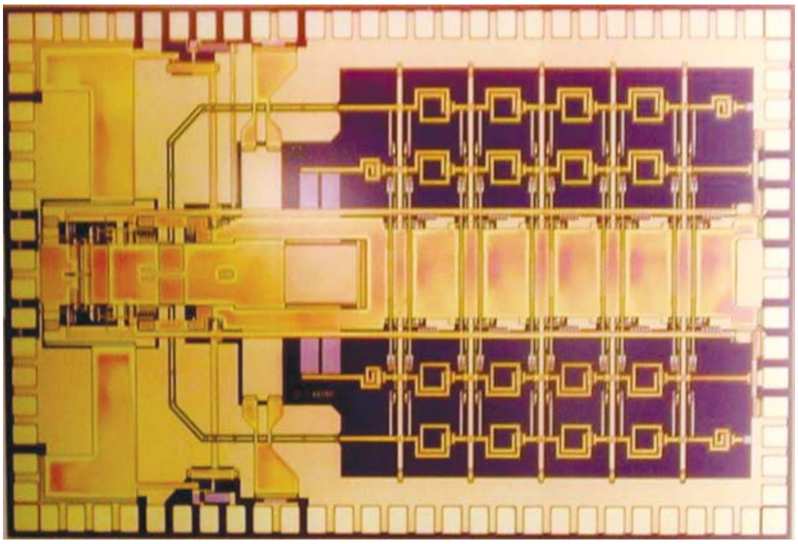
CONTENTS

CHAPTER 61

MULTISTAGE AND FEEDBACK AMPLIFIERS

Learning Objectives

- General
- Amplifier Coupling
- RC-coupled Two-stage Amplifier
- Impedance-coupled Two-stage Amplifier
- Advantages of Impedance Coupling
- Transformer-coupled Two-stage Amplifier
- Advantages of Transformer Coupling
- Frequency Response
- Direct-coupled Two-stage Amplifier Using Similar Transistors
- Direct-coupled Amplifier Using Complementary Symmetry of Two Transistors
- Darlington Pair
- Advantages of Darlington Pair
- Comparison Between Darlington Pair and Emitter Follower
- Special Features of a Differential Amplifier
- Common Code Input
- Differential Amplifier



In a multistage amplifier, a number of single amplifiers are connected an cascade arrangement *i.e.* the output of first stage is connected to the input of second stage.

CONTENTS

61.1. General

Often, the voltage amplification or power gain or frequency response obtained with a single stage of amplification is insufficient to meet the requirements of either a composite electronic circuit or a load device. Hence, two or more single stages of amplification are frequently used to achieve greater voltage or current amplification or both. In such cases, the output of one stage serves as input of the next stage as shown in Fig. 61.1. Such amplifiers may be divided into following two categories :

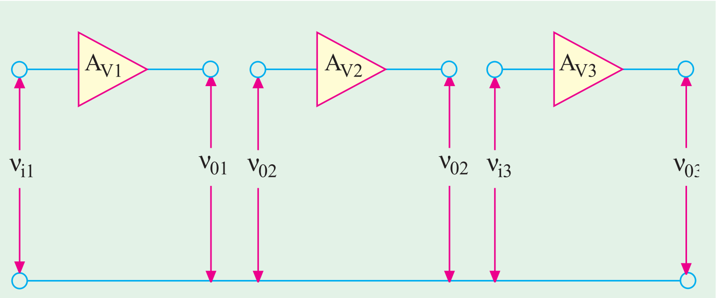


Fig. 61.1

(*a*) Cascaded Amplifiers

In these amplifiers, each stage as well as the type of interstage coupling used are identical.

(*b*) Compound Amplifiers

In these amplifiers, each stage may be different from the other (one may be *CE* and the other may be *CC* stage) and also different types of interstage couplings may be employed.

As stated above, in cascaded amplifiers, the output ac voltage of the first stage becomes the input voltage of the second stage and the ac output of the second stage becomes the input of the third stage and so on. The overall voltage gain of the cascaded amplifier is equal to the ***product*** (not the sum) of the gain of the individual stages.

$$\therefore \qquad A_v = A_{v1} \times A_{v2} \times A_{v3} \times \ldots\ldots\ldots$$

However, when the voltage gain is expressed in decibels (dB), then the overall decibel gain of the multistage amplifier is equal to the ***sum*** of the dB gains of the individual stage *i.e.*

$$G = G_1 + G_2 + G_3 + \ldots\ldots\ldots$$

Similarly, the overall current amplification is given by

$$A_i = A_{i1} \times A_{i2} \times A_{i3} \times \ldots\ldots\ldots$$

The overall power gain is given by

$$A_p = A_v . A_i \qquad \text{and} \qquad G_p = 10 \log_{10} A_p \text{ dB}$$

Suppose in a two-stage cascaded amplifier, first stage has a voltage amplification of 2000 (dB gain of the 20 $\log_{10}$ 2000 = 66 dB) and second stage has corresponding values of 1000 (60 dB). If the ac output of first stage is fed into the second stage, the overall amplification would theoretically become = 1000 × 2000 = 2 × 10^6 which corresponds to a dB gain of (60 + 66) = 126 *i.e.* 20 $\log_{10}$ 2 × 10^6 = 20 × 6.3 = 126. The above result would be true only when we ***neglect the loading effect of first stage by the second stage.*** It would be approximately true so long as the impedance looking into the input of second stage is much greater than the output impedance of the first stage. Otherwise, the overall gain would be much less.

61.2. Amplifier Coupling

All amplifiers need some ***coupling network***. Even a single-stage amplifier has to be coupled to the input and output devices. In the case of multistage systems, there is ***interstage*** coupling. The type of coupling used determines the characteristics of the cascaded amplifier. In fact, amplifiers are classified according to the coupling network used.

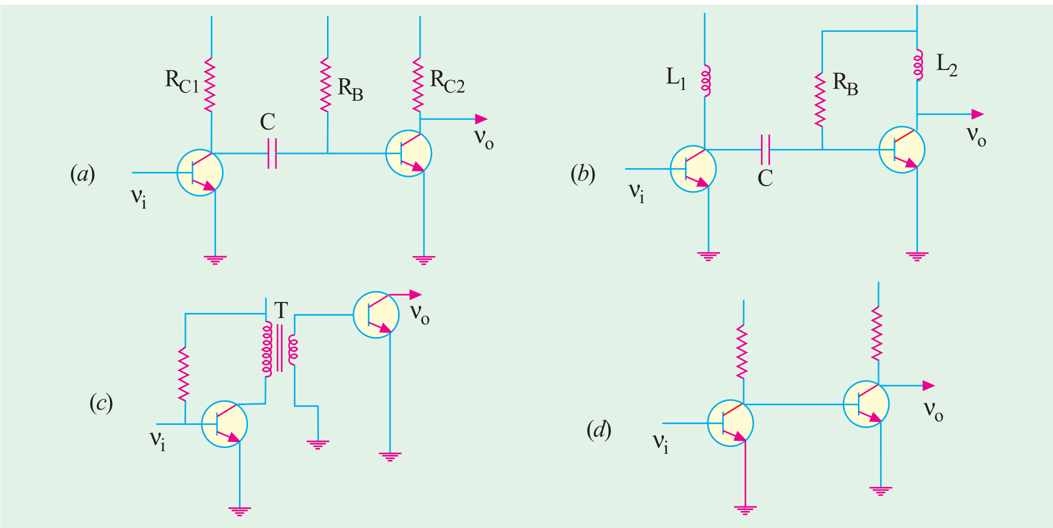


Fig. 61.2

The four basic methods of coupling are :

Modern coupling transformer

1. Resistance-Capacitance (RC) Coupling

It is also known as ***capacitive*** coupling and is shown in Fig. 61.2 (*a*). Amplifiers using this coupling are known as *RC*-coupled amplifiers. Here, *RC* coupling network consists of two resistors R_{C1} and R_{C2} and one capacitor *C*. The connecting link between the two stages is *C*. The function of the *RC*-coupling network is two-fold :

(*a*) to pass ac signal from one stage to the next,

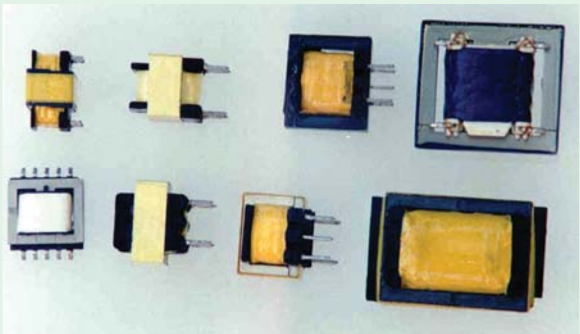
(*b*) to block the passage of dc voltages from one stage to the next.

2. Impedance Coupling or Inductive Coupling

It is also known as choke-capacitance coupling and is shown in Fig. 61.2 (*b*). Amplifiers using this coupling are known as **impedance-coupled** amplifiers. Here, the coupling network consists of L_1, *C* and R_B. The impedance of the coupling coil depends on **(*i*)** its inductance and **(*ii*)** signal frequency.

3. Transformer Coupling

It is shown in Fig. 61.2 (*c*). Since secondary of the coupling transformer conveys the ac component of the signal directly to the base of the second stage, there is ***no need for a coupling capacitor.*** Moreover, the secondary winding also provides a base return path, hence there ***is no need for a base resistance***. Amplifiers using this coupling are called ***transformer-coupled amplifiers***.



R.C. Coupled two-stage amplifier

4. Direct Coupling

It is shown in Fig. 61.2 (*d*). This coupling is used where it is desirable to connect the load directly in series with the output terminal of the active circuit element. The examples of such load devices are **(*i*)** headphones **(*ii*)** loud-speakers **(*iii*)** dc meters **(*iv*)** relays and **(*v*)** input circuit of a transistor etc. Of course, direct coupling is permissible only when

(*i*) dc component of the output does not disturb the normal operation of the load device,

(*ii*) device resistance is so low that it does not appreciably reduce the voltage at the electrodes.

61.3. RC-coupled Two-stage Amplifier

Fig. 61.3 shows a two-stage *RC*-coupled amplifier which consists of two single-stage transistor amplifiers using the *CE* configuration. The resistors R_2 and R_3 and capacitor C_2 form the coupling network. R_2 is collector load of Q_1 and R_4 is that of Q_2. Capacitor C_1 couples the input signal whereas C_3 couples out the output signal. R_1 and R_3 provide dc base bias.

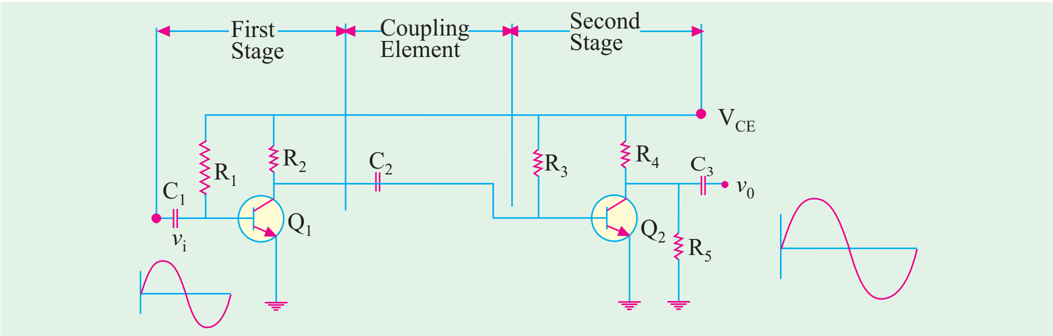


Fig. 61.3

(*i*) Circuit Operation

The brief circuit operation is as under :

1. the input signal n_i is amplified by Q_1. It is phase ***reversed*** (usual with C_E connection);
2. the amplified output of Q_1 appears across R_2;
3. the output of the first stage across R_2 is coupled to the input at R_3 by coupling capacitor C_2. This capacitor is also sometimes referred to as ***blocking capacitor*** because it blocks the passage of dc voltages and currents;

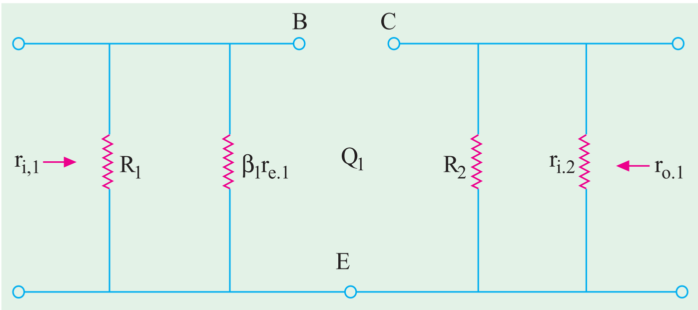


Fig. 61.4

4. the signal at the base of Q_2 is further amplified and ***its phase is again reversed;***
5. the ac output of Q_2 appears across R_4;
6. the output across R_4 is coupled by C_3 to load resistor R_5;
7. the output signal v_0 is the ***twice-amplified replica of the input signal v_i.*** It is in phase with v_i *because it has been reversed twice*.

(*ii*) AC Equivalent Circuit

The ac equivalent circuits for the two stages have been shown separately in Fig. 61.4 and Fig. 61.5 respectively.

If Fig. 61.4, $r_{i.1} = R_1 \,||\, \beta_1 . r_{e.1}$

It is the input impedance of the first stage and not $r_{in(base)}$.

The output impedance of the first stage is

$r_{0.1} = R_2 \,||\, r_{i.2}$

It is so because the input of the second stage forms a part of the output of the first stage. As seen from Fig. 61.5.

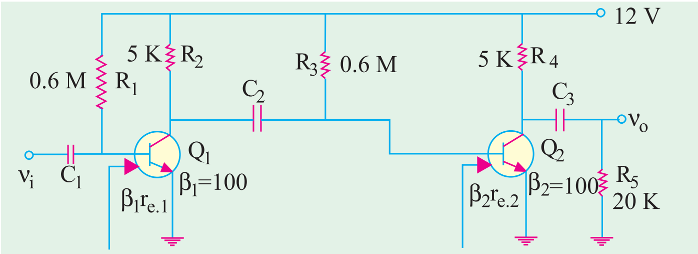


Fig. 61.5

$r_{i.2} = R_3 \,||\, \beta_2 . r_{e2} \cong \beta_2 r_{e.2}$,

where $r_{e.1}$ and $r_{e.2}$ are ac junction resistances of the two transistors and are given by

$$r_{e.1} = \frac{25\,\text{mV}}{I_{E.1}} \text{ or } \frac{50\,\text{mV}}{I_{E.1}} \quad \text{and} \quad r_{e.2} = \frac{25\,\text{mV}}{I_{E.2}} \text{ or } \frac{50\,\text{mV}}{I_{E.2}}$$

The output impedance of Q_2 is $r_{0.2} = R_4 \,||\, R_5$

(*iii*) Voltage Gain

$$r_{1.2} = \beta_2 r_{e.2} \qquad \text{Now} \qquad A_{v2} = \beta_2 \frac{r_{0.2}}{\beta_2 . r_{1.2}} = \frac{r_{0.2}}{r_{e.2}}$$

$$\text{Also,} \quad r_{i.2} = \beta_2 r_{e.2} \qquad \therefore \qquad A_{v2} = \beta_2 \frac{r_{0.2}}{\beta_2 . r_{e.2}} = \frac{r_{0.2}}{r_{e.2}}$$

The voltage gain of the first stage is also given by a similar equation

$$A_{vi} = \frac{r_{0.1}}{r_{e.1}}$$

Example 61.1. *For the two-stage RC-coupled low-level audio amplifier shown in Fig. 61.6, compute the following :*

(i) r_i *(ii)* A_{v1} *(iii)* A_{v2} *and (iv)* A_v *in dB. Neglect* V_{BE} *and take* $r_e = 25\ \text{mV}/I_E$.

(Electronic Circuits, Mysore Univ.)

Solution. The input impedance of the cascaded amplifier is

(*i*) $r_i = R_1 \,||\, \beta_1 . r_{e.1}$

For finding $r_{e.1}$, we need $I_{E.1}$ which approximately equals $I_{C.1}$

Now, $I_{C.1} = \beta . I_{B.1}$

Also, $I_{B1} = 12/R_1 = 12/0.6\ \text{M}$

$= 20\ \mu\text{A}$

$\therefore \quad I_{C1} = 100 \times 20$

$= 2000\ \mu\text{A} = 2\ \text{mA}$

$\therefore \quad I_{E.1} = 2\ \text{mA}$

$\therefore \quad r_{e.1} = 25/2 = 12.5\ \Omega$;

$\beta_1 r_{e.1} = 100 \times 12.5 = 1250$

$\therefore \quad r_i = R_1 \,||\, \beta_1 . r_{e.1}$

$= 0.6\ \text{M} \,||\, 1250\ \Omega$

$\cong$ **1250 Ω**

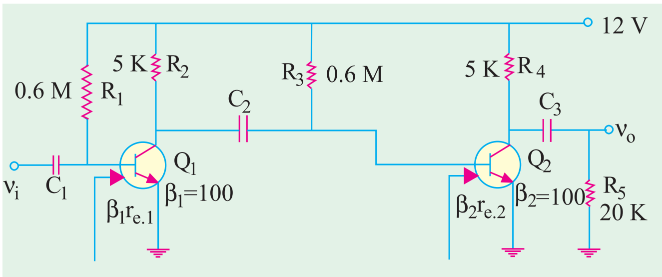


Fig. 61.6

(*ii*) $A_{v1} = \dfrac{r_{0.1}}{r_{e.1}} \qquad \text{Now,} \qquad r_{0.1} = R_2 \,||\, r_{i.2}$

$r_{i.2} = R_3 \,||\, \beta_2 r_{e.2} = 0.6\ \text{M} \,||\, 1250\ \Omega \cong 1250\ \Omega$

$r_{0.1} = 5\ \text{K} \,||\, 1250\ \Omega = 1000\ \Omega$; $r_{e.1} = 12.5\ \Omega \qquad \therefore \qquad A_{v.1} = 1000/12.5 = 80$

(iii) $A_{v2} = \dfrac{r_{0.2}}{r_{e.2}}$

Now, $r_{0.2} = R_4 \| R_5 = 5\text{ K} \| 20\text{ K} = 4\text{ K}$, $I_{E.2} = 2\text{ mA}$ – same as $I_{E.1}$

$r_{e.2} = 25/2 = 12.5\ \Omega$ $\therefore$ $A_{v2} = 4000/12.5 =$ **320**

(iv) $A_v = A_{v.1} \times A_{v.2} = 80 \times 320 =$ **25,600**

(v) $G_v = 20 \log_{10} A_v\ dB = 20 \log_{10} 25{,}600 =$ **88 dB**.

Example 61.2. *For the two-stage RC-coupled amplifier shown in Fig. 61.7 compute the following :*

(i) r_i, *(ii)* $A_{v.1}$, *(iii)* $A_{v.2}$, *(iv)* A_v *in decibels.*

Take $\beta_1 = \beta_2 = 100$. *Neglect* V_{BE} *and use* $r_e = 25\ mV/I_E$.

(Applied Electronics-I, Punjab Univ. 1991)

Solution. *(i)* The input impedance of the stage is $r_i = R_1 \| \beta_1.r_{e.1}$

It should be noted that R_6 does not come into the picture because it has been ac grounded by C_4. However, it would affect the dc emitter current.

$$I_{E.1} = \frac{V_{CC}}{R_6 + R_1/\beta_1} = \frac{25}{10{,}000 + 1.5\times10^6/100} = 1\text{mA}$$

$r_{e.1} = 25/1 = 25\ \Omega$; $\beta_1.r_{e.1} = 100 \times 25 = 2500\ \Omega$

$r_i = 1.5\text{ M} \| 2500\ \Omega \cong$ **2500 Ω**

(ii) $A_{v.1} = \dfrac{r_{0.1}}{r_{e.1}}$

Now, $r_{0.1} = R_2 \| r_{i.2}$ and $r_{i.2} = R_3 \| \beta_2 r_{e.2}$

Now, $I_{E.2} = \dfrac{25}{10{,}000 + 1.5\times10^6/100} = 1\text{mA}$

$\therefore$ $r_{e.2} = 25/1 = 25\ \Omega$; $\beta_2.r_{e.2} =$ **2500 Ω**

$r_{i.2} = 1.5\text{ M} \|\ 2500\ \Omega$

$\cong 2500\ \Omega$

$r_{0.1} = 5\text{ K} \| 2.5\text{ K}$

$= 1{,}667\ \Omega$

$\therefore$ $A_{v.1} = 1667/25 =$ **66.7**

(iii) $A_{v.2} = \dfrac{r_{0.2}}{r_{e.2}}$,

Now, $r_{0.2} = R_4 \| R_5$

$= 5\text{ K} \| 20\text{ K} = 4\text{ K}$

$\therefore$ $A_{v.2} = 4000/25 =$ **160**

(iv) $A_v = A_{v.1} \times A_{v.2}$

$= 66.7 \times 160 =$ **10,672** ;

$G_v = 20 \log_{10} 10{,}672 =$ **80.3 dB**

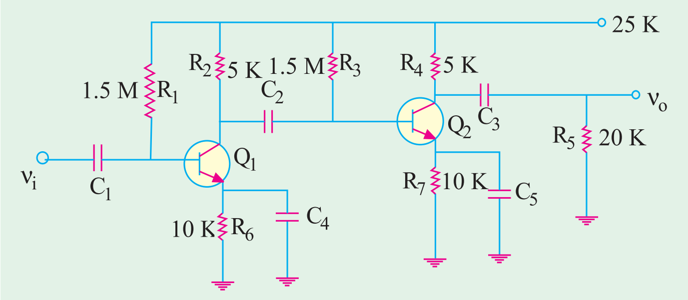


Fig. 61.7

Example 61.3. *Compute the overall voltage amplification for the two-stage RC-coupled amplifier shown in Fig. 61.8. Express the answer in decibels. Neglect* V_{BE} *and use* $r_e = 50\ mV/I_E$. *Take* $\beta_1 = \beta_2 = 100$.

(Electronics-I, Allahabad Univ. 1990)

Solution. For finding the overall gain, we will have to find each stage gain.

(i) $A_{v1} = \dfrac{r_{0.1}}{r_{e.1}}$, Now, $r_{0.1} = R_3 \| r_{i.2}$ and $r_{i.2} = R_5 \| R_6 \| \beta_2.r_{e.2}$

Now, $r_{e.2} = 50/I_{E.2}$

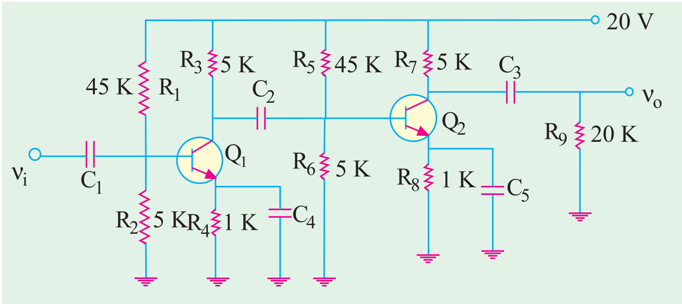


Fig. 61.8

Drop across

$$R_6 = 20 \times \frac{5}{5+45} = 2\text{V}$$

It also represents the approximate drop across R_8.

$\therefore\ I_{E2} = 2/1\text{ K} = 2\text{ mA}$

$\therefore\ r_{e.2} = 50/2 = 25\ \Omega.$

$\beta_2 . r_{e.2} = 100 \times 25 = 2.5\text{ K}$

$r_{i.2} = 45\text{ K} \parallel 5\text{ K} \parallel 2.5\text{ K} = 1.6\text{ K};\quad \therefore\ r_{0.1} = 5\text{ K} \parallel 1.6\text{ K} = 1.2\text{ K}$

$\therefore\quad r_{e.1} = 50/I_{E.1} = 50/2 = 25\ \Omega$

$\therefore\quad A_{v.1} = 1200/25 = 48$

$$A_{v.2} = \frac{r_{o.2}}{r_{e.2}};\quad r_{0.2} = R_7 \parallel R_9 = 5\text{K} \parallel 20\text{K} = 4\text{K}$$

$\therefore\quad A_{v.2} = 4000/25 = 160 \quad \therefore\ A_v = 48 \times 160 = 7{,}680\ ;\ G_v = 20\log_{10} 7{,}680 =$ **77.6 dB**

61.4. Advantages of RC Coupling

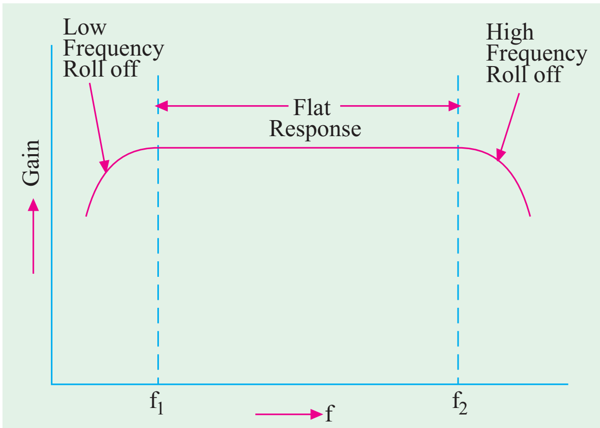


Fig. 61.9

1. It requires no expensive or bulky components and no adjustments. Hence, it is small, light and inexpensive.
2. Its overall amplification is higher than that of the other couplings.
3. It has minimum possible nonlinear distortion because it does not use any coils or transformers which might pick up undesirable signals. Hence, there are no magnetic fields to interfere with the signal.
4. As shown in Fig. 61.9, it has a very flat frequency ***versus*** gain curve *i.e.* it gives uniform voltage amplification over a wide range from a few hertz to a few megahertz because resistor values are independent of frequency changes.

As seen from Fig. 61.9, amplifier gain falls off at very low as well as very high frequencies. At low frequencies, the fall in gain (called ***roll-off***) is due to capacitive reactance of the coupling capacitor between the two stages. The high-frequency roll-off is due to output capacitance of the first stage, input capacitance of the second stage and the stray capacitance.

The only drawback of this coupling is that due to large drop across collector load resistors, the collectors work at relatively small voltages unless higher supply voltage is used to overcome this large drop.

61.5. Impedance-coupled Two Stage Amplifier

The circuit is shown in Fig. 61.10. The coupling network consists of L, C_2 and R_3. The only basic difference between this circuit and the one shown in Fig. 61.3 is that inductor **L *has replaced the resistor R_2*.**

(*i*) AC Equivalent Circuit

The ac equivalent circuit (at mid-frequency) of the cascaded amplifier has been shown in Fig. 61.11. Because of mid-frequency range, effects of all capacitances have been ignored.

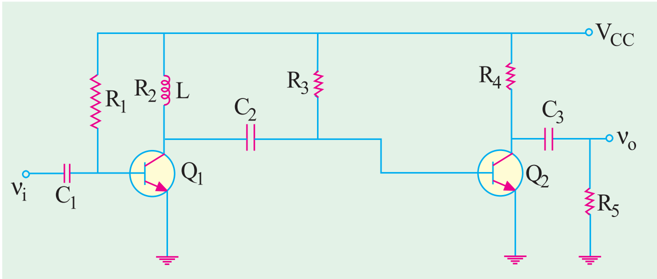


Fig. 61.10

(*ii*) Circuit Operation

The operation of this circuit is the same as that of the RC-coupled circuit described earlier.

(*iii*) Voltage Gain

It is given by the product of two stage gains $A_v = A_{v1} \times A_{v2}$

Now, $\quad A_{v.1} = \dfrac{Z_{0.1}}{r_{e.1}} \quad$ where $\quad Z_{0.1} = X_L \| r_{i.2}$ and $r_{i.2} = R_3 \| \beta_2.r_{e.2}$

In case, $X_L \gg r_{i.2}$, then, $Z_{0.1} \cong r_{i.2}$

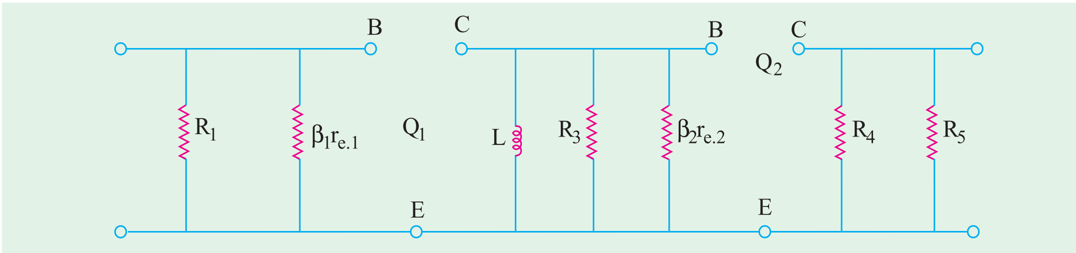


Fig. 61.11

$\therefore \quad A_{v.1} = \dfrac{r_{i.2}}{r_{e.1}} \quad$ and $\quad A_{v.2} = \dfrac{r_{0.2}}{r_{e.2}}$

$\therefore \quad A_v = A_{v.1} \times A_{v.2}$

Example 61.4. *For the impedance-coupled two-stage amplifier shown in Fig. 61.12, compute the values of*

(i) $A_{v.2}$, *(ii)* $A_{v.1}$ *at 4 kHz and (iii)* A_v *in dB.*

Neglect V_{BE} *and use* $r_e = 25\ mV/I_E$. *Take* $\beta_1 = \beta_2 = 100$.

(Industrial Electronics, Calcutta Univ. 1991)

Solution. (*i*) $\quad A_{v.2} = \dfrac{r_{0.2}}{r_{e.2}}$

Now, $\quad r_{0.2} = R_4 \| R_5 = 8\text{ K} \| 24\text{ K} = 6\text{ K}$

$I_{B2} = 12/1.2\text{M} = 10\ \mu\text{A},\ I_{C.2} = \beta_2 \,.\, I_{B.2} = 100 \times 10 = 1000\ \mu\text{A} = 1\text{ mA}$

$\therefore \quad I_{E2} \cong 1\text{ mA}$

$\therefore \quad r_{e.2} = 25/1 = 25\ \Omega$

$$A_{v.2} = \frac{6{,}000}{25} = \mathbf{240}$$

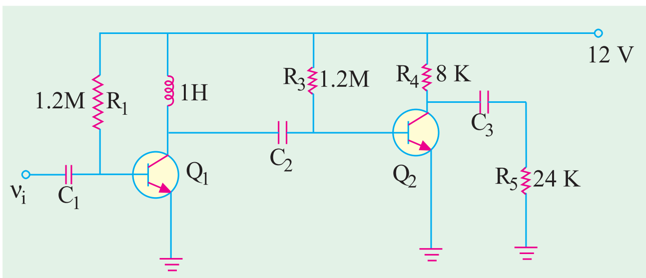


Fig. 61.12

(*ii*) $\quad A_{v.1} = \dfrac{Z_{0.1}}{r_{e.1}} \cong \dfrac{r_{i.2}}{r_{e.1}}$

Now, $\quad r_{e.1} = 25\ \Omega$ – equal to $r_{e.2}$

$X_L = 2\pi fL$

$= 2\pi \times 4 \times 10^3 \times 1$

$= 25,130\ \Omega \quad r_{i.2} = R_3$

$|| \beta_2.r_{e.2} = 1.2\text{M} || 2500\ \Omega \cong 2500\ \Omega$

Obviously, $X_L \gg r_{i.2}$ thus justifying the above approximation.

$\therefore \quad A_{v.1} = 2500/25 =$ **100**

(*iii*) $\quad A_v = 100 \times 240 = 24{,}000,\ G_v = 20 \log_{10} 24{,}000 =$ **87.6 dB**

61.6. Advantages of Impedance Coupling

The biggest advantage of this coupling is that there is hardly any dc drop across L so that low collector supply voltages can be used.

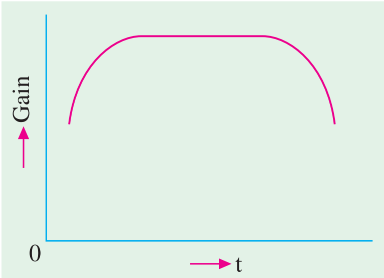


Fig. 61.13

However, it has many disadvantages :

1. It is larger, heavier and costlier than *RC* coupling.
2. In order to prevent the magnetic field of the coupling inductor from affecting the signal, the inductor turns are wound on a closed core and are also shielded.
3. Since inductor impedance depends on frequency, the frequency characteristics of this coupling are not as good as those of *BC* coupling. The flat part of the frequency ***versus*** gain curve is small (Fig. 61.13).

At low frequencies, the gain is low due to large capacitance offered by the coupling capacitor just as in R_C coupled amplifiers. The gain ***increases with frequency*** till it levels off at the middle frequencies of the audio range.

At relatively high frequencies, gain drops of again because of the increased reactance.

Hence, impedance coupling is rarely used beyond audio range.

61.7. Transformer-coupled Two Stage Amplifier

The circuit for such a cascaded amplifier is shown in Fig. 61.14. T_1 is the coupling transformer whereas T_2 is the output transformer. C_1 is the input coupling capacitor whereas C_2, C_3 and C_4 are the bypass capacitors. Resistors R_1 and R_2 as well as R_4 and R_5 form voltage divider circuits whereas R_3 and R_6 are the emitter-stabilizing resistors.

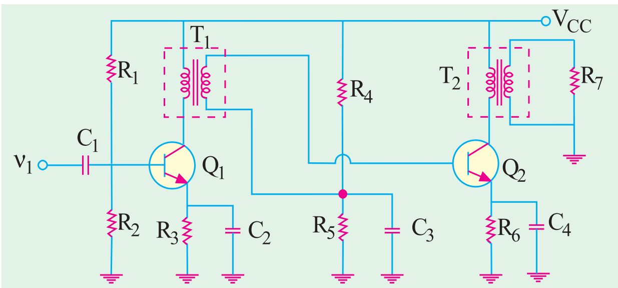


Fig. 61.14

(*i*) Circuit Operation

When input signal is coupled through C_1 to the base of Q_1, it appears in an amplified form in the primary of T_1. From there, it is passed on to the secondary by magnetic induction. Moreover, T_1 provides dc isolation between the input and output circuits. The secondary of T_1 applies the signal to the base of Q_2 which appears in an amplified form in the primary of T_2.

From there, it is passed on to the secondary by magnetic induction and finally appears across the matched load R_7.

(*ii*) Voltage Gain

$$A_{v.1} = \frac{r_{0.1}}{r_{e.1}} \qquad \text{Now} \quad r_{0.1} = a^2 r_{i.2} \qquad \text{— where } a = N_1/N_2 \text{ for } T_1$$

$$r_{i.2} = R_4 || R_5 || \beta_2.r_{e.2}$$

Similarly, $A_{e.2} = \dfrac{r_{0.2}}{r_{e.2}}$

where $r_{e.2} = a^2 R_7$

Example 61.5. *For the transformer-coupled two-stage amplifier shown in Fig. 61.15, calculate* ***(i)*** $A_{v.1}$ ***(ii)*** $A_{v.2}$ *and* ***(iii)*** A_v *in dB.*

Neglect V_{BE} and use r_e = 50 mV/ I_E. Take $\beta_1 = \beta_2 = 50$ and treat the transformers as ideal ones.

(Electronics, Indore Univ.)

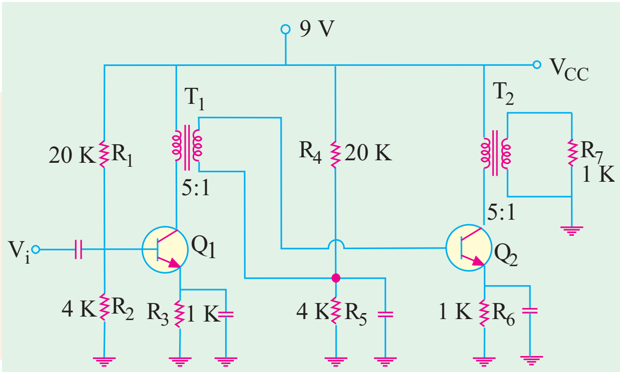


Fig. 61.15

Solution. Here, for each transformer a = 5

Drop across R_2 = 9 × 4/24 = 1.5 V

Drop across $R_3 \cong$ 1.5 V and $I_{E.1}$ = 1.5/1 = 1.5 mA

$r_{e.1}$ = 50/1.5 = 33.3 Ω

and $r_{e.2}$ = 33.3 Ω — same as $r_{e.1}$

$\beta_2 . r_{e.2}$ = 50 × 33.3 = 1665 Ω

$r_{i.2} = R_4 \parallel R_5 \parallel \beta_2 . r_{e.2}$

= 20 K || 4 K || 1665 Ω = 1110 Ω

$r_{0.1} = a^2 . r_{i.2} = 5^2 \times 1110$ = 27,750 Ω

(i) $$A_{v.1} = \frac{r_{0.1}}{r_{e.1}} = \frac{27,750}{33.3} = \mathbf{830}$$

(ii) $$A_{v.2} = \frac{r_{0.2}}{r_{e.2}} = \frac{25 \times 100}{33.3} = \mathbf{750}$$

(iii) A_v = 830 × 750 = 622,500 ; G_v = 20 $\log_{10}$ 622,500 = **116 dB**

61.8. Advantages of Transformer Coupling

1. The operation of a transformer-coupled system is basically ***more efficient*** because of low dc resistance of the primary connected in the collector circuit,
2. It provides a ***higher*** voltage gain,
3. It provides ***impedance matching*** between stages which is desirable for maximum power transfer. Typically, the input impedance of a transistor stage is less than its output impedance. Hence, secondary impedance of the interstage (or coupling) transformer is typically lower than the primary impedance.

This coupling is effective when the final amplifier output is fed to a low-impedance load. For example, the impedance of a typical loud-speaker varies from 4 Ω to 16 Ω whereas output impedance of a transistor stage is several hundred ohms. Use of an output audio transformer can avoid the bad effects of such a mismatch.

Disadvantages

1. The coupling transformer is costly and bulky particularly when operated at audio frequencies because of its heavy iron core,
2. At radio frequencies, the inductance and winding capacitance present lot of problems,
3. It has poor ***frequency response*** because the transformer is frequency sensitive. Hence, the frequency range of the transformer-coupled amplifiers is limited.
4. It tends to introduce ***'hum'*** in the output,

61.9. Frequency Response

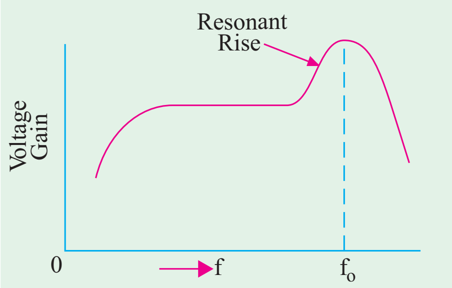


Fig. 61.16

The characteristics of a coupling transformer are that **(*i*)** it introduces inductances in both the input and output circuits **(*ii*)** leakage inductance exists between the primary and secondary windings and **(*iii*)** both windings introduce shunting (distributed) capacitance especially at high frequencies.

A typical gain ***versus*** frequency curve for a transformer-coupled amplifier is shown in Fig. 61.16.

It is seen that

1. There is decrease in gain at low frequencies and
2. Also there is decrease in gain at high frequencies except for the ***resonant rise*** in gain at resonant frequency of the tuned circuit formed by inductance and winding capacitance in the circuit.

The output voltage is equal to ac collector current multiplied by the primary reactance of the coupling transformer. Since at low frequencies, primary reactance is small, the gain is less.

At high frequencies, the distributed capacitance existing between different turns of the winding acts as a ***bypass capacitor*** and so reduces the output voltage and hence the gain. The peak or exaggerated gain occurs due to resonance or tuning effect of inductance and distributed capacitance which ***form a tuned circuit.***

Moreover, there is frequency distortion *i.e.* all frequencies are not amplified equally. In fact, the flat response part of the curve is small as compared to *RC* coupling. However, transformer-coupled amplifiers can be designed to have a flat frequency response curve and excellent fidelity over the entire audio frequency range.

61.10. Applications

Transformer coupling is often employed in the last stage of a multistage amplifier where concerted effort is made to maximise power transfer by perfect impedance matching.

Example 61.6. *In a multistage transformer-coupled amplifier, the output impedance of the first stage is 5 K and the input impedance of the second stage is 1 K. Determine the primary and secondary inductances of the tranformer for perfect impedance matching at f = 2000 Hz. If one turn gives an inductance of 10 μH, find the number of primary and secondary turns.*

(Electronic Engg.-I, Osmania Univ. 1991)

Solution. It should be clearly understood that primary has to match with the output impedance of the first stage and secondary with the input of the second stage.

$\therefore \qquad X_{Lp}$ = output of 1st stage or $2\pi f L_p = 5000$

$\therefore \qquad L_p = 5000/2\pi \times 2000 =$ **0.4 H**

Also, $\qquad X_{Ls}$ = input of 2nd stage

$\therefore \qquad 2\pi f_{Ls} = 1000$; $L_s = 1000/2\pi \times 2000 =$ **0.08 H**

Now, inductance of a coupling varies as the square of its turns.

$\therefore \qquad L \propto N^2 = kN^2$

When, $N = 1$, $\quad L = 10\ \mu$H $\qquad \therefore \qquad 10 \times 10^{-6} = k \times 12^2$ or $k = 10^{-5}$

For primary winding $0.4 = 10^{-5}\ Np^2 \times 5$ or $N_p =$ **632**

For secondary winding, $\quad L_s = kN_s^2$ or $0.08 = 10^{-5}\ Ns^2$ or $N_s =$ **89**

As seen, it is a nearly 7 : 1 step-down transformer.

61.11. Direct-coupled Two-stage Amplifier Using Similar Transistors

These amplifiers operate without the use of frequency-sensitive components like capacitors, inductors and transformers etc. They are especially suited for amplifying

(a) ac signals with frequencies as low as a fraction of a hertz,

(b) change in dc voltages.

Fig. 61.17 shows the circuit of such an amplifier which uses two similar transistors each connected in the *CE* mode. Both stages employ direct coupling **(i)** collector of Q_1 is connected directly to the base of Q_4 and **(ii)** load resistor R_2 is connected to the collector of Q_2. The resistor R_1 establishes the forward bias of Q_1 and also indirectly that of Q_2.

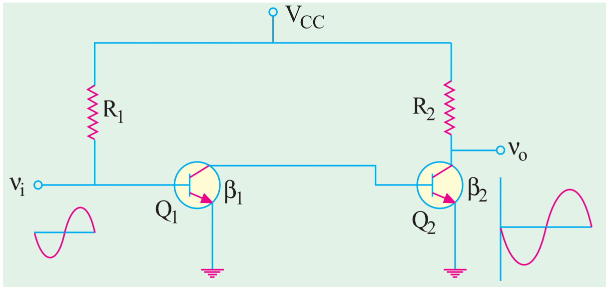


Fig. 61.17

Any signal current at the base of Q_1 is amplified β_1 times and appears at the collector of Q_1 and becomes base signal for Q_2. Hence, it is further amplified β_2 times. Obviously, signal current gain of the amplifier is

$$A_i = \beta_1 \times \beta_2 = \beta^2 \qquad \text{— if transistors are identical}$$

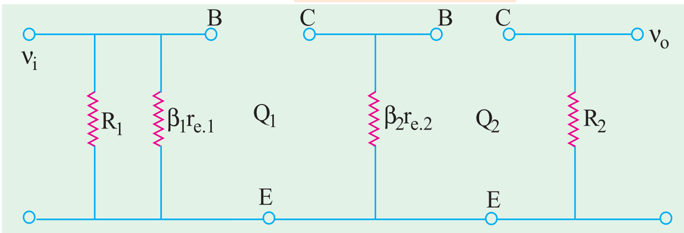


Fig. 61.18

(i) AC Equivalent Circuit

The ac equivalent circuit is shown in Fig. 61.18

(ii) Voltage Gain

The first stage *i.e.* Q_1 does not produce any voltage gain *i.e.* $A_{v\cdot 1} = 1$ as proved below :

$$A_{v.1} = \frac{r_{0.1}}{r_{e.1}} = \frac{\beta_2 \,.\, r_{e.2}}{r_{e.1}} \qquad \text{... (i)}$$

As seen from Fig. 61.17, $I_{E.2} \cong \beta_2 \,.\, I_{B.2}$

Also $\qquad I_{B.2} = I_{C.1} = I_{E.1} \quad \therefore \quad I_{E.2} = \beta_2 . I_{E\cdot 1}$ or $\beta_2 = \dfrac{I_{E.2}}{I_{E.1}}$

Also $\qquad r_{e.1} = \dfrac{25}{I_{E.1}} \qquad$ and $\qquad r_{e.2} = \dfrac{25}{I_{E.2}}$

Substituting all these values in Eq. (*i*) above, we get

$$A_{v.1} = \frac{I_{E.2}}{I_{E.1}} \times \frac{25}{I_{E.2}} \times \frac{I_{E.1}}{25} = 1$$

It proves the statement made above.

Now, $\qquad A_{v.2} = \dfrac{r_{0.2}}{r_{e.2}} \qquad$ and $\qquad A_v = A_{v.1} \times A_{e.2} = A_{v.2}$

(iii) Advantages

1. The circuit arrangement is very simple since it uses ***minimum number of components.***

2. It is quite ***inexpensive.***

3. It has the outstanding ability to ***amplify direct current*** (*i.e.* as dc amplifier) and ***low-frequency signals.***

4. It has ***no coupling or by-pass capacitors*** to cause a drop in gain at low frequencies. As seen from Fig. 61.19, the frequency-response curve is flat upto upper cut-off frequency determined by stray wiring capacitance and internal transistor capacitances.

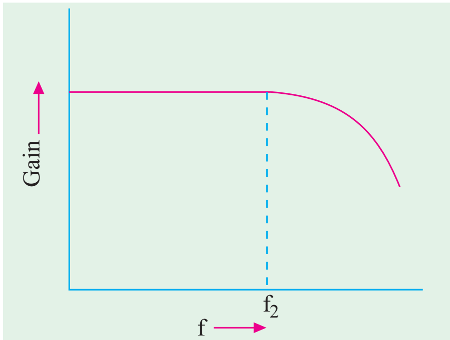


Fig. 61.19

(*iv*) Disadvantages

1. It cannot amplify high-frequency signals.

2. It has poor temperature stability.

It is due to the fact that any variation in base current (due to temperature changes) in one stage is amplified in the following stage (or stages) thereby shifting the Q-point. However, stability can be improved by using emitter-stability resistor (Fig. 61.21).

(*v*) Applications

Some of the applications of direct-coupled amplifiers are in

1. regulator circuits of electronic power supplies,
2. pulse amplifiers **3.** differential amplifiers,
4. computer circuitry, **5.** electronic instruments.

Example 61.7. *For the direct-coupled amplifier of Fig. 61.20, calculate*
(*a*) *current gain ,* **(*b*)** *voltage gain of first stage,*
(*c*) *voltage gain of second stage,* **(*d*)** *overall voltage gain in dB,*
(*e*) *overall power gain in dB,* **(*f*)** *input resistance.*
Neglect V_{BE} *and use* $r_e = 50\ mV/I_E$.

Solution. (*a*) $A_i = \beta_1\beta_2 = 100 \times 50 =$ **5000** **(*b*)** $A_{v.1} = 1$ — Art 61.11

(*c*) $A_{v.2} = \dfrac{r_{0.2}}{r_{e.2}}$ Now, $r_{e.2} = \dfrac{50}{I_{E.2}}$

Let us find the value of $I_{E.2}$ starting from the value of $I_{B.1}$. As seen from Fig. 61.20,

$I_{B.1} = 12/1.2M = 10\ \mu A$
$I_{C.1} = \beta_1 .\ 1_{\beta 1} = 100 \times 10$
$= 1000\ \mu A$
$I_{E.1} = I_{C.1} = 1000\ \mu A$
$= 1\ mA$
$I_{B.2} = I_{C.1} = 1\ mA$
$I_{C.2} = \beta_2 .\ I_{C1} = 50 \times 1$
$= 50\ mA$
∴ $I_{E.2} = 50\ mA$
and $r_{e.2} = 50/50 = 1\ \Omega$
Also, $r_{e.2} = R_2 = 200\ \Omega$

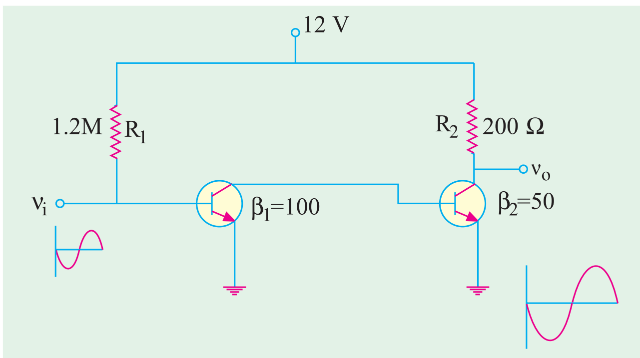


Fig. 61.20

∴ $A_{v.2} = \dfrac{200}{1} =$ **200**

(*d*) $A_n = 1 \times 200 = 200$; $G_v = 20 \log_{10} 200 =$ **46 dB**
(*e*) $A_p = A_v .\ A_i = 200 \times 5{,}000 = 10^6$; $Gp = 20 \log_{10} 106 =$ **60 dB**
(*f*) $r_i = R_1 \parallel \beta_1 . r_{e.1}$ — Fig. 61.18

$r_{e.1} = \dfrac{50}{I_{E.1}} = \dfrac{50}{1} = 50\,\Omega$ ∴ $r_i = 1.2\ M \parallel (50 \times 100) \cong$ **5 K**

Example 61.8. *For the emitter-stabilized direct-coupled amplifier of Fig. 61.21, find* ***(i)*** $A_{v.1}$, ***(ii)*** $A_{v.2}$, ***(iii)*** A_v *and* ***(iv)*** r_i. *Neglect* V_{BE} *and use* r_e = 50 mV/I_E.

(Electronics-I, Mysore Univ. 1992)

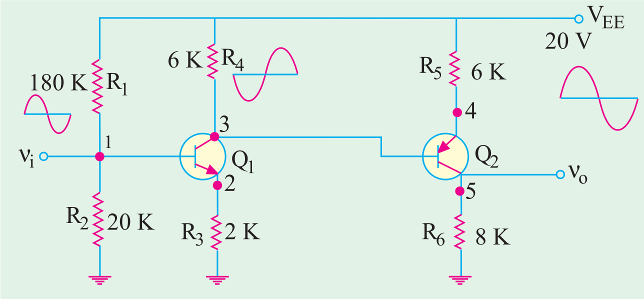


Fig. 61.21

Solution. As seen, emitter resistors R_3 and R_5 have been used to improve temperature stability. The voltage divider $R_1 - R_2$ together with R_3 determines the emitter current of Q_1. The resistor R_4 has dual function ***(i)*** it acts as load resistor for Q_1 and ***(ii)*** it establishes base bias of Q_2.

(i) Since unbypassed resistor R_3 is present

$$A_{v.1} = \frac{r_{0.1}}{r_{e.1} + R_3}$$

As seen from the ac equivalent diagram of Fig. 61.22

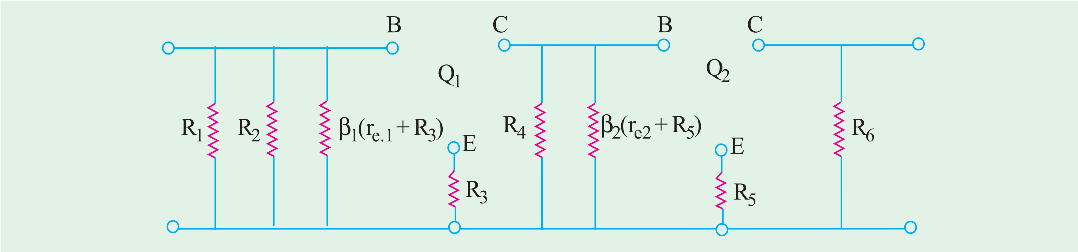


Fig. 61.22

$$r_{0.1} = R_4 \,||\, \beta_2 . (r_{e.2} + R_5)$$

Now $$r_{e.2} = \frac{50}{I_{E.2}}$$

For finding $I_{E.2}$, let us first find $I_{E.1}$

Drop across $$R_2 = 20 \times \frac{20}{180 + 20} = 2\text{ V}$$

Same is the drop across R_3 since V_{BE} has been neglected.

$\therefore$ $$I_{E.1} = 2V/1\text{ K} = 2\text{ mA}$$

Now, $$I_{E.2} = \frac{V_{CC} - I_{E.1}R_4}{R_5} = \frac{20 - 2 \times 8}{2} = 2\text{ mA}$$

$\therefore$ $$r_{e.2} = 50/2 = 25\ \Omega \quad \text{and} \quad \beta_2 (r_{e.2} + R_5) \cong 200\text{ K}$$

$$r_{0.1} = 8\,K \,||\, 200\,K = 7.7\,K;\ r_{e.1} = \frac{50}{2} = 25\,\Omega$$

$\therefore$ $$A_{v.1} = \frac{7,700}{(25 + 1000)} = 7.5$$

(ii) $$A_{v.2} = \frac{r_{0.2}}{(r_{e.2} + R_5)};\ r_{0.2} = R_6 = 6000\,\Omega \therefore\ A_{V.2} = \frac{6,000}{(25 + 2000)} \cong 3$$

(iii) A_v = 7.5 × 3 = **22.5**

(iv) As seen from Fig. 61.22

$$r_i = R_1 \,||\, R_2 \,||\, \beta_1 (r_{e.1} + R_3) = 180\text{ K} \,||\, 20\text{ K} \,||\, 100\text{ K} \qquad \text{—neglecting } r_{e.1}$$

= **15.25 K**

Example. 61.9. *In the circuit of Fig. 61.21, find dc voltage at points marked 1, 2, 3 and 4. Neglect V_{BE}.*

If a 1-V dc signal at input 1 changes by 0.01 V, what would be the voltage variation at the output?

Solution. V_1 = drop across R_2 = **2 V**

$V_2 \cong V_1$ = **2 V**; $V_3 = V_{CC} - I_{C.1}$ R_3 = 20 – 2 × 8 = **4 V**

$V_4 \cong V_3$ = **4 V**; $V_5 = V_{CC} - I_{C.2}$ R_6 = 20 – 2 × 6 = **8 V**

$\Delta v_0 = A_v \cdot \Delta v_i$ = 22.5 × 0.01= 0.225 V = **225 mV.**

61.12. Direct-coupled Amplifier Using Complementary Symmetry of Two Transistors

In this case, an *NPN* transistor is directly-coupled to its complementary *i.e.* a *PNP* transistor. Fig. 61.23 shows a two-stage cascaded amplifier using two complementary transistors connected in CE configuration.

The circuit differs from that shown in Fig. 61.17 in the following three ways :

1. It uses **complementary** transistors rather than **similar** ones,
2. Instead of V_{CC}, V_{EE} power battery has been used,
3. Output is taken directly from terminal of load resistor R_2.

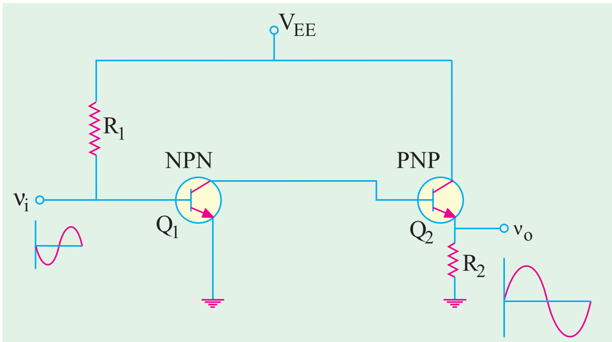


Fig. 61.23

More Practical Circuit

A more practical circuit of the above type is shown in Fig. 61.24. Here, bias current of Q_1 is determined by voltage divider $R_1 - R_2$ and R_3. As before, R_4 performs two functions :

1. It acts as load for Q_1 and **2.** Establishes bias voltage for Q_2

The emitter resistors R_3 and R_6, as usual, meant to improve amplifier stability.

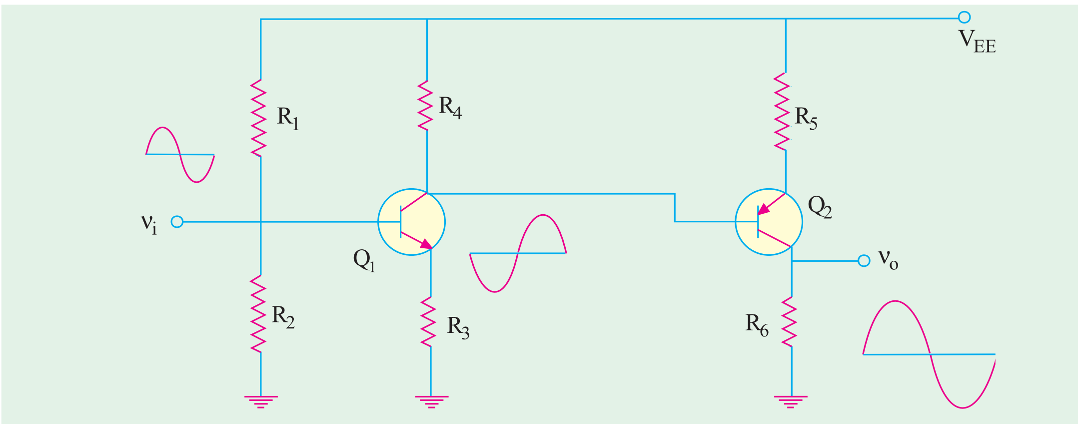


Fig. 61.24

(*i*) Circuit Operation

When a positive-going signal is applied to the base of Q_1, then

1. its base current ***increases,***

2. hence, its collector current increases ($I_C = \beta I_B$), voltage drop across ***R_4 increases,***
4. consequently, voltage at the collector of Q_1 and the base of Q_2 becomes ***less positive*** or in other words, ***more negative,***
5. hence, a negative-going signal is applied to the base of Q_2.

The negative-going signal applied to the base of Q_2 causes,

1. an ***increase*** in its forward bias (remember, it is a *PNP* transistor),
2. an ***increase*** in collector current
3. an ***increase*** in the voltage developed across R_6,
4. an amplified ***positive going*** output signal at R_6.

Hence, it is seen that a signal applied to the input of a two-stage complementary amplifier appears at the output in an amplified form and ***of the same polarity.***

Voltage Gain

It is the same as for the circuit of Fig. 61.17.

Example 61.10. *For the complementary symmetry circuit of Fig. 61.25, find **(a)** A_v **(b)** V_1, V_2, V_3, V_4 and V_5. Neglect V_{BE} and assume R_3, $R_5 \gg r_e$.*

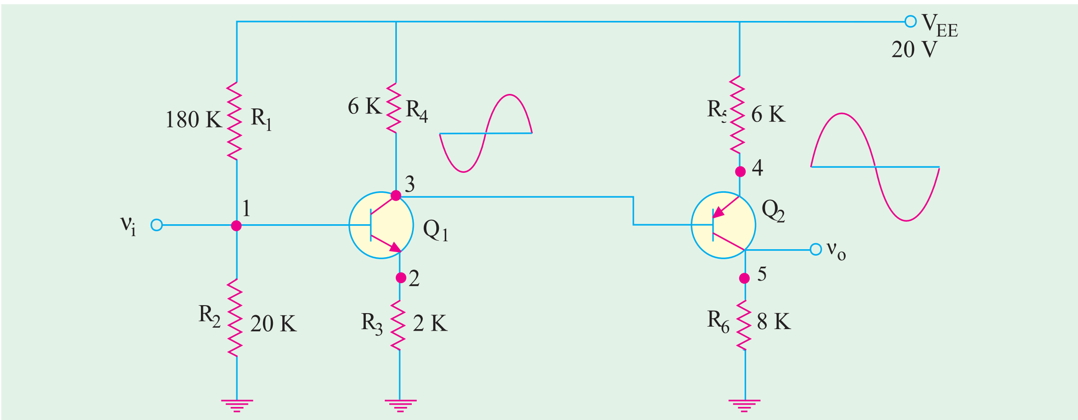


Fig. 61.25

Solution. (*a*) The overall voltage gain is

$$A_v = A_{v.1} \times A_{v.2} \cong \frac{R_4}{R_3} \times \frac{R_6}{R_5} = \frac{6}{2} \times \frac{6}{8}$$

(*b*)
$$V_1 = V_{EE}\frac{R_2}{R_1 + R_2} = 2V \qquad \therefore\ V_2 \cong V_1 = \mathbf{2V}$$

$$\therefore \quad I_{E.1} = \frac{2V}{R_3} = \frac{2V}{2\,K} = 1\text{mA}, \qquad I_{C1} \cong I_{E.1} = 1\text{mA}$$

$$V_3 = V_{EE} - I_{C.1}R_3 = 20 - 1 \times 6 = \mathbf{14\ V}, \qquad V_4 \cong V_3 = \mathbf{14\ V};$$

$$I_{C.2}\frac{20-14}{6\text{K}} = 1\text{mA}$$

$$= \frac{20-14}{6\text{K}} = 1\text{mA}$$

$$\therefore \quad I_{E.2} \cong I_{C.2} = 1\text{mA}$$

$\therefore \quad V_5 = I_{E.2} \times R_6$

$= 1 \times 8 = \mathbf{8\ V}$

61.13. Darlington Pair

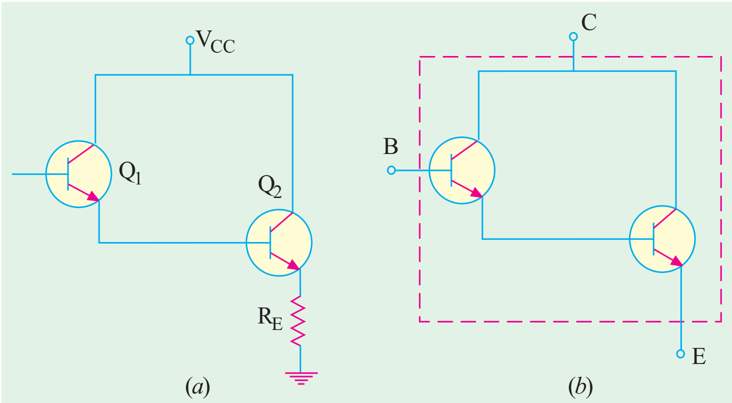


Fig. 61.26

It is the name given to a ***pair of similar*** transistors so connected that emitter of one is directly joined to the base of the other as shown in Fig. 61.26 (*a*). Obviously, the emitter current of Q_1 becomes the base current of Q_2.

Darlington pairs are commercially mounted in a single package that has only three leads : base, collector and emitter as shown in Fig. 61.26 (*b*). It often forms a ***double CC stage*** in multistage amplifiers. It is so because a Darlington connection can be considered equivalent to two ***cascaded emitter followers.***

Main Characteristics

(*i*) Current Gain

It can be proved that current gain of a Darlington pair is $(1 + \beta_1)(1 + \beta_2) = (1 + \beta)^2 \cong \beta^2$ if the transistors are ***identical*** (*i.e.* $\beta_1 = \beta_2$).

Proof

$I_{B.2} = I_{E.1} = (1 + \beta_1)\, I_{B.1} \cong \beta_1 I_{B.1}$

$I_{E.2} \cong \beta_2 . I_{B.2} = \beta_1 \beta_2 I_{B.1} \qquad \therefore \qquad A_i = \dfrac{I_{E.2}}{I_{B.1}} = \beta_1\beta_2 = \beta^2$

It means that a Darlington pair behaves like a ***single transistor having a beta*** of β^2.

(*ii*) Input Impedance

In Fig. 61.26 (*a*), the input impedance seen from the base of Q_2 is

$$r_{i.2} = \beta_2 (r_{e.2} + R_E) \cong \beta_2 . R_E$$

Input impedance as seen from the base of Q_1 is

$$r_{i.1} = \beta_1 (r_{e.1} + r_{i.2}) = \beta_1 r_{e.1} + \beta_1 r_{i.2} = \beta_1 r_{e.1} + \beta_1 \beta_2 R_E \cong \beta_1 \beta_2 R_E$$

or $\quad r_{in(base)}$ of $Q_1 = \beta_2 R_E$

Note. If there is a load resistance R_L coupled to the emitter of Q_2, then

$$r_{i.1} - \beta^2 (R_E \,||\, R_L) = \beta^2 . r_E$$

As seen, load impedance R_E has been transformed into $\beta^2 R_E$. Obviously, a Darlington pair is capable of high input impedance. In fact, whenever a load causes a severe loss in voltage gain (loading effect), it is usual to step up load impedance *via* a *FET* stage, a single *CC* stage or Darlington pair when much greater impedance transformation is required.

(*iii*) Voltage Gain

Assuming $r_{e.1} = r_{e.2} = r_e$ we have

$$A_v \cong \frac{R_E}{r_e + R_E} = \frac{1}{1 + \dfrac{r_e}{R_E}} \cong 1 \qquad \text{—as in an emitter follower}$$

61.14. Advantages of Darlington Pair

1. It can be readly formed from two adjacent transistors in an IC.
2. It has enormous ***impedance transformation capability i.e.*** it can transform a low-impedance load into a high impedance load. Hence, it is used in a high-gain operational amplifier which depends on very high input impedance for its operation as an integrator or summing amplifier in analogue applications.
3. It uses very few components.
4. It provides very high β-value.

61.15. Comparison Between Darlington Pair and Emitter Follower

We will refer to Fig. 9.28 and Fig. 61.26.

1. Input impedance of Darlington pair is $\beta^2 R_E$ whereas that of emitter follower is βR_E (Art. 9.8).
2. Current gain of Darlington pair is β^2 whereas that of emitter follower is β.
3. However, voltage gains of the two are identical.

Example. 61.11. *For the Darlington pair shown in Fig. 61.27, calculate the value of 1. β, 2.input impedance,3. voltage amplification.*

Assume $\beta_1 = \beta_2 = 100$ *and* $R_L \gg (r_{e.1} + r_{e.2})$.

Solution. The approximate values are as under :

1. β of Darlington pair

$= \beta_1 \times \beta_2$

$= 100 \times 100 =$ **10,000**

2. $r_E = R_E \| R_L$

$= 10\text{ K} \| 500\ \Omega = 475\ \Omega$

$r_{in(base)}$ of $Q_1 \cong \beta^2 r_E$

$= 10{,}000 \times 475 = 4.75\text{ M}$

r_i = input impedance of the pair

$= R_B \| r_{in(base)}$ of Q_1

$= 1\text{ M} \| 4.75\text{ M} = 0.826\text{ M} =$ **826 K**

3. $A_v \cong 1$

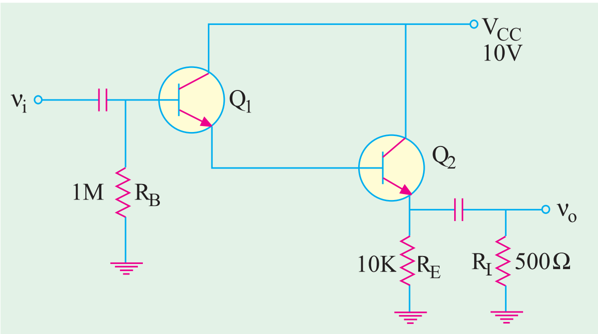


Fig. 61.27

Example 61.12. *A CE amplifier stage shown in Fig.61.28 is to drive a 100 Ω load to 10* V_{p-p} *level. An input signal of 1* V_{p-p} *is available. Find out if the stage is overloaded or not. Also, find out if this overloading has been avoided by using a Darlington pair as a buffer between* Q_1 *and the load as shwon in Fig. 61.29. Take* $\beta_1 = \beta_2 = 50$.

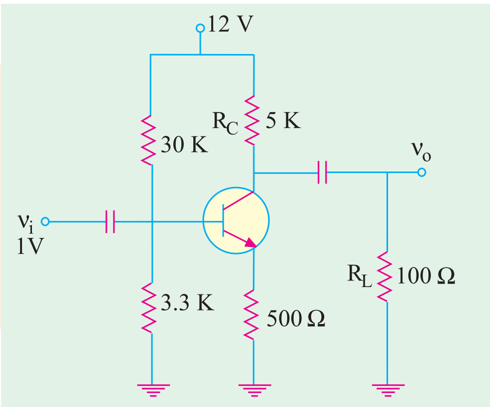


Fig. 61.28

Solution. The approximate voltage gain of Q_1 is given by

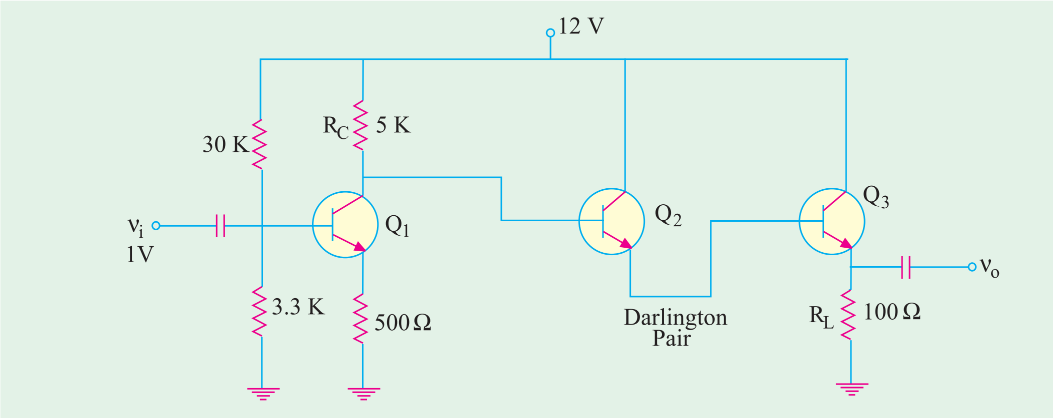


Fig. 61.29

$$A_v = \frac{r_L}{r_E} = \frac{R_C \| R_L}{R_E} = \frac{5\text{K} \| 100\,\Omega}{500\,\Omega} \cong \frac{1}{5}$$

$$\therefore \quad v_0 = 1 \times \frac{1}{5} = 0.2\,\text{mV}$$

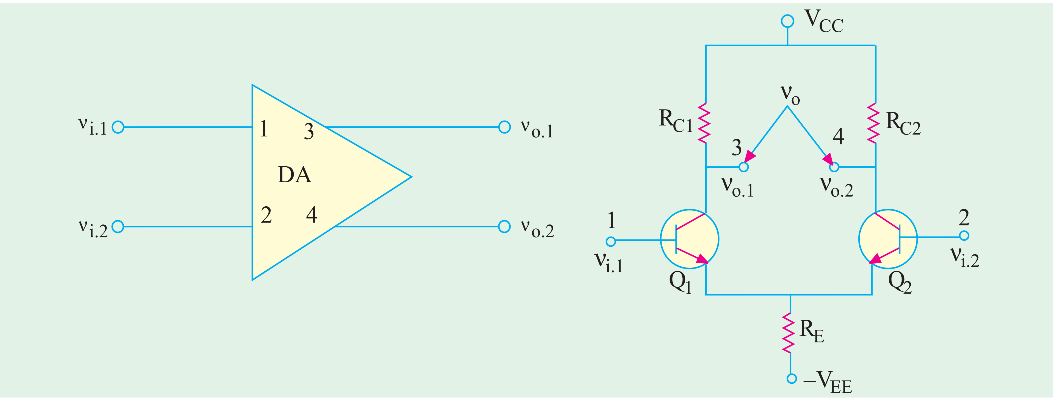


Fig. 61.30

Obviously, ***due to overloading of the stage,*** severe attenuation has occurred, Hence, the amplifier stage cannot, ***by itself,*** drive the heavy load.

By using a Darlington pair, a 100 Ω load has been transformed to

$$\beta^2 R_L = 2500 \times 100 = 250\text{ K}$$

Now, $r_L = R_C \| \beta^2 R_L = 5\text{ K} \| 250\text{ K}$

$$\cong 5K \quad \therefore \; A_v = \frac{5\text{K}}{500\,\Omega} = 10$$

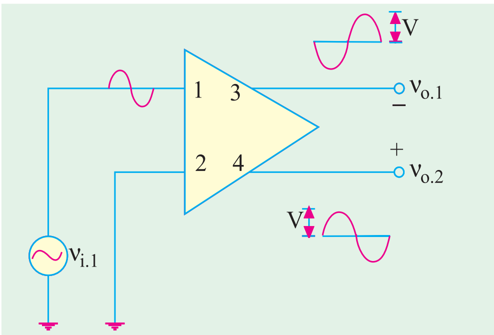


Fig. 61.31

This also represents total voltage gain because voltage gain of Darlington pair is one.

$\therefore \qquad v_0 = A_v \times v_i = 10 \times 1 =$ **10 Vp–p**

As seen, now the stage would be able to drive the load since the design goal of 10 V_{P-P} has been met.

61.16. Special Features of a Differential Amplifier

It consists of two basic *CE* amplifiers having their ***emitters directly-coupled to each other***. Fig. 61.30 shows both the block diagram and the circuit diagram of such an amplifier.

As seen, it has two separate input terminals 1 and 2 and two separate output terminals 3 and 4. Voltages may be applied to either or both input terminals and output may be taken from either or both output terminals.

There are certain specific phase relationships between both input and both output terminals as discussed below.

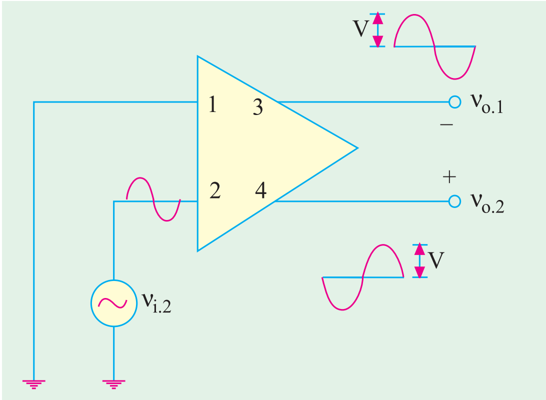
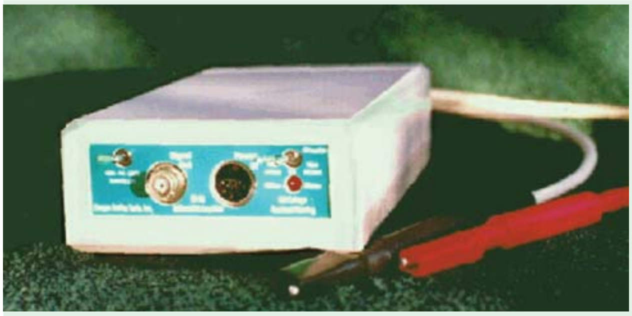


Fig. 61.32

(*a*) Single-ended Operation

In Fig. 61.31, input signal $v_{i.1}$ is applied to terminal 1 with terminal 2 grounded.

It is seen that an ***amplified*** and ***inverted*** output signal is obtained at terminal 3 (phase inversion of a *CE* amplifier) but an ***equally-amplified*** and ***in-phase*** signal appears across output terminal 4. The differential output voltage has the polarity shown in the figure.


Differential amplifier

As shown in Fig. 61.32, when input signal v_{1-2} is applied to input terminal 2, an amplified and inverted signal appears at output terminal 4 whereas ***equally-amplified*** but ***in-phase*** signal appears at terminal 3.

In summary, we can say that input at any of the two terminals causes outputs at both terminals 3 and 4. The two output are opposite in phase but of equal amplitude.

(*b*) Double-ended Operation

Fig 61.33 illustrates the double ended mode of operation when two input signals of opposite phase are applied to the two input terminals.

Input signal at each input terminal causes signals to appear at both output terminals. The resultant output signals have a peak value of 2 V – twice the value for single-ended operation.

However, if two in-phase and equal signals were applied at the two input terminals, the resultant output signal at each output terminal would be zero as shown in Fig. 61.34. It means that output *between* the collectors would be zero.

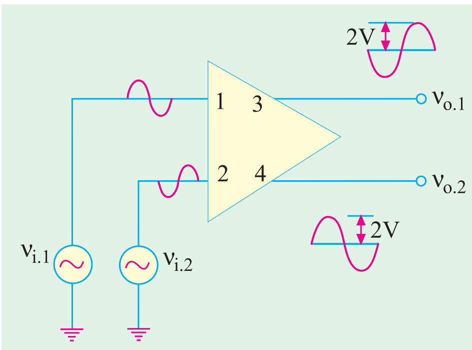


Fig. 61.33

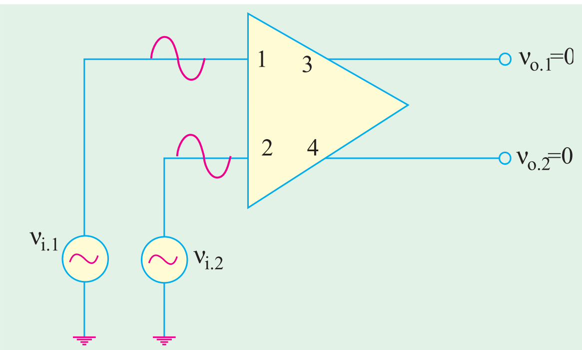


Fig. 61.34

If $v_{i.1}$ and $v_{i.2}$ change by *exactly* the same amount, even then output voltage between terminals 4 and 3 remains zero because of symmetry. Only when $v_{i.1}$ and $v_{i.2}$ differ from each other, we get an output voltage. When $v_{i.1}$ is more positive than $v_{i.2}$, the output terminal 4 is more positive than terminal 3.

(*c*) Inverting and Non-inverting Inputs

When positive $v_{i.1}$ acts alone, it produces a differential output voltage with terminal 4 positive with respect to terminal 3 as shown in Fig. 61.35. That is why the input terminal 1 is called non-inverting input terminal. How ever, when positive $v_{i.2}$ acts alone, the output voltage is inverted i.e. terminal 3 becomes positive with respect to terminal 4. That is why input terminal 2 is called ***inverting terminal.***

61.17. Common Mode Input

Fig. 61.36 illustrates the common-mode input of a differential amplifier *i.e.* when similar or same input signal is applied to both inputs. If the two halves of the diff-amp are identical, the ac output voltage will be zero. The diff-amp is then said to the perfectly balanced.

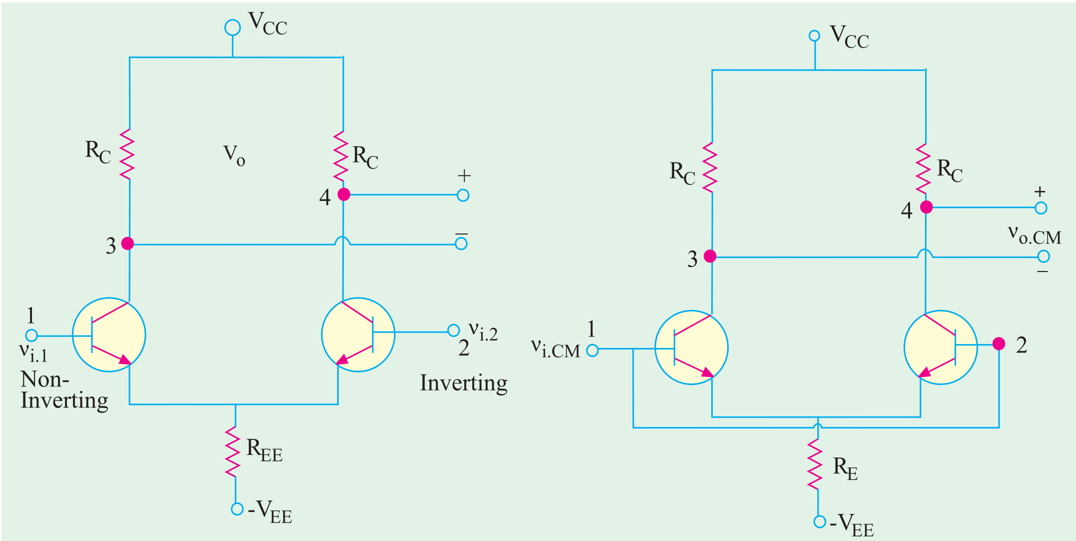


Fig. 61.35 **Fig. 61.36**

The common-mode rejection ratio (*CMMR*) is defined as

$$CMMR = \frac{A \times v_{i.cm}}{v_{o.cm}}$$

Suppose, $v_{i.cm}$ = 1 V. In a perfectly-balanced and symmetrical diff-amp, the output should be zero. But, in practice, there is always a small output signal because of *non-symmetry*. Suppose, A = 100 and $v_{no.em}$ = 0.01V. Then

$$CMMR = \frac{100 \times 1\,V}{0.01\,V} = 10,000 = 20 \log_{10} 10,000 = \mathbf{80\ dB}$$

Larger the value of CMMR (*i.e.* smaller the value of $v_{o.cm}$), better the diff-amp. Ideally, a common-mode input should produce zero output voltage. Hence, an ideal diff-amp has a CMMR of ***infinity.***

Example 61.13. *Calculate the approximate output voltage for the diff-amp of Fig. 61.37 which uses only a single-ended non-inverting input of n-1 = 1 mV. Take r_e = 25 mV/I_E and neglect V_{BE}.*

Solution. $I_E \cong V_{EE}/R_E = 12/6 = 2$ mA

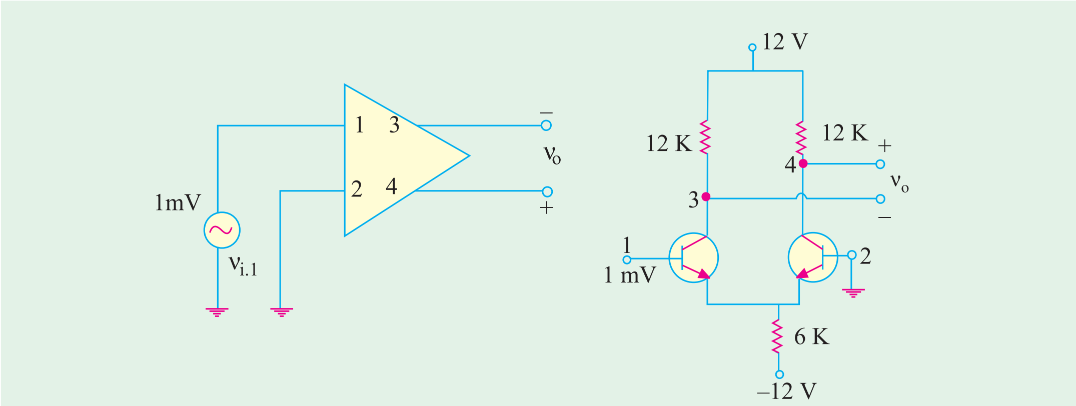


Fig. 61.37

The current is divided equally between the two transistors so that $I_{E.1} = I_{E.2} = 1$ mA.

Voltage amplification of each half is approximately given by A = R_C/r_e

Now, $r_e = 25/1 = 25\ \Omega$

$$\therefore \quad A = \frac{12,000}{25} = 480$$

$$\therefore \quad v_0 = A \times v_{i.1} = 480 \times 1$$

$$= \textbf{480 mV}$$

The ac output signal is in phase with the input.

Example 61.14. *If a differential input signal of 1 mV is applied to the diff-amp shown in Fig. 61.38, calculate the output voltage. Neglect* V_{BE} *and take* $r_e = 25\ mV/I_E$.

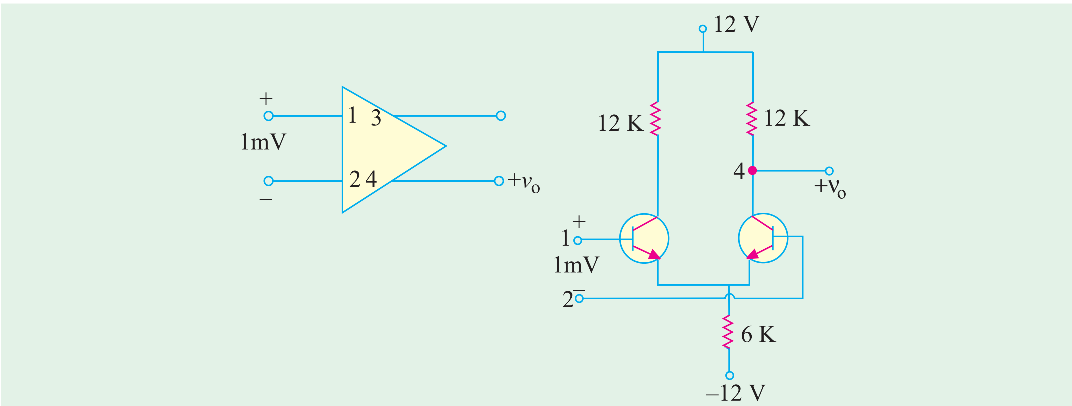


Fig. 61.38

Solution.

Here, $v_{i.1} - v_{i.2} = 1$ mV

As seen from Ex. 61.13,

A = **480**

$\therefore\ v_o = A\,(v_{i.1} - v_{i.2}) = 480 \times 1 =$ **480 mV**

Example 61.15. *A differential input signal of 1 mV is applied to the diff-amp of Fig. 61.39 when used in single-ended output mode. Calculate the approximate value of output voltage. Neglect V_{BE} and take r_e = 25 mV/I_E.*

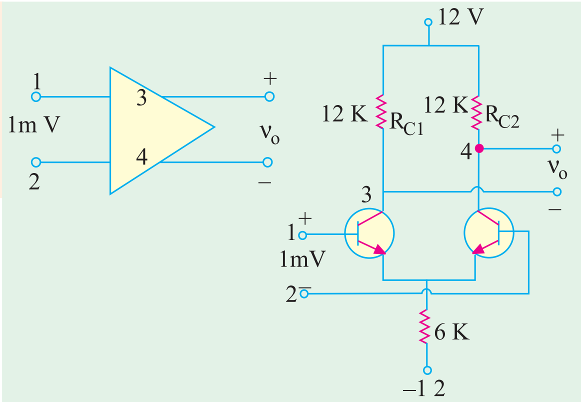


Fig. 61.39

Solution. Here, again 1 mV is the differential input signal *i.e.* $v_{i.1} - v_{i.2}$ = 1 mV

Since single-ended mode is being used, A = 480/2 = **240**

$$\therefore \quad v_0 = A(v_{i.1} - v_{i.2})$$

$$= 240 \times 1 = \mathbf{240}$$

61.18. Differential Amplifier

Fig. 61.40 shows the circuit of a differential or difference amplifier. As seen

1. it contains two *CE* amplifiers,
2. it uses only resistors and transistors
3. it is directly-coupled (emitter-to-emitter) amplifier,
4. it can accept two inputs by means of T_1 and ground and also T_2 and ground,
5. it can provide two separate outputs by means of T_3 and ground and T_4 and ground,
6. it can provide a single output between T_3 and T_4 *i.e.* differential output.

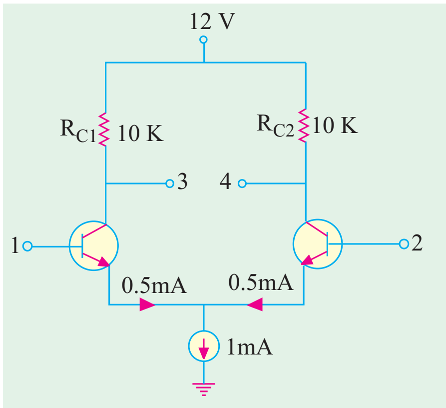


Fig. 61.40

Circuit Operation

We will consider a balanced differential amplifier in which Q_1 and Q_2 are identical and their associated components are matched. In that case, each amplifier stage produces same voltage gain. A = r_0/r_e

In Fig. 61.40. $\quad r_o = R_2 \quad$ or $\quad R_3$

The output voltage between terminals T_3 and T_4 is

$$v_0(T_3 - T_4) = A(v_{i.1} - v_{i.2})$$

where, $\quad A$ = voltage gain of each stage

Advantages

1. ***It uses no frequency-dependent coupling or bypassing capacitors***. All that it requires is resistors and transistors both of which can be easily integrated on a chip. Hence, it is extensively used in linear IC_5.
2. It can compare any two signals and ***detect any difference***. Thus, if two signals are fed into its inputs, identical in every respect except that one signal has been slightly distorted, then only the difference between the two signals *i.e.* distortion will be amplified.
3. It gives higher gain than two cascaded stages of ordinary direct coupling.
4. It provides very ***uniform amplification*** of signal from dc upto very high frequencies.

5. It provides isolation between input and output circuits.
6. It is almost a universal choice for amplifying dc.
7. It finds a wide variety of applications such as amplification, mixing, signal generation, amplitude modulation, frequency multiplication and temperature compensation etc.

Example 61.16. *Calculate the single-ended and differential gain of the diff-amp shown in Fig. 61.41. Use $r_e = 25\ mV/I_E$.*

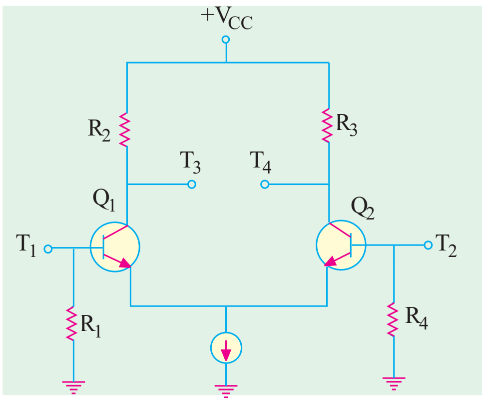


Fig. 61.41

Solution. The current of 1 mA from a constant-current source divides into two equal parts.

$$I_{E.1} = I_{E.2} = 1/2 = 0.5 \text{ mA}$$

$$r_{e.1} = r_{e.2} = \frac{25}{0.5} = 50\,\Omega$$

Hence, single-ended voltage gain is

$$A = \frac{r_0}{r_e} = \frac{R_C}{r_e} = \frac{10\,K}{50\,\Omega} = \mathbf{200}$$

Hence, each stage has a voltage gain of 200.

If we consider differential (double-ended) gain, its value is twice *i.e.* 2 × 200 = **400.**

Example 61.17. *For the diff-amp shown in Fig. 61.41, voltage gain of each stage is 200, $v_{i.1}$ = 30 mV and $v_{i.2}$ = 20 mV. Find the voltages between*

(i) *T_3 and ground,* ***(ii)*** *T_4 and ground,* ***(iii)*** *T_3 and T_4.*

What are the polarities of output terminals T_3 and T_4 ?

(Basic Electronics, Bombay Univ.)

Solution. As stated earlier in Art. 61.18.

(i) $v_0(T_3) = A_1 \times v_{i.1}$ = 200 × 30 mV = **6 V**

(ii) $v_0(T_4) = A_2 \times v_{i.2}$ = 200 × 20 mV = **4 V**

(iii) $v_0(T_3 - T_4) = A(v_{i.1} - v_{i.2})$ = 200 (30 × 20) mV = **2 V**

Since $v_{i.1} > v_{i.2}$; $i_{c.1}\ R_2 > i_{.2} R_3$, hence T_4 will be positive with respect to T_3.

Example 61.18. *Calculate the overall voltage gain of the two-stage RC coupled amplifier shown in Fig. 61.42. Neglect V_{BE} and take $\beta_1 = \beta_2 = 100$.*

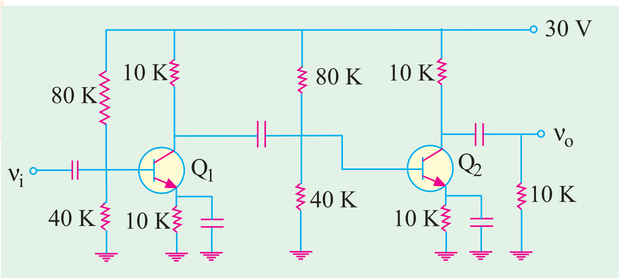


Fig. 61.42

Solution. We will first find gain of Q_2 and then multiply it with that of Q_1 to find the overall gain.

DC voltage from base to ground for Q_2 = drop across 40 K

$$= 30 \times 40/(40 + 80) = 10 \text{ V}$$

Hence, $I_{E.2} \cong$ 10 V/10 K = 1 mA

Assuming silicon transistor

$r_{e.2}$ = 50/1 mA = 50 Ω

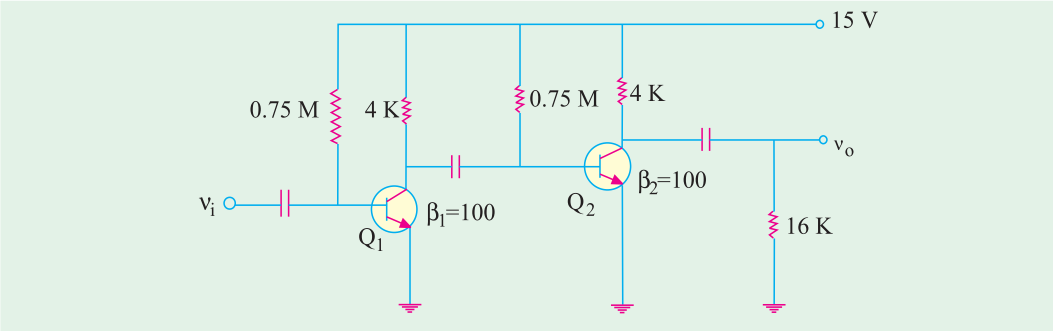


Fig. 61.43

$$\therefore \quad A_{v2} = \frac{r_{L2}}{r_{e2}} = \frac{10K \,||\, 10K}{50} = 100$$

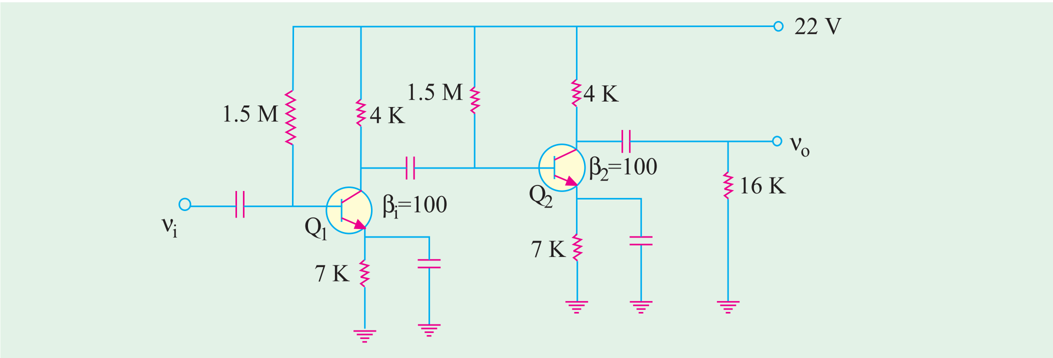


Fig. 61.44

For finding A_{v1}, we must first calculate the ac load resistance r_L as seen by Q_1. It equals the parallel combination of 10 K, 80 K, 40 K and βr_e = 100 × 50 = 5 K (because it forms part of the load on Q_1)*.

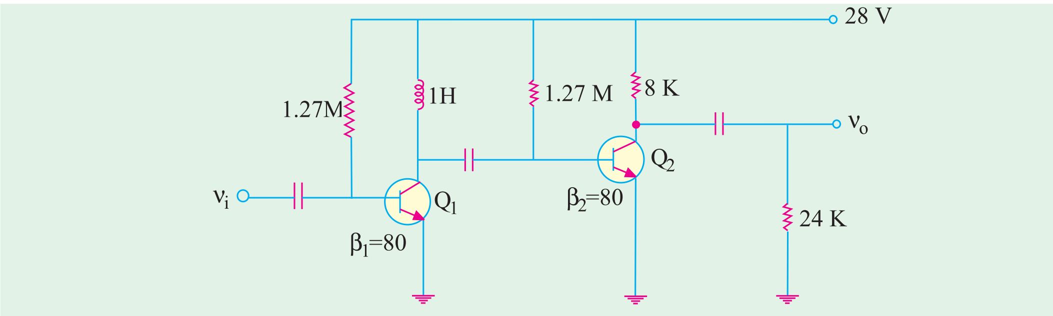


Fig. 61.45

$\therefore \quad r_{L1} = 10 \text{ K} \,||\, 80 \text{ K} \,||\, 40 \text{ K} \,||\, 5 \text{ K} \cong 3 \text{ K}$

$\therefore \quad A_{v1} = r_{L1}/R_{e1} = 3 \text{ K}/50\ \Omega = 60$

$\therefore \quad A = A_{v1} \times A_{v2} = 100 \times 60 = \mathbf{6000}$

* (Emitter resistance does not come into the picture because it has been ac grounded by the capacitor.

Tutorial Problems No. 61.1

1. For the two-stage R_C-coupled amplifier shown in Fig. 61.43 calculate the approximate values of
(*a*) voltage gain for the first stage, (*b*) voltage gain for the second stage,
(*c*) voltage gain for the amplifier, (*d*) ac input resistance of the amplifier.
Neglect V_{BE} and use r_e = 25 mV/I_E **[(*a*) 76.2 (*b*) 256 (*c*) 19,500 or 85.8 dB (*d*) 1250 Ω]**

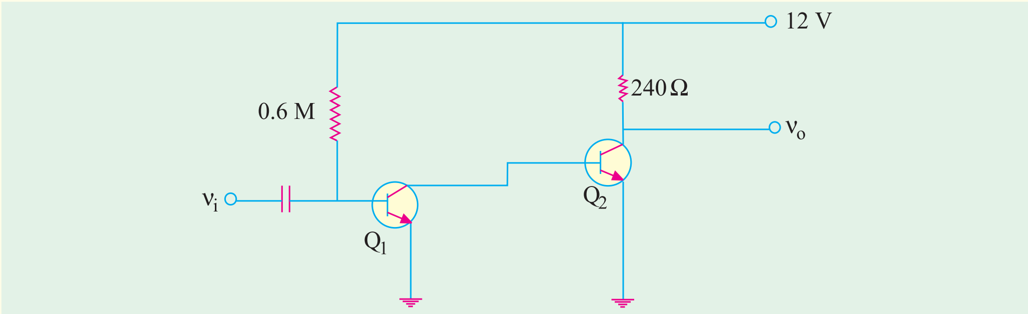


Fig. 61.46

2. For the two-stage *RC*-coupled amplifier using base and emitter bias and shown in Fig. 61.44, calculate approximate values of
(*i*) $A_{v.1}$ (*ii*) $A_{v.2}$ (*iii*) A_v (*iv*) r_i
Neglect V_{BE} and use r_e = 25 mV/I_E **[(*i*) 61.6 (*ii*) 128 (*iii*) 7,900 or 78 dB (*iv*) 2.6 K]**

3. Fig. 61.45 shows the circuit of a two-stage impedance-coupled amplifier. Compute the approximate values of
(*i*) voltage gain of 1st stage,
(*ii*) voltage gain of the 2nd stage ; both at f = 2 kHz,
(*iii*) voltage gain of the amplifier.
Neglect V_{BE} and take r_e = 25 mV/I_E. **[(*i*) 80 (*ii*) 420 (*iii*) 33,600 or 90.5 dB]**

4. For the direct-coupled amplifier shown in Fig. 61.46, calculate the approximate value of
(*i*) A_i, (*ii*) $A_{v.1}$, (*iii*) $A_{v.2}$, (*iv*) A_v, (*v*) A_p and (*vi*) r_4
Neglect V_{BE} and assume r_e = 25 mV/I_E. Also, β_1 = 50 and β_2 = 25.
[(*i*) 1250 (*ii*) 1 (*iii*) 240 (*iv*) 240 (*v*) 300,000 or 55 dB (*vi*) 1250 Ω]

OBJECTIVE TESTS – 61

1. The decibel gain of a cascaded amplifier equals the
(*a*) product of individual gains
(*b*) sum of individual gains
(*c*) ratio of stage gains
(*d*) product of voltage and current gains.

2. If two stages of a cascaded amplifier have decibel gains of 60 and 30, then overall gain is .... dB.
(*a*) 90 (*b*) 1800
(*c*) 2 (*d*) 0.5

3. Cascading two amplifiers will result in
(*a*) reduction in overall gain and increase in overall bandwidth.
(*b*) reduction in overall gain and reduction in overall bandwidth
(*c*) increase in overall gain increase in overall bandwidth
(*d*) increase in overall gain and reduction in overall bandwith

4. The overall bandwidth of two identical voltage amplifiers connected in cascade will
(*a*) remain the same as that of a single stage
(*b*) be worse than that of a single stage
(*c*) be better than that of a single stage
(*d*) be better if stage gain is low and worse if stage gain is high.

5. *RC* coupling is popular in low-level audio amplifiers because it
(*a*) has better low frequency response
(*b*) is inexpensive and needs no adjustments
(*c*) provides an output signal in phase with the input signal
(*d*) needs low voltage battery for collec- tor supply.

6. Frequency response characteristic at a single-stage RC coupled amplifier is shown in Fig. 61.47. The fall in gain at both ends of the characteristic is due to

(*a*) transistor shunt capacitances

(*b*) bypass and coupling capacitances of the circuit

(*c*) transistor shunt capacitances of the lower end and bypass and coupling capacitances at the higher end

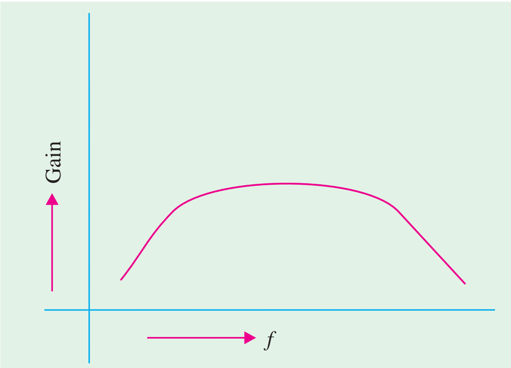


Fig. 61.47

(*d*) transistor shunt capacitances at the higher end and bypass and coupling capacitances at the lower end.

7. The most desirable feature of transformer coupling is its

(*a*) higher voltage gain

(*b*) wide frequency range

(*c*) ability to provide impedance match- ing between stages

(*d*) ability to eliminate hum from the output.

8. A transformer coupled amplifier would give

(*a*) maximum voltage gain

(*b*) impedance matching

(*c*) maximum current gain

(*d*) larger bandwidth

9. In multistage amplifiers, direct coupling is especially suited for amplifying

(*a*) high frequency ac signals

(*b*) changes in dc voltages

(*c*) high-level voltages

(*d*) sinusoidal signals.

10. The outstanding characteristic of a direct-coupled amplifier is its

(*a*) utmost economy

(*b*) temperature stability

(*c*) avoidance of frequency-sensitive components

(*d*) ability to amplify direct current and low-frequency signals.

11. A signal may have frequency components which lie in the range of 0.001 Hz to 10 Hz. Which one of the following types of couplings should be chosen in a multistage amplifier designed to amplify this signal ?

(*a*) *RC* coupling

(*b*) transformer coupling

(*c*) direct coupling

(*d*) double-tuned transformer

12. Darlington pairs are frequently used in linear *ICs* because they

(*a*) do not require any capacitors or inductors

(*b*) have enormous impedance transformation capability

(*c*) can be readily formed from two adjacent transistors

(*d*) resemble emitter followers.

13. When same input signal is applied to both the inputs of an ideal diff-amp, the output

(*a*) is zero

(*b*) depends on its *CMMR*

(*c*) depends on its voltage gain

(*d*) is determined by its symmetry.

14. The common-mode rejection ratio of an ideal diff-amp is

(*a*) zero

(*b*) infinity

(*c*) less than unity

(*d*) greater than unity.

15. One of the advantages of a Darlington pair is that it has enormous .... transformation capacity.

(*a*) voltage

(*b*) current

(*c*) impedance

(*d*) power

16. A Darlington pair and an emitter follower have the same

(*a*) input impedance

(*b*) current gain

(*c*) voltage gain

(*d*) power gain.

17. Which of the following mode of operation is possible with a differential amplifier ?

(a) single-ended input
(b) differential input
(c) common-mode input
(d) all of the above.

18. The gain of a Darlington amplifier pair is determined by .... the beta values.
(a) subtracting
(b) adding
(c) dividing
(d) multiplying

19. The amplifier in which the emitter and collector leads of one transistor are connected to the base and collector leads of a second transistor is called an .... amplifier.
(a) push-pull
(b) Darlington
(c) differential
(d) complementary

ANSWERS

1. (b) **2.** (a) **3.** (c) **4.** (c) **5.** (b) **6.** (d) **7.** (c) **8.** (b) **9.** (b) **10.** (d) **11.** (c)
12. (c) **13.** (a) **14.** (b) **15.** (c) **16.** (c) **17.** (d) **18.** (d) **19.** (b)

GO To FIRST