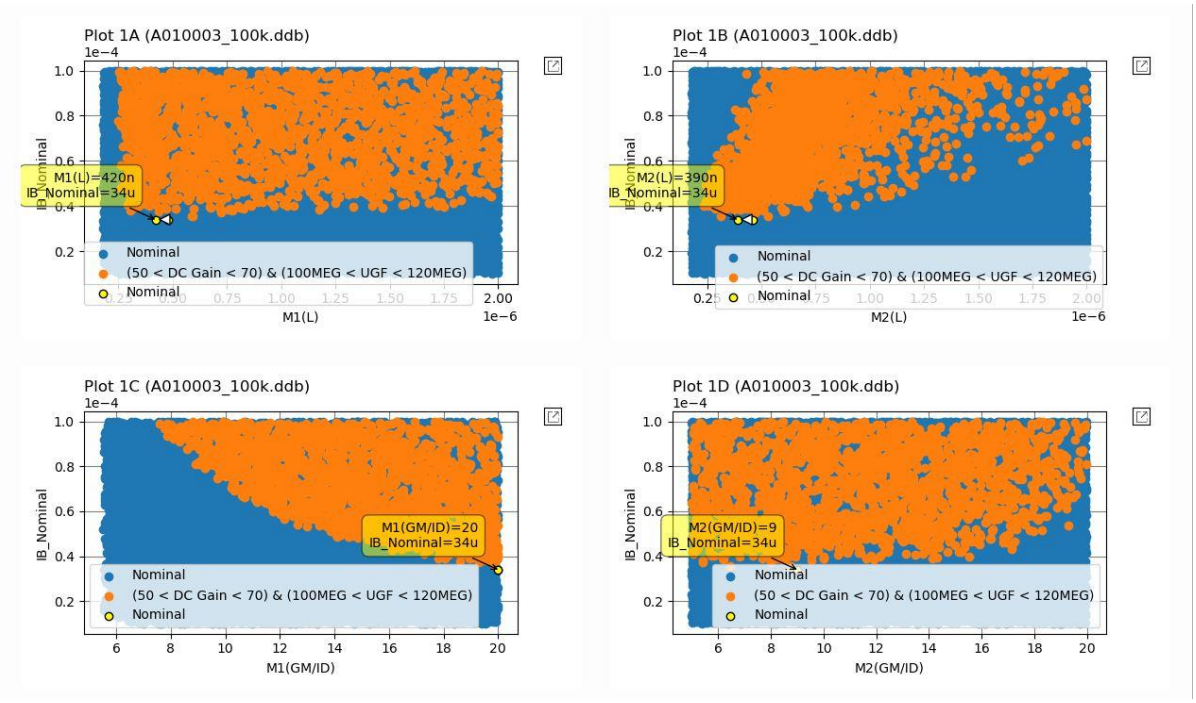
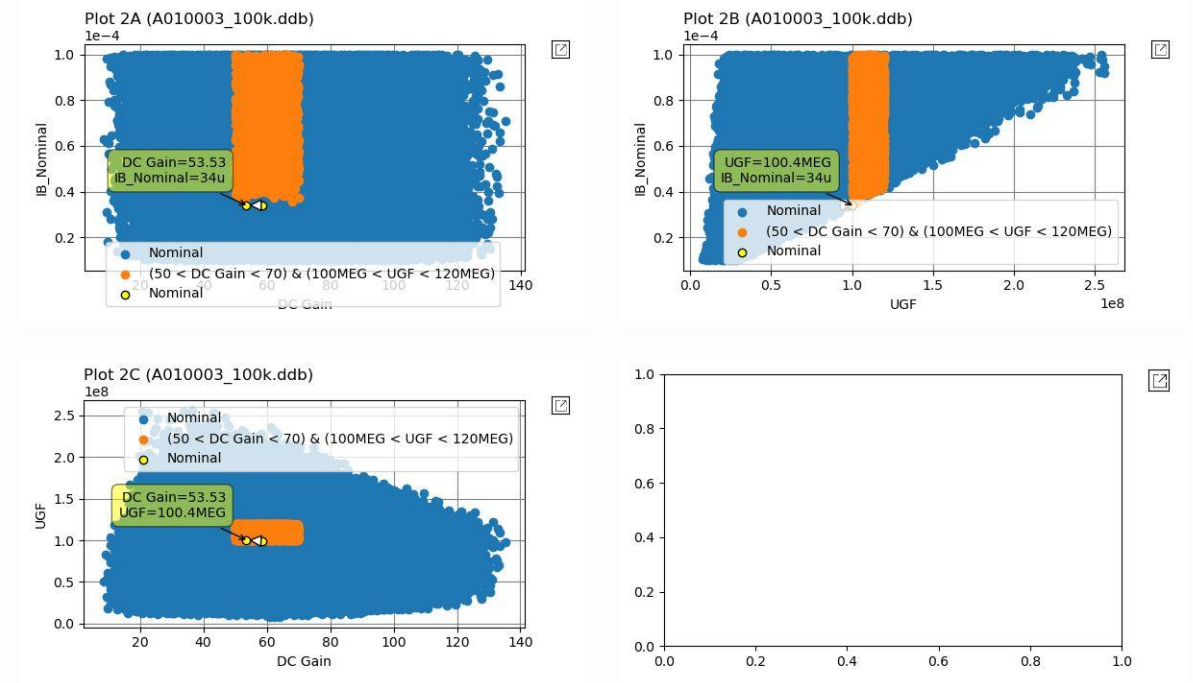
Lab 05: Analog Design Optimization

Part (1)

(1) ADT Design Xplore





DOF	Value
M1(L)	420n
M2(L)	390n
M3(L)	1u
M1(GM/ID)	20
M2(GM/ID)	9
M3(GM/ID)	15
IB_Nominal	34u

Output Variable	Nominal
DC Gain	53.53
DC PSR (dB)	-1.261m
DC CMR (dB)	-37.4
Total Input ...	24.81u
Thermal Input ...	119.9a
Output Swing	1.174
BW	1.897MEG
UGF	100.4MEG
PM	85.17
Vout Max	1.578
Vout Min	404.1m
Vin CM Min	685.9m
Vin CM Max	1.637

Minimum IB = 34 uA

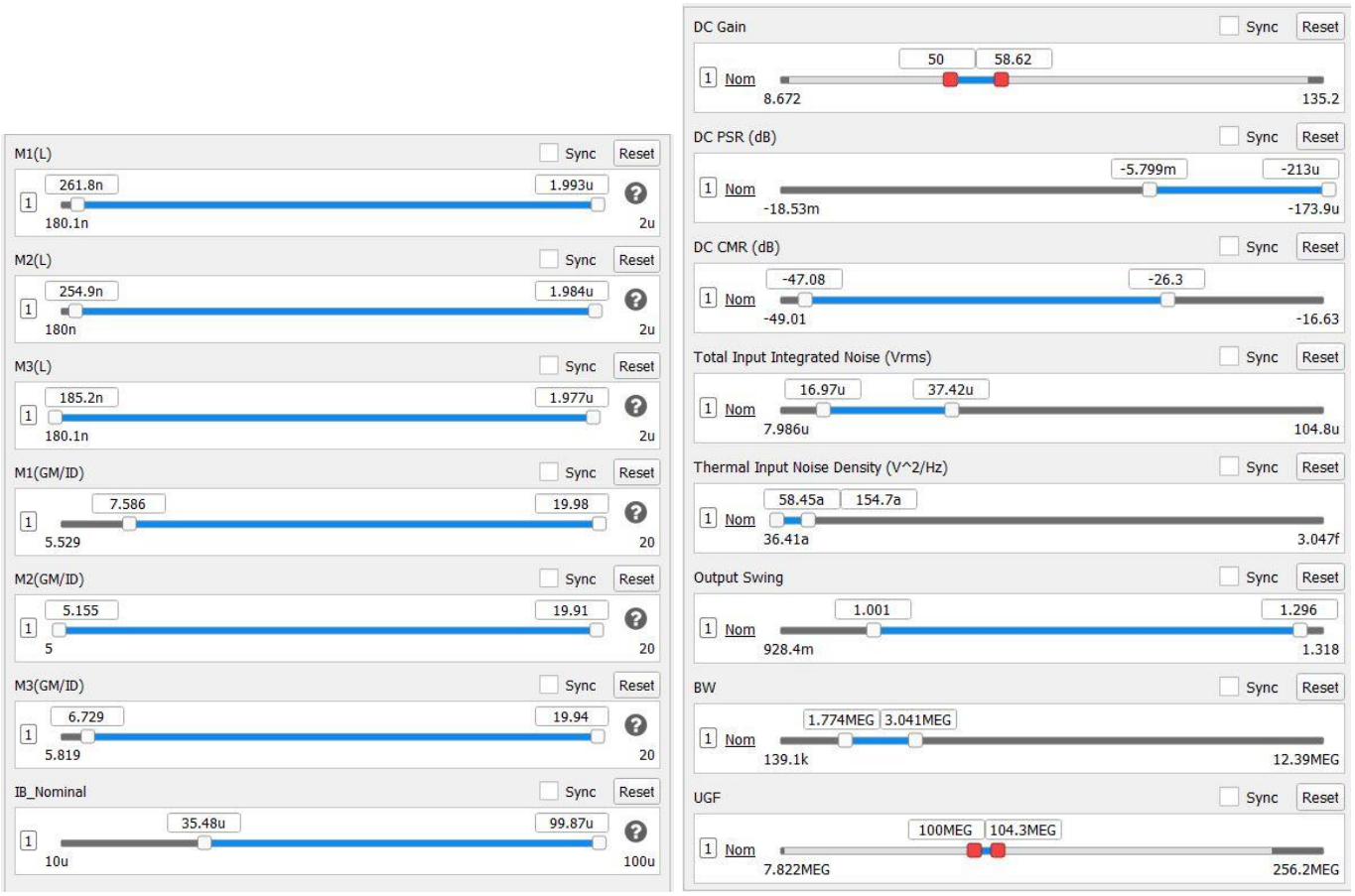
(2) ADT Verify

```
***simulator lang =LTspice

.include "D:\Summer2022\AMS Course\ADT Windows Release v1.1.8\ADT/ltspice_example/ex_180nm.sp"
.include "D:\Summer2022\AMS Course\ADT Windows Release v1.1.8\ADT\Core/ElectronicsCore/Amplifiers/circuits/A010001F/Ideal_Balun.txt"

.params L_1 = 4.2e-07
.params W_1 = 1.0578478319991733e-05
.params L_2 = 3.9e-07
.params W_2 = 3.999176059603685e-06
.params L_3 = 1e-06
.params W_3 = 1.9505835082778885e-05
.params VICM = 0.9
.params VGATE = 0.5370239962292114
.params CL = 500f
.params VDD = 1.8
.params TEMP = 27.0

M0 net20 VINP net19 0 nch l={L_1} w={W_1} ad={0.64u*{W_1}} as={0.64u*{W_1}} pd={2*(0.64u+{W_1})} ps={2*(0.64u+{W_1})}
M1 VOUTP VINN net19 0 nch l={L_1} w={W_1} ad={0.64u*{W_1}} as={0.64u*{W_1}} pd={2*(0.64u+{W_1})} ps={2*(0.64u+{W_1})}
M2 net20 net20 AVDD AVDD pch l={L_2} w={W_2} ad={0.64u*{W_2}} as={0.64u*{W_2}} pd={2*(0.64u+{W_2})} ps={2*(0.64u+{W_2})}
M3 VOUTP net20 AVDD AVDD pch l={L_2} w={W_2} ad={0.64u*{W_2}} as={0.64u*{W_2}} pd={2*(0.64u+{W_2})} ps={2*(0.64u+{W_2})}
M4 net19 VGATE 0 0 nch l={L_3} w={W_3} ad={0.64u*{W_3}} as={0.64u*{W_3}} pd={2*(0.64u+{W_3})} ps={2*(0.64u+{W_3})}
V3 VGATE 0 {VGATE}
C1 VOUTP 0 {CL}
X_INPUT N3 VINP VICM1 VINN ideal_balun
Rtemp VIDD1 n3 1e-6 noiseless
V1  AVDD 0 {VDD}
Vdiff VIDD1 0 0 AC 1
Vcm VICM1 0 {VICM}



.op
.AC dec 100 1 10G
.MEAS AC DC_GAIN max mag(V(VOUTP))
.MEAS AC BW WHEN mag(V(VOUTP)) = DC_GAIN / sqrt(2)
.MEAS AC UGF WHEN mag(V(VOUTP))=1
.MEAS AC PM FIND V(VOUTP) WHEN mag(V(VOUTP))=1
```

```
dc_gain: MAX(mag(v(voutp)))=(34.6057dB,0°) FROM 1 TO 1e+010
bw: mag(v(voutp))=dc_gain / sqrt(2) AT 1.88592e+006
ugf: mag(v(voutp))=1 AT 9.92666e+007
pm: v(voutp)=(-6.11683e-006dB,-94.5144°) at 9.92666e+007
```

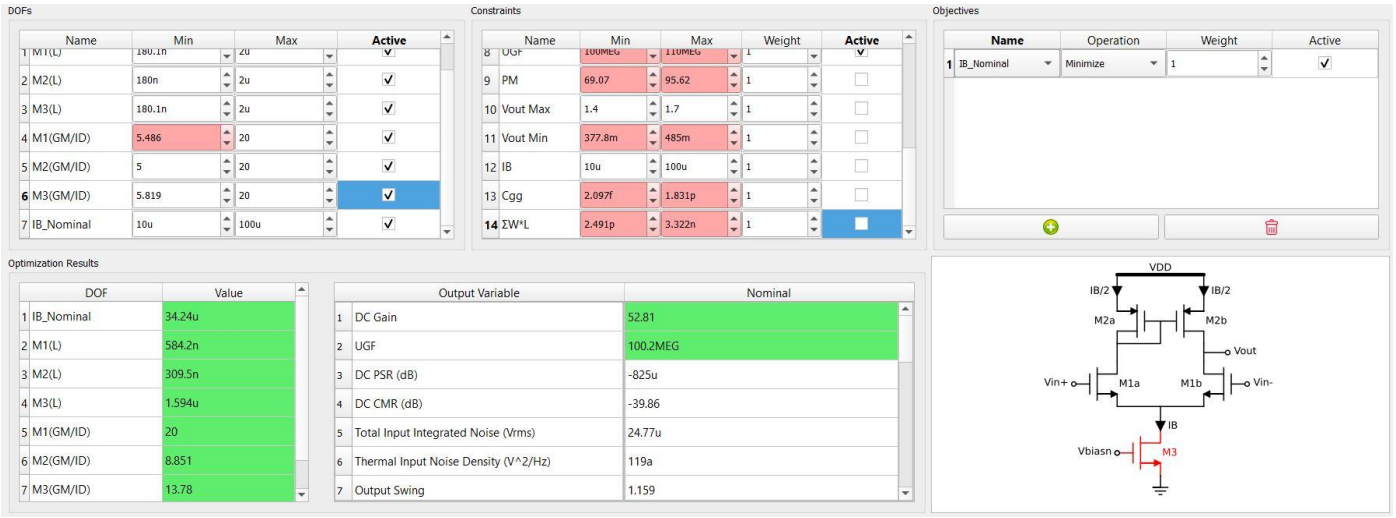
DC Gain = 34.6057 dB, GBW = [10^(34.6/20)]*[1.88592*10^6] = 101.346 MHz

(3) ADT Design Cockpit



Minimum IB = 35.48 uA

(4) ADT Optimize



Minimum IB = 34.24 uA

(5) "loptOTA.m"

```
function OTA = loptOTA(specs)
% inputs in the form of [ M1.L , M3.L , M5.L , M1.RHO , M2.RHO , M3.RHO ,
% IB]
OTA = designOTA(specs);
load 180nch.mat;
```

```
load 180pch.mat;
UB = [1, 2.00, 1.5 , 20, 15 , 20, 1e-4];  % upper limits for inputs
LB = [0.18, 0.18, 0.5, 10 , 10 , 10 ,1e-6];  % lower limits for inputs

% Add line here for inital inputs (X0 = ??)
X0 = [0.28 1.7 1 15 10 10 45.88e-6];
% Add line for the objective function (ObjFn= @ (X) ( ???? )
ObjFn= @ (X) (X(7));
NonLinConFn = @(X)NonLinCon(X, OTA, specs,nch,pch);  %% some lines are missing inside
NonLinCon file
% calling fmincon
X = fmincon(ObjFn, X0, [], [], [], [], LB, UB,NonLinConFn);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% Save all variables
% Assign X to the corresponding OTA variables (Same lines as loptOTA)
OTA.M1.L = X(1);
OTA.M3.L = X(2);
OTA.M5.L = X(3);
OTA.M1.gm_ID = X(4);
OTA.M3.gm_ID = X(5);
OTA.M5.gm_ID = X(6);
OTA.M5.ID = X(7);
OTA.M3.ID = 0.5*X(7);
OTA.M1.ID = 0.5*X(7);

OTA.M1.ID_W = look_up(nch, 'ID_W', 'GM_ID', OTA.M1.gm_ID, 'VDS', OTA.M1.VDS, 'L',
OTA.M1.L);
OTA.M1.W = OTA.M1.ID / OTA.M1.ID_W;
OTA.M3.ID_W = look_up(pch, 'ID_W', 'GM_ID', OTA.M3.gm_ID, 'VDS', OTA.M3.VDS, 'L',
OTA.M3.L);
OTA.M3.W = OTA.M3.ID / OTA.M3.ID_W;
OTA.M5.ID_W = look_up(nch, 'ID_W', 'GM_ID', OTA.M5.gm_ID, 'VDS', OTA.M5.VDS, 'L',
OTA.M5.L);
OTA.M5.W = OTA.M5.ID / OTA.M5.ID_W;
OTA.M1.VGS = look_upVGS(nch, 'GM_ID', OTA.M1.gm_ID, 'VDS', OTA.M1.VDS, 'L', OTA.M1.L);
OTA.M1.VG = OTA.M1.VGS + OTA.M5.VDS;
```

(6) “goptOTA.m”

```
function OTA = goptOTA(specs)
% inputs in the form of [ M1.L , M3.L , M5.L , M1.RHO , M2.RHO , M3.RHO ,
% IB]
OTA = designOTA(specs);
load 180nch.mat;
load 180pch.mat;
UB = [0.5, 2.00, 1.5 , 20, 15 , 20, 1e-4];  % upper limits for inputs
LB = [0.18, 1, 0.5, 10 , 10 , 10 ,1e-6];  % lower limits for inputs


ObjFn = @(X)(X(:,7)); %% vectorized objective function
NonLinConFn = @(X)NonLinConV(X, OTA, specs,nch,pch);
% calling fmincon
options=optimoptions('ga','UseVectorized',true,'PopulationSize',20);
X = ga(ObjFn, 7, [], [], [], [], LB, UB,NonLinConFn,options);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% Save all variables
% Assign X to the corresponding OTA variables , for example:
OTA.M1.L = X(1);
OTA.M3.L = X(2);
```

```
OTA.M5.L = X(3);
OTA.M1.gm_ID = X(4);
OTA.M3.gm_ID = X(5);
OTA.M5.gm_ID = X(6);
OTA.M5.ID = X(7);
OTA.M3.ID = 0.5*X(7);
OTA.M1.ID = 0.5*X(7);
% continue the rest (multiple lines)
% note that if you did not write the lines , the values from the previous lab will be
used automaticlly
OTA.M1.ID_W = look_up(nch, 'ID_W', 'GM_ID', OTA.M1.gm_ID, 'VDS', OTA.M1.VDS, 'L',
OTA.M1.L);
OTA.M1.W = OTA.M1.ID / OTA.M1.ID_W;
OTA.M3.ID_W = look_up(pch, 'ID_W', 'GM_ID', OTA.M3.gm_ID, 'VDS', OTA.M3.VDS, 'L',
OTA.M3.L);
OTA.M3.W = OTA.M3.ID / OTA.M3.ID_W;
OTA.M5.ID_W = look_up(nch, 'ID_W', 'GM_ID', OTA.M5.gm_ID, 'VDS', OTA.M5.VDS, 'L',
OTA.M5.L);
OTA.M5.W = OTA.M5.ID / OTA.M5.ID_W;
OTA.M1.VGS = look_upVGS(nch, 'GM_ID', OTA.M1.gm_ID, 'VDS', OTA.M1.VDS, 'L', OTA.M1.L);
OTA.M1.VG = OTA.M1.VGS + OTA.M5.VDS;
```

(7) “optOTA_test.m”

```
% OTA Design Script
% Write the SPECS
clear all;
clc;

AVDC = 34; %dB
GBW = 1e8; %Hz
CL = 500e-15; %Farad
specs = struct('AVDC', AVDC,...
'CL', CL,...
'GBW', GBW);

OTA = loptOTA(specs);
% Print the solution
fprintf('**** Local opt OTA Design ****\n\n');
fprintf('Input Pair:\n');
fprintf('    L = %.2f um\n    W=%.2f um\n ViCM=%.4f
V\n\n',OTA.M1.L,OTA.M1.W,OTA.M1.VG);
fprintf('CM Load:\n');
fprintf('    L = %.2f um\n    W=%.2f um\n\n',OTA.M3.L,OTA.M3.W);
fprintf('Tail Current Source:\n');
fprintf('    L = %.2f um\n    W=%.2f um\n\n',OTA.M5.L,OTA.M5.W);
fprintf('    Optimized current = %.2f uA\n\n', OTA.M5.ID*1e6);

OTA = goptOTA(specs);
% Print the solution
fprintf('**** Global opt OTA Design ****\n\n');
fprintf('Input Pair:\n');
fprintf('    L = %.2f um\n    W=%.2f um\n ViCM=%.4f
V\n\n',OTA.M1.L,OTA.M1.W,OTA.M1.VG);
fprintf('CM Load:\n');
fprintf('    L = %.2f um\n    W=%.2f um\n\n',OTA.M3.L,OTA.M3.W);
```

```
fprintf('Tail Current Source:\n');
fprintf('    L = %.2f um\n    W=%.2f um\n\n',OTA.M5.L,OTA.M5.W);
fprintf('    Optimized current = %.2f uA\n\n', OTA.M5.ID*1e6);
```

Results:

```
**** Local opt OTA Design ****

Input Pair:
    L = 0.42 um
    W=11.10 um
    ViCM=1.1159 V

CM Load:
    L = 0.52 um
    W=8.35 um

Tail Current Source:
    L = 1.00 um
    W=19.17 um

    Optimized current = 33.58 uA
```

```
**** Global opt OTA Design ****

Input Pair:
    L = 0.27 um
    W=8.46 um
    ViCM=1.1282 V

CM Load:
    L = 1.00 um
    W=16.66 um

Tail Current Source:
    L = 0.87 um
    W=17.42 um

    Optimized current = 38.95 uA
```

Comparison:

	ADT	Matlab local opt	Matlab global opt
Input pair			
L	0.42 um	0.42 um	0.27 um
W	10.58 um	11.10 um	8.46 um
ViCM	1.16145 V	1.1159 V	1.1282 V
CM load			
L	0.39 um	0.52 um	1 um
W	3.999 um	8.35 um	16.66 um
Tail current source			
L	1 um	1 um	0.87 um
W	19.51 um	19.17 um	17.42 um

Tool	Min current
ADT Design Xplore	34 uA
ADT Design Cockpit	35.48 uA
ADT Optimize	34.24 uA
Matlab Local Optimization	33.58 uA
Matlab Global Optimization	38.95 uA

Comment: Matlab local optimizer gives best results w.r.t the power minimization.

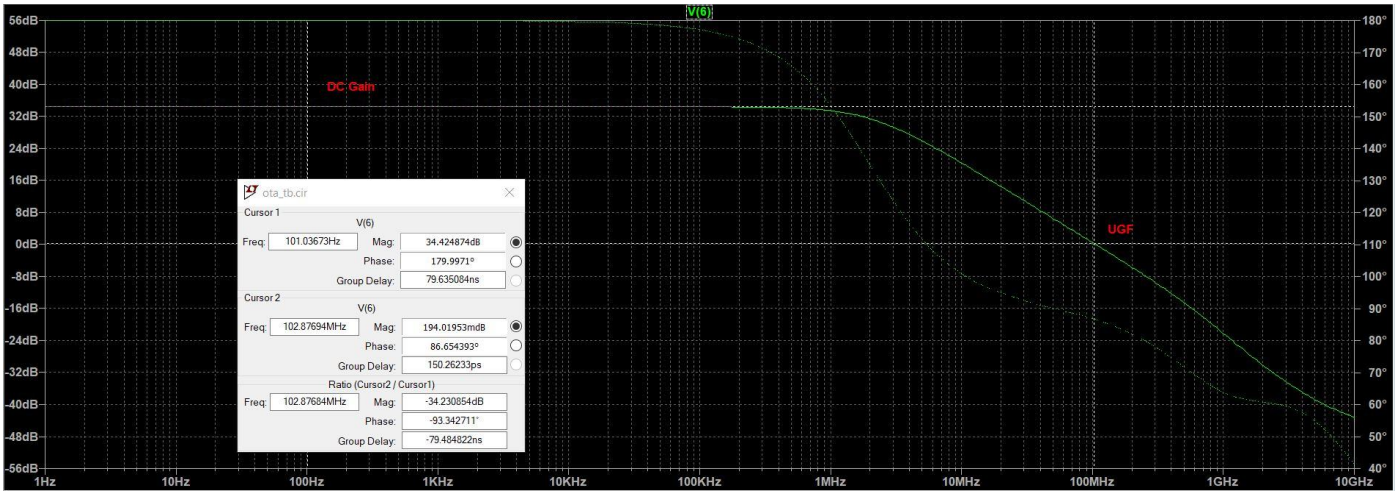
(8) "ota_tb.cir"

netlist:

ota_tb.cir

```
* Include external file that contains MOSFET Mode
.INCLUDE ee214b_hspice.sp
** Circuit Description **

* power supply
VDD 7 0 DC 1.8
* input

* Add lines here to add the input (voltage)source
V1 4 0 1.1937 AC 0.5
V2 3 0 1.1937 AC -0.5

* circuit
* 5T OTA
M1 6 4 2 0 nch L=0.42u W=10.58u
M2 5 3 2 0 nch L=0.42u W=10.58u
M3 6 5 7 7 pch L=0.39u W=3.999u
M4 5 5 7 7 pch L=0.39u W=3.999u
M5 2 1 0 0 nch L=1u W=19.51u
CL 6 0 500f
* Current Mirror
M6 1 1 0 0 nch L=1u W=19.51u
Iref 7 1 34u

** Analysis Requests **
.op
.ac dec 10 1 10e9

.MEAS AC dc_gain max mag(V(6))
.MEAS AC BW WHEN mag(V(6)) = dc_gain/sqrt(2)
** Outputs Requests **
*.PROBE

.END
```

Simulation results:




```
dc_gain: MAX(mag(v(6)))=(34.4249dB,0°) FROM 1 TO 1e+010
bw: mag(v(6))=dc_gain/sqrt(2) AT 2.00207e+006
```

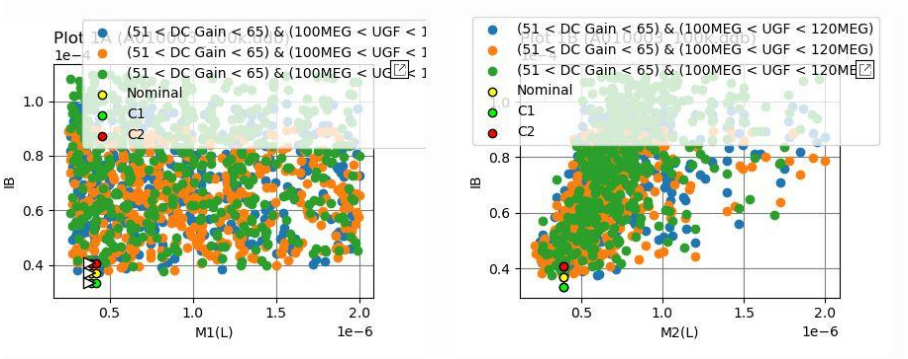
Comparison table:

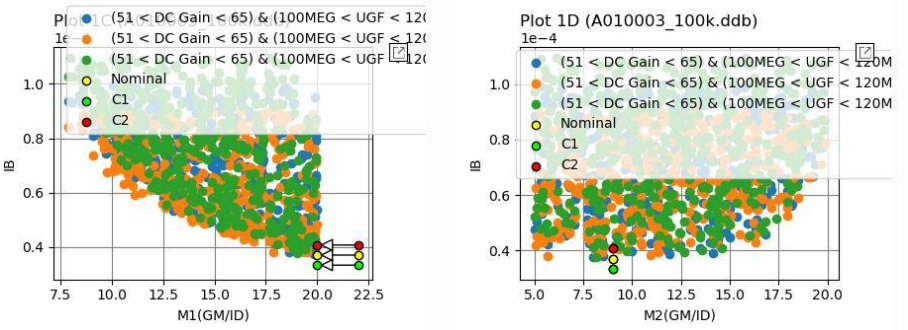
	Specification	ADT
AVDC	34 dB	34.4249 dB
GBW	100 MHz	105.372 MHz

Comment: all specifications are met using the sizing results of ADT that achieves minimum power consumption.

Part (2)

(1) ADT Design Xplore





Plot 1D (A010003_100k.ddb)

Plot | Tune

DDB: A010003_100k.ddb — Properties

Corners: Nominal, C1, C2

No of Points: 2

Live Updates

DOF	Value
M1(L)	420n
M2(L)	390n
M3(L)	1u
M1(GM/ID)	20
M2(GM/ID)	9
M3(GM/ID)	15
IB_Nominal	37u

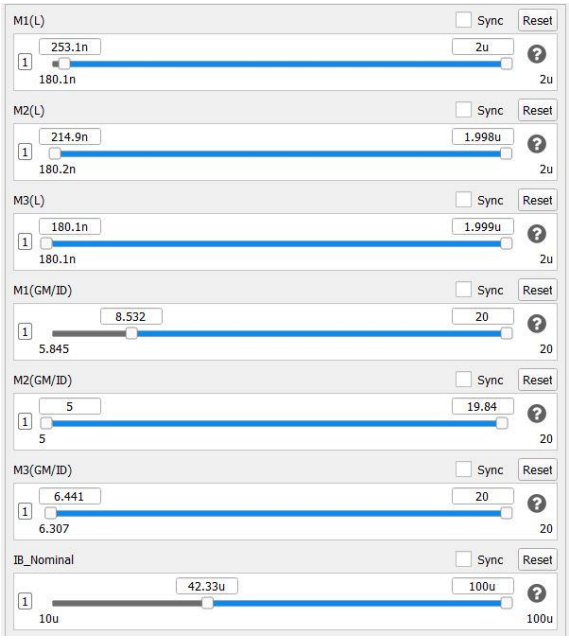
Output Variable	Nominal	C1	C2
DC Gain	53.53	53.37	53.57
DC PSR (dB)	-1.261m	-1.201m	-1.329m
DC CMR (dB)	-37.4	-37.83	-36.94
Total Input ...	24.4u	24.53u	24.3u
Thermal Input ...	110.1a	120.5a	101.6a
Output Swing	1.174	1.182	1.163
BW	2.06MEG	1.904MEG	2.211MEG
UGF	108.5MEG	100.3MEG	116.4MEG
PM	84.72	84.88	84.58
Vout Max	1.578	1.589	1.565
Vout Min	404.1m	407.2m	402m
Vin CM Min	685.9m	676m	697.1m
Vin CM Max	1.637	1.645	1.628

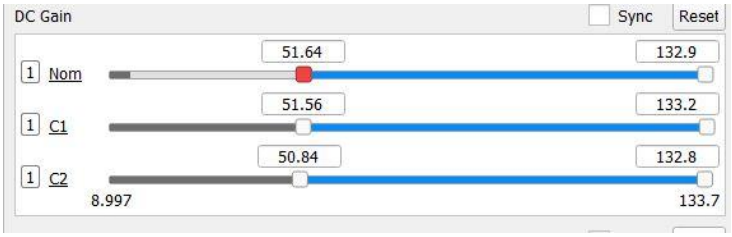
IB	37u	33.3u	40.7u

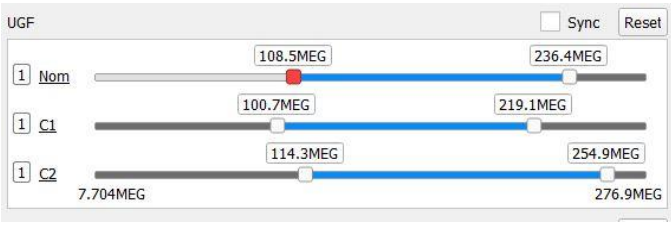
	Nominal	C1	C2

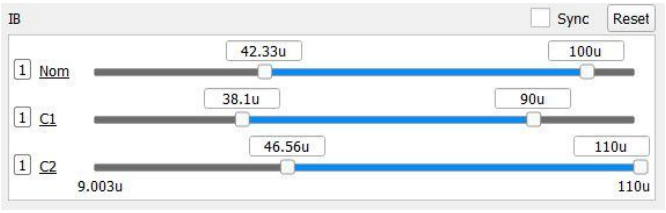
Min Current (ADT Design Xplore)	37 uA	33.3 uA	40.7 uA

(2) ADT Design Cockpit









	Nominal	**C1**	**C2**
Min Current (Design Cockpit)	42.33 uA	38.1 uA	46.56 uA

(3) ADT Optimize

DOFs

	Name	Min	Max	Active
1	M1(L)	180.1n	2u	☐
2	M2(L)	180n	2u	☑
3	M3(L)	180.1n	2u	☐
4	M1(GM/ID)	5.486	20	☑
5	M2(GM/ID)	5	20	☐
6	M3(GM/ID)	5.819	20	☑
7	IB_Nominal	10u	100u	☐

Constraints

	Name	Min	Max	Weight	Active
5	Thermal ...	36.4a	3.015f	1	☐
6	Output Swing	928.4m	1.317	1	☐
7	BW	69.57k	6.5MEG	1	☐
8	UGF	100MEG	120MEG	1	☑
9	PM	69.07	95.62	1	☐
10	Vout Max	1.4	1.7	1	☐
11	Vout Min	377.8m	485m	1	☐

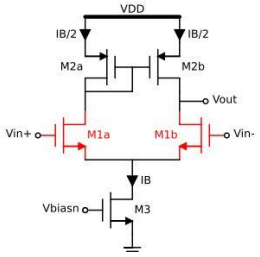
Objectives

	Name	Operation	Weight	Acti
1	IB_Nominal	Minimize	1	☑

Optimization Results

	DOF	Value
1	IB_Nominal	40.45u
2	M1(L)	909n
3	M2(L)	257.6n
4	M3(L)	247.7n
5	M1(GM/ID)	18.71
6	M2(GM/ID)	5.666
7	M3(GM/ID)	18.68

	Output Variable	Nominal	C1	C2
1	DC Gain	56.63	56.32	57.18
2	UGF	107.6MEG	100MEG	115.9MEG
3	DC PSR (dB)	-3.774m	-3.564m	-3.959m
4	DC CMR (dB)	-25.42	-25.91	-25.03
5	Total Input ...	27.29u	27.31u	27.08u
6	Thermal Input Nois...	97.77a	106.3a	89.67a
7	Output Swing	1.022	1.038	996.5m



	Output Variable	Nominal	C1	C2
13	Vin CM Max	1.493	1.508	1.476
14	IB	40.45u	36.4u	44.49u
15	Cgg	138f	136.6f	139.2f

	Nominal	C1	C2
Min Current (ADT Optimize)	40.45 uA	36.4 uA	44.49 uA

(4) ADT Verify

Nominal:

```
dc_gain: MAX(mag(v(voutp)))=(35.1455dB,0°) FROM 1 TO 1e+010
bw: mag(v(voutp))=dc_gain / sqrt(2) AT 1.91917e+006
ugf: mag(v(voutp))=1 AT 1.07334e+008
pm: v(voutp)=(-2.18742e-006dB,-95.46°) at 1.07334e+008
```

DC Gain = 35.1455 dB, GBW = [10^(35.1455/20)]*[1.91917*10^6] = 109.746 MHz

C1(IB/IB_Nominal = 0.9):

```
dc_gain: MAX(mag(v(voutp)))=(35.0747dB,0°) FROM 1 TO 1e+010
bw: mag(v(voutp))=dc_gain / sqrt(2) AT 1.78667e+006
ugf: mag(v(voutp))=1 AT 9.9259e+007
pm: v(voutp)=(-6.95425e-006dB,-95.2665°) at 9.9259e+007
```

DC Gain = 35.0747 dB, GBW = [10^(35.0747/20)]*[1.78667*10^6] = 101.34 MHz

C2 (IB/IB_Nominal = 1.1):

```
dc_gain: MAX(mag(v(voutp)))=(35.2051dB,0°) FROM 1 TO 1e+010
bw: mag(v(voutp))=dc_gain / sqrt(2) AT 2.04682e+006
ugf: mag(v(voutp))=1 AT 1.15114e+008
pm: v(voutp)=(-3.31399e-006dB,-95.6349°) at 1.15114e+008
```

DC Gain = 35.2051 dB, GBW = [10^(35.2051/20)]*[2.04682*10^6] = 117.851 MHz

	Nominal	**C1**	**C2**
DC Gain	35.1455	35.0747	35.2051
GBW	109.746 MHz	101.34 MHz	117.851 MHz
Min Current (ADT Design Xplore)	37 uA	33.3 uA	40.7 uA
Min Current (Design Cockpit)	42.33 uA	38.1 uA	46.56 uA
Min Current (ADT Optimize)	40.45 uA	36.4 uA	44.49 uA