Example Problem Set 4

1. $$IM_3 = \frac{1}{16}\left(\frac{\hat{V}_i}{V_T}\right)^2 \frac{1}{\left(1+\frac{1}{2}\frac{I_{EE}R_E}{V_T}\right)^3}$$

$$\therefore \quad \frac{1}{100} = \frac{1}{16}\left(\frac{\hat{V}_i}{V_T}\right)^2 \frac{1}{\left(1+\frac{1}{2}\ \frac{100}{26}\right)^3}$$

$$\therefore \quad \hat{V}_i = 52mV$$

2. Without FB

$$i_0 = a_1 v_i + a_2 v_i^2 \qquad V_{GS} = 1.74V$$

$$a_1 = g_m = k'\frac{W}{L}(V_{GS} - V_t) = 564\mu A/V$$

$$a_2 = \frac{k'}{2}\frac{W}{L} = 300\mu A/V^2$$

with FB

$$i_0 = b_1 v_i + b_2 v_i^2 + b_3 v_i^3$$

$$b_1 = \frac{a_1}{1+a_1 f} = \frac{g_m}{1+g_m R} = \frac{564\mu A/V}{1.564} \qquad f = 1K\Omega$$

$$= 361\mu A/V$$

$$b_2 = \frac{a_2}{(1+a_1 f)^3} = \frac{300}{1.564^3}\mu A/V^2 = 78.4\mu A/V^2$$

$$b_3 = \frac{-2a_2^2 f}{(1+a_1 f)^5} = 19\mu A/V^3$$

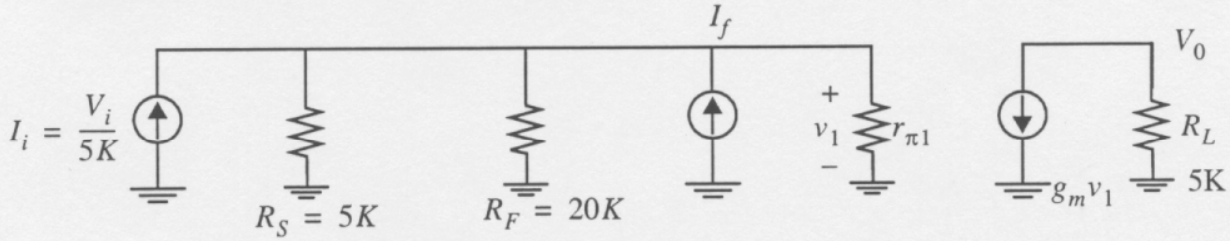
$$IM_2 = \frac{b_2}{b_1}\hat{S}_1 = \frac{78.4}{361}\times 0.3 = 6.5\%$$

$$IM_3 = \frac{3}{4}\frac{b_3}{b_1}\hat{S}_1^2$$

$$= \frac{3}{4}\frac{19}{361}0.3^2 = 0.36\,\%$$

3. Shunt-shunt FB.

(a) assume Q_2 loading on V_0 is negligible.



$$\text{bias } I_{C1} \cong \frac{V_{CC} - 2V_{BE}}{5K} = \frac{5 - 1.6}{5K} = 0.68mA$$

$$r_{\pi 1} = \frac{\beta}{g_{m1}} = 100\frac{26}{0.68} = 3.8K$$

$$g_{m1} = \frac{0.68}{26}$$

Forward gain with FB disabled

$$a = \frac{v_0}{I_i} = [R_S \| R_F \| r_{\pi 1}]g_{m1}R_L$$

$$= 2.55\times10^5\,\Omega$$

$$f = \frac{I_f}{V_0} = \frac{1}{20K} \quad \left(\text{actually } f = \frac{1}{20K + \frac{1}{g_{m2}}}\right)$$

$\therefore$ loop gain = a f = 12.8

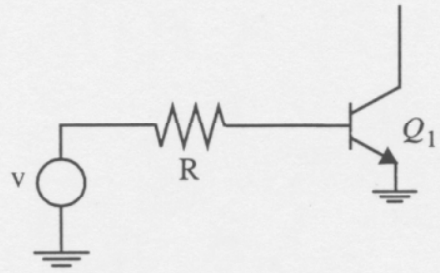
Forward gain with FB

$$\frac{V_0}{I_i} = \frac{a}{1 + af} = \frac{2.55\times10^5}{13.8} = 18.5\times10^4$$

$$\frac{V_0}{V_i} = \frac{18.5\times10^4}{5K} = 3.7$$

(b) Forward path distortion with FB disabled

<u>ac</u>



$$R = R_S \| R_F = 4K, R_E = \frac{4000}{\beta_0} = 40\Omega \text{ EQUIVALENT}$$

$$HD_2 = \frac{1}{4}\frac{\hat{i}_c}{I_A}\frac{1}{1+g_m R_E}$$

$$O-P \;\; \hat{v}_0 = 0.5V \rightarrow \hat{i}_0 = 0.1mA$$

$$I_A = 0.68mA$$

$$\therefore \; HD_2 = \frac{1}{4}\;\frac{0.1}{0.68}\;\frac{1}{1+\frac{0.68}{26}40} = 1.8\,\%$$

Now consider the overall FB connected, for the same output signal

$$HD_2 = \frac{1.8\%}{1+af} = \frac{1.8\%}{13.8} = 0.13\%$$

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* homework 3, problem 2
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vdd    vdd 0 5
m1     vdd vin vout 0 nmos w=10u l=1u
rs     vout 0 1k

vgg    bias 0 2
vi     vin bias 0 sin (0 300m 1e6)

.model nmos nmos kp=60u vt=0.8

.option post=2 nomod
.op
.tran .005u 10u
.four 1e6 v(vout)
.end

**********************************************************************
* Output file
**********************************************************************

***** operating point status is all       simulation time is     0.

+0:bias     =    2.0000  0:vdd     =   5.0000  0:vin     =   2.0000
+0:vout     = 236.7124m

**** mosfets

element  0:m1
model    0:nmos
 id        236.7124u
 ibs        -2.3671f
 ibd       -50.0000f
 vgs         1.7633
 vds         4.7633
 vbs      -236.7124m
 vth       875.0075m
 vdsat     888.2801m
 beta      600.0000u
 gam eff   527.6252m
 gm        532.9680u
 gds         0.
 gmb       155.5982u
 cdtot     2.193e-17
 cgtot       2.3412f
 cstot       2.3021f
 cbtot     1.718e-17
 cgs         2.3021f
 cgd       2.193e-17

******
fourier components of transient response v(vout)
dc component =    2.397D-01
harmonic    frequency   fourier    normalized  phase      normalized
   no         (hz)      component  component   (deg)      phase (deg)

    1       1.0000x   94.1871m     1.0000    930.6385u    0.
    2       2.0000x    2.9279m    31.0859m   -90.0017    -90.0017
    3       3.0000x   99.4871u     1.0563m  -135.5861m  -136.5167m
    4       4.0000x    5.2102u    55.3174u    89.5201     89.5192
    5       5.0000x  627.4467n     6.6617u   -19.7795    -19.7804
    6       6.0000x  [illegible]  [illegible]  62.7716    -62.7745
    7       7.0000x  350.7638n     3.7241u  -147.8364   -147.8373
    8       8.0000x  304.3689n     3.2315u   -73.5713    -73.5723
    9       9.0000x  410.1653n     4.3548u   -24.3269    -24.3278

total harmonic distortion =     3.1104   percent
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$IM_2 = 2HD_2 = 6.2\%$

$IM_3 = 3HD_3 = .3\%$

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******
* homework 3, problem 3
******

vcc     vcc 0 5
ibias   3 0 0.5m

rl      vcc vout 5k
rf      2 3 20k

q1      vout 2 0 npn
q2      vcc vout 3 npn

c1      1 2 1u
rs      vin 1 5k

vi      vin 0 sin(0 135m 1e6)

.model npn npn bf=100 is=1e-16

.option post=2 nomod
.op
.tran  .01u 10u
.four  1e6 v(vout)
.end

**********************************************************************
* Output file
**********************************************************************

***** operating point status is all       simulation time is     0.

+0:1        =   0.       0:2        = 758.6199m 0:3        = 891.8880m
+0:vcc      =   5.0000   0:vin      =   0.      0:vout     =   1.6432

**** bipolar junction transistors

element  0:q1        0:q2
model    0:npn       0:npn
 ib         6.6634u     5.0165u
 ic       666.3408u   501.6469u
 vbe      758.6199m   751.3258m
 vce        1.6432      4.1081
 vbc     -884.5940m    -3.3568
 vs        -1.6432     -5.0000
 power      1.1000m     2.0646m
 betad    100.0000    100.0000
 gm        25.9359m    19.5255m
 rpi        1.8557k     5.1215k
 rx         0.          0.
 ro       8.845e+15   3.356e+16
 cpi        0.          0.
 cmu        0.          0.
 cbx        0.          0.
 ccs        0.          0.
 betaac   100.0000    100.0000
 ft       4.127e+12   3.107e+12

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fourier components of transient response v(vout)
dc component =   1.643D+00
harmonic   frequency   fourier    normalized  phase      normalized
   no        (hz)     component  component   (deg)      phase (deg)
   1        1.0000x  497.5426m    1.0000   -179.9990     0.
   2        2.0000x  687.0600u    1.3809m    86.3626   266.3616
   3        3.0000x   42.5149u   85.4498u   171.6260   351.6250
   4        4.0000x    4.7511u    9.5492u    84.2851   264.2841
   5        5.0000x    7.7368u   15.5501u   134.0702   314.0692
   6        6.0000x    6.1530u   12.3669u   122.9118   302.9108
   7        7.0000x    6.8560u   13.7797u   140.3529   320.3519
   8        8.0000x    6.1364u   12.3334u   140.6452   320.6442
   9        9.0000x    6.2454u   12.5526u   151.2732   331.2722

total harmonic distortion =    138.3904m  percent
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$HD_2 = .13\%$