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ECEN 326-501

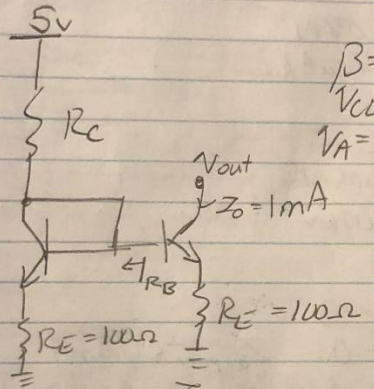
Lab 6: Design of Current Mirrors

Procedure:

In this lab we constructed several current mirrors with varying designs. Each of these current mirrors have unique properties and to determine them we ran multiple calculations on each.

Calculations:

Lab #6



$\beta = 140$

$V_{CE} = 0.2$

$V_A = 75v$

$$\text{KVL}: \quad -5 + R_C I_o + 0.7 + \frac{R_E(1+\beta) I_o}{\beta} = \phi$$

$$R_C = 4.199\,k\Omega$$

$$g_{m_2} = \frac{I_C}{V_t} = 0.04$$

$$r_{\pi 2} = \frac{\beta}{g_{m_2}} = 3500$$

$$r_{e_1} = \frac{25m}{I_{E_1}} = 24.82$$

$$r_{o2} = \frac{V_A}{I_C} = 75000\Omega$$

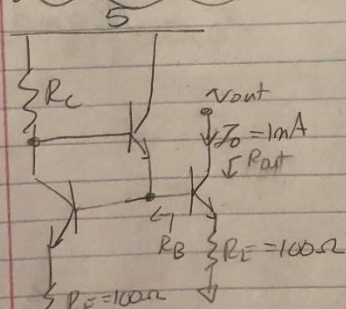
$$V_{o,min} = V_{CE,sat} + I_o R_{E_2} = 0.3v$$

$$R_o = g_{m_2}' r_{o2} R_E' + r_{o2} + R_E'$$

$$g_{m_2}' = g_{m_2} \frac{r_{\pi 2}}{r_{\pi 2} + R_B}, \quad R_E' = R_{E_2} \| (r_{\pi_2} + R_B)$$

$$R_B = R_C \| (r_{e_1} + R_{E_1})$$

$$\therefore R_B = 121.21\Omega \quad g_{m_2}' = 0.03866, \quad R_E' = 97.31 \quad R_o = 357.247k\Omega$$



$R_C = 3500\Omega \quad V_{o,min} = 0.3$

$$R_o = g_{m_2}' r_{o2} R_E' + r_{o2} + R_E'$$

$$g_{m_2}' = g_{m_2} \frac{r_{\pi 2}}{r_{\pi 2} + R_B}, \quad R_{E_2}' = R_{E_2} \| (r_{\pi 2} + R_B)$$

$$R_B = \left(\frac{R_C}{\beta+1} + \frac{(\beta+1) r_{e_1}}{N}\right) \| \left[\frac{r_{e_1} + R_{E_1}}{\beta}\left(1 + \frac{(\beta+1)^2 r_{e_1}}{N R_C}\right)\right] \| \frac{(\beta+1)(r_{e_1} + R_{E_1})}{2}$$

Where $N = 2$

$$1774.63 \| 62.84 \| 17599.22$$

$$\therefore R_B = 60.48\Omega \quad R_{E_2}' = 97.268\Omega$$

$$g_{m_2}' = 0.039 \quad R_o = 361.944k\Omega$$

$g_{m_2} = 0.04$

$r_{\pi 2} = 3500$

$r_{e_1} = 24.82$

$r_{o2} = 75000$

Lab #6

NPN Current mirror w/ β helper

$I_o = 2mA$

$R_{E_1} = 100\Omega$ $R_{E_2} = 50\Omega$, $Q_2 = 2 \times Q_1$ $\therefore N = 3$

$R_C = 3500\Omega$ $V_{o,min} = 0.3V$

$R_o = g_{m2} r_{o2} R_{E_2}' + r_{o2} + R_{E_2}'$

$g_{m_2}' = g_{m2} \frac{r_{\pi 2}}{r_{\pi 2} + R_B}$, $R_{E_2}' = R_{E_2} \| (r_{\pi 2} + R_B)$

$R_B = \left(\frac{R_C}{\beta+1} + \frac{(\beta+1) r_{e1}}{N} \right) \| \left[\frac{r_{\pi 1} + R_{E_1}}{\beta} \left(1 + \frac{(\beta+1)^2 r_{c1}}{N R_C} \right) \right] \| (\beta+1)(r_{\pi 1} + R_{E_1})$

$g_{m2} = 0.08$ $R_B = 608 \| 19.669 \| 15349.81 = 19.03\Omega$

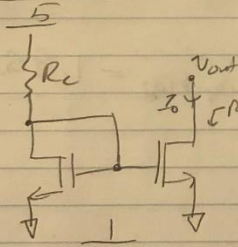
$r_{\pi_2} = 1750$ $g_{m_2}' = 0.079$ $R_{E_2}' = 48.625\Omega$ $R_o = 181.602 k\Omega$

$r_{e_1} = 12.41$

$r_{o2} = 37500$

NMOS simple Current Mirror

$K_n' = 70 \mu A/V^2$ $V_{tn} = 1.4V$ $W = 170\mu m$ $L = 10\mu m$ $\lambda_n = 0.016V^{-1}$



$I_o = 100\mu A$

$I_{D_1} = \frac{5 - V_{GS_1}}{R_C} = \frac{K_n'}{2} \left(\frac{W}{L} \right)_1 (V_{GS} - V_{tn})^2$

$I_o = I_{D_1}$ $V_{o,min} = 0.4V = V_{OV}$

$R_C = 31.9 k\Omega$ $V_{GS_1} = 1.809$ $R_o = r_{o2}$

$r_o = \frac{1}{\lambda I_D}$

$r_{o2} = \frac{1}{\lambda_n I_o} = 625 k\Omega$

NMOS Simp Current Mirror

$K_n' = 70 \mu A/V^2$ $V_{tn} = 1.4$ $I_o = 200\mu A$

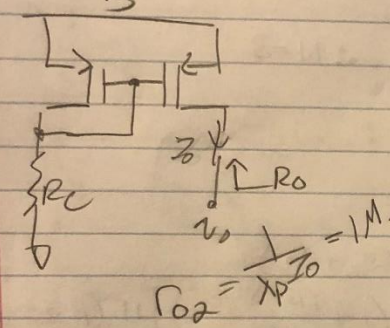
$V_{GS_1} = 1.809$ $\left(\frac{W}{L} \right)_1 = 17$ $\left(\frac{W}{L} \right)_2 = 34$

$I_{D_1} = 100\mu A$ $V_{o,min} = 0.4V$

$r_{o2} = \frac{1}{\lambda_n I_o} = 312.5 k\Omega = R_o$

Lab #6

PMOS Simp Current Mirror



$K_p' = 15\mu A/V^2$ $V_{tp} = -1.65V$ $\lambda_p = 0.01V^{-1}$

$\left(\frac{W}{L}\right)_{1,2} = 36$

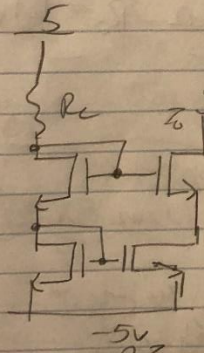
$I_o = 100\mu A$

$I_{D_1} = \frac{V_{cc} - V_{SG_1}}{R_c} = \frac{K_p'}{2}\left(\frac{W}{L}\right)_1 (V_{SG} - |V_{tp}|)^2$

$I_o = I_{D_1}$ $V_{SG_1} = 2.2586V$

$R_c = 27.414K\Omega$ $V_{o,max} = 4.39$

NMOS ~~Cascode~~ Current Mirror



$K_n' = 70\mu A/V^2$ $V_{tn} = 1.9V$ $\lambda_n = 0.016V^{-1}$

$\left(\frac{W}{L}\right)_{all} = 17$

$I_o = 100\mu A$

$I_{D_1} = \frac{2V_{cc} - 2V_{GS_1}}{R_c} = \frac{K_n'}{2}\left(\frac{W}{L}\right)_1 (V_{GS_1} - V_{tn})^2$

$I_o = I_{D_1}$ $V_{GS_1} = 1.809V$ $R_c = 63.8K\Omega$

$V_{o,min} = -2.782$

$R_o = g_{m4} r_{o4} r_{o2} + r_{o4} + r_{o2} = 1.9G\Omega$

$g_{m4} = \frac{2I_D}{V_{OV}} = 4.89 \times 10^{-4}$

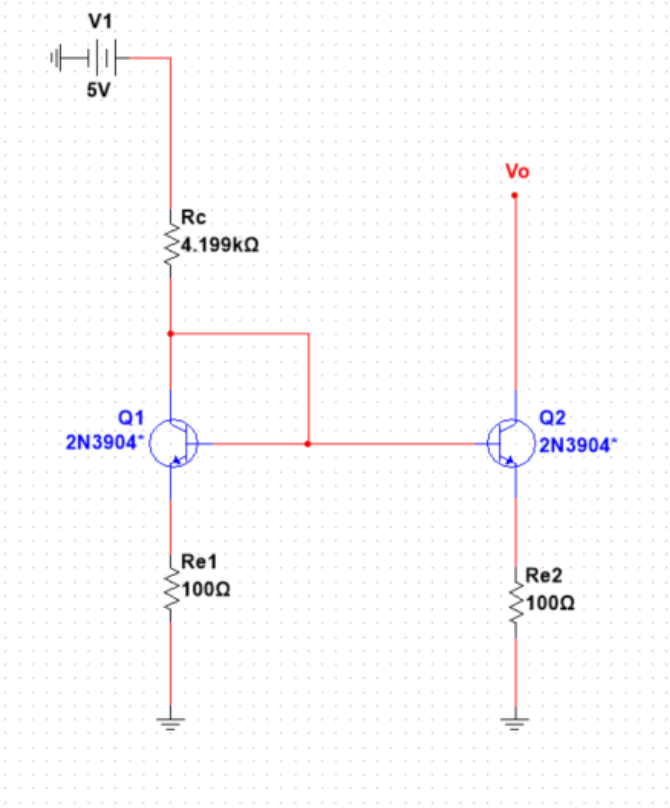
$r_{o4} = \frac{1}{\lambda_n I_o} = 625K\Omega$

$r_{o2} =$

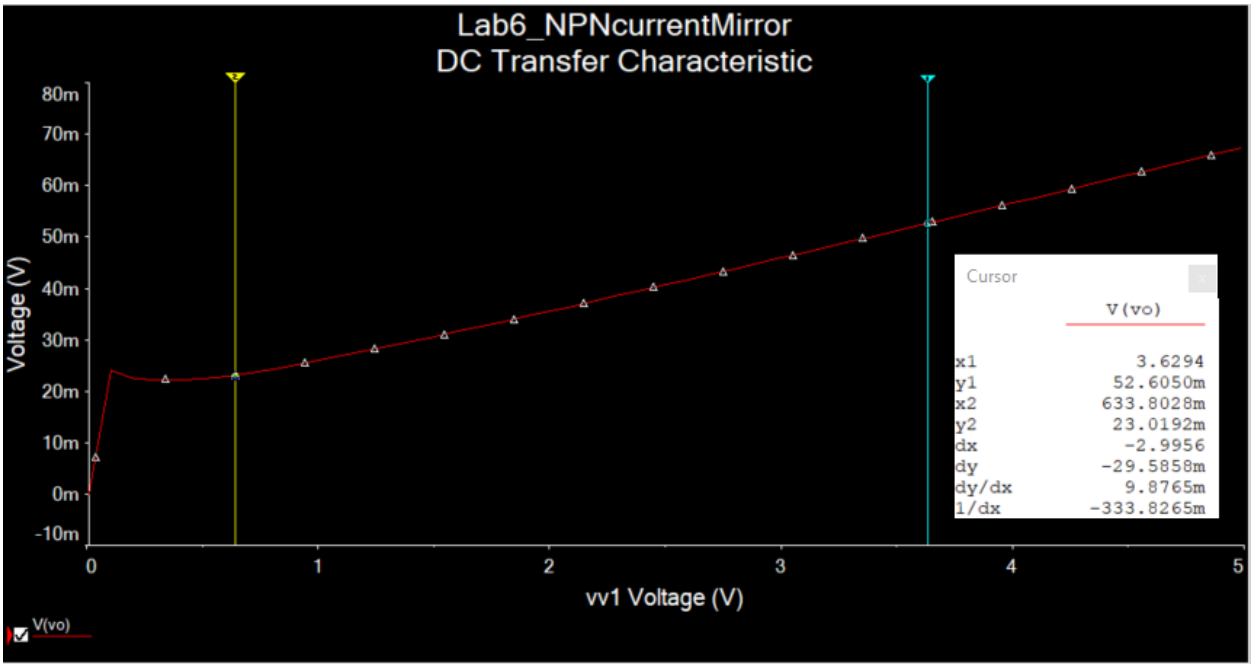
Data:

Simple NPN Current Mirror

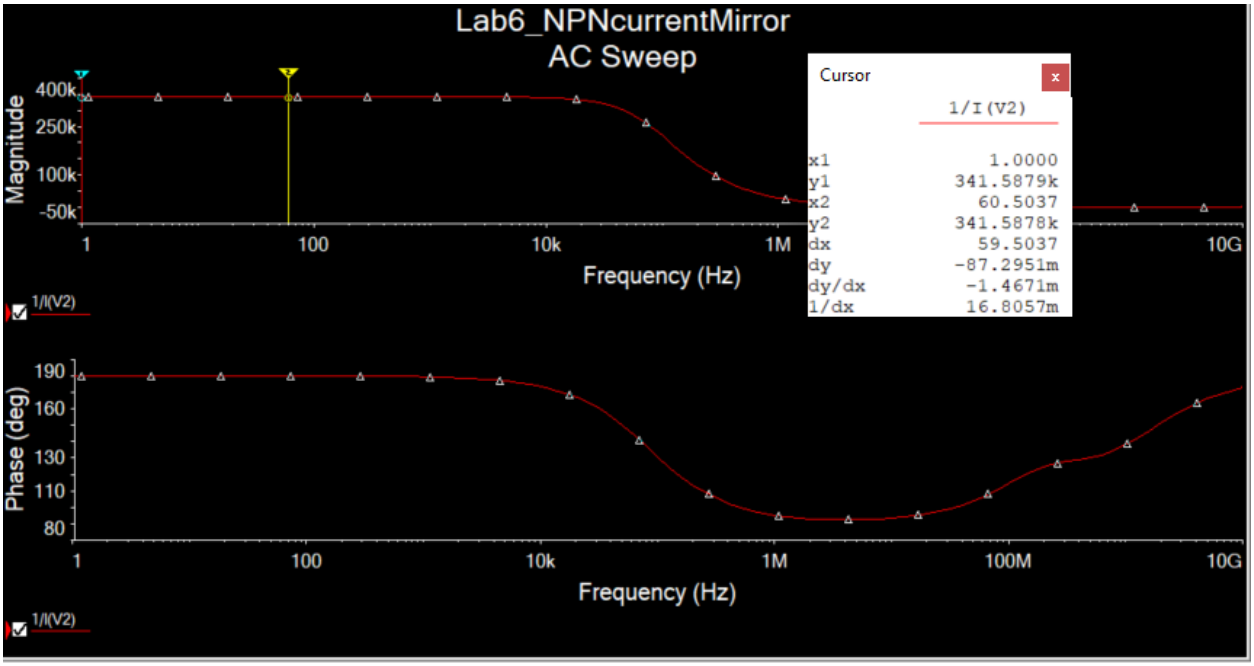
Circuit:



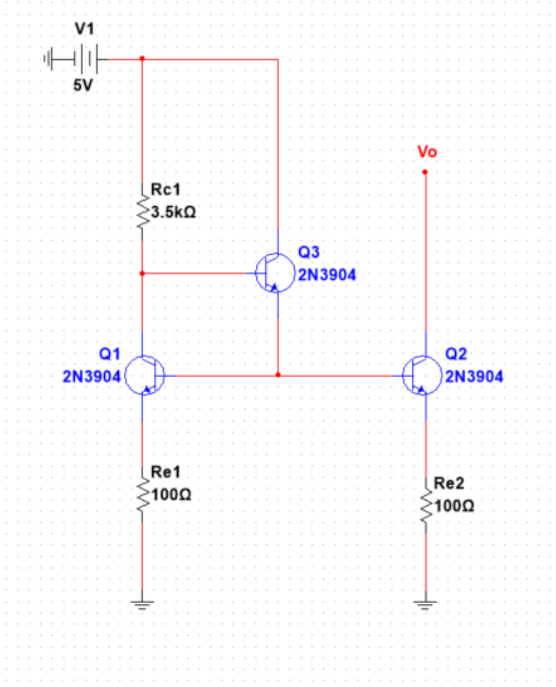
DcSweep:



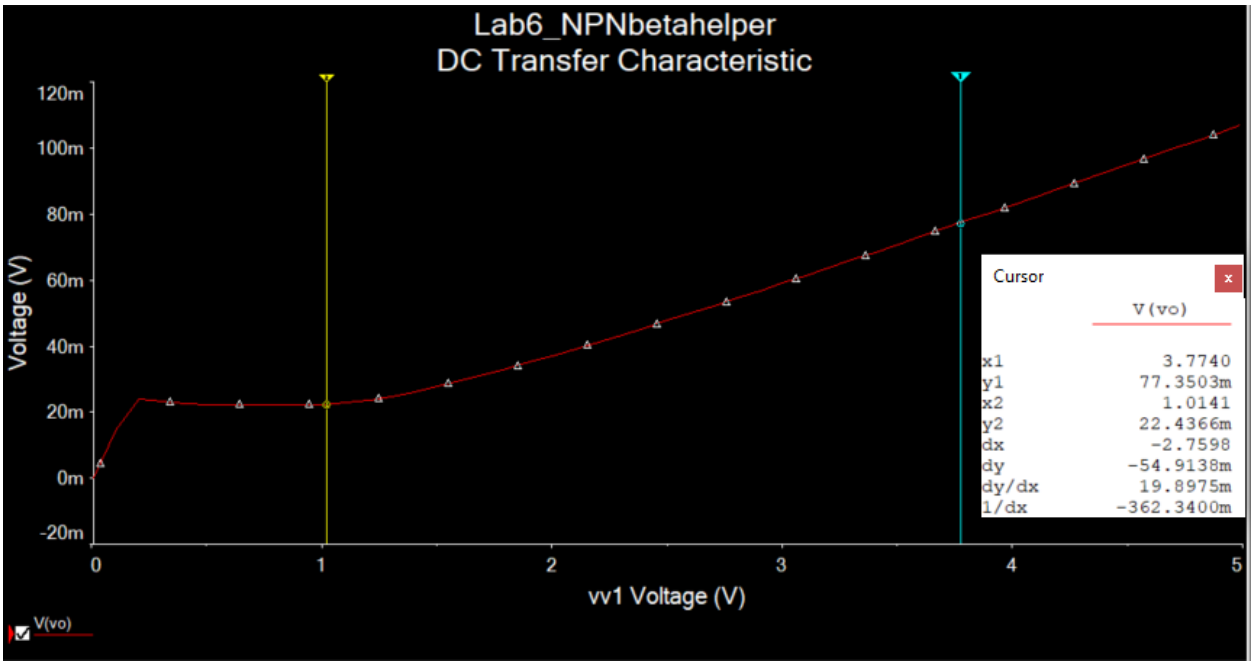
Rout:



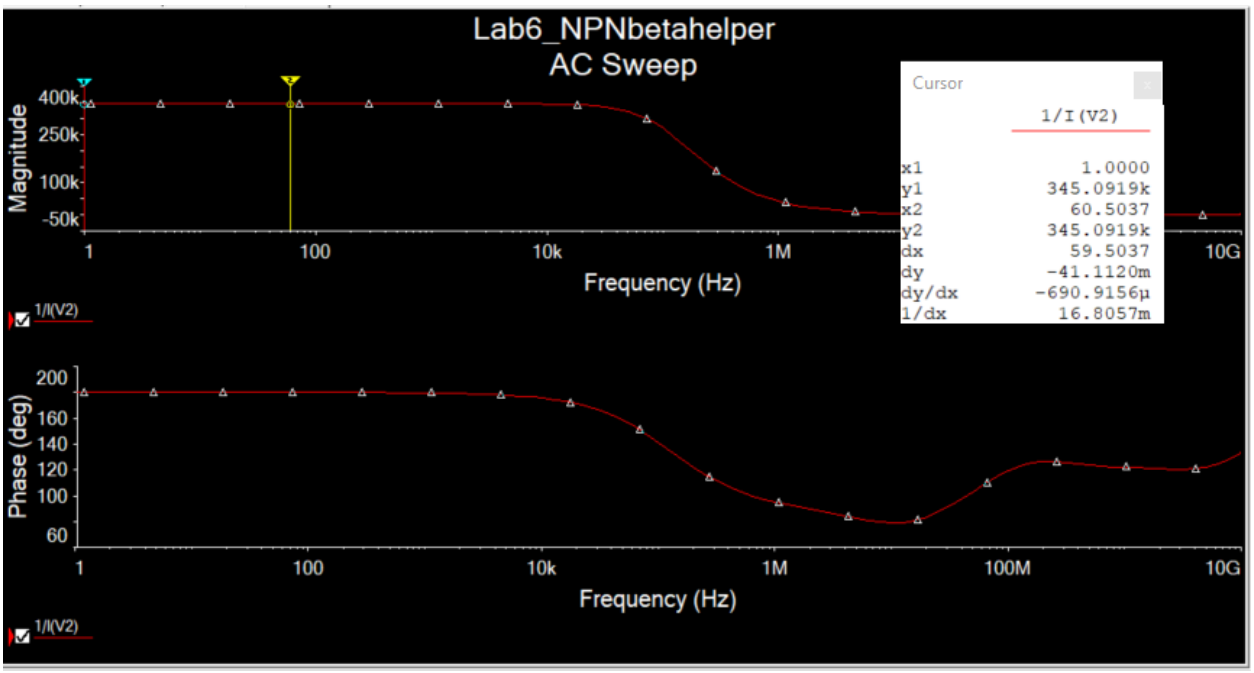
NPN Beta Helper:


V1
5V
Rc1
3.5kΩ
Q3
2N3904
Vo
Q1
2N3904
Q2
2N3904
Re1
100Ω
Re2
100Ω

DcSweep:

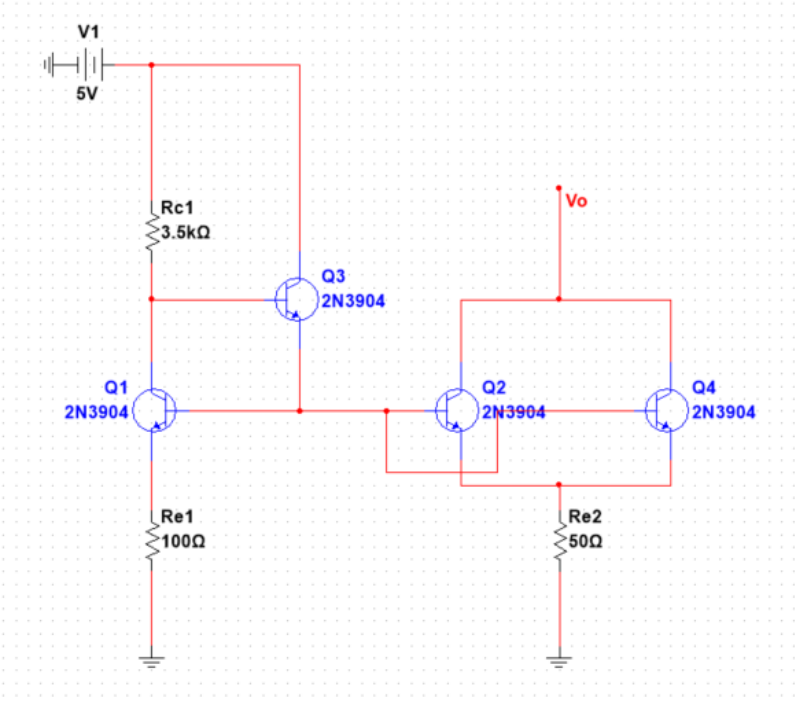

Lab6_NPNbetahelper
DC Transfer Characteristic
120m
100m
80m
60m
40m
20m
0m
-20m
Voltage (V)
0
1
2
3
4
5
vv1 Voltage (V)
V(vo)
Cursor
V(vo)
x1 3.7740
y1 77.3503m
x2 1.0141
y2 22.4366m
dx -2.7598
dy -54.9138m
dy/dx 19.8975m
1/dx -362.3400m

Ro:

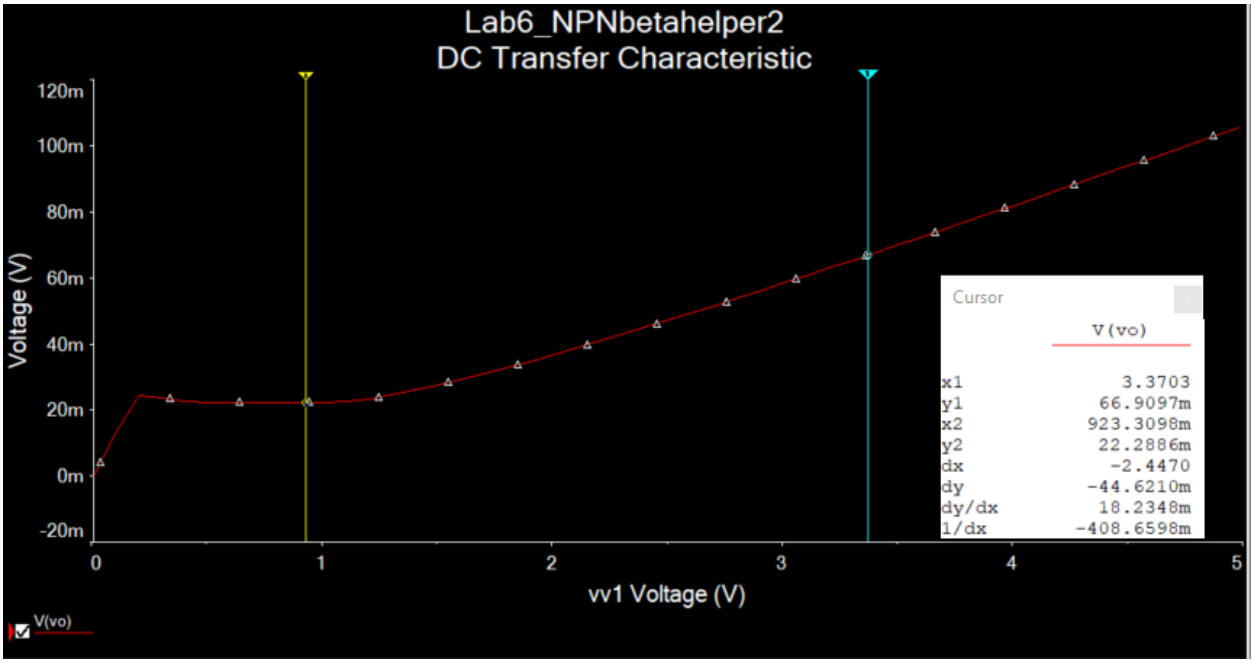


NPN Beta Helper with second stage

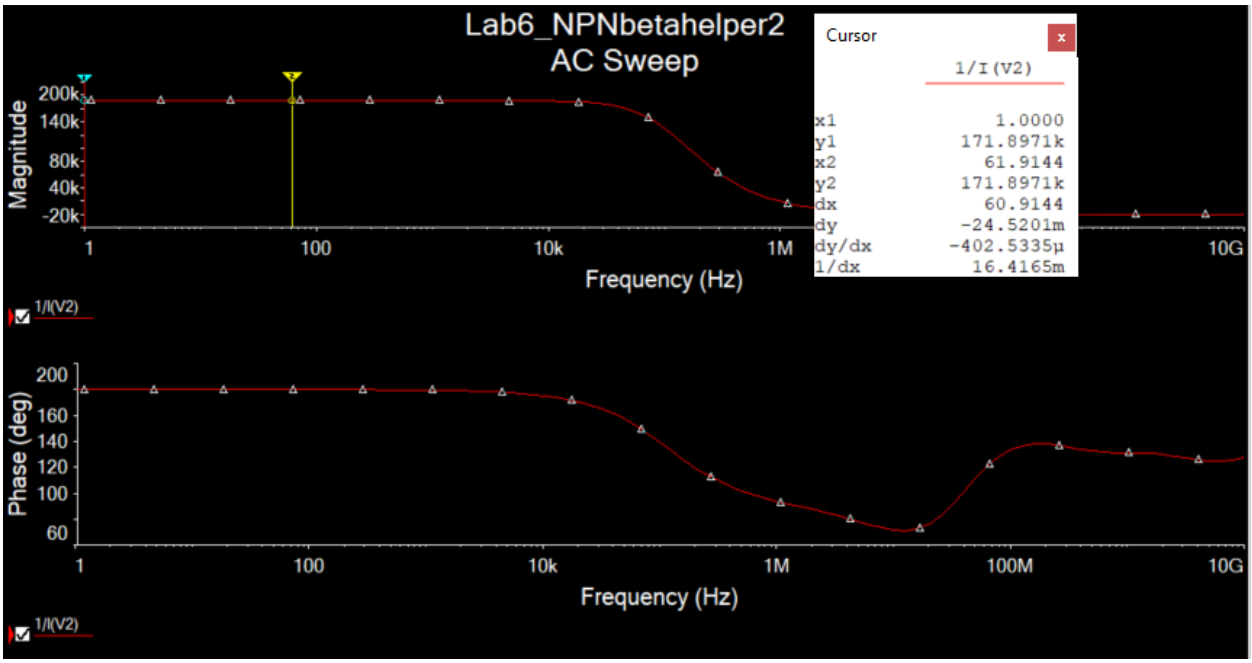
Circuit:



DcSweep:

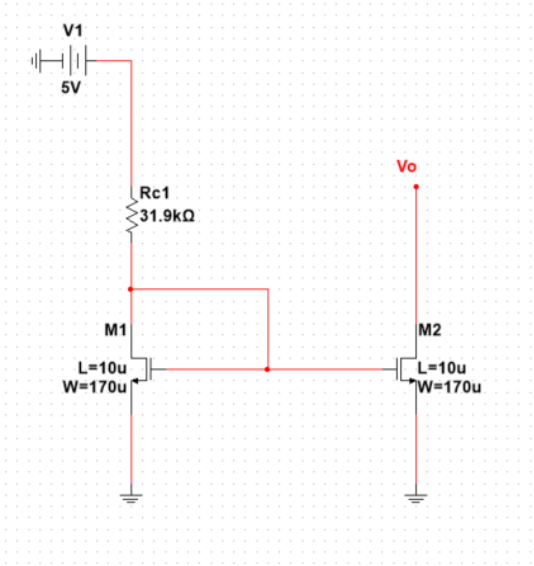


Ro:

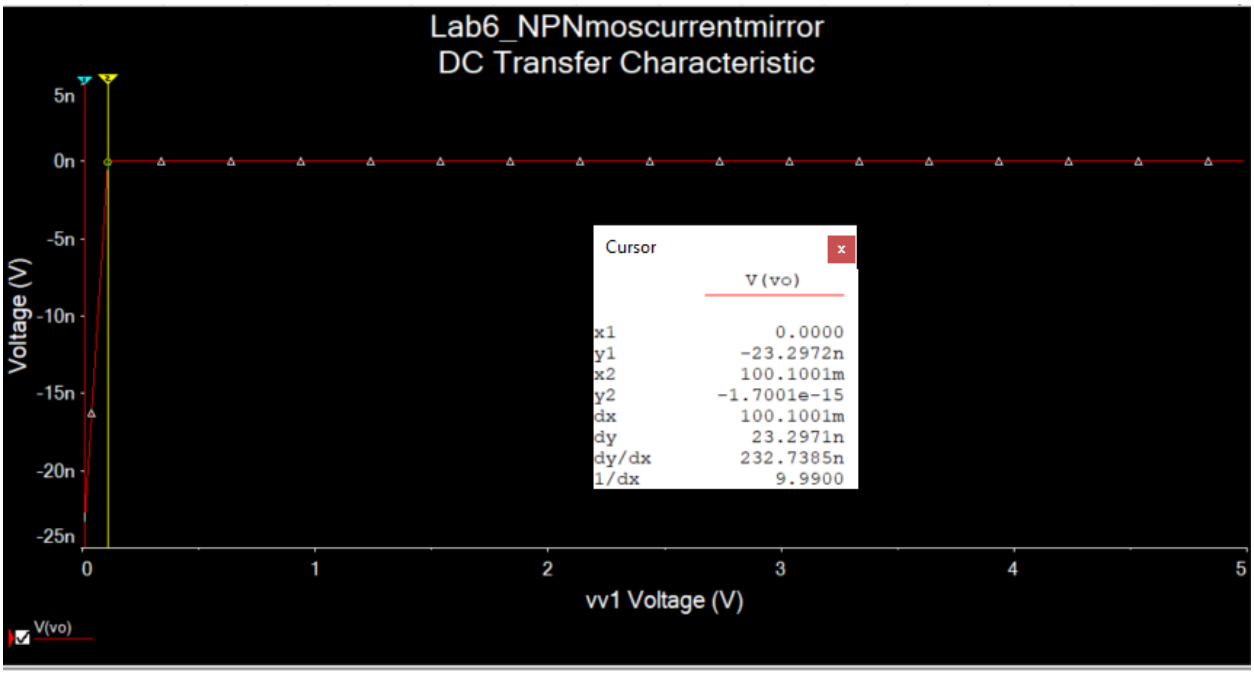


NMOS Simple Current Mirror:

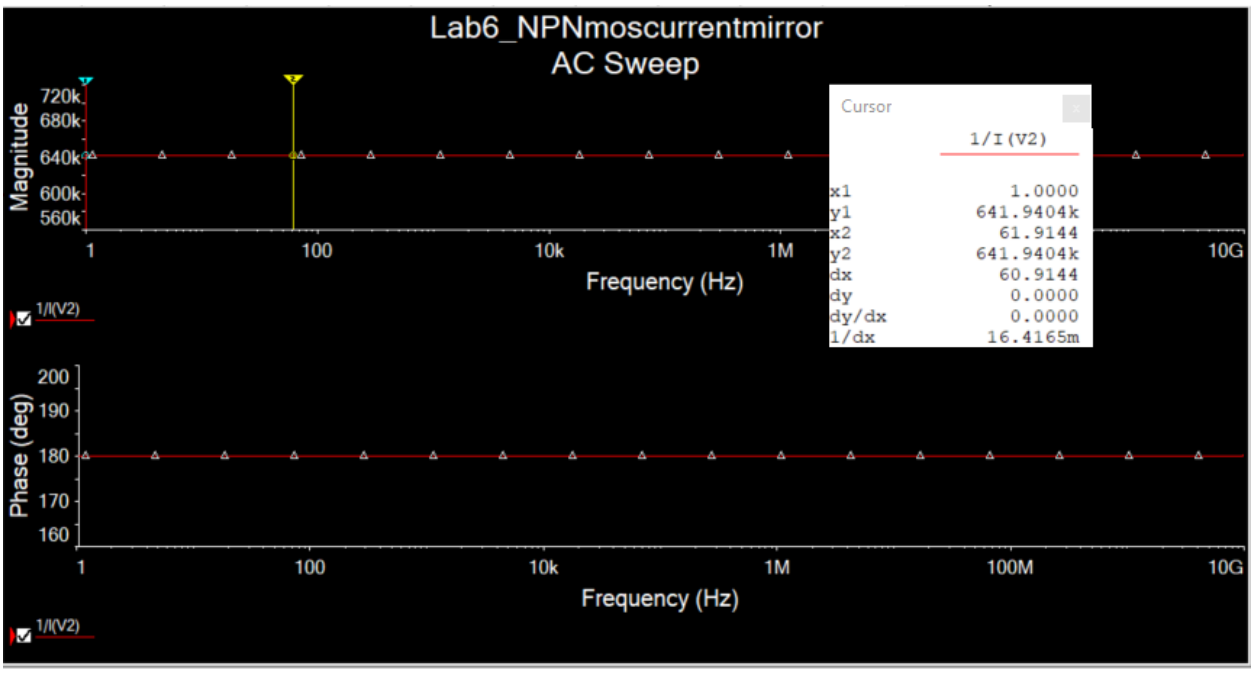
Circuit:


V1
5V
Rc1
31.9kΩ
Vo
M1
L=10u
W=170u
M2
L=10u
W=170u

DcSweep:

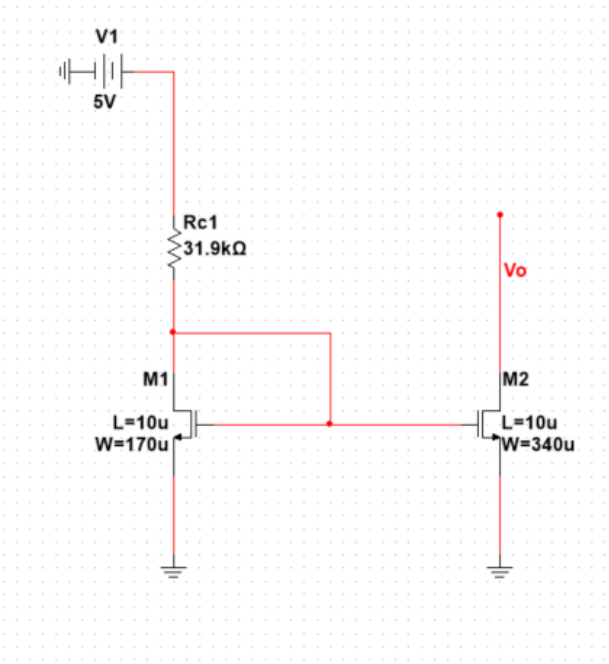

Lab6_NPNmoscurrentmirror
DC Transfer Characteristic
5n
0n
-5n
-10n
-15n
-20n
-25n
Voltage (V)
0
1
2
3
4
5
vv1 Voltage (V)
V(vo)
Cursor
V(vo)
x1 0.0000
y1 -23.2972n
x2 100.1001m
y2 -1.7001e-15
dx 100.1001m
dy 23.2971n
dy/dx 232.7385n
1/dx 9.9900

Ro:

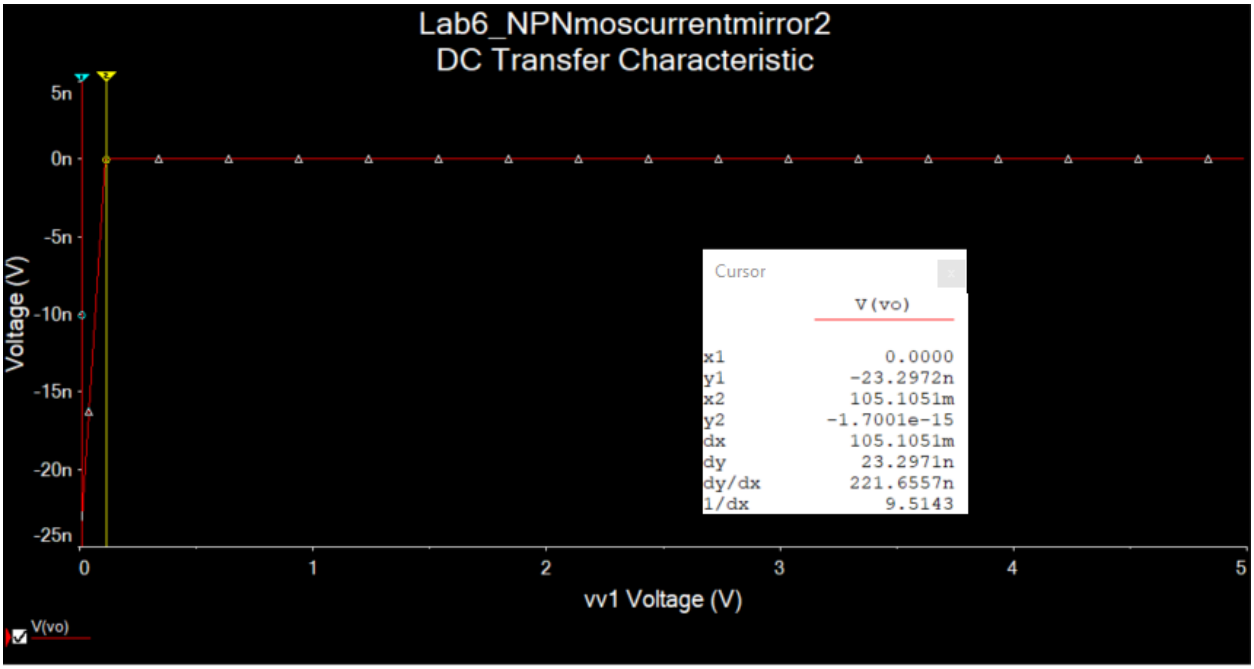


NPN MOS Simple Current Mirror:

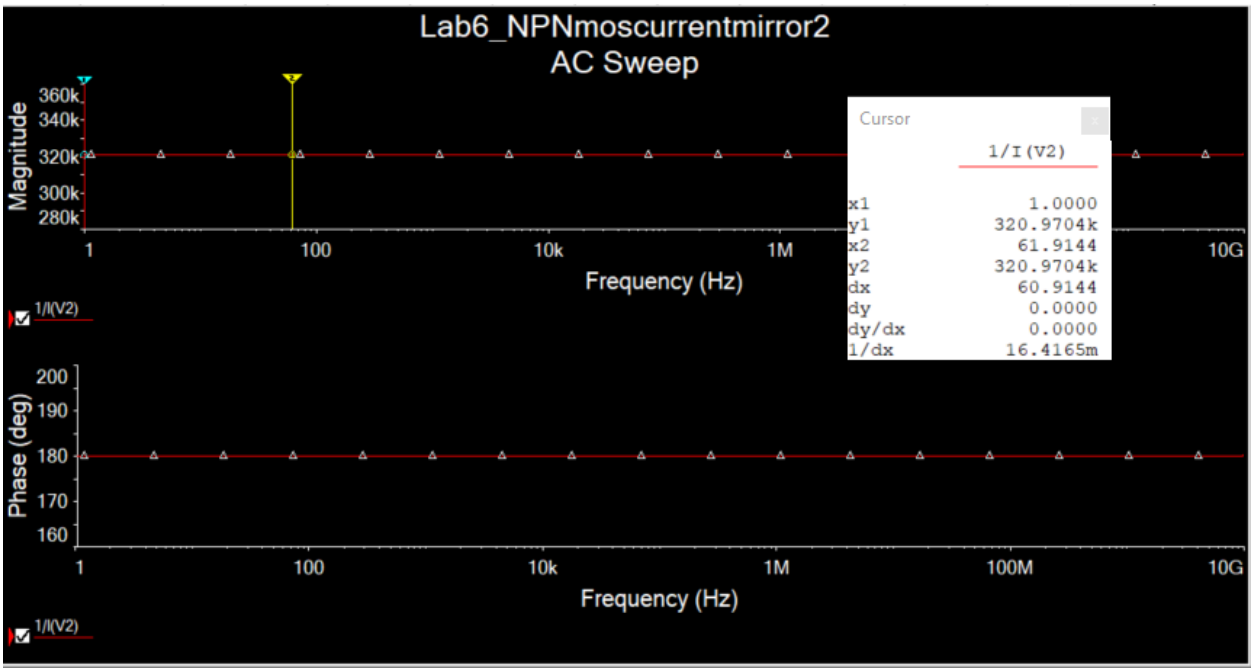
Circuit:



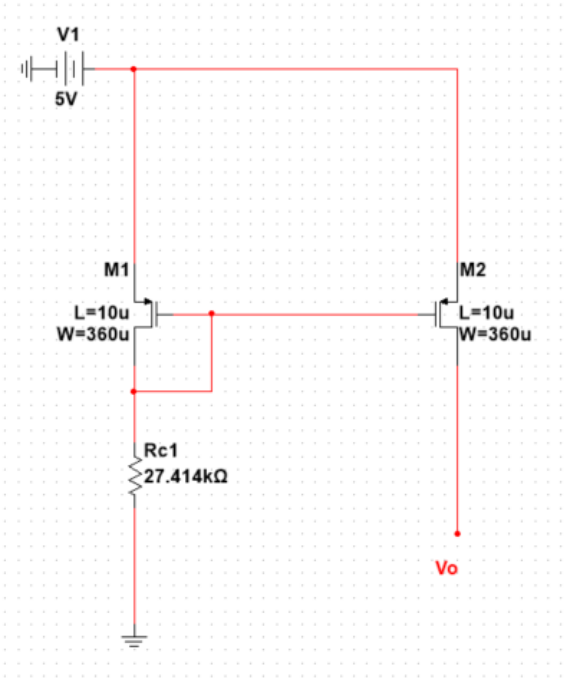
DcSweep:



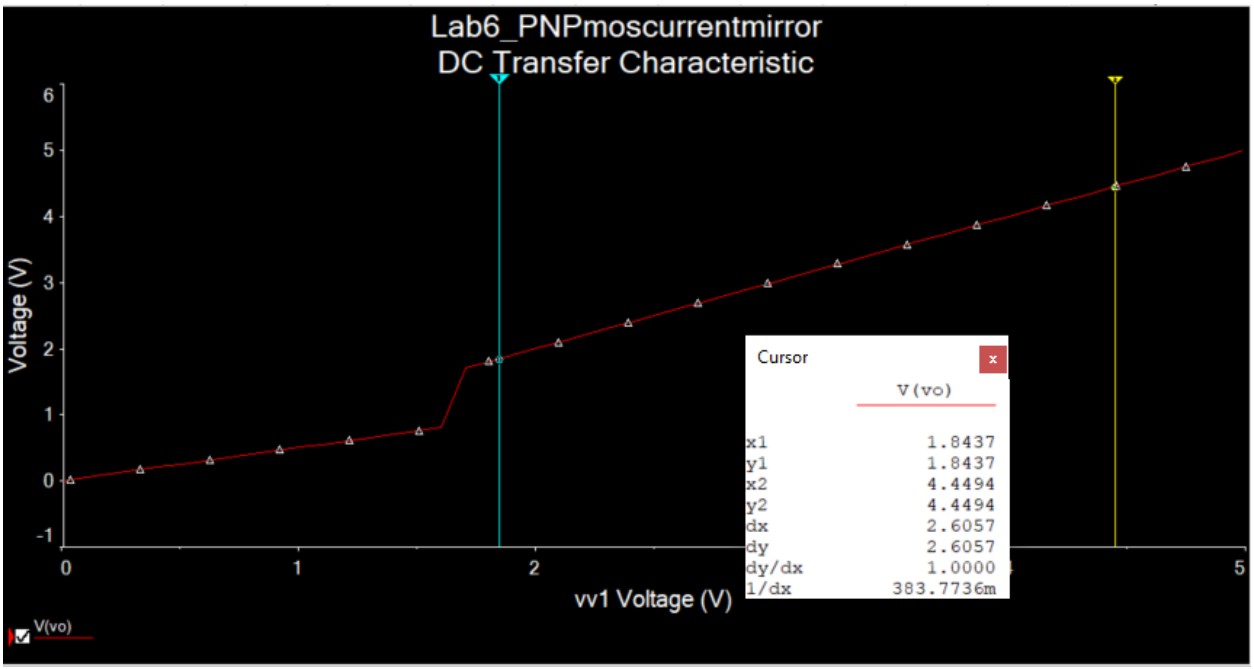
Ro:



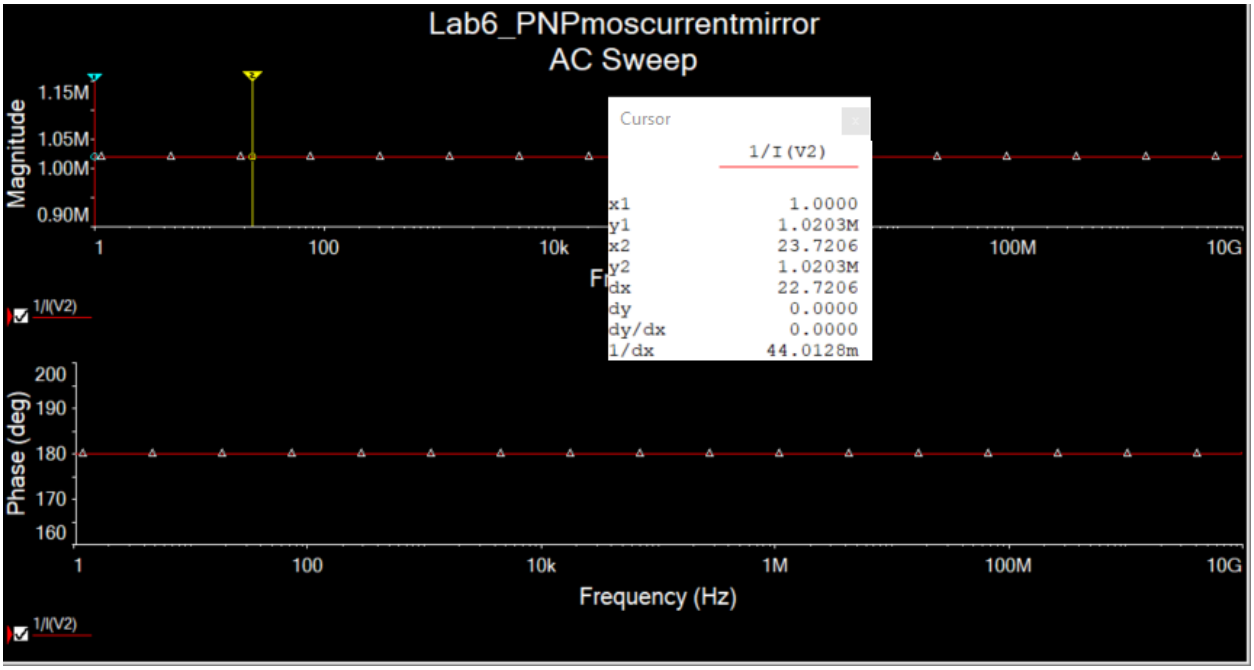
PNP MOS Current Mirror:


V1
5V
M1
L=10u
W=360u
M2
L=10u
W=360u
Rc1
27.414kΩ
Vo

DcSweep:

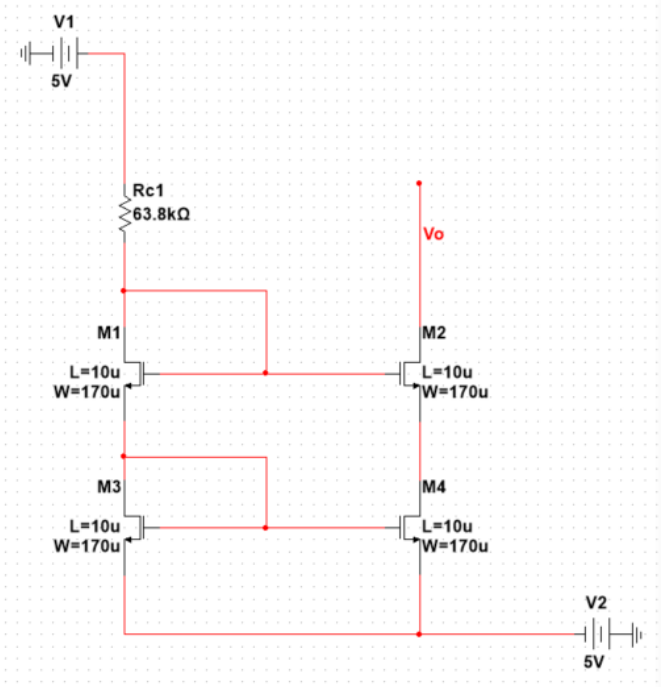

Lab6_PNPmoscurrentmirror
DC Transfer Characteristic
Voltage (V)
vv1 Voltage (V)
V(vo)
Cursor
V(vo)
x1 1.8437
y1 1.8437
x2 4.4494
y2 4.4494
dx 2.6057
dy 2.6057
dy/dx 1.0000
1/dx 383.7736m

Ro:

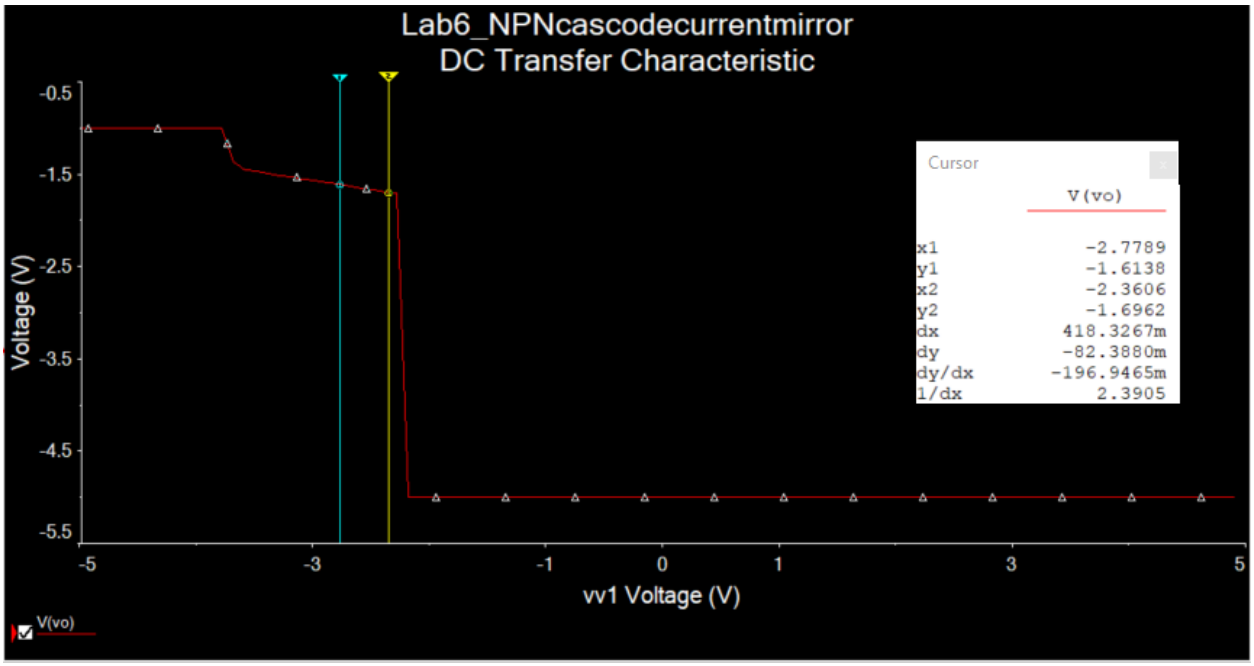


NMOS Cascode Current Mirror

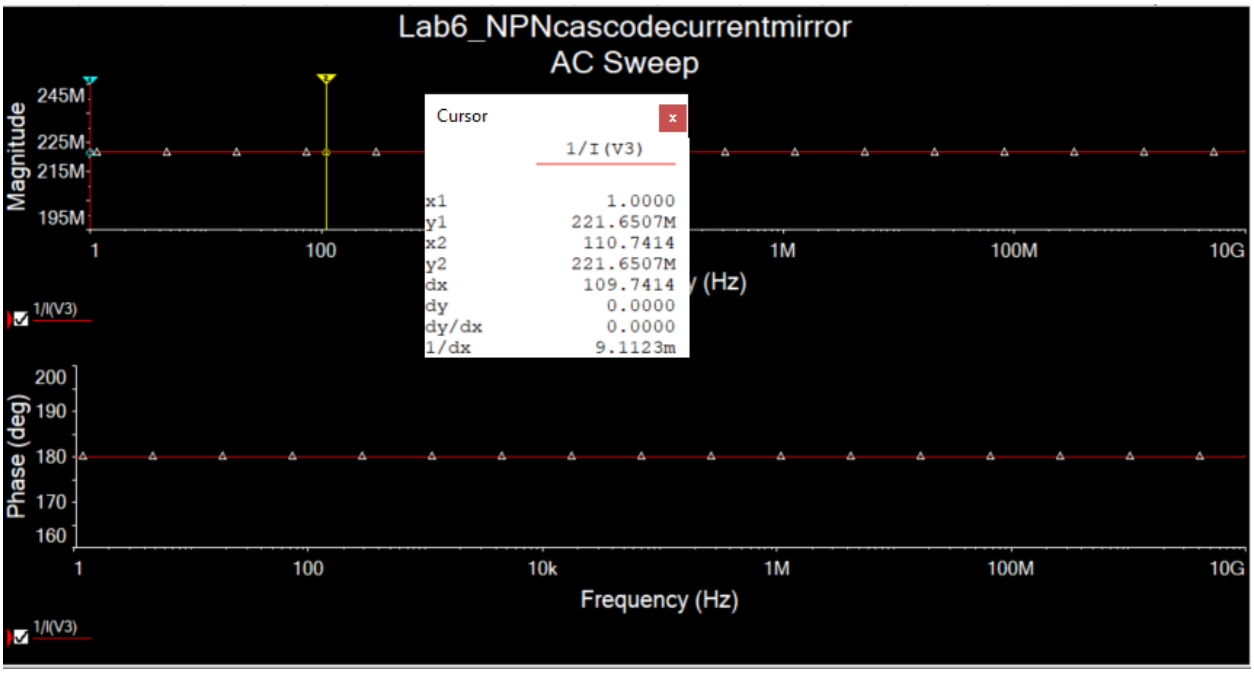
Circuit:



DcSweep:



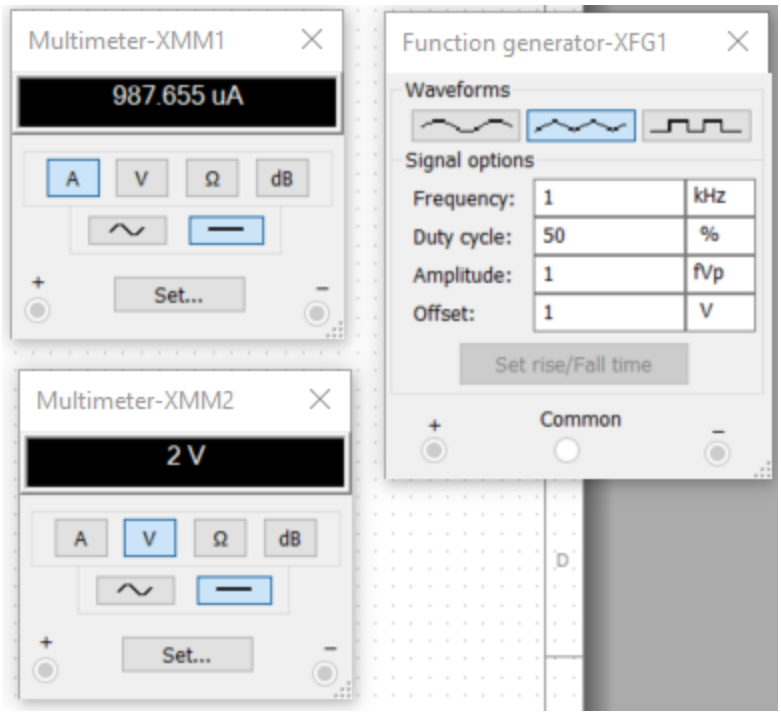
Ro:



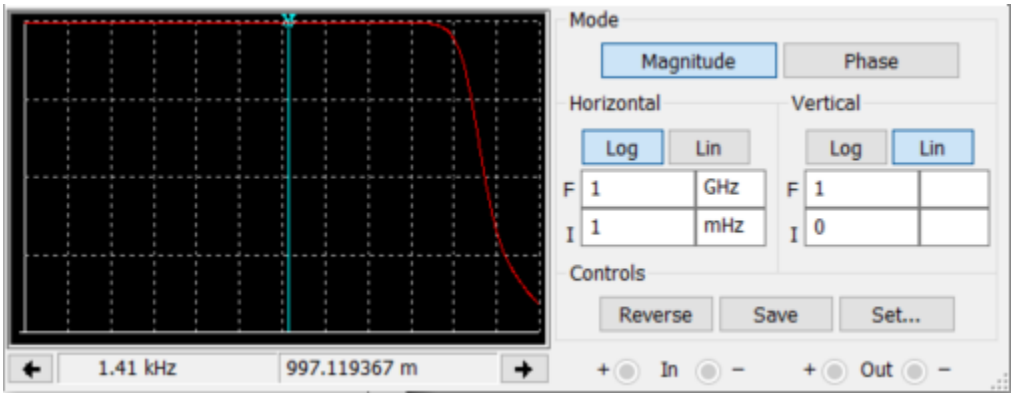
Measurements:

NPN Simple Current Mirror:

Io:

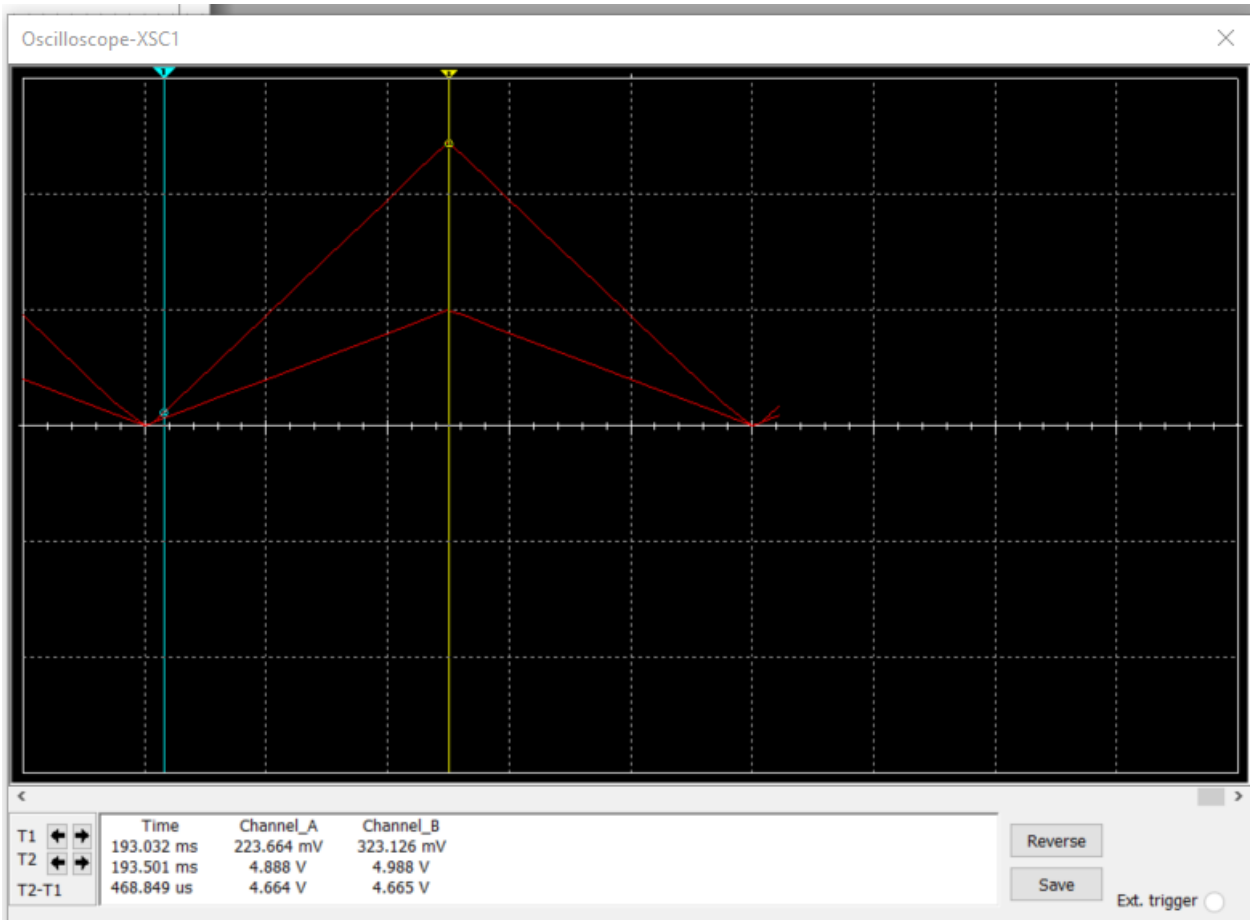


Ro:



== 332.3kohm

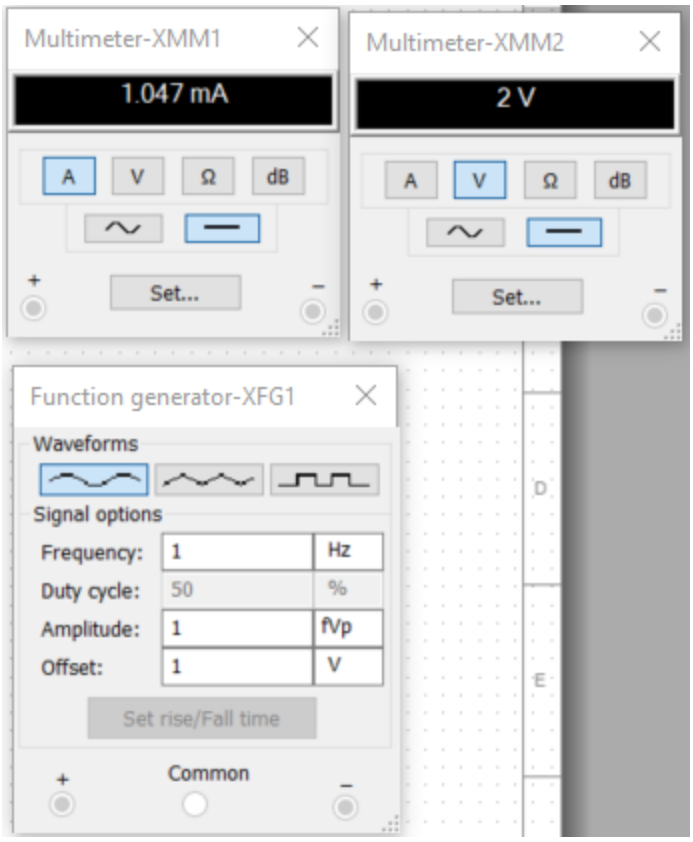
Operation Range



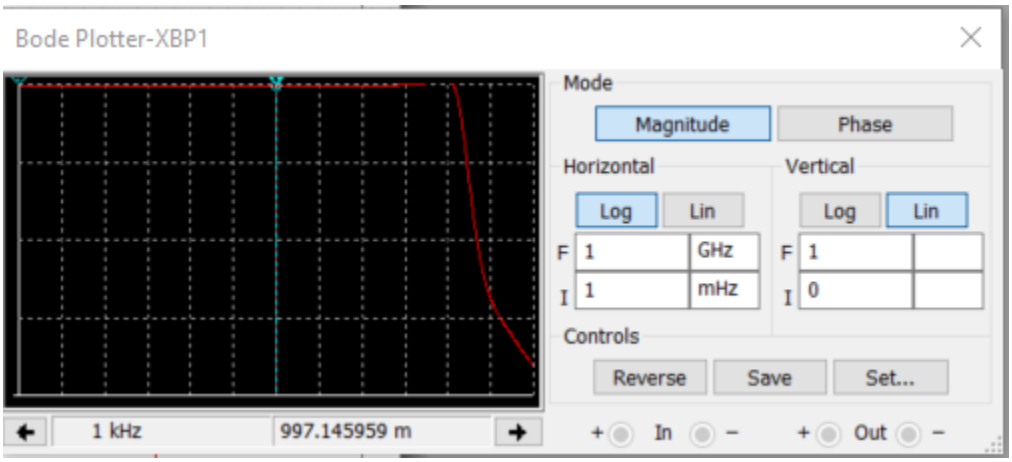
0.323v – 5v

NPN Beta helper single stage

Iout:

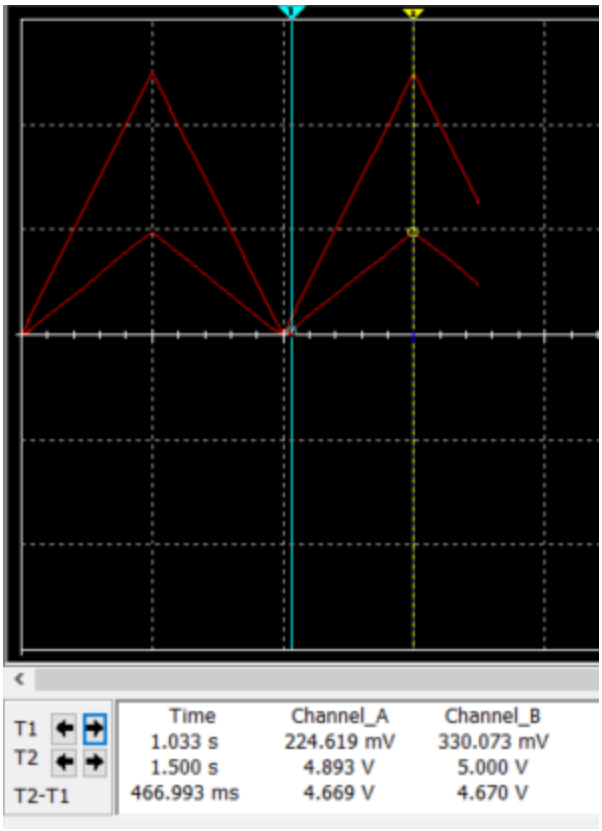


Ro:



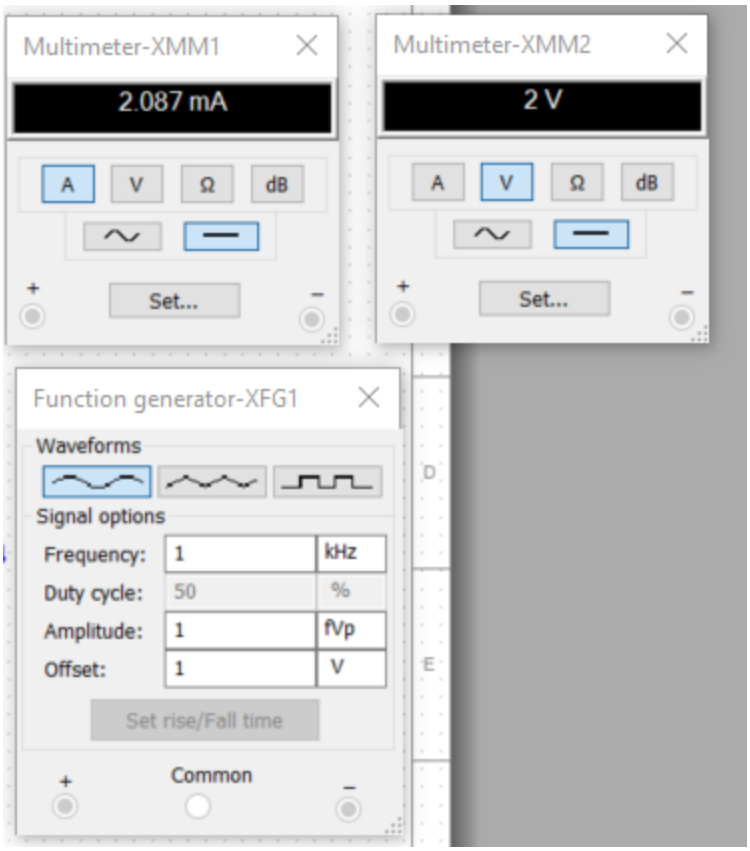
== 332.3kohm

Operation Range:

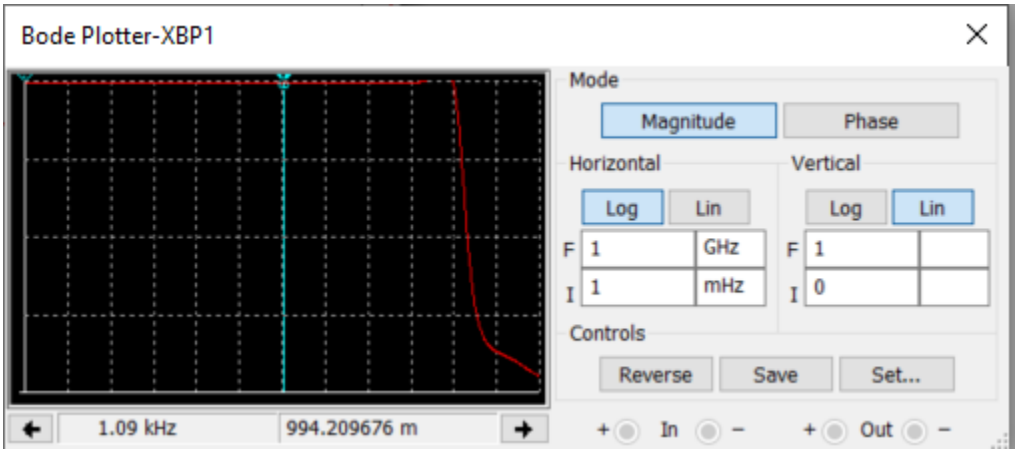


0.330v – 5v

NPN Beta Helper three stage
Iout:

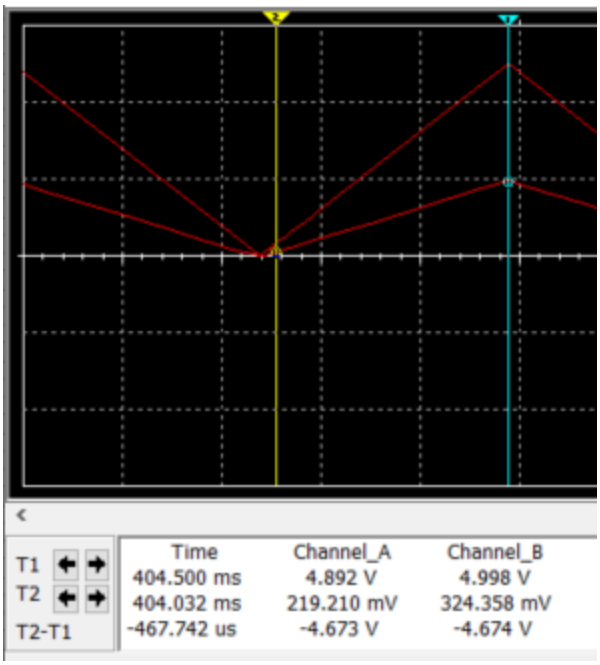


Rout:



==165.66kohm

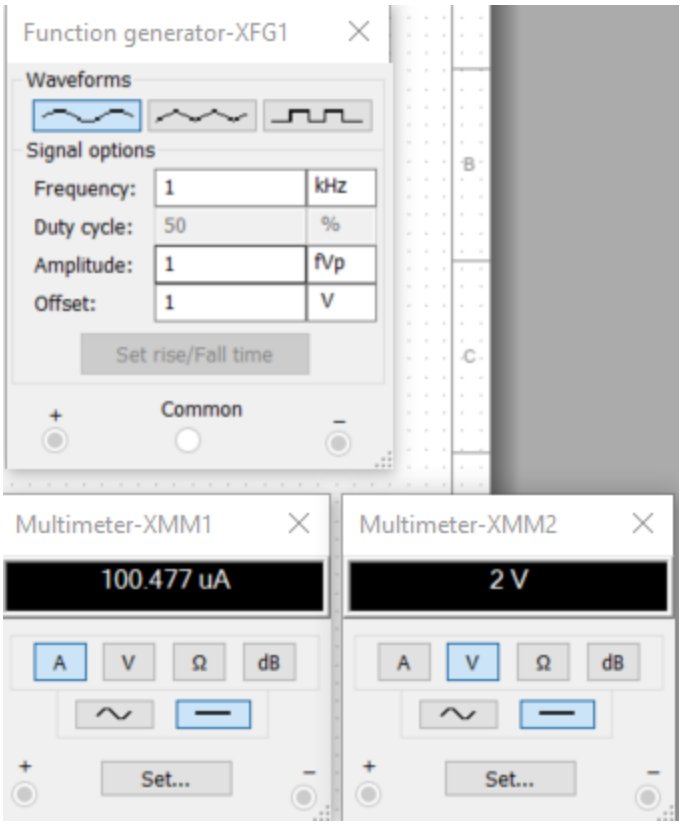
Operation Range



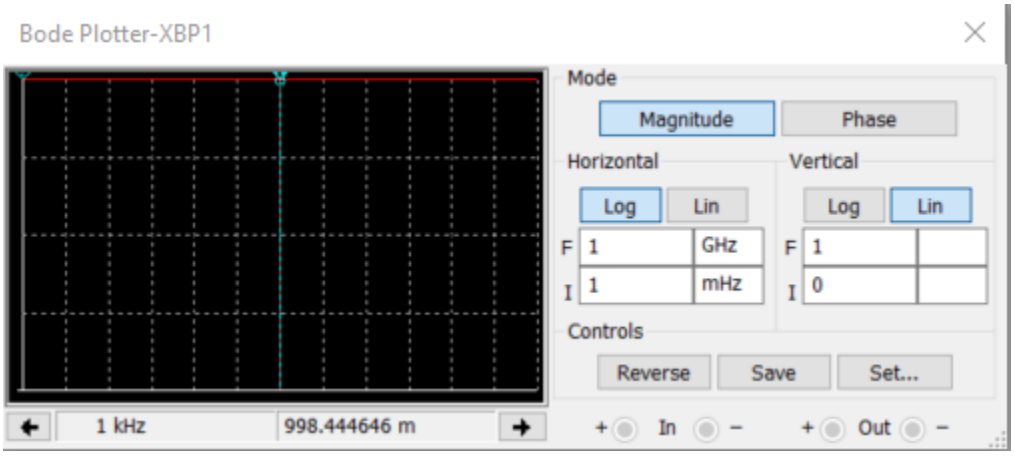
0.324v – 5v

NPN MOS Simple Current Mirror

Iout:

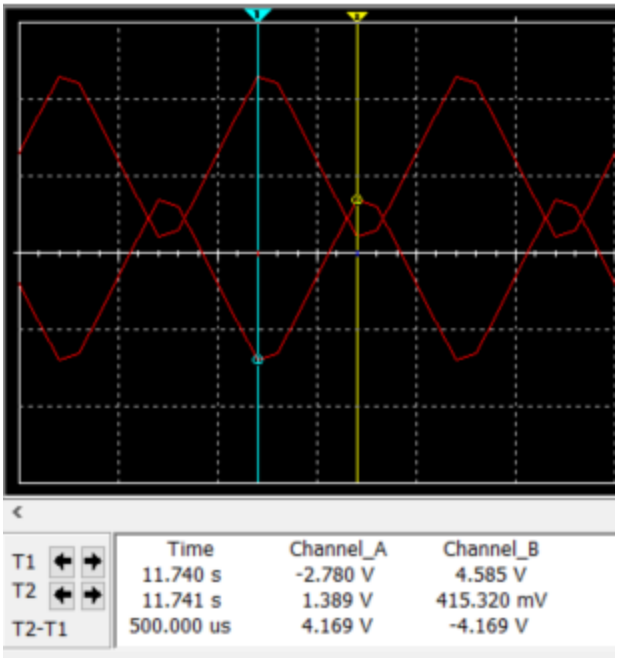


Rout:



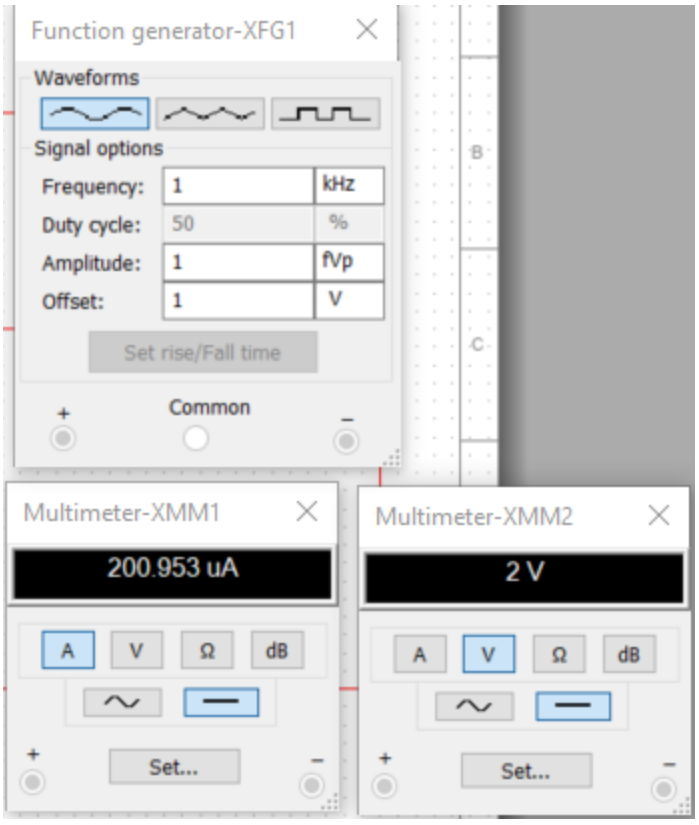
==641.67kohm

Operation Region:

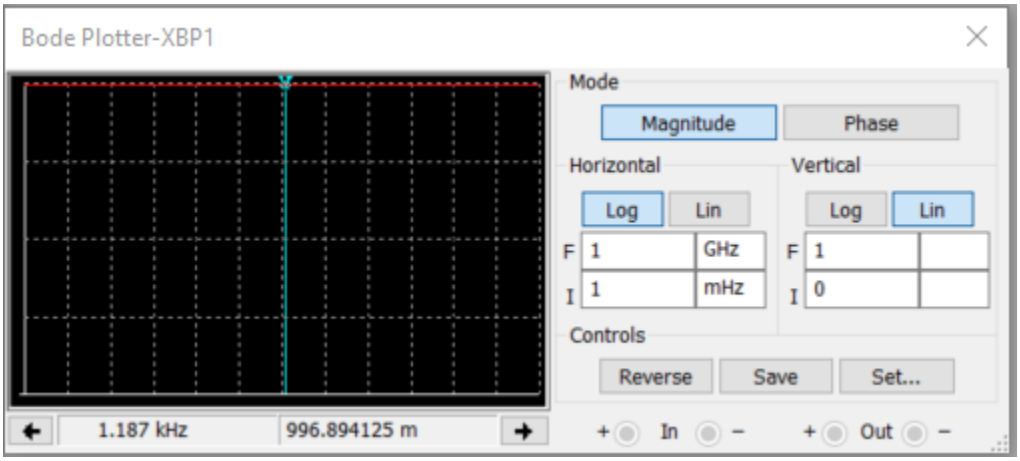


NMOS Simple Current Mirror w/ varying sized MOSFETs

Iout:

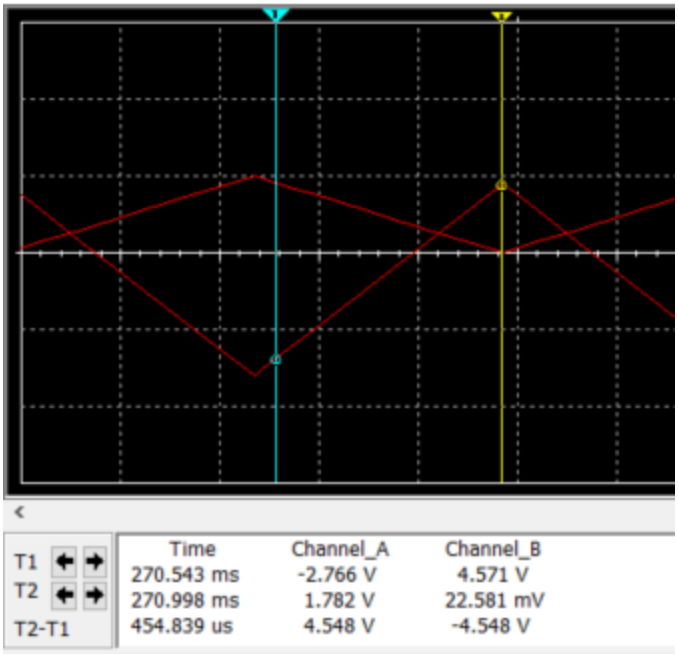


Rout:



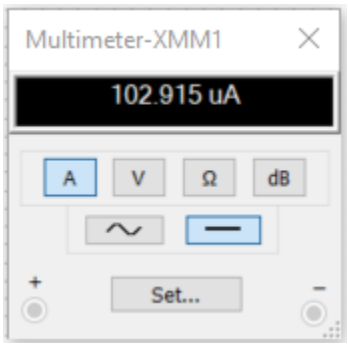
==320.97kohm

Operation Region:

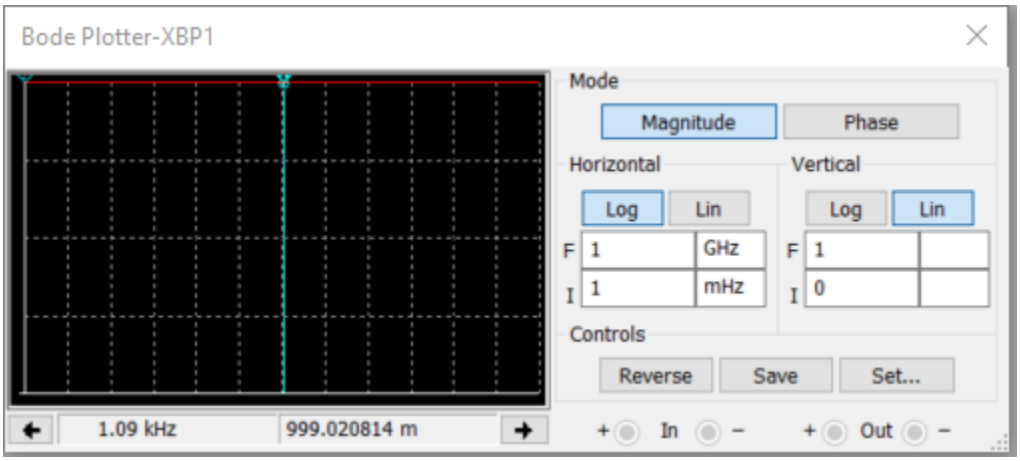


PMOS Simple Current Mirror

Iout:

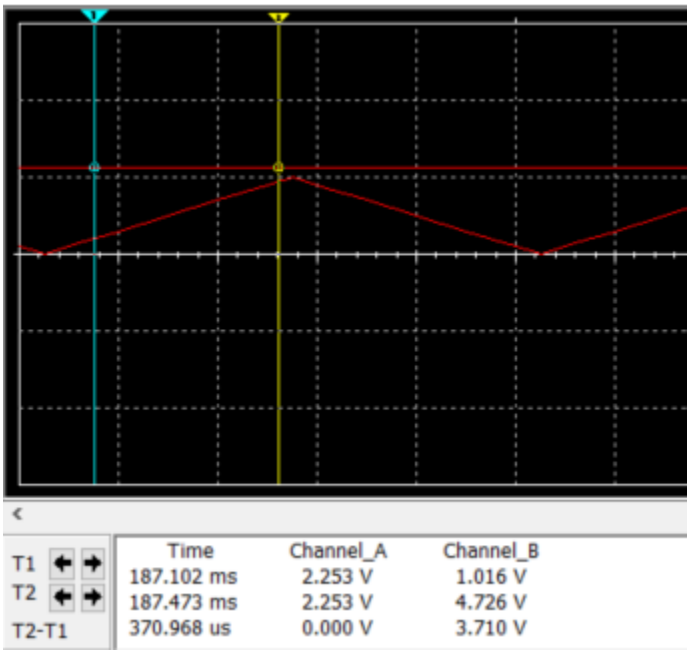


Rout:



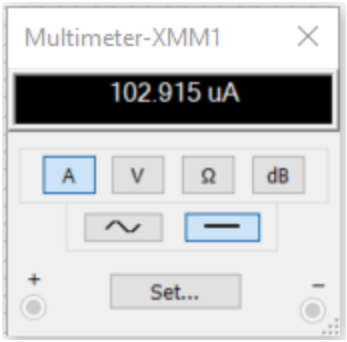
== 1.02Mohm

Operation Region:

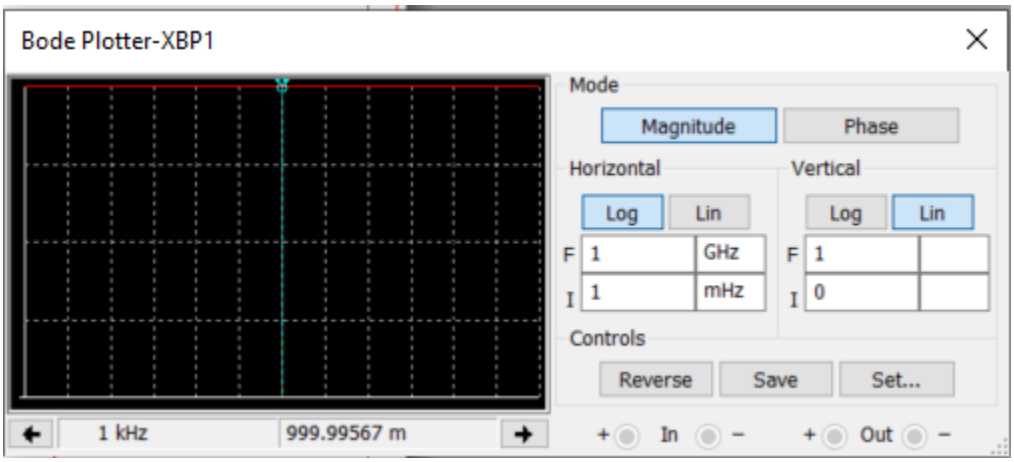


NMOS Cascode Current Mirror

Iout:

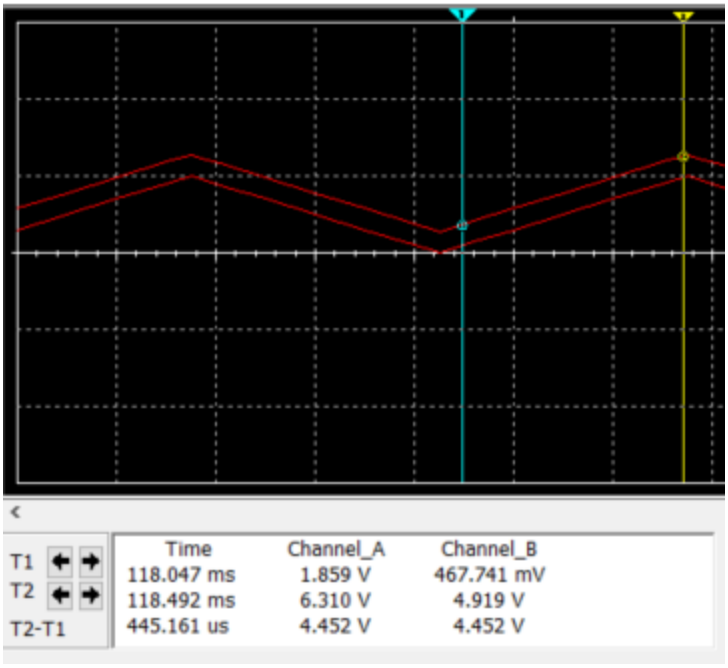


Rout:



== 230Mohm

Active Region:



Results

NPN Current Mirror

	Calculated	Simulated	Measured
Io	1mA	9.8mA	0.987mA
Ro	357.24kΩ	345kΩ	337kΩ
Active Region	0.3-5	-	0.323-4.988

NPN Beta Helper

	Calculated	Simulated	Measured
Io	1mA	19.87mA	1.047mA
Ro	361.944kΩ	345kΩ	332kΩ
Active Region	0.3-5	-	0.33-5

NPN Beta Helper with second cascade stage

	Calculated	Simulated	Measured
Io	2mA	19.24mA	2.087mA
Ro	181.602kΩ	171kΩ	165.66kΩ
Active Region	0.3-5	-	0.324-4.988

NMOS Simple Current Mirror

	Calculated	Simulated	Measured
Io	100uA	0.2uA	100.477uA
Ro	625kΩ	641kΩ	641kΩ
Active Region	1.4<1.809<5	-	1.4<1.908<4.998

NMOS Simple Current Mirror Differing Sizes

	Calculated	Simulated	Measured
Io	200uA	0.221uA	200.953uA
Ro	312.5kΩ	320kΩ	320.97kΩ
Active Region	1.4<1.809<5	-	1.4<2.015<4.98

PMOS Simple Current Mirror

	Calculated	Simulated	Measured
Io	100uA	0.2uA	102.3uA
Ro	1MΩ	1.02MΩ	1.02MΩ
Active Region	1.65<2.258<4.39	-	1.65<2.456<4.39

NMOS Cascode Current Mirror

	Calculated	Simulated	Measured
Io	100uA	802uA	102uA
Ro	1.9GΩ	221MΩ	230MΩ
Active Region	1.4<1.809<2.5	-	1.406<1.8756<2.489

Some differences in my simulation data comes from my failure to correctly measure the output current on the MOSFET designs. This is most likely a user error as the measured values is all correctly corresponding to the values calculated. Another source of change was from the last cascode mirror and the output resistances. The measured value was simple massive and while the simulated and measured value are large, not the same magnitude as the calculated value. This leads me to believe that the Multisim simulation is unable to register a value that large and caps out where my values are.