



Western Cape
Government

Western Cape Education Department
Directorate: Curriculum FET

ELECTRICAL TECHNOLOGY

(Electronics)

GRADE 12 REVISION BOOKLET

TERM 2

2026

The aim of this booklet is to help you preparing yourself better for the final year end exams by revising critical content and skills covered in Grade 12. The booklet will also focus on typical mistakes learners make when answering questions. It will try and guide you to obtain maximum marks for questions asked in the NSC exams.

This revision covers the following topic according to the Electronics ATP 2023/2024:

- Switching Circuits

It is important to prepare yourself by practice answering questions from past papers

You can download papers from:

[https://www.education.gov.za/Curriculum/NationalSeniorCertificate\(NSC\)Examinations/NSCPastExaminationspapers.aspx](https://www.education.gov.za/Curriculum/NationalSeniorCertificate(NSC)Examinations/NSCPastExaminationspapers.aspx)

There are also lessons on various grade 12 topics on the WCED e-Portal (<https://wcedportal.co.za/>)

GENERAL

Structure of the NSC Exam paper and Important points to remember:

- The paper consists of SIX compulsory questions, ONE multiple choice question covering all the topics proportionately and FIVE further questions covering the five topics in the syllabus.
- The multiple-choice questions will be of the type where a question is asked, and options is given where you must select the correct option.
- The weighting of the questions is as per the table below.
- The paper is out of 200 MARKS, and the time given is 3 HOURS: 200 marks = 180 min.
 - It is important to ensure that you manage your time properly when writing any test or exam.
 - You don't want to run out of time because of bad time management.
 - The following rough guide will help you manage your time a bit better:
1 Mark = 1 Minute.
(If a question is out of 10 marks, do not spend more than 10 minutes on that question)

- Try and start with the easiest question and work your way up to the more difficult questions.
- All questions and sub questions must be kept together. DO NOT MIX QUESTIONS
- Draw a line after each completed question.
- It is important that you read and interpret all instructions slowly before you start answering a question.
- Also, please note that you must receive a formula sheet with every test or exam you write, covering at least the topics of the test or exam.
 - The formulas are given per topic. Focus on the relevant formula section while answering the questions of a topic.
- The questions are asked in such a way that it will differentiate in terms of subject knowledge. It might start with an easy question and end off with more challenging question in the different questions per topic.

Final Examination Weighting in Power systems:

ELECTRONICS GRADE 12

Structure of the Electronics Question Paper: NOVEMBER

QUESTION	TOPIC	MARKS	TIME
1	Multiple Choice – All Topics	15	12 min
2	Occupational Health and Safety	10	9 min
3	RLC	35	32 min
4	Semi-Conductors	45	41 min
5	Switching Circuits	50	45 min
6	Amplifiers	45	41 min
TOTAL		200	180 min

Suggestions for improvement

It is important for learners to understand that components in a circuit may perform different functions

Learners should understand the following concepts:

- Triggering points and orientation of the output waveforms when input signals are applied in different switching circuits
- Active high trigger and active low trigger with reference to switching circuits
- The difference between integrator and differentiator when input signals are applied
- The explanation of a circuit must be coupled with calculations, drawing of input and the correlating output waveforms.

Focus on ensuring that:

- Writing the correct steps when doing calculations: Formula, Substitution, Answer with Unit.
- Draw a fully labelled diagrams.
- Practice with simulation software and building circuits in the workshop.

The difference between the verbs *calculate* and *determine* must be explained:

- **Calculate:** In this context involves the identification of formulae, the substitution of given values in the formulae and applying the mathematical operations to arrive at the answer.
- **Determine and deduce:** This does not involve doing calculations, but rather identifying information depicted in the given information.

TOPIC 1: SWITCHING CIRCUITS

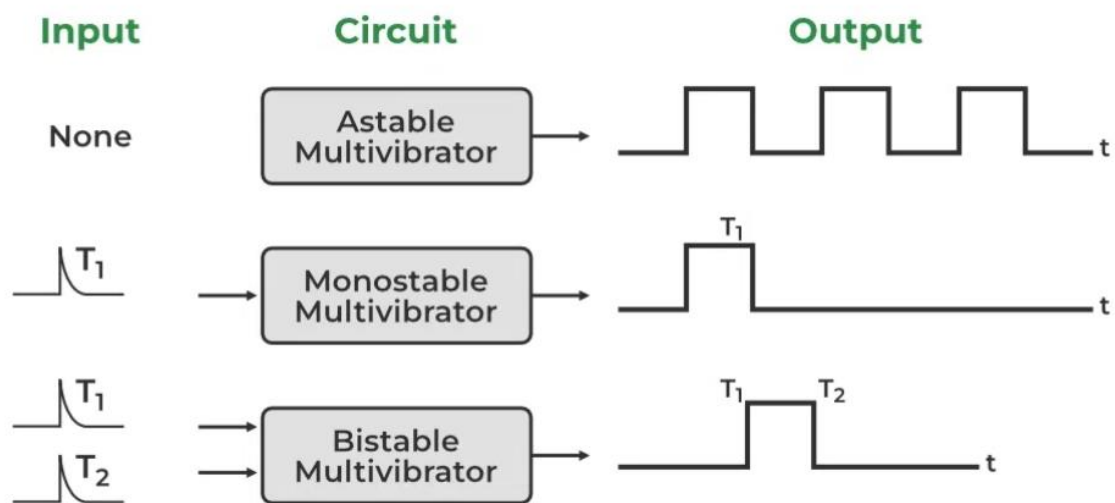
Pre-knowledge required.

- Voltage divider circuit
- Capacitor principle of operation
- Principle of operation of the 555-timer.
- Operational Amplifier Theory

Skills to attain:

- Define a multivibrator.
- Distinguish between the three different types of multivibrators.
- Identify the different types of multivibrators.
- Explain the operational principle of multivibrators implemented with either operational amplifiers or the 555-timer.
- Understand the working principle of operational amplifier applications in circuits such as the Schmitt Trigger, comparator, summing amplifier, differentiator, and integrator.
- Interpreting the response of a circuit to an input signal.
- Determining the output of a circuit when an input signal is applied.
- Determining the effect of changes in component values on the response of a circuit.
- Stating the applications of the different circuits.
- Understand different implementations of the circuits in the textbook.
- Drawing the circuits from memory

MULTIVIBRATORS



BISTABLE MULTIVIBRATOR

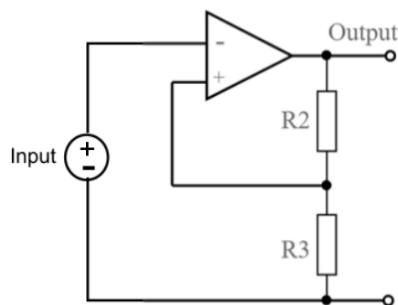
BASIC DESCRIPTION

The bistable multivibrator is a type of two-state device like a monostable and astable multivibrator. However, the two states are stable, and a trigger is required to change them. In the case of a bistable multivibrator, the output state is maintained indefinitely until an external trigger is applied to change the state.

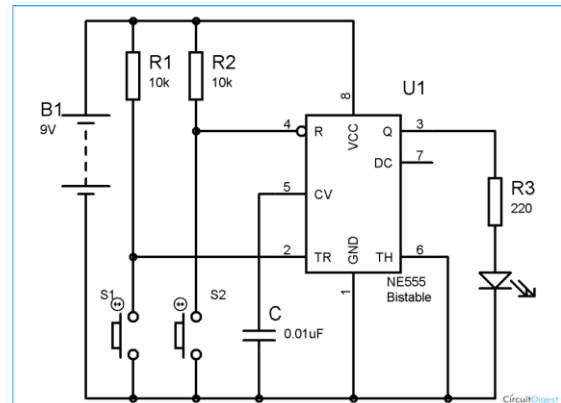
In a bistable multivibrator, a driving pulse is applied to the input, and the output state changes when triggering pulses are applied. Each output cycle is produced after two triggering pulses with the correct polarity and amplitude.

CIRCUIT DIAGRAMS

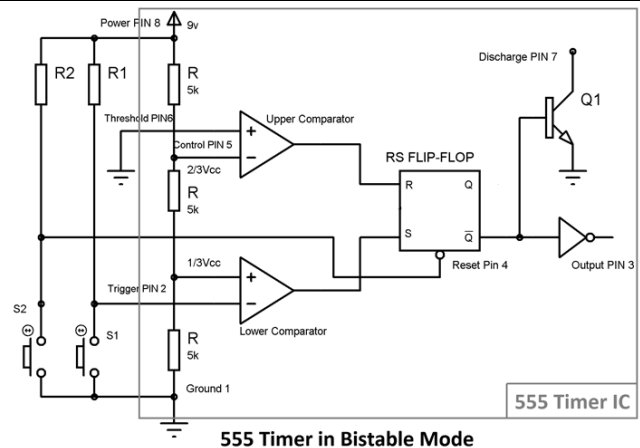
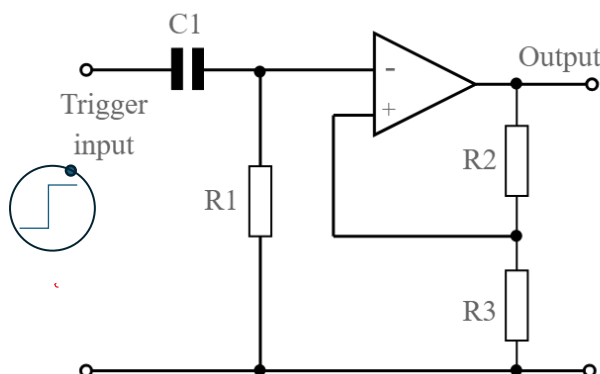
OP AMP IMPLEMENTATION



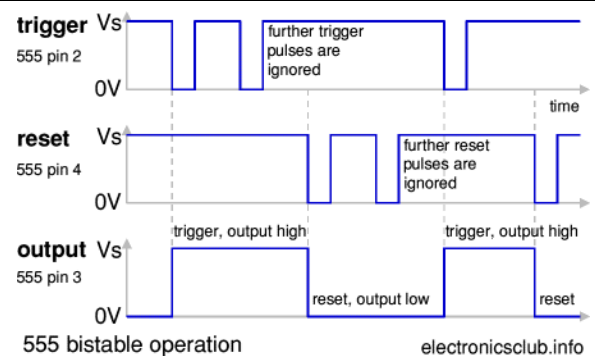
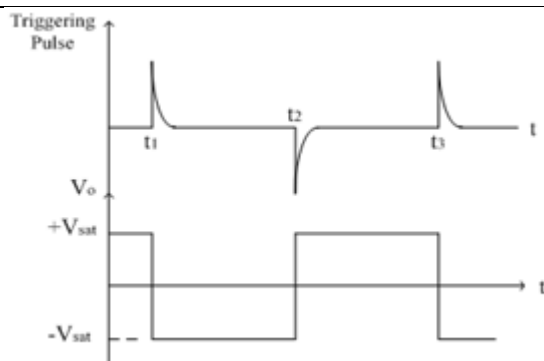
555 TIMER IMPLEMENTATION



BISTABLE WITH TRIGGER CIRCUIT



TIMING DIAGRAMS



PRINCIPLE OF OPERATION

- Positive feedback of a portion of the output signal to the non-inverting input of the op-amp through R_2 :
- When power is applied, the output voltage is LOW and the LED is off.
- When S1 is pressed, the TRIGGER voltage is pulled LOW to ground (0 V) and below the

$$V_+ = \frac{R_3}{R_2 + R_3} \times V_{OUT}$$

- Due to the positive feedback, the output may have one of two values: $V_{OUT} = \pm V_{SAT}$.
- The inverting input is supplied with a very short positive trigger pulse close to the size of the supply voltage, V_{CC} at time t_1 .
- As $V_- > V_+ \Rightarrow V_+ - V_- < 0$, $V_{OUT} = -V_{SAT}$ which is a stable state. The output will not change if any further positive trigger pulses are applied.
- The trigger pulse should be very short to ensure that the duration of pulse does not exceed the duration of the desired stable state. This trigger pulse can be generated by a passive differentiator.
- The output will stay in this stable state until a negative going input pulse is applied to put it in its second stable state,

NOTE: Duration in stable states is under external control (switches, input pulses)

voltage of $1/3V_{CC}$ on the non-inverting input of the lower comparator of the 555.

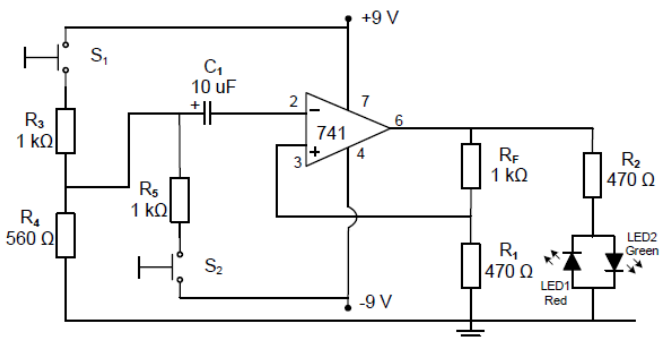
- The S input of the SR-latch is set to HIGH and the output of the 555 to HIGH.
- When S2 is pressed, the 555 is RESET by pulling the active LOW RESET pin 4 LOW and the output is LOW.
- Pin 6, the THRESHOLD, will normally be connected to GND to prevent it from floating to ensure that the reset (R) of the RS flip-flop is not accidentally triggered.

APPLICATIONS

Memory elements, frequency division, production of clock pulses, relay controllers, toggle switch, motor reversal.

NSC QUESTION EXAMPLES

Refer to the figure below and answer the questions that follow.

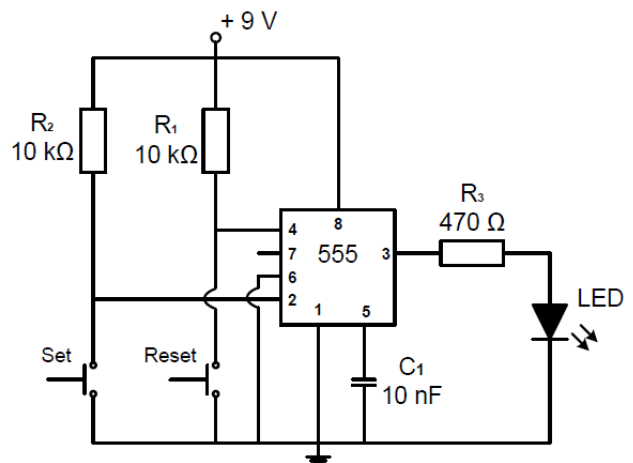


1. Identify the multivibrator circuit in the figure. Bistable multivibrator (positive feedback and two inputs that control the states of the output).
2. State the polarity of the pulse provided on the inverting input when switch S1 is pressed. The polarity will be positive as R3 and R4 forms a voltage divider that divides the +9V supply voltage and applies it to the inverting input. It may be calculated as

$$V_- = \frac{R_4}{R_3 + R_4} \times 9 = \frac{560}{1000 + 560} \times 9 = 3,23 \text{ V.}$$

3. State TWO functions of the 741 op amp in the circuit. The op amp compares the inverting and non-inverting inputs, in other words it serves as a comparator. Furthermore, through positive

Refer to the figure below and answer the questions that follow.



1. Name the function of resistors:

- (a) R1. R1 is a pull-up resistor that prevents pin 2 from floating by keeping the voltage HIGH (+9V)
- (b) R3. R3 is a current-limiting resistor that protects the LED.

2. Identify the state of the LED when trigger pin 2 is high. The LED must be OFF as it can only switch on when the output at pin 3 is HIGH when the trigger pin 2 is pulled LOW and the flip-flop is set.

feedback, the difference between the input voltages is amplified by a large amount causing the op amp to saturate and switch to one of its saturation states.

4. Which LED will be forward biased when S1 is pressed? LED1 (Red) as the inverting input will be larger than the non-inverting input, thus the op amp output will be driven to $-V_{SAT}$.

5. State the polarity of the voltage present on pin 3 after switch S2 is pressed. When S2 is pressed, the voltage on the inverting input will be negative, whether the output is at $+V_{SAT}$ or $-V_{SAT}$, the input signal ($V_+ - V_-$) will be positive and the output will be driven to the positive saturation state $+V_{SAT}$ thus the portion of the output that is fed back to pin 3 will be positive.

3. Explain what happens in the circuit when the set switch is pressed. When the set switch is pressed, pin 2 is pulled low, the voltage at the inverting input of the comparator is less than $3V$, the output of the comparator is HIGH, the SET input is HIGH, the output Q of the RS flip-flop becomes HIGH, $\bar{Q}$ is LOW which the output stage inverts to a HIGH output at pin 3.

4. Explain the purpose of connecting pin 6 to ground. It ensures that pin 6 which control the RESET input of the RS flip-flop never becomes more than 6 V which may cause an unexpected reset of the output.

QUESTIONS TO THINK ABOUT

Explain the operating principle of the circuit of the op amp bistable multivibrator in the NSC question. When both switches are open, the voltage on the inverting input will be 0V. Assume that $V_{OUT} = +V_{SAT}$. Then the voltage on the non-inverting input will be positive, stable and larger than 0V and the assumption is correct. When S1 is pressed, the voltage at the inverting input will be slightly higher (due to the bottom resistor R4 which is slightly larger than the bottom resistor on the feedback voltage divider) than the voltage on the non-inverting input, and the op amp will switch to $-V_{SAT}$. The reference voltage on the non-inverting input will be negative and stable. When S2 is pressed, the voltage at the inverting terminal will be negative, and more negative than the voltage on the inverting input. The op amp will thus switch to $+V_{SAT}$ and the timing period ends.

What is the purpose of the capacitor connected to pin 5? It removes noise by serving as a bypass capacitor that shorts high frequency noise to ground.

Why should C be small? When C is small the reactance of the capacitor is very large at low frequencies and can be seen as an open circuit that will not pass DC to ground. At high frequencies, the impedance become small, and short high frequency signals (noise) to ground.

Explain the purpose of the RESET pin 4: This pin overrides the TRIGGER and THRESHOLD inputs to reset the IC when it is pulled LOW. When the reset pin is pulled low, the reset transistor is switched on; the DISCHARGE transistor is switched on, enabling the discharge of a capacitor connected to it; the OUTPUT transistor is switched on, and the OUPUT is forced LOW, resetting the 555 timer.

TERMINOLOGY

Bypass capacitor: Shorts high frequency signals (noise) to ground. It provides an AC short to ground and can also be used to prevent an AC signal from seeing a component.

Decoupling capacitor: decoupling capacitors are normal placed in parallel with the power supply and stabilises the supply voltage by preventing voltage fluctuations by serving as a reservoir of energy.

Coupling capacitor: a coupling capacitor allows AC to pass while blocking DC and is connected in series with a signal source, between amplifier stages or before a load. The capacitor's reactance increases as the frequency of the signal passing through it decreases.

Trigger pulse: A square pulse of very short duration used to change the state of a circuit or trigger and event.

Pull-up resistor: Resistors that ensure a well-defined HIGH voltage level at a connection when the connection is not connected to an input signal. One end of the resistor is connected to the supply voltage and the other end is available for connection to an input signal.

Pull-down resistor: Resistors that ensures a well-defined LOW level at a connection when it is not connected to an input signal. One end of the resistor is connected to ground and the other end is available for an input signal.

Floating: A connection that is not connected to a HIGH or LOW voltage and is left unconnected. The voltage at the connection may be anything and cause unpredicted responses in a circuit.

Saturation: Refers to the state of a circuit output where it is fully turned on at maximum output voltage value.

Positive feedback: When part of the output of an op amp is fed back to the non-inverting terminal via a feedback resistor thereby increasing the size of the input signal until the op amp saturates.

Voltage divider: A circuit consisting of two series resistors connected to a voltage supply that is used to establish a voltage reference.

NOTES

Timing diagram: It is important to be able to use the timing diagrams to determine the output states of the bistable multivibrator.

555 Timer circuit diagram: It is important to visualise the circuit diagram and understand the different stages of the 555 timer in order to understand the different applications.

V_{CC}: The label normally used for the positive power supply of a circuit (+15V).

V_{EE}: The label normally used for the negative power supply of a circuit (-15V).

Resting state: When no triggers are applied to a circuit.

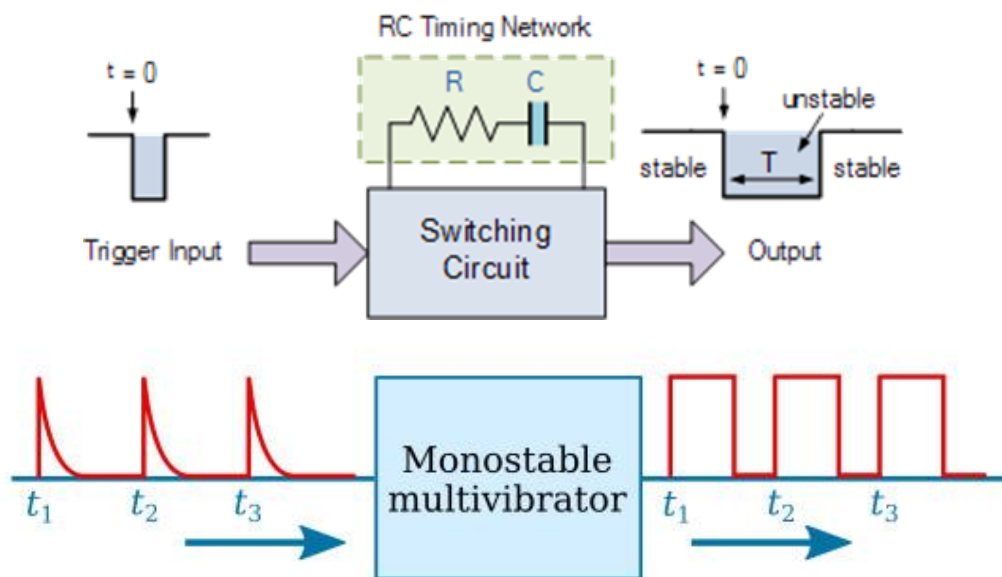
Charging: The voltage of a capacitor go from 0V or a positive voltage to a higher positive voltage or from a negative to a more negative value.

Discharging: The voltage of a capacitor go to 0V or from a positive voltage to a lower positive voltage, or from a negative to a less negative value.

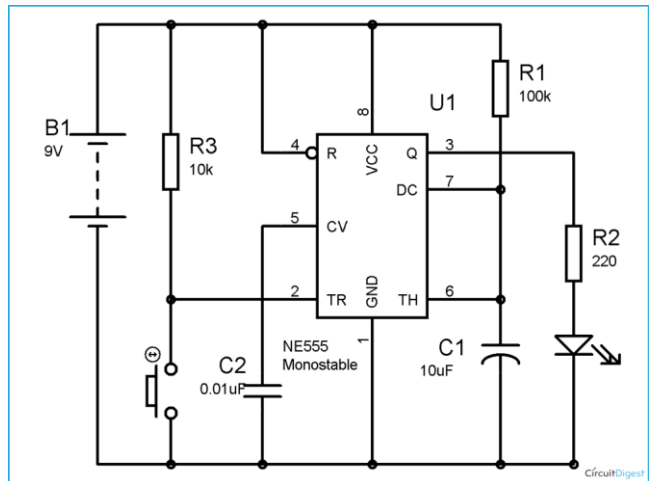
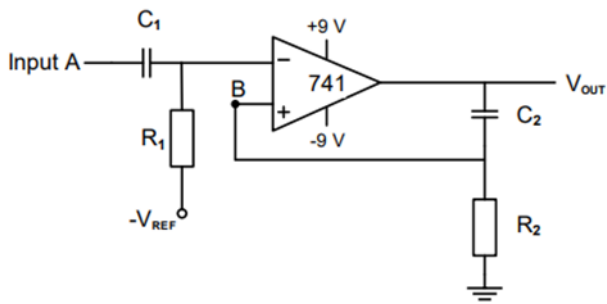
Saturation: The minimum or maximum output voltage that limits the response of a circuit to an input beyond which the input has no further effect on the output– limited by the power supply voltages

MONOSTABLE MULTIVIBRATOR

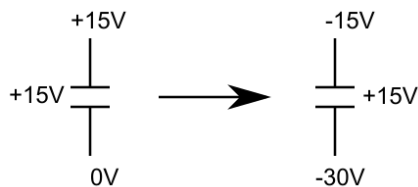
The monostable multivibrator (sometimes called a one-shot multivibrator) is a square- or rectangular-wave generator with just one stable output state. The input is triggered with a pulse of voltage. The output switches from one voltage level (stable state) to a different voltage level (unstable state). The output remains at this new voltage level for a specific time duration defined by an RC-network. Then the circuit automatically reverts to its stable state and remains that way until another trigger pulse is applied to the input. The monostable multivibrator takes this series of input triggers and converts them to uniform pulses.



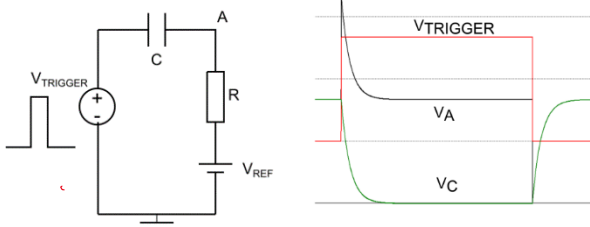
CIRCUIT DIAGRAMS



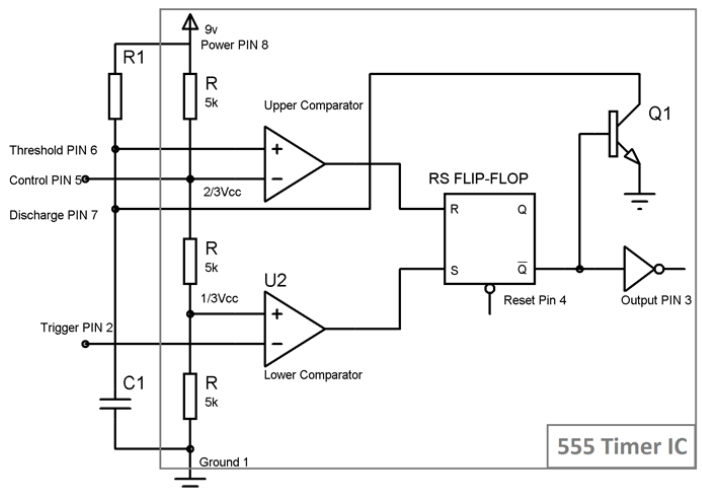
IMPORTANT CONCEPTS



The capacitor voltage cannot change immediately. When the voltage at the top plate changes, the voltage at the bottom plate must change to keep the voltage on the capacitor the same.

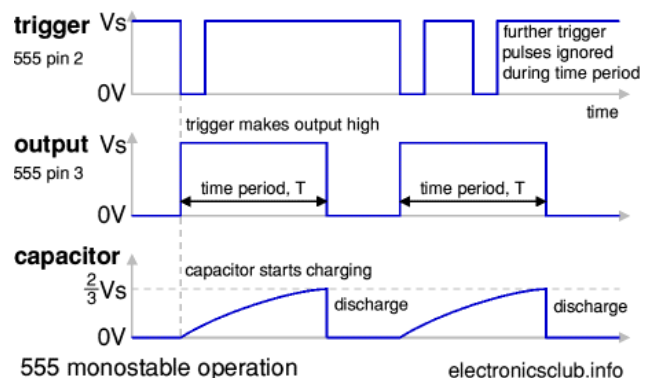
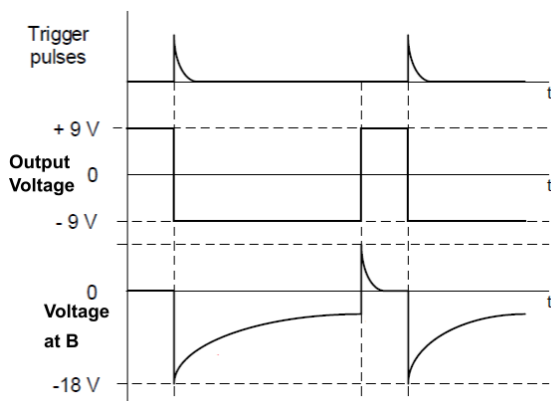


Before the trigger pulse is applied, the voltage at A, $V_A = V_{REF}$. When the trigger gets applied, $V_A = V_{TRIGGER} + V_{REF}$, both sides of the capacitor increase by the same voltage. The capacitor rapidly charges to $V_C = V_{TRIGGER} - V_{REF}$. When the pulse ends, V_A rapidly drops to V_C . The capacitor charges to $V_C = V_{REF}$.



The lower comparator is activated by a signal on the trigger pin 2 lower than $1/3V_{CC}$.
The upper comparator is activated by a signal on the threshold pin 6 higher than $2/3V_{CC}$.
The RS flip-flop is set when $S=1$ and reset when $R=1$. When $S=R=0$ the output is latched.
The output of the 555 timer is high when Q is high.
The discharge pin is connected to ground when $\bar{Q}$ is high.

TIMING DIAGRAMS



PRINCIPLE OF OPERATION

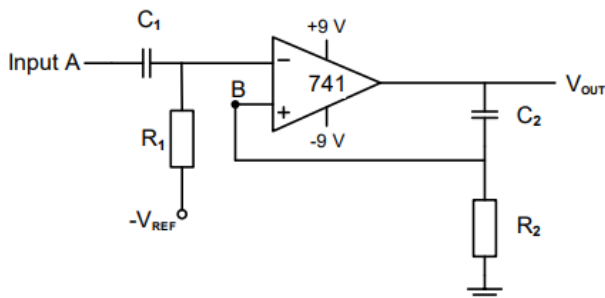
- With no trigger applied, C_1 is charged to $-V_{REF}$ and $V_- = -V_{REF}$.
- Thus $V_+ - V_- > 0$ and $V_{OUT} = +V_{SAT}$, which is the stable state.
- C is fully charged to $+V_{SAT}$, no current through R thus $V_+ = 0V$.
- The op-amp will change state to $-V_{SAT}$ should $V_- > V_+$.
- When a positive trigger larger than $+V_{REF}$ is applied, V_- will change to $V_{TRIGGER} - V_{REF}$ as V_{C1} cannot change immediately.
- If $V_- = V_{TRIGGER} - V_{REF} > V_+$, $V_+ - V_- < 0$ as $V_+ = 0$ and the op amp will change state to $V_{OUT} = -V_{SAT}$. This will happen when $V_{TRIGGER} > V_{REF}$.
- As the voltage across C cannot change immediately, but the voltage on the top plate changed to $-V_{SAT}$, it means that the bottom plate must change to $-2V_{SAT}$. (Practically this cannot happen, as the power supply limits the minimum negative voltage to $-V_{SAT}$. The output voltage thus does not switch immediately to $-V_{SAT}$, but instead gradually decreases until the capacitor discharged sufficiently towards $-V_{SAT}$ when it may switch)
- When the trigger voltage is zero again, C_1 rapidly discharges to $-V_{REF}$.
- Now, the input voltage to the op amp, $V_+ - V_- = -V_{SAT} + V_{REF} < 0$ which corresponds with $V_{OUT} = -V_{SAT}$ as the input is negative.
- C discharges from $+V_{SAT}$ towards $-V_{SAT}$ with the voltage across R, which is the voltage at the non-inverting input, decreasing towards 0 as C gets fully charged.
- As soon as the voltage at $V_+ > -V_{REF}$ the op amp output changes towards its stable state which is $+V_{SAT}$.
- When power is applied, C_1 is kept low by the DISCHARGE pin that is shorted to ground by the high $\bar{Q}$ of the RS flip-flop which switches the discharge transistor on. The output at pin 3 is LOW, the LED is OFF.
- When the push-button is pressed, TRIGGER pin 2 is pulled low, the output Q of the RS flip-flop goes high and the output goes HIGH. The LED is ON and the DISCHARGE pin is floating and at capacitor voltage.
- The capacitor C_1 starts to charge and the THRESHOLD pin 6 voltage rises. As soon as $V_{C1} > 2/3V_{CC}$, the circuit is reset by the THRESHOLD voltage, the discharge transistor switches on and the output goes LOW, ending the timing period.
- C_1 discharges through DISCHARGE pin 7 and the circuit returns to its initial state.

APPLICATIONS

Eliminating switch bounce, on/off time delay, switching something on for a period of time (timer), temporary memory, to trigger another circuit to perform a task, frequency division, pulse generation, waveform generators, sequential logic circuits as latches and flip-flops, communication systems, recovers a distorted pulse.

NSC QUESTION EXAMPLES

The diagram below shows a 741 op-amp monostable multivibrator. Answer the questions that follow.

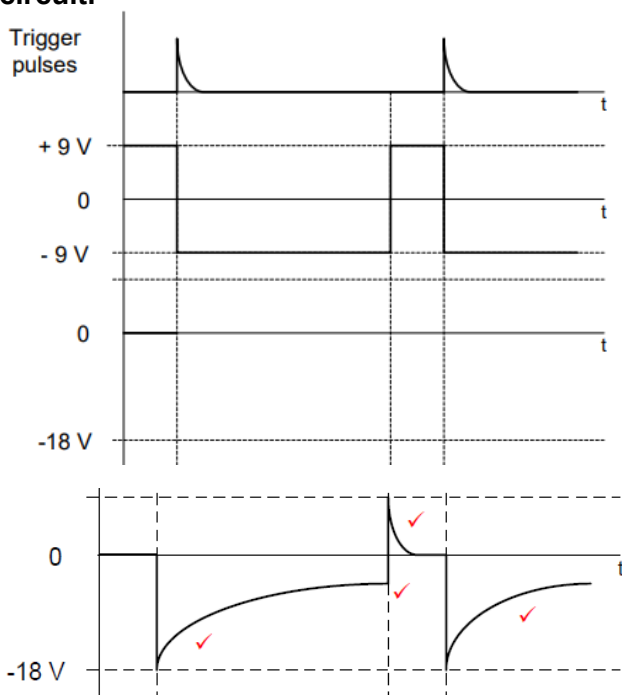


1. Write down the value of the voltage across capacitor C_2 when the circuit is in its natural resting position. Resting position means that no trigger has been applied and the circuit is in its stable state. $V_+ = 0V$ and $V_- = -V_{REF}$ (both capacitors are charged), thus $V_+ - V_- = V_{REF} > 0$ and the op amp is in its positive state of saturation with $V_{OUT} = V_{C_2} = +V_{SAT} = +9V$.

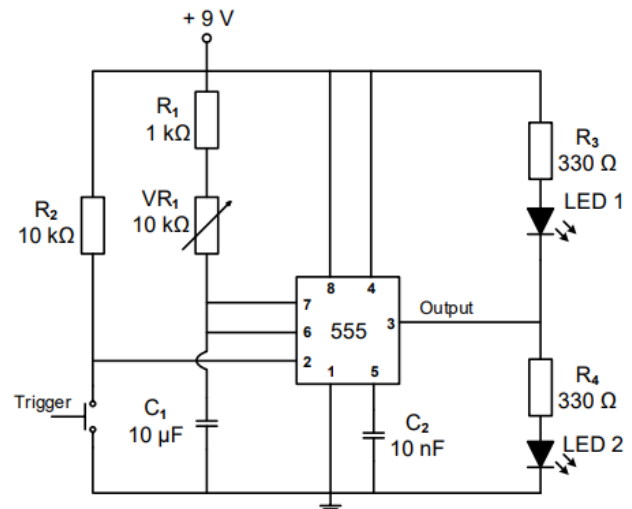
2. Write down the voltage at point B when the circuit is in its reset state. $V_B = 0V$ as C_2 is fully charged and no current flows through R_2 .

3. Explain when the circuit output will change state. The output will change state towards $-V_{SAT}$ as soon as $V_+ - V_- < 0$ which will happen when a trigger voltage larger than V_{REF} is applied as $V_- = V_{TRIGGER} - V_{REF} > 0$.

4. Draw the voltage at point B if the input signal below is applied to the input of the circuit.



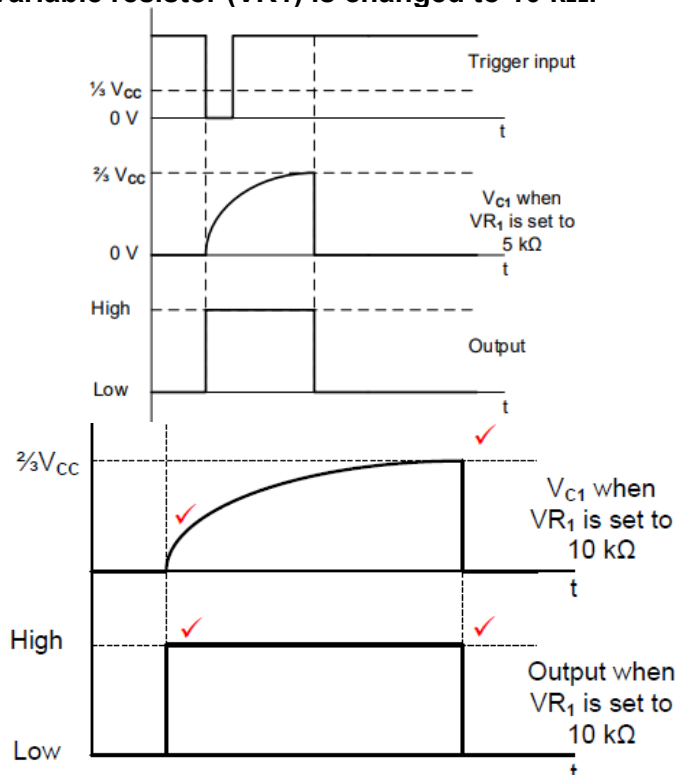
The diagram below shows a monostable multivibrator using a 555 IC.



1. State the function of capacitor C_2 . C_2 is a bypass capacitor that shorts random high frequency signals, noise, to ground to prevent its interference with the functioning of the circuit.

2. State whether LED 1 or LED 2 will be ON after the trigger switch is pressed. Motivate your answer. LED₂ will be on as the trigger voltage at pin 2 will be lower than $1/3V_{CC}$, setting V_{OUT} of the 555 to HIGH, forward biasing LED₂ and reverse biasing LED₁.

3. The trigger input, capacitor charge and output signals of the multivibrator is shown below. The variable resistor (VR1) is set to 5 kΩ. Draw the charging voltage V_{C1} and corresponding output if variable resistor (VR1) is changed to 10 kΩ.



The voltage at point B will start at $V_B = 0V$, change to $V_B = -2V_{SAT}$ when the output switches to $V_{OUT} = -V_{SAT}$ due to the voltage across C_2 that cannot change instantaneously. As V_{C_2} charge towards $-V_{SAT}$, the current through R_2 will gradually decrease and with that the voltage V_B also decreases. When $V_B > V_{REF}$ the timing period ends, the op amp change state towards $V_{OUT} = +V_{SAT}$, V_B changes to $V_B = V_{REF} + 2V_{SAT}$ and then gradually towards $0V$ as V_{C_2} charges towards $V_{C_2} = -V_{SAT}$.

QUESTIONS TO THINK ABOUT

TERMINOLOGY

Switch bounce: When a switch close, its contacts never closes immediately in a fixed position. The contacts normally springs up and down before settling in a closed position. The output of the switch thus creates a short series of pulses, that may seem like information to a circuit.

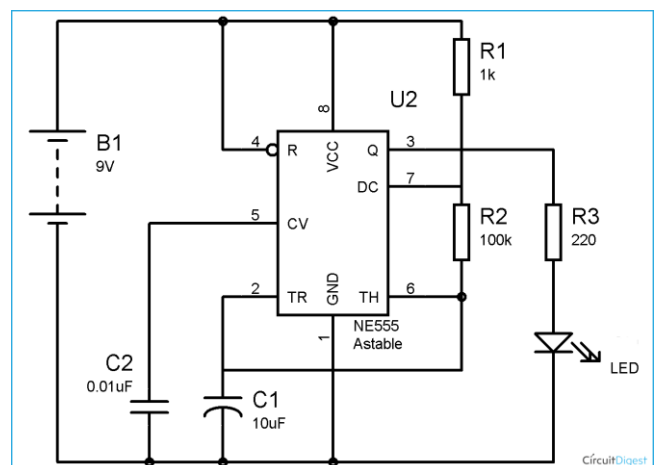
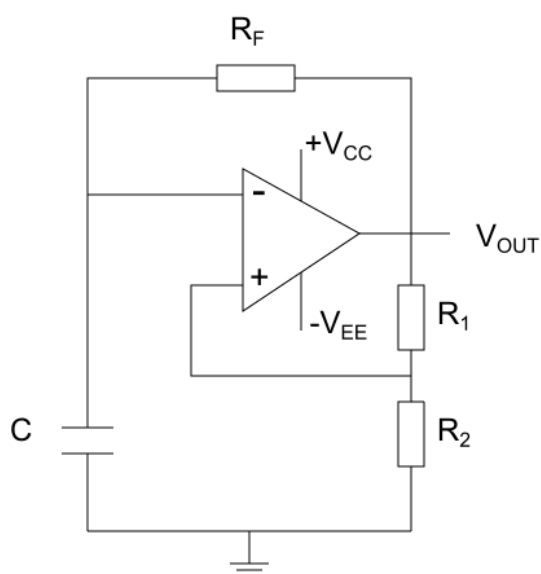
NOTES

Timing diagram: It is important to be able to use and draw the timing diagrams to determine the output states of the bistable multivibrator.

ASTABLE MULTIVIBRATOR

Astable Multivibrators are free running oscillators which oscillate between two states continually producing two square wave output waveforms. Regenerative switching circuits such as the Astable Multivibrator are the most commonly used type of relaxation oscillator produce a constant square wave output waveform. Unlike the Monostable Multivibrator or the Bistable Multivibrator that require an "external" trigger pulse for their operation, the Astable Multivibrator has automatic built in triggering which switches it continuously between its two unstable states during both set and reset.

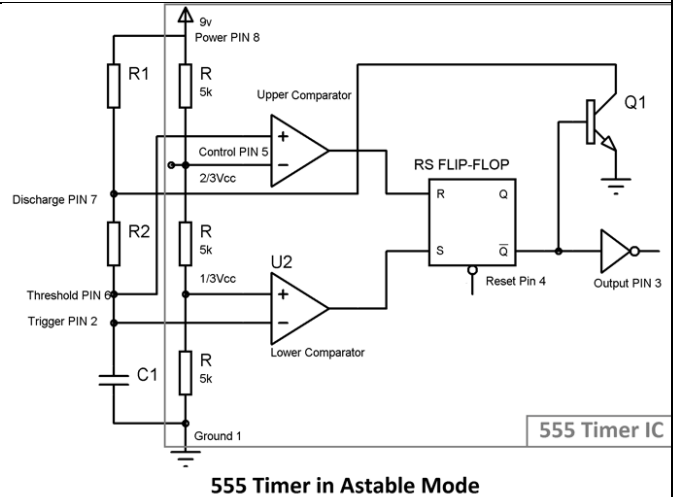
CIRCUIT DIAGRAMS



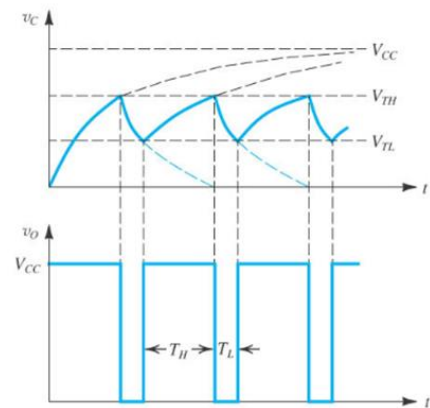
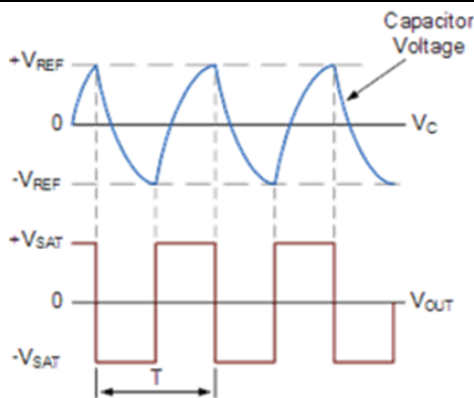
IMPORTANT CONCEPTS

Note that when the circuit is off, after a long time the capacitor will be discharged, and $V_C = 0$.

When power is applied the output may switch to either $+V_{SAT}$ or $-V_{SAT}$ depending on the voltage difference between the inverting and non-inverting inputs.



TIMING DIAGRAMS



PRINCIPLE OF OPERATION

- Assume initially when power is applied that $V_{OUT} = +V_{SAT}$, this initial state is determined by whatever voltage is initially on the two input terminals, random noise will normally decide this.
- C has not charged yet, and the voltage at the inverting terminal is at $0V$.
- A portion of V_{OUT} is fed back to the non-inverting terminal, this voltage will be a fraction of $V_{OUT} = +V_{SAT}$ and determined by the resistor values of the voltage divider:

$$V_+ = V_{REF} = \frac{R_2}{R_1 + R_2} \times (+V_{SAT}).$$
- Thus $V_+ > V_-$ and due to positive feedback the op amp will be saturated at $+V_{SAT}$. This establishes the reference voltage V_{REF} where the op amp will switch states.
- The capacitor C starts to charge towards $+V_{SAT}$. As soon as it becomes higher than the reference voltage at the non-inverting input, the output switches to $-V_{SAT}$.
- The reference voltage changes to

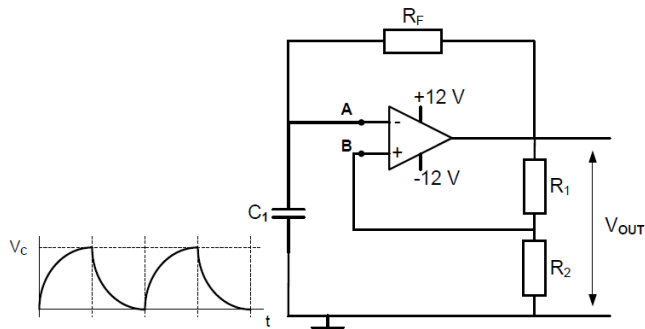
$$V_+ = V_{REF} = \frac{R_2}{R_1 + R_2} \times (-V_{SAT}).$$
- The capacitor charges towards $-V_{SAT}$ and as soon as it surpasses the reference voltage at the non-inverting terminal, the output switches to $+V_{SAT}$ and the timing period ends.
- Initially, when power is applied, capacitor C_1 is discharged and the voltages at pin 2 and 6 is LOW.
- TRIGGER voltage is low and bottom comparator output is HIGH setting the RS flip-flop. V_{OUT} is HIGH.
- C_1 charges through R_1 and R_2 and increases the voltage at the THRESHOLD pin 6. When the THRESHOLD voltage exceeds $2/3V_{CC}$, the RS flip-flop is reset and V_{OUT} switches LOW and the HIGH time duration of the output pulse ends.
- The discharge circuit at pin 7 is activated and C_1 discharges through the DISCHARGE pin to ground.
- When the voltage on C_1 is less than $1/3V_{CC}$, the lower comparator is set, the RS flip-flop is SET and V_{OUT} is high and the LOW time duration of the output pulse ends.

APPLICATIONS

Wave form generation, frequency modulation circuits, analog and digital timers, voltage to frequency converters, digital communication, clocks in computer systems, morse code generation, flip-flop circuits, flashing lights, and automatic switching circuit, speed control of DC motors with Pulse Width Modulation.

NSC QUESTION EXAMPLES

Refer to the diagram and answer the questions that follow.



1. Identify the multivibrator in the diagram.

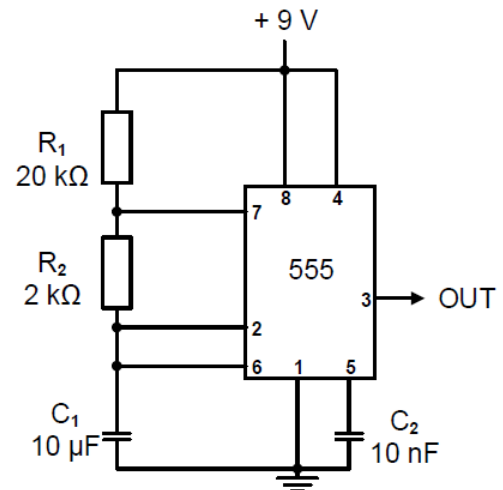
Astable multivibrator (as there are no external inputs that controls the circuit)

2. Describe the operation of the multivibrator in the diagram from a point where the capacitor has just discharged and point A is low. If point A is low it causes the op-amp to saturate and its output to rise to +12V (assume). This raises the potential across the voltage divider pair R_1 and R_2 , making point B more positive than point A. With the output voltage high, it induces the capacitor to charge towards +12 V through resistor R_F , gradually lifting the voltage at point A. When the voltage at point A becomes more positive than the voltage at point B, the op-amp immediately saturates in the opposite direction with its output falling to -12 V. This forces the capacitor to discharge (or charge towards -12 V) through resistor R_F , lowering the voltage at point A. When the voltage at point A falls below that of point B, the op-amp saturates back to +12 V and the process repeats itself.

3. Explain how the frequency of the multivibrator in the diagram can be increased.

The frequency of the multivibrator can be increased by either decreasing the value of R_F or C .

Refer to the diagram below and answer the questions that follow.

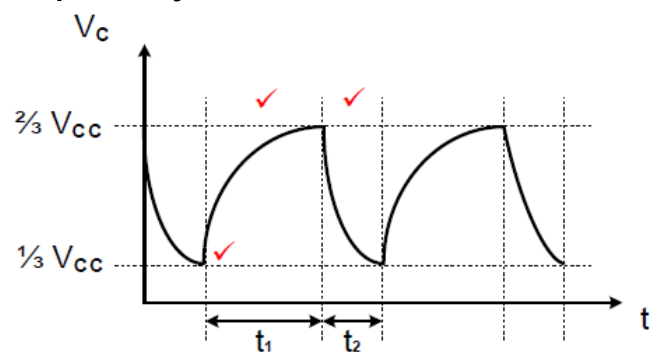


1. Identify the multivibrator in the diagram above.

Astable multivibrator (note that there are no external inputs to control the circuit)

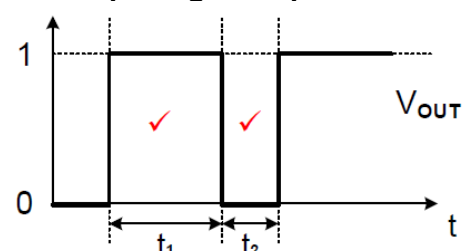
2. Draw the charging and discharging waveform of capacitor C1.

3. Explain why there is a difference in the



charging and discharging times of the capacitor. The capacitor charges through $(R_1 + R_2)$, causing a long RC time constant, but discharges through only R_2 causing a short time constant.

4. Draw the output signal at pin 3.



QUESTIONS TO THINK ABOUT

Discuss the influence of the resistors R_1 and R_2 on the functioning of the multivibrator.

Explain how the duty cycle of the multivibrator may be increased. By decreasing the value of R_2 the duty cycle increases towards 100% and by increasing R_2 the duty cycle reduces towards 50%. If resistor, R_2 is very large relative to resistor R_1 the output frequency of the 555 astable circuit will be determined by $R_2 \times C$ only.

TERMINOLOGY

Duty cycle: The duty cycle of an astable circuit is the proportion of the complete cycle for which the output is high (the mark time). It is usually given as a percentage.

Mark time: The time duration when a pulse wave is high.

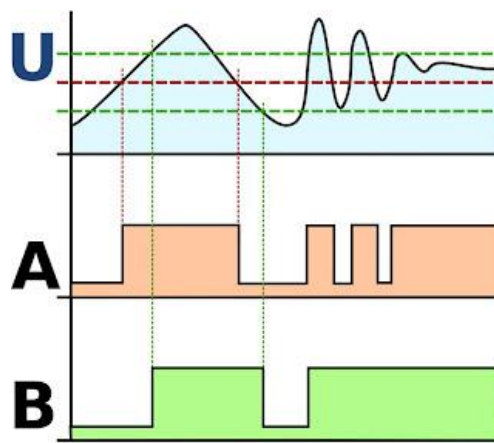
Space time: The time duration when a pulse wave is low.

NOTES

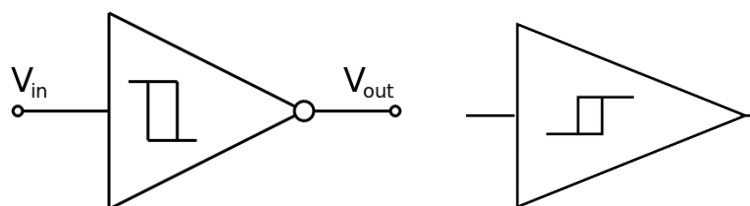
Duty cycle: Note that the duty cycle for the astable implemented with the 555 timer is always larger than 50%, as it charges through two resistors and discharges only through one.

SCHMITT TRIGGER

Schmitt trigger can be defined as it is a regenerative comparator. It employs positive feedback and converts a sinusoidal input into a square wave output. The output of Schmitt Trigger swings at upper and lower threshold voltages, which are the reference voltages of the input waveform. It is a bi-stable circuit in which the output swings between two steady-state voltage levels (High and Low) when the input reaches certain designed threshold voltage levels. The difference between the bistable multivibrator and the Schmitt trigger is that the bistable switches states based on two trigger pulses, while the Schmitt trigger switches states based on a continuously applied input signal that triggers the output based on two trigger reference voltages.

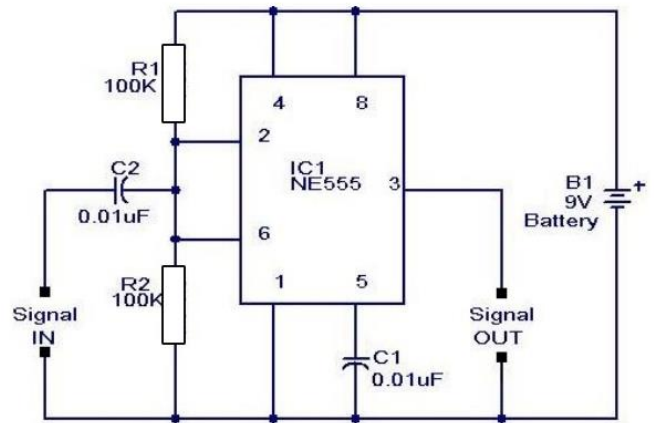
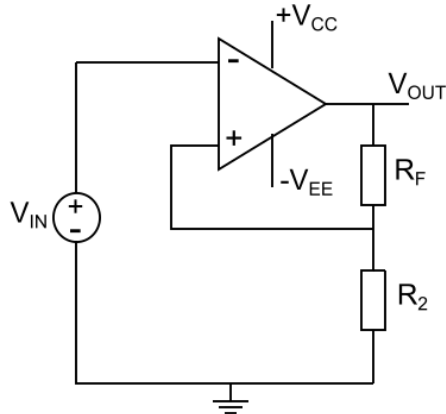


A is the output of a comparator where there is only one switch point, while B is the output of a Schmitt trigger with two switch points. The Schmitt trigger ignores small unwanted transients that may be due to noise.



SCHMITT TRIGGER SYMBOL: INVERTING AND NON-INVERTING

CIRCUIT DIAGRAMS



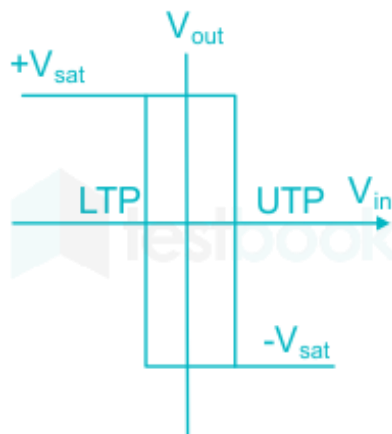
IMPORTANT CONCEPTS

Hysteresis: The dependence of the state of a circuit on its history. The output state of the circuit is different depending on whether the input increases or decreases.

Upper Trigger Voltage (V_{TH}): The high voltage where the Schmitt trigger changes state. Also called the Upper Threshold (UT) voltage.

Lower Trigger Voltage (V_{TL}): The low voltage where the Schmitt trigger changes state. Also called the Lower Threshold (LT) voltage.

Inverting Schmitt Trigger: Output is in positive saturation when the input is negative and lower than V_{TH} .

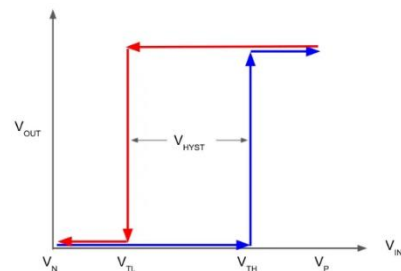


Coupling Capacitor, C_2 : The purpose of the capacitor is to block the DC component of the input signal, and only allow AC to pass.

Voltage divider resistors R_1 and R_2 : Applies a biasing voltage to the input signal with a value of $\frac{1}{2}V_{CC}$. This biasing voltage is centred between the switching voltages of the 555 comparators, $\frac{2}{3}V_{CC}$ (upper) and $\frac{1}{3}V_{CC}$ (lower).

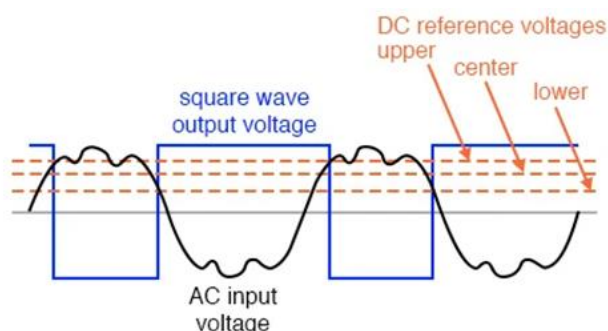
555 timer trigger points: established by the three 5kΩ resistors forming the internal voltage divider $\frac{1}{3}V_{CC}$ and $\frac{2}{3}V_{CC}$.

Input threshold voltages: $V_{TH} = \frac{2}{3}V_{CC} - \frac{1}{2}V_{CC} = \frac{1}{6}V_{CC}$ and $V_{LT} = \frac{1}{2}V_{CC} - \frac{1}{3}V_{CC} = -\frac{1}{6}V_{CC}$.



Note that it is important to distinguish between the 555 and the input voltage trigger points.

TIMING DIAGRAMS



PRINCIPLE OF OPERATION

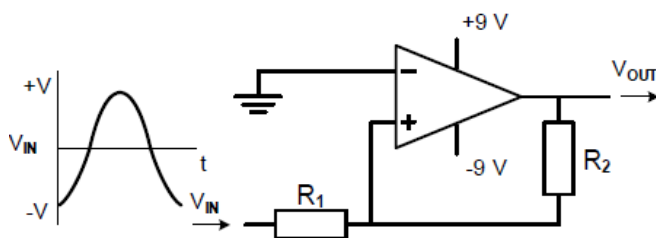
- The op amp Schmitt trigger has two reference voltages, $V_{REF} = \pm \frac{R_2}{R_2 + R_F} \times V_{SAT}$ that depends on whether the op amp is in positive or negative saturation. The positive voltage is called V_{UT} (upper threshold voltage) and the negative, V_{LT} (lower threshold voltage).
- When the input voltage is large negative and increasing, $V_{OUT} = +V_{SAT}$ (whether $V_{OUT} = \pm V_{SAT}$, the output will change to $+V_{SAT}$).
- V_{OUT} will stay in positive saturation until $V_{IN} > V_{UT}$ where the op amp will switch to negative saturation. It will stay here while V_{IN} increases further.
- When V_{IN} decreases from a large positive value, $V_{OUT} = -V_{SAT}$ until $V_{IN} < V_{LT}$ where it will switch into positive saturation, $+V_{SAT}$.
- Consider a sine wave with an amplitude of $\frac{1}{2} V_{CC}$ applied to the Schmitt trigger. This means the input signal will swing between $0V$ and V_{CC} with the AC part varying between $-1/2 V_{CC}$ and $+1/2 V_{CC}$.
- When $V_{IN} < -\frac{1}{6} V_{CC}$, pin 2 of the 555, $V_{TRIGGER} < \frac{1}{3} V_{CC}$ and $V_{OUT} = +V_{SAT} \approx V_{CC}$ when the lower comparator of the 555 sets the RS flip-flop and the 555 output to HIGH.
- As V_{IN} increases from $-\frac{1}{2} V_{CC}$ and goes above $-\frac{1}{6} V_{CC}$, the SET input of the RS flip-flop is LOW.
- When $V_{IN} > \frac{1}{6} V_{CC}$, pin 6 of the 555, $V_{THRESHOLD} > \frac{2}{3} V_{CC}$ the RESET input of the RS flip-flop is triggered and the output of the 555 goes LOW.

APPLICATIONS

Schmitt triggers are a fundamental circuit with several uses. In signal processing, they can pull and extract digital data from some extremely noisy environments. The hysteresis reduces the amount of noise that is passed to the output. Changing a sine wave to square wave; utilized in the switch debouncer circuits for a noisy otherwise slow input; signal conditioning for removing signals noise in digital circuits; implement relaxation oscillators for closed loop negative response designs; switching power supplies as well as function generators; memory element.

NSC QUESTION EXAMPLES

The diagram below shows a *non-inverting* Schmitt trigger. Answer the questions that follow.



1. Determine the voltage at which the circuit will trigger. Motivate your answer. The circuit will trigger when $V_+ = 0V$ as the inverting input is connected to ground, but this is not where the input signal will trigger the circuit. It can be shown that $V_{TH} = +V_{SAT} \frac{R_1}{R_2}$ and $V_{TL} = -V_{SAT} \frac{R_1}{R_2}$.

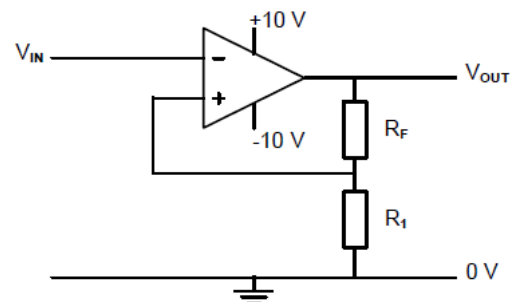
2. Name TWO uses of a Schmitt trigger.

A Schmitt trigger is used to clean up distorted signals in radio receivers and digital systems; convert analogue to digital signals, eliminates switch bounce.

3. Draw the output signal.

When $V_{IN} \ll 0$, the non-inverting input voltage will be negative, and $V_{OUT} = -V_{SAT}$. As V_{IN} increases and become positive, a voltage, V_{UT} , will be reached where $V_+ = 0$, and when this is exceeded, V_{OUT} switches to $+V_{SAT}$ and stays there as V_{IN}

Refer to the diagram below of the *inverting* Schmitt-trigger and answer the questions that follow.



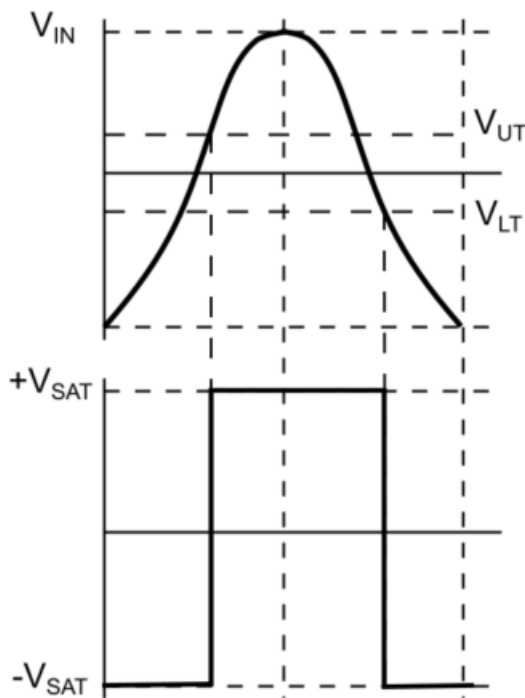
1. Explain the function of resistors R_F and R_1 . R_F and R_1 creates a voltage divider. It divides the output voltage resulting in a portion of the output voltage appearing across R_1 . The voltage across R_1 is fed back to the op-amp's non-inverting input.

3. Describe how an increase in the value of R_F will affect the trigger voltage. If the value of R_F increases, the voltage across R_1 will decrease according to Kirchhoff's voltage law. Therefore, the voltage fed back to the non-inverting input will decrease. This will lead to a decrease in trigger voltage.

4. Draw a fully labelled circuit diagram of a 741 op amp connected as an inverting Schmitt trigger.

See the diagram above.

becomes more positive. When V_{IN} decreases from a large positive value, a negative voltage, V_{LT} , will be reached where $V_{OUT} = 0$ and V_{OUT} switches to negative saturation, $-V_{SAT}$.

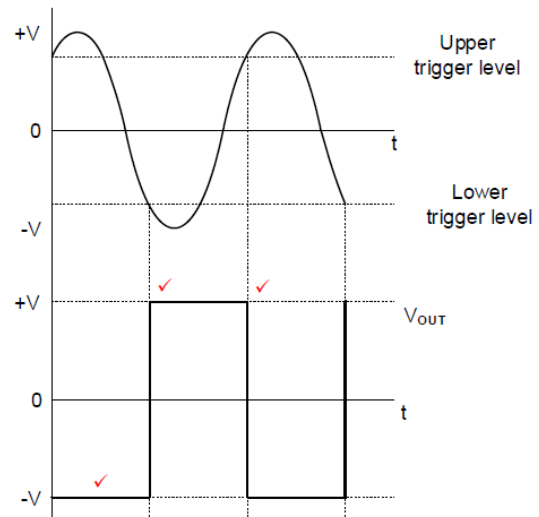


4. State how the trigger voltage levels of the Schmitt trigger can be adjusted without changing the supply voltage. The trigger voltage levels can be adjusted by changing the value of either R_F or R_1 .

5. Indicate whether this is an open-loop mode op-amp circuit or a closed-loop mode op-amp circuit. Motivate your answer. This is a closed loop mode op-amp circuit because R_F creates a positive feedback loop from the output to the non-inverting input.

5. State TWO applications other than a temperature sensitive switch of a Schmitt trigger. Radio receiver filters; Contact debouncer; Analogue to digital converter; Signal recovering.

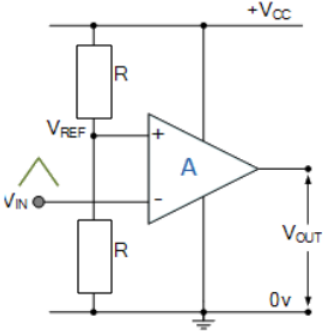
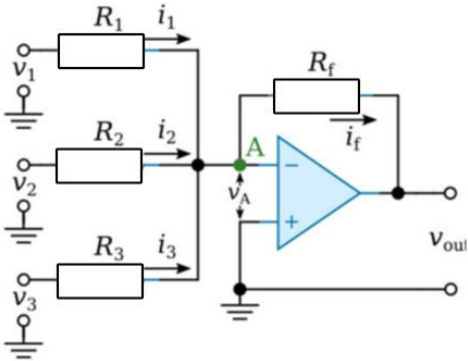
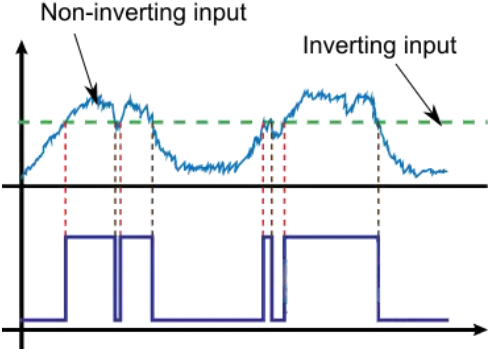
6. Draw the output signal if the signal below is applied to the input of the Schmitt trigger.



7. State TWO applications other than a temperature sensitive switch of a Schmitt trigger. Radio receiver filters; Contact debouncer; Analogue to digital converter; Signal recovering.

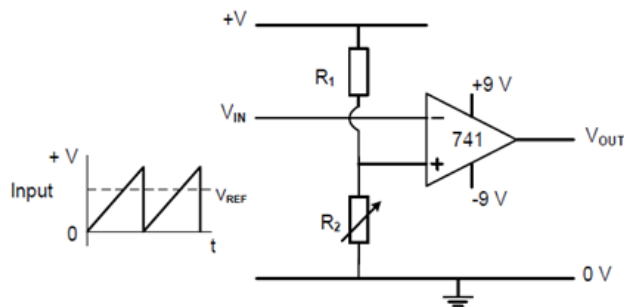
8. Explain the operation of the circuit. The signal is fed into the inverting input of the op-amp which acts as a comparator, comparing the voltages on its two input terminals. The difference on the two input terminals drives the output of the op-amp into one of its saturation states. This output is divided across the two resistors R_F and R_1 into a fraction which is fed back to the non-inverting input. The voltage on the non-inverting input determines (sets) the lower and upper trigger voltage levels. The voltage on the inverting input is compared to the voltage on the noninverting input (trigger voltage level), if it's lower than the trigger voltage level, the output is driven into positive saturation. If it is higher than the trigger voltage, it is driven into negative saturation.

OTHER OP AMP APPLICATIONS

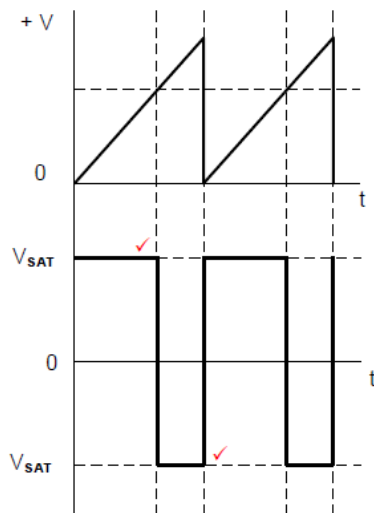
COMPARATOR	SUMMING AMPLIFIER
CIRCUIT DIAGRAMS	
	
PRINCIPLE OF OPERATION	
If voltage is higher on this pin, the output becomes +12V Input pins for voltage comparison Any op amp +12V DC Positive Supply Pin Output will be 0 V or +12 V depending on which input pin has higher voltage. homs-made-circuits.com Negative Supply Pin 0 V DC If voltage is higher on this pin, the output becomes 0V Non-inverting input Inverting input  The comparator is used in an open loop configuration. It amplifies the input signal $V_{IN} = V_+ - V_-$. If $V_+ > V_-$ the output is $V_{OUT} = +V_{SAT}$, otherwise $V_{OUT} = -V_{SAT}$.	Each input signal is amplified differently according to the ratio of the feedback resistor and the input resistor of the specific input. The output voltage is given by: $V_{OUT} = -(V_1 \frac{R_f}{R_1} + V_2 \frac{R_f}{R_2} + V_3 \frac{R_f}{R_3})$ Should $R_1 = R_2 = R_3 = R_{IN}$, then the gain of $V_{IN} = V_1 + V_2 + V_3$, can be defined as $A_V = \frac{V_{OUT}}{V_{IN}} = -\frac{R_f}{R_{IN}}$ When the resistors are not equal, the circuit is called a weighted summer. When the input resistors are variable, the gain of each input signal may be boosted or attenuated.
APPLICATIONS	
Light detector, temperature switch, any application where two signals or voltages must be compared with each other.	Audio mixer (mixing different sounds), digital to analog converter, level shifter (adding a DC offset to a signal).

NSC QUESTION EXAMPLES

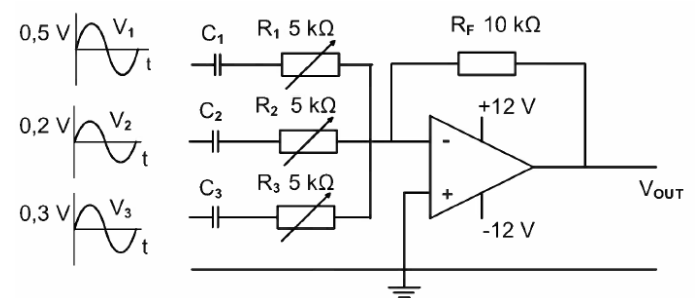
Refer to the diagram below and answer the questions that follow.



1. Name the components that determine the reference voltage. R1 and R2 that forms a voltage divider.
2. Draw the output voltage in relation to the input signal.



Refer to the diagram below and answer the questions that follow.



1. State the purpose of the capacitors in series with the input resistors. The capacitors are coupling capacitors that remove any DC component from the input signal and only allow high frequency AC to pass.
2. Explain the advantage of using variable resistors instead of fixed value resistors on the input of the amplifier. The gain of each input signal may be varied independently, to boost or attenuate the effect of either.
3. Calculate the output of the amplifier if all input resistors are set to $2\text{k}\Omega$.

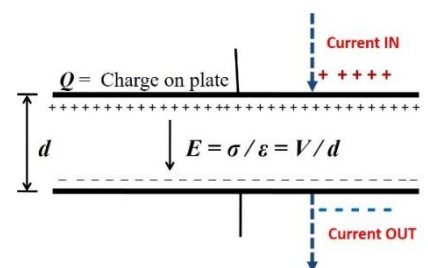
$$V_{OUT} = -\frac{R_F}{R_{IN}}(V_1 + V_2 + V_3)$$

$$= -\frac{10000}{2000} \times (0.5 + 0.2 + 0.3) = -5V$$

DIFFERENTIATOR

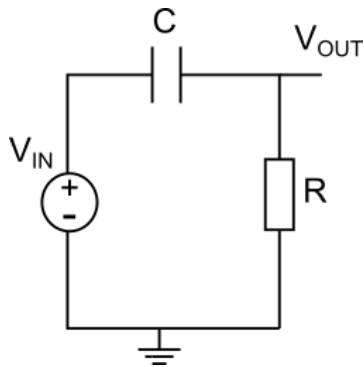
The differentiator gives an output signal that is proportional to the slope or gradient of the input signal. It makes use of the characteristic of a charging capacitor where the capacitor current is directly proportional to the derivative of the changing capacitor voltage. By putting the current through a resistor, the output voltage proportional to the input voltage gradient can be obtained.

When a battery (constant voltage) is connected to a capacitor, electrons accumulate on the negative plate and deplete on the positive plate with a large current flowing until the resulting electric field creates a voltage across the capacitor equal to the applied voltage, then current stops flowing. When the applied voltage increases, current flows again and deposits and removes electrons according to $I = \frac{\Delta Q}{\Delta t} = C \frac{\Delta V}{\Delta t}$, where ΔV means a change in voltage in a change of time Δt causing a change in charge ΔQ in Δt . In other words, the current is proportional to the rate of change of voltage, or the derivative of the voltage, mathematically it is expressed as $I = C \frac{dV}{dt}$.

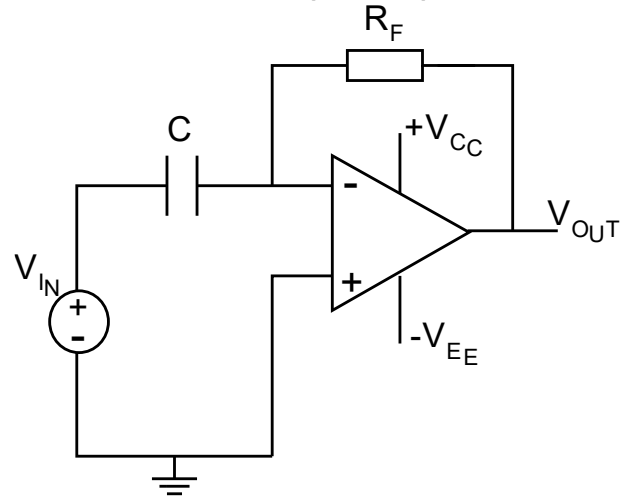


CIRCUIT DIAGRAMS

PASSIVE



ACTIVE (OP AMP)



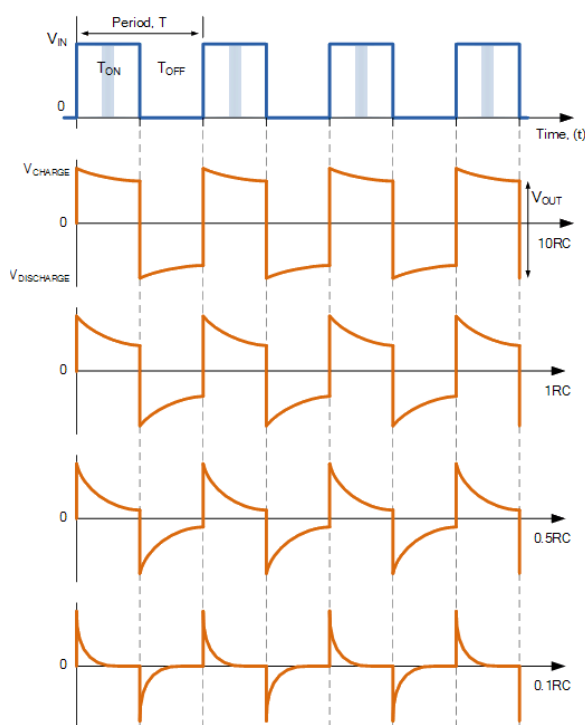
IMPORTANT CONCEPTS

The passive RC differentiator is not a very accurate differentiator due to the exponential charging rate of the capacitor. As the capacitor voltage depends on the input voltage and the charging current that develops a voltage across R, the output voltage actually changes exponentially and not exactly according to the gradient of the input signal.

The capacitor current is directly proportional to the rate of change of the capacitor voltage and not dependent on the voltage across the resistor. This is due to the presence of the virtual ground at the inverting input which makes the output voltage only dependent on the charging current and thus the derivative of the input voltage.

Note that if the circuit pick up any noise (high frequency signals), it will amplify it according to the ratio $-\frac{R_F}{X_C}$. This amplification factor can become very large at high frequencies due to X_C becoming very small and leads to instabilities or saturation of the op amp.

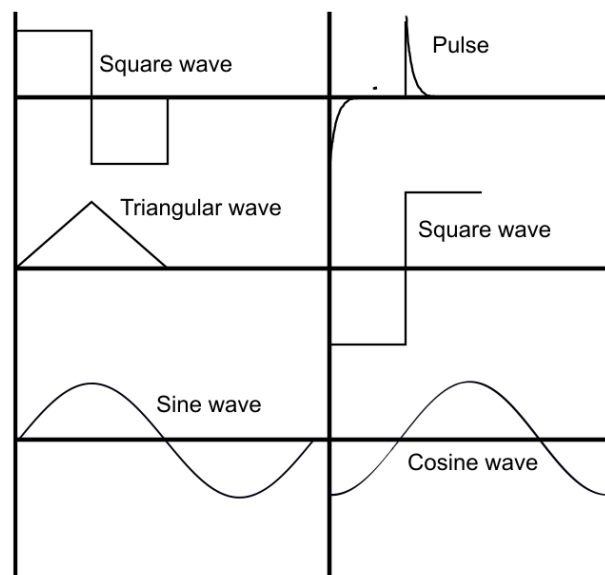
TIMING DIAGRAMS



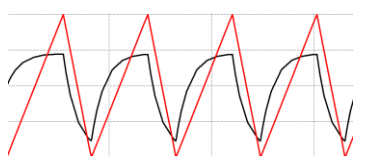
SQUARE WAVE INPUT

INPUT

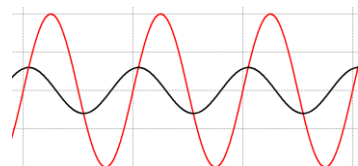
OUTPUT



Note that this is an inverting differentiator, in other words, the output is the negative of the gradient of the input.



TRIANGULAR WAVE INPUT



SINE WAVE INPUT

PRINCIPLE OF OPERATION

The current through a capacitor is given by $I_C = C \frac{dV_C}{dt}$, in other words the current is proportional to the rate-of-change of the voltage. For this circuit, the capacitor current is a function of the derivative (slope) of the input voltage V_{IN} as V_C is a function of V_{IN} . The output voltage from Ohm's Law is directly proportional to the current through the resistor and thus also a function of V_{IN} as $I_R = I_C$. The smaller the value of the RC time constant, the better the relationship between V_{OUT} and the slope of V_{IN} - otherwise some second order effects needs to be taken into account.

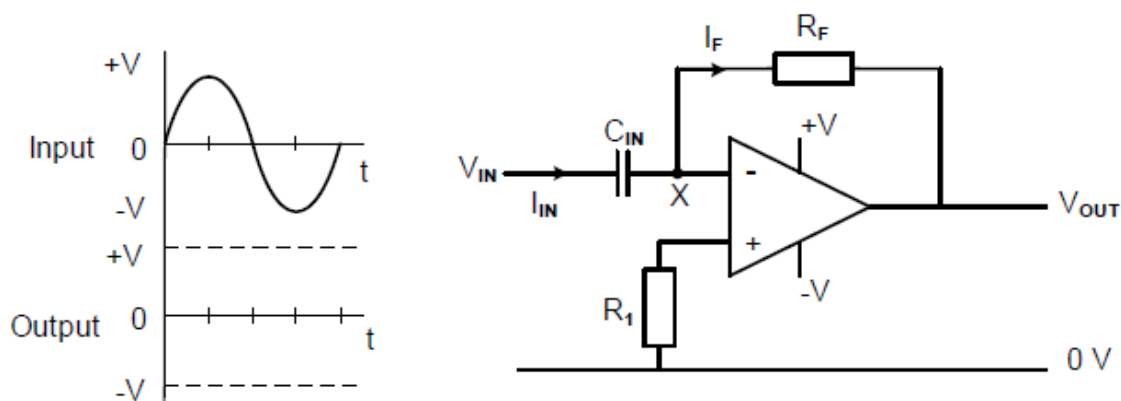
The current through the capacitor is directly proportional to the slope (gradient or rate of change) of the input voltage, V_{IN} . The current can be expressed as $I_C = C \frac{dV_C}{dt} = C \frac{dV_{IN}}{dt}$. The output voltage $V_{OUT} = -R_F I_C = -R_F C \frac{dV_{IN}}{dt}$ and thus the output voltage is directly proportional to the rate of change (or gradient) of the input voltage.

APPLICATIONS

Create short pulses to trigger electronic circuits, wave-shaping circuits, control circuits to regulate temperature, speed, and other process variables, high pass filter.

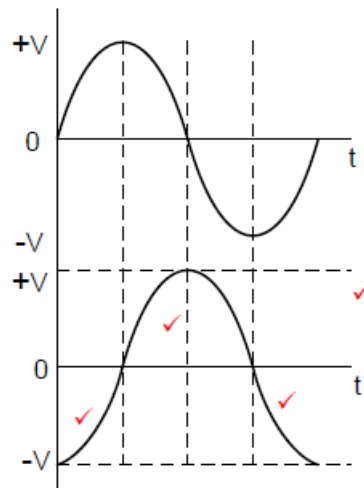
NSC QUESTION EXAMPLES

Refer to the diagram below and answer the questions that follow.



- State TWO advantages of changing a passive differentiator to an active differentiator.**
Improved input and output impedances
Improved gain
Improved stability
More correct output response to the rate-of-change of the input voltage
- State the purpose of R_1 :** R_1 serves to compensate for any input bias currents at the op amp inputs to ensure that $V_+ = V_-$ so that the output is zero when $V_{IN} = 0$, else the bias currents will cause an input voltage that will be amplified by the op amp which may distort the output signal.

3. Draw the output voltage.



TERMINOLOGY

Differentiation: Finding the gradient of a function mathematically. The result is the gradient of the function as a function of time.

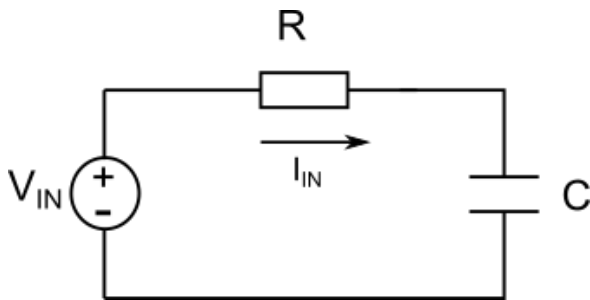
Rate-of-Change: The gradient of a curve

INTEGRATOR

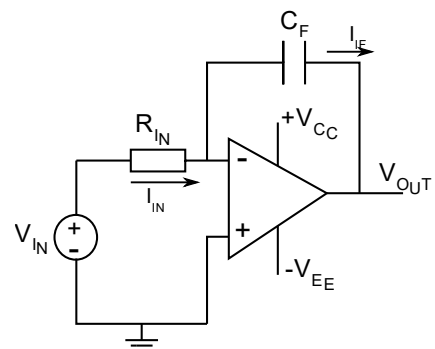
Integration is a fundamental mathematical operation that represents the process to compute the accumulation of quantities over time or the area under a curve.

CIRCUIT DIAGRAMS

PASSIVE



ACTIVE



IMPORTANT CONCEPTS

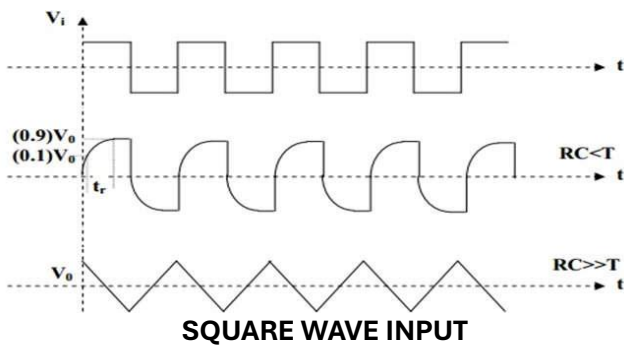
When a changing current $I = \frac{\Delta Q}{\Delta t}$ flows into a capacitor, it causes a change ΔQ in the charge stored on its plates. This change in charge alters the electric potential across the capacitor, resulting in a voltage change ΔV between its plates. The voltage across the capacitor is directly related to the amount of charge stored on its plates and the capacitance of the capacitor. When a current flow, more charge accumulate on the capacitor plates resulting in an increase in the potential difference across the plates.

Mathematically, this relationship is described by the capacitor equation: $V = \frac{Q}{C}$

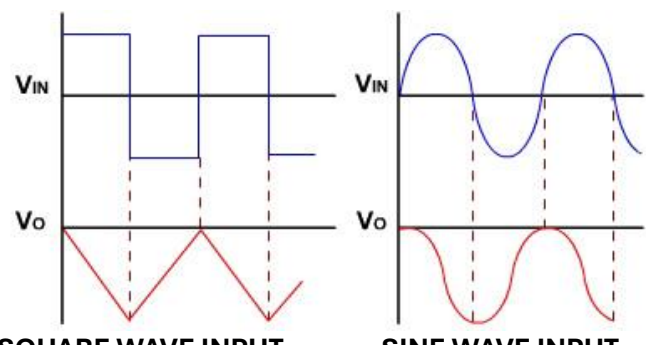
The voltage is thus proportional to the total charge on the capacitor plate, where the charge is deposited by the current. So if the current is 5A it means that 5C of charge is deposited every second. The voltage after 10s will thus be equal to $\frac{50}{C}$ volt. In other words, the voltage is equal to the area under the current curve divided by the capacitance, this is called integration. With current described by the equation $I = \frac{\Delta Q}{\Delta t} = C \frac{\Delta V}{\Delta t}$, voltage will be $\Delta V = \frac{1}{C} I \Delta t = \frac{1}{C} \Delta Q$ – the increase in voltage is proportional to the increase in the

charge, ΔQ in the time interval Δt . Mathematically, it is stated as $V = \frac{1}{C} \int I dt$ which states that the capacitor voltage is proportional to the integral of the current (area under the current curve).

TIMING DIAGRAMS

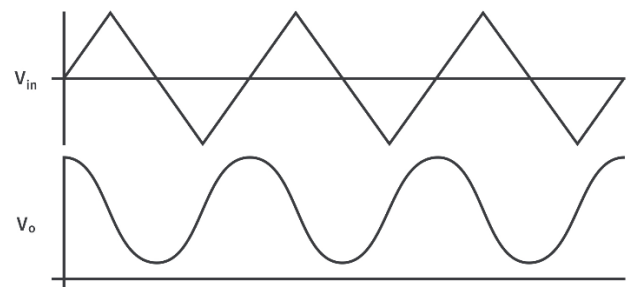


SQUARE WAVE INPUT



SQUARE WAVE INPUT

SINE WAVE INPUT



TRIANGULAR WAVE INPUT

PRINCIPLE OF OPERATION

The output voltage is equal to the capacitor voltage. The capacitor voltage is directly proportional to the charging current as it causes charge to accumulate on the capacitor plates. The charging current depends on the resistance R and the voltage across the capacitor, and thus changes as the capacitor charges.

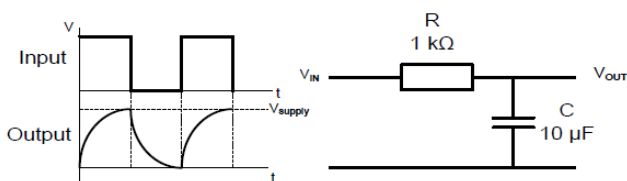
As the inverting input of the op-amp is at virtual ground due to the non-inverting input being at ground and negative feedback that minimise the difference between the two inputs, the current through R , $I_R = \frac{V_{IN}}{R}$ is directly proportional to the input voltage. This current $I_R = I_C$ is also the charging current of the capacitor. With $V_{OUT} = -V_C$, it results in $V_{OUT} = -\frac{1}{RC} \int V_{IN} dt$. The output voltage is thus directly proportional to the integral of the input voltage.

APPLICATIONS

Analog computers; Analog to Digital Converters; Analog signal conversion (modulators); Wave Shaping Circuits; Low pass filters.

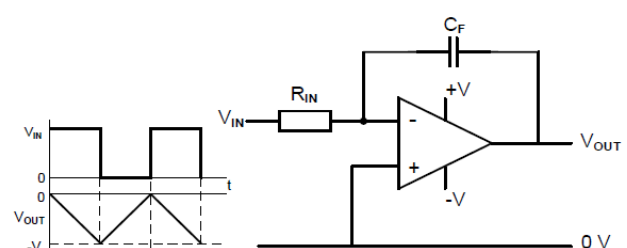
NSC QUESTION EXAMPLES

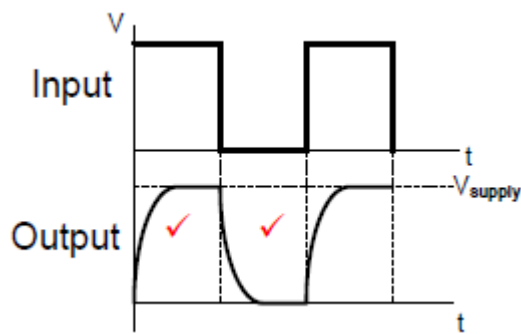
Refer to the diagram below and answer the questions that follow.



1. Draw the output when the value of C is changed to $1 \mu F$

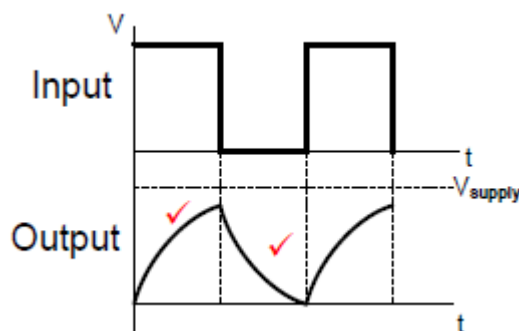
Refer to the diagram and answer the questions that follow.





The capacitor charges very fast to its final constant value due to the short time constant.

2. Draw the output when the value of C is changed to $100\ \mu\text{F}$



The output starts to look like a triangular wave, with a much lower amplitude than the input. The capacitor takes long to charge due to the long time constant, so that only the start of the charging curve is seen before the capacitor starts to discharge. If the value of C increased to an even larger value, eventually the output voltage will appear to be perfectly triangular, but with a very small amplitude.

1. State TWO factors that determine the output voltage of the circuit at any time.

How long the input voltage has been present.
The value of the input voltage.

The frequency

Value of the resistor and capacitor

The RC-time constant

The value of the supply voltage

2. Explain why capacitor C charges at a fixed linear rate towards $-V$ when a positive square wave is fed to the input.

Both inputs to the op amp are kept at 0 V due to negative feedback and the non-inverting input connected to ground. According to Ohm's law, when a constant positive voltage is applied across the input resistor it causes a constant fixed current to flow, which is fed via the virtual ground point to the capacitor, this means that the voltage on its right-hand plate will decrease at a fixed linear rate towards $-V$ as the current charges the capacitor.

3. Explain the effect of a long RC time constant on the output.

When the RC time constant is long, the capacitor will charge slowly causing the slope of the output to decrease. The output will change direction before reaching saturation.