Analog IC Design – Cadence Tools

Lab 03

Cascode Amplifier

Part 1: Sizing Chart

Use V* = 200 mV and ID = 20 uA. Use VDD = 1.8V

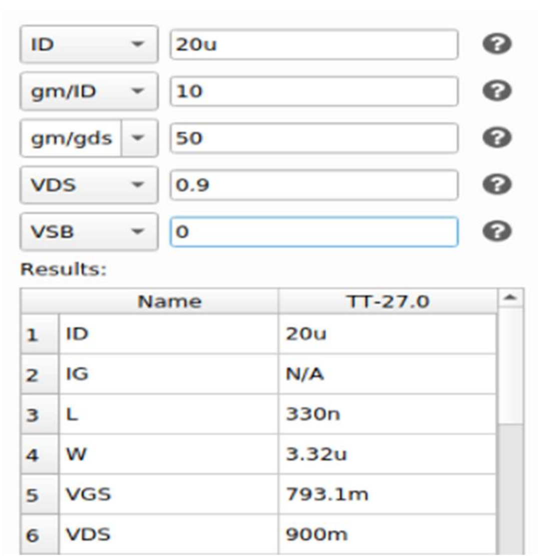
For a square-law device, $V* = Vov$, however, for a real MOSFET they are not equal.

The lower the $V*$ the higher the gain, but the larger the area and the lower the speed.

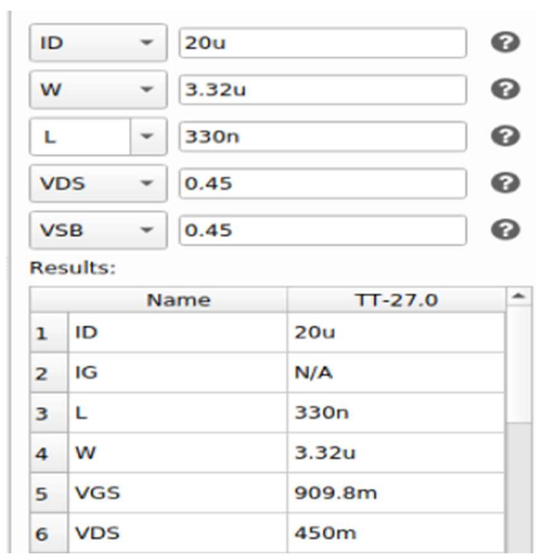
gm =2*ID /V* = (2*20*10^-6) /200*10^-3 = 200u

$$V\ ov = VGS - VTH$$

1. We use VDS =VDD/2 =3/2= 1.5 V, $\boldsymbol{gm/ID}$ =10 S/A
   Av=$\boldsymbol{gm\ ro}$ = 50 , $\boldsymbol{IB} = 20\mu A$



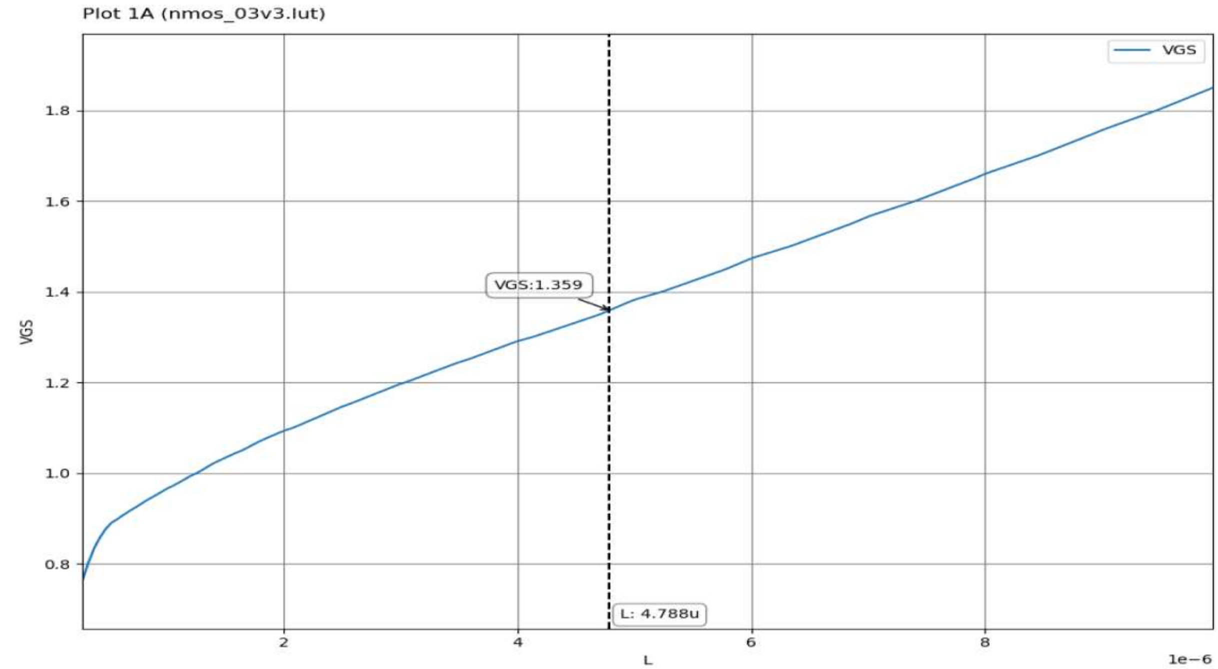
	Name	TT-27.0
1	ID	20u
2	IG	N/A
3	L	330n
4	W	3.32u
5	VGS	793.1m
6	VDS	900m



	Name	TT-27.0
1	ID	20u
2	IG	N/A
3	L	330n
4	W	3.32u
5	VGS	909.8m
6	VDS	450m

VGS1 =793.1mv VGS2 =909.8mv $\boldsymbol{VB}$ to set $\boldsymbol{VDS1} \approx \boldsymbol{VDS2} \approx \boldsymbol{0.45\ V}$
$\boldsymbol{VB} = \boldsymbol{VGS2} + \boldsymbol{VDS1}$ =909.8m+0.45 = 1.3598v

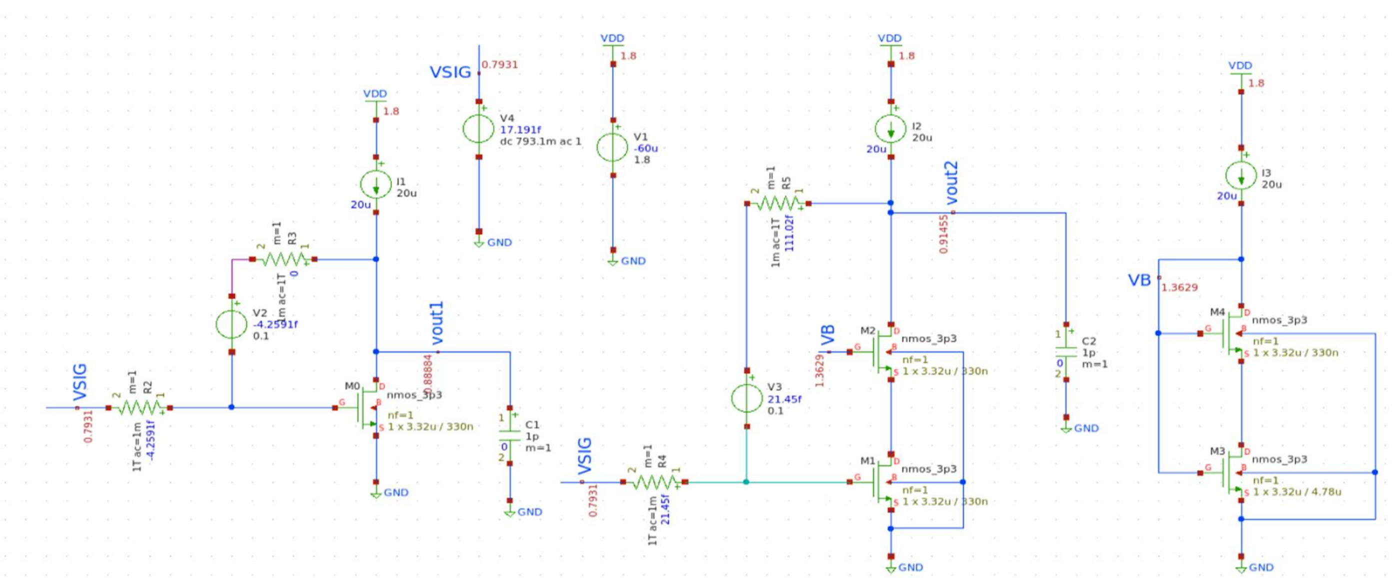
find L3.



L3= 4.788u w is constant in all transistors

Vout1 = 0.9   0.9-vgs1 =0.9-793.1m= 0.1

Vout2 = 0.9   0.9-vgs1 =0.9-793.1m= 0.1



Put the OP of all transistors in a table with the appropriate units

```
No. of Data Rows : 1
igain0 = 4.697477e+01
igain1 = 1.470747e+03
binary raw file "lab3.raw"
 BSIM4v5: Berkeley Short Channel IGFET Model-4
     device             m.xm4.m0             m.xm2.m0             m.xm1.m0
      model          nmos_3p3.8           nmos_3p3.8           nmos_3p3.8
         id               2e-05                2e-05                2e-05
        vgs             0.90218             0.915022             0.814542
        vds            0.902172               0.4667              0.44782
        vth            0.773009             0.780565             0.682219
      vdsat            0.164456             0.167975             0.164748
         gm         0.000198406          0.000195565          0.000195901
        gds          4.5533e-06          5.70778e-06          5.51981e-06
       gmbs         4.09662e-05          4.09682e-05          5.35256e-05
        cdb        -1.99264e-16         -2.05429e-16         -2.67635e-16
        cgd         2.53027e-17          2.06986e-17          1.42304e-17
        cgs        -2.36966e-15         -2.39504e-15         -2.34144e-15
        csb        -2.98496e-16         -3.05899e-16          -3.9823e-16

 BSIM4v5: Berkeley Short Channel IGFET Model-4
     device             m.xm0.m0             m.xm3.m0
      model          nmos_3p3.8          nmos_3p3.10
         id               2e-05                2e-05
        vgs            0.788833              1.36286
        vds            0.888826             0.460663
        vth            0.662441             0.656113
      vdsat             0.16076             0.548263
         gm         0.000199102           4.5917e-05
        gds          4.2385e-06          1.26435e-05
       gmbs         5.40445e-05          1.77984e-05
        cdb        -2.61442e-16          -8.1538e-15
        cgd         1.93885e-17         -4.44422e-15
        cgs        -2.31164e-15         -4.47538e-14
        csb        -3.91625e-16         -1.07572e-14
```

Parameters of M0, M1, M2, M3, M4

Parameters M0	Parameters M1	Parameters M2	Parameters M3	Parameters M4
Id= 2e-05	Id= 2e-05	Id= 2e-05	Id= 2e-05	Id= 2e-05
vgs= 0.7888	vgs= 0.8145	vgs= 0.915	vgs= 1.363	vgs= 0.9022
vds= 0.8888	vds= 0.4478	vds= 0.4667	vds= 0.4607	vds= 0.9022
vth= 0.6624	vth= 0.6822	vth= 0.7806	vth= 0.6561	vth= 0.773
vdsat= 0.1608	vdsat= 0.1647	vdsat= 0.168	vdsat= 0.5483	vdsat= 0.1645
gm= 0.0001991	gm= 0.0001959	gm= 0.0001956	gm= 4.592e-05	gm= 0.0001984
gds= 4.238e-06	gds= 5.52e-06	gds= 5.708e-06	gds= 1.264e-05	gds= 4.553e-06
gmbs= 5.404e-05	gmbs= 5.353e-05	gmbs= 4.097e-05	gmbs= 1.78e-05	gmbs= 4.097e-05

<u>Check that all transistors operate in saturation. Does any transistor operate in triode? Why?</u>

in simulation outputs,
All transistors operate in saturation as
But M3 not saturation the transistor operate in triode
As the transistor is vov increased to provide L and the ID is constant.

Do all transistors have the same vth? Why?

No, M4 > M1 > M2 > M3 > M0

It is reduced due to DIBL effect Higher VTH because it influences the body because Source voltage.

What is the relation (≪, <, =, >, ≫) between gm and gds?

$g_m >> g_{ds}$ to M0 M1 M2 M4

$g_m > g_{ds}$ to M3

What is the relation (≪, <, =, >, ≫) between gm and gmb?

$g_m >> g_{mb}$ to M0 M1 M2 M4

$g_m > g_{mb}$ to M3

What is the relation (≪, <, =, >, ≫) between cgs and cgd?

$|Cgs| << |Cgd|$

What is the relation (≪, <, =, >, ≫) between csb and cdb?

$|Csb| > |Cdb|$ to M0 M1 M2 M4

$|Csb| << |Cdb|$ to M3

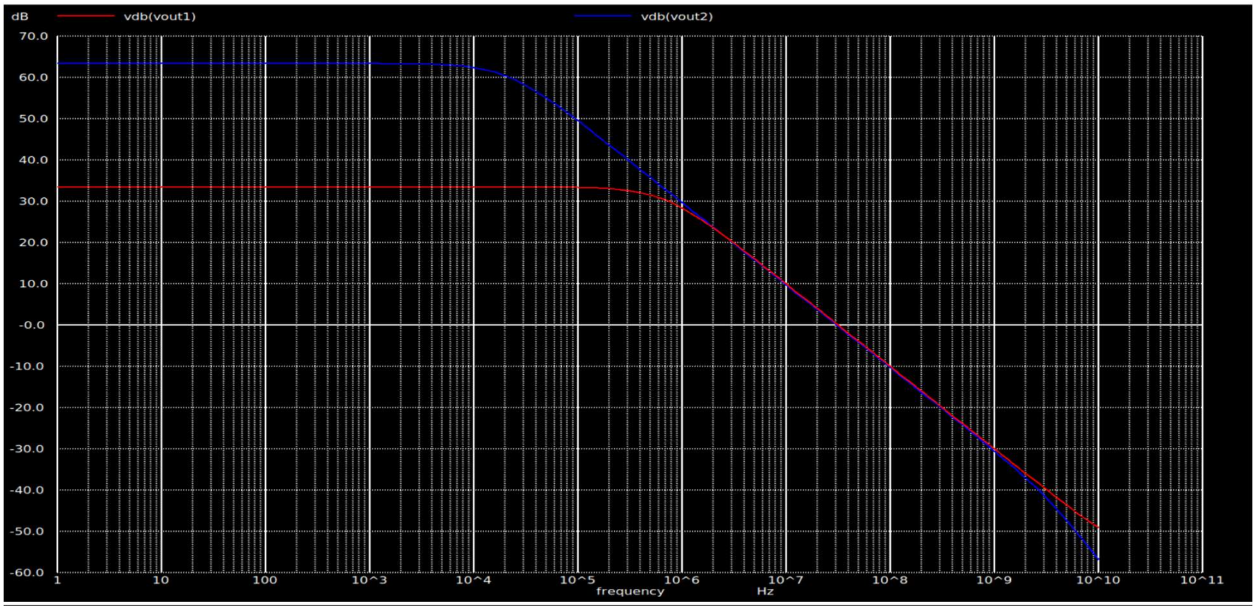
2. AC Analysis

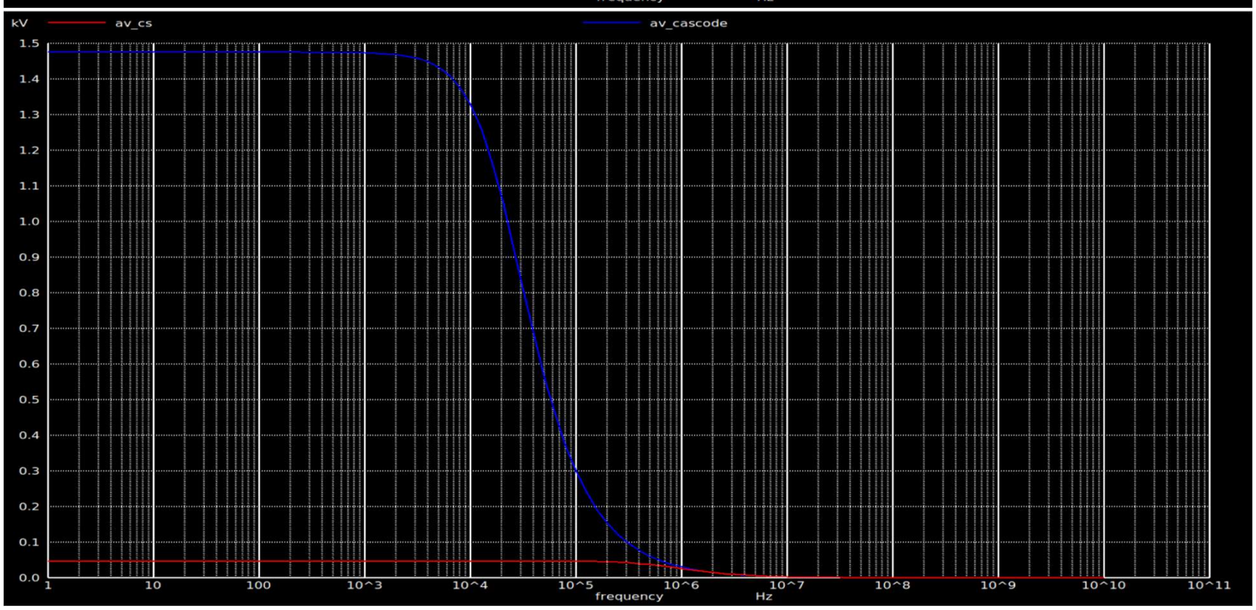
1) Create a new simulation configuration. Perform AC analysis (1Hz:10GHz, logarithmic, 10points/decade) to simulate gain and bandwidth.

2- Use calculator to create expressions for circuit parameters (DC gain, BW, GBW, and UGF) and export them to adexl.

```
No. of Data Rows : 101
peak1                  =   4.712516e+01 at=  1.000000e+00
f3db1                  =   6.717666e+05
ugf1                   =   3.156354e+07
gbw1 = 3.165711e+07
peak2                  =   1.475165e+03 at=  1.000000e+00
f3db2                  =   2.066319e+04
ugf2                   =   3.062239e+07
gbw2 = 3.048161e+07
```

3) Report the Bode plot (magnitude) of CS and cascode **appended on the same plot**.





4) Using small signal parameters from OP simulation, perform hand analysis to calculate DC gain, BW, and GBW of both circuits.

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         id                2e-05                2e-05                2e-05
        vgs              0.90218             0.915022             0.814542
        vds             0.902172               0.4667              0.44782
        vth             0.773009             0.780565             0.682219
      vdsat             0.164456             0.167975             0.164748
         gm          0.000198406          0.000195565          0.000195901
        gds           4.5533e-06          5.70778e-06          5.51981e-06
       gmbs          4.09662e-05          4.09682e-05          5.35256e-05
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        cgs         -2.36966e-15         -2.39504e-15         -2.34144e-15
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         id                2e-05                2e-05
        vgs             0.788833              1.36286
        vds             0.888826             0.460663
        vth             0.662441             0.656113
      vdsat              0.16076             0.548263
         gm          0.000199102           4.5917e-05
        gds           4.2385e-06          1.26435e-05
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gbw1 = 3.165711e+07
peak2                = 1.475165e+03 at= 1.000000e+00
f3db2                = 2.066319e+04
ugf2                 = 3.062239e+07
gbw2 = 3.048161e+07
```

Gain

CS Av =gm*ro = 50 dB

calculate DC $Av = (gm2 + gmb2)\, ro2\, gm3\, ro3$= 1469 dB

Bw

For CS: $BW = \frac{1}{(2\pi\, r_o C_L)} = 668.56$ kHZ

For Cascode: $BW = \frac{1}{2\pi(r_{o2}+(1+(g_{m2}+g_{mb2})r_{o2})r_{o3})\, C_L}$ = 20.57KHZ

GBW & UGF:

For CS: $GBW = UGF = Av * BW = 32.76\, MHz$

For Cascode: $GBW = UGF = Av * BW = 29.86\, MHz$

5) Report a table comparing the DC gain, BW, UGF, and GBW of both circuits from simulation and hand analysis.

Analysis	Analytical			Simulation		
Quantity	Gain	BW	GBW & UGF	Gain	BW	GBW & UGF
CS	50 dB	668.5 kHZ	32.7MHz	47.1dB	671.76k	31.6M
Cascode	1469 dB	20.57KHZ	29.86MHz	1475dB	20.66k	30.48M

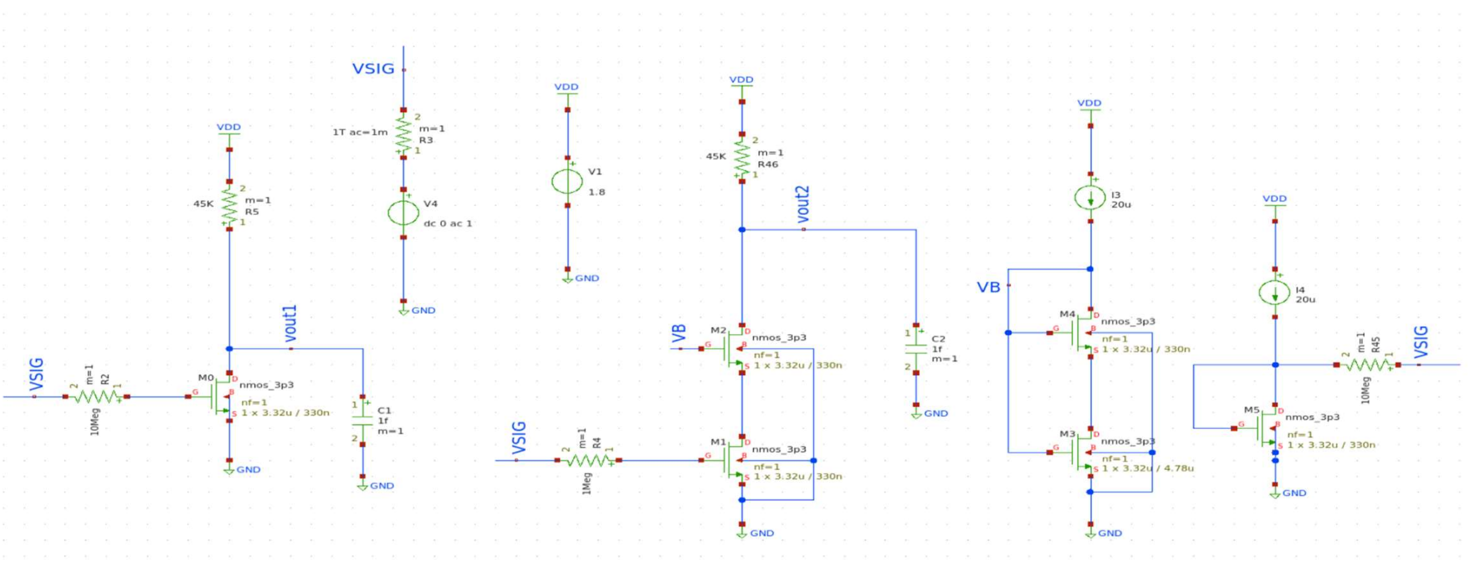
6) Comment on the results

The bandwidth of the cascode amplifier is much less than the conventional amplifier, but the gain of the cascode amplifier is much greater than the conventional amplifier. This means that almost the same bandwidth is achieved. It is a mixture of gain and bandwidth because more weight increases the bandwidth and vice versa.

Part 3: "Optional" Cascode for BW

1. OP Analysis

$$VDD = VD + VRD = VD + ID*RD$$
$$1.8 = 0.9 + 20u * RD \quad , RD = 45K$$



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igain1 = 1.978884e-03
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      model         nmos_3p3.8          nmos_3p3.8          nmos_3p3.8
         id              2e-05               2e-05           1.905e-05
        vgs           0.802474            0.894545            0.901974
        vds           0.802467            0.894538            0.486536
        vth           0.674905            0.765476            0.772919
      vdsat           0.161587            0.164358            0.164304
         gm        0.000198572         0.000198527         0.000190654
        gds        4.33782e-06         4.56545e-06          5.3774e-06
       gmbs        5.39751e-05         4.09315e-05         3.97485e-05
        cdb        -2.6236e-16         -1.9898e-16         -2.0279e-16
        cgd        1.92066e-17         2.53207e-17          2.1491e-17
        cgs       -2.31723e-15        -2.36962e-15        -2.37561e-15
        csb       -3.92848e-16        -2.98062e-16         -3.0225e-16

 BSIM4v5: Berkeley Short Channel IGFET Model-4
     device            m.xm1.m0            m.xm0.m0            m.xm3.m0
      model         nmos_3p3.8          nmos_3p3.8         nmos_3p3.10
         id          1.905e-05         2.12339e-05               2e-05
        vgs           0.802467            0.802466             1.35817
        vds           0.456183            0.844457            0.463611
        vth           0.675351            0.669362            0.652517
      vdsat            0.16125            0.165253            0.547433
         gm        0.000190862         0.000205641         4.62501e-05
        gds         5.2452e-06         4.45735e-06         1.21762e-05
       gmbs         5.2123e-05         5.58771e-05         1.78975e-05
        cdb       -2.65584e-16         -2.6402e-16        -8.11294e-15
        cgd         1.4666e-17         1.94804e-17        -4.27754e-15
        cgs       -2.32203e-15        -2.33691e-15        -4.47847e-14
        csb       -3.95403e-16        -3.95406e-16        -1.07428e-14
```
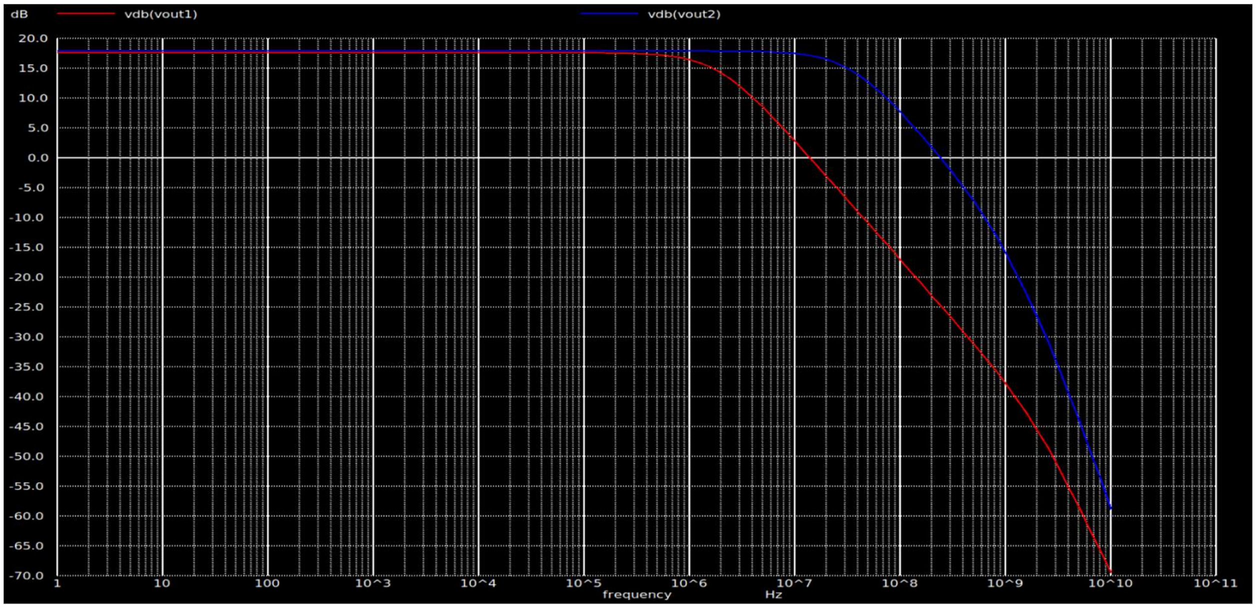
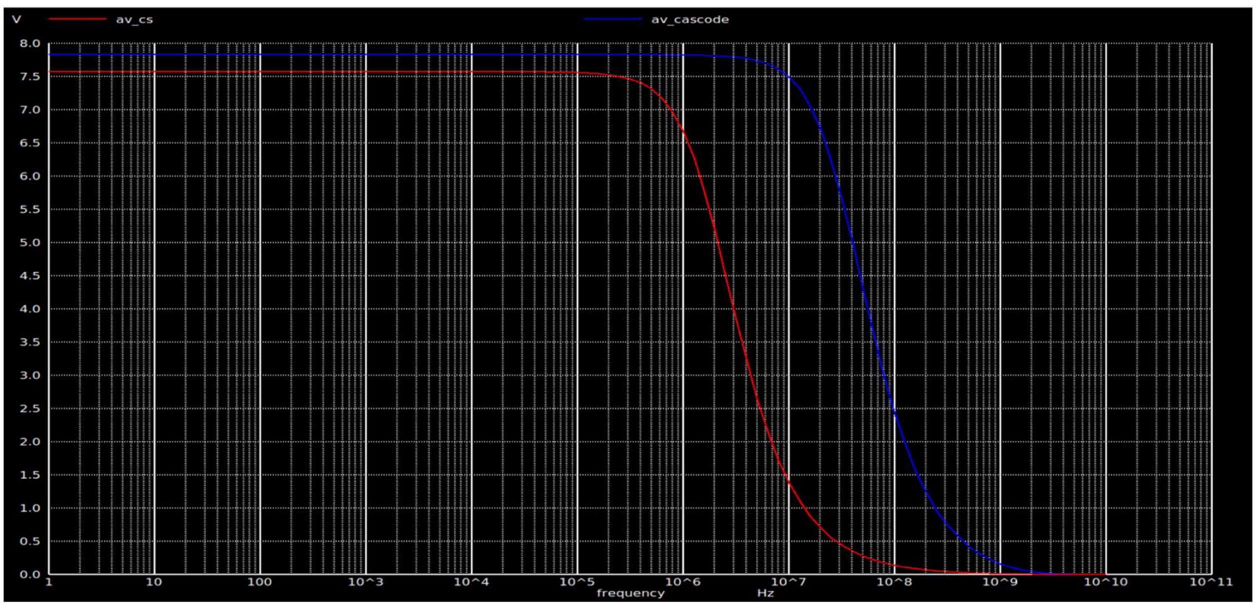

4) Check that all transistors operate in saturation. Does any transistor operate in triode? Why?

all transistors in saturation   but M3 in triode

saturation   **VDS > Vdsat*1.2**

2. AC Analysis






```
No. of Data Rows : 101
peak1                =  7.572658e+00 at=  1.000000e+00
f3db1                =  1.861416e+06
ugf1                 =  1.411224e+07
gbw1 = 1.409587e+07
peak2                =  7.830699e+00 at=  1.000000e+00
f3db2                =  3.289906e+07
ugf2                 =  2.429207e+08
gbw2 = 2.576226e+08
```

Analysis	Analytical			Simulation		
Quantity	Gain	BW	GBW & UGF	Gain	BW	GBW & UGF
CS	7.46dB	1.78MHZ	13.69MHz	7.57dB	1.86M	14.11M
Cascode	7.69 dB	3.19MHZ	241.5MHz	7.83dB	3.28M	242.9M

The comment

The bandwidth of the cascode amplifier is significantly lower than that of a conventional amplifier, but the gain of the cascode amplifier is much higher than that of the conventional amplifier. This results in nearly the same overall bandwidth. It is a balance between gain and bandwidth, where increasing one tends to decrease the other, and vice versa.