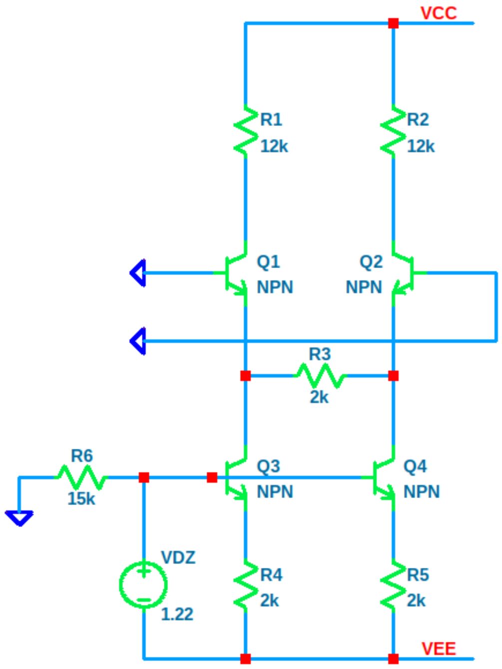

Figure 1 - differential amplifier

Design

The current mirrors realised with Q3 and Q4 transistors bias the differential amplifiers transistors T1 and T2 at:

$$-I_{C1,2}\cdot R_4 - V_{BE} + V_{DZ} = 0$$

$$I_{C1} = I_{C2} = \frac{(V_{DZ} - V_{BE})}{R_4} = \frac{(1.22 - 0.6)}{2e3} \approx 0.3\,mA$$

We can see that for a differential drive at the input, the applied voltages on the bases of T1 and T2 and found at their emitters are equal in magnitude but opposite in phase. We can consider that the potential at the median point of R3 resistor stays unchanged. So, the median point of R3 is a virtual common point, which drives to the drawing of the equivalent differential schematic of the amplifier illustrated in Figure 2:

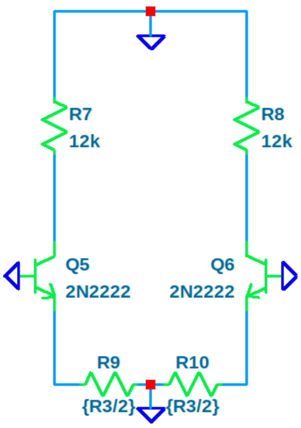

Figure 2

The differential gain is calculated using the half-circuit available for the differential amplifier, Figure 3:

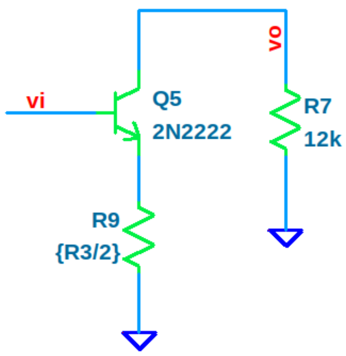

Figure 3

$$A_v = A_{dd} = V_{od}/V_{id} = -\beta R_l/[r_\pi + (\beta+1)\cdot R_3/2]$$

where $R_l = R_C \,||\, R_{01}$, R_{01} being the output resistance of the stage. R_{01} is enlarged as against to r_{01} because of the external emitter resistance.

$$R_{01} \approx r_{01}(1 + gm\cdot(R_3/2 + r_\pi))$$

Knowing that in the quiescent point I_{C1} ~ 0.3 mA we can find the equivalent transistor parameters:

$$gm = I_C/(kT/q) = 300\text{e-}6/26\text{e-}3 = 11.3\text{e-}3\ A/V$$

$$r_\pi = \beta/gm = 200/11.3\text{e-}3 = 17.7\,e3\,\Omega$$

$$r_{01} = r_0|_{at\,1\,mA}\ 1\,mA/0.3\,mA = 101\text{e}3\cdot(1/0.3) = 336\,e3\,\Omega$$

$$where\ r_0 = \frac{1}{(\eta\cdot gm)}$$

now we can get

$$R_{01}=336\text{e}3(1+11.3\text{e-}3(1\text{e}3+17.7\text{e}3))=71\,e\,6\,\Omega$$

$$R_l=R_{01}\|R_C\approx R_C=12\,k\,\Omega$$

which drives to

$$A_v=A_{dd}=V_{od}/V_{id}=-R_l/(R_3/2)=-12$$

For the common mode gain we start from the observation that having a common mode excitation, through R3 resistance in Figure 1, does not flow any current, so this resistance can be considered an open circuit. This observation permits to draw the half-circuit available for the common mode in Figure 4 in R_{03} is the resistance seen in the collector of T3. Solving for this resistance in the same way as for the R_{01} resistence we have:

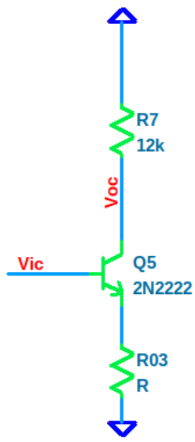

Figure 4

$$R_{03}\approx r_{03}(1+gm\cdot(R_4+r_\pi))=336\text{e}3(1+11.3\text{e-}3(2\text{e}3+17.7\text{e}3))=71\text{e}6\,\Omega$$

$$Acc=V_{oc}/V_{ic}=-R_C/R_{03}=571\text{e-}6$$

Simulation

Add (for a 1 mV differential signal):

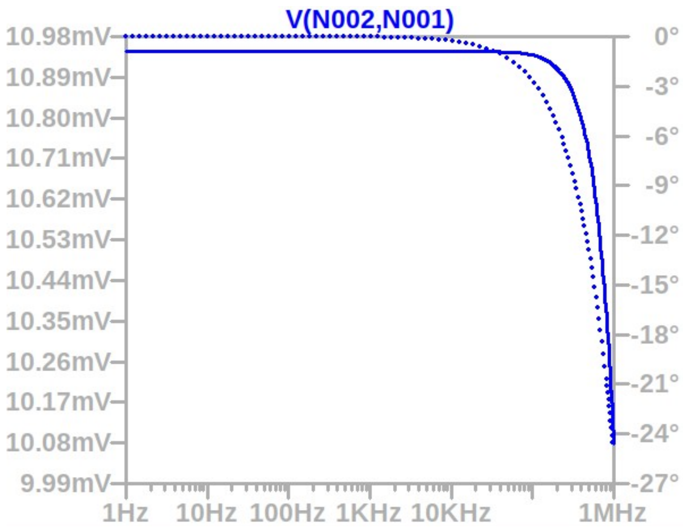

Figure 5

We can further enhance this differential amplifier to drive resistive loads as in Figure 6:

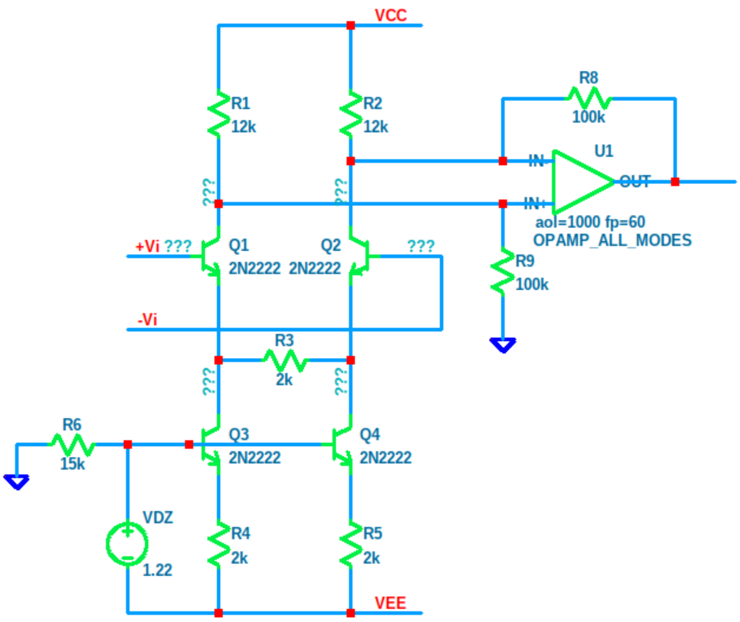

Figure 6

From the half-circuit available for the differential mode from Figure 3 we get Iid = Vid/[rπ + β(R3/2)] and because we saw that $R_{01} >> R_C$ we can find the collector current of T1 and T2:

$$I_C = \beta(V_i/2)/[r_\pi + \beta(R_3/2)]$$

Taking the fact that rπ << β(R3/2), we get:

$$I_C = V_i/R_3$$

Also taking into account the differential excitation of the stage, we find in the T2 collector a current equal in magnitude with Ic, but of opposite phase as we see in Figure 7:

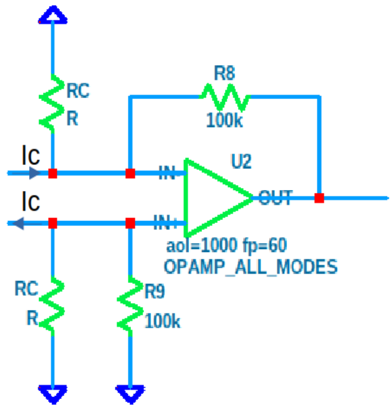

Figure 7

We will take U1 as an ideal operational amplifier, its positive and negative input potentials relative to ground must be equal:

$$V_{+}=V_{-}$$

V+, the noninverting input voltage relative to ground is:

$$-V_{+}-I_C(R_C \| R_9)=0$$

V-, can be found out by applying superposition theorem, finding immediately

$$V_{-}=I_C(R_C \| R_8)+V_O(R_C/(R_C+R_8))$$

From V+ = V- we get:

$$-I_C(R_C \| R_9)=I_C(R_C \| R_8)+V_O(R_C/(R_C+R_8)) \, where \, R_8=R_9$$

or

$$2I_C=-(V_O/R_8)$$

and knowing that $I_C = V_i/R_3$ we get

$$\frac{V_O}{V_i}=-2\frac{R_8}{R_3}$$

For R8 = 100k and R3 = 2k we have Add = -100.

Simulation

For Vi = 1 mV:

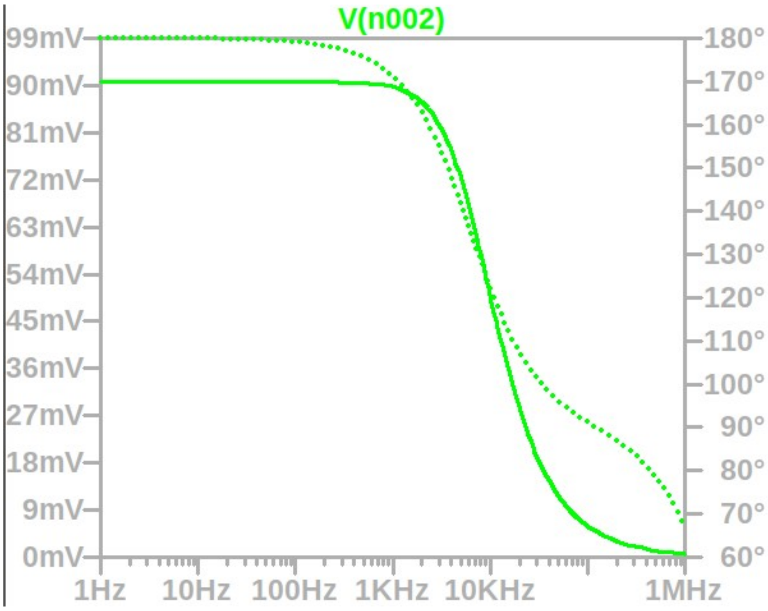
V(n002)
99mV
90mV
81mV
72mV
63mV
54mV
45mV
36mV
27mV
18mV
9mV
0mV
180°
170°
160°
150°
140°
130°
120°
110°
100°
90°
80°
70°
60°
1Hz
10Hz
100Hz
1KHz
10KHz
1MHz

Figure 8