Stage 1 Design

$\boxed{I_{B1} = 6\mu A}$

Setting $I_{B1} \cong 6\mu A$ $\boxed{I_{C1}, I_{E1} \cong 960\mu A}$ $\boxed{\beta = 160}$

$I_C = I_E = \beta I_B = (160)(6\mu A) = 960\mu A$

Resistances

Approximate: $\beta R_E \geq 10 R_2$ → Choosing R_E to be 680

$\boxed{R_2 \leq 10.88 k\Omega}$ → $\boxed{\text{Selecting } R_2 = 10\ k\Omega}$

$\boxed{R_E = 680}$ → If $R_2 = 10k$, $R_E \geq 625$

R_C:

$V_C = V_{CC} - I_C(R_C + R_E)$

$4.5V = 9V - (960\mu A)(R_C + 680) \rightarrow \left(\frac{4.5}{960\mu A}\right) - 680 = R_C$

$\boxed{R_C = 4007.5}$

→ 4.7k or $\boxed{3.3k}$

R_1: $V_B = V_{CC}\left(\frac{R_2}{R_1 + R_2}\right)$

→ $I_E = \frac{V_E}{R_E}$

→ $V_E = (960\mu A)(680) = \boxed{652.8 mV}$

$V_B = V_E + 0.7$

$\boxed{V_B = 1.35 V}$

$1.35V = 9V\left(\frac{10.88k}{10.88k + R_1}\right)$

→ $\boxed{R_1 = 61653.3\ \Omega \rightarrow 47k \text{ or } 68k}$

	SIMULATED	
R_1	47k	$I_{B(DC)} = 8.63\mu A$ X Increase R_1 / Decrease R_2
* R_2	10k	$V_{B(DC)} = 1.51 V$
R_C	3.3k	$I_{C(DC)} = 1.22 mA$
R_E	680	$V_{C(DC)} = 4.96 V$ X → increase R_C / Decrease R_E (≥ 625)

→ 68k

controlling @ 10k

→ ~~4.7k~~ 6.8k

~~$R_E = 625$~~

✓ Simulated

$R_1 = 68K$	$I_{B(DC)} = 5.08\mu A$
$R_2 = 10K$	$V_{B(DC)} = 1.11$ ✓
$R_C = 6.8K$	$I_{C(DC)} = 665\mu A$
$R_E = 680$	$V_{C(DC)} = 4.48V$

Stage 1 DC parameters

$R_1 = 68k\Omega$	$R_2 = 10k\Omega$	$R_C = 6.8k\Omega$	$R_E = 680\Omega$

Approximate test, $\boxed{\beta = 160}$

$\beta(R_E) \geq 10R_2$ ✓

$(160)(680\Omega) \geq 10(10k) \rightarrow 108k \geq 100k$

$V_B = 9V\left(\frac{10k}{68k+10k}\right) \cong \boxed{1.15V_B}$

$V_E = V_B - V_{BE} = 1.15V - 0.7V = \boxed{450mV = V_E}$

$I_E = V_E/R_E = \frac{450mV}{680\Omega} = \boxed{661.76\mu A\ I_E}$

$I_E \cong I_C, \boxed{I_C \cong 661.76\mu A}$

$V_C = V_{CC} - I_C(R_C + R_E)$

$= 9V - 661.76\mu A(6.8k + 680)$

$\boxed{V_C \cong 4.05V}$

$I_B = \frac{I_C}{\beta} = \frac{661.76\mu A}{160}$

$\boxed{I_B = 4.14\mu A}$

No LOAD

SIMULATED DC PARAMETERS

Calculated	Simulated Q1	Simulated Q2
$V_{B_1} = 1.15V$	$V_{B_1} = 1.11V$	V_{B2} 1.11V
$V_{C_1} = 4.05V$	$V_{C_1} = 4.48V$ ✓	V_{C2} 4.48V ✓
$V_{E_1} = 450mV$	$V_{E_1} = 456mV$	V_{E2} 456mV
$I_{B_1} = 4.14\mu A$	$I_{B_1} = 5.08\mu A$ ✓	I_{B2} 5.08μA ✓
$I_{C_1} = 661\mu A$	$I_{C_1} = 665\mu A$	I_{C2} 665μA
$I_{E_1} = 661\mu A$	$I_{E_1} = 670\mu A$	I_{E2} 670μA

$A_{V,NL} = \frac{R_C}{-R_E} = -\frac{6.8k}{680} \cong \boxed{A_{V,NL} \cong -10}$ ← $\boxed{A_{V0,1}}$ →

Simulated: $\frac{V_o}{V_i} = \frac{110.019mV}{-11.764mV} = \boxed{-9.35 V/V}$

Stage 2 DC Parameters

→ Copied Stage 1 for Stage 2

→ All Design requirements verified to be within spec using Multisim for Q1 & Q2

$\boxed{A_{V0,2} = \frac{-6.8k}{680} = \boxed{-10 V/V}}$

$\boxed{\text{Sim: } -9.31 V/V}$

Gain (2-stage)

Stage 1

$$R_{in} = R_1 \| R_2 \| \beta(r_e + R_E) \rightarrow r_e = \frac{26mV}{661 \mu A} = 39.33\,\Omega$$

$$= 68k \| 10k \| 160(39.33 + 680)$$

$$\boxed{R_{in,1} = 8.1k\Omega}$$

$$\boxed{R_{out} \cong R_C = 6.8k\Omega}$$

Stage 2

$$R_{in} = R_3 \| R_4 \| \beta(r_{e2} + R_{E2}) \rightarrow r_e = \frac{26mV}{2.04mA} = 12.75\,\Omega$$

$$= 68k \| 10k \| \beta(12.75 + 680)$$

$$\boxed{R_{in,2} = 7.18k\Omega}$$

$$A_{vo,1} = \frac{-R_C}{R_E} = -\frac{6.8k}{680} = \boxed{-10\,V/V}$$

$$\boxed{R_{out,2} = R_{C2} = 6.8k\Omega}$$

$$A_{v,1} = \frac{R_{C1} \| \overset{R_{in,2}}{R_L}}{-R_E} = -\frac{6.8k \| 7.18k\Omega}{680} = \boxed{-5.14\,V/V}$$

$$A_{vo,2} = \frac{-R_C}{R_E} = \boxed{-10\,V/V}$$

$$A_{vT,NL} = \overset{A_{v,1}}{(-5.14)}\overset{A_{vo,2}}{(-10)} = \boxed{51.4\,V/V}$$

$$A_{vT} = \left(\frac{R_L}{R_L + Z_o}\right) A_{vT,NL} = \left(\frac{100k}{100k + 6.8k}\right) 51.4 = \boxed{48.13\,V/V}$$

→ Too high: decrease R3 + decrease R4 to lower gain while maintaining $\beta R_{E2} \geq 10 R_4$

→ Through simulation, determined decrease by 2 standard Resistor values

→ $\boxed{R_3 = 33k}$ $\boxed{R_4 = 4.7k}$

Stage 2, adjusted

$R_{in} = 33k \| 4.7k \| (160 \cdot (12.75 + 680))$

$\boxed{R_{in} = 3.97\ k\Omega}$

$\boxed{R_{out} = 6.8\ k\Omega}$

Stage 1 (unchanged)

$\boxed{\begin{array}{c} R_{in} = 8.1\ k\Omega \\ R_{out} = 6.8\ k\Omega \end{array}}$

$A_{v,1} = \dfrac{-6.8k \| 3.97k}{680} = \boxed{-3.69\ V/V}$

$A_{vo,2} = \dfrac{-6.8k}{680} = \boxed{-10\ V/V}$

$A_{vT,NL} = (-3.69)(-10) = \boxed{36.9\ V/V}$

$A_{vT} = \left(\dfrac{100k}{100k+6.8k}\right) 36.9 = \boxed{34.55\ V/V}$ ✓

Measured: $\dfrac{V_o}{V_i} = \dfrac{715mV}{23.7mV} = \boxed{30.2\ V/V}$

Cutoff analysis

3x poles, formed by C_{c1}, C_{c2}, C_{c3}

$100\,Hz = \dfrac{1}{2\pi(R_{in,1})(C_1)} \rightarrow C_{c1} = \dfrac{1}{2\pi(100)(8.1k)} \cong \boxed{196\ nF}$ (C_{c1})
.196 μF

$100\,Hz = \dfrac{1}{2\pi \cdot (R_{c1})(C_{c2})} \rightarrow C_{c2} = \dfrac{1}{2\pi(100)(6.8k)} \cong \boxed{234\ nF}$ (C_{c2})
.234 μF

$100\,Hz = \dfrac{1}{2\pi(R_{c2})(C_{c3})} \rightarrow C_{c3} = \dfrac{1}{2\pi(100)(6.8k)} \cong \boxed{234\ nF}$ (C_{c3})
.234 μF

$\boxed{0.22\ \mu F \text{ standard}}$

$\rightarrow \dfrac{1}{2\pi(6.8k)(.22\mu F)} = \boxed{106.39\ Hz}$ ✓ $\boxed{\omega_{p3}}$

$\boxed{C_{c2}}$ Choosing $1\mu F \rightarrow \dfrac{1}{2\pi(6.8k)(1\mu F)} \cong \boxed{23\ Hz\ \omega_{p2}}$

$\boxed{f_L \cong 106\ Hz}$
→ using .22 μF standard cap

→ Choosing $1\mu F \rightarrow \dfrac{1}{2\pi(8.1k)(1\mu F)} \cong \boxed{20\ Hz\ \omega_{p1}}$