Analog & Digital Electronics

Course No: PH-218

Lec-13: Multistage Amplifiers

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Multistage Amplifier:

Characteristic	Common Base	Common Emitter	Common Collector
Input impedance	Low	Medium	High
Output impedance	Very High	High	Low
Phase Angle	0^o	180^o	0^o
Voltage Gain	High	Medium	Low
Current Gain	Low	Medium	High
Power Gain	Low	Very High	Medium

- **Common emitter amplifier is most popular BJT amplifier due to high power gain.**

- **Ideal amplifier should have high input impedance, low output impedance, high voltage and current gain.**

- **Single Stage amplifier is not able to provide enough gain, power and full-fill all the requirement of an ideal amplifier --------- Need Multistage amplifier**

Multistage Amplifier: Characteristics

Stage Number				Characteristics		
1	2	3	4	Rin	Rout	Voltage gain
CE	CE			Medium	Medium	High
CE	CC			Medium	Low	Medium
CC	CE			High	Medium	Medium
CC	CC			Very high	Very low	<1
CE	CE	CE		Medium	Medium	Extremely high
CE	CE	CC		Medium	Low	Very high
CE	CC	CE		Medium	Medium	Very high
CE	CC	CC		Medium	Very low	Medium
CC	CE	CE		High	Medium	Very high
CC	CE	CC		High	Low	Medium
CC	CC	CE		Very high	Medium	Medium
CC	CC	CC		Very high	Very low	<1
CC	CE	CE	CC	High	Low	Very high

Descriptor	Rin or Rout	Voltage gai
Low	less than a few hundred Ohms	
Medium	A few hundred to a few thousand Ohms	less than 50
High	a few thousand to a few ten thousand Ohms	50 to 500
Very high	many tens of thousands of Ohms	500 to 5000
Extremely high	Over one hundred thousand Ohms	Over 5,000

Multistage Amplifiers

Practical amplifiers usually consist of a number of stages connected in cascade.

- **The first (input) stage is usually required to provide**
  - **a high input resistance**
  - **a high common-mode rejection for a differential amplifier**

- **Middle stages are to provide**
  - **majority of voltage gain**
  - **conversion of the signal from differential mode to single-end mode**
  - **shifting of the dc level of the signal**

- **The last (output) stage is to provide**
  - **a low output resistance in order to**
  - **avoid loss of gain and**
  - **provide the current required by the load (power amplifiers)**

Multistage Amplifier: Gain Calculation

$$A_{vT} = A_{v1}A_{v2}A_{v3}\ldots$$

$$A_{iT} = A_{i1}A_{i2}A_{i3}\ldots$$

$$A_{pT} = A_{vT}A_{iT}$$

Procedure:

1. Do dc analysis
2. Find r'_e for each stage
3. Find r_C for each stage
4. Using r'_e and r_C to find A_v for each stage

Input impedance of next stage is the load of current stage.

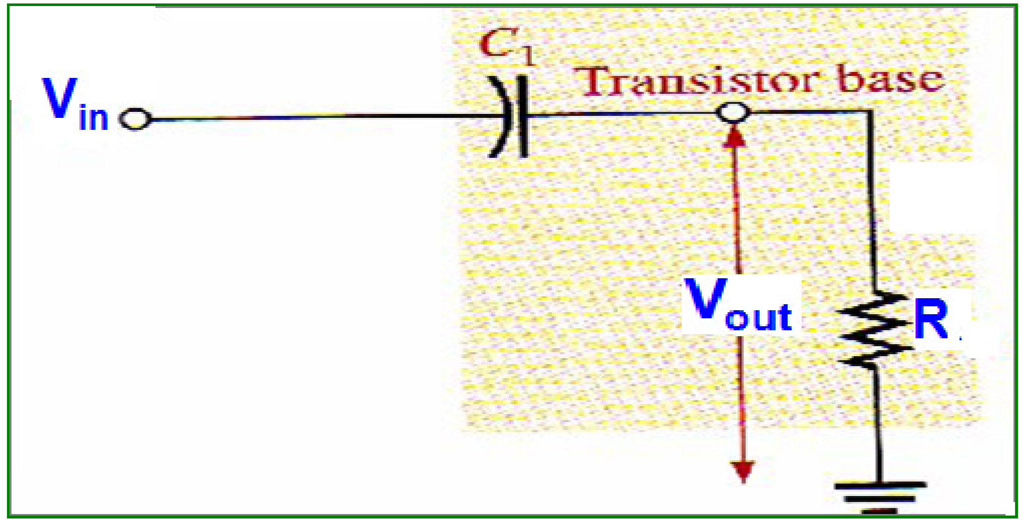
(Z_{in} of next stage is R_L of current stage)

Multistage Amplifiers: Frequency Response

$$V_o = \left(\frac{R}{R - jX_c}\right)V_{in}$$

$$A_v = \frac{V_{out}}{V_{in}} = \frac{R}{R - j(1/\omega C)}$$

$$A_v = \frac{1}{1 - j(1/2\pi fCR)}$$



$$A_v = \frac{1}{1 - j(f_1/f)}$$

$$f_1 = 1/2\pi RC$$

$$A_v = \frac{1}{\sqrt{1 + (f_1/f)^2}} \angle \tan^{-1}(f_1/f)$$

Multistage Amplifiers: Low cut off Frequency

If n identical stages are connected together then overall voltage gain at lower frequency is given by:

$$A_{v\text{-low}} = A_{v1\text{-low}} \times A_{v2\text{-low}} \times A_{v3\text{-low}} \cdots\cdots\cdots \times A_{vn\text{-low}} = (A_{v\text{-low}})^n$$

where *n* is the number of cascaded stages. Since

$$A_{v1\text{-low}} = A_{v2\text{-low}} \cdots\cdots = A_{vn\text{-low}}$$

$$\left(\frac{A_{v-low}}{A_{v-mid}}\right)_{overall} = \left(\frac{A_{v-low}}{A_{v-mid}}\right)^n = \frac{1}{\left(1 - j(f_1 / f\right)^n}$$

For lower cutoff frequency : $A_{v\text{-low}} / A_{v\text{-mid}})_{overall} = 1/\sqrt{2}$

$$\frac{1}{\sqrt{[1+(f_1 / f_{c-low})^2]^n}} = \frac{1}{\sqrt{2}}$$

$$\boxed{f_{c-low} = \frac{f_1}{\sqrt{2^{\frac{1}{n}} - 1}}}$$

Multistage Amplifiers: High Cutoff Frequency

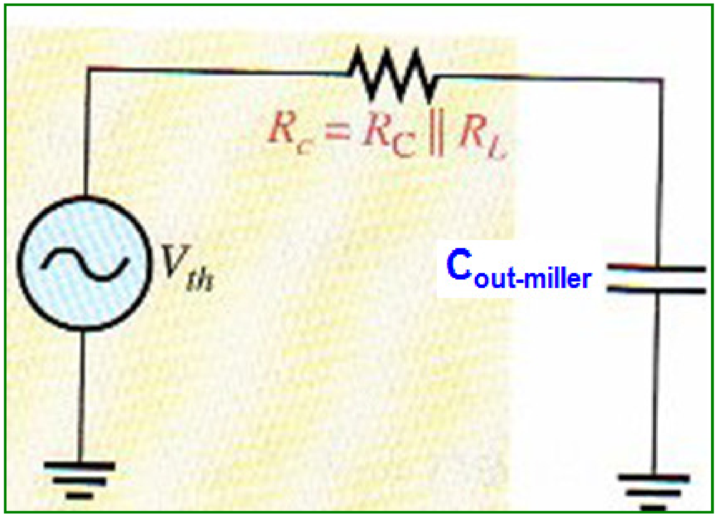
$$V_o = \left(\frac{-jX_c}{R - jX_c}\right)V_{in} \qquad A_v = \frac{V_{out}}{V_{in}} = \frac{1}{1 + j(R\omega C)}$$

$$A_v = \frac{1}{1 + j(2\pi fCR)} = \frac{1}{1 + j(f / f_2)}$$

$$A_v = \frac{1}{\sqrt{1 + (f / f_2)^2}} \angle \tan^{-1}(f / f_2)$$

where $f_2 = 1/2\pi RC$

$$\left(\frac{A_{v-high}}{A_{v-mid}}\right)_{overall} = \left(\frac{A_{v-high}}{A_{v-mid}}\right)^n = \frac{1}{(1 + j(f / f_2))^n}$$



For cutoff frequency : $A_{v\text{-high}}$ / $A_{v\text{-mid}})_{overall}$ = 1/√2

$$\frac{1}{\sqrt{[1 + (f_{c-high} / f_2)^2]^n}} = \frac{1}{\sqrt{2}}$$

$$f_{c-high} = f_2\sqrt{2^{\frac{1}{n}} - 1}$$

Multistage Amplifiers: Frequency Response

The cutoff frequencies for cascaded amplifiers with identical values of f_{c1} and f_{c2} are found using

$$f_{c-low} = \frac{f_{c1}}{\sqrt{2^{\frac{1}{n}} - 1}}$$

$$f_{c-high} = f_{c2}\sqrt{2^{\frac{1}{n}} - 1}$$

$$BW_{overall} = f_{c-high} - f_{c-low}$$

where *n* is the number of cascaded stages.

When Each stage has a different lower & upper critical frequency

- **When the lower critical frequency, f_{cL}, of each amplifier stage is different, the dominant lower critical frequency, f'_{cL} equals the critical frequency of the stage with the highest f_{cL}.**

- **When the upper critical frequency f_{cu}, of each amplifier stage is different, the dominant upper critical frequency f'_{cu}, equals the critical frequency of the stage with the lowest f_{cu}**

Types of Coupling:

In a multistage amplifier the output of one stage makes the input of the next stage. Normally a network is used between two stages so that a minimum loss of voltage occurs when the signal passes through this network to the next stage. Also the dc voltage at the output of one stage should not be permitted to go to the input of the next. Otherwise, the biasing of the next stage are disturbed.

The three couplings generally used are.

1.RC coupling

2. Transformer coupling

3. direct coupling

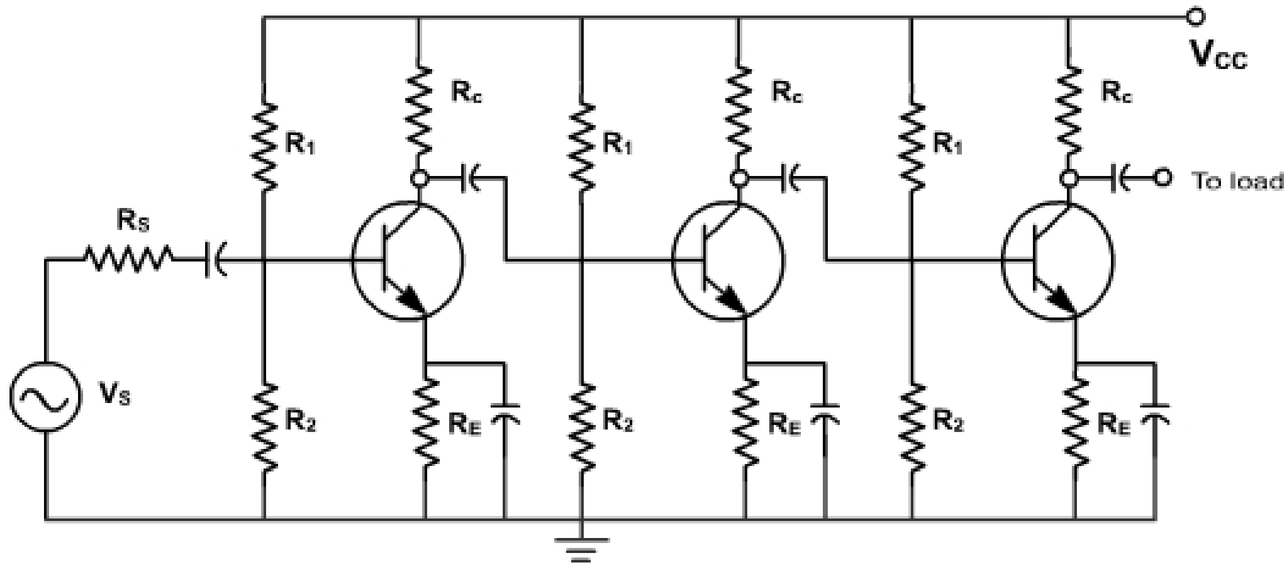
Problem: A transformer coupling is used in the final stage of a multistage amplifier. If the output impedance of transistor is 1kohm and the speaker has a resistance of 10ohm. Find the turn ratio of the transformer in order to transfer maximum power to the load (speaker).

Solution: For maximum power transfer, the impedance of the primary should be equal to the output impedance of the transistor and impedance of secondary should be equal to the load impedance. i.e.
Primary impedance = output impedance of transistor = 1kohm; Secondary impedance = impedance of load = 10ohm

$$\boxed{\frac{R_S}{R_p} = \left(\frac{N_S}{N_p}\right)^2}$$

$$N_s / N_p = 1:10$$

RC coupling



It has excellent frequency response in a audio frequency range and cheaper in cost.

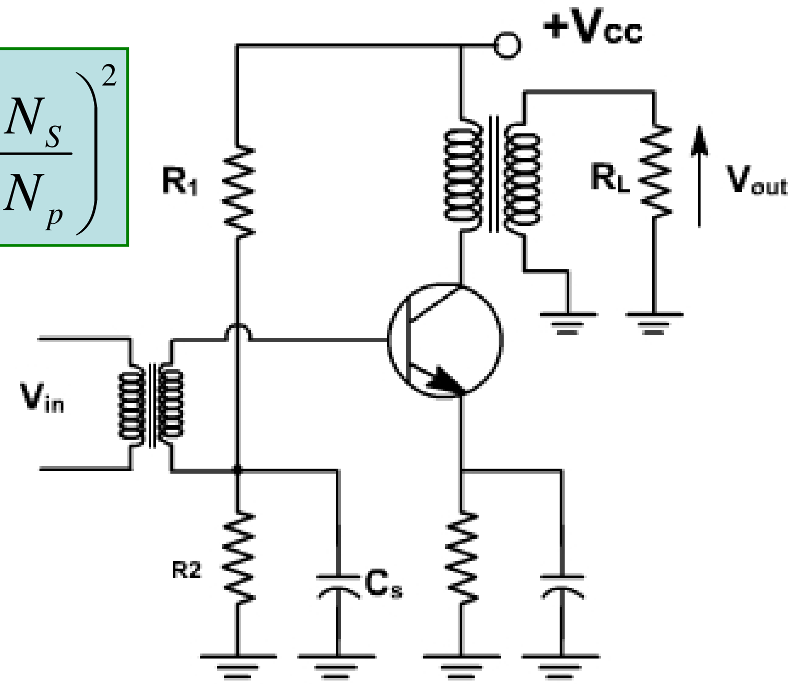
The drawback of this approach is the lower frequency limit imposed by the coupling capacitor and poor impedance matching.

Transformer coupling

Transformer coupling is mainly used in power amplifiers.

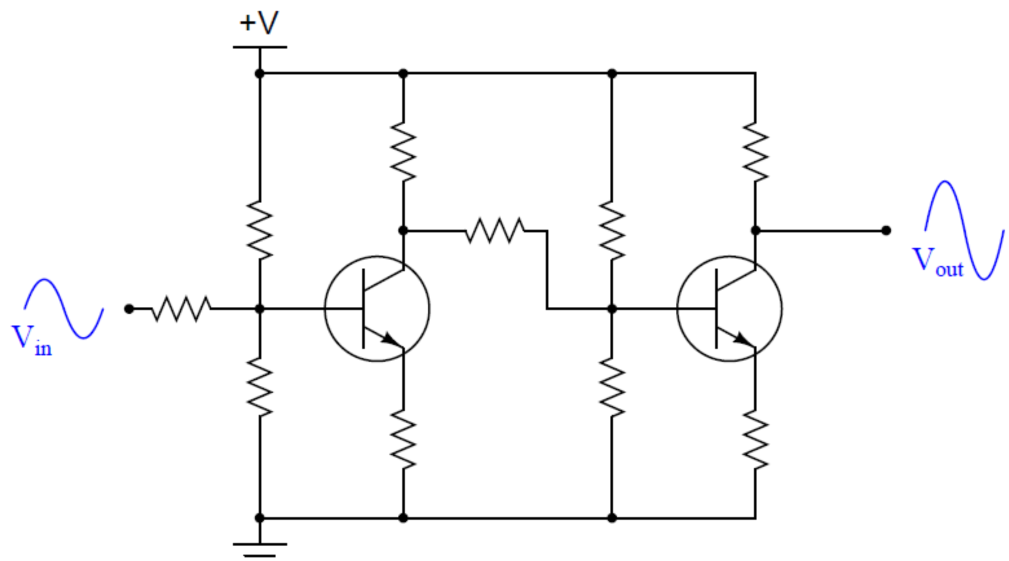
C_S capacitor is used to make other point of transformer grounded, so that ac signal is applied between base and ground.
The drawback of this approach is the poor frequency response.

$$\frac{R_S}{R_p} = \left(\frac{N_S}{N_p}\right)^2$$



Direct coupling

Direct coupling is the coupling method in which the output of one stage is directly connected to the input of the next stage.
Direct coupling is used in differential and operational amplifiers.



How the frequency response curve look like for direct coupling?

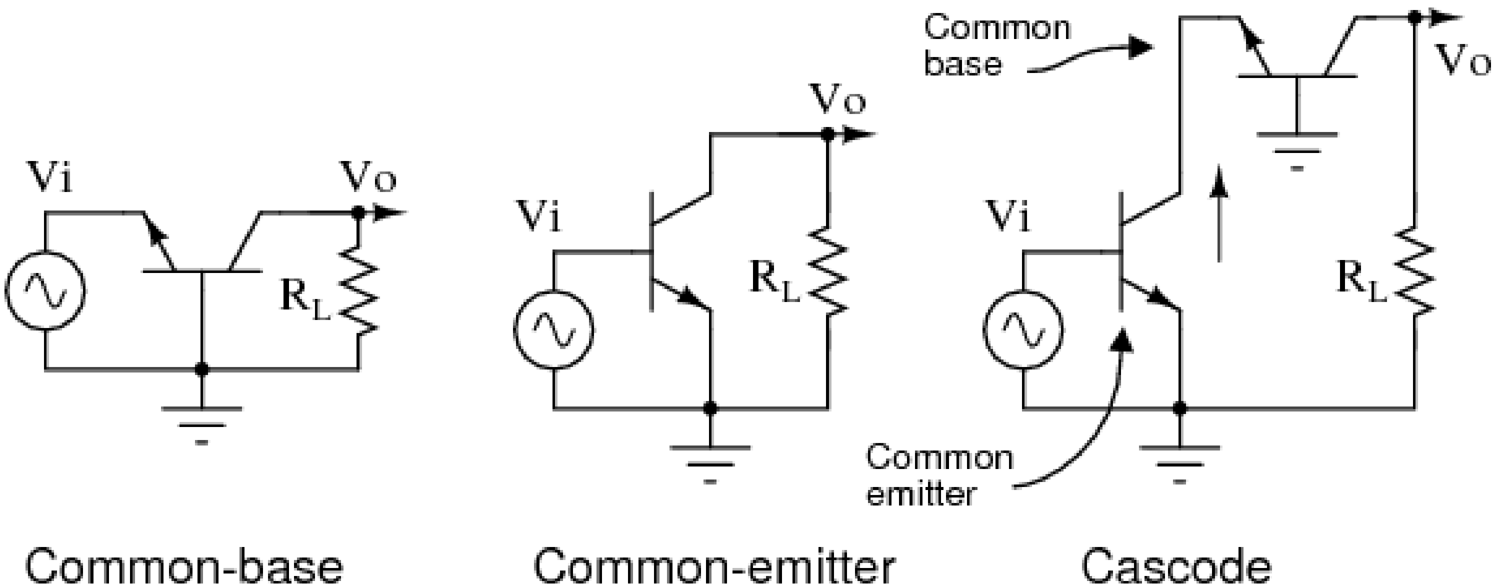
Comparison of different type of coupling

Characteristic	R-C coupling	Transformer coupling	Direct Coupling
Frequency Response	Excellent in audio frequency range	Poor	Best
Cost	Less	More	Least
Space & Weight	Less	More	Least
Impedance Matching	Not good	Excellent	Good
Use	Voltage amplification	Power amplification	amplifying extremely low frequency

Cascode amplifier

The cascode amplifier is combination of common-emitter and common-base amplifier.

While the C-B amplifier is known for wider bandwidth than the C-E configuration, the low input impedance (10s of Ω) of C-B is a limitation for many applications. The solution is to precede the C-B stage by a low gain C-E stage which has moderately high input impedance (kΩs).



The key to understanding the wide bandwidth of the cascode configuration is the *Miller effect*.

Cascode amplifier

A common-base configuration is not subject to the Miller effect because the grounded base shields the collector signal from being fed back to the emitter input. Thus, a C-B amplifier has better high frequency response.

The way to reduce the common-emitter gain is to reduce the load resistance. The gain of a C-E amplifier is approximately R_C/r_e. The collector load R_C is the resistance of the emitter of the C-B stage loading the C-E stage. CE gain amplifier gain is approximately $A_v = R_C/r_e=1$. This Miller capacitance is $C_{miller} = C_{cbo}(1-A_v) = C_{cbo}(1-(-1)=2C_{cbo}$.

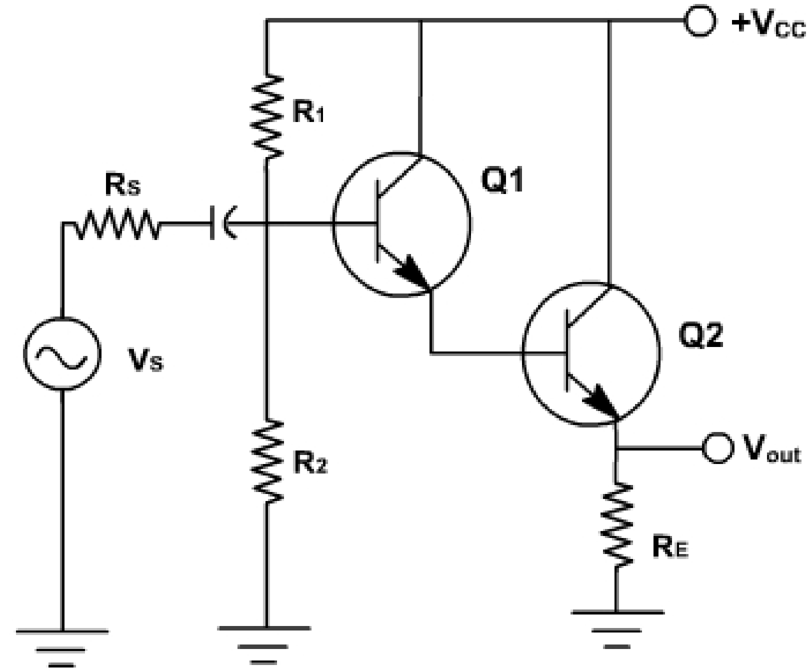
We now have a moderately high input impedance C-E stage without suffering the Miller effect, but no C-E stage voltage gain. The C-B stage provides a high voltage gain. The total current gain of cascode is β as current gain of the C-E stage is 1 for the C-B is β.

A cascode amplifier has a high gain, moderately high input impedance, a high output impedance, and a high bandwidth.

Darlington Amplifier

It consists of two emitter followers in cascaded mode. The overall gain is close to unity. The main advantage of Darlington amplifier is very large increase in input impedence and an equal decrease in output impedance **.**

Input impedance:



The first transistor has one V_{BE} drop and second transistor has second V_{BE} drop. The voltage divider produces V_{TH} to the input base.

DC emitter current of the 2nd stage

$$\mathbf{I_{E2} = (V_{TH} - 2\, v_{BE}) / (R_E)}$$

The dc emitter current of the first stage that is the base current of second stage:

$$\mathbf{I_{E1} = I_{E2} / \beta_2}$$

If $r'_{e(2)}$ is neglected then input impedance of second stage is $Z_{in\,(2)} = \beta_2 R_E$

Input impedance:

This is the impedance seen by the first transistor. If $r'_{e(1)}$ is also neglected then the input impedance of 1 becomes. $Z_{in\,(1)} = \beta_1\,\beta_2\,R_{E}$: which is extremely high because of the products of two betas, so the approximate input impedance of Darlington amplifier is $Z_{in} = R_1 \parallel R_2$

Output impedance:

The Thevenin impedance at the input is given by: $R_{TH} = R_S \parallel R_1 \parallel R_2$

Similar to single stage common collector amplifier, the output impedance of the two stages $z_{out(1)}$ and $z_{out(2)}$ are given by.

$$z_{out1} = r'_{e1} + \frac{R_{TH}}{\beta_1}$$

$$z_{out2} = r'_{e2} + \frac{z_{out1}}{\beta_2}$$

$$= r'_{e2} + \frac{r'_{e1} + \frac{R_{TH}}{\beta_1}}{\beta_2}$$

Therefore, the output impedance of the amplifier is very small.