Chapter 4

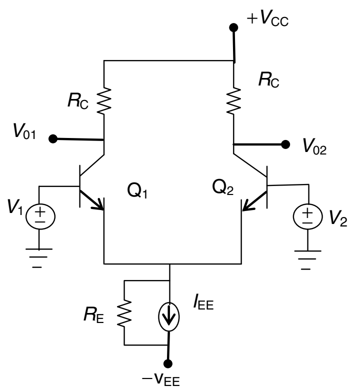
Differential and Feedback Amplifiers

CHAPTER HIGHLIGHTS

- *The Differential Amplifier*
- *Feed Back Amplifiers*
- *Effect of Negative Feedback on Amplifier*
- *Power Amplifiers*
- *Maximum Theoretical Efficiency*
- *Dissipation*
- *Distortion in Amplifiers*
- *Resonant Frequency*
- *Schmitt Trigger*
- *Voltage Controlled Oscillator*

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

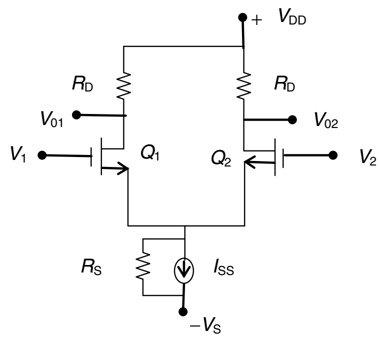
Differential mode output resistance

$$R_{O\ (DM)}^{1} = R_c \parallel r_o \cong R_C$$

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.



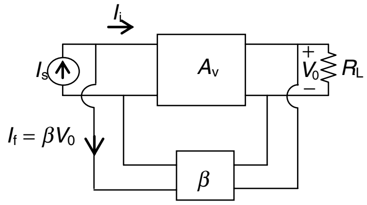
$$\text{CMRR} = 1 + \frac{2R_S(1+\mu)}{r_d + R_D}$$

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

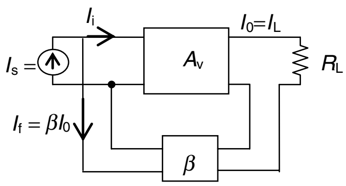
$$\text{CMRR} = 1 + 2g_m R_S \cong 2g_m R_S$$

Feedback Amplifiers

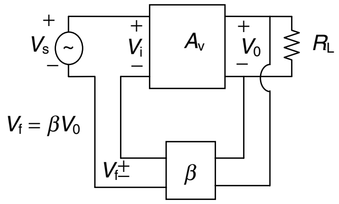
Feedback Amplifier Topologies



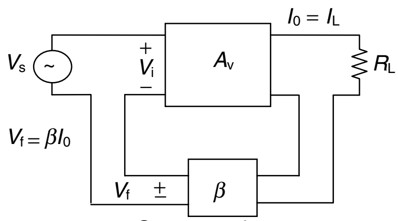
Voltage shunt



Current shunt

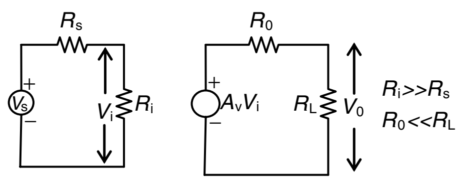


Voltage series

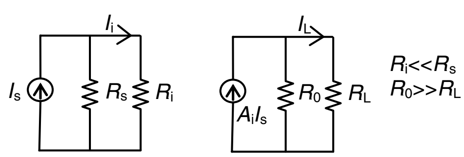


Current series

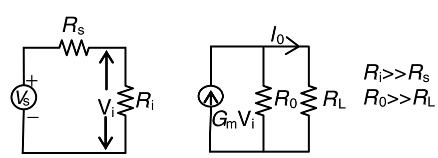
Classification of Amplifiers



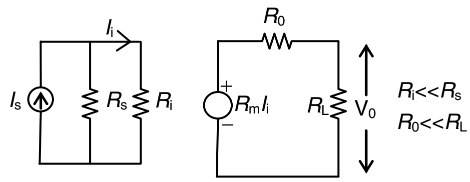
(i) Voltage amplifier



(ii) Current amplifier

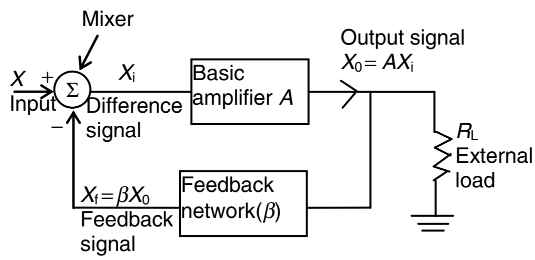


(iii) Transconductance amplifier



(iv) Transresistance amplifier

Schematic Representation of a Single-loop Feedback Amplifier



Advantages of Negative Feedback

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.

(1) **Stability of gain:**

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

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

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

$\frac{\partial A_f}{A_f}$ is the fractional change in amplifier voltage gain with feedback and $\frac{\partial A}{A}$ is the fractional change in amplifier voltage gain without feedback.

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

$$\text{Desensitivity} = 1 + A\beta$$

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

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

Reduction in distortion and noise

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

Increase in bandwidth with negative feedback lowers cut-off frequency:

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

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

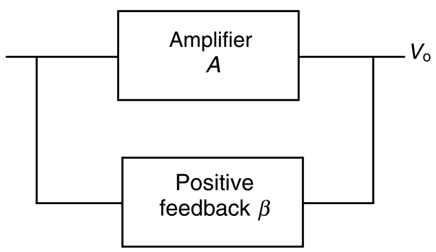
Therefore, overall $BW_f = BW\,(1 + A\beta)$.

Effect of Positive Feedback

In positive feedback circuits, feedback signal is in phase with input signal, so it aids the input. It is also known as regenerative feedback.

In oscillators, we will use positive feedback.

No input signal is given to the oscillator circuit.



$$\text{Gain } A_f = \frac{A}{1 - A\beta}$$

At a particular frequency $A\beta = 1$, this is known as Barkhausen criterion.

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 characteristics of	Voltage amplifier	Transconductance amplifier	Current amplifier	Transresistance amplifier
Desentisizes	A_{vf}	G_{mf}	A_{If}	R_{mf}
Bandwidth	Increases	Increases	Increases	Increases
Non-linear distortion	Decreases	Decreases	Decreases	Decreases

Solved Examples

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 1,000 (so that $A\beta >> 1$), then, maximum permissible variation in open loop gain is ____

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

Solution

Given $A_f = 20$

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

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

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

Example 2

If the input impedance and voltage gain of an 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

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

$$R_{inf} = R_{in}\,(1 + A\beta) = 3\text{ k}\Omega\left(1 + 100\frac{1}{50}\right)$$

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

NOTE

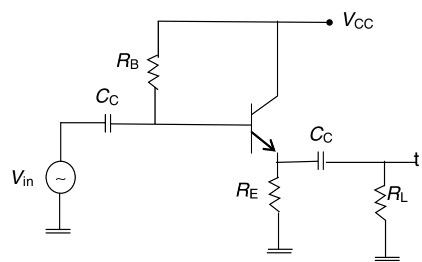
Voltage-series feedback

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

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

Example 3

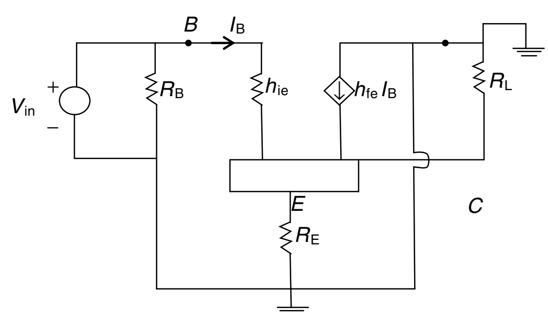
Find the type of the feedback in the given circuit



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

Solution

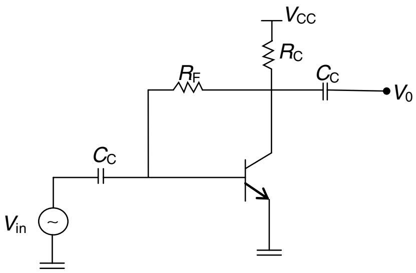
AC equivalent circuit:



Input series connection
Output shunt connection
Voltage series feedback

Example 4

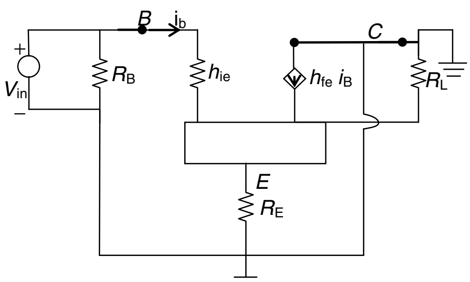
Find the type of the feedback in the given circuit.



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

Solution

AC Equivalent model:



Input: shunt connection
Output: shunt connection
Voltage shut feedback

Power Amplifiers

Classification

Class A:
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

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

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

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

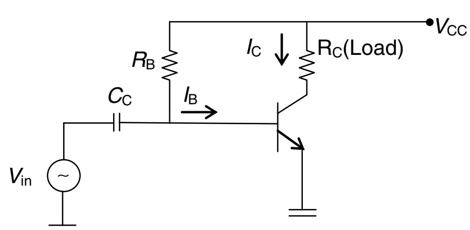
(ii) Class 'B'
- → Push - Pull
- → Complementary symmetry

(iii) Class 'C' circuits are used in tuned circuits like radio communications.

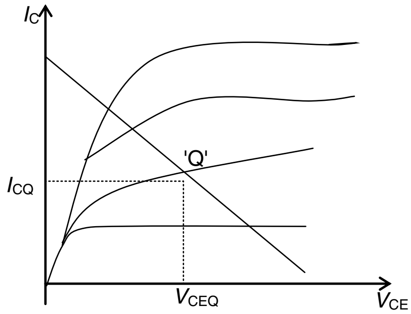
Amplifier efficiency (γ):

$$\eta = \frac{\text{a.c power delivered to the load}}{\text{d.c input power}}$$

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:

$$\eta = \frac{P_o(\text{a.c})}{P_i(\text{d.c})}$$

$$P_i\,(\text{DC}) = V_{cc}\,.I_{CQ}$$

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

To have maximum output swing,

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

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

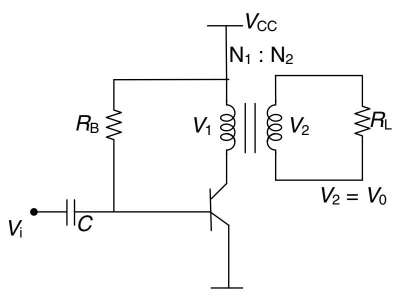
$$I_{CQ} = \frac{V_{CC}^2}{2R_C}$$

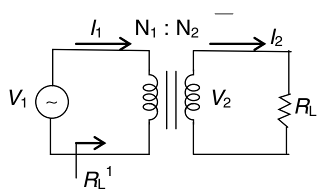
$$P_i(\text{DC}) = \frac{V_{CC}^2}{2R_C}$$

$$\eta = 25\%$$

The maximum efficiency of class 'A' amplifier is 25%.

Transformer-coupled Class 'A' Power Amplifier





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

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

$$R_L{}^1 = \left(\frac{N_1}{N_2}\right)^2 R_L$$

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

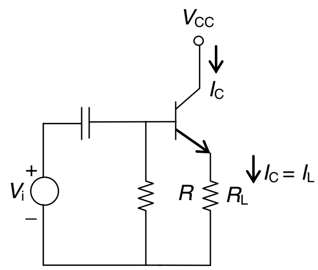
$$R_L{}^1 = \left(\frac{N_1}{N_2}\right)^2 R_L = (15)^2\, 8$$

$$R_L{}^1 = 1.8\text{ k}\Omega$$

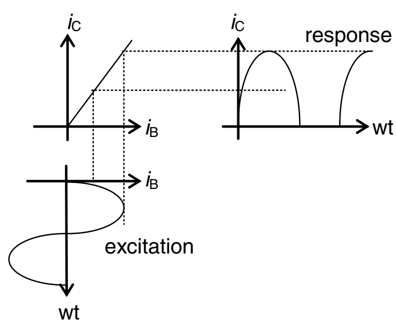
Maximum Theoretical Efficiency

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

Class B Push–pull Amplifier



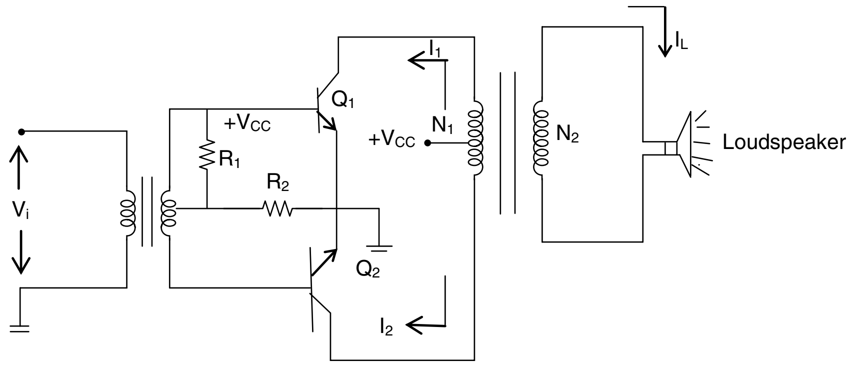
(1) Emitter follower with zero bias operating as class B amplifier.



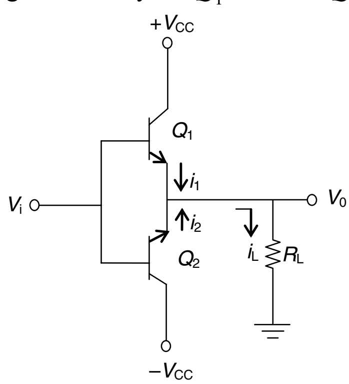
(2) Dynamic transfer characteristic

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.

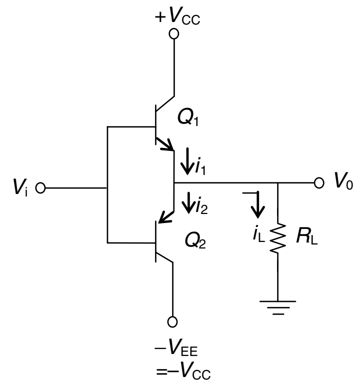
Transformer-coupled Push–pull Amplifier



During the positive half cycle: Q_1 ON and Q_2 OFF
During the negative half cycle: Q_1 OFF and Q_2 ON



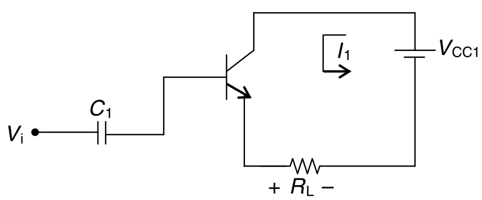
A complementary emitter follower



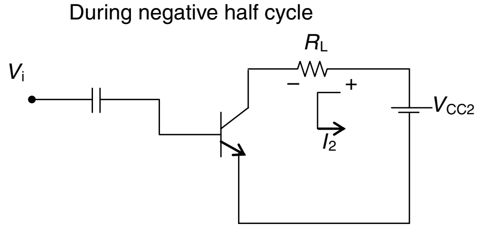
A complementary common emitter push–pull amplifier

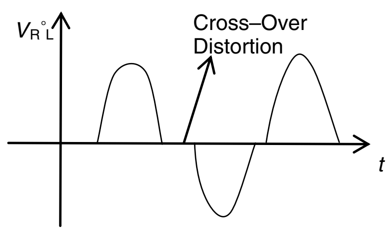
(i) Transformer-coupled push–pull amplifier

During positive half cycle



During negative half cycle





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 the 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 as follows:

It is possible to obtain great power output, high efficiency, and negligible power loss at no signal.

The disadvantages are high 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

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

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

$P_c\,(\max)$ is the maximum power dissipation and $P_{\max}$ is the maximum power that can be delivered.

Distortion in Amplifiers

Distortion is defined as mismatch between the input and the output. It can be amplitude, frequency, and phase distortion. If any distortion is occurred in harmonics, then it is said to be harmonic distortion.

In power amplifier, harmonic distortion is occurred due to non-linearity of amplifiers such as BJT, FET, and MOSFET.

$$\%n\text{th harmonic distortion} = \%D_n = \frac{|A_n|}{|A_1|} \times 100\%$$

where A_n is the amplitude of nth frequency component and A_1 is the amplitude of fundamental frequency component.

Total harmonic distortion [%THD]

$$= \sqrt{D_2^2 + D_3^2 + \ldots} \times 100\%.\pi$$

Example 6

Calculate the total harmonic distortion for the amplitude components as $A_1 = 1.5$ V, $A_2 = 0.25$, $A_3 = 0.05$

Solution

$$D_2 = \frac{|A_2|}{|A_1|} = \frac{0.25}{1.5} = \frac{1}{6}$$

$$D_3 = \frac{|A_3|}{|A_1|} = \frac{0.05}{1.5} = \frac{1}{30}$$

$$\text{THD} = \sqrt{\left(\frac{1}{6}\right)^2 + \left(\frac{1}{30}\right)^2}$$

$$= 0.17\%$$

Example 7

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

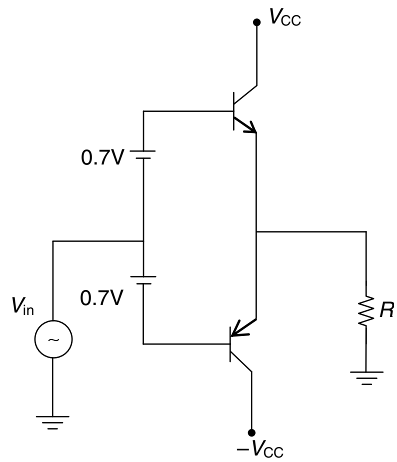
(A) 26.18% (B) 35.62%

(C) 40.25% (D) 52.36%

Solution

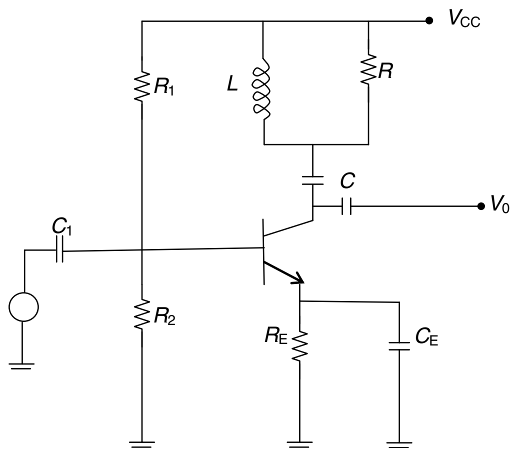
$$\eta = 78.54 \frac{V_L(p)}{V_{CC}} \% = 78.54 \times \frac{8}{24} = 26.18 \text{ V}$$

Class 'AB' Amplifier



(i) Cross-over distortion is eliminated by adding two diodes whose cut-in voltages were +0.7 v and –0.7 v.

Class 'C' Amplifier



1. Class 'C' amplifier is used to generate a pulse waveform whose conduction angle is less than 180°.
2. Efficiency of class 'C' amplifier is 90%.

Resonant Frequency:

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

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

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

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

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

Substitute $S = j\omega$

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

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

To find resonant frequency, make imaginary part = 0

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

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

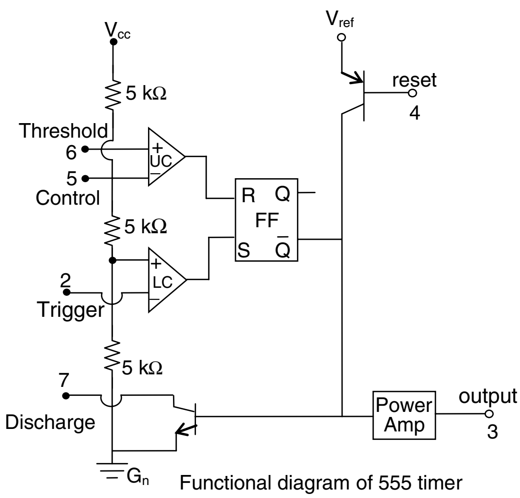
$$R^2C = \omega^2\,[RLC^2 - L^2C]$$

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

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

555 Timer

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



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 the control and the ground.

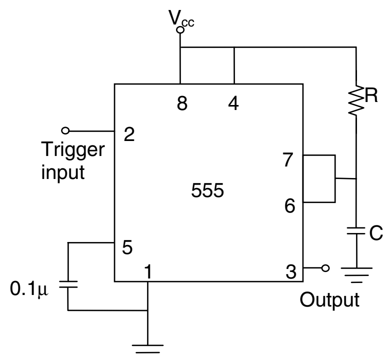
The reset pin provides a mechanism to reset FF, when reset is not used, it is returned to V_{cc}.

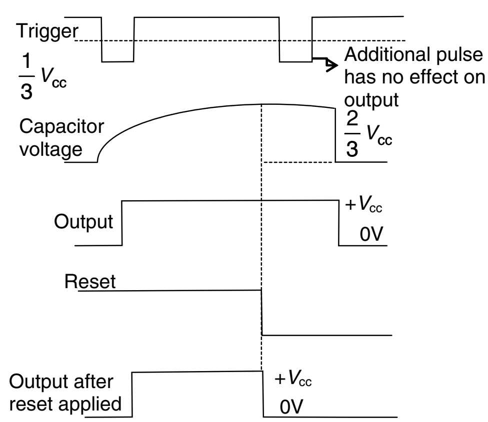
Operation

1. V_{cc} is typically 5 v, and the *R*s are 5 kΩ each, and act as a voltage divider to create voltages of value $V_{CC}/3, 2V_{CC}/3$
2. Comparator 1 compares the voltage applied at the 'threshold' terminal with $2V_{CC}/3$, and comparator 2 compares the voltage at the 'trigger' terminal with $V_{CC}/3$.
3. External connection to the 'control' terminal will override the $2V_{CC}/3$ existing at that node, and allows the user added flexibility.
4. When 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 comparator 1 output is high, it resets the Rs flip-flop, whose output goes low, which turns Q_1 OFF.

Monostable Operation

$T = 1\,.1\,RC$





Operation

Condition	R	S	Q	Output = $\bar{Q}$	Transistor status
$V_{cc} > \frac{2}{3}V_{cc}$	1	0	1	0	ON, capacitor starts discharging
V_{cc} = O volts	0	0	1	0	No change in state
apply trigger	0	1	0	1	OFF, capacitor starts charging
$V_{cc} > 1/3V_{cc}$	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} = O volts	0	0	1	0	No change in state

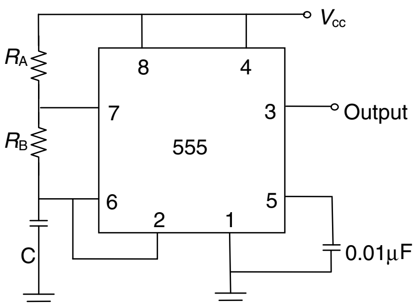
$$V_c(t) = V_{\text{final}} + (V_{\text{initial}} - V_{\text{final}})\ e^{\frac{-t}{RC}}$$

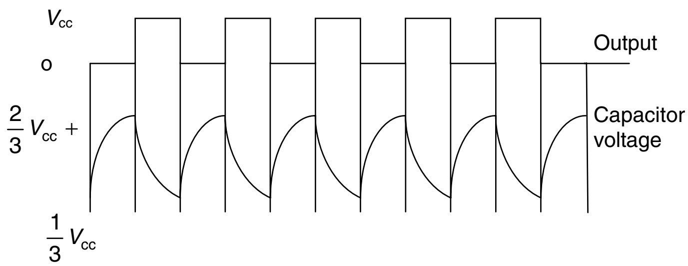
$$V_c(t) = V_{CC} + (0 - V_{CC})\ e^{\frac{-t}{RC}}$$

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

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

A Stable Operation





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

$\Rightarrow$ comparator 2 will have a high output and comparator 1 will have a low output.

$$\Rightarrow R = 0,\ S = 1, \text{ and } Q = 1.$$

Therefore, 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 $\Rightarrow Q = 0$

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

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

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

Similarly, during the time period T_2

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

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

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

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

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

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

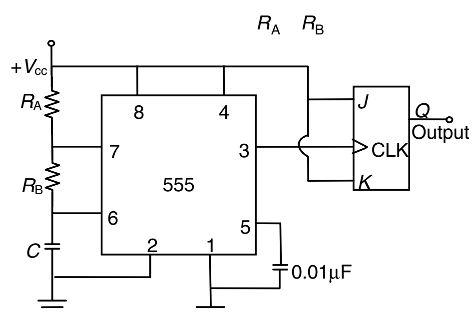
$$T = t_{\text{high}} + t_{\text{low}}$$

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

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

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

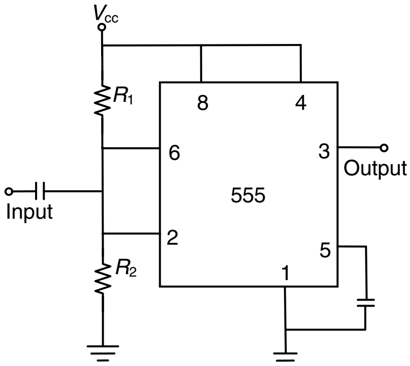
When R_A is much smaller than R_B, duty cycle approaches to 50%. If R_A is much greater than R_B, duty cycle approaches to 100%. The circuit can be modified to enable the duty cycle less than 50%. By placing a diode across R_B (anode at pin 7). The capacitor will effectively charge through R_A and diode. The capacitor will discharge through R_B, $D = \frac{R_A}{R_A + R_B}$



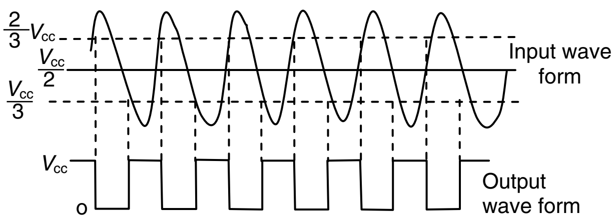
Symmetrical wave form generator.

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, and 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 the figure. Here, the two internal comparators are tied together and externally biased at $V_{cc}/2$ 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 waveform. Thus, sine wave of sufficient amplitude (>$V_{cc}/6$, i.e., $\frac{2}{3}V_{cc} - \frac{V_{cc}}{2}$) to exceed the reference levels causes the internal flip-flop to alternately set and reset, providing a square wave output.

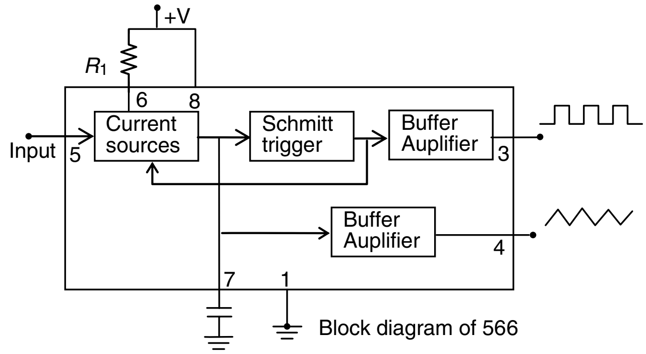


Unlike multivibrators, no frequency division is taking place and frequency of square wave remains same as that of input signal.

Voltage-Controlled Oscillator

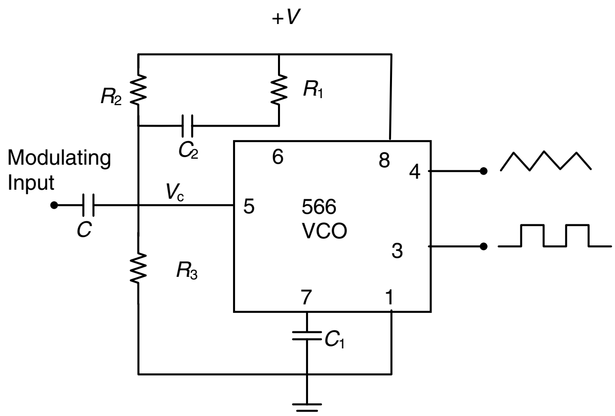
Voltage-controlled oscillator (VCO) or voltage to frequency converter can be found in applications such as frequency modulation, tone generators, and frequency shift keying (FSK), where frequency needs to be controlled by input voltage.

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

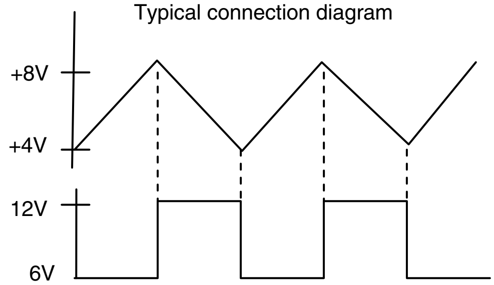


Block diagram of 566

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



Typical connection diagram



Output wave forms

$$f_0 = \frac{2(V - V_c)}{R_1\ C_1(+V)},$$

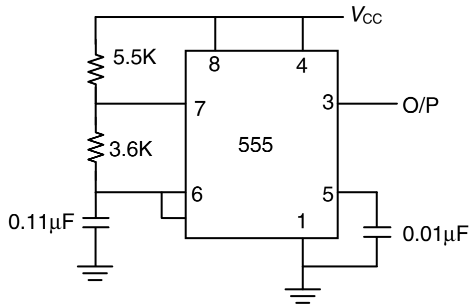
where $\frac{3}{4}(+V) \leq Vc \leq (+V)$ and 2 kΩ < R, <20 kΩ

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

Direction for questions 8 to 12: Select the correct alternative from the given choices.

Example 8

The 555 timer circuit to generate a rectangular waveform is shown in the 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

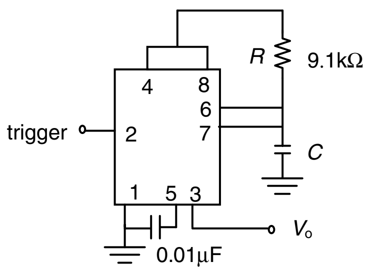
$$f = \frac{1.45}{(R_A + 2R_B)C} = \frac{1.45}{(5.5 + 2\times 3.6)\times 0.11\times 10^{-3}}$$

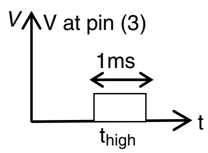
$$= 1.04 \text{ kHz} \approx 1 \text{ kHz}$$

$$\text{Duty cycle} = \frac{R_B}{R_A + 2R_B} = \frac{3.6}{5.5 + 2\times 3.6} = 0.28$$

Example 9

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



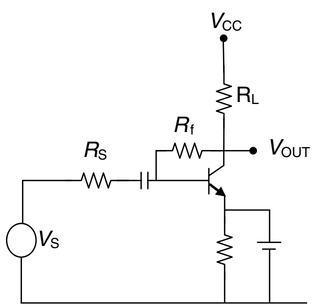


(A) 0.01 μF (B) 0.001 μF
(C) 0.1 μF (D) 1 μF

Solution

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

Direction for questions 10 to 11:



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 10

The type of feedback used in this circuit is
(A) voltage shunt. (B) current shunt.
(C) voltage series. (D) current series.

Solution

R_f is across the output and samples the output voltage V_0. At the input, it is in shunt, resulting in current feedback. The feedback in voltage shunt is

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

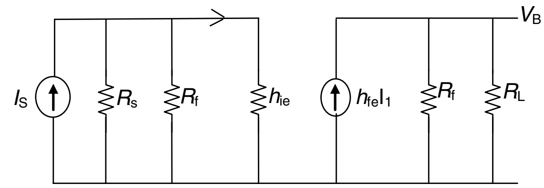
This feedback amplifier is a current-controlled voltage source, and hence both input and output impedances are reduced by feedback

Example 11

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

Solution

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 12

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

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

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

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

Exercises

Practice Problems I

Direction 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 positive feedback is applied, the distortion with feedback is ________.
(A) 0.1% (B) 10%
(C) 100% (D) None

2. The gain of amplifier is 1,000 and $\beta = 0.1$. Due to temperature variations, gain is changed by 15%, the change in gain with negative feedback is ________.
(A) 0% (B) 1.5%
(C) 0.15% (D) 1%

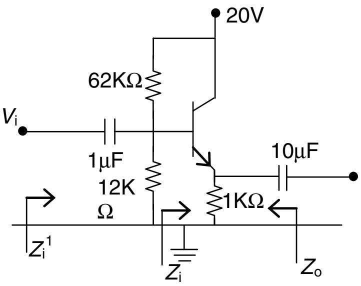
3. An amplifier has an open loop gain of 200, an input impedance of 5 kΩ, and output impedance of 600 Ω. A feedback factor of β = 20% is connected to the amplifier in a voltage shunt feedback mode, and the new input and output impedances are ____________.
(A) $Z_{if} = 205$ kΩ $Z_{of} = 14.63$ Ω
(B)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

4. The mid-band gain of an amplifier is 1,000. Its lower and upper cut-off frequencies are 60 Hz and 80 kHz, respectively. A feedback network with β = 0.05 is taken, and the new lower and upper cut-off frequencies are _________.
(A) $f_L^1 = 3.1$ kHz $f_H^1 = 1.568$ kHz
(B) $f_L^1 = 3.1$ kHz $f_H^1 = 4.08$ MHz
(C) $f_L^1 = 1.176$ Hz $f_H^1 = 4.08$ MHz
(D) $f_L^1 = 1.176$ Hz $f_H^1 = 1.568$ kHz

5. The gain bandwidth product of amplifier without feedback is 6 MHz with negative feedback, and the bandwidth is 1 MHz. Therefore, 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, and the resultant input and output impedances are ____
(A) $Z_{if} = 1.11$ kΩ $Z_{of} = 0.11$ kΩ
(B) $Z_{if} = 1.11$ kΩ $Z_{of} = 9$ kΩ
(C) $Z_{if} = 90$ kΩ $Z_{of} = 0.11$ kΩ
(D) $Z_{if} = 90$ kΩ $Z_{of} = 9$ kΩ

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

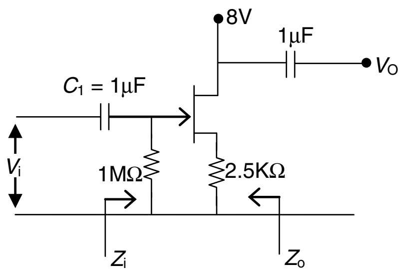


7. The input impedance Z_i is
(A) 1 kΩ (B) 101 kΩ
(C) 103 kΩ (D) 10.05 kΩ

8. The input impedance Z_i^1 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) ∞

Direction for questions 10 to 12:
A source follower is shown in the following figure with following specifications $I_{DSS} = 12$ mA, $V_P = 4$ V, $g_m = 2.28$ ms, and $r_d = \infty$

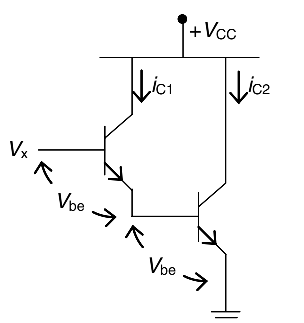


10. The input impedance Z_i is
(A) ∞ (B) 0 (C) 1 mΩ (D) none

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} $\mho$ and Q_2 is 6×10^{-3} $\mho$, the overall transconductance g_m is ______.



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

14. The feedback N/w of Hartley oscillator have $L_1 = 10$ mH, $L_2 = 5$ mH, and $C = 100$ pF. The mutual inductance between 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

$I_C = 4 \sin \omega t + 1.5 \sin 2\, \omega t + 0.6 \sin 3\, \omega t$ A

The percentage increase in power due to harmonic distortion is ________.

(A) 16.2% (B) 30.5% (C) 12% (D) 1.6%

Direction for questions 16 to 18:

A power amplifier working in class A operation has a zero signal collector current of 120 mA at $V_{CC} = 10$ v

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%

Direction 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.

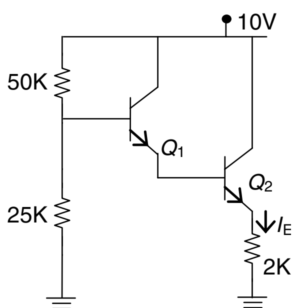
19. The collector efficiency is ________.

(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

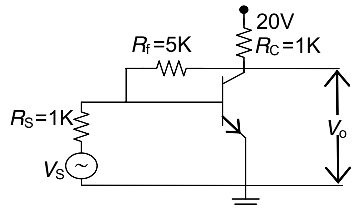
21. What is the emitter current I_E if $\beta = 100$ and $V_{BE} = 0.7$ V for each transistor of the Darlington pair given in the following figure?



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

Direction for questions 22 to 24:

The feedback amplifier shown in the following figure has an 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 _________.

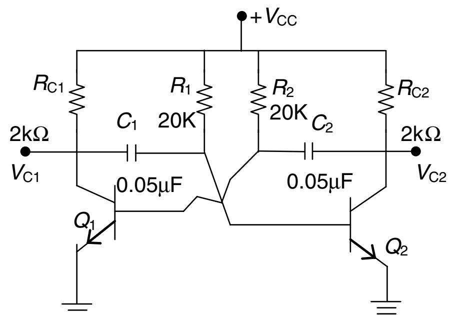
(A) 1.6×10^{-4} (B) 1×10^{-3}
(C) 2×10^{-4} (D) 0.2×10^{-4}

24. The closed loop gain A_f is ________.

(A) 833.3 (B) 100
(C) 1,000 (D) None

Direction for questions 25 and 26:

An astable multivibrator is shown in the following figure.



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 multivibrator using Si transistor is designed to generate a square wave of amplitude 12 V and frequency 1 kHz. The transistor has

$h_{fe_{min}} = 40, I_{C_{sat}} = 6\text{mA}$ and $V_{CE_{sat}} = 0.2\text{v}$. 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 maximum peak to peak of 24 V is desired across a load of 100 Ω. What is the power dissipated by each transistor?

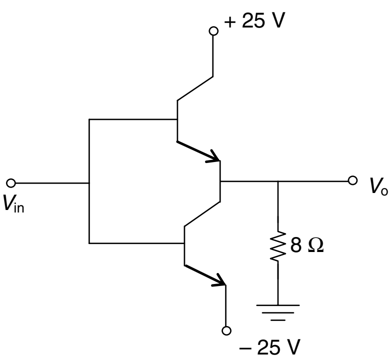
(A) 426 mW (B) 213 mW
(C) 1.146 W (D) 0.72 W

30. Match List-I and List-II:

List-I	List-II
P Class A Amplifier	**1.** High fidelity
Q Class B Amplifier	**2.** Tuned amplifier
R Class C Amplifier	**3.** Power amplifier
S Class AB Amplifier	**4.** Low distortion power amplifier

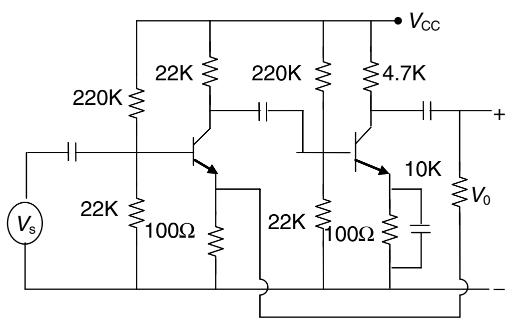
	P	Q	R	S
(A)	4	3	2	1
(B)	1	2	3	4
(C)	4	2	3	1
(D)	1	3	2	4

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

Direction for questions 32 to 34:



For the two stage feedback amplifier shown in figure h_{ie} = 1.1 kΩ and h_{fe} = 50

32. The nature of overall feedback is

(A) voltage shunt (B) voltage series
(C) current series (D) current shunt

33. The values of overall gain without feedback, and feedback factor are

(A) 600, 10 (B) 1,163, 10
(C) 600, 12.5 (D) 1,163, 12.5

34. The values of overall input and output resistance with feedback are

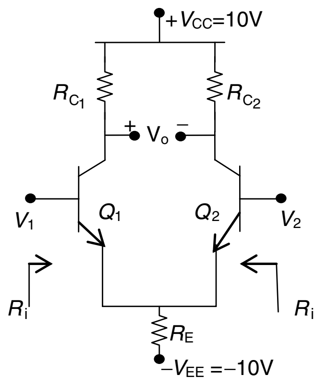
(A) 6.2 kΩ, 3.3 kΩ
(B) 77.63 kΩ, 3.3 kΩ
(C) 77.63 kΩ, 0.25 kΩ
(D) 6.2 kΩ, 0.25 kΩ

Direction for questions 35 to 39:

A differential amplifier is shown in the following figure with following specifications.

$$R_{C1} = R_{C2} = 2.2\text{k}\Omega, R_E = 4.5\text{k}\Omega, \beta = 100, V_{BE} = 0.7\text{V}$$

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) ∞

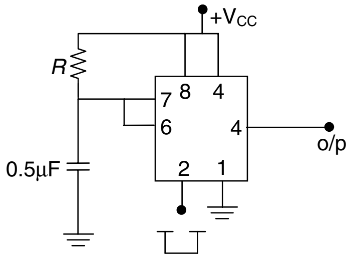
38. The common mode gain A_C is

(A) 0.48 (B) 0.24
(C) 0.97 (D) 0

39. CMRR in dB is

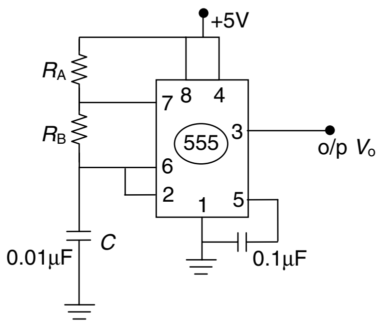
(A) 50.29 dB (B) 25.14 dB
(C) 2.51 dB (D) 44.27 dB

40. A monostable multivibrator is shown in the following figure. What is the value of R required for output rectangular frequency of 500 Hz?



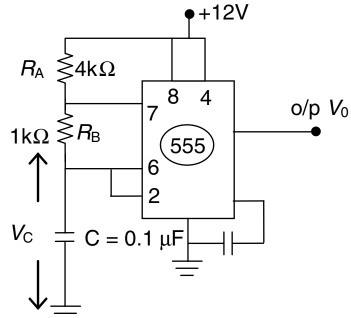
(A) 5.8 kΩ (B) 3.63 kΩ (C) 6.2 kΩ (D) 9.1 kΩ

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



(A) $R_B = R_A$ (B) $R_B = R_A/2$
(C) $R_B = 2R_A$ *(D)* $R_B = R_A/3$

42. An astable multivibrator using IC 555 is given in the following figure.



The capacitor voltage V_c limits are
(A) 12 V, −12 V (B) 4 V, −4 V
(C) 4 V, 8 V (D) 8 V, −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

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

1. An amplifier with negative feedback has a voltage gain of 80; without feedback, an input signal of 40 mv is required to produce a given output. While 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 1,000 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 1,000 ± 200 and feedback ratio is 4.2%. The percentage change in negative feedback gain is ________.
(A) 2.1% (B) 4.2%
(C) 0.46% (D) None

4. An amplifier has A = 48,000 and A_f = 6,000. The amount 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%

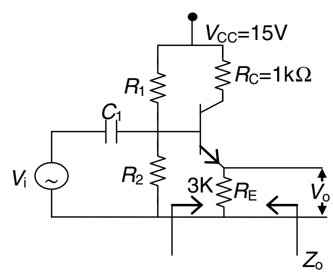
Direction for questions 5 and 6:
The total harmonic distortion of an amplifier is reduced from 20% to 8% when 5% negative feedback is used.

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

Direction for questions 7 to 10:
An emitter follower has following specifications.

$$h_{ie} = 1{,}000\ \Omega,\ h_{fe} = 100, \text{ and } R_1||R_2 = 10\ \text{k}\Omega$$



7. The voltage gain without feedback is ________.
(A) 1 (B) 300
(C) 101 (D) ∞

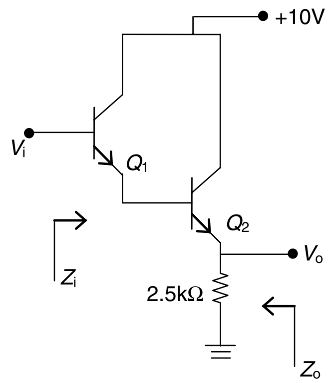
8. The voltage gain with feedback is _______.
(A) 0.99 (B) 0.85
(C) 30 (D) None

9. The input and output impedance are ____.
(A) $Z_i = 304$ kΩ $Z_o = 10$ Ω
(B) $Z_i = 10$ Ω $Z_o = 304$ kΩ
(C) $Z_i = 1.3$ kΩ $Z_o = 3$ kΩ
(D) $Z_i = 1$ kΩ $Z_o = 3$ kΩ

10. Current gain A_i is ________.
(A) 25 (B) 101
(C) 0.98 (D) 3

Direction 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 percentage loss in gain if $\frac{1}{50}^{th}$ 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 multivibrator, each transistor is cut-off for 1 ms. 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 collector 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

Direction 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%

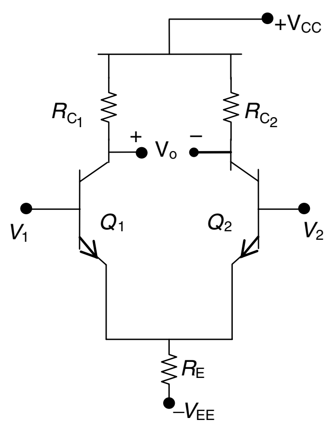
21. An amplifier has 10% non-linear distortion generated in its output stage. The amplifier gain without feedback is 200. If the distortions is reduced to 2% with negative feedback, the feedback ratio is ________.
(A) 0.5 (B) 0.2 (C) 0.02 (D) 1

22. Calculate the value of the capacitors to be used in astable multivibrator 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, $C_2 = 0.58$ nF
(B) $C_1 = 1.23$ nF, $C_2 = 1.23$ nF
(C) $C_1 = 0.58$ nF, $C_2 = 1.23$ nF
(D) $C_1 = 1.23$ nF, $C_2 = 0.58$ 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

Direction for questions 24 to 26:
A differential amplifier is shown in the following figure has the following specifications.

$R_{C1} = R_{C2} = 1.8\text{k}\Omega, R_E = 4\text{k}\Omega, V_{CC} = 10\text{V}, -V_{EE} = -10\text{V}$ $\beta = 100$ 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 monostable multivibrator using IC555 timer, the external circuit elements connected is $C = 0.01\mu F$ and $R = 2.7\ k\Omega$. 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. Voltage series feedback (also called series shunt feedback) results in **[2004]**

(A) increase in both input and output impedance
(B) decrease in both input and output impedance
(C) increase in input impedance and decrease in output impedance
(D) decrease in input impedance and increase in output impedance

2. The effect of current shunt feedback in an amplifier is to **[2005]**

(A) increase the input resistance and decrease the output resistance
(B) increase both input and output resistance
(C) decrease both input and output resistance
(D) decrease the input resistance and increase the output resistance.

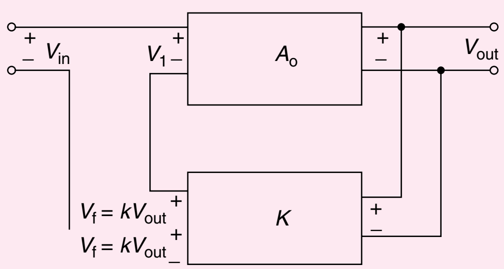
3. The input impedance (Z_i) and the output impedance (Z_0) of an ideal transconductance (voltage-controlled current source) amplifier are **[2006]**

(A) $Z_i = 0, Z_0 = 0$ (B) $Z_i = 0, Z_0 = \infty$
(C) $Z_i = \infty, Z_0 = 0$ (D) $Z_i = \infty, Z_0 = \infty$

4. In a transconductance amplifier, it is desirable to have **[2007]**

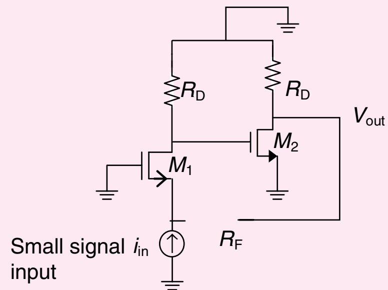
(A) a large input resistance and a large output resistance
(B) a large input resistance and a small output resistance
(C) a small input resistance and a large output resistance
(D) a small input resistance and a small output resistance

5. In a voltage–voltage feedback as shown in the following figure, which one of the following statements is TRUE if the gain k is increased? **[2013]**



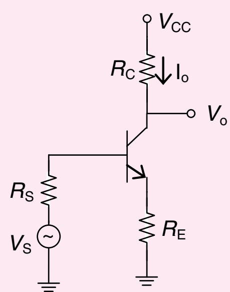
(A) The input impedance increases and output impedance decreases.
(B) The input impedance increases and output impedance also increases.
(C) The input impedance decreases and output impedance also decreases.
(D) The input impedance decreases and output impedance increases.

6. In the AC equivalent circuit shown in the figure, if i_{in} is the input current and R_F is very large, the type of feedback is **[2014]**



(A) voltage–voltage feedback
(B) voltage–current feedback
(C) current–voltage feedback
(D) current–current feedback

7. The feedback topology in the amplifier circuit (the base bias circuit is not shown for simplicity) in the figure is **[2014]**



(A) voltage shunt feedback
(B) current series feedback
(C) current shunt feedback
(D) voltage series feedback

8. The desirable characteristics of a transconductance amplifier are **[2014]**

(A) high input resistance and high output resistance.
(B) high input resistance and low output resistance.
(C) low input resistance and high output resistance.
(D) low input resistance and low output resistance.

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. C	**2.** D	**3.** D	**4.** A	**5.** A	**6.** B	**7.** B	**8.** A