Chapter 6

Differential and Feedback Amplifiers

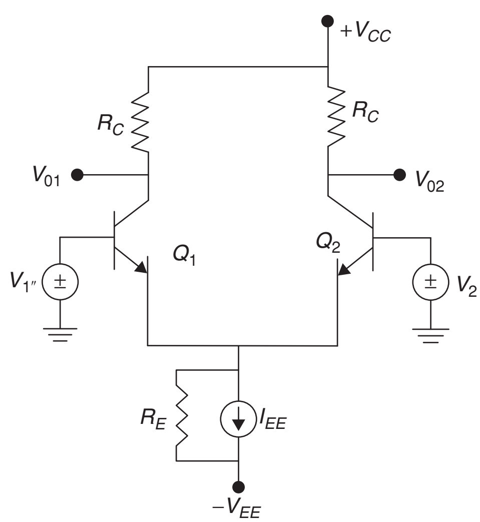
LEARNING OBJECTIVES

After reading this chapter, you will be able to understand:

- The differential amplifier
- FET differential amplifiers
- Feed back amplifiers
- Power amplifiers
- Amplifier efficiency
- Maximum theoretical efficiency
- Dissipation
- Class 'AB' amplifier
- Class 'C' amplifier
- Resonant frequency
- 555 timer
- Schmitt trigger
- Voltage controlled oscillator

The Differential Amplifier

The emitter coupled differential amplifier is an essential building block in modern IC amplifiers.



Differential mode voltage gain $A_{DM} = -g_m R_C$

Common mode voltage gain $A_{CM} = \dfrac{-R_C}{2R_E}$

Common mode rejection ratio

$$\text{CMRR} = \frac{A_{DM}}{A_{CM}} = 1 + 2g_m R_E$$

Output for arbitrary input signals: If V_1 and V_2 are inputs applied to transistors Q_1 and Q_2

$$V_{DM} = \frac{V_1 - V_2}{2}, V_{CM} = \frac{V_1 + V_2}{2}$$

$$V_{01} = A_{DM} V_{DM} + A_{CM} V_{CM}$$

$$= A_{DM} = \left(V_{DM} + \frac{V_{CM}}{\text{CMRR}}\right)$$

$$V_{02} = -A_{DM} V_{DM} + A_{CM} V_{CM}$$

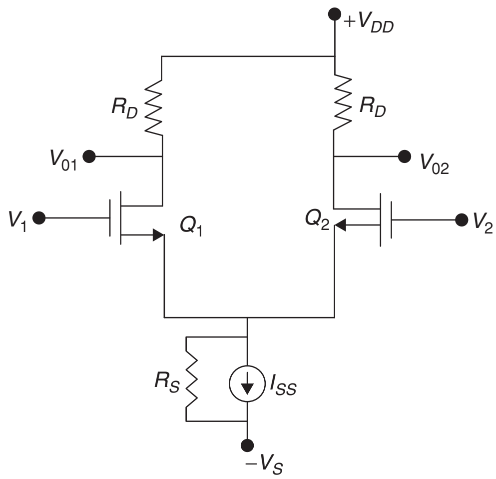
$$= -A_{DM}\left(V_{DM} - \frac{V_{CM}}{\text{CMRR}}\right)$$

Input and output resistances: Differential mode output resistance

$$R'_{O(DM)} = R_c \| r_o \cong R_C$$

Differential mode input resistance $R_{i(DM)} = 2r_e$

FET differential Amplifiers: The source-coupled pair differential amplifier with MOSFETS is shown in the figure



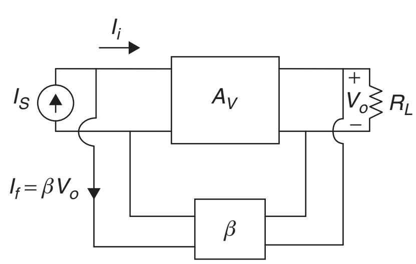
$$\text{CMRR} = 1 + \frac{2R_S\ (1+\mu)}{r_d + R_D}$$

For $r_d \gg R_D$ and $\mu \gg 1$

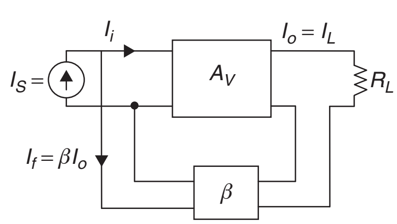
$$\text{CMRR} = 1 + 2g_m R_S \cong 2g_m R_S$$

Feedback Amplifiers

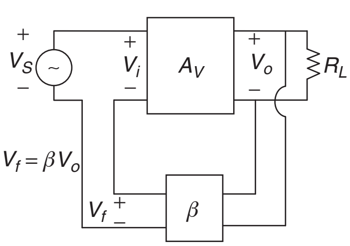
Feedback Amplifier Topologies



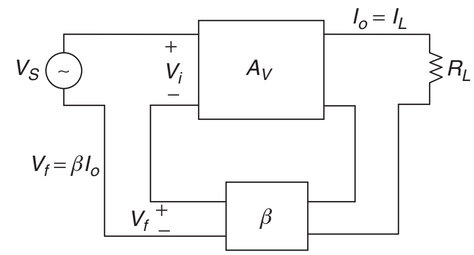
Voltage shunt



Current shunt



Voltage series



Current series

Classification of Amplifiers

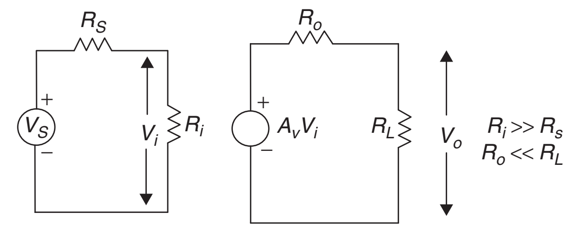


Figure 1 Voltage amplifier

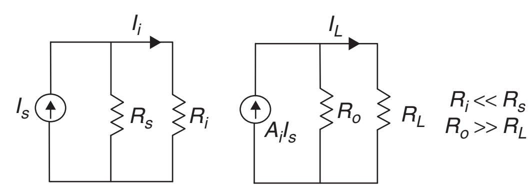


Figure 2 Current amplifier

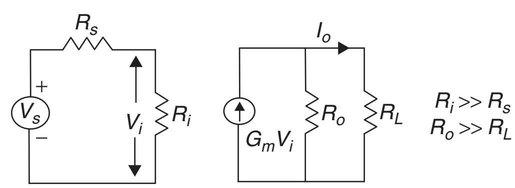


Figure 3 Transconductance amplifier

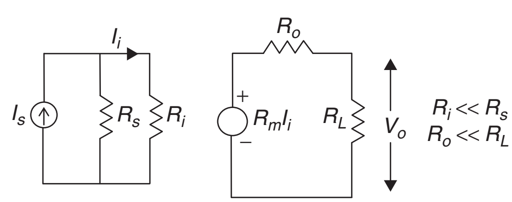


Figure 4 Transresistance amplifier

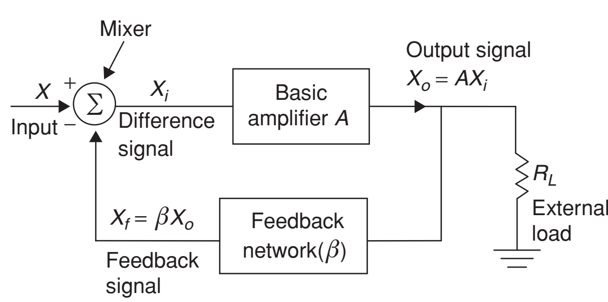


Figure 5 Schematic representation of a single loop feedback amplifier

Advantages of negativefeedback

High input resistance of a voltage amplifier can be made higher, and its lower output resistance can be lowered. The transfer gain A_f of the amplifier with feedback can be stabilized against variations of h-parameters of transistor. It improves frequency response.

Stability of gain

$$A_f = \frac{A}{1+A\beta}$$

if $A\beta \gg 1,\ A_f = \frac{A}{A\beta} = \frac{1}{\beta}$

$$\frac{\partial A_f}{A_f} = \frac{1}{(1+A\beta)}\frac{\partial A}{A}$$

$\frac{\partial A_f}{A_f}$ = fractional change in amplifier voltage gain with feedback

$\frac{\partial A}{A}$ = fractional change in amplifier voltage gain without feedback

Sensitivity $= \frac{1}{1+A\beta}$

Desensitivity = $1 + A\beta$

Increase in input impedance, $Z_{if} = Z_i\,(1 + A\beta)$

Decrease in output impedance, $Z_{of} = \frac{Z_0}{1+A\beta}$

Reduction in distortion and noise

$$D_f = \frac{D}{1+A\beta},\ N_f = \frac{N}{1+\beta}$$

Increase in bandwidth with negative feedback lower cut-off frequency

$$f_L' = \frac{f_L}{1+A_v\beta}$$

Upper cut-off frequency $f_H' = f_H\,(1 + A_v\beta)$

$\therefore$ Overall $B.\ W_f = BW\,(1 + A\beta)$.

Table 1 *Effect of negative feedback on amplifier*

	Voltage series	Current series	Current shunt	Voltage shunt
R_{output}	Decreases	Increases	Increases	Decreases
R_{input}	Increases	Increases	Decreases	Decreases
Improves char acteristics of	Voltage amplifier	Trans conductance amplifier	Current amplifier	Transresistance amplifier
Desentisizes	A_{vf}	G_{mf}	A_{lf}	R_{mf}
Bandwaidth	Increases	Increases	Increases	Increases
Non linear distortion	Decreases	Decreases	Decreases	Decreases

Example 1: The gain of an amplifier with feedback is to be nominally 20, and a variation of 5% is permissible. If the magnitude of loop gain must be at least 1000 (so that $A\beta \gg 1$), then maximum permissible variation in open loop gain is ____

(A) 20 (B) 50
(C) 40 (D) 30

Solution: (B)

Given $A_f = 20$

If $A\beta >> 1 \Rightarrow A_f = \frac{1}{\beta} \quad \therefore \quad \beta = \frac{1}{20} = 0.05$

$$\left|\frac{dA_f}{A_f}\right| = \frac{1}{|1+A\beta|}\left|\frac{dA}{A}\right|$$

$$\Rightarrow \left|\frac{dA}{A}\right| = 50$$

Example 2: If the input impedance and voltage gain of a open loop voltage series feedback amplifier are 3 kΩ and 100, and the feedback factor is $\frac{1}{50}$, then the input impedance of closed loop configuration is _______

(A) 9 kΩ (B) 6 kΩ
(C) 3 kΩ (D) 12 kΩ

Solution: (A)

$$A = 100,\ R_{in} = 3\text{ k}\Omega$$

$$R_{inf} = R_{in}\,(1 + A\beta)$$

$$= 3\text{ k}\Omega\left(1 + 100\frac{1}{50}\right)$$

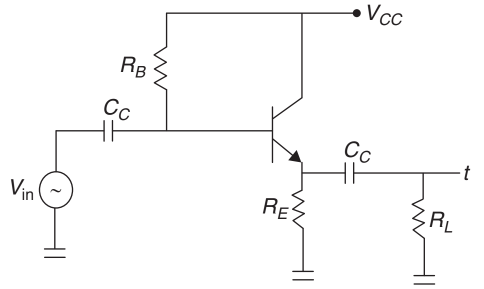
$$R_{inf} = 9\text{ k}\Omega$$

Note: Voltage-series feedback

(i) $R_{inf} = R_{in}\,(1 + A\beta)$

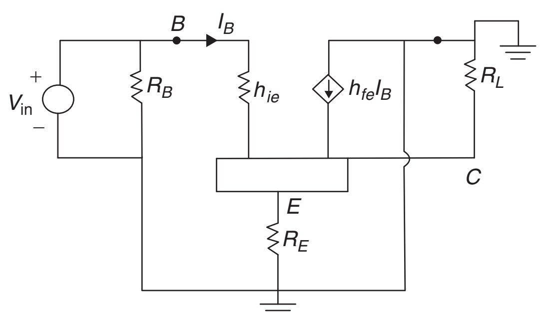
(ii) $R_{of} = \frac{R_o}{(1+A\beta)}$

Example 3: Find the type of the feedback in the given circuit



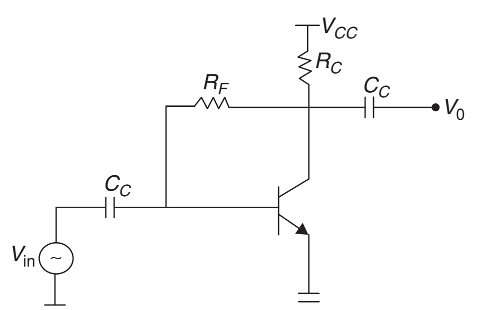
(A) Current series (B) Voltage shunt
(C) Voltage series (D) Current shunt

Solution: (C)
AC equivalent circuit:



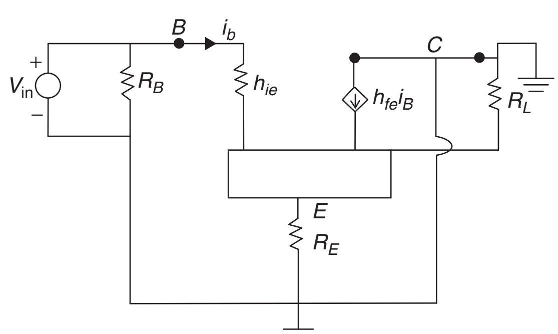
Input-series connection
Output-shunt connection
∴ Voltage series feedback.

Example 4: Find the type of the feedback in the given circuit.



(A) Voltage-series (B) Current-series
(C) Current-shunt (D) Voltage-shunt

Solution: (D)
AC equivalent model:



Input-shunt connection
Output-shunt connection
∴ Voltage-shunt feedback

Power Amplifiers

Classification

Class A

Class A amplifier is one in which the operating point and the input signal are such that the current in the output circuit flows all the times. Normally class A amplifier operates essentially over a linear portion of its characteristic.

Class B

A class B amplifier is one in which the operating point is at an extreme end of its characteristic, so that the quiescent power is very small, hence either the quiescent current or voltage is approximately zero. If the input signal is sinusoidal, amplification takes place for only one half of the cycle.

Class AB

A class AB, amplifier is one operating between the two extremes defined for class A and class B, hence the output signal is zero, for part but less than one half of an input sinusoidal signal cycle.

Class C

A class C amplifier is one in which the operating point is chosen so that the output current (voltage) is zero, for more than one half of an input sinusoidal signal cycle.

Efficiency of Class a Amplifier

$$\eta = \frac{\text{signal power delivered to load}}{\text{DC power supplied to output circuit}} \times 100$$

$$\eta = \frac{\frac{1}{2} \cdot V_m \cdot I_m}{V_{cc} \cdot I_{CQ}} \times 100$$

Where V_m (I_m) represents the peak sinusoidal voltage (current) swing.

Class of Operation	Conduction Angle	Efficiency
Class 'A'	360°	25–50%
Class 'AB'	108° to 360°	50–75%
Class 'B'	180°	78.5%
Class 'C'	Less than 180°	80–90%
Class 'D'	Pulse operation	>90%

(i) Class A → Series-fed; → Transformer Coupled

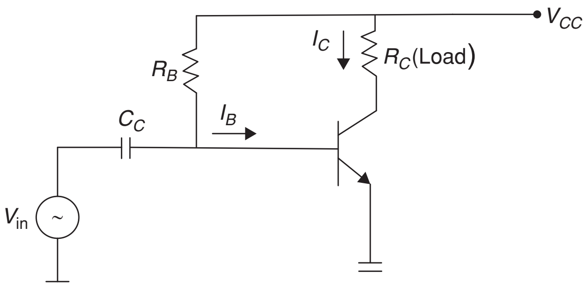
(ii) Class B → Push-Pull; → Complementary symmetry

(iii) Class C circuits are used in tuned circuits, such as radio communications.

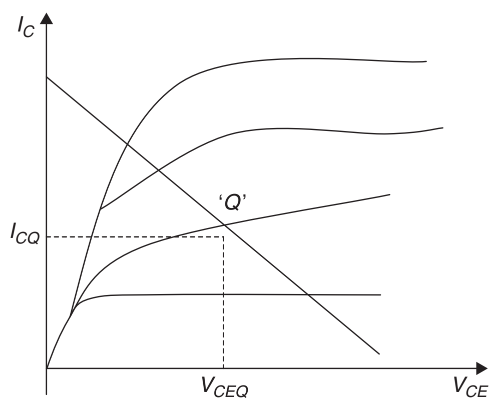
Amplifier efficiency (η):

$$\eta = \frac{\text{AC power delivered to the load}}{\text{DC input power}}$$

Series Fed Class A Amplifier



To have maximum output swing, 'Q' point should be located at the middle of the DC load line



Efficiency calculations

$$\eta = \frac{P_O(\text{AC})}{P_i(\text{DC})}$$

$$\text{P}_i\,(\text{DC}) = V_{cc} \cdot I_{CQ}$$

$$P_o(\text{AC}) = \frac{V_{CE}(P-P) I_C(P-P)}{8}$$

To have maximum output swing,

$$V_{CE}\,(P-P) = V_{cc}$$

$$I_C(P-P) = \frac{V_{CC}}{R_C},\; P_O(\text{AC}) = \frac{V^2{}_{CC}}{8R_C}$$

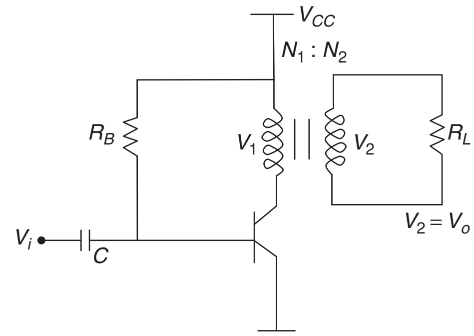
$$I_{CQ} = \frac{V_{cc}}{2R_C}$$

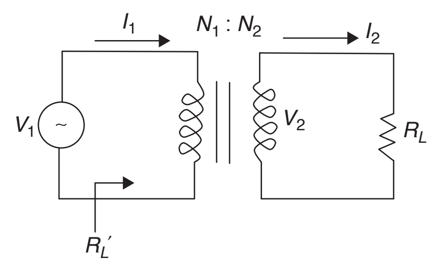
$$P_i(\text{DC}) = \frac{V_{CC}{}^2}{2R_C}$$

$\therefore\ \eta = 25\%$

$\therefore$ Maximum efficiency of class A amplifier is 25%.

Transformer coupled class A power amplifies





$$\frac{V_2}{V_1} = \frac{N_2}{N_1}$$

$$\frac{I_1}{I_2} = \frac{N_2}{N_1}$$

$$R_L' = \left(\frac{N_1}{N_2}\right)^2 R_L$$

Example 5: Calculate the effective resistance seen looking into the primary of a 15 : 1 transformer connected to an 8 Ω load

(A) 2 kΩ (B) 1.8 kΩ
(C) 3 kΩ (D) 4 kΩ

Solution: (B)

$$R_L' = \left(\frac{N_1}{N_2}\right)^2 R_L = (15)^2 8$$

$$R_L' = 1.8\text{ k}\Omega$$

Maximum theoretical efficiency:

$$\eta = 50\left(\frac{V_{\text{CE}_{\max}} - V_{\text{CE}_{\min}}}{V_{\text{CE}_{\max}} + V_{\text{CE}_{\min}}}\right)^2 \%$$

Class B Push-Pull Amplifier

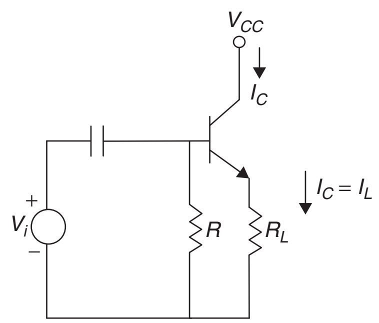


Figure 6 Emitter follower with zero bias operating as class B amplifier

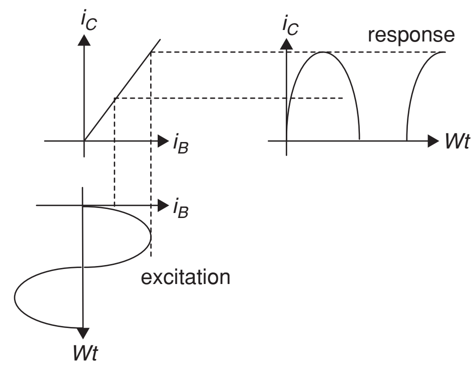
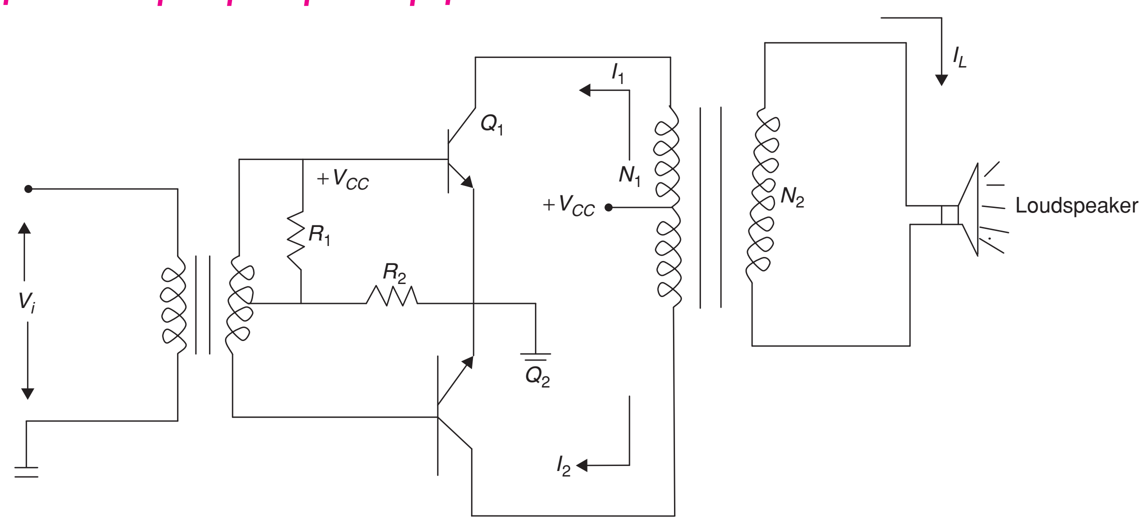


Figure 7 Dynamic transfer characteristic

The emitter follower operates in class B. Let us assume that the transistor output characteristics are equally spaced for equal intervals of excitation for such an idealized transistor the dynamic transfer curve (i_c vs i_B) is a straight line, passing through the origin. The graphical construction from which to determine the collector current wave shape is indicated.

Transformer coupled push-pull amplifier



During positive half cycle: Q_1 ON and Q_2 OFF
Negative half cycle: Q_1 OFF and Q_2 ON

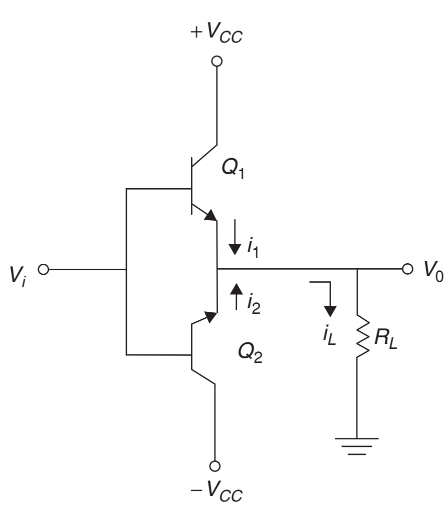


Figure 8 A complementary emitter follower

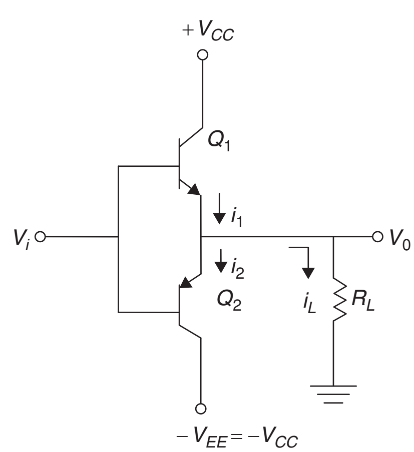
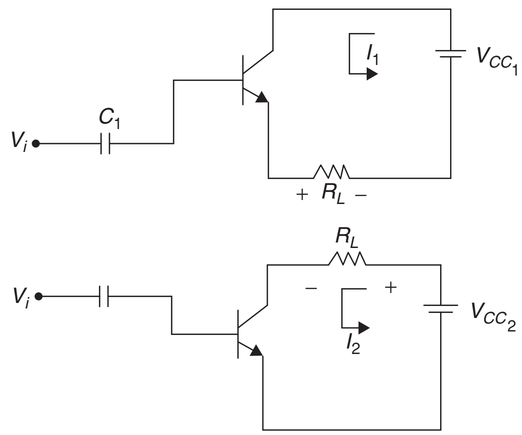
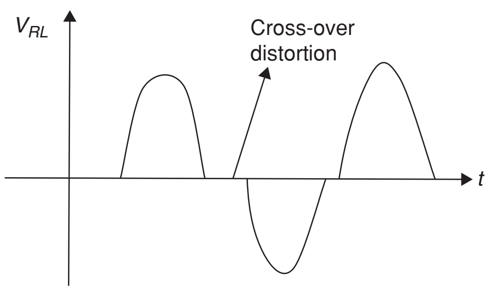


Figure 9 A complementary common-emitter push-pull amplifier

Transformer coupled push-pull amplifier





For positive values of sinusoidal input (V_1) Q_1 conducts and Q_2 is OFF ($i_2 = 0$) so that i_1 is the positive half sine wave.

For negative values of V_i, Q_1 is non conducting ($i_1 = 0$) and Q_2 conducts, resulting in a positive half sinusoid for i_2 which is 180° out of phase with that i_1

Since load current is difference between the two transistor emitter currents $i_L = i_1 - i_2$

Consequently for idealized transfer characteristics the load current is a perfect sinusoid.

The advantage of class B as compared with class A operating are:

It is possible to obtain greater power output, and efficiency is higher, and there is negligible power loss at no signal.

The disadvantages are higher harmonic distortion and power supply voltages must have good regulation.

Efficiency: If peak load voltage $V_m = I_m R_L$

$$\eta = \frac{P}{P_i} \times 100 = \frac{\pi}{4}\left[1 - \frac{V_{\min}}{V_{cc}}\right] \times 100\%$$

Dissipation

$$P_c = P_i - P = \frac{2}{\pi} \cdot \frac{V_{cc} \cdot V_m}{R_L} - \frac{V_m^2}{2R_L}$$

$$P_c(\max) = \frac{2V_{cc}^2}{\pi^2 R_L} = \frac{4}{\pi^2} \cdot P_{\max}$$

P_c (max) = maximum power dissipation
$P_{\max}$ = maximum power which can be delivered

Example 6: Calculate the efficiency of a class B amplifier for a supply voltage of 24 V with peak voltage of 8 V.

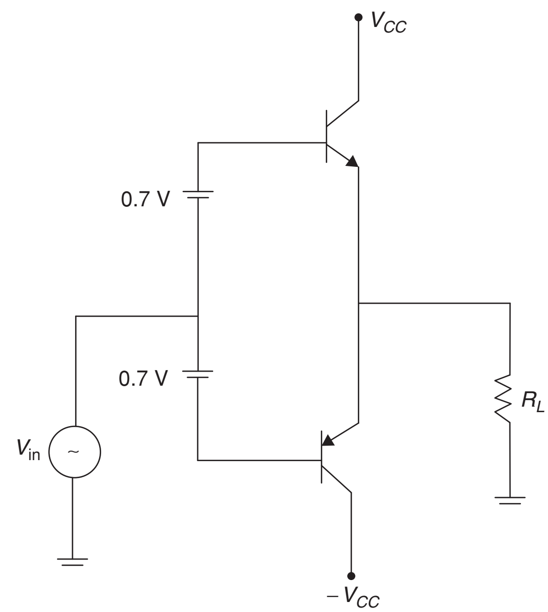
(A) 26.18% (B) 35.62%
(C) 40.25% (D) 52.36%

Solution: (A)

$$\eta = 78.54 \frac{V_L(p)}{V_{CC}} \% = 78.54 \times \frac{8}{24}$$

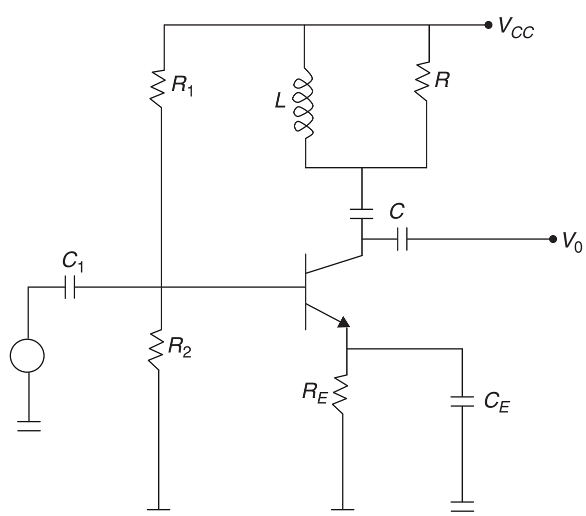
$$= 26.18 \text{ V}$$

Class AB Amplifier



Cross over distortion is eliminated by adding two diodes whose cut in voltages were +0.7 V and –0.7 V.

Class C Amplifier



Class C amplifier is used to generate a pulse wave form whose conduction angle is less than 180°. Efficiency of class C amplifier is 90%.

Resonant frequency

$$Z_L = (R \| SL) + \frac{1}{sC}$$

$$R \| SL = \frac{(R)(sL)}{(R)+(sL)}$$

$$Z_L = \frac{(R)(SL)}{(R)+(SL)} + \frac{1}{SC}$$

$$Z_L = \frac{s^2LCR + R + sL}{sC(R+sL)}$$

$$Y_L = \frac{sC(R+sL)}{s^2LCR + R + sL}$$

Put $S = j\omega$

$$Y_L = \frac{j\omega RC - \omega^2 LC}{-\omega^2 LCR + R + j\omega L}$$

$$Y_L = \frac{j\omega RC - \omega^2 LC}{[R-\omega^2 LCR] + (j\omega L)} \cdot \frac{[R-\omega^2 LCR] - j\omega L}{[R-\omega^2 LCR] - (j\omega L)}$$

To find resonant frequency, make imaginary part = 0

i.e., $j_\omega RC\,[R - \omega^2 LC] + j_{\omega^3} L^2C = 0$

$_\omega R^2C - \omega^2RLC^2 + \omega^3L^3C = 0$

$R^2C = \omega^2[RLC^2 - L^2C]$

$$\omega^2 = \frac{R^2C}{RLC^2 - L^2C}$$

$$\omega = \sqrt{\frac{R^2C}{RLC^2 - L^2C}}$$

555 Timer

The 555 timer is a highly stable device for generating accurate time delay or oscillation.

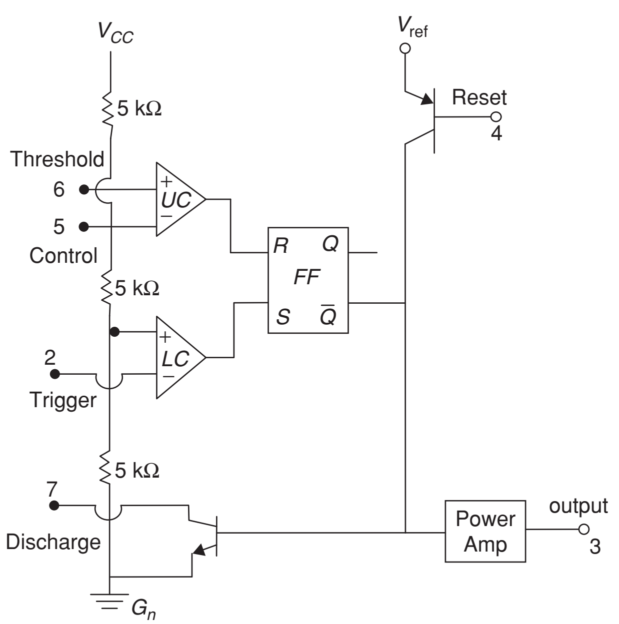


Figure 10 Functional diagram of 555 timer

Three 5 kΩ internal resistors act as voltage divider, providing bias voltage of $\frac{2}{3}V_{CC}$ to upper comparator (UC) and $\frac{1}{3}V_{CC}$ to lower comparator (LC). Since these two voltages fix the necessary comparator threshold voltage, they also aid in determining the timing interval. It is possible to vary time by applying a modulating voltage to control input terminal.

In applications where no such modulation is intended, it is recommended to connect a capacitor between control and ground.

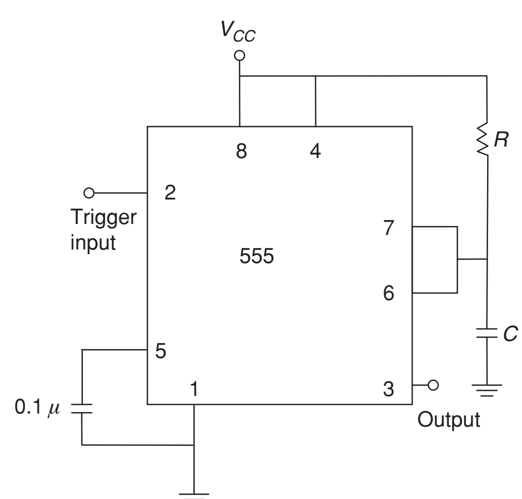
The reset pin provides a mechanism to reset *FF*, when reset is not used, it is returned to V_{cc}.

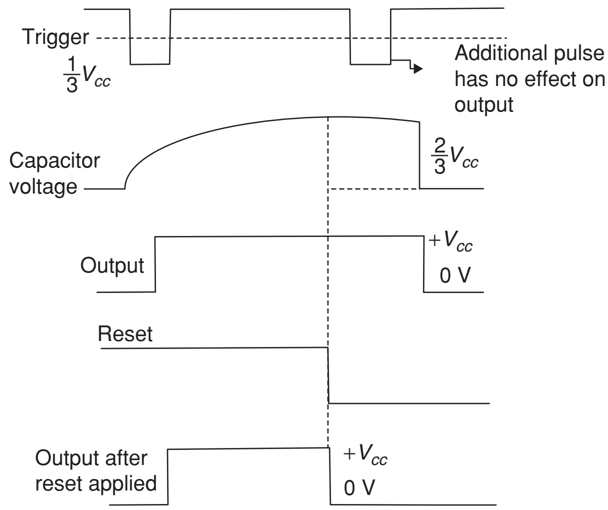
Operation:

1. V_{cc} is typically 5 V, The *R*'*s* are 5 kΩ each, and act as a voltage divider, to create voltages of value $\frac{V_{CC}}{3}, \frac{2V_{CC}}{3}$
2. Comparator 1 compares the voltage applied at the 'threshold' terminal with $\frac{2V_{CC}}{3}$, and comparator 2 compares the voltage at the 'trigger' terminal with $\frac{V_{CC}}{3}$.
3. External connection to the 'control' terminal will override the $\frac{2V_{CC}}{3}$ existing at that node, and allows the user added flexibility.
4. When the comparator 2 output is high, it 'sets' the *RS* flip-flop whose output (*Q*) goes high. This turns on the discharge transistor Q_1, and causes the 'discharge' terminal to be discharged to the ground.
5. When the comparator 1 output is high, it resets the *Rs*-flipflop, whose output goes low, which turns Q_1 OFF.

Monostable Operation

$$T = 1.1\ \text{RC}$$





Operation

Condition	R	S	Q	Output = Q	Transistor status
$V_{cc} > \frac{2}{3}V_{cc}$	1	0	1	0	ON, capacitor starts discharging
$V_{cc} = 0$ V	0	0	1	0	No change in state
Apply Trigger	0	1	0	1	OFF, capacitor starts charging
$V_{cc} > \frac{1}{3}V_{cc}$	0	0	0	1	No change in state
$V_{cc} > \frac{2}{3}V_{cc}$	1	0	1	0	ON, capacitor starts discharging
$V_{cc} = 0$ V	0	0	1	0	no change in state

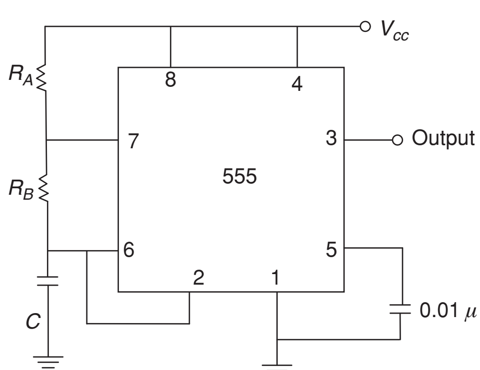
$$V_C(t) = V_{\text{final}} + (V_{\text{initial}} - V_{\text{final}})e^{\frac{-t}{RC}}$$

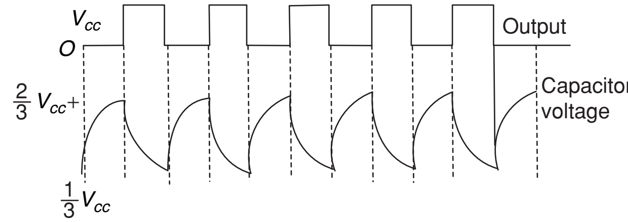
$$V_C(t) = V_{CC} + (0 - V_{CC})e^{\frac{-t}{RC}}$$

At $t = T, V_c(t) = \frac{2}{3}V_{cc}$, where '$T$' represents duration which 'Q' output goes high

$$\therefore \quad \frac{2}{3}V_{cc} = V_{cc}\left[1 - e^{\frac{-T}{RC}}\right] \quad \Rightarrow \quad T = 1.1\text{ RC}$$

Astable Operation





Assume capacitor discharges, when power is switch ON, $V_{\text{trigger}} = V_{\text{threshold}} = 0$

$\Rightarrow$ comparator 2 will have a high output

Comparator 1 will have a low output.

$\Rightarrow R = 0, S = 1$ and $Q = 1$

So capacitor will charge through $(R_A + R_B)$

$V_C(t) > \frac{V_{cc}}{3}$, comparator 2 output will go low $\Rightarrow S = 0$

$V_C(t) > \frac{2V_{cc}}{3}$, comparator 2 output will go high $\Rightarrow Q = 0$

$$V_C(t) = \frac{2V_{cc}}{3}\exp\left(\frac{-t}{R_B \cdot C}\right)$$

$$V_C(T_1) = \frac{V_{cc}}{3} = \frac{2V_{CC}}{3}\exp\left(\frac{-T_1}{R_B C}\right)$$

$$T_1 = R_B C\ \ln^{(2)} = 0.69\ R_B\ C$$

Similarly, during the time period T_2

$$V_C(t) = V_{CC} - \left(V_{CC} - \frac{V_{CC}}{3}\right)\exp\left[\frac{-t}{(R_A + R_B)C}\right]$$

$$T_2 = (R_A + R_B)\ \ln(2) = 0.69\ (R_A + R_B)\ c$$

$$T = T_1 + T_2 = 0.69\ (R_A + 2R_B)\text{C}$$

$$\text{Duty cycle } = \frac{T_1}{T_1 + T_2} = \frac{R_A + R_B}{R_A + 2R_B}$$

$$t_{\text{high}} = 0.69(R_A + R_B)C$$

$$t_{\text{low}} = 0.69 R_B C$$

$$T = t_{\text{high}} + t_{\text{low}}$$

$$= 0.69(R_A + 2R_B)C$$

$$f = \frac{1}{T} = \frac{1.45}{(R_A + 2R_B)C}$$

$$\text{Duty Cycle } = \frac{t_{\text{high}}}{T} \times 100 = \frac{R_A + R_B}{R_A + 2R_B} \times 100$$

When R_A is much smaller than R_B duty cycle approaches to 50%. If R_A is much greater than R_B duty cycle approaches to 100%. The circuit can be modified to enabled the duty cycle less than 50%. By placing a diode across R_B (anode at pin 7).

The capacitor will effectively charge through R_A and diode.

The capacitor will discharge through R_B, $D = \dfrac{R_A}{R_A + R_B}$

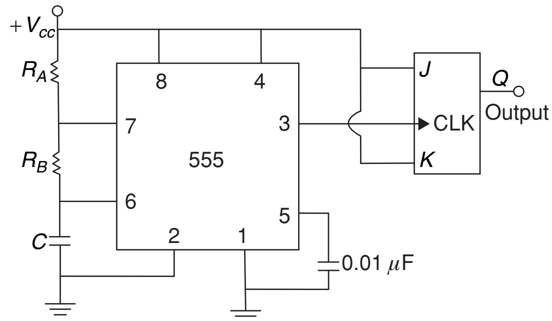
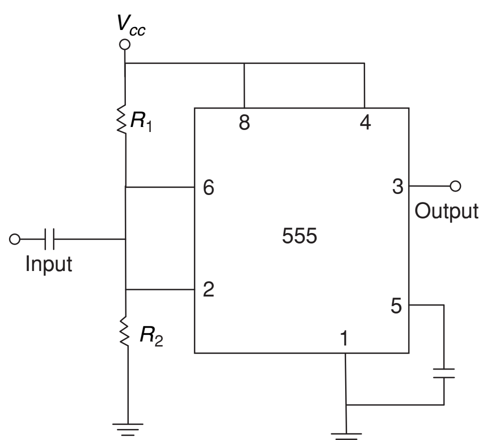


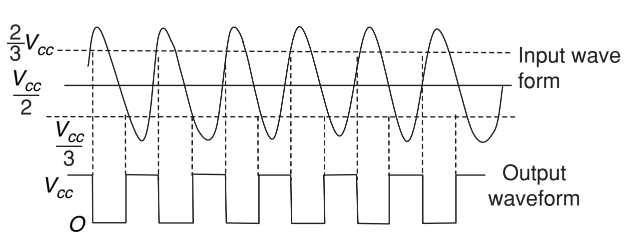
Figure 11 Symmetrical wave form generator.

The clocked flip-flop acts as binary divider to the timer output. The output frequency in this case will be one half that of the timer, the advantage of this circuit is of having output of 50% duty cycle, without any restriction on the choice of R_A and R_B.

Schmitt Trigger



The use of 555 timer as a Schmitt trigger input is shown in figure. Here the two internal comparators are tied together and externally biased at $\frac{V_{cc}}{2}$ by R_1 and R_2 resistors. The threshold levels of (UC) $= \frac{2}{3}V_{CC}$ and LC $= \frac{1}{3}V_{CC}$ and the bias provided by R_1 and R_2 determine the output wave form. Thus sine wave of sufficient amplitude, $\left(> \frac{V_{CC}}{6}, \text{ i.e., } \frac{2}{3}V_{CC} - \frac{V_{CC}}{2}\right)$ to exceed the reference levels causes the internal flip-flop to alternately set and reset, providing a square wave output



Unlike multivibrators, no frequency division is taking place and frequency of square wave remains same as that of input signal.

Voltage Controlled Oscillator

Voltage controlled oscillator (VCO) or voltage to frequency converter can be found in Applications like frequency modulation, tone generators, and frequency shift keying (FSK) etc, where frequency needs to be controlled by input voltage.

A typical example for VCO is IC 566, which provides simultaneous square wave and triangular wave outputs as a function of input voltage.

The frequency of osculation is determined by an external resistor R_1, capacitor C_1, and the voltage V_c applied.

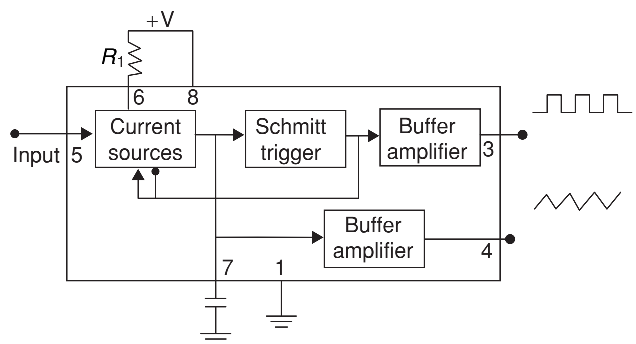


Figure 12 Block diagram. of 566

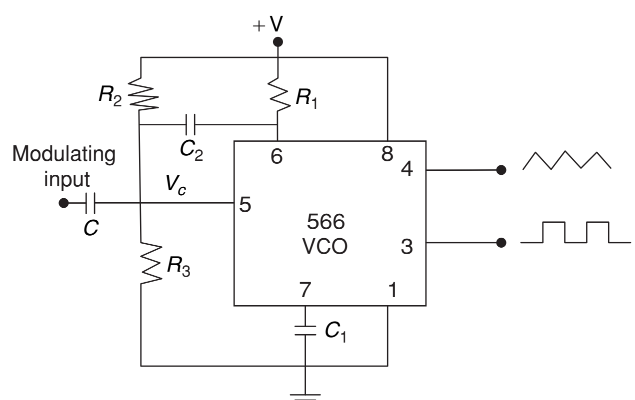


Figure 13 Typical connection diagram

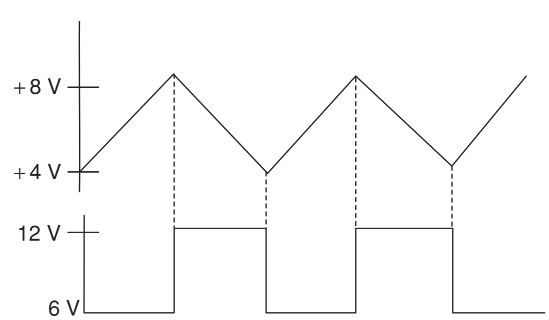


Figure 14 Output waveforms

$$f_o = \frac{2(V - V_c)}{R_1 C_1 (+V)},$$

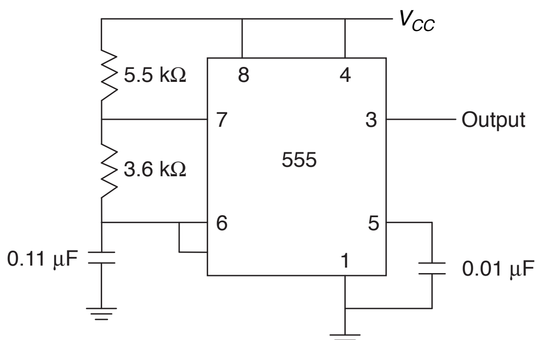
Where $\frac{3}{4}(+V) \le V_C \le (+V)$ and 2 kΩ < R, < 20 kΩ

VCO is commonly used in converting low frequency signal such as electroencephalograms (EEG) or electrocardiograms (ECG) into an audio frequency range.

Solved Examples

Directions for questions 7 to 11: Select the correct alternative from the given choices.

Example 7: The 555 timer circuit to generate a rectangular waveform is shown in figure. The frequency and duty cycle of the waveform are



(A) 1 kHz, 0.43 (B) 2 kHz, 0.43
(C) 2 kHz, 0.28 (D) 1 kHz, 0.28

Solution: (D)

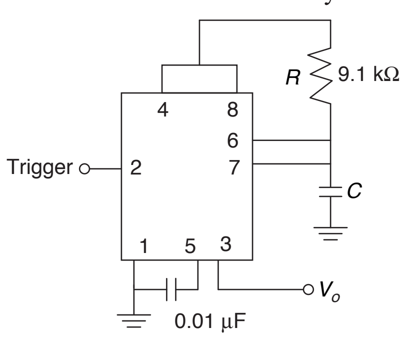
$$f = \frac{1.45}{(R_A + 2R_B)C} = \frac{1.45}{(5.5 + 2\times 3.6)\times 0.11\times 10^{-3}}$$

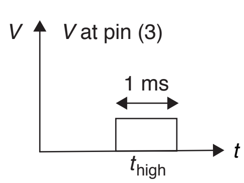
$$= 1.04 \text{ kHz} \approx 1 \text{ kHz}$$

$$\text{Duty cycle} = \frac{R_B}{R_A + 2R_B} = \frac{3.6}{5.5 + 2\times 3.6}$$

$$= 0.28$$

Example 8: A monostable multivibrator circuit is shown in the figure. The value of C would be nearly





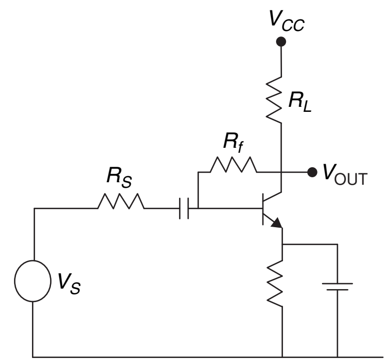
(A) 0.01 μF (B) 0.001 μF
(C) 0.1 μF (D) 1 μF

Solution: (C)

$T_{high} = 1{\cdot}1\ R.C$

$$\Rightarrow \quad C = \frac{1.0\times 10^{-3}}{1.1\times 9.1\times 10^{3}} = 0.1\ \mu\text{F}$$

Common Data for Questions 9 to10: For the circuit shown in the figure, the transistor parameters are h_{fe} = 100, h_{ie} = 1 kΩ, R_s = 2 kΩ, R_L = 20 kΩ, R_f = 200 kΩ.



Example 9: The type of feedback used in this circuit is
(A) Voltage shunt. (B) Current shunt.
(C) Voltage series. (D) Current series.

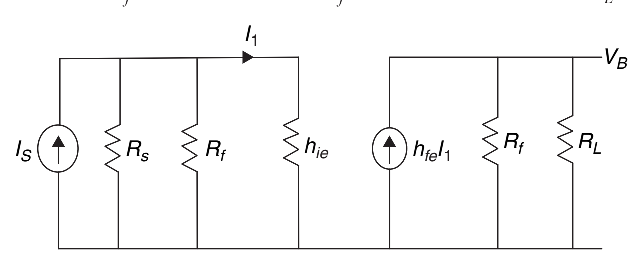
Solution: (A)
R_f is across the output and samples the output voltage V_0. At the input it is in shunt, resulting current feedback, the feedback in voltage shunt is

$$\beta = \frac{I_f}{V_0} = -\frac{1}{R_f} = \frac{1}{200\times 10^{3}} \text{ mho}$$

This feedback amplifier is a current controlled voltage source, hence both input and output impedances are reduced by feedback.

Example 10: The feedback factor is
(A) 5.543 (B) 4.636
(C) 3.423 (D) 2.942

Solution: (B)
The equivalent current of the amplifier without feedback will have R_f across input, and R_f across load resistance R_L



$$A_Z = \frac{V_0}{I_s} = \frac{V_0}{I_i}\times\frac{I_i}{I_s} \text{ (Total gain without feedback)}$$

Here $R_s = 2$ K, $h_{ie} = 1$ K, $R_f = 200$ K >> h_{ie}
Input resistance $R_i = 0.66$ kΩ

$$\frac{I_i}{I_s} = \frac{0.66}{1+0.66} = 0.397$$

$$R_f \parallel R_L = 200 \text{ K} \parallel 20 \text{ K} = 18.18 \text{ k}\Omega$$

$$\frac{V_0}{I_i} = -h_{ie} \times R_f \parallel R_L = -100 \times 18.18 \text{ k}\Omega$$

$$A_Z = \frac{V_0}{I_i} \times \frac{I_i}{I_s} = 72.72 \times 10^4$$

$$D = 1 + A_z\beta$$

$$= 1 + 72.72 \times 10^4 \times \frac{1}{200 \times 10^3} = 4.636$$

Example 11: The input and output impedance values in mid-band are
(A) 142 Ω, 3.92 kΩ
(B) 3.92 kΩ, 142 Ω
(C) 0.66 kΩ
(D) 18.18 kΩ, 0.66 kΩ

Solution: (A)

$$R_{\text{in}} = \text{Input resistance} = \frac{0.66 \text{ k}\Omega}{4.636} 0.142 \text{ k}\Omega$$

$$R_{\text{out}} = \text{Output resistance} = \frac{18.182}{4.636}$$

$$= 3.92 \text{ k}\Omega$$

Exercises

Practice Problems I

Directions for questions 1 to 43: Select the correct alternative from the given choices.

1. An amplifier has an open loop gain of 100 with 10% harmonic distortion at output. If 40 dB of negative feedback is applied, the distortion with feedback is ________.
(A) 0.1% (B) 10%
(C) 100% (D) None

2. The gain of amplifier is 1000 and $\beta = 0.1$. Due to temperature variations, gain is changed by 15%, the change in gain with –ve feedback is ________.
(A) 0% (B) 1.5%
(C) 0.15% (D) 1%

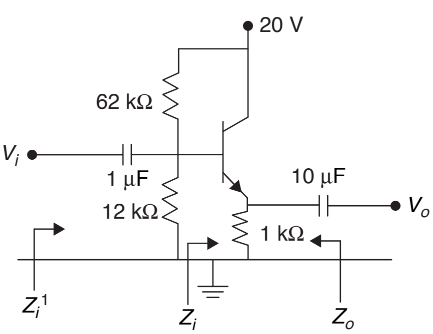
3. An amplifier has an open loop gain of 200, an input impedance of 5 kΩ and output impedance of 600 Ω. A feedback factor of $\beta = 20\%$ is connected to the amplifier in a voltage shunt feedback mode, the new input and output impedances are ________.
(A) $Z_{\text{if}} = 205$ kΩ $Z_{\text{of}} = 14.63$ Ω
(B) $Z_{\text{if}} = 122$ Ω $Z_{\text{of}} = 24.6$ kΩ
(C) $Z_{\text{if}} = 205$ kΩ $Z_{\text{of}} = 24.6$ kΩ
(D) $Z_{\text{if}} = 122$ Ω $Z_{\text{of}} = 14.63$ Ω

4. The mid-band gain of an amplifier is 1000. Its lower and upper cut-off frequencies are 60 Hz and 80 kHz respectively. A feedback Network with $\beta = 0.05$ is taken, the new lower and upper cut-off frequencies are ________.
(A) $f'_L = 3.1$ kHz $f'_H = 1.568$ kHz
(B) $f'_L = 3.1$ kHz $f'_H = 4.08$ MHz
(C) $f'_L = 1.176$ Hz $f'_H = 4.08$ MHz
(D) $f'_L = 1.176$ Hz $f'_H = 1.568$ kHz

5. The gain-band width product of amplifier without feedback is 6 MHz. with negative feedback, the bandwidth is 1 MHz, the closed loop gain is ________.
(A) 6 (B) 60
(C) 100 (D) 10

6. An amplifier has a voltage gain 200 with $Z_i = 10$ kΩ and $Z_o = 1$ kΩ. A negative feedback with $\beta = 0.04$ in current shunt feedback is applied, the result input and output impedance are ________.
(A) $Z_{\text{if}} = 1.11$ kΩ $Z_{\text{of}} = 0.11$ kΩ
(B) $Z_{\text{if}} = 1.11$ kΩ $Z_{\text{of}} = 9$ kΩ
(C) $Z_{\text{if}} = 90$ kΩ $Z_{\text{of}} = 0.11$ kΩ
(D) $Z_{\text{if}} = 90$ kΩ $Z_{\text{of}} = 9$ kΩ

Common Data for Questions 7 to 9: For the given emitter follower, the specifications are $\beta = 100$, $h_{ie} = 2$ kΩ

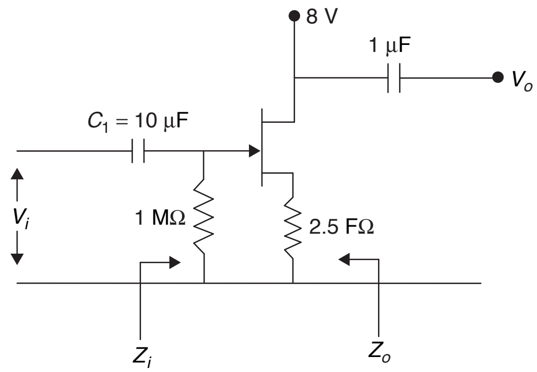


7. The input impedance Z_i is
(A) 1 kΩ (B) 101 kΩ
(C) 103 kΩ (D) 10.05 kΩ

8. The input impedance Z'_i as seen from source is ________.
(A) 9.156 kΩ (B) 10.05 kΩ
(C) 12 kΩ (D) 62 kΩ

9. The output impedance Z_o is ________.
(A) 1 kΩ (B) 20 Ω
(C) 1.02 kΩ (D) ∝

Common Data for Questions 10 to 12: A source follower is shown below with following specifications $I_{DSS} = 12$ mA, $V_P = 4$ V, $g_m = 2.28$ ms and $r_d = \infty$

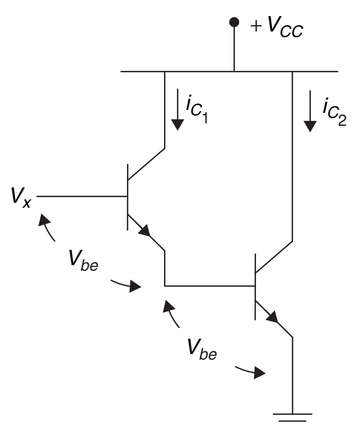


10. The input impedance Z_i is
(A) ∝ (B) 0
(C) 1 MΩ (D) None

11. The output impedance Z_o is
(A) 2.5 kΩ (B) 37 Ω
(C) 3.7 kΩ (D) 372 Ω

12. Voltage gain A_V is
(A) 0.85 (B) 1
(C) 99 (D) None

13. The Darlington pair stage is shown in the following figure. If the transconductance of Q_1 is 8×10^{-3} ℧ and Q_2 is 6×10^{-3} ℧, the overall transconductance g_m is _______.



(A) 14×10^{-3} ℧
(B) 2×10^{-3} ℧
(C) 3×10^{-3} ℧
(D) 6×10^{-3} ℧

14. The feedback N/w of Hartley oscillator have $L_1 = 10$ mH, $L_2 = 5$ mH and $C = 100$ PF. The mutual inductance b/w L_1 and L_2 is 2.5 mH. The frequency of oscillation is _______.
(A) 0.13 MHz (B) 11.3 kHz
(C) 0.113 MHz (D) None

15. The expression for output collector current in a power amplifier is given by
$I_C = 4 \sin \omega t + 1.5 \sin 2\,\omega t + 0.6 \sin 3\,\omega t$ amp
The % increase in power due to harmonic distortion is _______.
(A) 16.2% (B) 30.5%
(C) 12% (D) 1.6%

Common Data for Questions 16 to 18: A power amplifier working in class A operation has a zero signal collector current of 120 mA at $V_{CC} = 10$ volt

16. The maximum ac Output power is _______.
(A) 0.3 W (B) 0.15 W
(C) 0.6 W (D) 1.2 W

17. The power rating of transistor is _______.
(A) ≥ 1.2 W (B) ≥ 0.6 W
(C) ≤ 1.2 W (D) ≥ 0.3 W

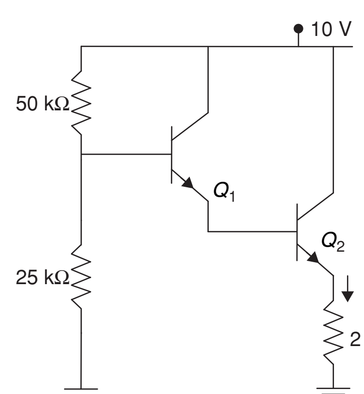
18. The power amplifier maximum collector efficiency is _______.
(A) 50% (B) 25%
(C) 78.5% (D) 18%

Common Data for Questions 19 and 20: A class B amplifier works on 20 V DC supply. The output impedance is 10 Ω and turn ratio is 5. The peak voltage across the load is 15 V.

19. The collector efficiency is _______.
(A) 28% (B) 50%
(C) 78.5% (D) 58.8%

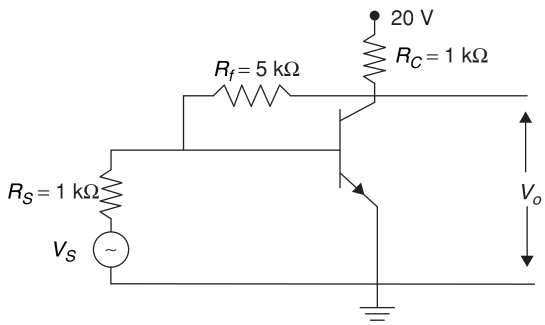
20. The power rating of transistor is _______.
(A) 0.45 W (B) 0.225 W
(C) 4.5 W (D) 2.25 W

21. What is the emitter current I_E if $\beta = 100$ and $V_{BE} = 0.7$ V for each transistor of the Darlington pair given below



(A) 1.5 mA (B) 0.964 mA
(C) 0.48 mA (D) None

Common Data for Questions 22 to 24: The feedback amplifier shown below has a open loop gain 1000.

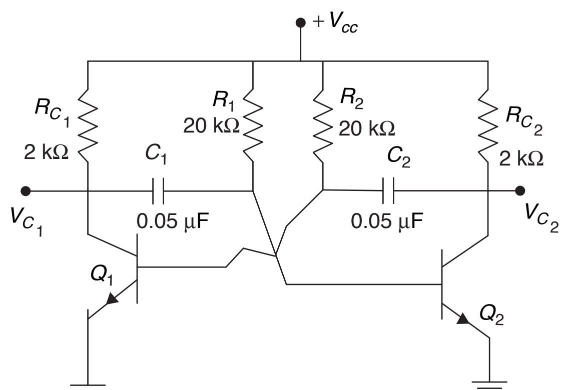


22. What is the type of feedback employed?
(A) series-series feedback
(B) series-shunt feedback
(C) shunt-series feedback
(D) shunt-shunt feedback

23. The feedback ratio β is ________.
(A) 1.6×10^{-4} (B) 1×10^{-3}
(C) 2×10^{-4} (D) 0.2×10^{-4}

24. The closed loop gain A_f is ________.
(A) 833.3 (B) 100
(C) 1000 (D) None

Common Data for Questions 25 and 26: An astable multi vibrator is shown below



25. The frequency of square wave Output is ________.
(A) 7.24 kHz (B) 5 kHz
(C) 0.5 kHz (D) 0.724 kHz

26. The minimum value of h_{fe} of transistor to ensure oscillations is ________.
(A) 1 (B) 0.2
(C) 10 (D) 8

27. An astable multi vibrator using Si transistor is designed to generate a square wave of amplitude 12 V and frequency 1 kHz.
The transistor has
$h_{fe_{mim}} = 40$, $I_{C_{sat}} = 6$ mA and $V_{CE_{sat}} = 0.2$ V. Assume $R_1 = R_2 = R$, $C_1 = C_2 = C$, calculate the value of R and C.
(A) $R = 1.96$ kΩ $C = 9$ nF
(B) $R = 1.96$ kΩ $C = 0.9$ μF
(C) $R = 196$ Ω $C = 9$ nF
(D) $R = 196$ Ω $C = 9$ μF

28. The AC power output of a class A amplifier is 4 W. If the collector efficiency is 45%, what is the power rating of transistor?
(A) ≥ 8.9 W
(B) < 8.9 W
(C) ≥ 4 W
(D) < 4 W

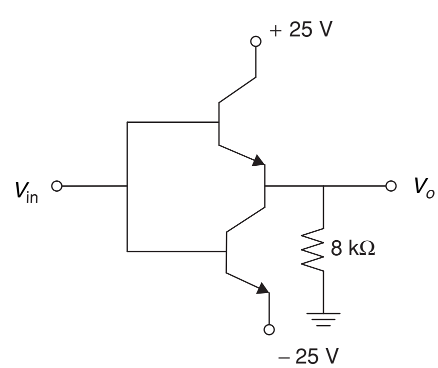
29. A class B push-pull amplifier uses 15 V DC supply, with sinusoidal input; a max peak to peak of 24 V is desired across a load of 100 Ω. What is the power dissipated by each transistor?
(A) 426 mW (B) 213 mW
(C) 1.146 W (D) 0.72 W

30. Match List I and List II:

List I	List II
P Class A amplifier	**1** Hifidelity
Q Class B amplifier	**2** Tuned amplifier
R Class C amplifier	**3** Power amplifier
S Class AB amplifier	**4** Low distortion power amplifier

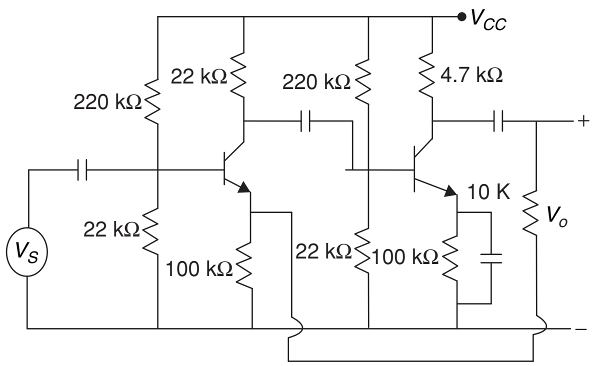
	P	Q	R	S
(A)	4	3	2	1
(B)	1	2	3	4
(C)	4	2	3	1
(D)	1	3	2	4

31. The circuit of a class B push pull amplifier is shown in the figure. If the peak output voltage V_o is 16 V. The power drawn from the DC source would be



(A) 10 W (B) 15 W
(C) 27 W (D) 32 W

Common Data for Questions 32 to 34: For the two stage feed back amplifier shown in figure h_{ie} = 1.1 kΩ, h_{fe} = 50



32. The nature of over-all feedback is?
(A) Voltage shunt
(B) Voltage series
(C) Current series
(D) Current shunt

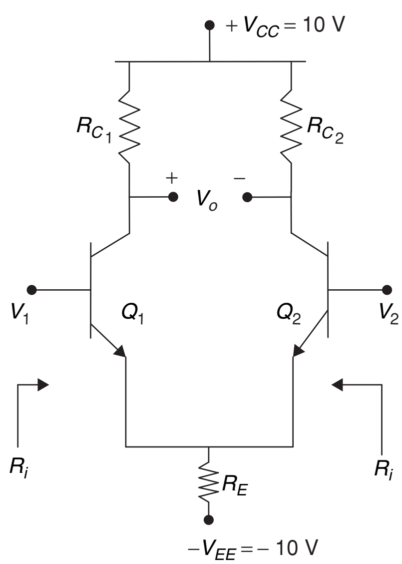
33. The values of over-all gain without feedback, and feed-back factor are
(A) 600 and 10 (B) 1163 and 10
(C) 600 and 12.5 (D) 1163 and 12.5

34. The values of overall input and output resistance with feedback are
(A) 6.2 kΩ and 3.3 kΩ
(B) 77.63 kΩ and 3.3 kΩ
(C) 77.63 kΩ and 0.25 kΩ
(D) 6.2 kΩ and 0.25 kΩ

Common Data for Questions 35 to 39: A differential amplifier is shown below with following specifications.

$R_{C_1} = R_{C_2} = 2.2$ kΩ, $R_E = 4.5$ kΩ, $\beta = 100$, $V_{BE} = 0.7$ V

And r_e = 28 Ω



35. The input resistance R_i seen from each source is
(A) 5.6 kΩ (B) 28 Ω
(C) 1.4 kΩ (D) 2.8 kΩ

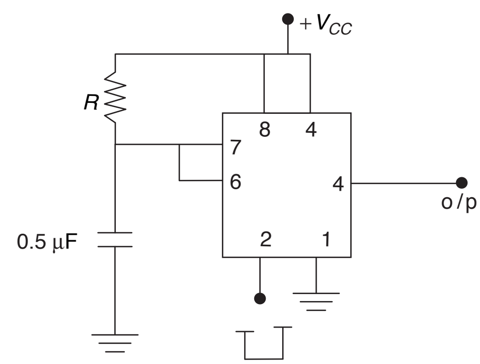
36. The output resistance R_O is
(A) 6.9 kΩ (B) 4.7 kΩ
(C) 2.2 kΩ (D) None

37. The differential mode gain is
(A) 39.3 (B) 78.5
(C) 0.48 (D) ∞

38. The common mode gain A_C is
(A) 0.48 (B) 0.24
(C) 0.97 (D) 0

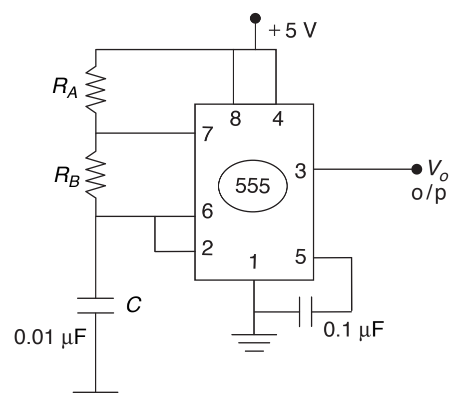
39. CMRR in dB is
(A) 50.29 dB (B) 25.14 dB
(C) 2.51 dB (D) 44.27 dB

40. A monostable multi vibrator is shown below. What is the value of R required for output rectangular frequency of 500 Hz.



(A) 5.8 kΩ (B) 3.63 kΩ
(C) 6.2 kΩ (D) 9.1 kΩ

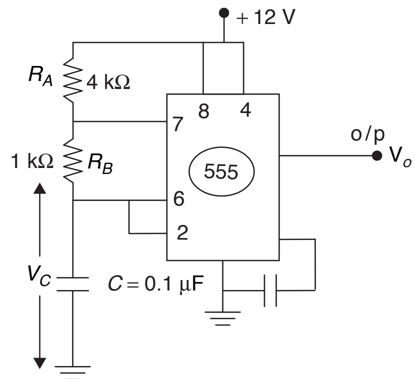
41. An astable multivibrator using *IC* 555 timer is given below; generate a square pulse of frequency 1 kHz with duty cycle 60%, what is the Relation between R_A and R_B?



(A) $R_B = R_A$ (B) $R_B = \frac{R_A}{2}$

(C) $R_B = 2R_A$ (D) $R_B = \frac{R_A}{3}$

42. An astable multivibrator using *IC* 555 is given below



The capacitor voltage V_c limits are

(A) 12 V and −12 V
(B) 4 V and −4 V
(C) 4 V and 8 V
(D) 8 V and −8 V

43. The frequency of output is

(A) 2. 4 kHz
(B) 1 kHz
(C) 1.2 kHz
(D) None of these

Practice Problems 2

Directions for questions 1 to 27: Select the correct alternative from the given choices.

1. An amplifier with −ve feedback has a voltage gain of 80, without feedback, an input signal of 40 mV is required to produce a given output where as with feedback; the input signal must be 0.5 V for the same output. The feedback ratio β is ______

(A) 1.5% (B) 1.15%
(C) 10% (D) 6.25%

2. An amplifier gives 1000 mV output with input of 1 mV without feedback. The desensitivity factor with negative feedback is 10. The feedback ratio β is ______.

(A) 2×10^{-3} (B) 9.9×10^{-2}
(C) 1×10^{-2} (D) 9×10^{-3}

3. The open loop gain of amplifier is 1000 ± 200 and feedback ratio is 4.2%, the % change in negative feedback gain is ______.

(A) 2.1% (B) 4.2%
(C) 0.46% (D) None

4. An amplifier has $A = 48000$ and $A_f = 6000$. The amounts of feedback in dB and feedback factor β are ______ respectively.

(A) 18.06 dB, 1.45%
(B) 18.06 dB, 0.145×10^{-3}
(C) 8 dB, 0.145×10^{-3}
(D) 8 dB, 1.45%

Common Data for Questions 5 and 6: The total harmonic distortion of an amplifier is reduced from 20% to 8% when 5% negative feedback is used.

5. The voltage gain without feedback is ______.

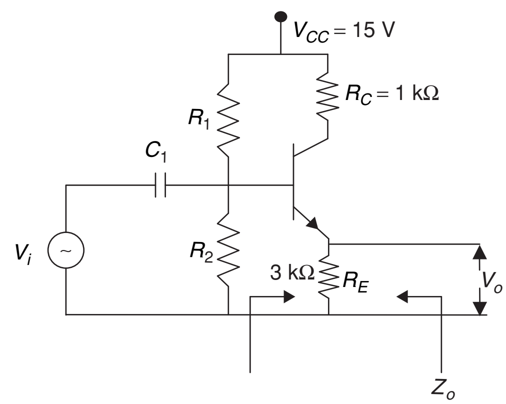
(A) 12 (B) 3
(C) 18 (D) 30

6. The voltage gain with negative feedback is ______.

(A) 1.2 (B) 30
(C) 8 (D) 12

Common Data for Questions 7 to 10: An emitter follower has following specifications.

$$h_{ie} = 1000\ \Omega,\ h_{fe} = 100 \text{ and } R_1 \parallel R_2 = 10\ \text{k}\Omega$$



7. The voltage gain without feedback is ______.

(A) 1 (B) 300
(C) 101 (D) ∞

8. The voltage gain with feedback is ______.

(A) 0.99
(B) 0.85
(C) 30
(D) None

9. The input and output impedance are ______.

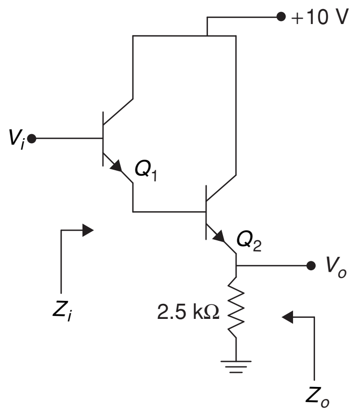
(A) Z_i = 304 kΩ and Z_o = 10 Ω
(B) Z_i = 10 Ω and Z_o = 304 kΩ
(C) Z_i = 1.3 kΩ and Z_o = 3 kΩ
(D) Z_i = 1 kΩ and Z_o = 3 kΩ

10. Current gain A_i is ______.

(A) 25 (B) 101
(C) 0.98 (D) 3

Common Data for Questions 11 to 14: Each transistor in the Darlington pair has following specifications

$$h_{fe} = 99,\ h_{ie} = 1\ \text{k}\Omega$$



11. The input impedance Z_i is ______.
(A) 2.5 kΩ (B) 25 MΩ
(C) 2.5 MΩ (D) 25 Ω

12. The output impedance Z_o is ______.
(A) 2.5 kΩ (B) 1 kΩ
(B) 100 Ω (D) 10.1 Ω

13. Current gain A_i is ______.
(A) 10^2 (B) 10^4
(C) 1 (D) 10

14. Voltage gain A_V is
(A) 0.8 (B) 10
(C) 1 (D) 12

15. An amplifier has a gain of 60 dB without feedback. What is the % loss in gain if $\frac{1}{50}$ of Output is feedback to input in out of phase?
(A) 4.76% (B) 8.3%
(C) 1% (D) 15%

16. In a certain amplifier, an output of 40 V is obtained when the input signal is 0.4 V. If 20% of the output is feedback to input in out of phase, by what value is the input signal to be changed so that the Output voltage remains constant?
(A) 10 V (B) 0.4 V
(C) 6 V (D) 8.4 V

17. In an astable multi vibrator each transistor is cutoff for 1m sec. The frequency of square wave output is ______.
(A) 500 Hz (B) 1 kHz
(C) 2 kHz (D) None

18. A transformer coupled class A amplifier has a turn ratio of 6:1 and the load is 25 Ω. If the zero signal collectors current is 80 mA, the maximum AC Output power is ______.
(A) 1.4 W (B) 2.88 W
(C) 5 W (D) 0.8 W

Common Data for Questions 19 and 20: An amplifier has voltage gain with feedback 50. If the gain without feedback change by 10% and the gain with feedback should not vary more than 1%.

19. The value of open loop gain A is ______.
(A) 500 (B) 250
(C) 1000 (D) 125

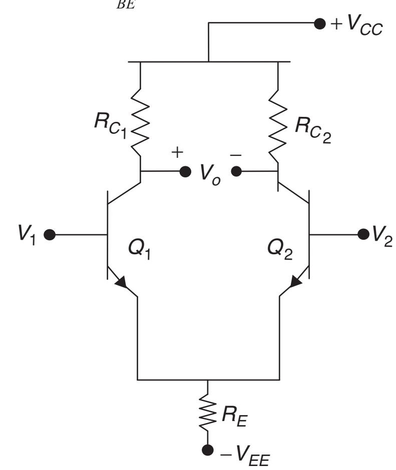
20. The feedback ratio β is ______.
(A) 0.9% (B) 0.45%
(C) 2.2% (D) 1.8%

21. An amplifier has 10% non linear distortion generated in its output stage. The amplifier gain without feedback is 200. If the distortions are reduced to 2% with negative feedback, the feedback ratio is ______.
(A) 0.5 (B) 0.2
(C) 0.02 (D) 1

22. Calculate the value of the capacitors to be used in astable multi vibrator to provide a train of pulse 4 μs wide at a repetition rate of 80 kHz if $R_1 = R_2 = 10$ kΩ.
(A) $C_1 = 0.58$ nF and $C_2 = 0.58$ nF
(B) $C_1 = 1.23$ nF, and $C_2 = 1.23$ nF
(C) $C_1 = 0.58$ nF, and $C_2 = 1.23$ nF
(D) $C_1 = 1.23$ nF, and $C_2 = 0.58$ nF

23. A power transistor used in class A amplifier is transformer coupled to a load of 10 Ω. If the signal has peak to peak swing of 200 mA and transformer turn ratio of 10, the AC Output power is ______.
(A) 5 W (B) 50 mW
(C) 10 W (D) 2.5 W

Common Data for Questions 24 to 26: A differential amplifier is shown below, has following specifications.
$R_{C_1} = R_{C_2} = 1.8$ kΩ, $R_E = 4$ kΩ $V_{CC} = 10$ V, $-V_{FE} = -10$ V, $\beta = 100$ and $V_{BE} = 0.7$ V



24. The emitter current I_E is
(A) 2.3 mA (B) 1.16 mA
(C) 1.7 mA (D) 0.98 mA

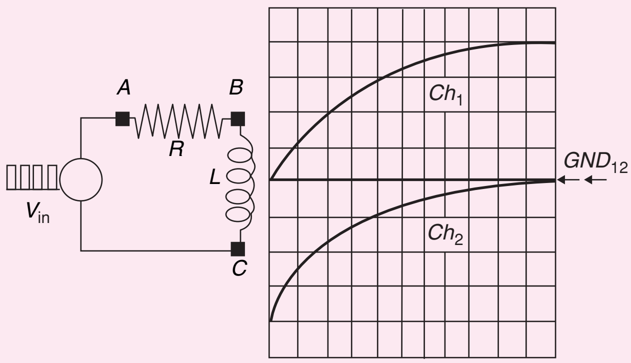
25. The differential mode voltage gain A_d is
(A) 10 (B) 8
(C) 80 (D) 40

26. What is the output V_O if $V_1 = 30$ mV and $V_2 = 40$ mV
(A) 0.8 V (B) 5.6 V
(C) 2.8 V (D) 0 V

27. In the mono stable multivibrator using IC555 timer, the external circuit elements connected is $C = 0.01$ μF and $R = 2.7$ kΩ. Calculate the duration of output pulse width.
(A) 18.6 μs (B) 29.7 μs
(C) 37.2 μs (D) None

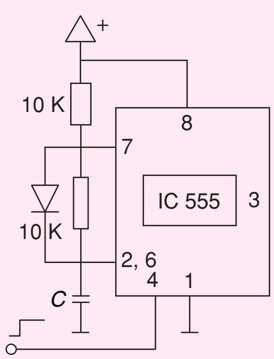
PREVIOUS YEARS' QUESTIONS

1. The probes of a non-isolated, two-channel oscilloscope are clipped to points *A*, *B* and *C* in the circuit of the adjacent figure. V_{in} is a square wave of a suitable low frequency. The display on Ch_1 and Ch_2 are as shown on the right. Then the 'Signal' and 'Ground' probes S_1, G_1 and S_2, G_2 of Ch_1 and Ch_2 respectively are connected to points. **[2007]**

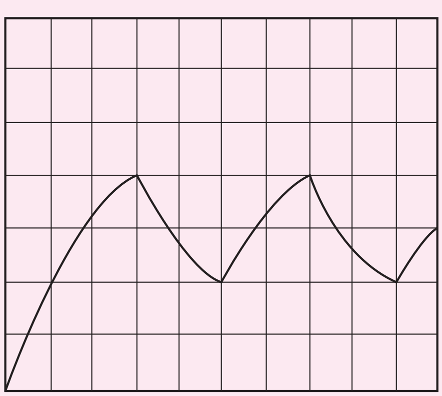


(A) *A*, *B*, *C* and *A*
(B) *A*, *B*, *C* and *B*
(C) *C*, *B*, *A* and *B*
(D) *B*, *A*, *B* and *C*

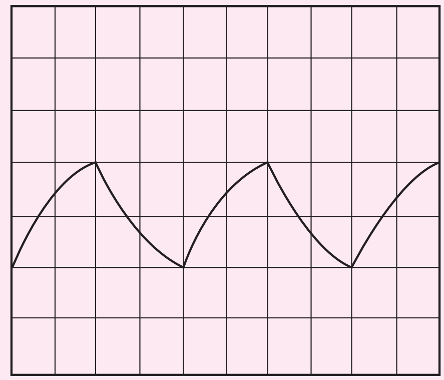
2. *IC* 555 in the adjacent figure is configured as an astable multi-vibrator. It is enabled to oscillate at $t = 0$ by applying a high input to pin 4. The pin description is: 1 and 8–supply: 2–trigger; 4–reset; 6–threshold; 7–discharge. The waveform appearing across the capacitor starting from $t = 0$, as observed on a storage CRO is **[2007]**



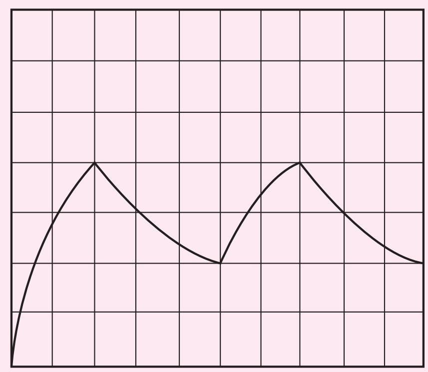
(A)



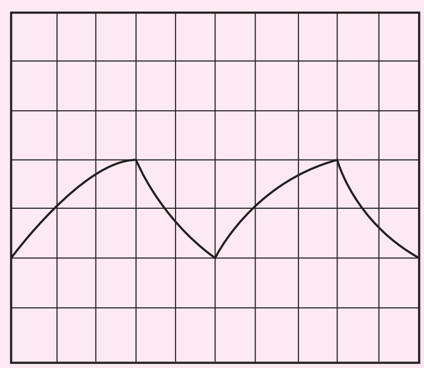
(B)



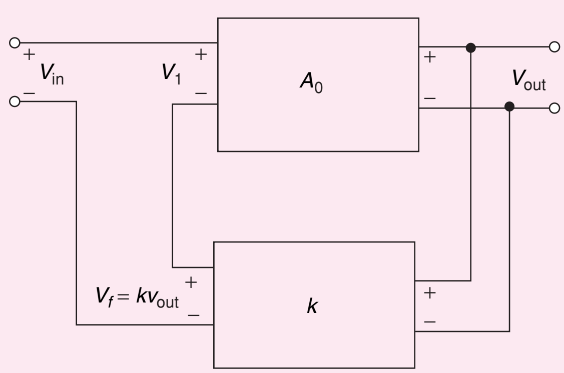
(C)



(D)



3. In the feedback network shown below, if the feedback factor *k* is increased, then the **[2013]**



(A) Input impedance increases and output impedance decreases.
(B) Input impedance increases and output impedance also increases
(C) Input impedance decreases and output impedance also decreases.
(D) Input impedance decreases and output impedance increases.

Answer Keys

Exercises

Practice Problems 1

1. A	**2.** C	**3.** D	**4.** C	**5.** A	**6.** B	**7.** C	**8.** A	**9.** B	**10.** C
11. D	**12.** A	**13.** C	**14.** C	**15.** A	**16.** C	**17.** A	**18.** A	**19.** D	**20.** B
21. B	**22.** D	**23.** C	**24.** A	**25.** D	**26.** C	**27.** A	**28.** A	**29.** B	**30.** D
31. D	**32.** B	**33.** D	**34.** C	**35.** C	**36.** C	**37.** B	**38.** B	**39.** A	**40.** B
41. C	**42.** C	**43.** A							

Practice Problems 2

1. B	**2.** D	**3.** C	**4.** B	**5.** D	**6.** D	**7.** B	**8.** A	**9.** A	**10.** B
11. B	**12.** D	**13.** B	**14.** C	**15.** A	**16.** D	**17.** A	**18.** B	**19.** A	**20.** D
21. C	**22.** C	**23.** A	**24.** B	**25.** C	**26.** A	**27.** B			

Previous Years' Questions

1. B	**2.** A	**3.** A