Module – 3

Contents:

Multistage amplifiers: Cascade and cascode connections, Darlington circuits, analysis and design.
Feedback amplifiers: Feedback concept, different types, practical feedback circuits, analysis and design of feedback circuits.

Objectives:

1. To study the design and analysis of multistage amplifiers.
2. To study the design and analysis of feedback amplifiers.

3.1. Multistage Amplifiers

3.1.1. Cascade Amplifier:

When the amplification from a single stage amplifier is not sufficient for a particular purpose, or when the input or output impedance is not of suitable magnitude for the intended application, two or more amplifier stages are connected in cascade. The output of a given stage is connected to the input of the next stage. Such an arrangement is called Multistage amplifier. The figure 3.1 shows three amplifier stages connected in cascade.

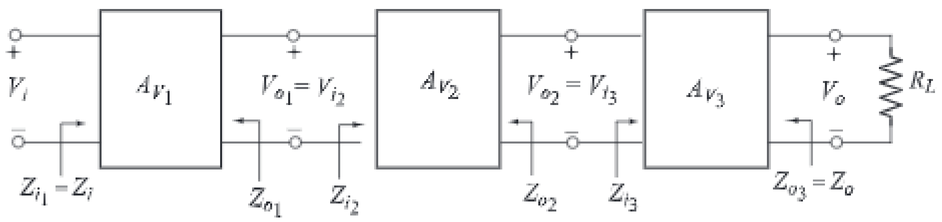


Fig.3.1: Cascaded amplifier

It is important to note that, the input impedance of a given stage loads the output of the proceeding stage. Thus the voltage gains A_{V1}, A_{V2} & A_{V3} whose values can be calculated using corresponding no load gains. Also for the cascaded system, the input impedance is that of the first stage and the output impedance is that of the last stage ($Z_i = Z_{i1}$ and $Z_O = Z_{O1}$).

Since output of one stage is connected as input to the next stage,

$$V_{i2} = V_{O1} \text{ and } V_{i3} = V_{O2}$$

The overall voltage gain of the cascaded system can be obtained as follows:

$$A_{VT} = \frac{V_O}{V_I}$$

$$\boldsymbol{A_{VT}} = \frac{\boldsymbol{V_O}}{\boldsymbol{V_{i3}}} * \frac{V_{i3}}{V_{i2}} * \frac{V_{i2}}{V_i}$$

Using $V_{i2} = V_{O1}$ and $V_{i3} = V_{O2}$

$$\boldsymbol{A_{VT}} = \frac{\boldsymbol{V_O}}{\boldsymbol{V_{i3}}} * \frac{V_{O2}}{V_{i2}} * \frac{V_{O1}}{V_i}$$

$$\boldsymbol{A_{VT}} = A_{V3} * A_{V2} * A_{V1}$$

$$\boldsymbol{A_{VT}} = A_{V1} * A_{V2} * A_{V3} \text{----------- (1)}$$

For n cascaded amplifier stages, the total voltage gain is given by

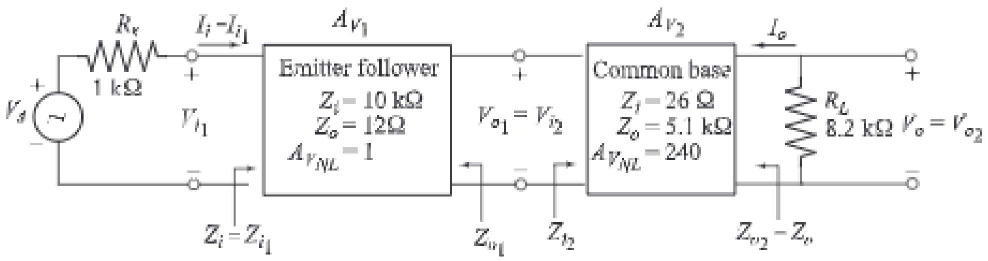
$$\boldsymbol{A_{VT}} = A_{V1} * A_{V2} * A_{V3} - - - - - A_{Vn}$$

The total current gain is given by,

$$\boldsymbol{A_{IT}} = -\boldsymbol{A_{VT}} \frac{\boldsymbol{Z_{i1}}}{\boldsymbol{R_L}} \text{------------ (2)}$$

<u>Solved Examples on Cascaded amplifiers:</u>

1. **For the cascaded system shown below, determine**
   a. **The loaded gain of each stage.**
   b. **The total gain of the system, A_V and A_{VS}.**
   c. **The total current gain of the system**



Solution:

a. **For the emitter follower the load is Zi2,**

$$A_{V_1} = \frac{V_{o_1}}{V_{i_1}} = \frac{Z_{i_2}}{Z_{i_2} + Z_{o_1}} A_{V_{NL}} = \frac{26\Omega}{26\Omega + 12\Omega} = 0.684$$

For the common base configuration,

$$A_{V_2} = \frac{V_o}{V_{i_2}} = \frac{R_L}{R_L + Z_{o_2}} A_{V_{NL}}$$

$$= \frac{8.2\text{k}\Omega}{8.2\text{k}\Omega + 5.1\text{k}\Omega}(240) = 147.97$$

b. **The total voltage gain is,**

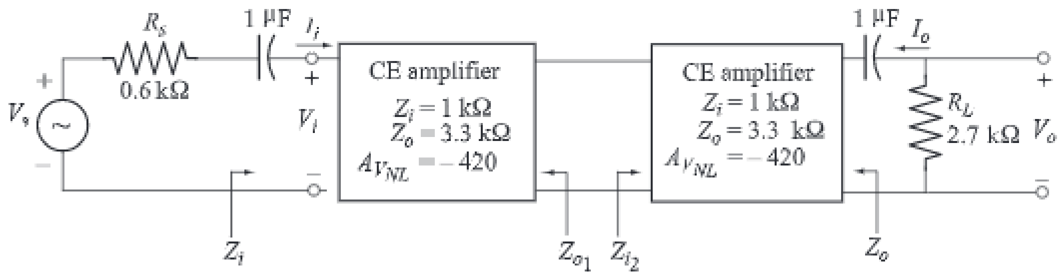
$$A_{V_T} = A_{V_1} A_{V_2} = (0.684)\,(147.97) = 101.20$$

$$A_{V_S} = \frac{Z_{i_1}}{Z_{i_1} + R_S} A_{V_T} = \frac{10\text{k}\Omega}{10\text{k}\Omega + 1\text{k}\Omega}(101.20) = 92$$

c. **The total current gain is,**

$$A_{I_T} = -A_{V_T} \frac{Z_{i_1}}{R_L} = -(101.20)\,\frac{10\text{k}\Omega}{8.2\text{k}\Omega} = -123.41$$

2. **For the cascaded arrangement shown below calculate,**
   a. **The loaded voltage gain of each stage.**
   b. **The total gain of the system, A_V and A_{VS}.**
   c. **The loaded current gain of each stage.**
   d. **The total current gain of the system.**



Solution:

a. **The loaded voltage gain of each stage,**

$$A_{V_1} = \frac{Z_{i_2}}{Z_{o_1} + Z_{i_2}} A_{V_{NL}} = \frac{1\text{k}\Omega}{3.3\text{k}\Omega + 1\text{k}\Omega}(-420) = -97.67$$

$$A_{V_2} = \frac{R_L}{Z_o + R_L} A_{V_{NL}} = \frac{2.7\text{k}\Omega}{3.3\text{k}\Omega + 2.7\text{k}\Omega}(-420) = -189$$

b. **The total voltage gain is,**

$$A_{V_T} = A_{V_1} A_{V_2} = (-97.67)\,(-189) = 18.45 \times 10^3$$

$$A_{V_s} = \frac{Z_i}{R_s + Z_i} A_{V_T}$$

$$= \frac{1\text{k}\Omega}{0.6\text{k}\Omega + 1\text{k}\Omega}(18.45 \times 10^3) = 11.53 \times 10^3$$

c. The loaded current gain of each stage,

$$A_{I_1} = -A_{V_1} \frac{Z_i}{Z_{i_2}} \quad \text{[Since load on first stage is } Z_{i_2}\text{]}$$

$$= -(-97.67) \frac{1\text{k}\Omega}{1\text{k}\Omega} = 97.67$$

$$A_{I_2} = -A_{V_2} \frac{Z_{i_2}}{R_L} = -(-189) \frac{1\text{k}\Omega}{2.7\text{k}\Omega} = 70$$

d. The total current gain is,

$$A_{I_T} = A_{I_1} \cdot A_{I_2} = (97.67)(70) = 6.84 \times 10^3$$

3.1.2. Cascode Connection:

In cascode connection the output of Common Emitter stage drives the input of Common Base stage as shown in figure.3.2. The cascode connection has low input capacitance, which is an advantage at high frequencies such VHF and UHF. At these higher frequencies, the input capacitance becomes a limiting factor on the voltage gain.

Cascode connection has high input impedance and high output impedance. The CB stage provides an excellent high frequency response. The low input impedance of CB stage loads the output of CE stage. Thus the voltage gain of the CE stage is very low. A large voltage gain is provided by the CB stage, thus overall voltage gain is high with a good input impedance level.

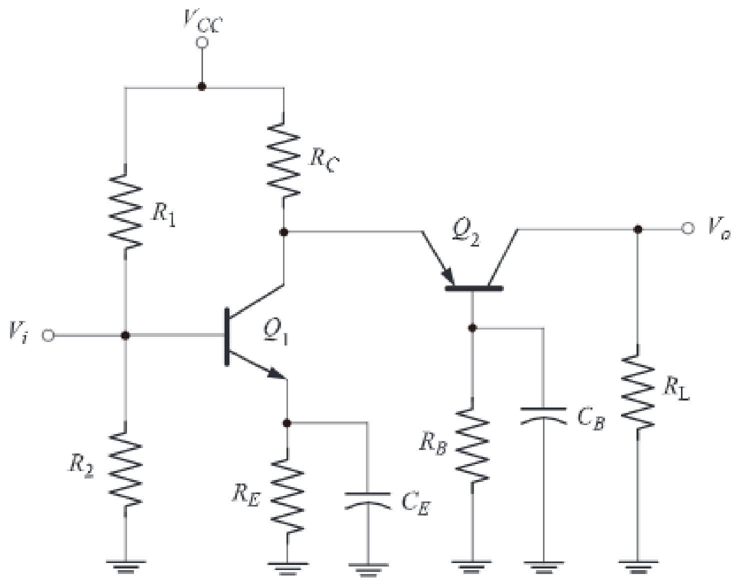


Fig.3.2: Cascode connection

3.1.3. Darlington Connection

A Darlington connection is a popular connection of two transistors for operation as one super beta transistor. The composite transistor acts as a single unit with a current gain equal to the product of the current gains of individual transistors. The Darlington connection is shown in figure.3.3.

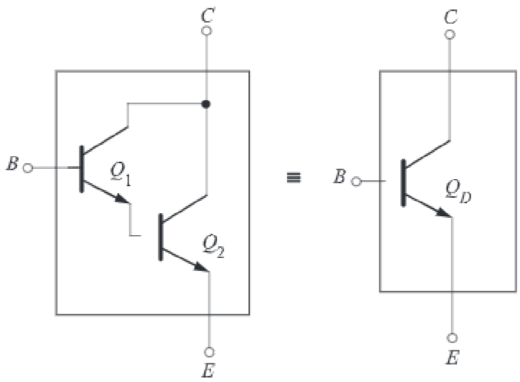


Fig.3.3: Darlington Connection

If β_1 and β_2 are the current gains of Q_1 and Q_2 respectively, the current gain of Darlington connection is,

$$\beta_D = \beta_1 * \beta_2$$

A Darlington transistor acts as a single transistor with a large current gain, typically a few thousand. Darlington connection is available as a single package containing two BJTs internally connected as a Darlington transistor. The device provides three terminals, base, emitter and collector for external connection.

DC Bias of Darlington Circuit:

A Darlington circuit with biasing arrangement is shown in figure.3.4. The current gain of Darlington transistor is β_D which is very high.

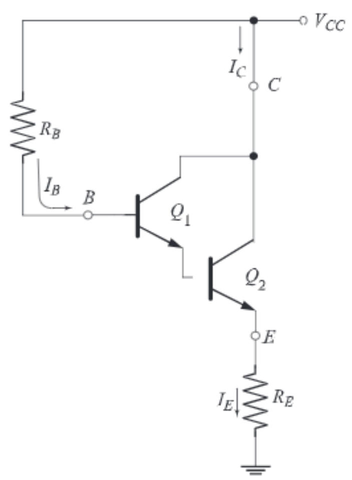


Fig.3.4: DC Bias of Darlington Circuit

Applying KVL to the base-emitter circuit we get;

$$V_{CC} - I_B R_B - V_{BE} - I_E R_E = 0$$

$$V_{BE} = V_{BE1} + V_{BE2}$$

$$I_E = (1+\beta_D) I_B \approx \beta_D I_B$$

$$I_B R_B = V_{CC} - V_{BE} - I_E R_E$$

It should be noted that, VBE is the drop for two base-emitter junctions which is typically in the range of 1.4V to 1.8V.

$$I_B = \frac{V_{CC} - V_{BE}}{R_B + (1+\beta_D) R_E} \text{ -------- } (3)$$

$$V_E = I_E * R_E \text{ ----------- } (4)$$

$$V_B = V_{BE} + V_E$$

Darlington Emitter-Follower:

The ac input signal V_i is coupled to the base of the Darlington transistor through the coupling capacitor C_1. The ac output voltage V_O is taken at the emitter through the output coupling capacitor C_2.The circuit of Darlington Emitter-follower is shown in figure.3.5.

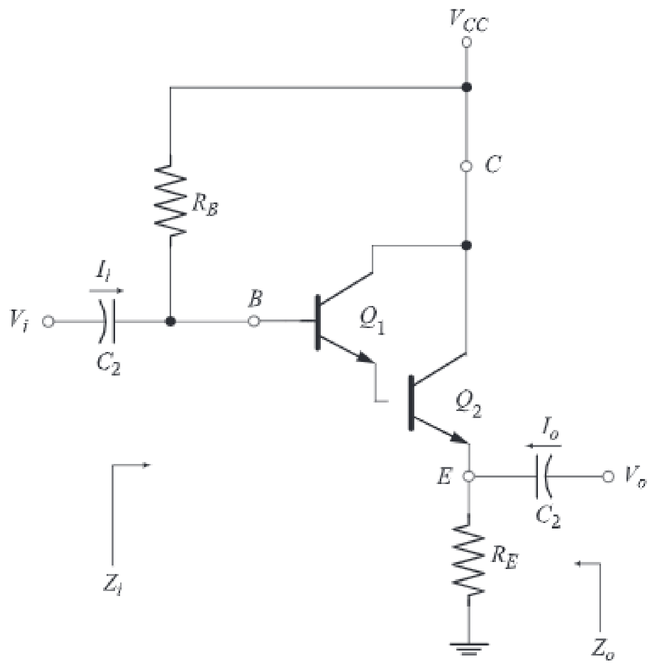


Fig.3.5: Darlington Emitter-Follower

The ac equivalent circuit of Darlington emitter follower is shown in figure.3.6. **The Darlington transistor is replaced by an input resistance r_i between base and emitter terminals and a controlled current source $\beta_D I_b$ between collector and the emitter terminals.**

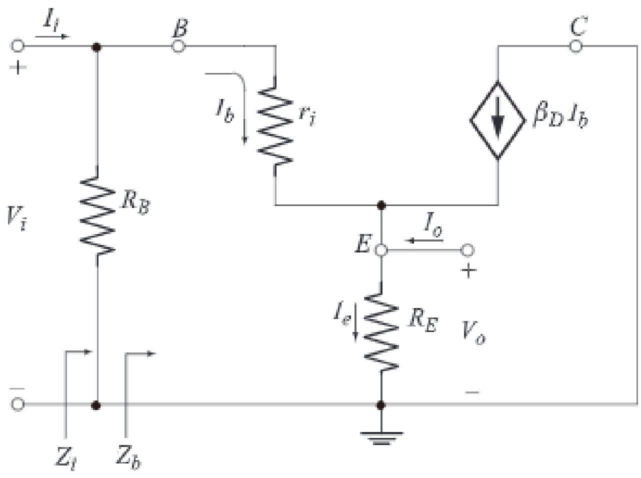


Fig.3.6: AC equivalent circuit of Darlington emitter follower

AC Input Impedance (Z_I):

Applying KVL to the circuit (Fig.3.6) we get;

$$V_I = I_b r_i + I_e R_E$$

$$I_e = (1+\beta_D)I_b$$

$$V_I = I_b r_i + (1+\beta_D)I_b R_E$$

$$\mathbf{Z_b = \frac{V_I}{I_b} = r_i + (1+\beta_D)R_E \approx \beta_D R_E}$$

$$\mathbf{Z_I = \frac{V_I}{I_I} = R_B \parallel Z_b} \text{------ (5)}$$

AC Current Gain (A_I):

$$A_I = \frac{I_O}{I_I} = \frac{I_O}{I_b} * \frac{I_b}{I_I}$$

$$I_O = I_e$$

$$\boldsymbol{A_I = \frac{I_e}{I_I} = \frac{I_e}{I_b} * \frac{I_b}{I_I}}$$

$$I_e = (1+\beta_D)I_b \approx \beta_D I_b$$

$$\boldsymbol{\frac{I_e}{I_b} = \beta_D} \text{ -------- (6)}$$

Applying KCL to the circuit (Fig.3.6) we get;

$$I_I = \frac{V_I}{R_B} + I_b$$

$$V_i = I_b Z_b$$

$$I_I = \frac{I_b Z_b}{R_B} + I_b = [\frac{Z_b}{R_B} + 1] * I_b$$

$$I_I = [\frac{Z_b + R_B}{R_B}] * I_b$$

$$\boldsymbol{\frac{I_b}{I_I} = \frac{R_B}{Z_b + R_B}} \text{ ------ } \mathbf{(7)}$$

$$\boldsymbol{A_I = \frac{\beta_D R_B}{Z_b + R_B} = \frac{\beta_D R_B}{\beta_D R_E + R_B}} \text{ -------- } \mathbf{(8)}$$

AC Voltage Gain (A_V):

$$V_O = I_e R_E$$

$$V_O = (1+\beta_D) I_b R_E$$

$$V_I = I_b[r_i + (1+\beta_D)R_E]$$

$$A_V = \frac{V_O}{V_I} = \frac{(1+\beta_D) I_b R_E}{I_b[r_i + (1+\beta_D)R_E]}$$

$$\boldsymbol{A_V = \frac{V_O}{V_I} = \frac{(1+\beta_D)R_E}{[r_i + (1+\beta_D)R_E]} \approx 1} \text{ ---------- (9)}$$

AC Output Impedance (Z_O):

To determine the ac output impedance V_i is reduced to zero (replaced by short circuit equivalent) and a voltage source V is connected between the output terminals.

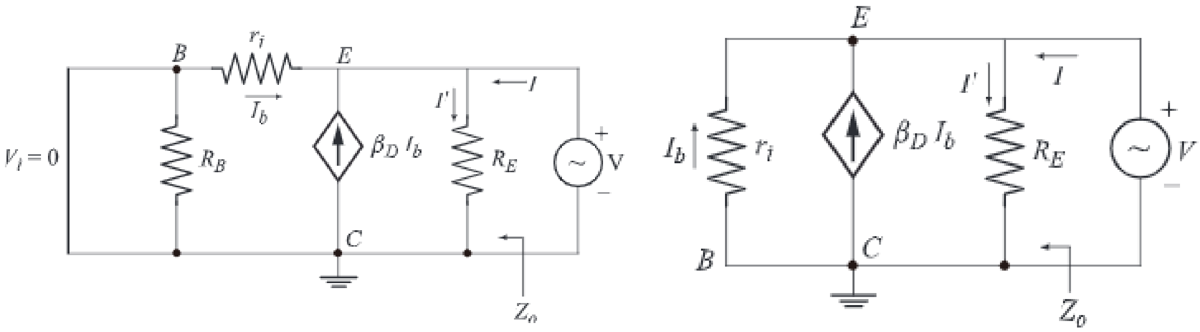


Fig.3.7: Simplified circuit to find output impedance

Applying KCL to the circuit we get;

$$I_b + \beta_D I_b - I^I + I = 0$$

$$I_b = \frac{-V}{r_i} \quad \text{and} \quad I^I = \frac{V}{R_E}$$

$$\frac{-V}{r_i} + \beta_D \frac{-V}{r_i} - \frac{V}{R_E} + I = 0$$

$$\left[\frac{1}{r_i} + \frac{\beta_D}{r_i} + \frac{1}{R_E}\right] V = I$$

$$Z_O = \frac{V}{I} = \frac{1}{\left[\frac{1}{r_i} + \frac{\beta_D}{r_i} + \frac{1}{R_E}\right]}$$

$$Z_O = \frac{V}{I} = \frac{1}{\left[\frac{1}{r_i} + \frac{1}{r_i/\beta_D} + \frac{1}{R_E}\right]}$$

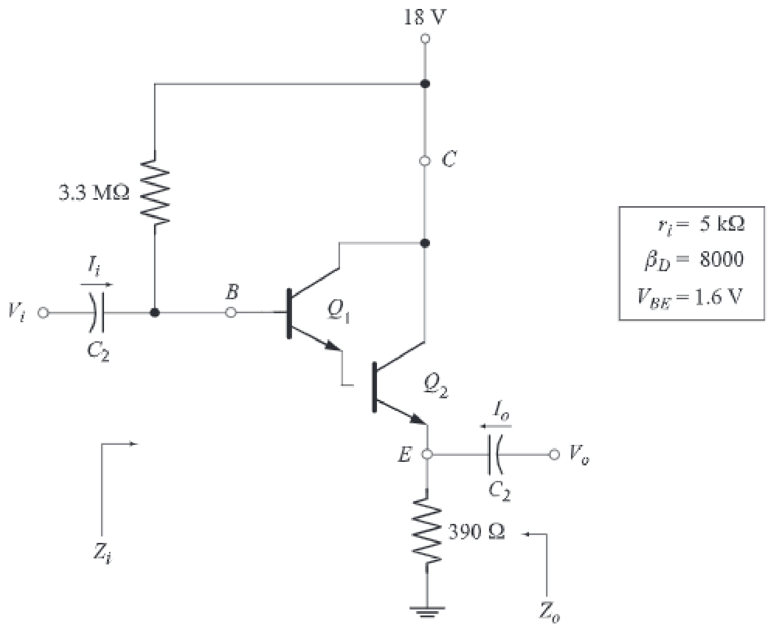
$$\boldsymbol{Z_O = \left[r_i \parallel R_E \parallel \frac{r_i}{\beta_D}\right] \approx \frac{r_i}{\beta_D}} \text{ --------- } \mathbf{(10)}$$

<u>Characteristics of Darlington Emitter – Follower:</u>

1. Very high current gain.
2. Very high input impedance.
3. Very low output impedance.
4. Approximately unity voltage gain.
5. Input and output voltages are in phase.

<u>Solved Examples on Darlington amplifiers:</u>

1. **For the Darlington Emitter-follower shown below,**
   a. **Calculate the dc bias voltages V_B, V_E, V_C and currents I_B and I_C.**
   b. **Calculate the input and output impedances.**
   c. **Determine voltage and current gains.**
   d. **The ac output voltage for V_i = 120 mV**.



Solution:

(a)

$$I_B = \frac{V_{CC} - V_{BE}}{R_B + \beta_D R_E}$$

$$= \frac{18\text{V} - 1.6\text{V}}{3.3\text{M}\Omega + (8000)(390\Omega)} = 2.55\ \mu\text{A}$$

$$I_E = I_{E_2} \approx I_{C_2} = \beta_D I_B$$

$$= (8000)\ (2.55\ \mu\text{A}) = 20.4\ \text{mA}$$

$$V_E = I_E R_E = (20.4\ \text{mA})\ (390\ \Omega) = 7.96\ \text{V}$$

$$V_B = V_{BE} + V_E = 1.6\ \text{V} + 7.96\ \text{V} = 9.56\ \text{V}$$

Since the collector is directly tied to V_{CC}, the collector voltage equals the dc supply voltage V_{CC}.

$$\therefore \quad V_C = V_{CC} = 18\ \text{V}$$

(b)

$$Z_b = r_i + (1 + \beta_D)\ R_E$$

$$= 5\ \text{k}\Omega + (8001)\ (390\ \Omega) = 3.13\ \text{M}\Omega$$

$$Z_i = R_B \parallel Z_b = 3.3\ \text{M}\Omega \parallel 3.13\ \text{M}\Omega = 1.6\ \text{M}\Omega$$

$$Z_o = r_i \parallel R_E \parallel \frac{r_i}{\beta_D}$$

$$= 5\ \text{k}\Omega \parallel 390\ \Omega \parallel \frac{5\text{k}\Omega}{8000} = 0.625\ \Omega$$

(c)

$$A_V = \frac{R_E\,(1+\beta_D)}{r_i + R_E\,(1+\beta_D)}$$

$$= \frac{(390\Omega)(8001)}{5\text{k}\Omega + (390\Omega)(8001)} = 0.998$$

$$A_I = \frac{\beta_D R_B}{R_B + \beta_D R_E}$$

$$= \frac{(8000)(3.3\text{M}\Omega)}{3.3\text{M}\Omega + (8000)(390\Omega)} = 4112.15$$

(d)

$$V_o = A_V V_i = (0.998)\ (120\ \text{mV})$$

$$= 119.76\ \text{mV}$$