Lab 03

Cascode Amplifier

Part 1: Sizing Chart

- We choose the following parameters in this lab:

MOSFET Length L	0.5um
Supply Voltage V_{ds}	1.8V
Drain Current I_D	40uA
Real MOSFET Overdrive Voltage V^*	0.16V

The selection of real MOSFET overdrive voltage $V^* = 160mV$, because it gives a good compromise between different trade-offs.

- Determine MOSFET Width W:
We assume first W=10um and L=0.5um, then use the following schematic

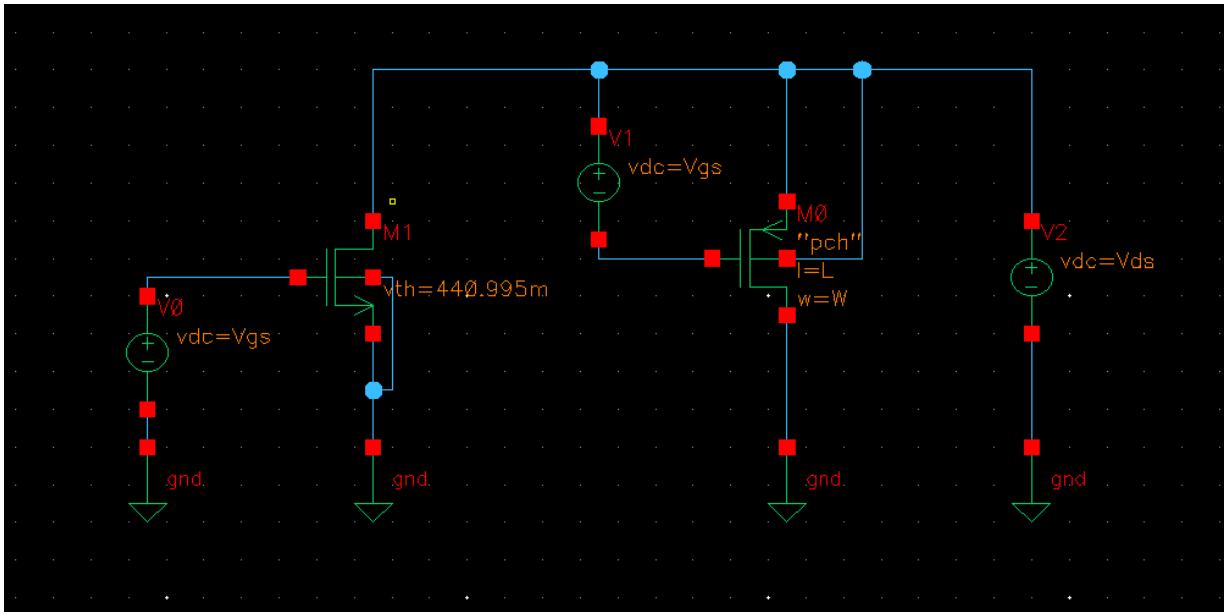

Fig.1 Circuit -schematic from cadence used for selecting MOSFET width

And as shown in fig.1 that the threshold voltage of MOSFET will be $V_{th} = 440.995mV$, so we will sweep input voltage $V_{gs} = 0 \rightarrow V_{th} + 0.4 = 0{:}\,10mV{:}\,840.995mV$.

- We set $V_{ds} = {Vdd}/{2} = 0.9V$.
- V^* and V_{ov} versus V_{gs} overlaid on the same plot:

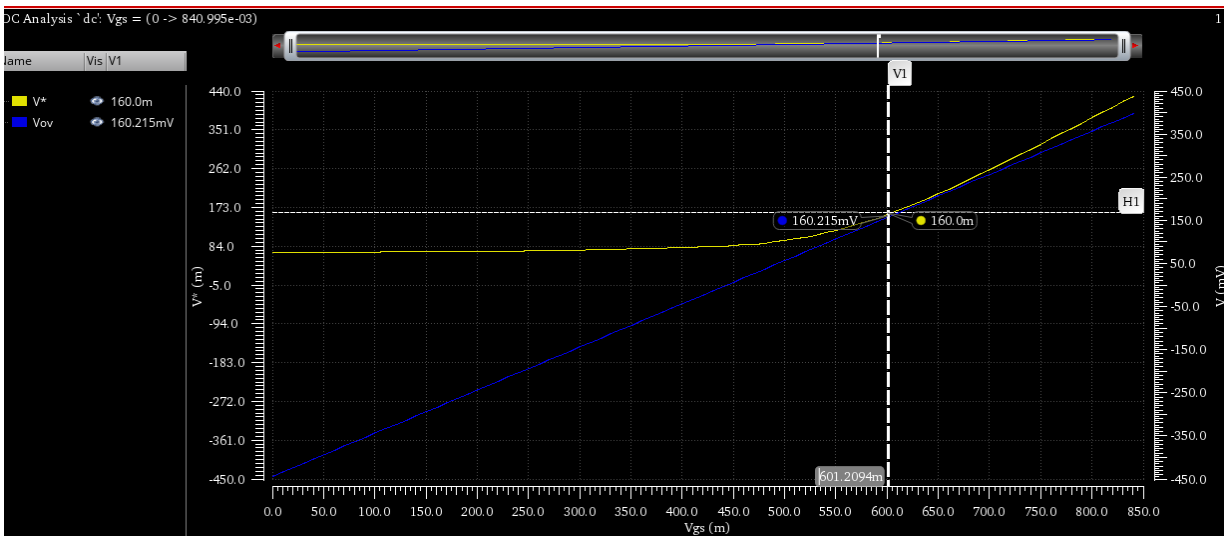

Fig.2 V_{ov}& V^* versus V_{gs}

So from fig.2 at $V_Q^* = 160mV$, we get the square-law overdrive voltage and value of V_{gs} which will be: $V_{gsQ} = 601.2094mV\ and\ V_{ovQ} = 160.215mV$.

- $I_d, g_m\ and\ g_{ds}\ versus\ V_{gs}$:

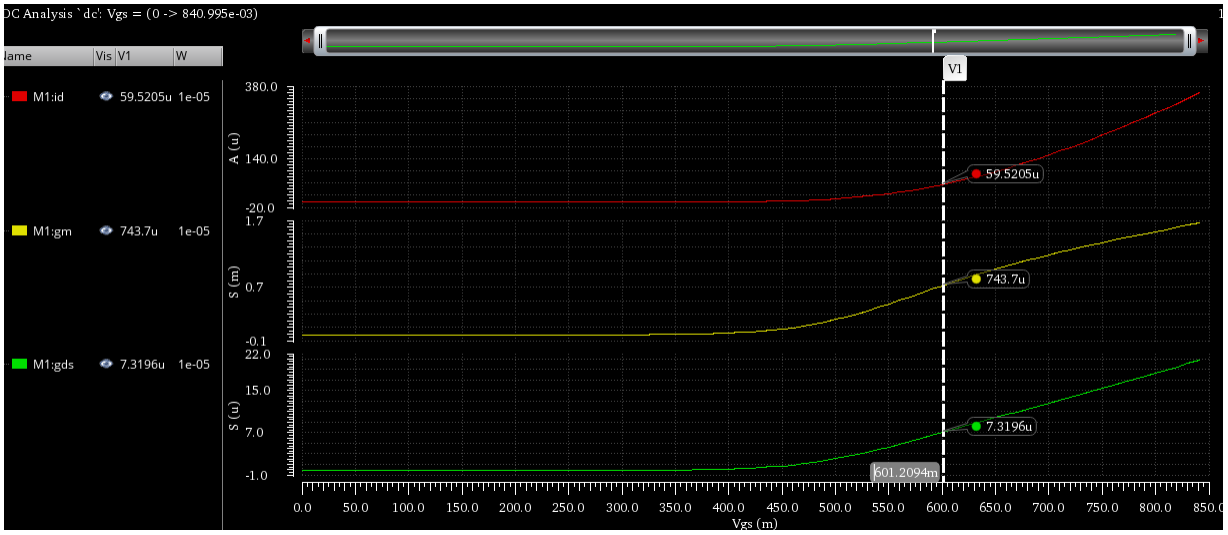

Fig.3 $I_D, g_m\ and\ g_{ds}$versus V_{gs}

As shown in fig.3 that at operating voltage $V_{gs} = 601.2094mV$, we have OP parameters of values $I_{dX} = 59.5205uA, g_{mX} = 743.7uS\ and\ g_{dsX} = 7.3196uS$.

- Determine width of MOSFET W:
  As $I_d \propto W$ at all times even square-law is valid or not, so we use cross multiplication property to get W of MOSFET at certain $I_d = 40uA$, so width of MOSFET will be: $I_d = 40uA \rightarrow W = 6.72um$.

- g_m and r_o calculations:
  As we have constant overdrive voltage V_{ov}, so g_m is proportional to width of MOSFET $g_m \propto W$, so using cross multiplication at $W = 6.72um \rightarrow g_m = 499.8uS$.
  And the same for g_{ds} at constant overdrive voltage V_{ov}, so $g_{ds} \propto W$, therefor by using cross multiplication at $W = 6.72um \rightarrow g_{ds} = 4.919uS$, and by knowing that we will have $r_o = \frac{1}{g_{ds}} = 203.3k\Omega$.

Parameter	Value
V_Q^*	160mV
V_{ovQ}	160.215mV
V_{gsQ}	601.2094mV
L	0.5um
W	6.72um
g_m	499.8uS
g_{ds}	4.919uS
r_o	203.3kΩ

Part 2: Cascode For Gain

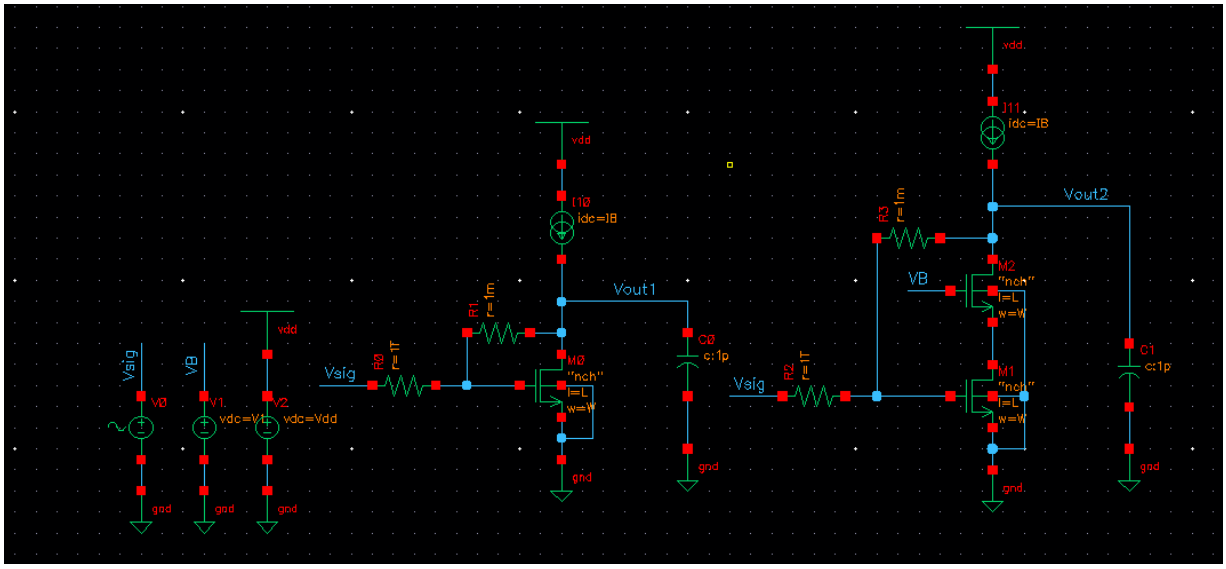

Fig.4 Cascode circuit schematic from cadence

1.OP Analysis:

- Select value of bias voltage for 2nd MOSFET in Cascode:

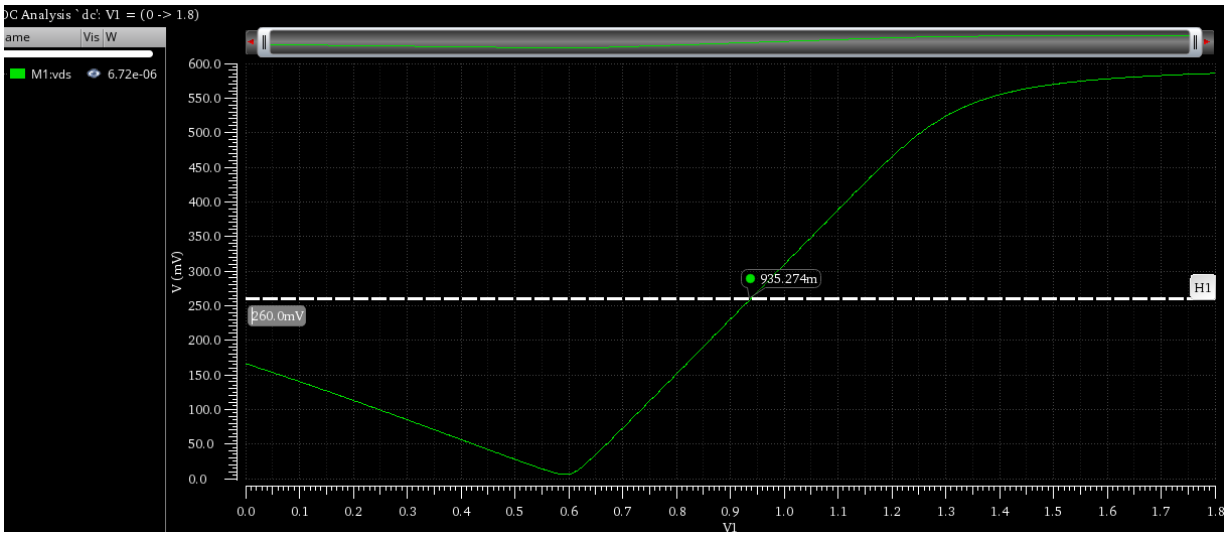

Fig.5 sweep bias voltage of Cascode to choose suitable VB

So as shown in fig.5 by sweeping bias voltage of 2nd MOSFET at cascode and plot V_{ds} by this sweep and selecting $V_{ds} = 160 + 100 = 260mV$, we find that value of V_B=1.04561V.

- OP parameters of MOSFETs in CS & Cascode Amplifiers:

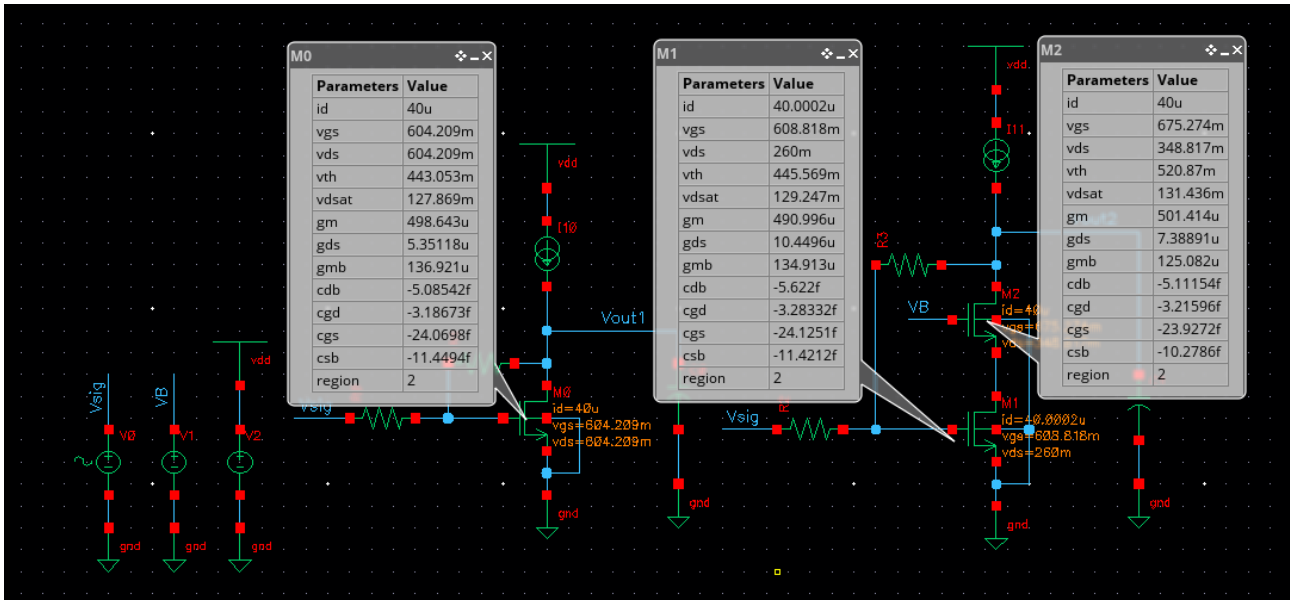

Fig.6 OP parameters simulation

- As shown in fig.6 that region of all MOSFETs equal 2 which mean that all MOSFETs of CS and Cascode amplifiers are in saturation region.

- All transistors don't have the same threshold voltage even they have the same channel length L, this due to body effect as it's clear in fig.6 that MOSFETs 0 and 1 have the same V_{th}, but MOSFET 2 have different value of V_{th} because it suffer from body effect as its source and bulk are not connected together so we have value of V_{sb} which increase threshold voltage.
- $g_m \gg g_{ds}$
- $g_m > g_{mb}$
- $C_{gs} > C_{gd}$
- $C_{sb} > C_{db}$

2.AC Analysis:

- AC analysis simulation results from cadence:

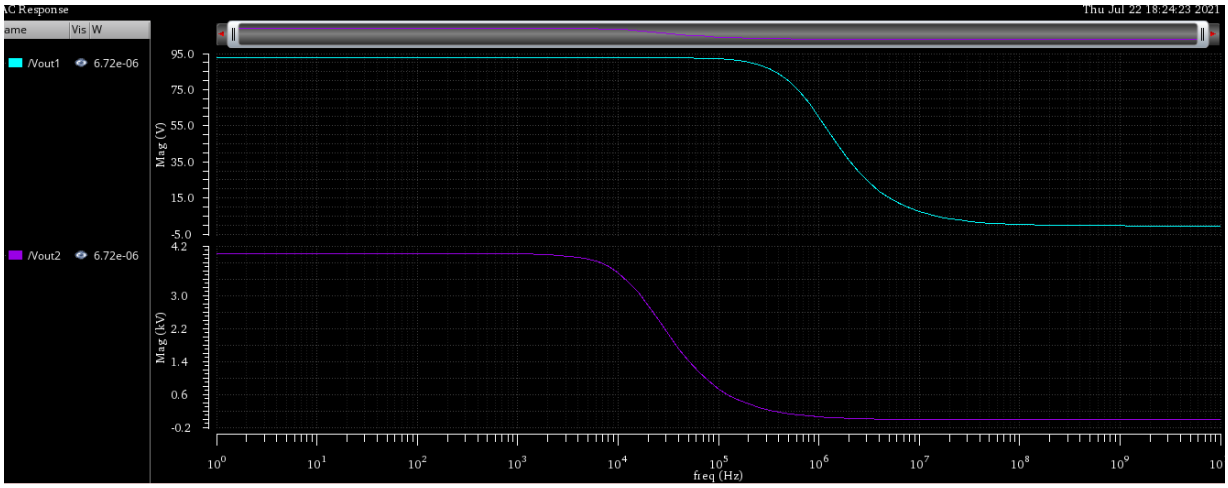

Fig.7 magnitude of CS and cascode amplifier gain

As shown in fig.7 that gain of cascode amplifier is much greater than gain of CS amplifier as following: $A_{vCS} = 93.184$ and $A_{vCascode} = 4.02k$.

- Circuit parameters simulation from ADEXL:

Test	Output	Nominal	Spec	Weight	Pass/Fail
TrainLAB:Cascode:1	CS Bode Plot Mag				
TrainLAB:Cascode:1	CS Gain dB	39.39			
TrainLAB:Cascode:1	CS Gain	93.18			
TrainLAB:Cascode:1	CS Bandwidth	845k			
TrainLAB:Cascode:1	CS GBW	78.93M			
TrainLAB:Cascode:1	Cascode Bode Plot Mag				
TrainLAB:Cascode:1	Cascode Gain dB	72.11			
TrainLAB:Cascode:1	Cascode Gain	4.031k			
TrainLAB:Cascode:1	Cascode Bandwidth	18.9k			
TrainLAB:Cascode:1	Cascode GBW	76.36M			

Fig. 8 circuit parameters for CS and Cascode amplifiers

- Bode plot of CS and Cascode amplifiers in dB:

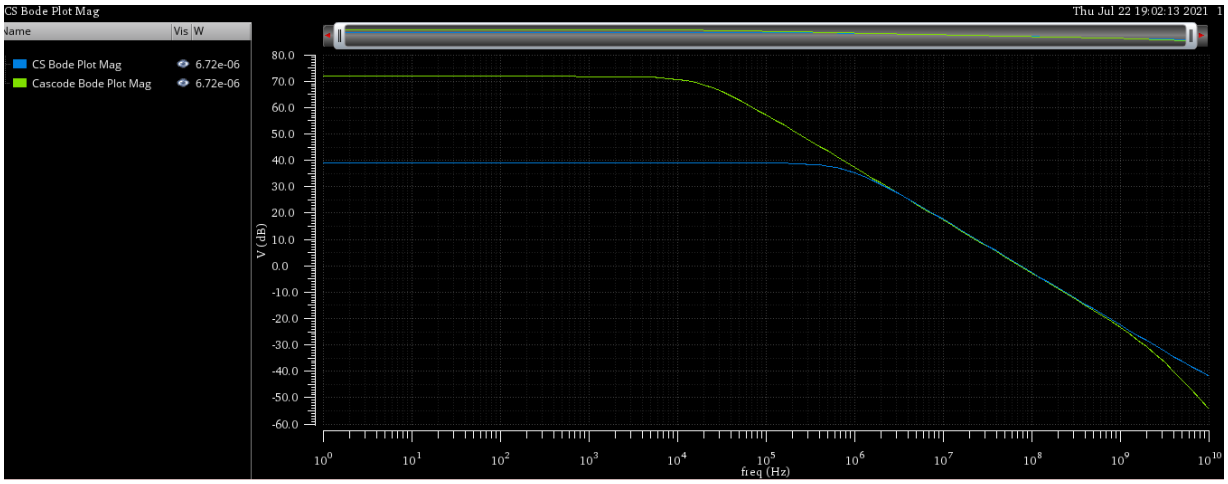

Fig.9 magnitude bode plot of CS and Cascode amplifiers

- Hand Analysis Results:
  CS Amplifier:

$$DC\ Gain \rightarrow A_v = g_m * r_o = g_m * \frac{1}{g_{ds}} = 498.654u * \frac{1}{5.3513u} = 93.184.$$

$$Bandwidth \rightarrow BW = \frac{1}{R_{th}C_{th}},$$

$$where\ R_{tn} = r_o = \frac{1}{g_{ds}} = \frac{1}{5.3153u}\ and\ C_{th} = C_L = 1p = 6.0845p,$$

$$so\ BW = 5.35Mrad/sec = 851.69kHz.$$

$$GBW = A_V * BW = 93.184 * 851.69k = 79.364MHz.$$

Cascode Amplifier:

$$DC\ Gain \rightarrow A_v = g_{m1}r_{o1}(g_{m2} + g_{mb2})r_{o2} = \frac{g_{m1}(g_{m2}+g_{mb2})}{g_{ds1}g_{ds2}},$$

$$A_v = \frac{490.996u*(501.414+125.082)u}{10.4496u*7.38891u} = 3.984k.$$

$$Bandwidth \rightarrow BW = \frac{1}{R_{th}C_{th}}, where\ R_{tn} = r_{o1}(g_{m2} + g_{mb2})r_{o2} = \frac{(g_{m2}+g_{mb2})}{g_{ds1}g_{ds2}} = \frac{(501.414+125.082)u}{10.4496u*7.38891u} = 8.11M\Omega, and\ C_{th} = C_L = 1p.$$

$$so\ BW = 123.243krad/sec = 19.615kHz.$$

$$GBW = A_V * BW = 3.984k * 19.615k = 78.14MHz.$$

- Comparison between Analytical results and simulation results:

Circuit Parameter	Hand Analysis Results	Simulation Results
CS DC Gain	93.184	93.18
CS Bandwidth	851.69kHz	845kHz
CS Gain GBW	79.364MHz	78.94MHz
CS UGF≈GBW	79.364MHz	78.94MHz
Cascode DC Gain	3.984k	4.03k
Cascode Bandwidth	19.614kHz	18.9kHz
Cascode GBW	78.1MHz	76.36MHz
Cascode UGF≈GBW	78.1MHz	76.36MHz

- As shown in previous analysis that cascode boost the gain significant boosting but decreases the bandwidth of gain which make a trade of between bandwidth and gain, and also as shown that gain bandwidth of CS and cascode amplifiers is almost the same due to this trade off between gain and bandwidth.
  CS amplifier has less gain but larger bandwidth.
  Cascode amplifier has very large gain but less bandwidth.