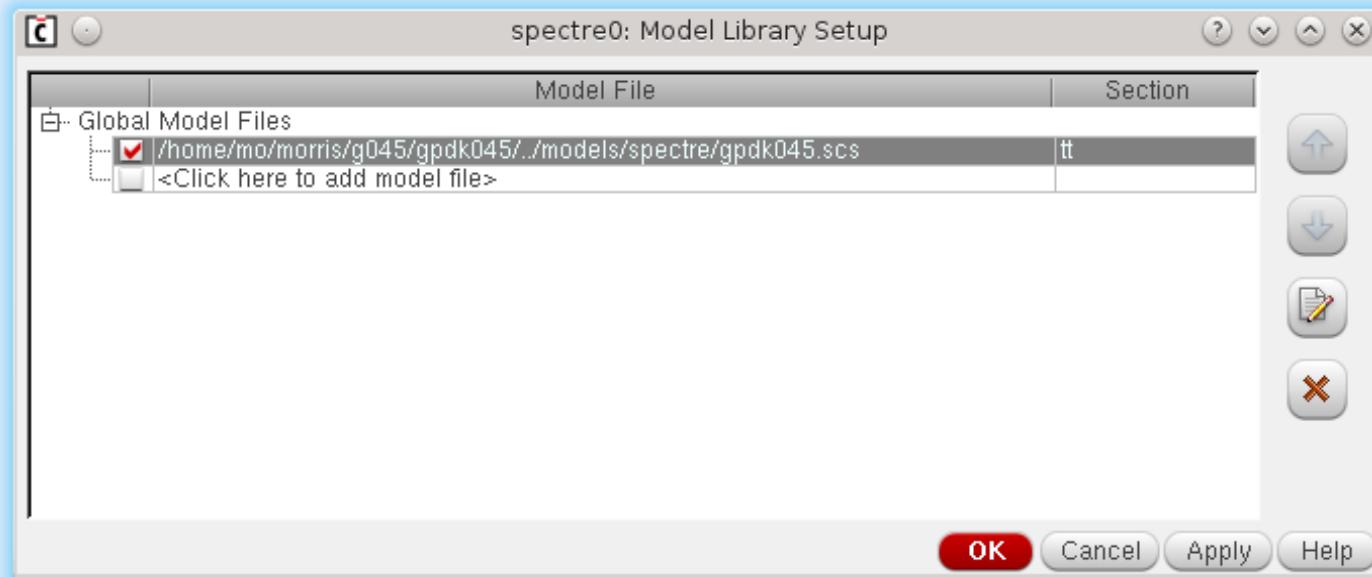
WAIT – Unless you wanna get your unix account frozen , don't select this option. Most students fail to realize that in Cadence 6.1.3, you gotta get the .scs file from Prof.Jones' directory. So now type this on your terminal :



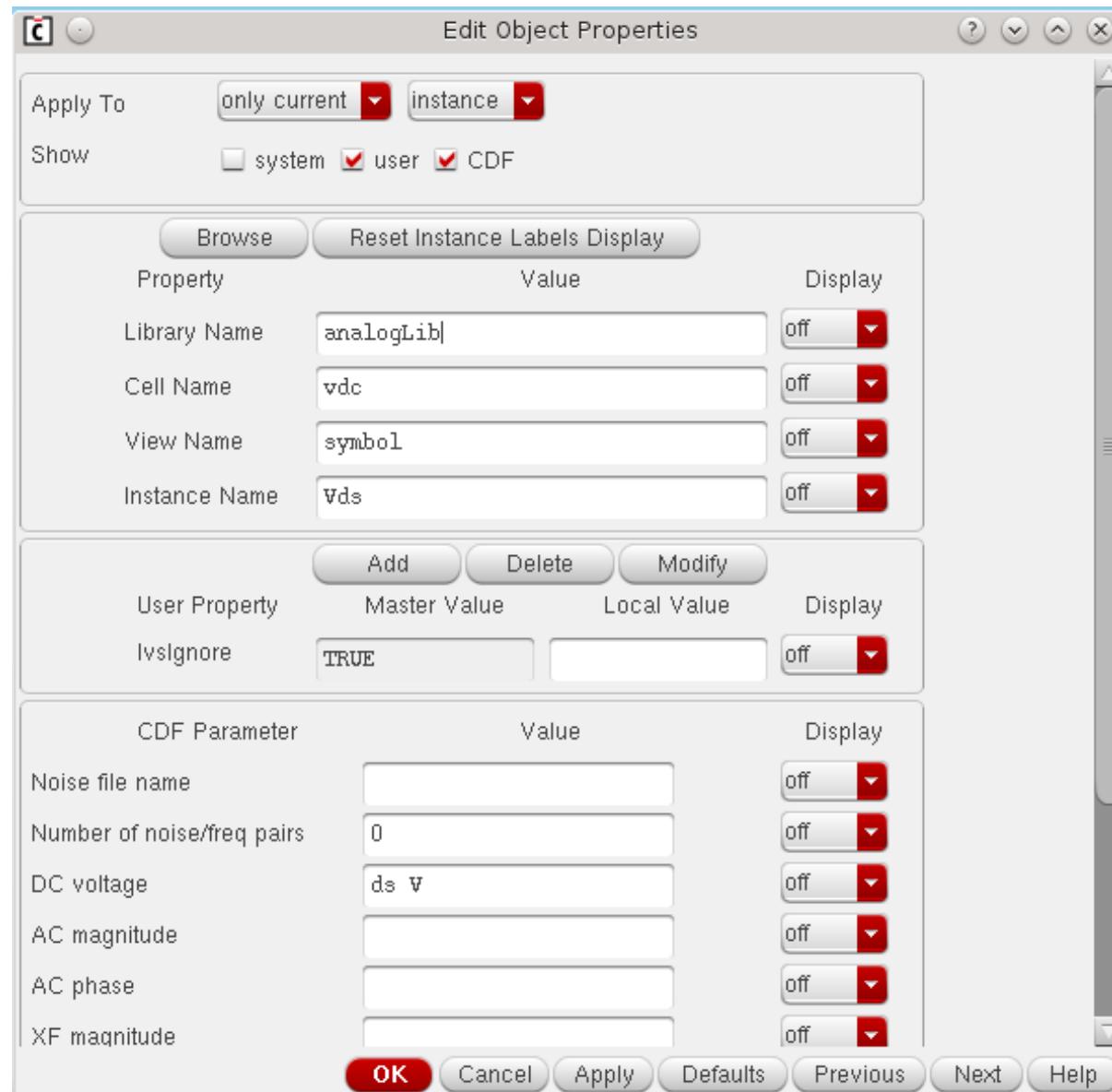
When you run this command, these files will be copied to your /Home/ directory. The one under interest (godfather of all files) is gpdk045.scs



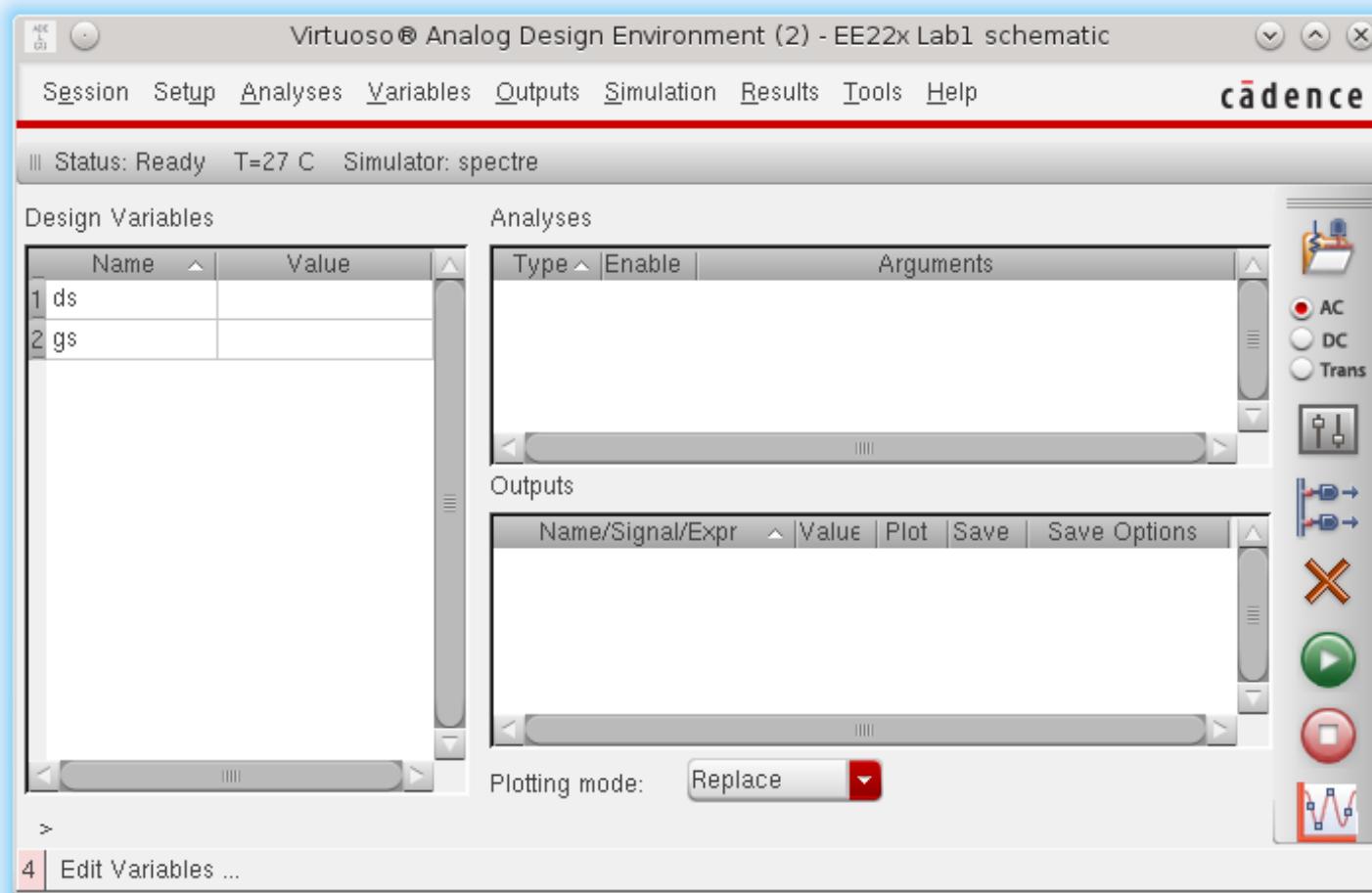
Now when you goto your ModelLibrarySetup window, you will have gpdk045.scs visible under your Global Model Files. By **default the section is mc** and so it's your job to go to this menu and select **tt every time you run ADE-L** (Note: you don't have to copy gpdk045.scs files from Prof.Jones' folder everytime you run ADE-L, it's just a one time step)



16. Now go back to Schematics-XL and then Select your Vds source to assign a D.C voltage to your Vds source. Now, there are two ways – either you can assign a fixed voltage in your DC Voltage field or you can assign a variable like we have assigned here called *ds* (acronym for drain-source). This is called a **Design Variable**. We even assigned design variable *gs* to Vgs voltage source.



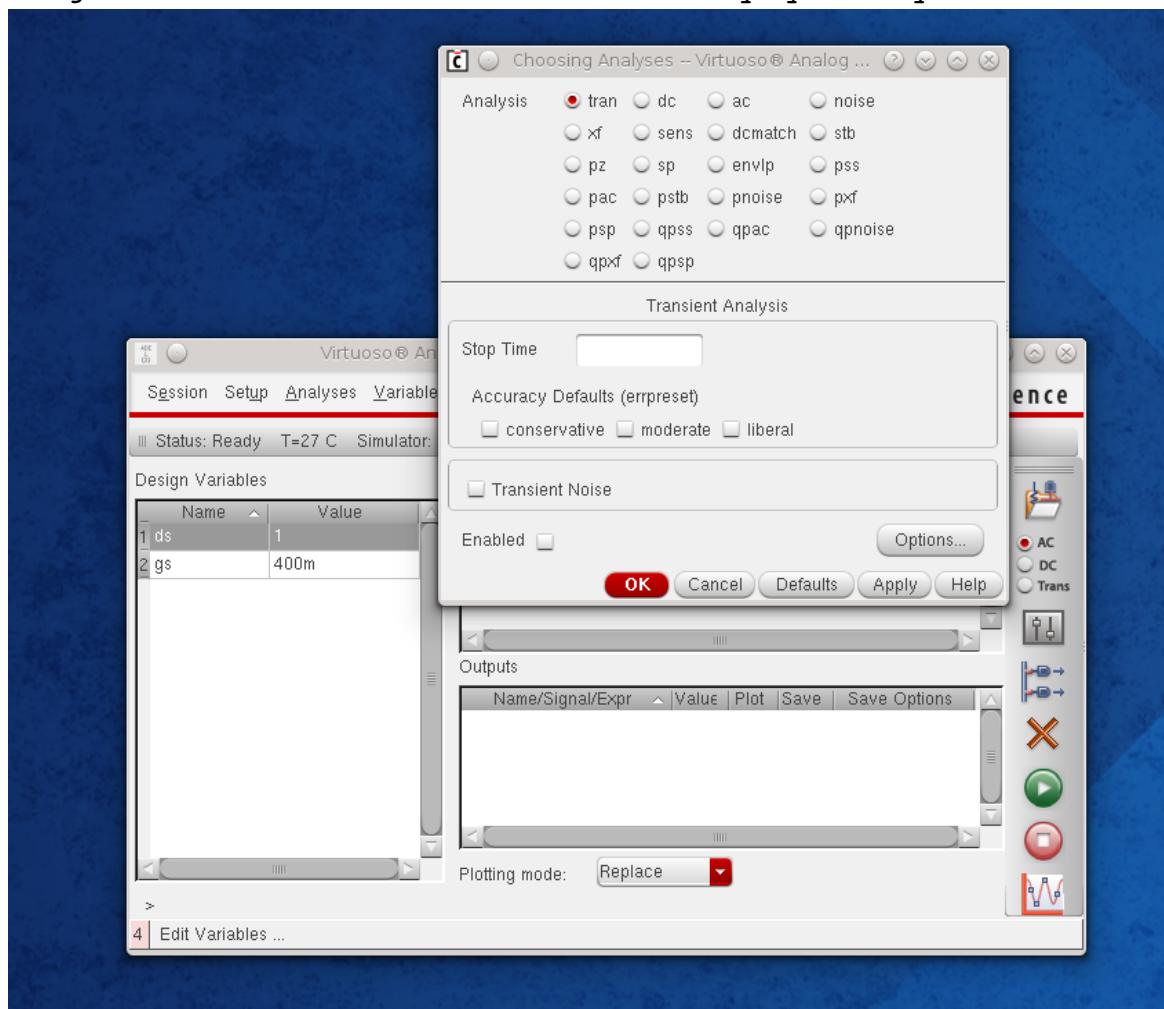
17. Now go back to your ADE-L window and right click on Design Variables field and click on *Copy from Cell View*. Once you click on it, notice that *ds* and *gs* from schematic is copied to your ADE-L test environment. What does this mean ? It means that now you can control your V_{gs} and V_{ds} voltages from ADE-L much like your Function Generator in Lab.



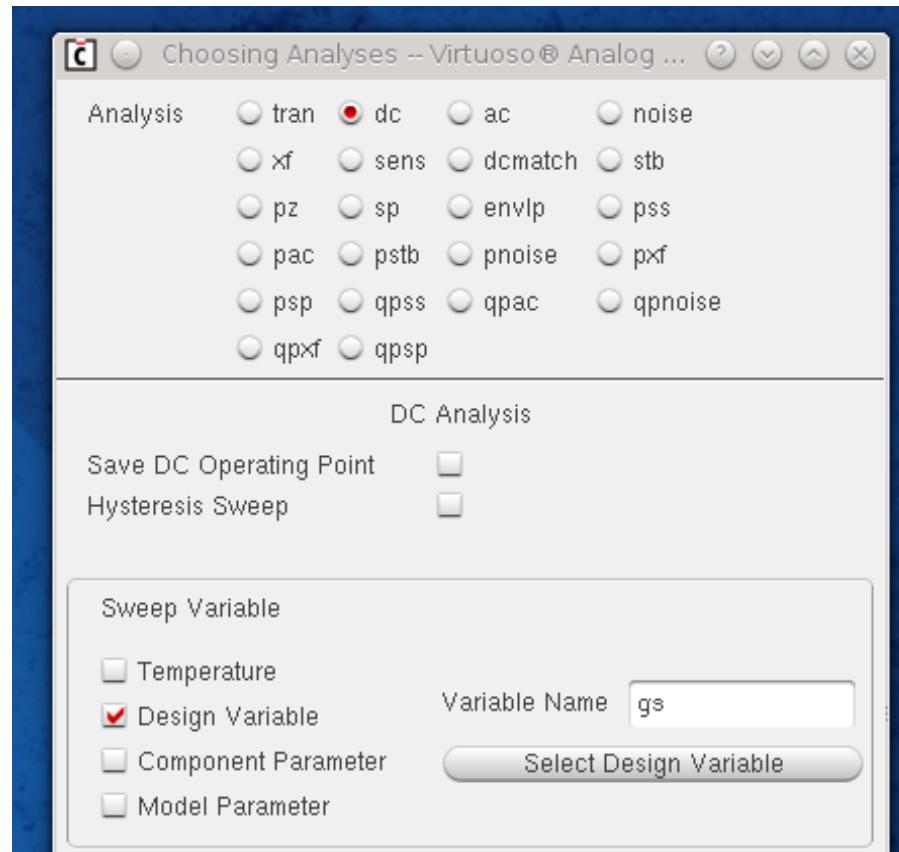
18. Also make sure that you assign some voltage (no matter anything for sake of cadence) to your design variable. Your simulation will encounter an error if you leave this field blank.

Name	Value
1 ds	1
2 gs	400m

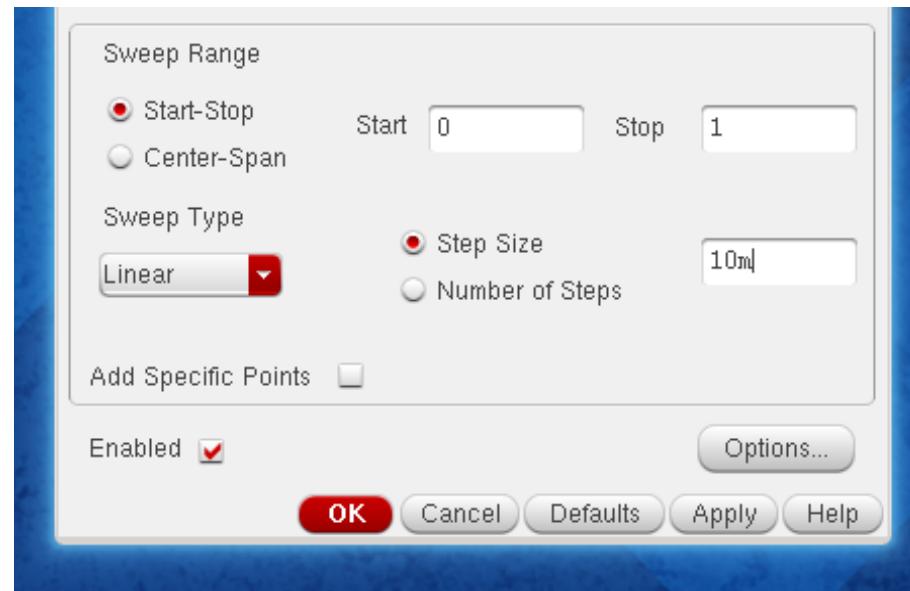
19. When you click on Analyses>Choose in ADE-L you will get this windows. This allows you to select the type of simulation you wanna run on your circuit in schematics. You use transient if you want to plot let's say voltage vs time or current vs time or any quantity vs time



For this tutorial we are gonna use d.c. analyses which is first by sweeping Vgs and keeping Vds at a constant voltage and then by sweeping Vgs and then keeping Vds at a fixed voltage. For this tutorial we will just show you how to do the former , the latter simulation is just a repetition of what we will be covering in coming few pages. Thus we will be plotting Ids vs Vgs for a fixed Vds and then using Calculator in ADE-L we will show you how to plot rds vs

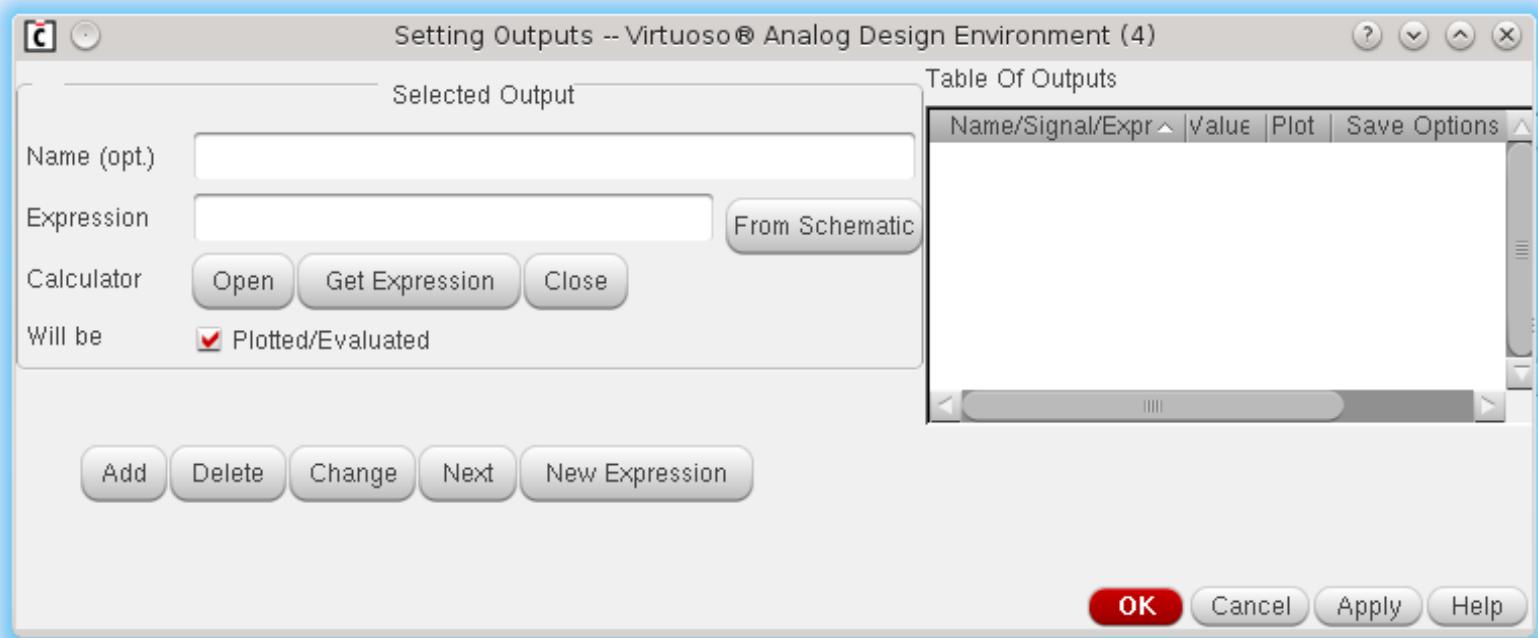


Notice that we have ticked Design Variable and selected **gs** as we wanted to sweep Vgs for fixed value of Vds.



You need to define the nature of sweep range , here we are sweeping from 0v to 1v with 10mV increment steps. Feel free to explore other sweep types (we have used *Linear* sweep type for this example).

20. Now you gotta select the outputs across that you wanna observe. Since we are already sweeping Vgs, that becomes our **X-axis**, while if we wanna see the effect on drain current Ids for changing gate-source voltage Vgs, we will select Ids as **observable output** to represent it on Y-axis. For this, goto Outputs>Setup.

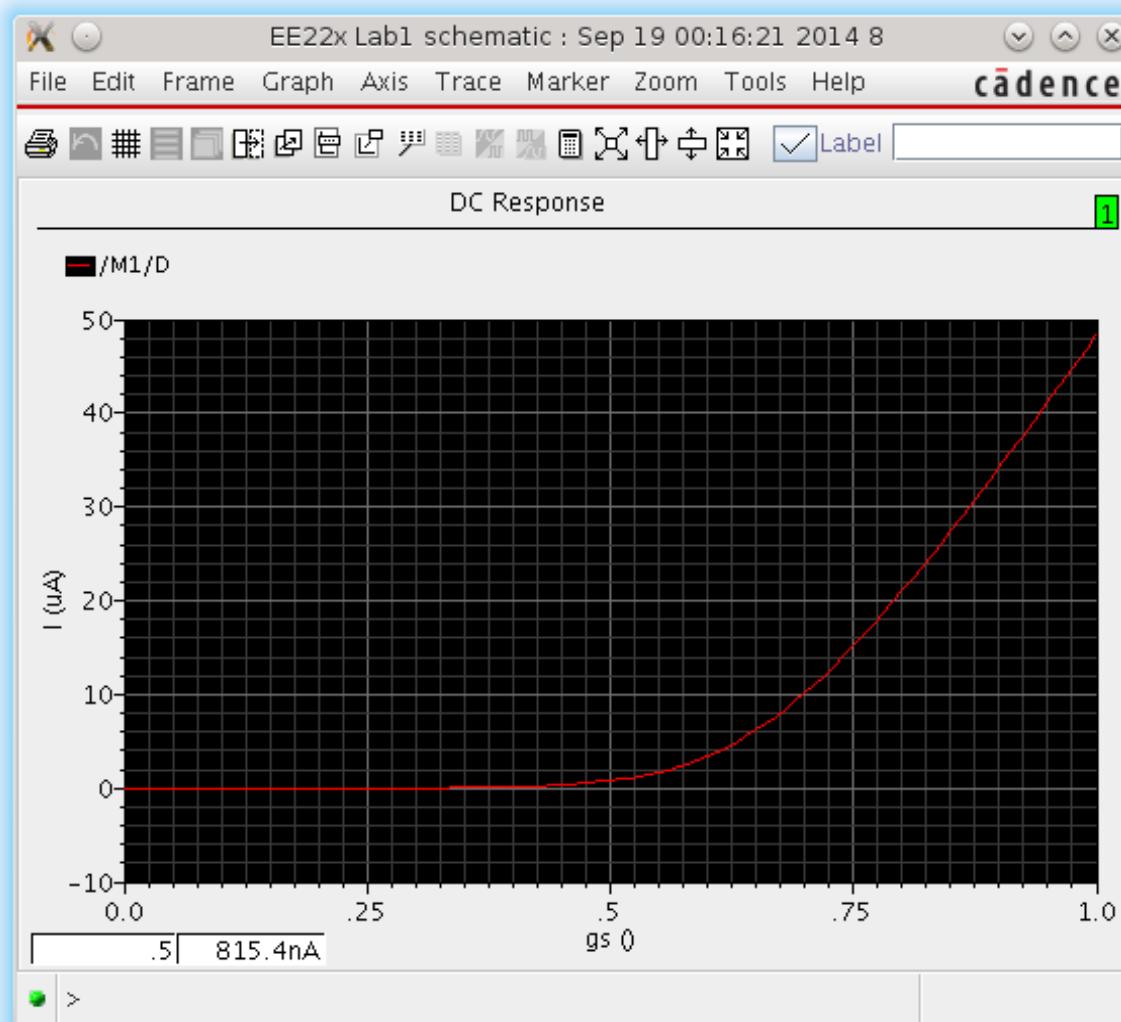


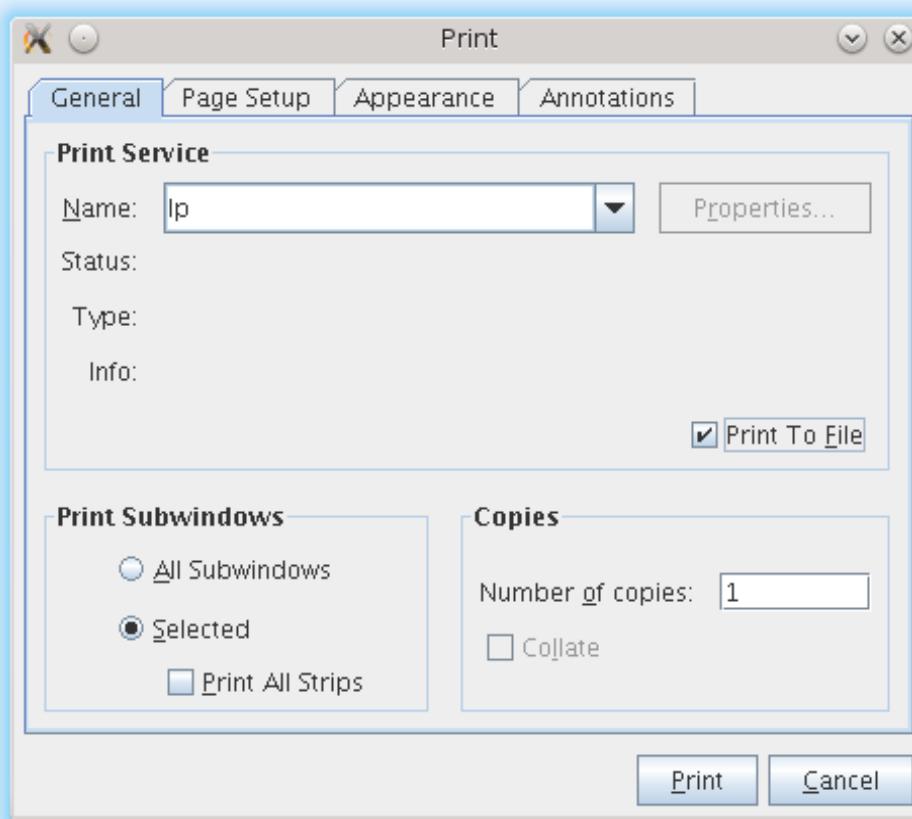
Now click on *From Schematic* and then goto your Schematics window and then **select the Drain node** and then press the Esc key. You will notice that drain node is selected on your Settings Output windows in ADE-L. Rule of thumb :

To select voltage as output – always click on wire whose voltage is to be determined in Schematics
To select current as output – always click on node of transistor/voltage source or any other component on your schematic. Note that **cadence will always measure current entering the node.**

Make sure that you **save state** by going to **Sessions>Save State** and selecting Cellview. By doing this , you can directly open your ADE-L session from Library Manager saved as **spectre_state1** in our example. This saves a lot of time when you have to leave your design halfway. Now click on OK.

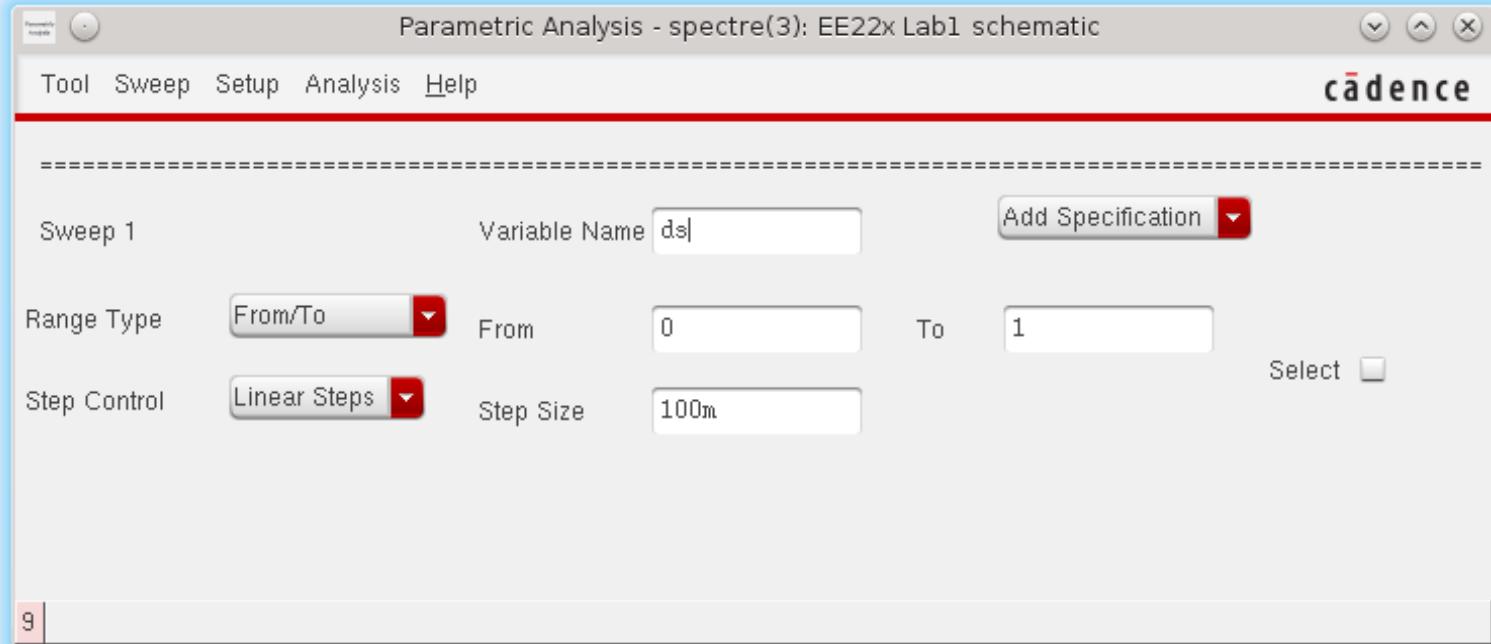
21. The fruit of going through 23 pages worth of instructions : your first plot! This is called a graph plot. Now in Cadence 6.1.3 you can save this file as image (png,bmp etc) but the quality is gonna be really bad. One way to get good pictures is by going to File>Print and make sure that you select the option *Print to File*.





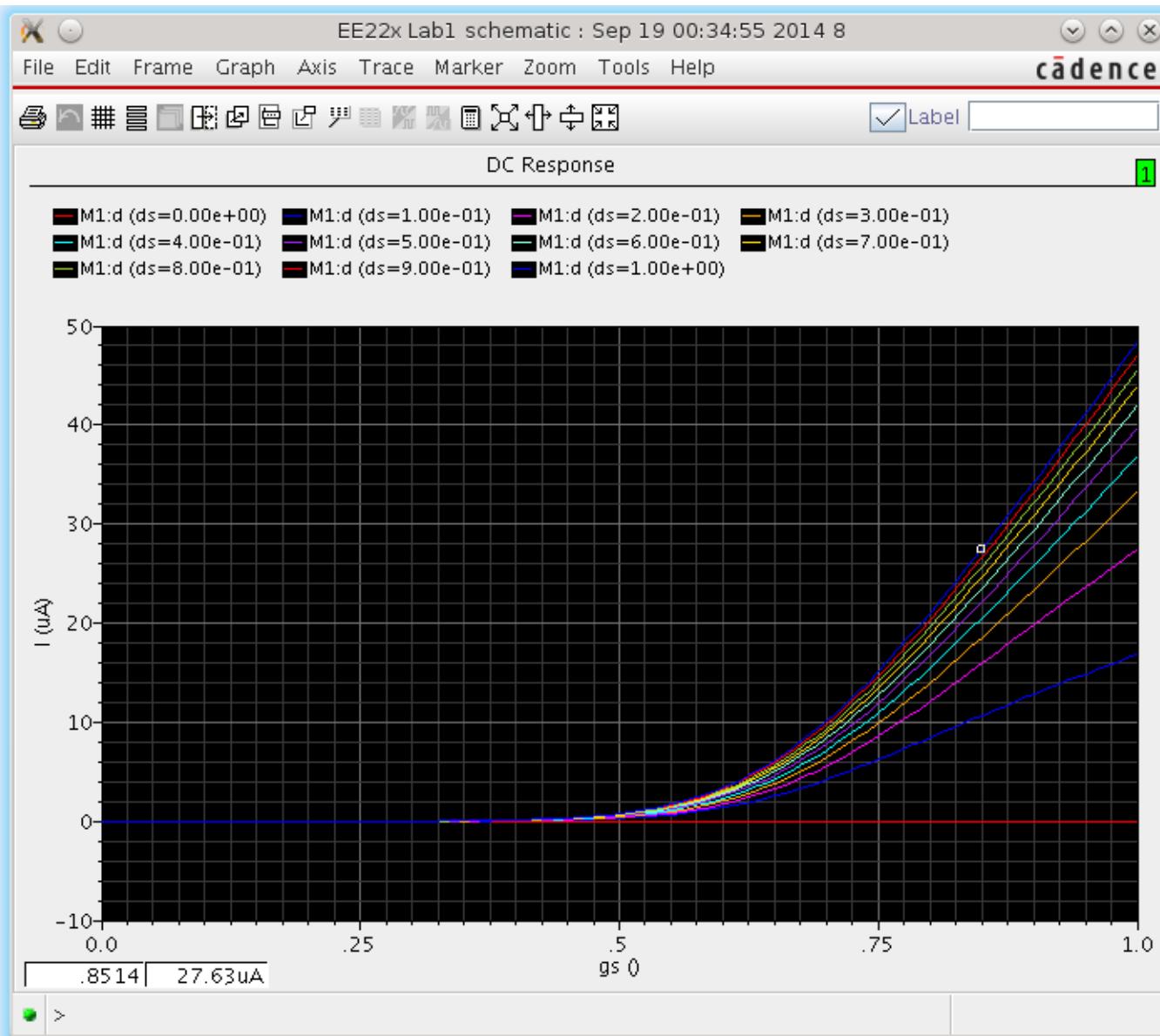
Then click on Print and save the file in your documents. This is a **postscript file**, you can use any image editor or PDF viewer to open and rotate this file (it's high quality graphics compared to Save as image option).

So far we have seen the effect of V_{GS} on I_D s for a fixed value of V_{DS} . What is we want to see this V_{GS} effect on I_D s for various values of V_{DS} ? The answer to this is parametric analysis. Parametric analysis lets you see I_D s vs V_{GS} plots for various values of V_{DS} . Thus, to perform parametric analyses, goto Tools>ParametricAnalyses and then since you have to **parametrize V_{DS}** , enter **Variable name as ds**.

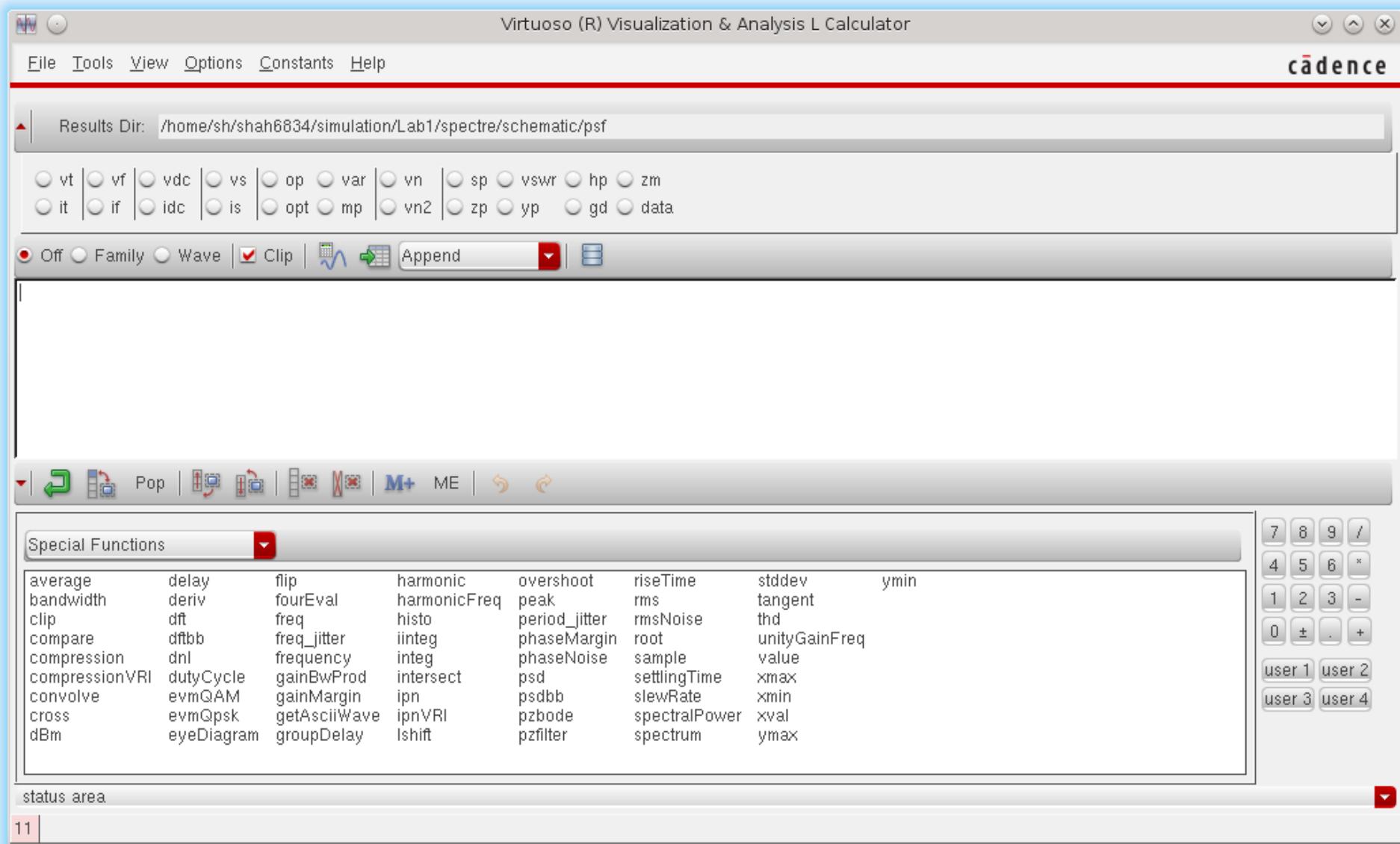


Again, the type of Step control is linear (linear increments of Vds). Note that if your step size goes to 10m, you will have to wait for minutes instead of seconds to finish your simulation.

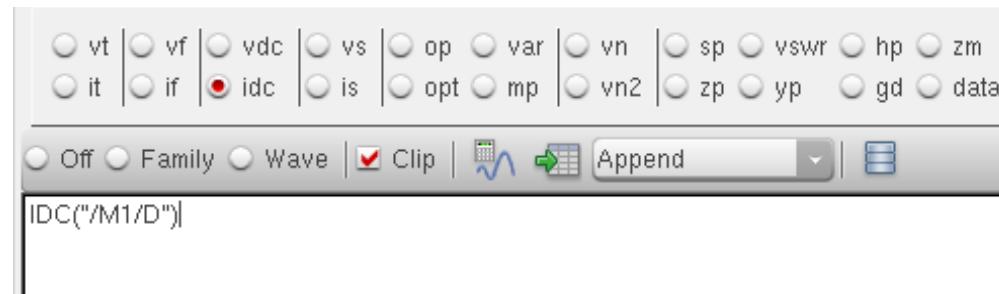
Voila – this is the output. Looks beautiful, isn't it ? Well this is your I_{ds} plot for various values of V_{gs} . What does this plot say ? Well first of all, I_{ds} for any V_{ds} value rises only after roughly 0.4 volts. This tells us that the threshold voltage of this nmos is roughly 400mV. Next, the current curve slope becomes high as we increase the value of V_{ds} – a crucial observation helpful for matching transistor biasing (which you might encounter in later assignments/Lab while you will be designing amplifiers or LNA)



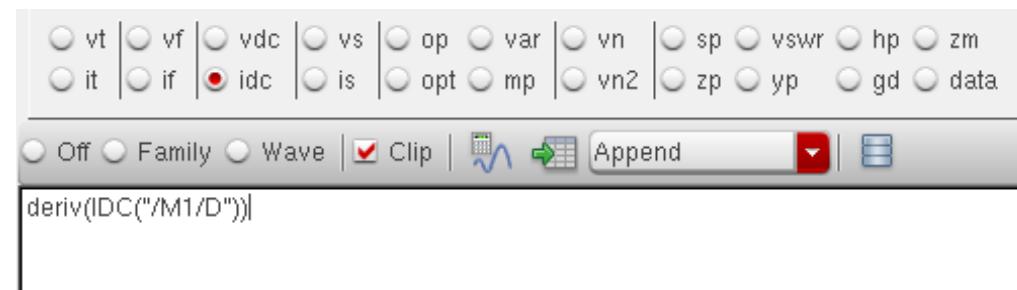
22. You might have studied about trans-conductance gm in your theory class (if not, ask your Professor about it). So lets plot the trans-conductance of this nmos1v. To do that , goto Tools>Calculator in your ADE-L window.



Now click on idc (2nd row 3rd Column on top of calculator window) and after clicking on idc, goto your Schematics windows and select the drain node of transistor.



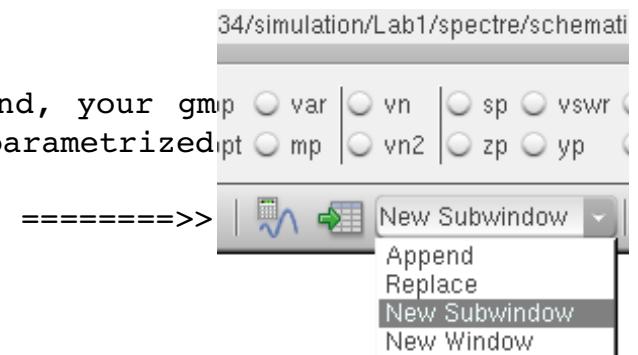
Now, locate the function deriv in special functions section on bottom of calculator window. Once you click on it, you will get something like this



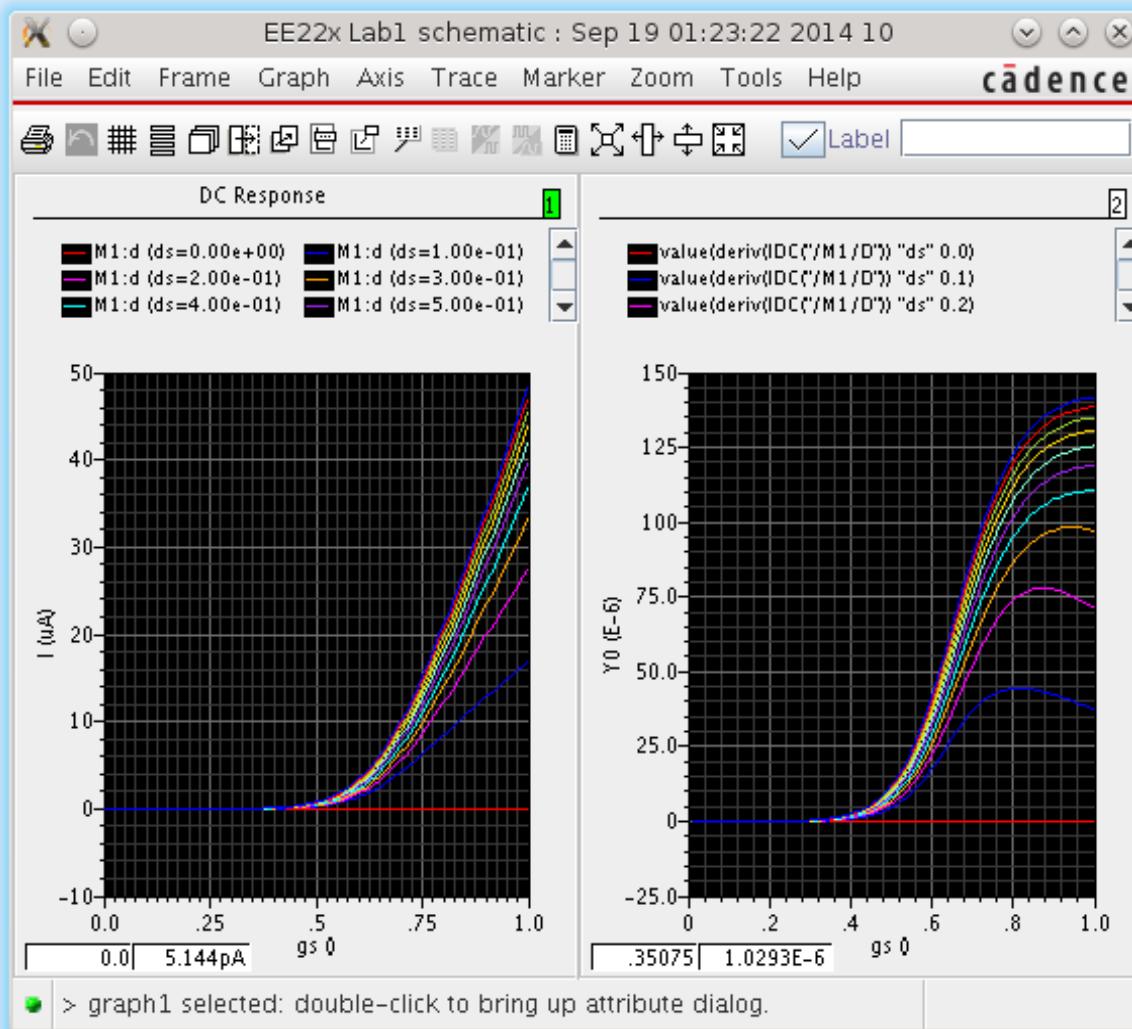
What did we do so far ? Well, we wanted to find transconductance, so we found it using this equation

$$g_m = \frac{\Delta I_{out}}{\Delta V_{in}}$$
 and thus we used deriv function to find derivative of Ids vs Vgs.

Now, make sure that you select New Subwindow (if you select, append, your gmp plot will be overwritten on your existing plot of Ids vs Vgs with parametrized Vds). Then click on button with a calculator and sine wave



The result :



Notice how transconductance changes with increasing V_{gs} . The plot on left is I_{ds} vs V_{gs} for various V_{ds} while plot on right is g_m vs V_{gs} for various V_{ds} values. If you look, you have to answer two questions – What values of V_{gs} yields maximum g_m ? And why g_m reaches maximum and then decreases? These are the questions that you gotta answer yourself! This ends just one part of 4 parts in Lab 1.

So far,

We have found I_{ds} vs V_{gs} for various values of V_{ds} and plotted gm (transconductance) vs V_{gs} for various V_{ds} values using calculator function.

Now you gotta perform *similar* set of steps to find,

I_{ds} vs V_{ds} for various values of V_{gs} and plot r_{ds} (dynamic resistance) for various V_{gs} values , again, using calculator function (r_{ds} is $\{\text{deriv}[I_{ds}]/\text{deriv}[V_{ds}]\}^{-1}$; hint – use deriv on I_{ds} and then use inverse function in calculator).

Once you have performed these two parts, you gotta perform them on pmoslv device !

This brings an end to Lab 1 for EE223 students (and first half of Lab 1 for EE220 students, the second half will be emailed by your Professor soon).

Some thoughts:

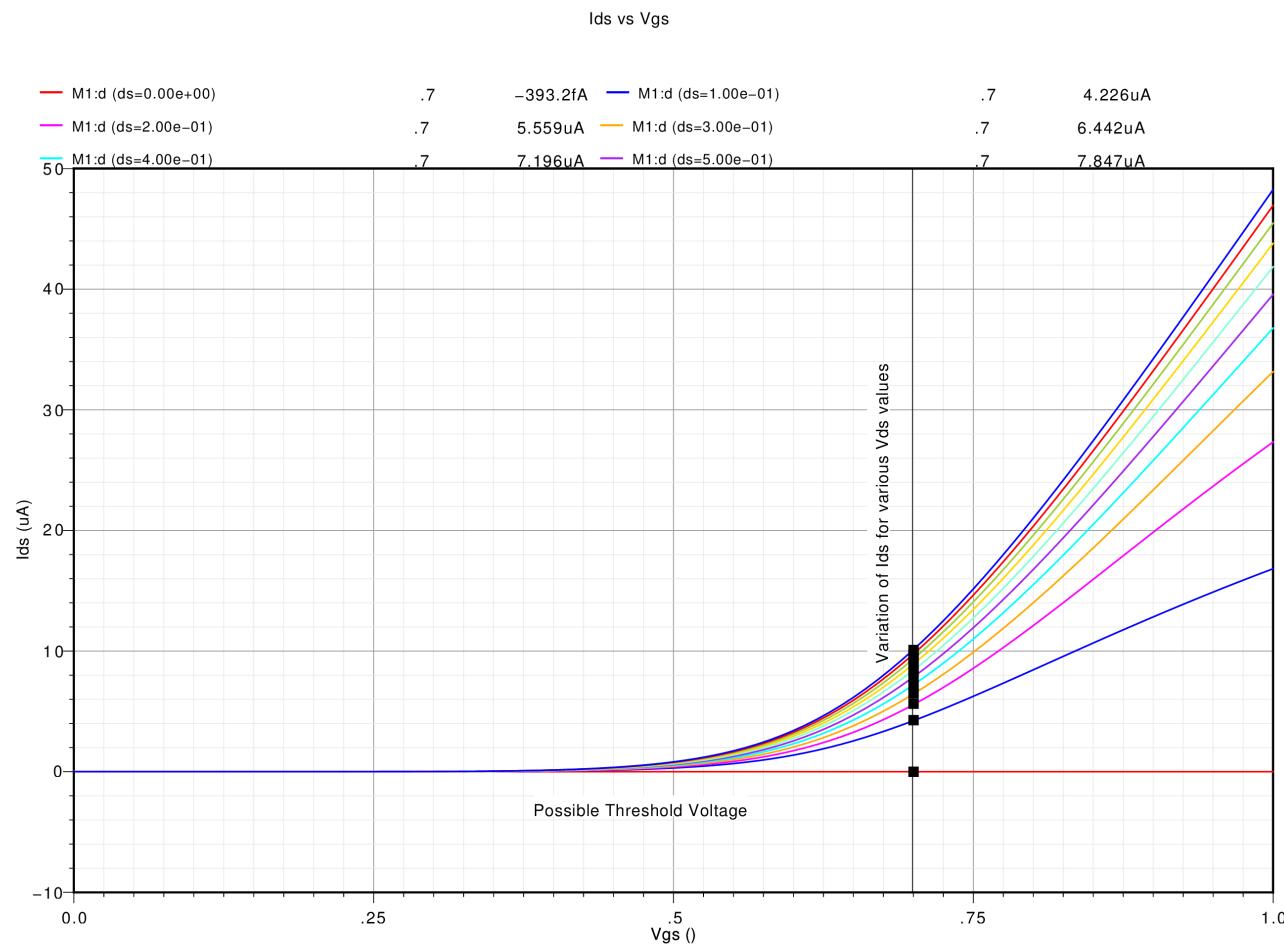
1. Try to explore as many functions as you can in calculator. They are really helpful and you can even use calculator to sometimes automate your task to find any specific value in your simulation plot graphs.
2. We haven't discussed about model parameters – when running d.c analyses make sure that you select *save d.c operating points* and after running simulation, go to Result>Print>Model Parameters on your ADE-L window and then select your nmos/pmos on Schematic windows. What do you see ?
3. Sometimes your Unix session might disconnect or you might abruptly logout of your system while cadence is still running. In this case , cadence creates a .cdslck lock files and when you rerun your cadence virtuoso again, you might come across this error :

WARNING file /home/ugrad/(yourusernamehere)/CDS.log Connection refused

or you won't be able to edit your schematic file. In that case you can simply delete all lock files in your cadence directory. However we prefer to clear these lock files using this command that we use in our everyday simulation sessions :

```
find . -name "*.cdslck" -exec rm -f {} \;
```

4. Can you create such a graph ? Make sure that you spend some time experimenting with various options in your graph editor



Hope you find this tutorial helpful. Feel free if you come across any mistakes in this tutorial. S-Parameters tutorial might be uploaded soon. Click [here](#) and [here](#) to email us.