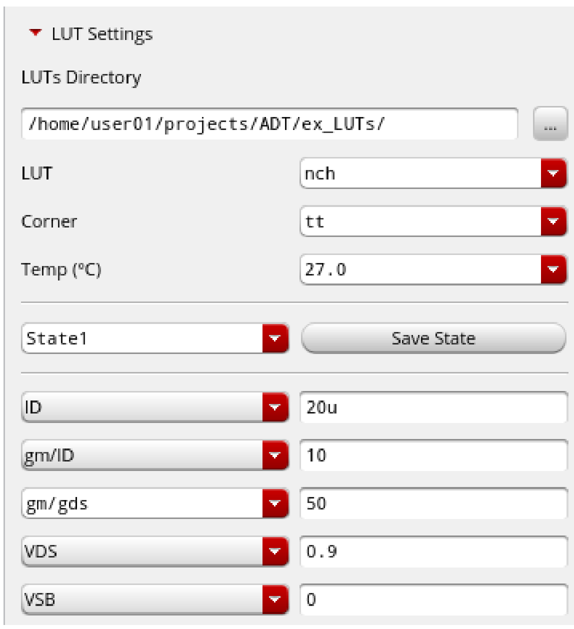
Analog IC Design

Lab 3

Part 1: Sizing Chart

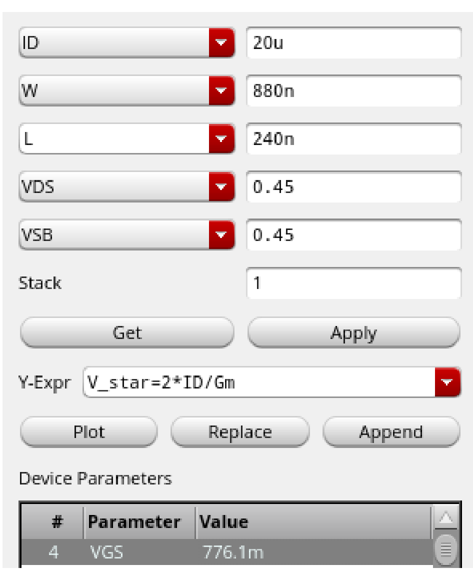
CS Sizing



Device Parameters

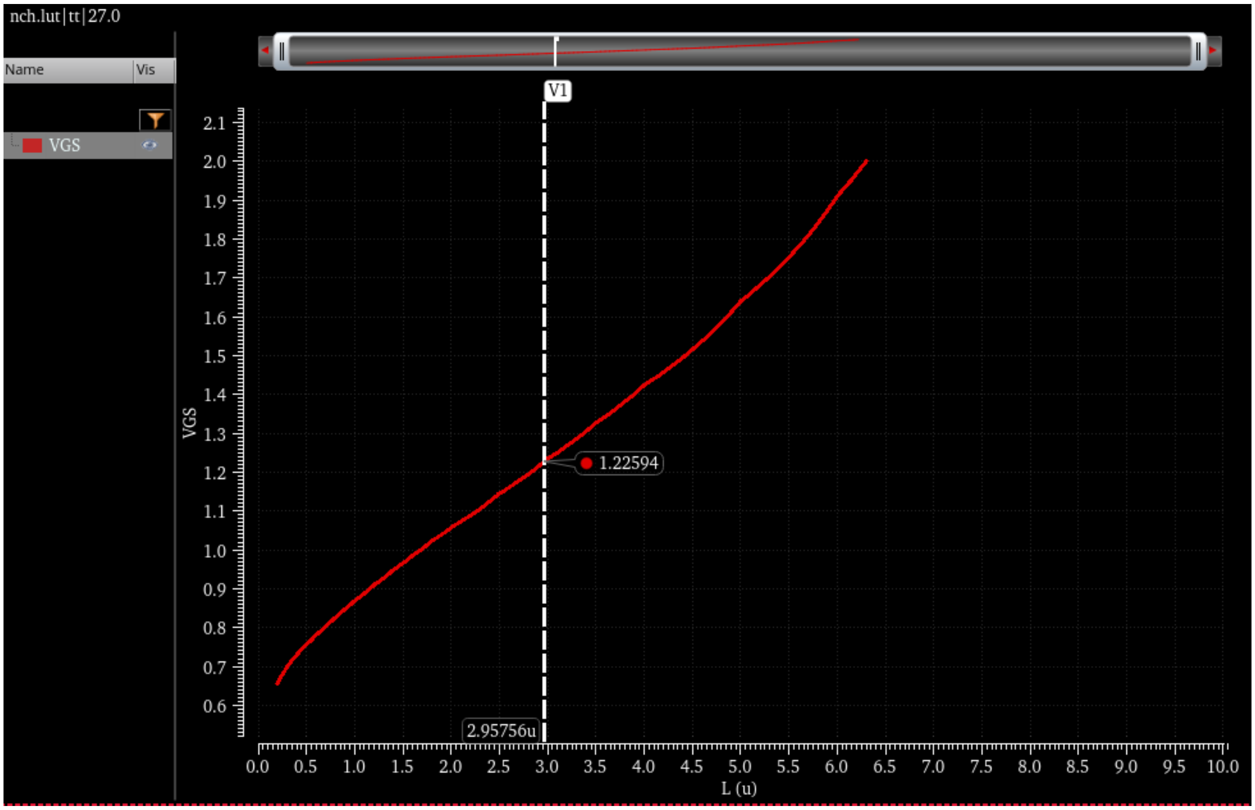
#	Parameter	Value
1	ID	20u
2	L	240n
3	W	880n
4	VGS	664.6m
5	VDS	900m
6	VSB	0
7	gm/ID	9.832
8	Vstar	203.4m
9	fT	14.72G
10	gm/gds	48.56
11	VA	4.939
12	ID/W	22.73
13	gm/W	223.5
14	AREA	211.2f
15	gm	196.6u
16	gmb	47.77u
17	gds	4.05u
18	ro	246.9k
19	VTH	471m
20	VDSAT	146.3m

VB Calculation



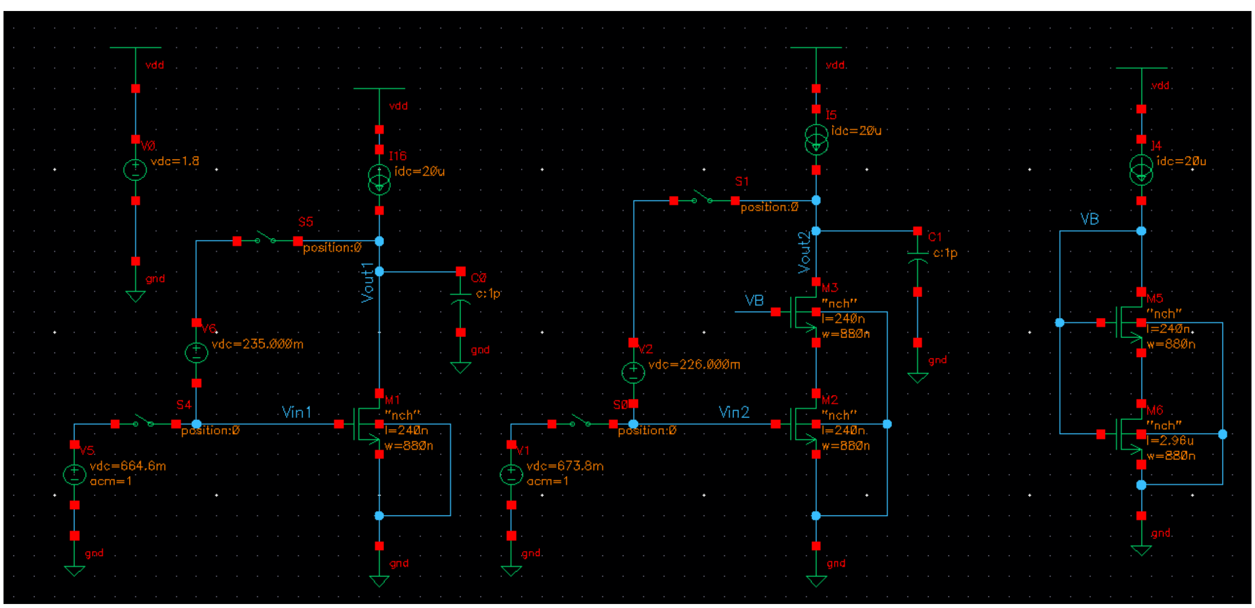
$VB = VGS_{M3} + VSB_{M2} = 0.776 + 0.45 = 1.22V$

Triode Transistor in Biasing Circuit Sizing (L = 2.96u)



Part 2: Cascode for Gain

Schematic



Transistors Parameters (DC OP)

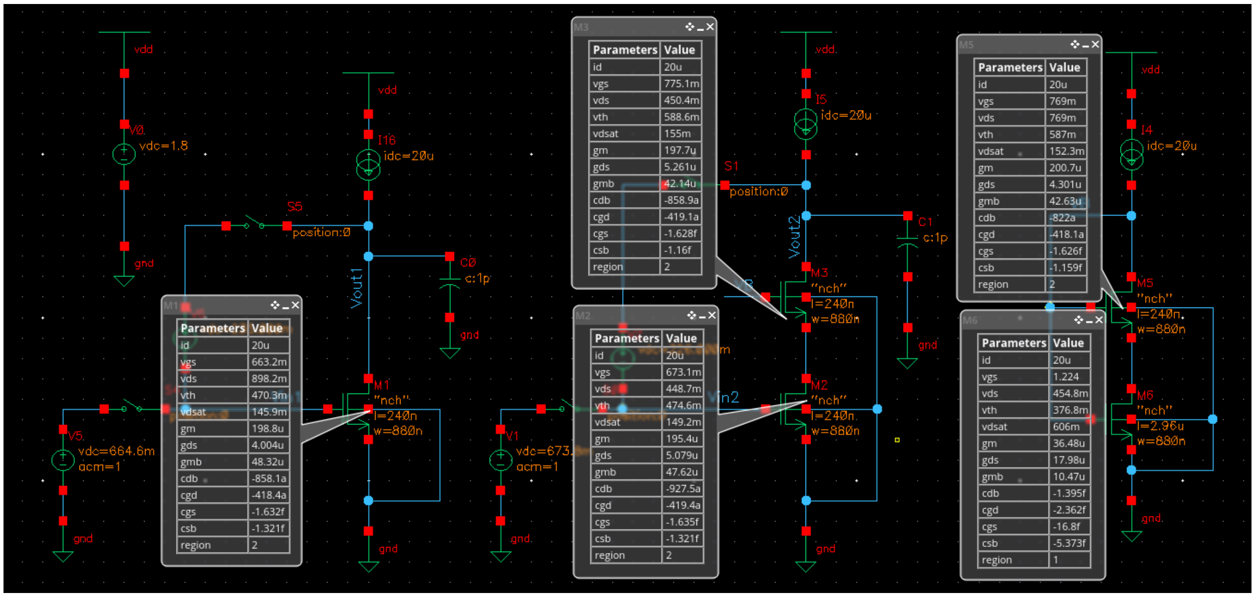
Transistors Names

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. VGS_{M6} = VB, VDS_{M6}= VB - VGS_{M5}, and VGS_{M5} will be always known thanks to bias current, so $VDS_{M6} < Vov_{M6}$ will always be satisfied. Also, from IV characteristics, having a high VGS while forcing a bias current would lead to the transistor operating in triode.
2) **Vth:** Vth1≈ Vth2, because both transistors (1 & 2) have their source and body terminals connected to the ground (VSB =0). Vth3 ≈ Vth5, because transistors (3 & 5) have the same value of VSB.

3-6)

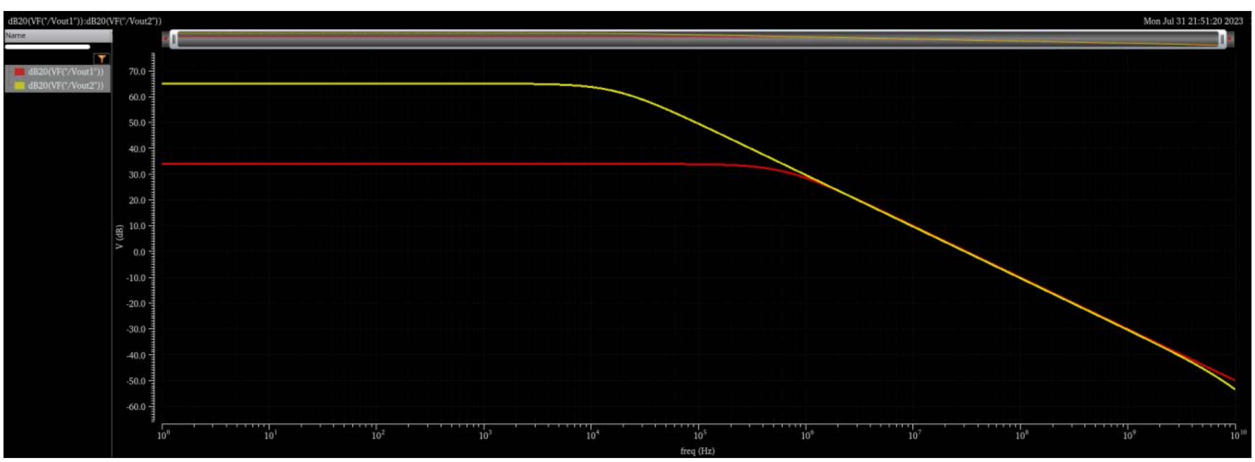
	M1, M2, M3 & M5	M6
gm vs gds	gm >> gds	gm > gds
gm vs gmb	gm > gmb	gm > gmb
cgs vs cgd	cgs >> cgd	cgs >> cgd
csb vs cdb	csb >> cdb	csb > cdb

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

$$Gm \approx -gm1 \ \& \ Rout = ro = 1/gds$$

$$|Av| = (Gm)(Rout) = (198.8\mu)/(4\mu) = 49.7 = 33.93 \text{ dB}$$

2. Bandwidth

$$\omega = \frac{1}{Rout(CL+CGD+CDB)} = \frac{4\mu}{(418+858)10^{-18}+10^{-12}} = 4M$$

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

3. GBW & UGF

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

Cascode Amplifier

1. Gain

$$|Av| = (gm1ro1)(gm2 + gmb2)(ro2)$$

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

2. Bandwidth

$$\omega = \frac{1}{(|Av|/gm2)(CL+CGD1+CDB1)} = \frac{197.7\mu}{(1.753k)[(419+927)10^{-18}+10^{-12}]} = 112.6k$$

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

3. GBW & UGF

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

Comparison

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

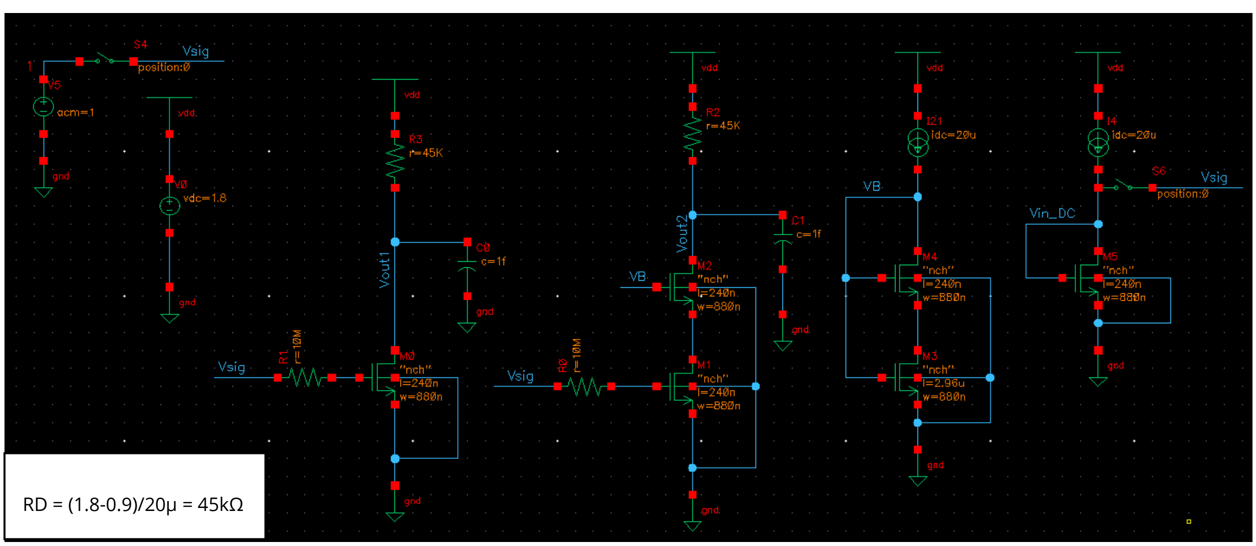
Cascode Amplifier	Gain	Bandwidth (kHz)	GBW (MHz)	UGF (kHz)
Simulation	1.792 k	16.99	30.5	30.6
Hand analysis	1.753 k	17.9	31.3	31.3

Comments

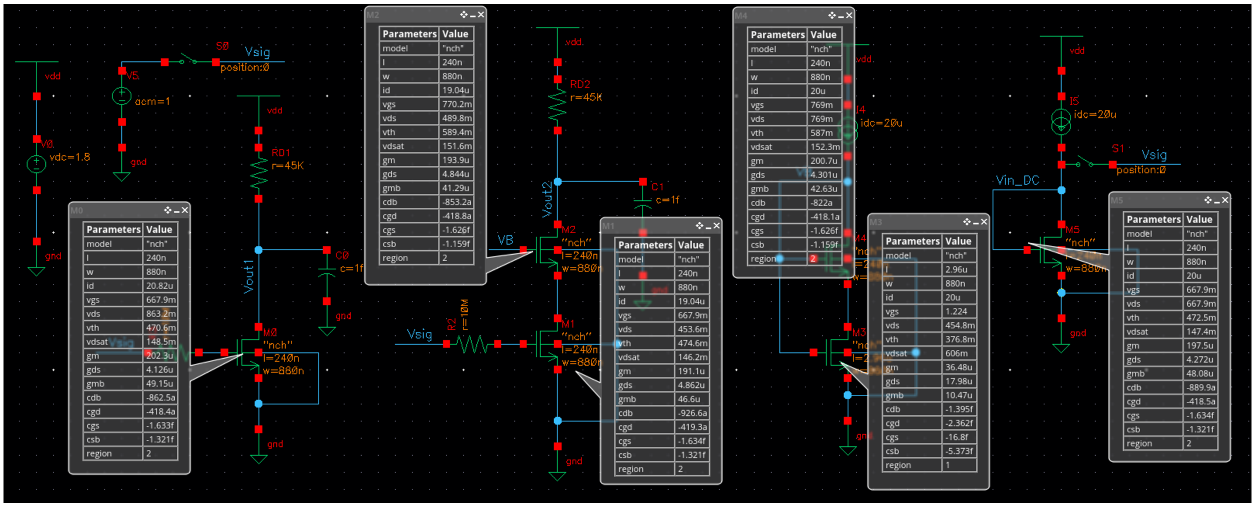
- $Av_{cascode} >> Av_{CS}$, but the cascode gain < Av_{CS}^2 (theoretical gain), as ro1 ≠ ro2 and also due to body effect.
- The BW of the cascode amplifier is less than that of the CS amplifier.
- The GBW & UGF is approximately the same for both CS and Cascode amplifiers.

Part 3: Cascode for BW

Schematic



OP Analysis



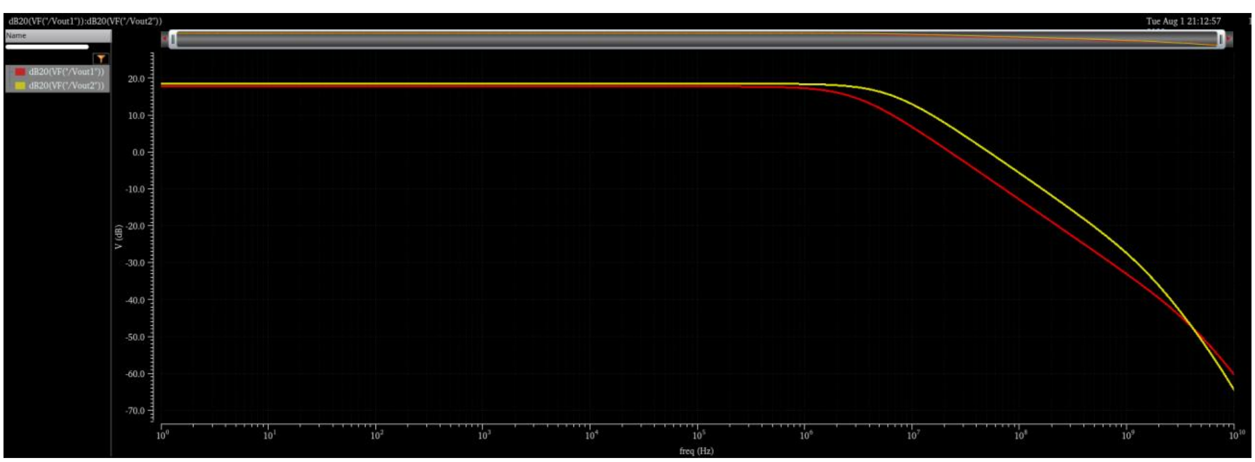
Comment: All CS & cascode amplifiers' transistors operate in saturation region.

AC Analysis

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

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

Bode Plot (Magnitude)



Hand Analysis

Note: DC OP values are used in calculations.

Common Source Amplifier

1. **Gain**

$$Gm \approx -gm1 \ \&\ Rout = ro \,||\, RD = 38\text{ k}$$

$$|Av| = (Gm)(Rout) = (202.3\mu)(38k) = 7.68 = 17.7\text{ dB}$$

2. **Bandwidth**

$$\omega \approx \frac{1}{\mathrm{Rsig[cgs + cgd\ (1 + Av)]}} = \frac{1}{(10^7)[1.63f + (418a)(1+7.68)]} = 19\text{ M}$$

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

3. **GBW & UGF**

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

Cascode Amplifier

1. **Gain**

$$|Av| = (gm1)[(ro1(gm2 + gmb2)(ro2)) \,||\, RD]$$

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

2. **Bandwidth**

$$\omega \approx \frac{1}{\mathrm{Rsig[cgs1 + cgd1]}} = \frac{1}{(10^7)[1.63f + (2*418a)]} = 40.5\text{ M}$$

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

3. **GBW & UGF**

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

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 Rsig and relatively small RD, 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 Rout in cascode).
- GBW increases in cascode amplifier.