EE214a Project

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Table : Summary of Specs

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| --- | --- | --- | --- | --- | --- |
|  | **Gain** | **Bandwidth** | **Power** | **G\*BW/Power** | **CM Output Voltage** |
| **Required** | 30.000 kΩ | 90.0000 MHz | 2.0000 mW |  | [-150 mV, 150 mV] |
| **Achieved** | 30.019 kΩ | 96.6133 MHz | 1.9444 mW |  | -114.45 mV |

Table : Summary of Areas

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **Core Circuit** | **Bias Circuit** | **VPMOS-bias** | **VNMOS-bias** |
| **Area** | 134.236 µm | 493.4545 µm | 46 µm | 54 µm |
| **% of Core Circuit** | 100% | 367.6% | 34.3% | 42.5% |

We started by identifying the following key blocks of the circuit.

1. Common Gate Input stage (Mn1, R1, R2)
   1. Provides a low input impedance to capture the input current generated by the Capacitive Micromachined Ultrasonic Transducer (CMUT).
   2. Provides a large trans-impedance gain over the parallel combination of R1 and R2 that converts the input current to a voltage
2. Cascode Gain Stage (Mp4, Mp5, R3, R4)
   1. A CS transistor connected to a CG transistor, both of which are sized such that the Miller Effect is minimized, which speeds up the input node.
   2. Achieves high gain by the parallel combination of R3 and R4
3. Common Source Stage (Mn7, Mp8)
   1. Provides a buffer between the high output-impedance of the cascade stage and the high input impedance of the final CD stage.
   2. Provides a small amount of gain, based on the size of Mp8, which acts as a resistor in small signal
4. Common Drain Stage (Mp10)
   1. Provides a low output impedance to drive the 20kΩ, 250fF load.

Additionally, we noticed that the circuit was divided into four transistor “stacks” and two resistor “stacks” and attempted to design the circuit assuming that no current leaks from stack to stack. With this assumption, each stack had

Next, we looked at the valid voltage ranges for each of the nodes in DC, considering that no transistor should have an overdrive voltage less than 0.15V.

1. V\_in
2. V\_x
3. V\_y
4. V\_z
5. -0.15 < V\_o < 0.15 (based on circuit specifications)

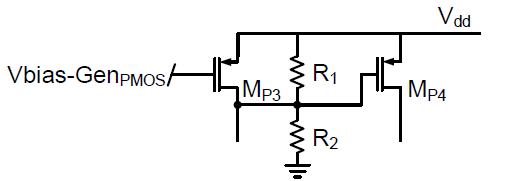
|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Node | Time Constant | Assumptions/Simplifications |  | Simplified Time Constant |
| 1 - Input |  | * Cin >> Cgs2 | 20% |  |
| 2 - Vx |  | * R2/R1 < 4 |  |  |
| 3 - Vy |  | * R3/R4 < 4 |  |  |
| 4 - Vz |  |  |  |  |
| 5 - Vout |  | Cgs = 10, >> 1 => tau = | 100% |  |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Stage | Gain1 | R in terms of gain | Equals | Simplified Time Constant |
| 1 - CG |  | R2 = 4R1  = gain  => = = gain  => R1 = 5/4\* gain | 5000 |  |
| 2 – Cascode |  | R3 = 4R4  = 5  => = 5  => = 5  => R4 = | 5 |  |
| 3 – CS |  |  | 1.2 |  |
| 4 – CD |  |  | 1 |  |
|  |  |  |  |  |

|  |  |  |  |
| --- | --- | --- | --- |
| Assumptions | Independent Variables | Derived quantities | Performance Characteristics |
| * Length[1..10] | * I\_branch[1...4]   Random for now   * Gain\_stage[1..4]   CG, cascade  CS,CD ~ 1 always   * $R3 = x\*$R2;   10-10k, increment of 1k   * All gm’s except (4, 7, 8, 10):   0.0000005-0.003 | * Width[1..10] * Cgs[1..10] * Miller Gain (Mn10) * Gm[1..10] * Vov[1..10] | * DC Gain * 3db Bandwidth * Power |

# First resistive divider

Calculating bounds on the ratio of R2/R1:



Assume that the current through Mp3 is matched with the current through Mn2, such that no current flows between the R1/R2 resistive divider and into the transistor stack. Assume that there is no body effect on Vt. In order to keep Mp4 in saturation, we must have the following condition:

In other words

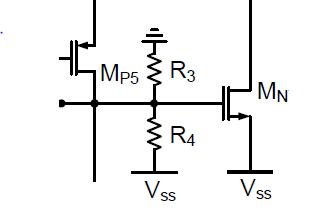
Then R1||R2 = <ratio>/(<1+ratio>R1) = Gain\_CG

R1 = 5/4 Gain\_CG

# First Cgs4

# Second resistor divider

Similarly for R3/R4:



In other words

Use same values as first divider, since GBW product will be less affected by gain since there is a gm factor in this stage.

# third xtor stack

Gain = gm7/gm8

# fourth xtor stack

Script overview

Choose current allocations -> Calculate gm’s -> Calculate Vov’s -> Calculate sizings

1. Find gain equation at each of the 4 stages
   1. Ignore ro, assume ro >> R1-4
2. Find RC time constant at each node
   1. Ignore Cgd b/c Cgd = Cov << Cgs = 2/3WLCox + Cov
   2. Ignore bulk terminal caps b/c hard to estimate
3. Power ≤ 2mW, Vdd - Vss = 5V→ Itot ≤ = 400uA
4. Allocate gain per stage
5. Find R1/R2 ratio = 4
6. Assume R3/R4 = 3
7. Calculate gm from gain and R’s
8. Find power dissipated by the R’s to figure out how much left for xtor stacks
9. Allocate current through 4 stacks based on #5
10. For each xtor,
    1. calculate Vov from its Ids and gm
    2. calculate W from Ids, Vov
    3. calculate Cgs
11. Calculate time constants at each stage. 1/sum must meet our target bandwidth

Gm/id design methodology

1. Start with output stage, MN10. Pick gm/id of 10. Time constant ~ gm10/Cl = allocated 110% of target 90MHz -> solve for gm10. From gm10 and gm/id of 10, solve for id10. From gm and Id, solve for Vov10. Pick min L of 1u for MN10 (CD gain stage). From L, Vov, and id, get W10.
2. MN9 has same Id as MN10 (b/c within same branch). Since MN9 is a bias xtor, pick min L (1u) and min W (2u). Calculate Vov10 from Id, L, and W.
3. Next tackle input stage, MN2. Pick gm/id of 10. Time constant on the input node ~ Cin/gm2 = allocated 20% of total 110Mhz -> solve for gm2. From gm2 and gm/id of 10, solve for id2. From id and gm, solve for Vov2. Pick min L of 1 us for MN2 (CG gain stage). From L, Vov, and id, get W2.
4. Id2 = Id1 = Id3 (within same branch).
   1. Vov1 = Vov9 -> find W1 from Id1 and Vov1
   2. For MP3, since it’s a bias xtor, pick small w=2u and small L=2u. From Id3, w3, and l3, we can solve for Vov3 (how much voltage needed for pmos biasing)
5. 2nd stack, MN6 is a bias xtor. Pick l6=2u, w6=2u. Vov6 = Vov9. From Vov, l, and w, solve for Id6.
6. Id4 = Id5 = Id6
   1. For MP4, pick Gm/id=10 -> find gm4 from Id4 and gm/id. From Id and gm, find Vov4. Pick l4=1u. From l, Vov, Id, solve for w4.
   2. For MP5, we want gm5 ~ gm4 (both in cascade). From gm and Id, solve for Vov. Pick l5=1u. From l, Vov, and Id, solve for w5.
7. Third stack Id = remaining Id after what the other 3 branches + 4 R’s have already used up = Id8 = id 7
   1. For MP8, we know its Vg8 = Vov10. So Vov8 = Vs8 – Vg8 – Vt = Vov10 – Vdd – Vt. Pick l=1u. From l, Id and Vov, solve for w8.
   2. For MN7, pick gm/id = 10. With Id know, solve for gm7. From gm and Id, solve for Vov7. Pick l=1u. From l, Vov, Id, solve for w7.

We know that Vout = 0V and M10 overdrive is about 1. This means Vz must be bigger than 1.150V. Let’s set it equal to 1.2V.

Vz = 1.2V

And we want W7/W8 = 1 so that the miller effect is minimized

Vy = -1.43V

Which means we can get the R3R4 ratio

R3/R4 = 1.346

We want M4 to be balanced with M6. We know that M5 has some body effect, so let’s say it’s Vt is about .9. This means the node between 4 and 5 has to be about 1.05

For M4 to be in saturation, we cannot let Vx drop below 1.05-.5 = 0.55. or above 1.8

We want M4 and M5 to have same size to minimize miller

Vnbias must be between -1.85 and -0.15 to keep M1 and M2 both saturated. But it must also be less than 0.5 + Vy = -0.93

Vpbias must be between 1.85 and Vx+.5

Want biggest gm possible, so make a lot of current go through M2 and give M2 smallest possible overdrive. This means Vn should be as low as possible, but W1 should be as big as possible

We want gm10 big to get good BW on output node, so W10 should be big

To match M4 and M6 currents