

Lab 3

Part 1: Sizing Chart

CS Sizing

▼ LUT Settings

LUTs Directory
/home/user01/projects/ADT/ex_LUTs/ ...

LUT: nch ▼

Corner: tt ▼

Temp (°C): 27.0 ▼

State1 ▼ Save State

ID: 20u ▼

gm/ID: 10 ▼

gm/gds: 50 ▼

VDS: 0.9 ▼

VSB: 0 ▼

Device Parameters			Device Parameters		
#	Parameter	Value	#	Parameter	Value
1	ID	20u	11	VA	4.939
2	L	240n	12	ID/W	22.73
3	W	880n	13	gm/W	223.5
4	VGS	664.6m	14	AREA	211.2f
5	VDS	900m	15	gm	196.6u

Device Parameters			Device Parameters		
#	Parameter	Value	#	Parameter	Value
6	VSB	0	16	gmb	47.77u
7	gm/ID	9.832	17	gds	4.05u
8	Vstar	203.4m	18	ro	246.9k
9	ft	14.72G	19	VTH	471m
10	gm/gds	48.56	20	VDSAT	146.3m

VB Calculation

ID: 20u ▼

W: 880n ▼

L: 240n ▼

VDS: 0.45 ▼

VSB: 0.45 ▼

Stack: 1

Get Apply

Y-Expr: V_star=2*ID/Gm ▼

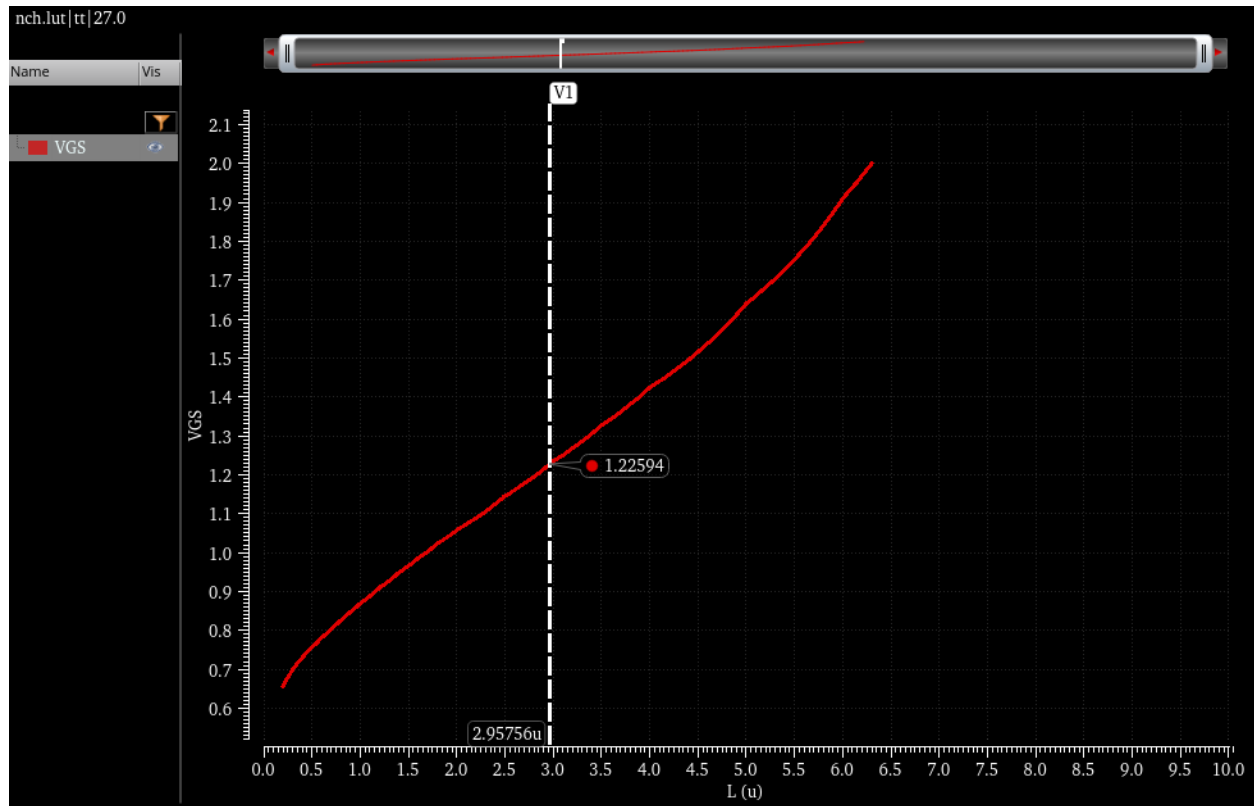
Plot Replace Append

Device Parameters

#	Parameter	Value
4	VGS	776.1m

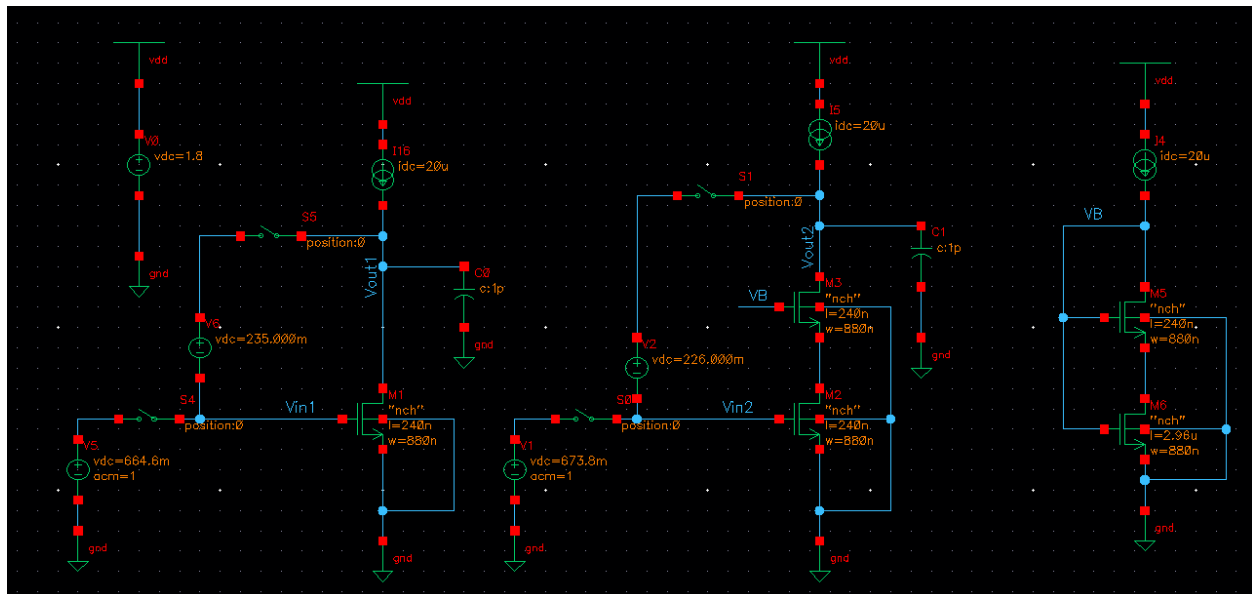
$$V_B = V_{GS_{M3}} + V_{SB_{M2}} = 0.776 + 0.45 = 1.22V$$

Triode Transistor in Biasing Circuit Sizing ($L = 2.96\mu$)



Part 2: Cascode for Gain

Schematic



Transistors Parameters (DC OP)

Transistors Names

M1: Common Source Amplifier

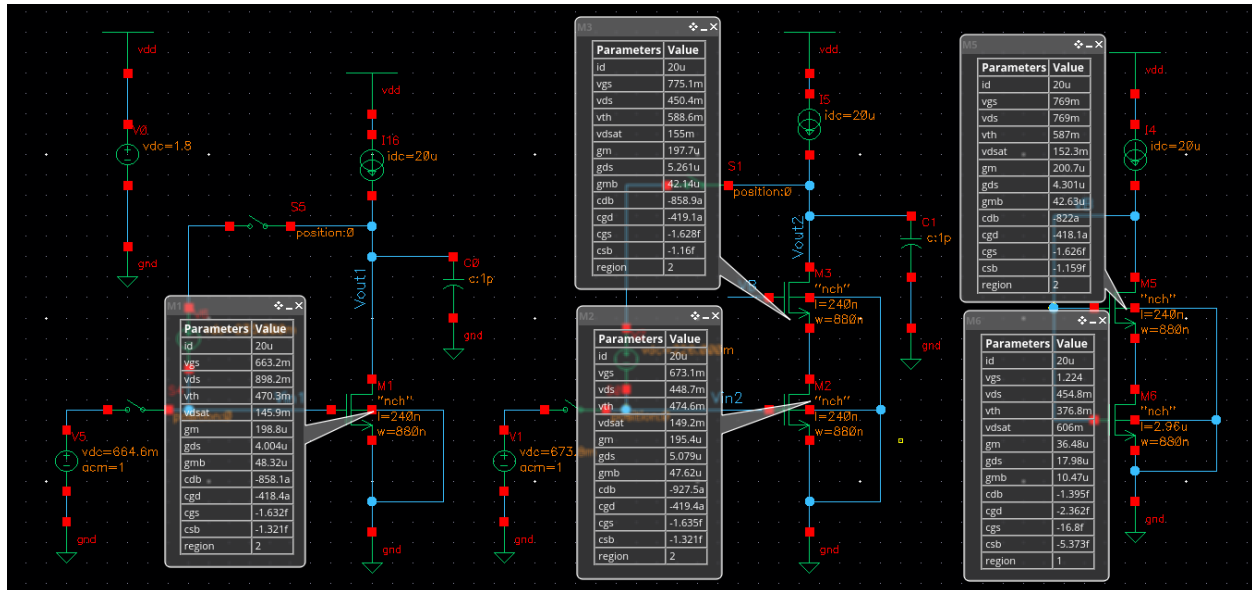
M2: Common Source in Cascode Amplifier

M3: Common Gate in Cascode Amplifier

M5: Saturation transistor in biasing circuit

M6: Triode transistor in biasing circuit

Results



Parameters Comparison

- 1) **Region of Operation:** All transistors operate at saturation region except M6, which operates in triode. $V_{GS_{M6}} = V_B$, $V_{DS_{M6}} = V_B - V_{GS_{M5}}$, and $V_{GS_{M5}}$ will be always known thanks to bias current, so $V_{DS_{M6}} < V_{ov_{M6}}$ will always be satisfied. Also, from IV characteristics, having a high V_{GS} while forcing a bias current would lead to the transistor operating in triode.
- 2) **Vth:** $V_{th1} \approx V_{th2}$, because both transistors (1 & 2) have their source and body terminals connected to the ground ($V_{SB} = 0$). $V_{th3} \approx V_{th5}$, because transistors (3 & 5) have the same value of V_{SB} .

3-6)

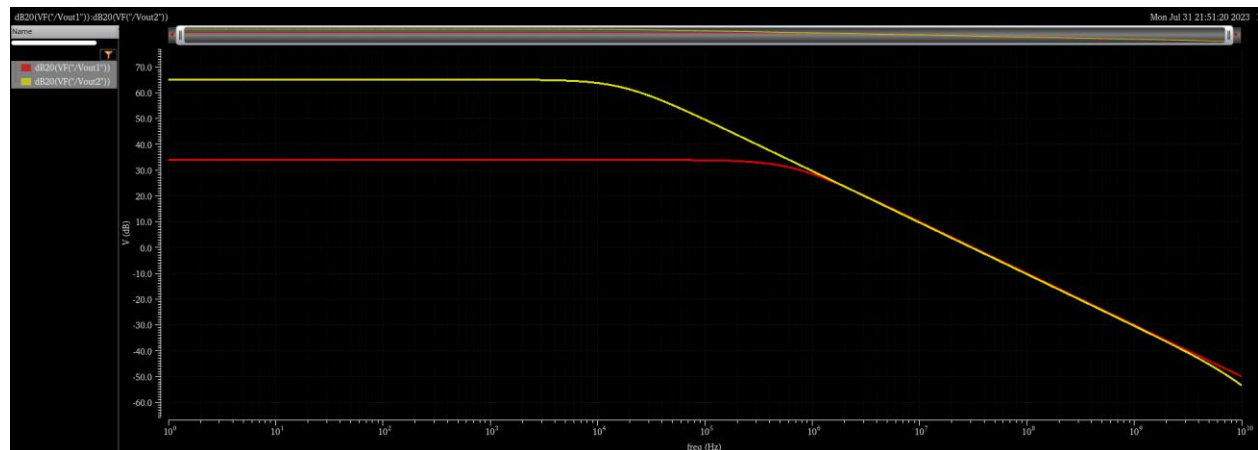
	M1, M2, M3 & M5	M6
gm vs gds	gm >> gds	gm > gds
gm vs gmb	gm > gmb	gm > gmb
cgs vs cgd	cgs >> cgd	cgs >> cgd
csb vs cdb	csb >> cdb	csb > cdb

AC Analysis

Circuit Parameters (DC gain, BW, GBW, and UGF)

Name	Type	Details	Value
	expr	dB20(VF("/Vout1"))	
	expr	ymax(dB20(VF("/Vout1")))	33.92
	expr	ymax(mag(VF("/Vout1")))	49.64
	expr	bandwidth(VF("/Vout1") 3 "low")	635.3K
	expr	gainBwProd(VF("/Vout1"))	31.62M
	expr	unityGainFreq(VF("/Vout1"))	31.6M
	expr	dB20(VF("/Vout2"))	
	expr	ymax(dB20(VF("/Vout2")))	65.07
	expr	ymax(mag(VF("/Vout2")))	1.792K
	expr	bandwidth(VF("/Vout2") 3 "low")	16.99K
	expr	gainBwProd(VF("/Vout2"))	30.52M
	expr	unityGainFreq(VF("/Vout2"))	30.63M

Bode Plot (Magnitude)



Hand Analysis

Note: DC OP values are used in calculations.

Common Source Amplifier

1. Gain

$$G_m \approx -g_{m1} \text{ \& } R_{out} = r_o = 1/g_{ds}$$

$$|A_v| = (G_m)(R_{out}) = (198.8\mu)/(4\mu) = 49.7 = 33.93 \text{ dB}$$

2. Bandwidth

$$\omega = \frac{1}{R_{out}(C_L + C_{GD} + C_{DB})} = \frac{4\mu}{(418+858)10^{-18}+10^{-12}} = 4\text{M}$$

$$BW = \omega/2\pi = 635.8 \text{ kHz}$$

3. GBW & UGF

$$GBW = UGF = A_v * BW = 49.7 * 635.8\text{k} = 31.6 \text{ MHz}$$

Cascode Amplifier

1. Gain

$$|A_v| = (g_{m1}r_{o1})(g_{m2} + g_{mb2})(r_{o2})$$

$$= \left(\frac{195.4\mu}{5.08\mu}\right)(197.7\mu + 42.14\mu)(1/5.261\mu) = 1.753 \text{ k} = 64.9 \text{ dB}$$

2. Bandwidth

$$\omega = \frac{1}{(|A_v|/g_{m2})(C_L + C_{GD1} + C_{DB1})} = \frac{197.7\mu}{(1.753\text{k})[(419+927)10^{-18}+10^{-12}]} = 112.6\text{k}$$

$$BW = \omega/2\pi = 17.9 \text{ kHz}$$

3. GBW & UGF

$$GBW = UGF = A_v * BW = (1.75\text{k})(17.9\text{k}) = 31.3 \text{ MHz}$$

Simulation vs Hand Analysis (for both amplifiers)

CS Amplifier	Gain	Bandwidth (kHz)	GBW (MHz)	UGF (kHz)
Simulation	49.6	635.3	31.6	31.6
Hand Analysis	49.7	635.8	31.6	31.6

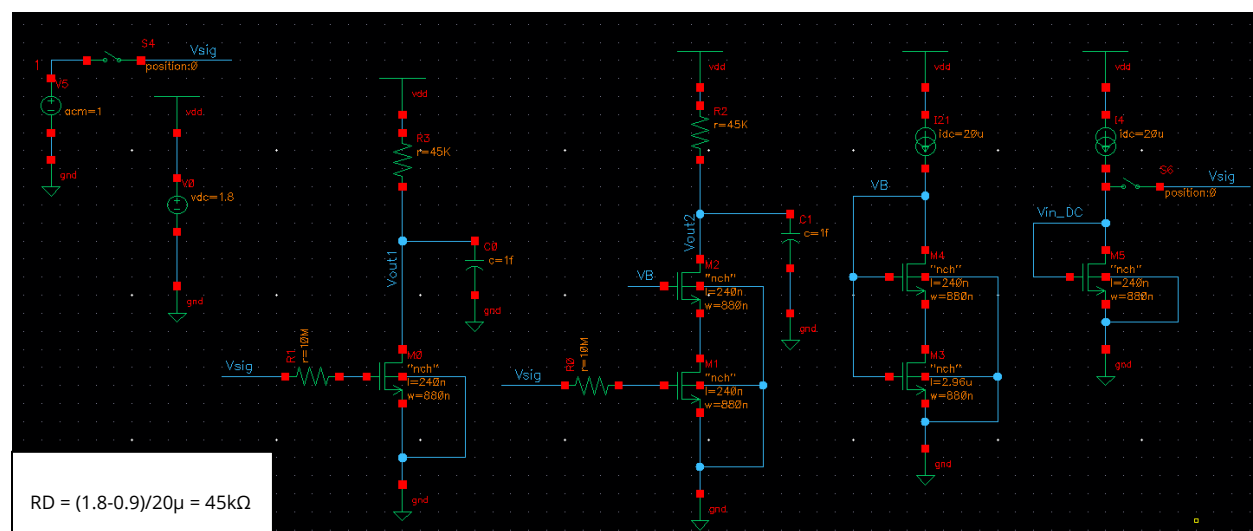
Cascode Amplifier	Gain	Bandwidth (kHz)	GBW (MHz)	UGF (kHz)
Simulation	1.792 k	16.99	30.5	30.6
Hand analysis	1.753 k	17.9	31.3	31.3

Comments

- $A_{v_{\text{cascode}}} \gg A_{v_{\text{CS}}}$, but the cascode gain $< A_{v_{\text{CS}}}^2$ (theoretical gain), as $r_{o1} \neq r_{o2}$ and also due to body effect.
- The BW of the cascode amplifier is less than that of the CS amplifier.
- The GBW & UGF is approximately the same for both CS and Cascode amplifiers.

Part 3: Cascode for BW

Schematic



The schematic diagram illustrates a 1.5-V, 200-fA, 100-dB CMRR, 100-MHz OTA. The circuit is composed of several key blocks and components:

- PMOS Differential Pair (M1, M2):** The main output stage, biased by a PMOS current mirror (M4, M5) and a resistor (R2). The PMOS gates are biased by a PMOS current mirror (M8, M9) and a resistor (R3).
- NMOS Differential Pair (M6, M7):** The main input stage, biased by a PMOS current mirror (M10, M11) and a resistor (R4). The NMOS gates are biased by a PMOS current mirror (M12, M13) and a resistor (R5).
- Tail Current Source (M3):** A PMOS current source connected to the gates of M1 and M2, biased by a PMOS current mirror (M14, M15) and a resistor (R6).
- Biasing and Reference:** The circuit includes a biasing network (M16, M17) and a reference voltage (Vref) to set the operating point.
- Parameters and Values:** The schematic includes various parameters and values for the components, such as model, width, length, and biasing voltages.

The schematic is divided into several sections, each with its own parameter table:

- Section 1 (Left):** Parameters for the PMOS differential pair (M1, M2) and the tail current source (M3).
- Section 2 (Middle):** Parameters for the NMOS differential pair (M6, M7) and the biasing network (M16, M17).
- Section 3 (Right):** Parameters for the PMOS current mirror (M4, M5) and the resistor (R2).
- Section 4 (Far Right):** Parameters for the PMOS current mirror (M8, M9) and the resistor (R3).

The schematic also includes a table of parameters for the PMOS differential pair (M1, M2) and the tail current source (M3):

Parameters	Value
model	"nch"
l	240n
w	880n
id	20.82u
vgs	667.9m
vds	863.2m
vth	270.6m
vdssat	145.5m
gm	902.3u
gds	4.126u
gmb	49.15u
cbd	-862.5a
cgd	-418.4a
cgs	-1.633f
csb	-1.321f
region	2

AC Analysis

Name	Type	Details	Value
	expr	$\text{dB20}(\text{VF} / \text{Vout1})$	
	expr	$\text{ymax}(\text{dB20}(\text{VF} / \text{Vout1}))$	17.71
	expr	$\text{ymax}(\text{mag}(\text{VF} / \text{Vout1}))$	7.678
	expr	$\text{bandwidth}(\text{VF} / \text{Vout1}) \ 3 \ \text{"low"}$	2.962M
	expr	$\text{gainBwProd}(\text{VF} / \text{Vout1})$	22.79M
	expr	$\text{unityGainFreq}(\text{VF} / \text{Vout1})$	22.83M
	expr	$\text{dB20}(\text{VF} / \text{Vout2})$	
	expr	$\text{ymax}(\text{dB20}(\text{VF} / \text{Vout2}))$	18.48
	expr	$\text{ymax}(\text{mag}(\text{VF} / \text{Vout2}))$	8.391
	expr	$\text{bandwidth}(\text{VF} / \text{Vout2}) \ 3 \ \text{"low"}$	6.222M
	expr	$\text{gainBwProd}(\text{VF} / \text{Vout2})$	52.33M
	expr	$\text{unityGainFreq}(\text{VF} / \text{Vout2})$	52.22M

The Bode plot shows the magnitude of the closed-loop transfer function, $|G_{cl}(j\omega)|$, in dB, versus frequency ω in rad/s. The plot is a log-log graph. The magnitude is constant at 20 dB for frequencies below approximately 100 rad/s. At higher frequencies, the magnitude decreases, with a roll-off rate of -20 dB/decade. The red curve represents the magnitude of the closed-loop transfer function, and the yellow curve represents the magnitude of the open-loop transfer function. The two curves intersect at approximately 100 rad/s, which is the crossover frequency.

Hand Analysis

Note: DC OP values are used in calculations.

Common Source Amplifier

1. Gain

$$G_m \approx -g_{m1} \text{ \& } R_{out} = r_o \parallel R_D = 38 \text{ k}$$

$$|A_v| = (G_m)(R_{out}) = (202.3\mu)(38\text{k}) = 7.68 = 17.7 \text{ dB}$$

2. Bandwidth

$$\omega \approx \frac{1}{R_{sig}[c_{gs} + c_{gd}(1 + A_v)]} = \frac{1}{(10^7)[1.63f + (418a)(1 + 7.68)]} = 19 \text{ M}$$

$$BW = \omega/2\pi = 3 \text{ MHz}$$

3. GBW & UGF

$$GBW = UGF = A_v \cdot BW = (7.68)(3\text{M}) = 23 \text{ MHz}$$

Cascode Amplifier

1. Gain

$$|A_v| = (g_{m1})[(r_{o1}(g_{m2} + g_{mb2})(r_{o2})) \parallel R_D]$$

$$= (191.1\mu) \left[\left(\frac{1}{4.86\mu} \right) (193.9\mu + 42.29\mu)(1/4.844\mu) \right] \parallel 45\text{k} = 8.60 = 18.7 \text{ dB}$$

2. Bandwidth

$$\omega \approx \frac{1}{R_{sig}[c_{gs1} + c_{gd1}]} = \frac{1}{(10^7)[1.63f + (2 \cdot 418a)]} = 40.5 \text{ M}$$

$$BW = \omega/2\pi = 6.45 \text{ MHz}$$

3. GBW & UGF

$$GBW = UGF = A_v \cdot BW = (8.6)(6.45\text{M}) = 55.5 \text{ MHz}$$

Comparison

Simulation vs Hand Analysis (for both amplifiers)

CS Amplifier	Gain	Bandwidth (MHz)	GBW (MHz)	UGF (kHz)
Simulation	7.68	2.96	22.8	22.8
Hand Analysis	7.68	3.00	23.0	23.0

Cascode Amplifier	Gain	Bandwidth (MHz)	GBW (MHz)	UGF (kHz)
Simulation	8.39	6.22	52.3	52.2
Hand analysis	8.60	6.45	55.5	55.5

Comments

Since we have a large R_{sig} and relatively small R_D , the bandwidth is limited to input pole.
Therefore:

- Miller effect is significantly reduced.
- Cascode provides higher BW.
- The cascode gain is slightly higher than CS's gain (higher R_{out} in cascode).
- GBW increases in cascode amplifier.