Analog Electronics (313324)

MSBTE K-Scheme · Model Question Paper — Set B · Model Answers

Q.1 Attempt any FIVE of the following: 10 marks

a) Define the following terms related to amplifiers: i) Gain ii) Distortion 2 M

Gain: Gain of an amplifier is the ratio of output to input. Power gain $A_P = P_{out}/P_{in}$ (voltage gain $A_V = V_o/V_{in}$, current gain $A_I = I_o/I_{in}$). In decibels, $A_P(dB) = 10 \log_{10}(P_{out}/P_{in})$.

Distortion: When the output waveform is not an exact amplified replica of the input waveform, the amplifier is said to produce distortion. Types: amplitude (harmonic / non-linear) distortion, frequency distortion and phase distortion (crossover distortion in class B).

(Each definition 1 M)

b) State any two advantages of negative feedback. 2 M

- Gain becomes stable (less dependent on transistor parameters, temperature, supply).
- Bandwidth increases (gain × bandwidth remains constant).
- Distortion and noise are reduced.

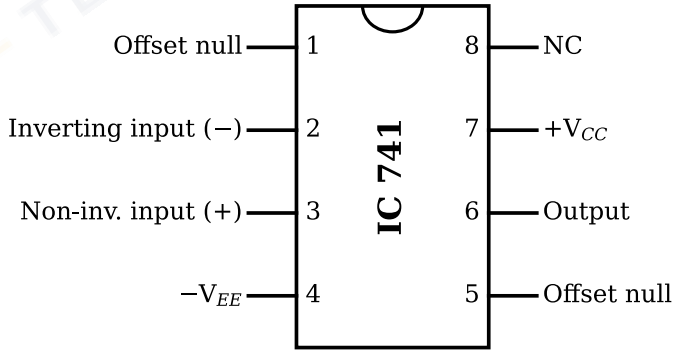
(Any two, 1 M each)

c) Compare amplifier and oscillator. (Any two points) 2 M

Amplifier	Oscillator
Uses negative feedback (or none).	Uses positive feedback.
Needs an external input signal.	No external input signal is needed.

(Each point 1 M)

d) Draw the labelled pin diagram of op-amp IC 741. 2 M



Pin diagram of op-amp IC 741 (8-pin DIP, top view)

Pins 1 & 5: offset null (a 10 kΩ pot is connected to null the output offset); pin 2: inverting input; pin 3: non-inverting input; pin 4: $-V_{EE}$; pin 6: output; pin 7: $+V_{CC}$; pin 8: no connection.

(Labelled pin diagram 2 M)

e) State ideal and practical values of the following parameters of IC 741: i) Input resistance ii) Output resistance 2 M

Parameter	Ideal value	Practical (IC 741, typical)
Input resistance (R_i)	∞	2 MΩ
Output resistance (R_o)	0	75 Ω

(Each parameter 1 M)

f) Define: i) Order of a filter ii) Centre frequency 2 M

Order of filter: The number of reactive (RC) sections / poles in the filter; it decides the roll-off rate (n × 20 dB/decade). E.g. first order: −20 dB/decade, second order: −40 dB/decade.

Centre frequency (f_C): For a band pass / band reject filter, the frequency at the centre of the band: $f_C = \sqrt{(f_H\, f_L)}$ (geometric mean).

(Each definition 1 M)

g) State the function of the following pins of IC 555: i) Threshold ii) Discharge 2 M

Pin 6: Threshold — when voltage exceeds $2V_{CC}/3$ the upper comparator resets the flip-flop and output goes LOW.

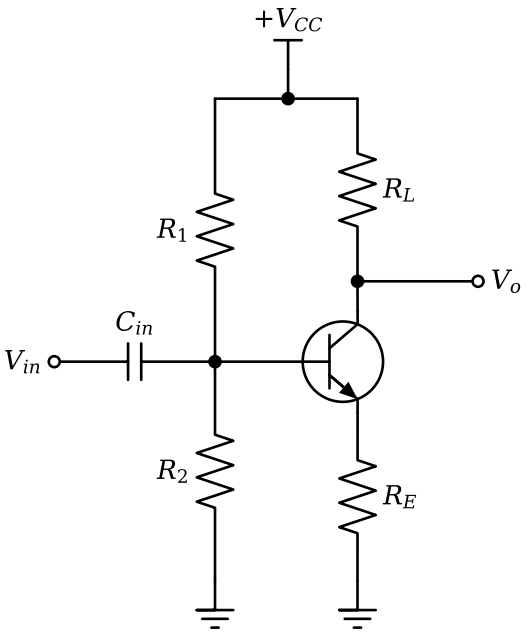
Pin 7: Discharge — collector of internal discharge transistor; it discharges the timing capacitor when output is LOW.

(Each function 1 M)

Q.2 Attempt any THREE of the following: 12 marks

a) Explain the working of single stage directly coupled class A power amplifier with the help of circuit diagram and waveforms. 4 M

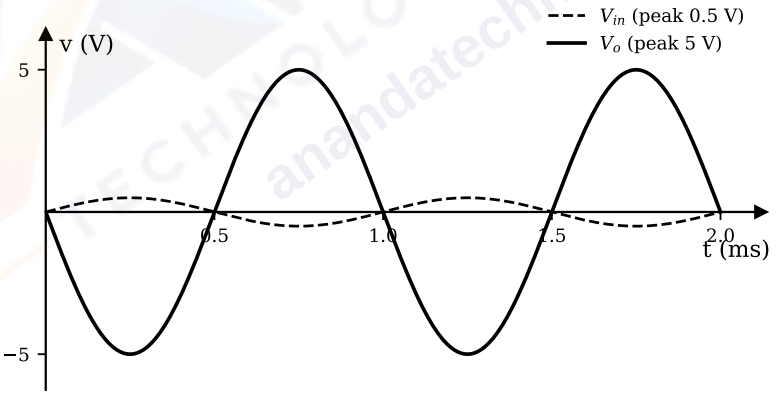
Circuit: In a single stage directly coupled class A power amplifier, the load R_L (speaker / resistive load) is connected directly in the collector circuit. R_1–R_2 give voltage divider bias and R_E gives stabilization.



Single stage directly coupled class A power amplifier

Working:

- The Q-point is fixed at the **centre of the AC/DC load line**, so the transistor conducts for the full 360° of the input cycle.
- During the positive half cycle of input, base current increases → collector current increases → V_{CE} decreases. During the negative half cycle, I_C decreases → V_{CE} increases.
- Thus an amplified output appears across R_L which is **180° out of phase** with input; output is an exact replica (minimum distortion).
- Even with no signal, the quiescent current I_{CQ} flows, so a large DC power is wasted in the transistor and R_L.



Input and output waveforms of class A amplifier (output 180° out of phase)

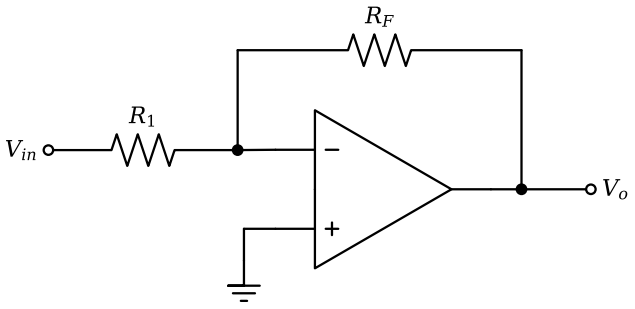
Efficiency: $\eta_{max} = P_{ac}/P_{dc} = 25$ % for directly (resistance) coupled load (50 % with transformer coupled load). Low efficiency is its main drawback.

(Circuit 2 M, working with waveforms 2 M)

b) Name the op-amp configuration in which virtual ground exists. Explain the virtual ground

concept with a suitable diagram. 4 M

Configuration: Virtual ground is present in the **inverting amplifier** (and in circuits based on it: inverting adder, integrator, differentiator, I-to-V converter).



Inverting amplifier — point A (inverting input) is at virtual ground

Concept:

- The open loop gain of op-amp is very large (ideally ∞). Since V_o is finite, the differential input $V_{id} = V_o/A \approx 0$.
- The non-inverting input is grounded, so the inverting input (point A) is also at 0 V — although it is **not physically connected** to ground. This is called virtual ground.
- Also, since R_i of op-amp is very high, no current flows into the op-amp input; the current through R_1 flows entirely through R_F: $I = V_{in}/R_1 = -V_o/R_F \Rightarrow A_V = -R_F/R_1$.

(Name 1 M, diagram 1 M, explanation 2 M)

c) Design an RC phase shift oscillator using IC 741 to produce a sinusoidal output at f_o = 800 Hz. Draw the designed circuit. (Assume C = 0.01 µF) 4 M

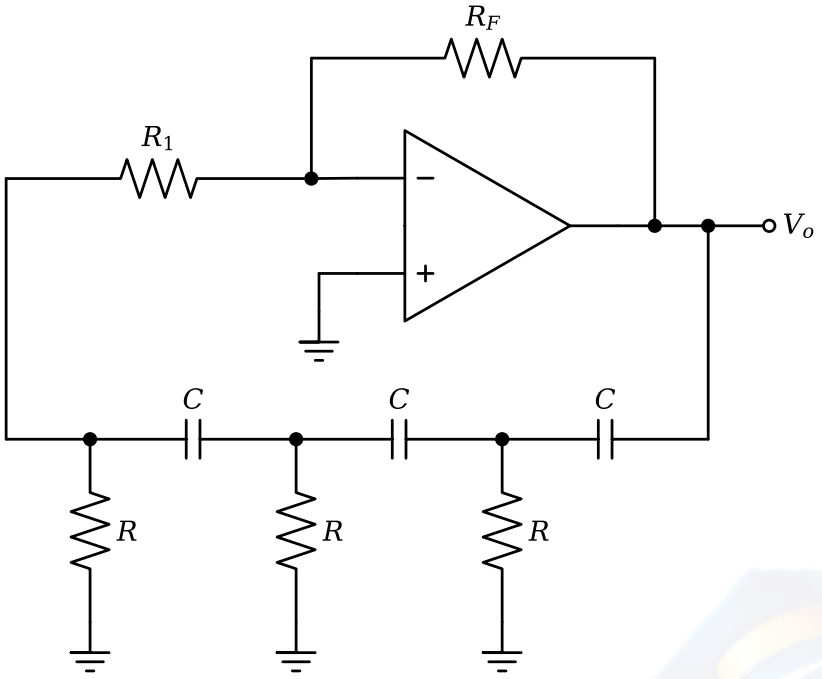
Given: f_o = 800 Hz. Choose C = 10 nF.

$f_o = 1/(2\pi\sqrt{6}\,RC) \Rightarrow R = 1/(2\pi\sqrt{6}\,f_o\,C)$

$R = 1 / (2\pi \times 2.449 \times 800 \times 10 \times 10^{-9}) =$ **8.122 kΩ** → use standard **8.2 kΩ** (gives f_o = 792.4 Hz).

To prevent loading: $R_1 = 10R =$ **82 kΩ**.

For $|A\beta| \geq 1$: $R_F = 29\,R_1 = 29 \times 82$ kΩ = **2.378 MΩ** (use a 3.3 MΩ potentiometer to adjust for clean sine output).



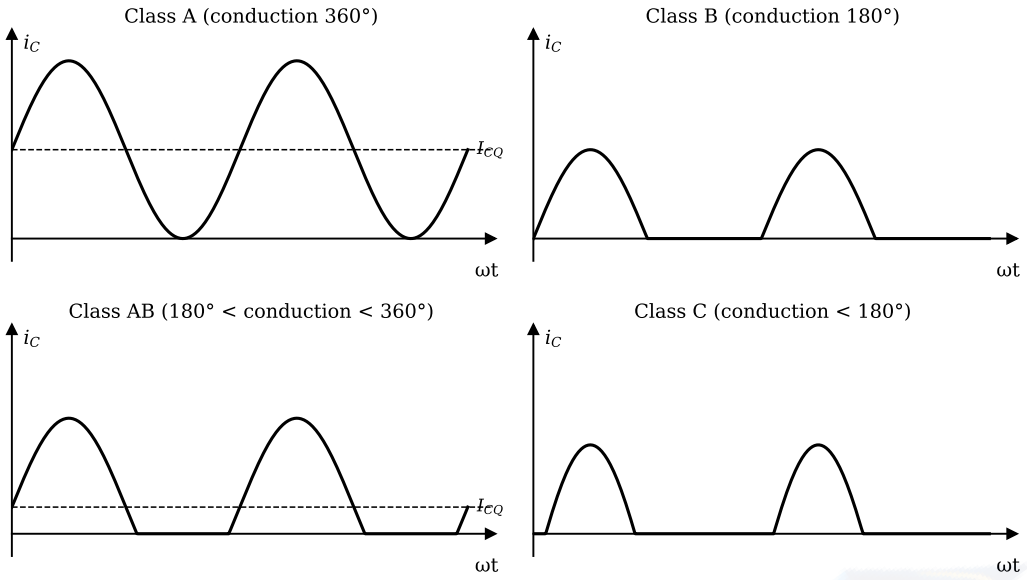
RC feedback network: 3 sections, total phase shift 180°

Designed RC phase shift oscillator: R = 8.2 kΩ, C = 10 nF, R1 = 82 kΩ, RF ≈ 2.38 MΩ

(Design 3 M, circuit 1 M)

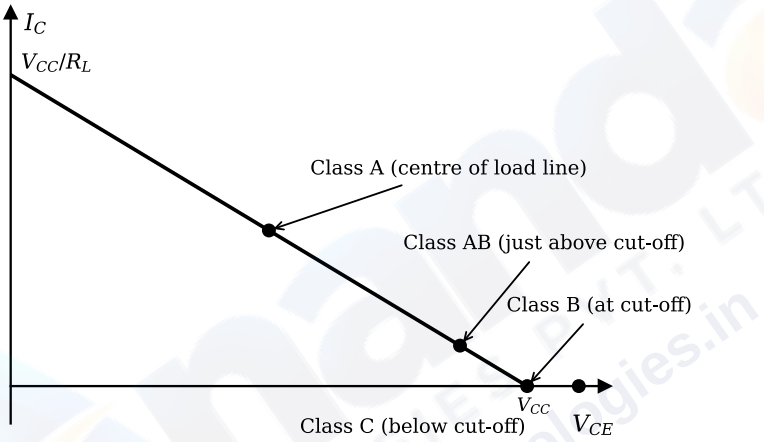
d) Compare class A, class B, class AB and class C power amplifiers on the basis of: i) Efficiency ii) Power dissipation in transistor iii) Conduction angle iv) Position of Q-point 4 M

Parameter	Class A	Class B	Class AB	Class C
Maximum efficiency	25 % (resistive load), 50 % (transformer coupled)	78.5 %	Between 50 % and 78.5 %	More than 78.5 % (up to ≈ 95 %)
Power dissipation in transistor	Maximum (even with no signal)	Zero at no signal; low	Low	Very low
Conduction angle	360°	180°	Between 180° and 360°	Less than 180°
Position of Q-point	Centre of DC load line	At cut-off (on X-axis)	Slightly above cut-off	Below cut-off (beyond X-axis)



Collector current waveforms of class A, B, AB and C amplifiers

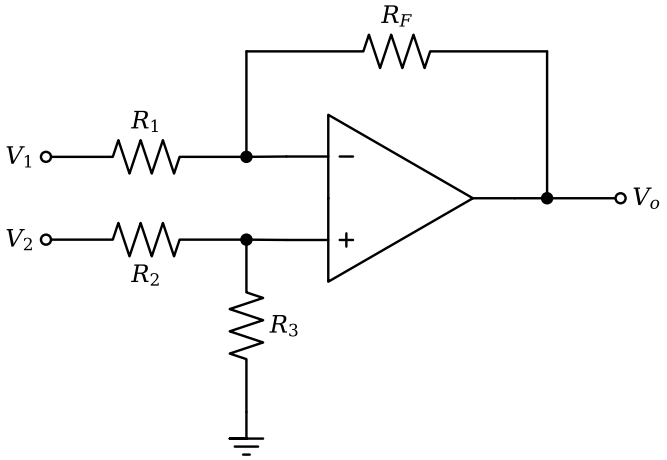
(Each correct parameter 1 M)



Position of Q-point on the DC load line for different classes

Q.3 Attempt any THREE of the following: 12 marks

a) Draw the circuit diagram of op-amp as a subtractor and derive the equation for its output voltage. 4 M



Op-amp subtractor (difference amplifier)

Derivation (superposition):

- With $V_2 = 0$: circuit is inverting amplifier, $V_{o1} = -(R_F/R_1)\, V_1$.
- With $V_1 = 0$: voltage at (+) input = $V_2\, R_3/(R_2 + R_3)$; non-inverting gain $(1 + R_F/R_1)$: $V_{o2} = (1 + R_F/R_1) \cdot R_3/(R_2 + R_3) \cdot V_2$.
- $V_o = V_{o1} + V_{o2}$. If $R_1 = R_2 = R_3 = R_F = R$:

$$\mathbf{V_o = V_2 - V_1}$$

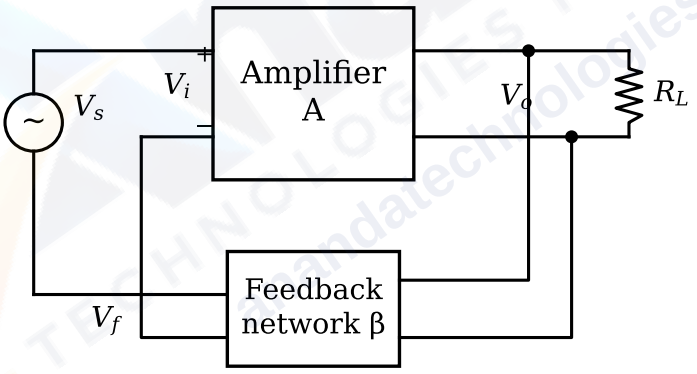
Thus the circuit subtracts V_1 from V_2. (With $R_F/R_1 = R_3/R_2$, $V_o = (R_F/R_1)(V_2 - V_1)$.)

(Circuit 2 M, equation 2 M)

b) List the types of feedback connections. Draw the diagram of voltage-series feedback. 4 M

Types of feedback connections (according to how output is sampled and how feedback is mixed at input):

Type	Sampling at output	Mixing at input	Effect on R_i, R_o
Voltage-series (series-shunt)	Voltage (shunt)	Series	$R_i \uparrow$, $R_o \downarrow$
Voltage-shunt (shunt-shunt)	Voltage (shunt)	Shunt	$R_i \downarrow$, $R_o \downarrow$
Current-series (series-series)	Current (series)	Series	$R_i \uparrow$, $R_o \uparrow$
Current-shunt (shunt-series)	Current (series)	Shunt	$R_i \downarrow$, $R_o \uparrow$



Output voltage sampled (shunt); V_f mixed in series with V_s: $V_i = V_s - V_f$

Voltage-series (series-shunt) feedback amplifier

In voltage-series feedback a fraction $V_f = \beta V_o$ of the output voltage is fed back in series with the input. Example: emitter follower, op-amp non-inverting amplifier.

(Types 2 M, any one diagram 2 M)

c) Define oscillator. Classify oscillators and state the Barkhausen criteria. 4 M

Oscillator: An oscillator is an electronic circuit which generates a repetitive (sinusoidal or non-sinusoidal) output waveform of desired frequency without any external input signal. It converts DC power into AC power, using positive feedback.

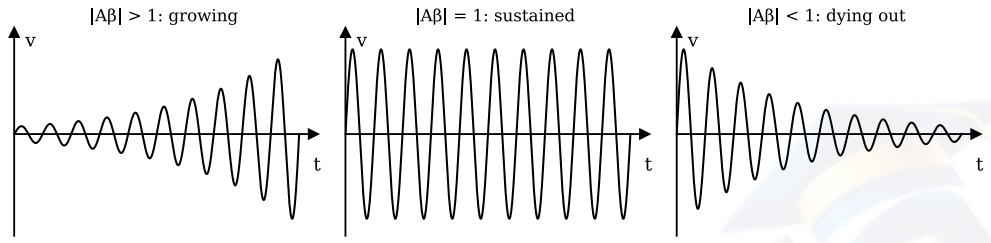
Classification:

- According to waveform: sinusoidal (harmonic) and non-sinusoidal (relaxation – square, triangular, saw-tooth).
- According to feedback network: RC oscillators (RC phase shift, Wien bridge), LC oscillators (Hartley, Colpitts, Clapp), crystal oscillator.
- According to frequency: AF (audio), RF (radio), VHF/UHF, microwave oscillators.

Barkhausen criteria:

For sustained oscillations, the following two conditions (Barkhausen criteria) must be satisfied:

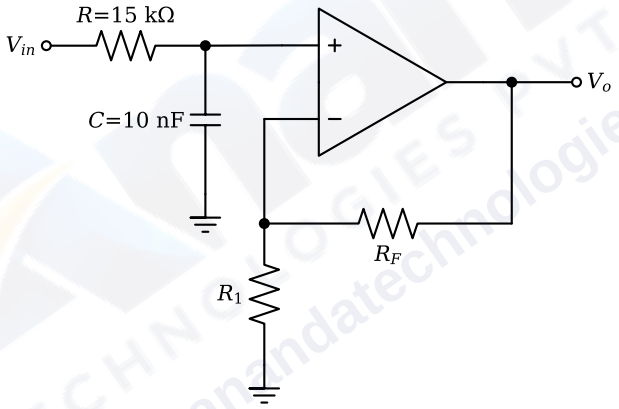
1. The magnitude of loop gain must be unity: **|Aβ| = 1**.
2. The total phase shift around the loop must be **0° or 360°** (i.e. feedback must be positive).



Effect of loop gain |Aβ| on oscillations

(Definition 1 M, classification 1 M, Barkhausen criteria 2 M)

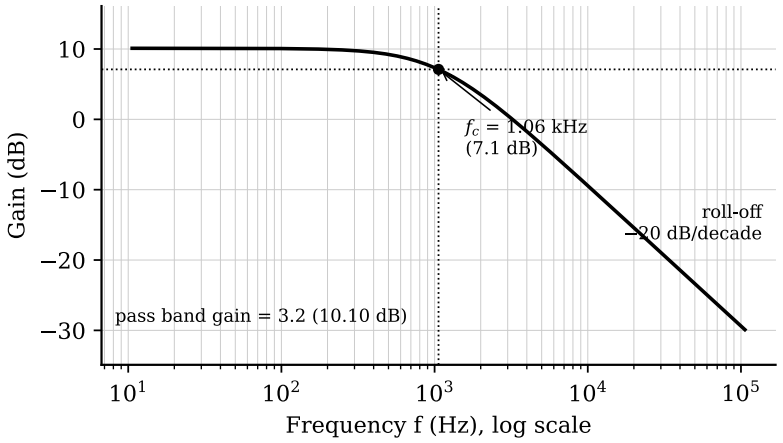
d) For a first order Butterworth low pass filter R = 15 kΩ, C = 0.01 µF, R_1 = 10 kΩ and R_F = 22 kΩ. Calculate the cut-off frequency and pass band voltage gain. 4 M



First order Butterworth low pass filter

Cut-off frequency: $f_H = 1/(2\pi RC) = 1/(2\pi \times 15000 \times 10 \times 10^{-9})$ = **1.061 kHz**

Pass band gain: $A_F = 1 + R_F/R_1 = 1 + 22000/10000$ = **3.2** (10.10 dB)

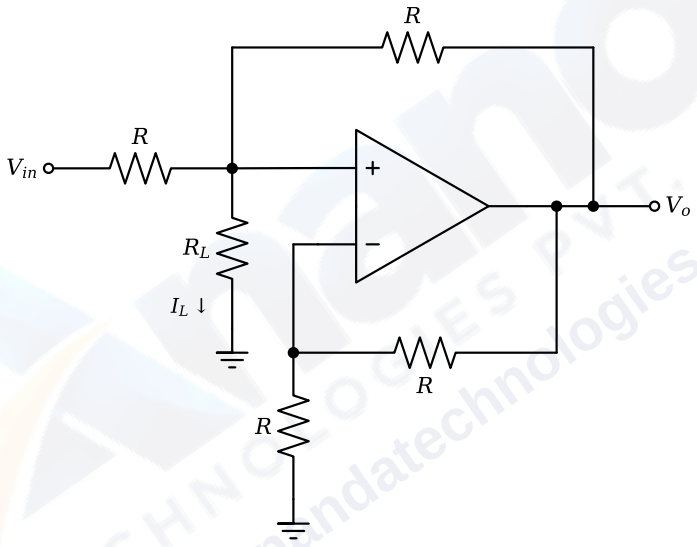


Frequency response of designed first order LPF

(f_H 2 M, gain 2 M)

Q.4 Attempt any THREE of the following: 12 marks

a) Draw the circuit of voltage to current converter with grounded load and derive the expression for load current. 4 M



V-to-I converter with grounded load

Derivation: Let V_1 be the voltage at the (+) input (top of R_L). All resistors except R_L are equal to R.

- The op-amp with R and R_F = R on the inverting side is a non-inverting amplifier of gain 1 + R/R = 2, so $V_o = 2V_1$.
- Applying KCL at the (+) node: $(V_{in} - V_1)/R + (V_o - V_1)/R = I_L$
- Substituting $V_o = 2V_1$: $(V_{in} - V_1 + 2V_1 - V_1)/R = I_L$

$$\mathbf{I_L = V_{in} / R}$$

Thus the load current depends only on V_{in} and R, and is independent of the load resistance R_L (one end of which is grounded). Used in low-voltage DC/AC voltmeters, LED and zener diode testers.

(Circuit 2 M, derivation 2 M)

b) Compare integrator and differentiator. (Any four points) 4 M

Integrator	Differentiator
Output is proportional to integral of input: $V_o = -(1/RC)\int V_{in}dt$	Output is proportional to derivative of input: $V_o = -RC\, dV_{in}/dt$
Resistor at input, capacitor in feedback path.	Capacitor at input, resistor in feedback path.
Square wave input → triangular output; sine → cosine.	Triangular input → square output; square → spikes.
Gain decreases with frequency (acts like a low pass filter).	Gain increases with frequency (acts like a high pass filter); sensitive to noise.
Used in analog computers, ramp / triangular wave generators, ADCs.	Used in wave shaping, rate-of-change detectors, FM demodulators.

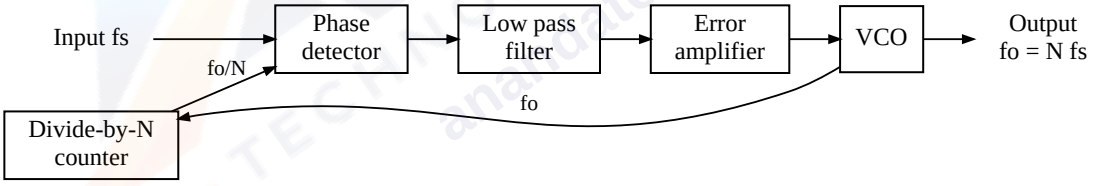
(Any four points, 1 M each)

c) Differentiate between active and passive filters. (Any four points) 4 M

Active filter	Passive filter
Uses active elements (op-amp / transistor) along with R and C.	Uses only passive elements R, L, C.
Can provide gain (pass band gain ≥ 1).	Gain is always less than 1 (insertion loss).
Inductors are not needed, so small size, light weight and low cost at low frequencies.	Inductors are bulky, heavy and costly at low frequencies.
High input and low output impedance — no loading problem; easy cascading.	Loading effect is present; cascading changes the response.

(Any 4 points, 1 M each)

d) Explain the use of PLL as a frequency multiplier with block diagram. 4 M



PLL as frequency multiplier (fo = N × fs)

Working: A divide-by-N counter is inserted between the VCO output and the phase detector. In lock, the two inputs of the phase detector are equal: $f_s = f_o/N$, so

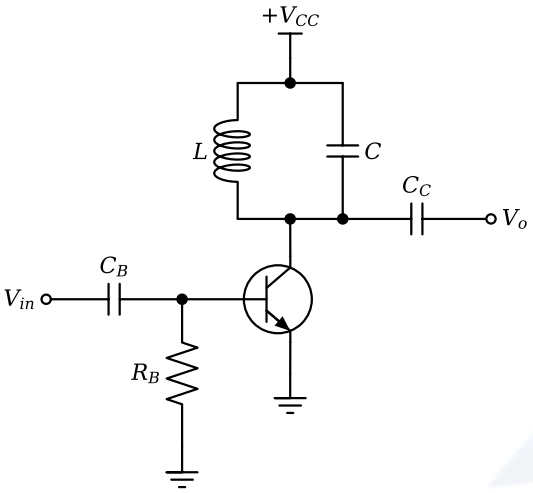
$$\mathbf{f_o = N \times f_s}$$

The VCO free running frequency is set near N f_s. The LPF must have a low cut-off so that the VCO output is clean. By changing N (programmable counter, e.g. 7490/7493), different multiples of f_s are obtained — used in frequency synthesizers.

(Block diagram 2 M, working 2 M)

e) Explain class C power amplifier with neat circuit diagram. 4 M

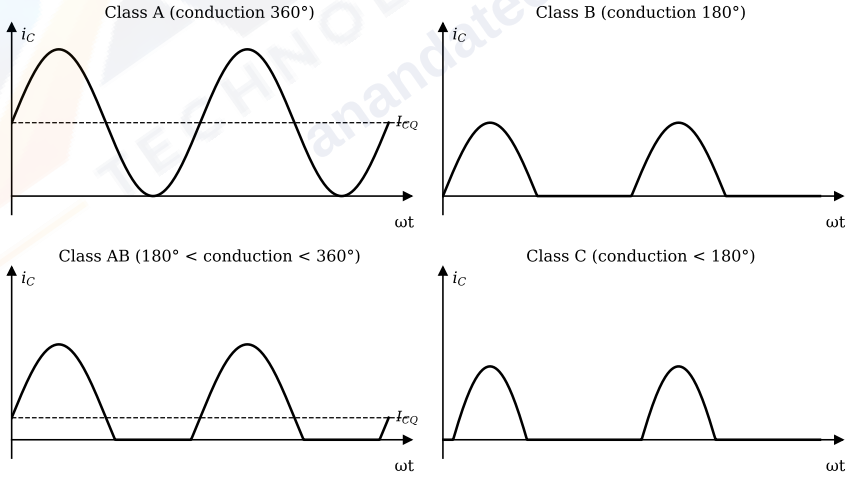
Circuit: The transistor is reverse biased (base returned to ground through R_B; C_B–R_B give signal-developed negative bias), so the Q-point lies **below cut-off**. A parallel LC tank circuit is the collector load.



Class C tuned power amplifier

Working:

- The transistor conducts only near the positive peaks of input, i.e. for less than 180° (typically 120°–150°). Collector current is a train of narrow pulses.
- The tank circuit tuned to the input frequency $f_r = 1/(2\pi\sqrt{LC})$ receives an energy pulse every cycle and, due to the flywheel effect, produces a complete sine wave output.
- Since the transistor conducts for a very short time, dissipation is very low and efficiency is very high (above 78.5 %, up to about 95 %).
- Distortion is high, so it is used only as a **tuned RF amplifier**, e.g. in radio transmitters and frequency multipliers.



Collector current: class C conducts for less than 180° (lower right)

(Circuit 2 M, working 2 M)

Q.5 Attempt any TWO of the following: 12 marks

a) Design an astable multivibrator using IC 555 for frequency 1 kHz and duty cycle 60 %. Draw the designed circuit and output waveform. (Assume C = 0.1 µF) 6 M

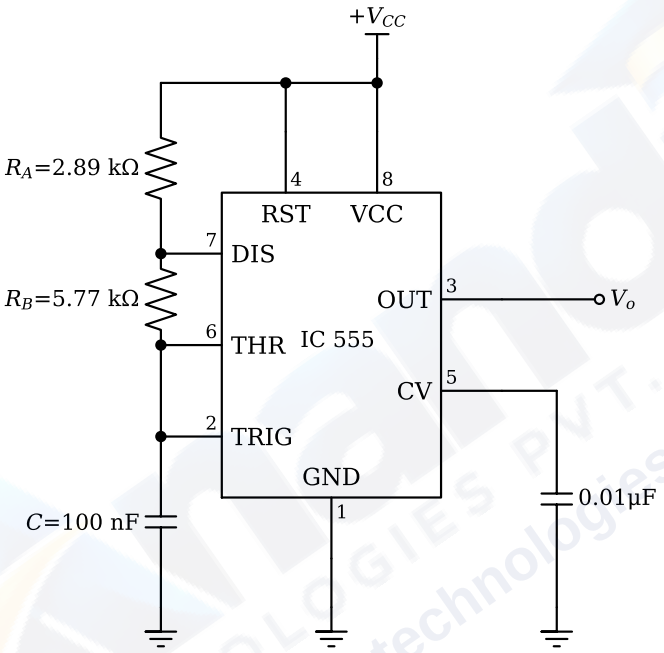
Given: f = 1 kHz, duty cycle D = 60 %, C = 100 nF.

$T = 1/f = 1$ ms; $T_{ON} = D \times T = 600$ µs; $T_{OFF} = T - T_{ON} = 400$ µs

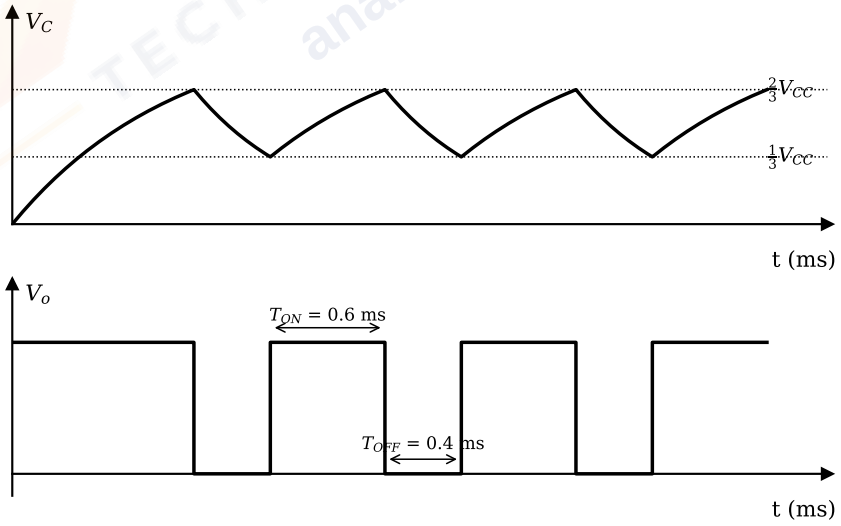
$T_{OFF} = 0.693\, R_B C \Rightarrow R_B = 400 \times 10^{-6}/(0.693 \times 100 \times 10^{-9}) =$ **5.772 kΩ**

$T_{ON} = 0.693(R_A + R_B)C \Rightarrow R_A + R_B = 600 \times 10^{-6}/(0.693 \times 100 \times 10^{-9}) = 8.658$ kΩ $\Rightarrow$ **R_A = 2.886 kΩ**

Use standard values / presets: $R_A \approx 2.7$ kΩ, $R_B \approx 5.6$ kΩ (fine-tune with presets). Check: $f = 1.44/((R_A + 2R_B)C) = 997.9$ Hz.



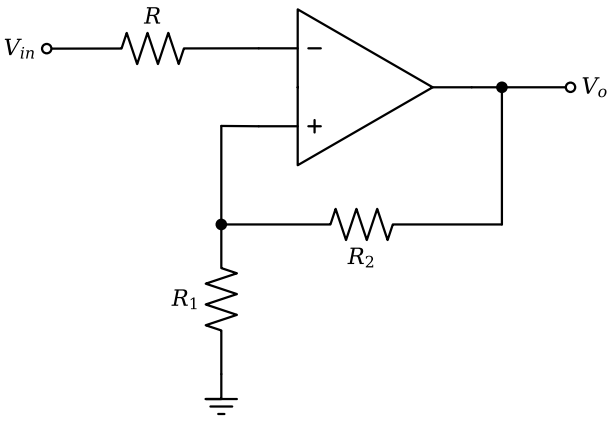
Designed astable multivibrator



Capacitor voltage and output waveform of 555 astable multivibrator

(Design 3 M, circuit 2 M, waveform 1 M)

b) In an inverting Schmitt trigger R_1 = 150 Ω, R_2 = 68 kΩ, V_{sat} = ±14 V and V_{in} = 1 V_{p-p} sine wave. Explain its working and determine V_{UT}, V_{LT} and hysteresis voltage. Draw the hysteresis curve and output waveform. 6 M



Inverting Schmitt trigger: R1 from (+) input to ground, R2 from output to (+) input

Working: Positive feedback through R_2–R_1 gives a reference $V_{ref} = R_1 V_o/(R_1 + R_2)$ at the (+) input. When $V_o = +V_{sat}$ the input must rise above V_{UT} to switch the output to $-V_{sat}$; it then switches back only when the input falls below V_{LT}.

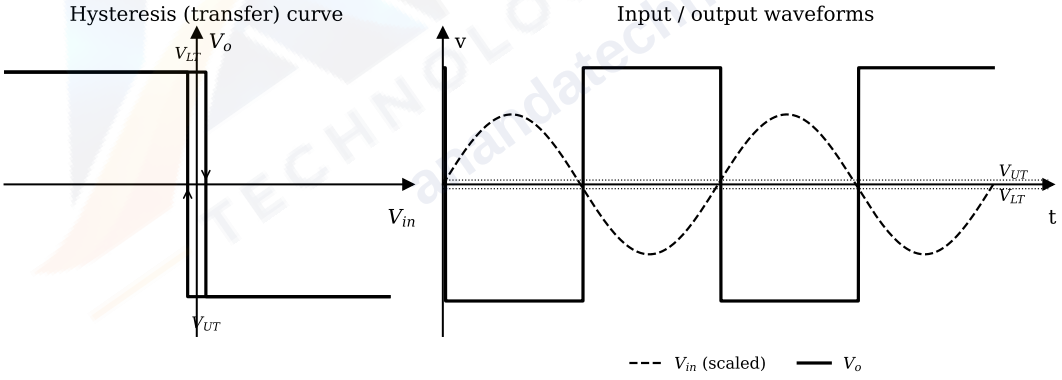
Given: R_1 = 150 Ω, R_2 = 68 kΩ, V_{sat} = ±14 V, V_{in} = 1 V_{p-p} (peak 0.5 V).

(i) $V_{UT} = R_1(+V_{sat})/(R_1 + R_2) = 150 \times 14 / (150 + 68000)$ = **30.81 mV**

(ii) $V_{LT} = R_1(-V_{sat})/(R_1 + R_2)$ = **-30.81 mV**

(iii) Hysteresis $V_H = V_{UT} - V_{LT} = 2R_1V_{sat}/(R_1 + R_2)$ = **61.63 mV**

Since the input peak (0.5 V) is larger than V_{UT}, the output switches every cycle and a square wave is obtained.



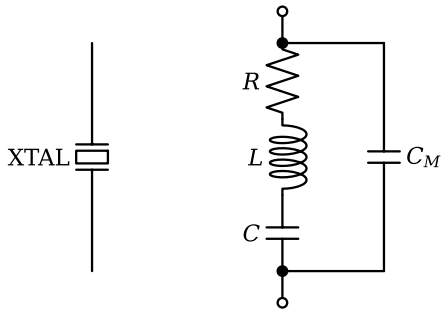
Schmitt trigger characteristics

(Circuit 1 M, working 1 M, V_{UT}, V_{LT}, V_H 3 M, waveforms 1 M)

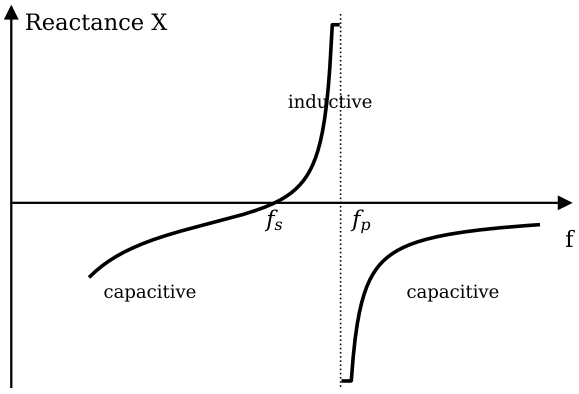
c) Describe the working principle of BJT based crystal oscillator with circuit diagram. Draw the equivalent circuit of crystal. 6 M

Principle (piezo-electric effect): When an AC voltage is applied across a quartz crystal it vibrates mechanically, and the mechanical vibrations in turn produce an AC voltage. The crystal vibrates

most strongly at its natural (resonant) frequency, which depends on its cut and thickness and is very stable.



Crystal symbol and its electrical equivalent circuit

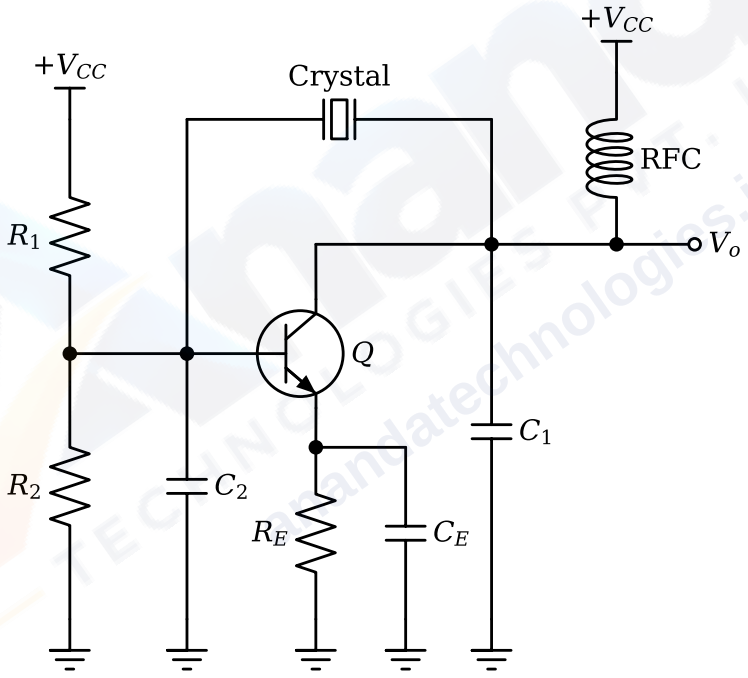


Reactance–frequency curve of crystal

Electrically the crystal is a series R-L-C circuit (mass → L, compliance → C, friction → R) in parallel with the mounting capacitance C_M. It has two resonant frequencies:

$$\mathbf{f_s = 1/(2\pi\sqrt{(LC)}) \quad and \quad f_p = 1/(2\pi\sqrt{(L\,C\,C_M/(C + C_M))})}$$

Between f_s and f_p the crystal behaves as a very high-Q inductor.



Crystal oscillator using BJT (Pierce / Colpitts-crystal type)

Working (BJT crystal oscillator — Pierce / Colpitts type):

- The transistor in CE configuration with voltage divider bias R_1, R_2 and R_E–C_E acts as the amplifier (180° phase shift). RFC blocks RF from the supply.
- The crystal is connected in place of the inductor of a Colpitts circuit, between collector and base; with C_1 and C_2 it forms the feedback network giving another 180°.
- The crystal operates in its inductive region (just above f_s), so the circuit oscillates at practically the crystal frequency; any drift is opposed because the crystal reactance changes very sharply

with frequency ($Q \approx 10^4$–10^6).

- Hence the output frequency is highly stable. Uses: clocks in microcontrollers/computers, quartz watches, radio transmitters and receivers.

(Principle / equivalent circuit 2 M, circuit 2 M, working 2 M)

Q.6 Attempt any TWO of the following: 12 marks

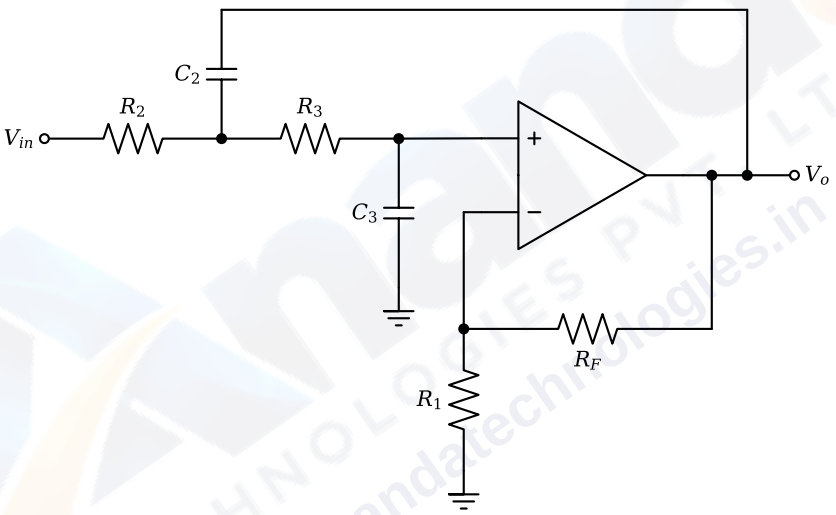
a) Design a second order Butterworth low pass filter with higher cut-off frequency f_H = 2 kHz. Draw the designed circuit and sketch its frequency response. (Assume C = 0.01 µF) 6 M

Given: f_H = 2 kHz. For a second order Butterworth response (Sallen-Key, equal components $R_2 = R_3 = R$, $C_2 = C_3 = C$), the pass band gain must be A_F = 1.586 (damping 0.707).

Step 1: $f_H = 1/(2\pi RC)$ (equal components). Choose C = 10 nF.

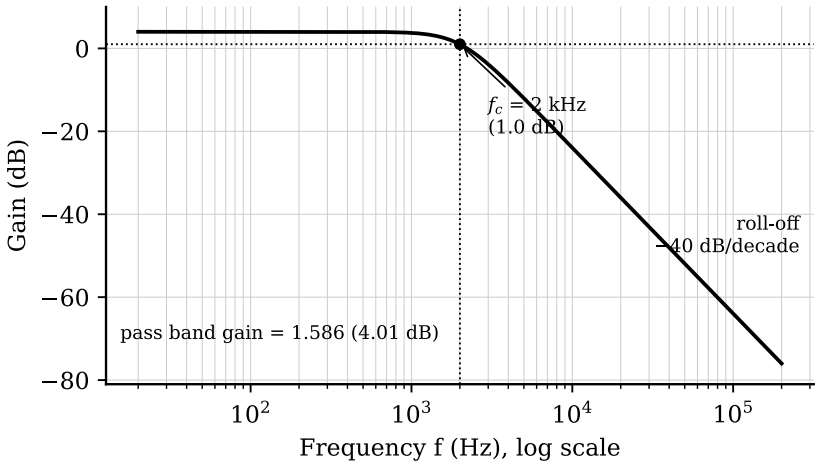
Step 2: $R = 1/(2\pi f_H C) = 1/(2\pi \times 2000 \times 10 \times 10^{-9})$ = **7.958 kΩ** → use 8.2 kΩ standard (f = 1.941 kHz) or a preset for exact value.

Step 3: $A_F = 1 + R_F/R_1 = 1.586 \Rightarrow R_F = 0.586\ R_1$. Choose R_1 = 10 kΩ ⇒ R_F = **5.86 kΩ** (use 5.6 kΩ + 270 Ω, or a 10 kΩ pot).



Designed second order Butterworth low pass filter

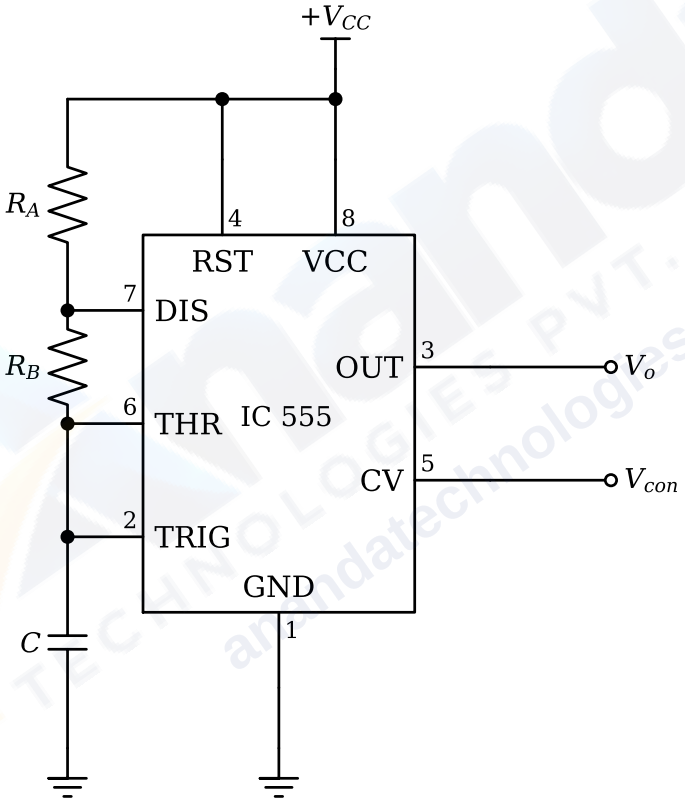
Component values: $R_2 = R_3$ = 8.2 kΩ, $C_2 = C_3$ = 10 nF, R_1 = 10 kΩ, R_F = 5.86 kΩ, op-amp IC 741 with ±15 V supply.



Actual frequency response: gain 1.586 (4.0 dB) in pass band, −3 dB at 2 kHz, roll-off 40 dB/decade

(Design 3 M, circuit 2 M, frequency response 1 M)

b) Explain the working of IC 555 as a voltage controlled oscillator (VCO) with circuit diagram and waveforms. 6 M



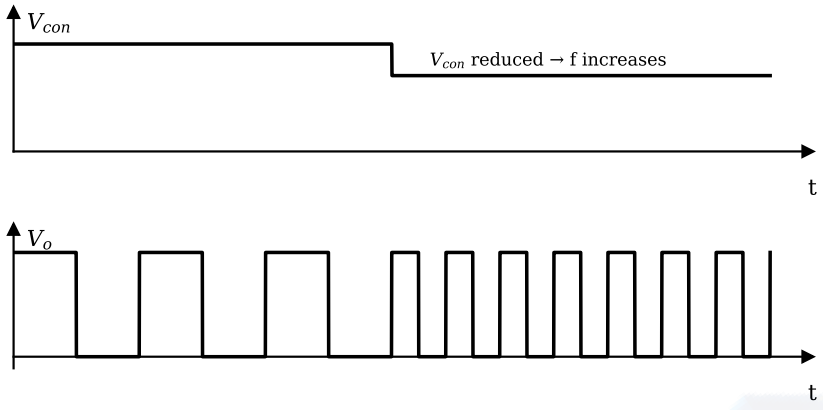
IC 555 as voltage controlled oscillator (VCO)

Working:

- The 555 is connected as an astable multivibrator, but the control voltage pin 5 is driven by an external voltage V_{con} instead of being bypassed.
- V_{con} directly sets the upper threshold ($2V_{CC}/3 \rightarrow V_{con}$) and lower threshold ($V_{CC}/3 \rightarrow V_{con}/2$) at which the capacitor switches.
- If V_{con} is increased, C must charge to a higher voltage and discharge to a higher voltage → T_{ON} and T_{OFF} increase → frequency decreases. If V_{con} is decreased, the frequency increases.

- Thus the output frequency is controlled by the input voltage — a voltage controlled oscillator (voltage-to-frequency converter).

$$T_{ON} = (R_A + R_B)C \ln[(V_{CC} - V_{con}/2)/(V_{CC} - V_{con})], \quad T_{OFF} = R_B C \ln 2$$



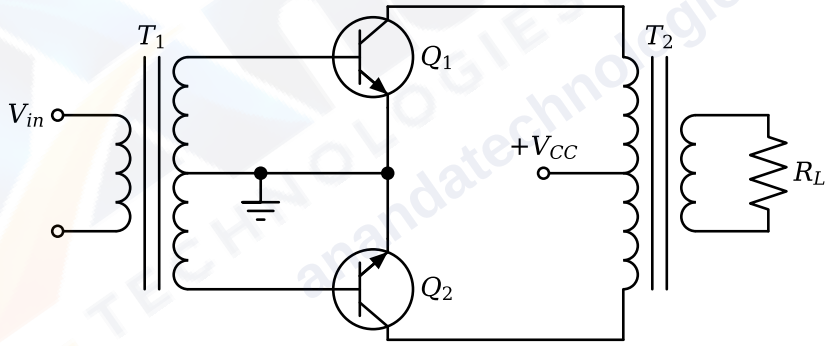
VCO output: frequency changes with control voltage

Applications: FM generation, frequency shift keying (FSK), PWM / PPM, voltage-to-frequency conversion.

(Circuit 2 M, working 3 M, waveform 1 M)

c) Draw and explain the transformer coupled class B push-pull amplifier with input and output waveforms. State its efficiency. 6 M

Circuit: Two identical transistors Q_1 and Q_2 are connected with a centre-tapped input transformer T_1 (phase splitter) and a centre-tapped output transformer T_2. Both are biased at cut-off (no forward bias), so each conducts for only 180°.

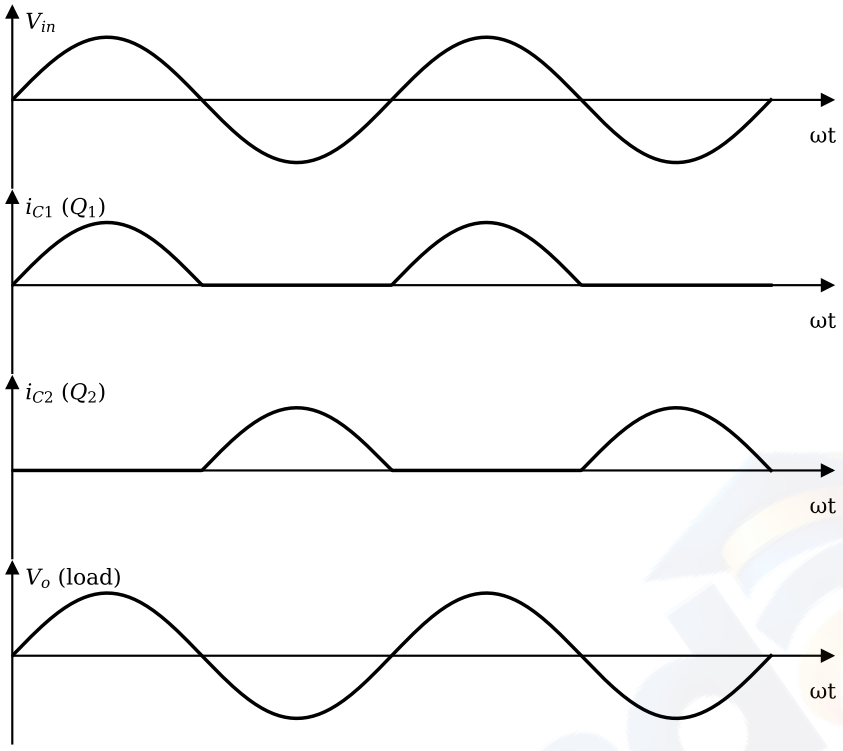


Transformer coupled class B push-pull amplifier

Working:

- T_1 gives two signals equal in magnitude and 180° out of phase at the bases of Q_1 and Q_2.
- **Positive half cycle:** base of Q_1 is positive → Q_1 conducts, Q_2 is OFF. Collector current i_{C1} flows through upper half of T_2 primary.
- **Negative half cycle:** Q_2 conducts, Q_1 is OFF. i_{C2} flows through lower half of primary in the opposite direction.
- T_2 combines the two half cycles, so a complete amplified sine wave appears across R_L.

- No current flows at zero signal, so efficiency is high: $\eta_{max} = \pi/4 = 78.5\ \%$. Even harmonics cancel in the output transformer.



Input, collector currents and output of class B push-pull amplifier

Drawback: Since the transistors need about 0.7 V (V_{BE}) to start conducting, the output is zero for small input near zero crossing → **crossover distortion**. It is removed by giving a small forward bias (class AB).

(Circuit 2 M, working 2 M, waveforms 2 M)

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