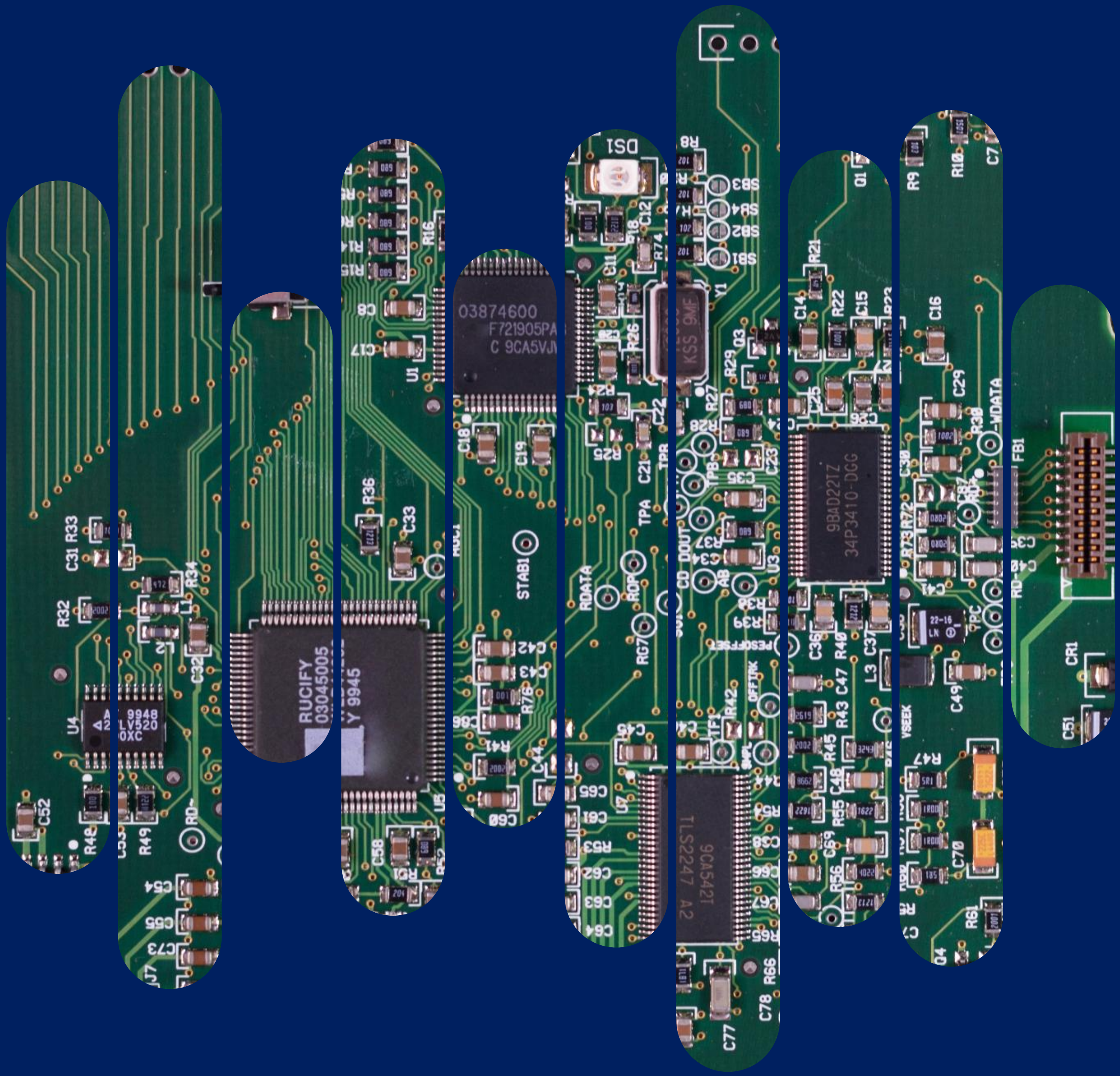
# Electronic Devices



# CHAPTER 6

## Multistage Amplifier

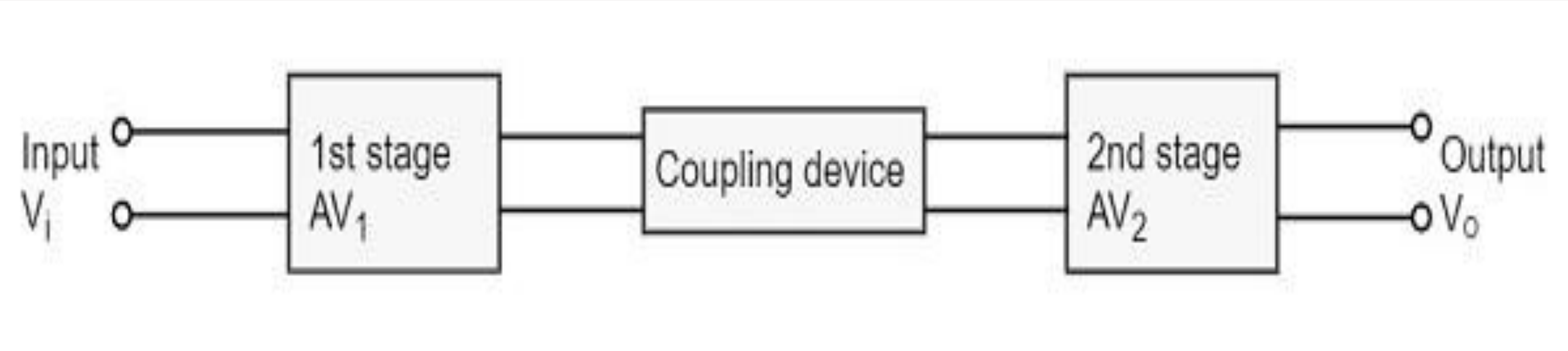
# Chapter Goals

Understanding of concepts related to:

- Concept of multistage amplifier and various coupling methods
- Analyze multistage amplifier in term of voltage gain, current gain, input and output impedance using $r_e$ model
- Explain the Darlington-pair amplifier and calculate its effective beta

# Multistage Transistor Amplifier

- In practical applications, the output of a single state amplifier is usually insufficient, though it is a voltage or power amplifier. Hence, they are replaced by **Multi-stage transistor amplifiers**.
- In Multi-stage amplifiers, the output of first stage is coupled to the input of next stage using a coupling device. These coupling devices can usually be a capacitor or a transformer. This process of joining two amplifier stages using a coupling device can be called as **Cascading**.
- The following figure shows a two-stage amplifier connected in cascade.



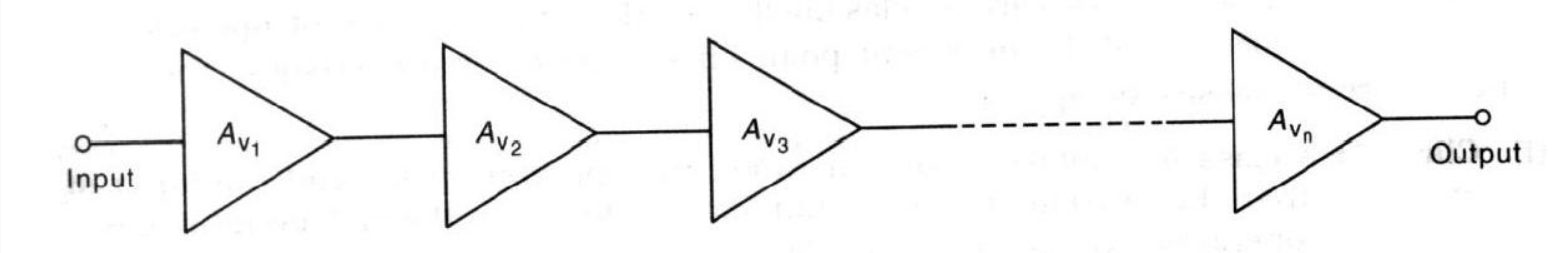
# Reasons for Multistage Transistor Amplifier

- **Gain**: Multi-stage amplifiers provide a higher overall voltage or power gain compared to a single-stage amplifier. This is essential when the input signal is very weak, and you need a substantial output signal.
- **Bandwidth**: Multi-stage amplifiers can be designed to have wider bandwidths, making them suitable for amplifying a broader range of frequencies.
- **Impedance Matching**: This is especially important when connecting a source with a high output impedance to a load with a low input impedance or vice versa. Each stage can be designed to provide the appropriate impedance transformation.
- **Reduced Noise**: Multi-stage amplifiers can help reduce the impact of noise introduced by each stage. In some cases, the noise from one stage can be partially canceled out by the following stages, resulting in a cleaner output signal.

# Loading Effect

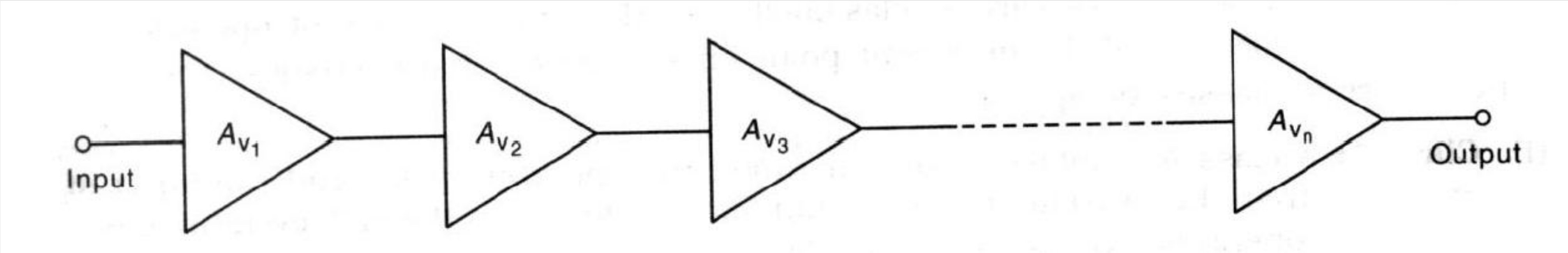
- The **loading effect** in multistage amplifiers occurs when the input impedance of a subsequent stage "loads" the previous stage, reducing its effective gain and altering its performance. This happens because the output impedance of one stage and the input impedance of the next stage form a voltage divider, reducing the signal transferred between stages.

# Gain of Multistage Transistor Amplifier




- Mathematically, if you have 'n' amplifier stages with gains represented as A1, A2, A3, ..., An, then the total gain calculated as:
- $A_{total} = A_{V1} \times A_{V2} \times A_{V3} \times \ldots \times A_{Vn}$
- It's important to note that the actual gain may also take into account factors such as the input and output impedances of the stages, and any loading effects. Therefore, while this multiplication of gains gives an idealized view of the gain, real-world considerations may affect the actual gain. Additionally, the frequency response and bandwidth of each stage can also impact the overall performance of the multi-stage amplifier.

# Gain of Multistage Transistor Amplifier




- Amplifier voltage gain is often expressed in decibels(dB) as follows:

$$A_V(dB) = 20\log_{10} A_V$$

- The overall voltage gain in dB is the sum of the individual voltage gain in dB.

$$A_{total}(dB) = A_{v1}(dB) + A_{v2}(dB) + \ \ldots + A_{vn}(dB)$$

# Gain of Multistage Transistor Amplifier

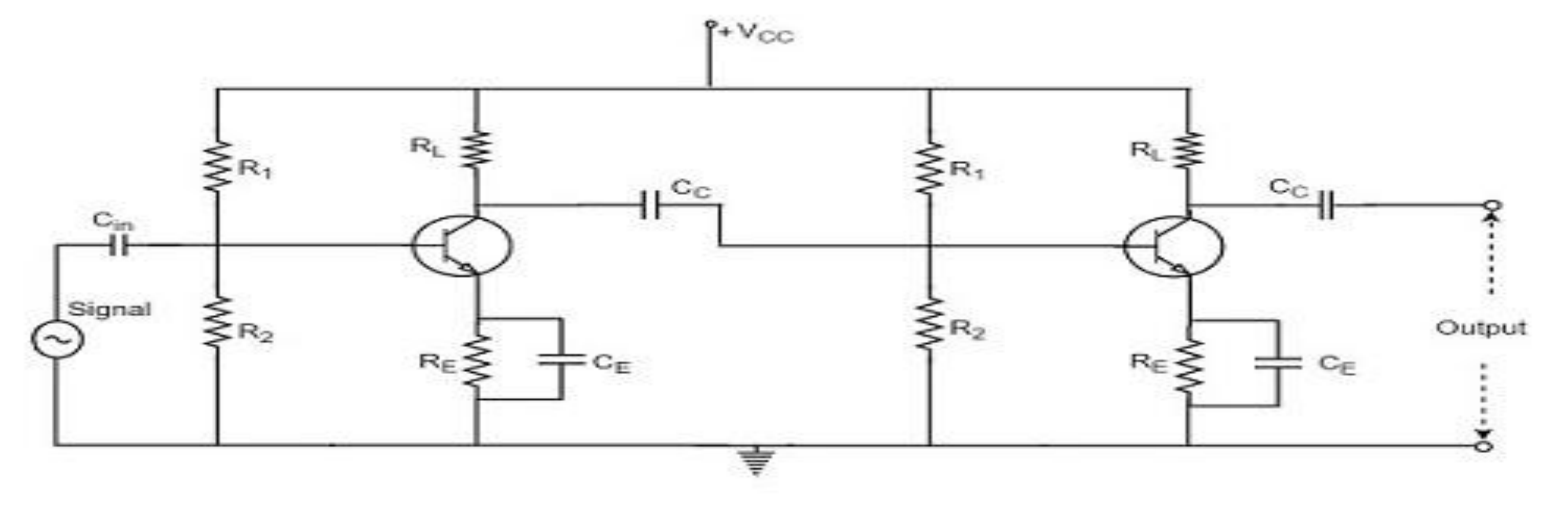
An amplifier has an input of 5microwatts. The power gain of the amplifier is 40dB. Find the output power of the amplifier.

$$Power\ gain\ in\ dB = 10\log_{10} P_o/P_i$$

If a three-stage amplifier has individual stage gains of 10db, 6db and 15db. What will be the overall gain in dB and watt?

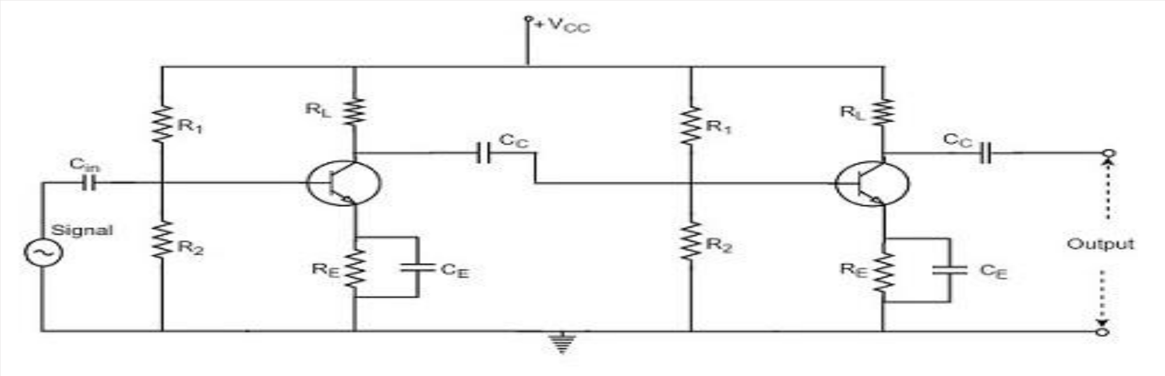
# RC Coupled Amplifier

- The resistance-capacitance coupling is, in short termed as RC coupling.
- **The constructional details of a two-stage RC coupled transistor amplifier circuit are** as follows. The two-stage amplifier circuit has two transistors, connected in CE configuration and a common power supply $V_{CC}$ is used. The potential divider network $R_1$ and $R_2$ and the resistor $R_E$ form the biasing and stabilization network. The emitter by-pass capacitor $C_E$ offers a low reactance path to the signal.



# RC Coupled Amplifier

- The resistor $R_L$ is used as a load impedance. The input capacitor $C_{in}$ present at the initial stage of the amplifier couples AC signal to the base of the transistor. The capacitor $C_C$ is the coupling capacitor that connects two stages and prevents DC interference between the stages and controls the shift of operating point. The figure below shows the circuit diagram of RC coupled amplifier.

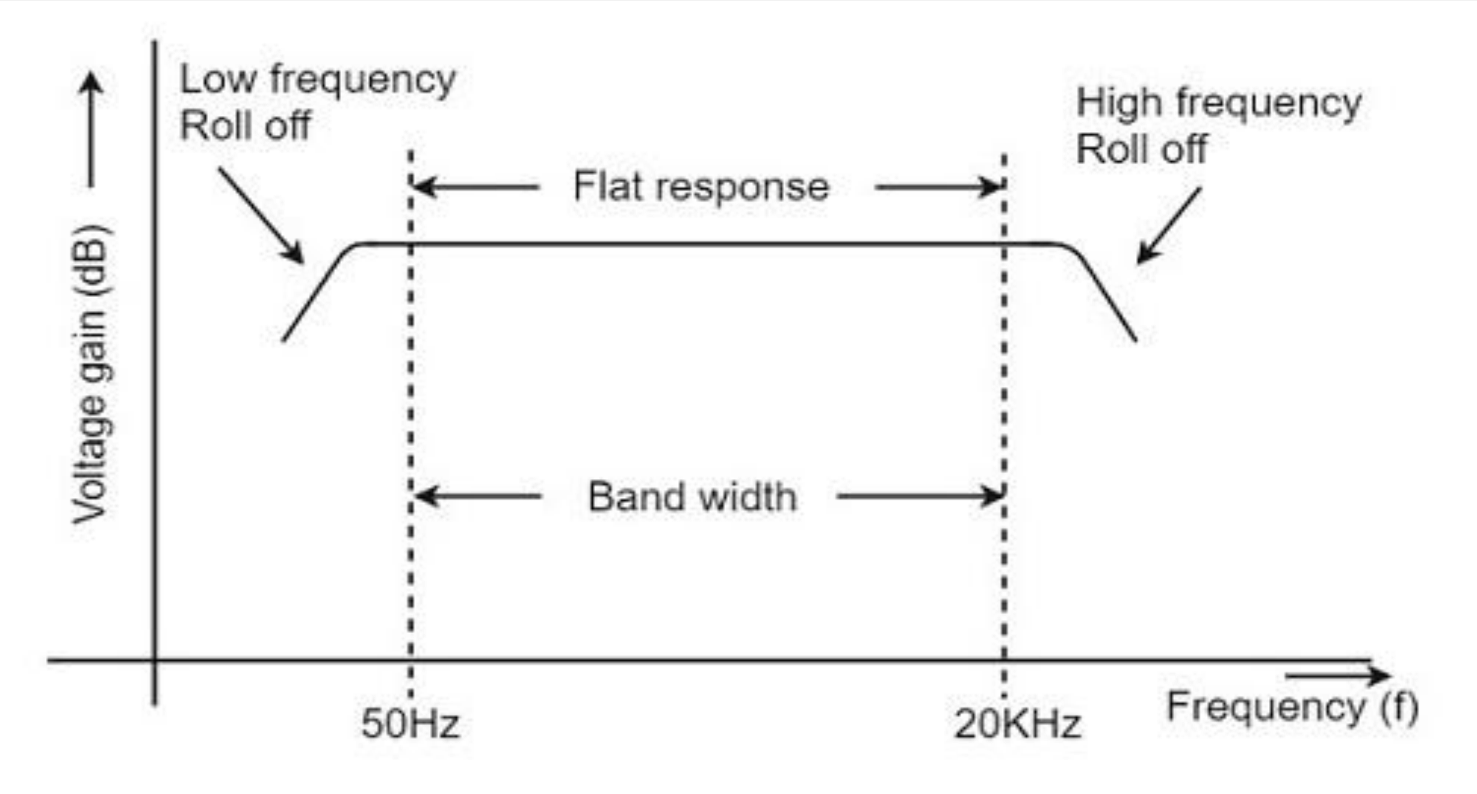


# RC Coupling Amplifier

- When an AC input signal is applied to the base of first transistor, it gets amplified and appears at the collector load $R_L$ which is then passed through the coupling capacitor $C_C$ to the next stage. This becomes the input of the next stage, whose amplified output again appears across its collector load. Thus, the signal is amplified in stage-by-stage action.
- The important point that has to be noted here is that the total gain is less than the product of the gains of individual stages. This is because when a second stage is made to follow the first stage, the **effective load resistance** of the first stage is reduced due to the shunting effect of the input resistance of the second stage. Hence, in a multistage amplifier, only the gain of the last stage remains unchanged.
- As we consider a two-stage amplifier here, the output phase is same as input. Because the phase reversal is done two times by the two stage CE configured amplifier circuit.

# Frequency Response RC Coupled Amplifier

- Frequency response curve is a graph that indicates the relationship between voltage gain and function of frequency. The frequency response of a RC coupled amplifier is



# RC Coupling Amplifier

## Advantages

- The frequency response of RC amplifier provides constant gain over a wide frequency range, hence most suitable for audio applications.
- The circuit is simple and has lower cost because it employs resistors and capacitors which are cheap.
- It becomes more compact with the upgrading technology.

## Disadvantages

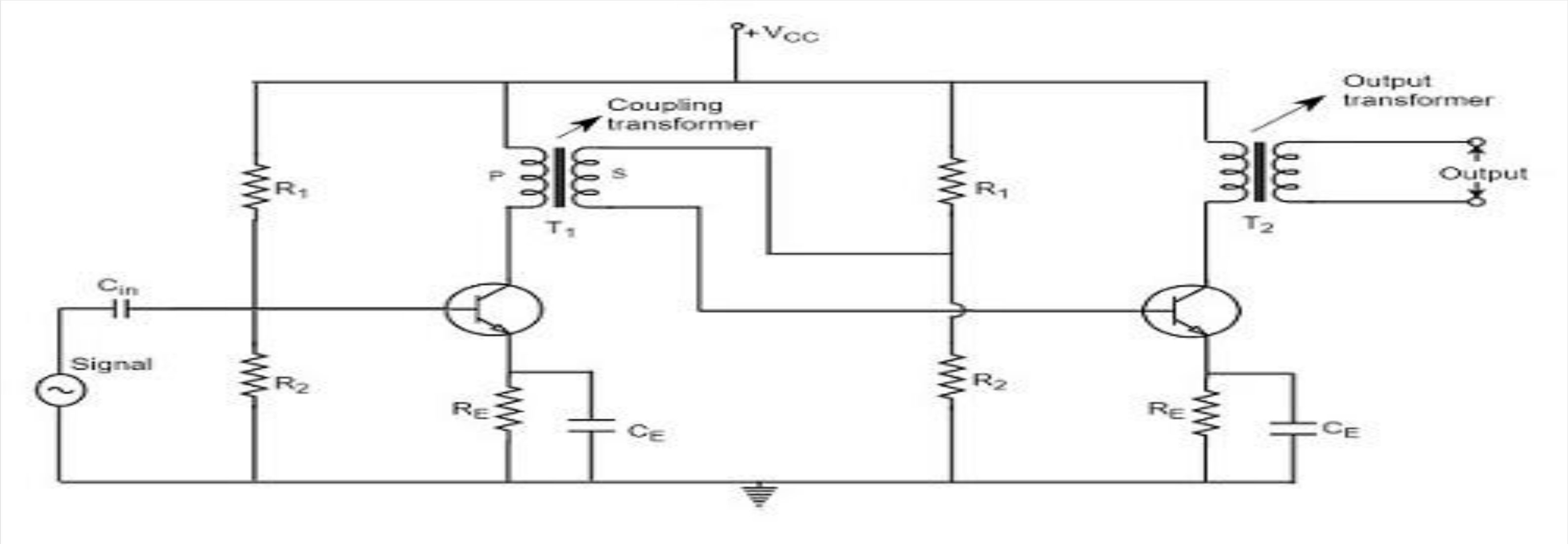
- The voltage and power gain are low because of the effective load resistance.
- They become noisy with age.
- Due to poor impedance matching, power transfer will be low.

## Applications

- They have excellent audio fidelity over a wide range of frequency.
- Widely used as Voltage amplifiers
- Due to poor impedance matching, RC coupling is rarely used in the final stages.

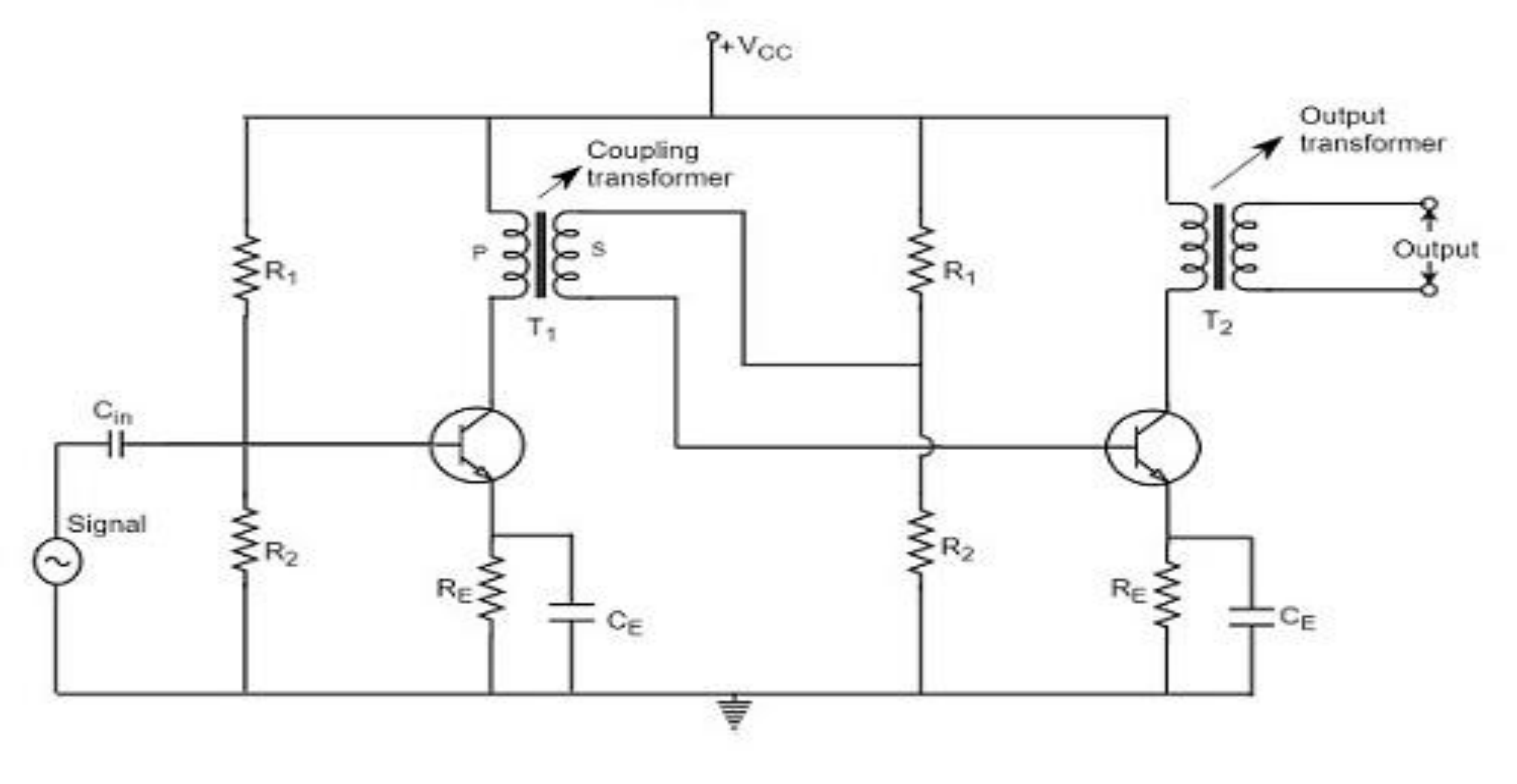
# Transformer Coupled Amplifier

- We have observed that the main drawback of RC coupled amplifier is that the effective load resistance gets reduced. This is because, the input impedance of an amplifier is low, while its output impedance is high.
- When they are coupled to make a multistage amplifier, the high output impedance of one stage comes in parallel with the low input impedance of next stage. Hence, effective load resistance is decreased. This problem can be overcome by a **transformer coupled amplifier**.
- In a transformer-coupled amplifier, the stages of amplifier are coupled using a transformer.



# Transformer Coupled Amplifier

- The amplifier circuit in which, the previous stage is connected to the next stage using a coupling transformer, is called as Transformer coupled amplifier.



# Transformer Coupled Amplifier

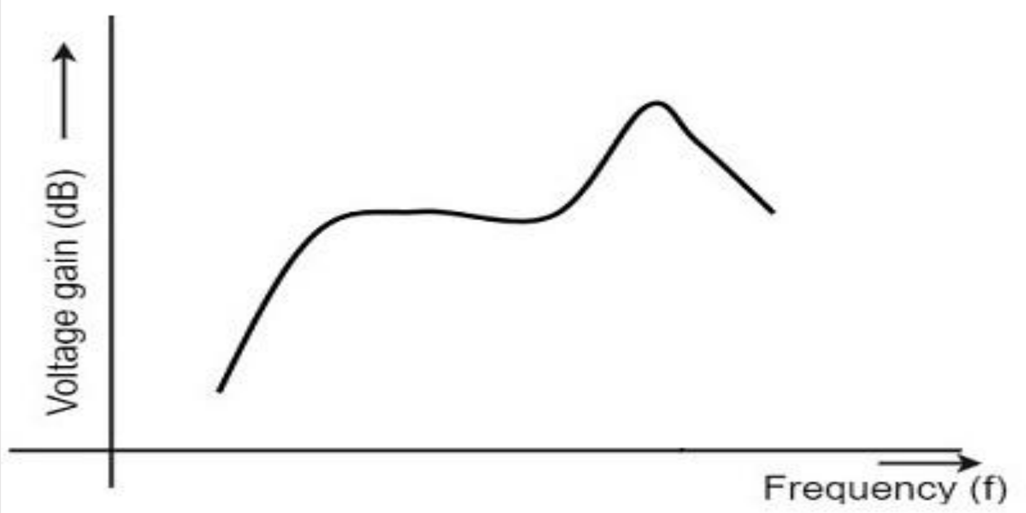
- The potential divider network $R_1$ and $R_2$ and the resistor $R_E$ together form the biasing and stabilization network. The emitter by-pass capacitor $C_E$ offers a low reactance path to the signal. The resistor $R_L$ is used as a load impedance. The input capacitor $C_{in}$ present at the initial stage of the amplifier couples AC signal to the base of the transistor. The capacitor $C_C$ is the coupling capacitor that connects two stages and prevents DC interference between the stages and controls the shift of operating point.

## Operation of Transformer Coupled Amplifier

- When an AC signal is applied to the input of the base of the first transistor then it gets amplified by the transistor and appears at the collector to which the primary of the transformer is connected.
- The transformer which is used as a coupling device in this circuit has the property of impedance changing, which means the low resistance of a stage (or load) can be reflected as a high load resistance to the previous stage. Hence the voltage at the primary is transferred according to the turn ratio of the secondary winding of the transformer.
- This transformer coupling provides good impedance matching between the stages of amplifier. The transformer coupled amplifier is generally used for power amplification.

# Frequency Response Transformer Coupled Amplifier

- The gain of the amplifier is constant only for a small range of frequencies. The output voltage is equal to the collector current multiplied by the reactance of primary.
- At low frequencies, the reactance of primary begins to fall, resulting in decreased gain. At high frequencies, the capacitance between turns of windings acts as a bypass condenser to reduce the output voltage and hence gain.
- So, the amplification of audio signals will not be proportionate and some distortion will also get introduced, which is called as **Frequency distortion**.



# Transformer Coupled Amplifier

## Advantages of Transformer Coupled Amplifier

- An excellent impedance matching is provided.
- Gain achieved is higher.
- There will be no power loss in collector and base resistors.
- Efficient in operation.

## Disadvantages of Transformer Coupled Amplifier

- Though the gain is high, it varies considerably with frequency. Hence a poor frequency response.
- Frequency distortion is higher.
- Transformers tend to produce hum noise.
- Transformers are bulky and costly.

## Applications

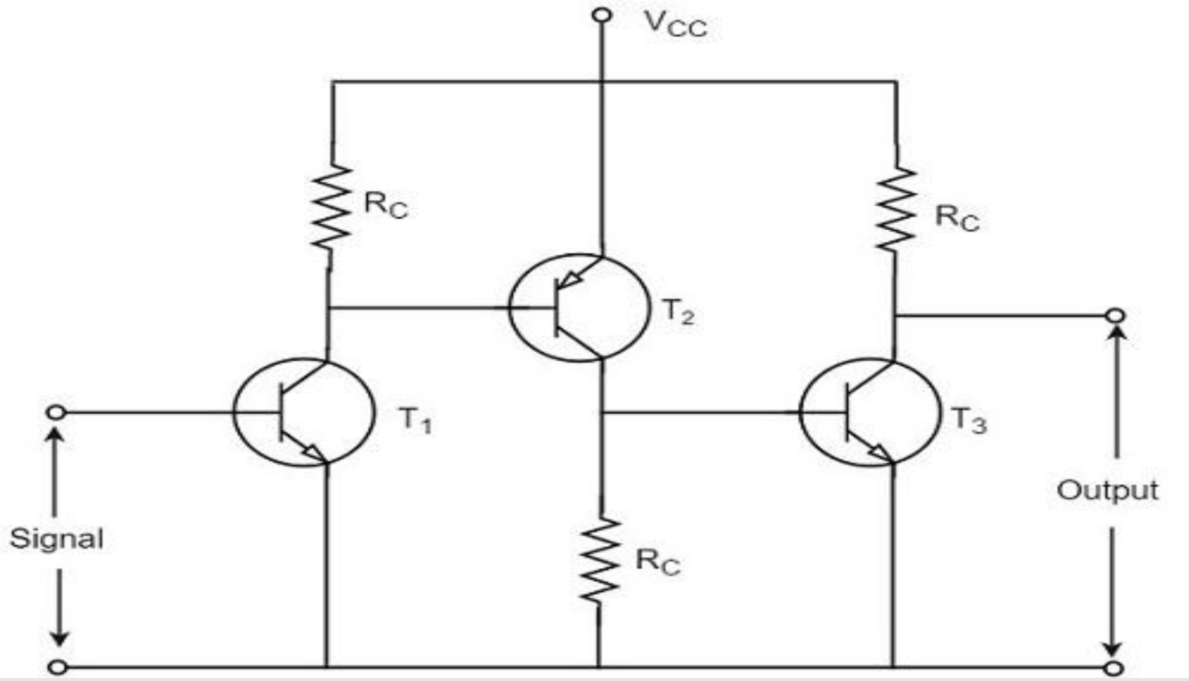
- Mostly used for impedance matching purposes.
- Used for Power amplification.
- Used in applications where maximum power transfer is needed.

# Direct Coupled Amplifier

- As no coupling devices are used, the coupling of the amplifier stages is done directly and hence called as **Direct coupled amplifier**.

## Construction

- The figure below indicates the three stage direct coupled transistor amplifier. The output of first stage transistor $T_1$ is connected to the input of second stage transistor $T_2$.



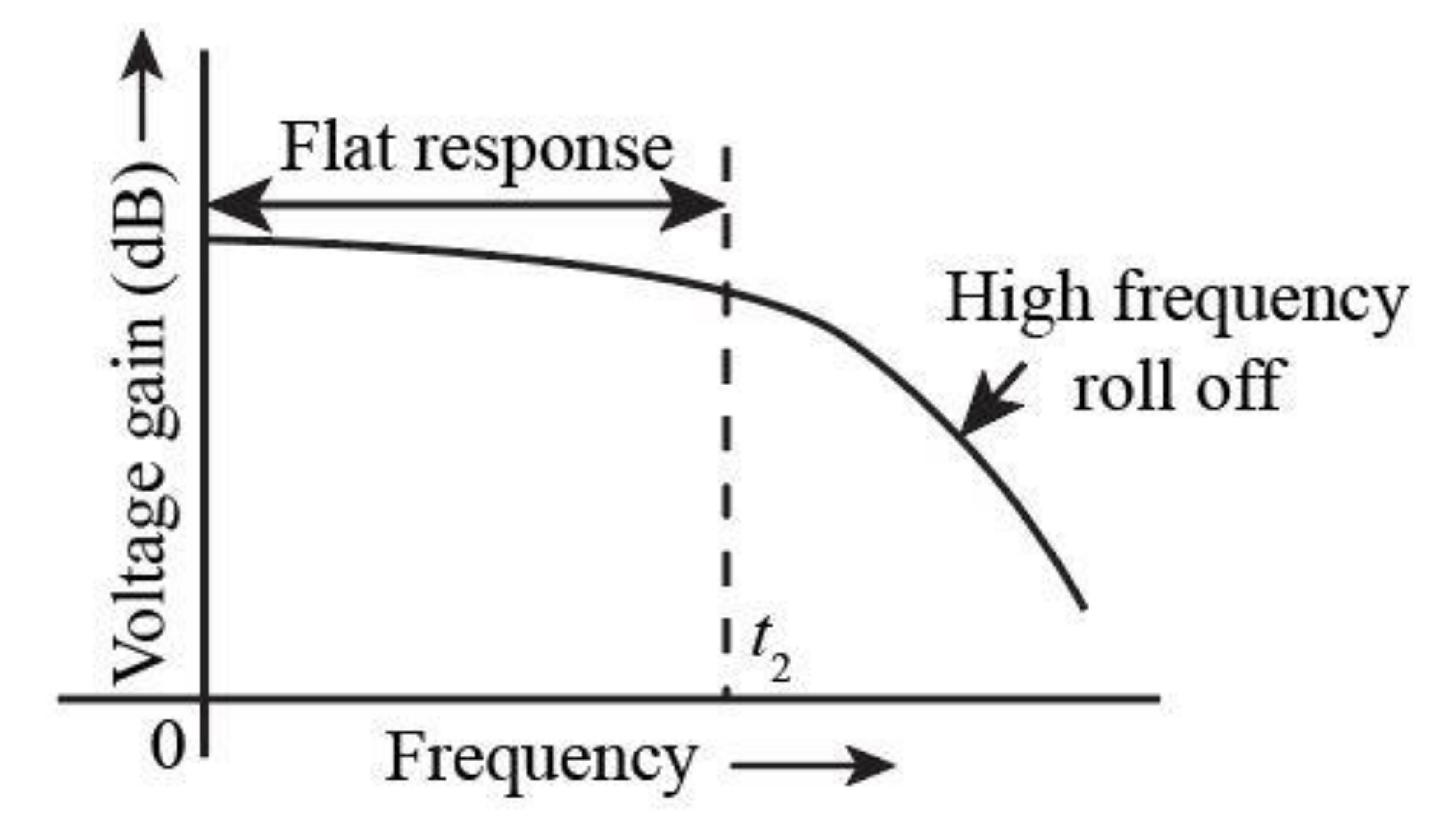
# Direct Coupled Amplifier

- The transistor in the first stage will be an NPN transistor, while the transistor in the next stage will be a PNP transistor and so on. This is because, the variations in one transistor tend to cancel the variations in the other. The rise in the collector current and the variation in $\beta$ of one transistor gets cancelled by the decrease in the other.

## Operation

- The input signal when applied at the base of transistor $T_1$, it gets amplified due to the transistor action and the amplified output appears at the collector resistor $R_c$ of transistor $T_1$. This output is applied to the base of transistor $T_2$ which further amplifies the signal. In this way, a signal is amplified in a direct coupled amplifier circuit.

# Frequency Response of Direct Coupled Amplifier



# Direct Coupled Amplifier

## Advantages

- The circuit arrangement is simple because of minimum use of resistors.
- The circuit is of low cost because of the absence of expensive coupling devices.

## Disadvantages

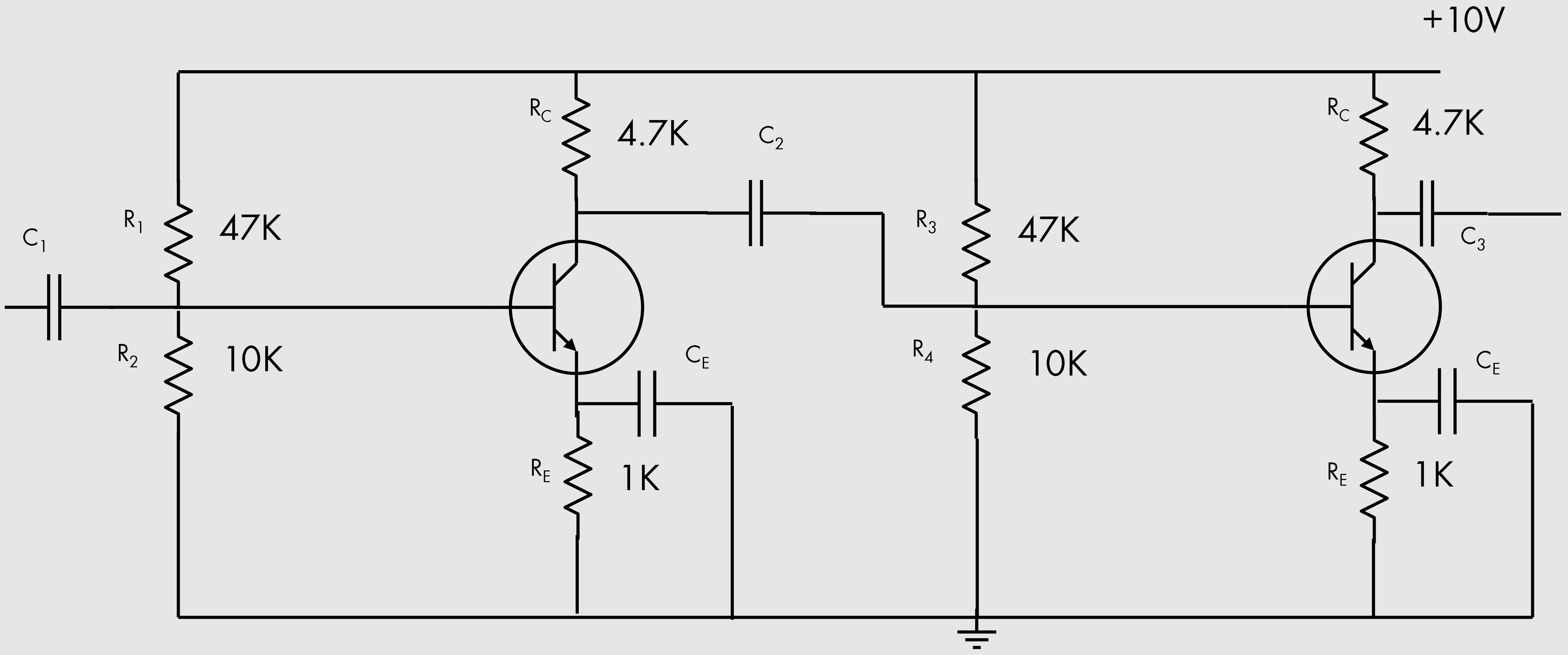
- It cannot be used for amplifying high frequencies.
- The operating point is shifted due to temperature variations.

## Applications

- Low frequency amplifications.
- Low current amplifications.

# 2-stage amplifier

Find the overall voltage gain of cascaded transistor amplifier as shown in the figure below. $r_{e1} = r_{e2} = 23.8\Omega$ and $\beta_1 = \beta_2 = 150.$



# 2-stage amplifier

Find the overall voltage gain of cascaded transistor amplifier as shown in the figure below. $r_{e1} = r_{e2} = 23.8\Omega$ and $\beta_1 = \beta_2 = 150$.

Given,

$r_{e1} = r_{e2} = 23.8\Omega$

$\beta_1 = \beta_2 = 150$

$R_1 = 47K\Omega$

$R_2 = 10K\Omega$

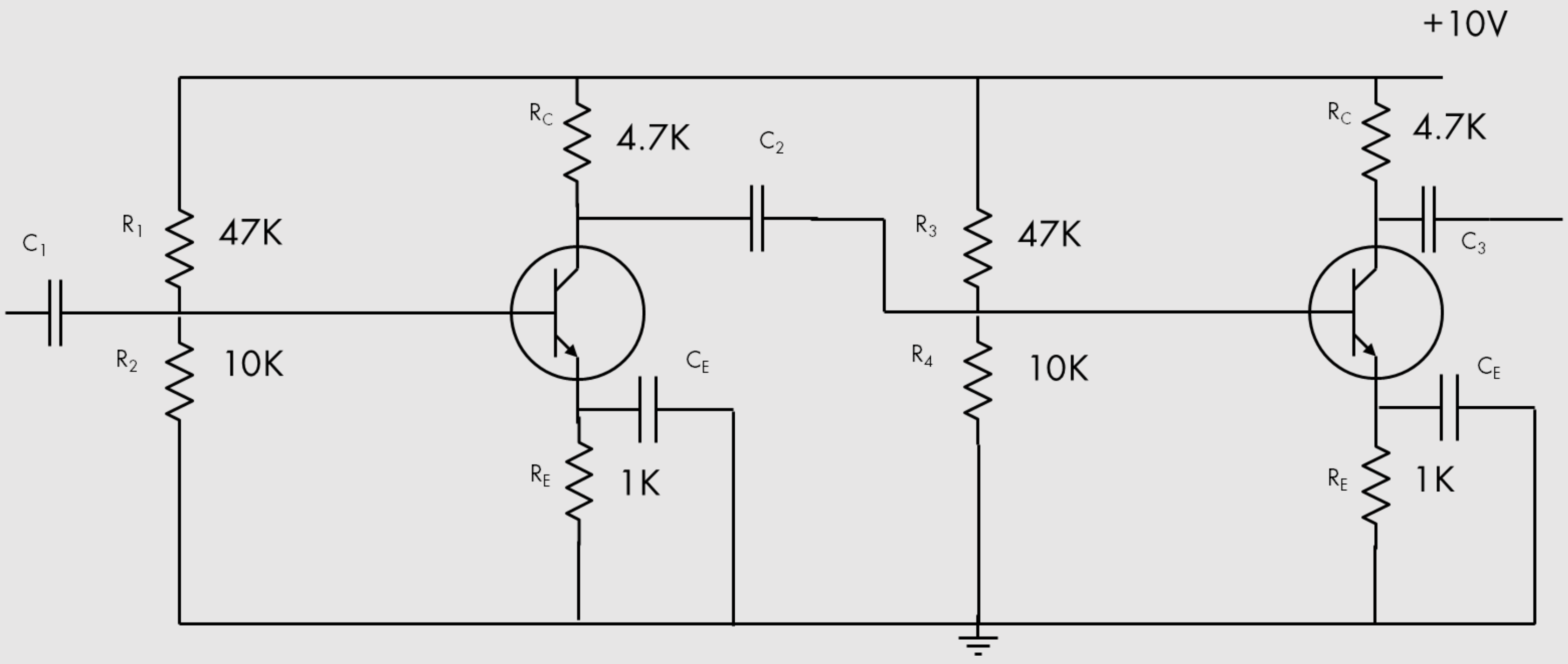
$R_{C1} = R_{C2} = 4.7K\Omega$

$R_3 = 47K\Omega$

$R_4 = 10K\Omega$

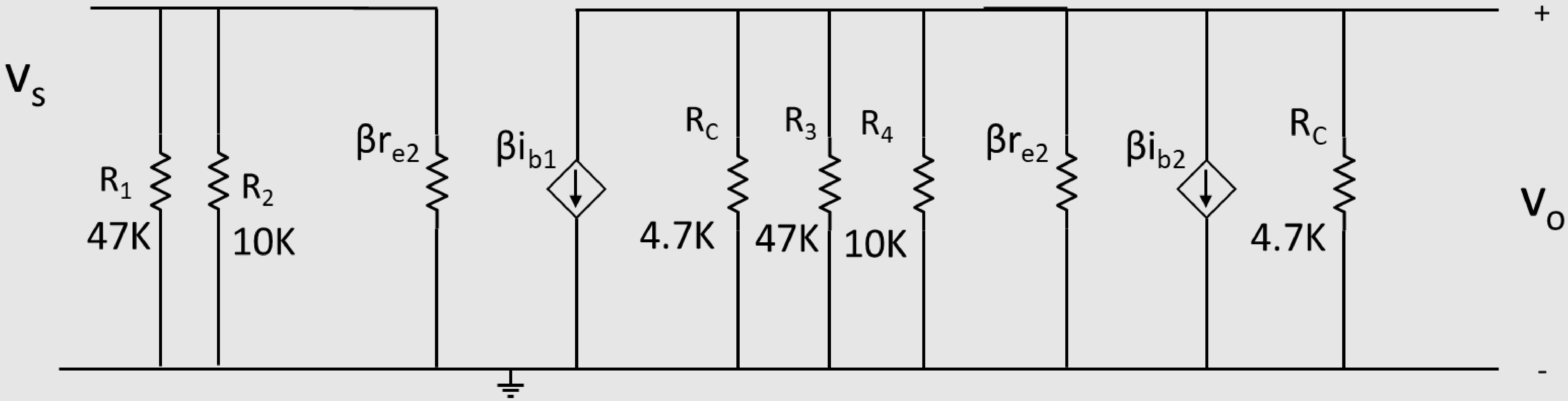
$R_{E2} = 1\text{K}\Omega$

$R_{E1} = 1\text{K}\Omega$



# 2-stage amplifier

Find the overall voltage gain of cascaded transistor amplifier as shown in the figure below. $r_{e1} = r_{e2} = 23.8\Omega$ and $\beta_1 = \beta_2 = 150.$



# 2-stage amplifier

## Voltage gain of the first stage

The ac output impedance of the first stage is

$$Z_{o1} = R_C \parallel R_3 \parallel R_4 \parallel \beta r_e$$

$$Z_{o1} = 4.7k \parallel 47k \parallel 10k \parallel (150 \times 23.8)/1000$$

$$Z_{o1} = \left(\frac{1}{4.7} + \frac{1}{47} + \frac{1}{10} + \frac{1}{3.57}\right)^{-1} = 1.63k\Omega$$

The base-to-collector voltage gain of the first stage is

$$A_{v1} = \frac{Z_{o1}}{r_e} = \frac{1630}{23.8} = 68.5$$

## Voltage gain of the second stage

The ac output impedance of the second stage is

$$Z_{o2} = R_C = 4.7k\Omega$$

The base-to-collector voltage gain of the second stage is

$$A_{v2} = \frac{Z_{o2}}{r_e} = \frac{4700}{23.8} = 197$$

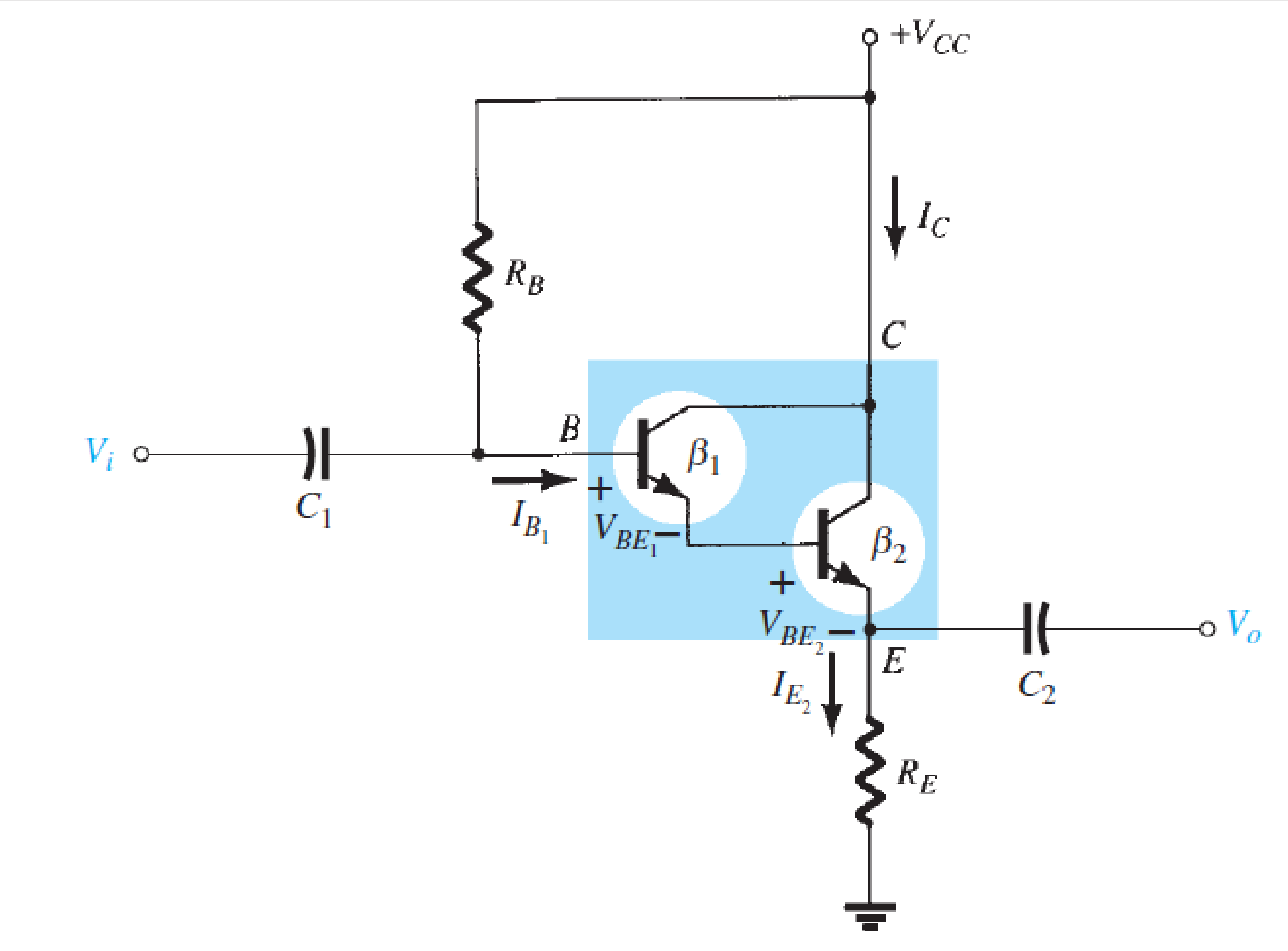
## Overall voltage gain

$$A_T = A_{v1} \times A_{v2} = 68.5 \times 197 = 13494.5$$
$$A_T(dB) = 20 \log 13494.5 = 82.6dB$$

# Choice of configuration in a cascade

| Characteristics | CE configuration | CB configuration | CC configuration |
|---|---|---|---|
| **Input resistance** | Low (50 KΩ) | Very low (40 Ω) | Very high (750 KΩ) |
| **Output resistance** | High (10 KΩ) | Very high (1 MΩ) | Low (50 Ω) |
| **Current Gain** | High (100) | Less than unity (0.98) | High (100) |
| **Input voltage** | Applied between base and emitter. | Applied between emitter and base. | Applied between base and collector. |
| **Output voltage** | Applied between `emitter and collector. | Applied between collector and emitter. | Applied between emitter and ground. |
| **Voltage Gain** | High (500) | Small (150) | Less than unity |
| **Applications** | Used in amplifier circuits. | Used for high-frequency applications. | Used for impedance matching. |

# Darlington Pair




$$\beta = \beta_1 \beta_2$$

$$I_{E1} = (\beta_1 + 1) I_{B1}$$

$$I_{E2} = (\beta_2 + 1) I_{B2} = (\beta_2 + 1)(\beta_1 + 1) I_{B1}$$