20EC105
Linear Integrated Circuit Applications

Program Core

(Common to: B.Tech ECE & also its splns. AIML & IOT)

by

Dr. Vijaya Gunturu

Professor in ECE & The Director Extension Services

20EC105 LIC Course Objectives (COs)

1. Illustrate and analyze the basic principles and important characteristics of Linear ICs.
2. Design and develop solutions using Integrated Circuits for specific applications.
3. Elucidate and design the interfacing applications through ICs that promote health and well-being.

Linear Integrated Circuit Applications (LICAs)

Semester	Hours/Week			C	Marks		
	L	T	P/D		CIE	SEE	Total
III	2	-	2	3	60	40	100
Pre-requisite	20ES103 Analog Circuit Analysis						
Note	1. Vide the R22 Course structure is L:T:P/D:C :: 2 : 0 : 2 : 3 2. R22 Lab Integrated Course Academic regulations apply						

Module I: Introduction to ICs (05 Hrs.)

- Integrated circuits - basics, types, block diagram, Features & Characteristics: DC and AC Characteristics, Modes of operation. Illustrative Example Overview of ICs (OPAMP IC, Timer IC, Regulator ICs, ADCs, DACs)

LIC: Syllabus & Course Brief (continued)

Module II: Linear Applications of Op-Amp. (06 Hrs.)

- Introduction, Inverting and Non-Inverting OPAMPs, Adder, Subtractor, Integrator, Differentiator, Instrumentation amplifier, Voltage follower, V-I/ I-V Converters. Filters First Order and Second Order Active Low Pass Filters; An overview of Band Pass, Band Reject, All Pass Filters.

Module III:Non-Linear Applications of Op-Amp (04 Hrs.)

- S/H Circuits, Comparators, Schmitt triggers, Waveform generators, Precision Rectifiers, Clippers and Clampers

LIC: Syllabus & Course Brief (continued)

Module IV: Special Purpose ICs (05 Hrs.)

- 555 timer: Functional diagram, Multi vibrators- Astable and Mono stable operations, Illustrative applications; Voltage Regulator ICs – Basics, 78xx/79xx series ICs, 723 General purpose regulator.

Module V:D-A and A-D Converters (05 Hrs.)

- DAC – basics, Weighted Resistor type, R-2R Ladder type;
- ADCs- basics, Parallel Comparator Type, Successive Approximation Register Type; ADC and DAC specifications and applications

LIC Practical -Experiments List:

1. OPAMP Inverting Amplifier
2. OPAMP Non-Inverting Amplifier
3. OPAMP Adder
4. OPAMP Subtractor
5. OPAMP Integrator,
6. OPAMP Differentiator,
7. OPAMP Voltage follower,
8. OPAMP Comparators,
9. OPAMP Schmitt triggers,
10. OPAMP Precision Rectifiers (Half wave/ Full Wave)
11. IC 555/ OPAMP Astable Multivibrator
12. IC 555/ OPAMP Monostable Multivibrator
13. IC 78xx/79xx series or IC 723 Voltage Regulator

Linear Integrated Circuits: Learning Resources

TEXT BOOKS

1. D.Roy Choudhry, Shail Jain, Linear Integrated Circuits, New Age International Pvt. Ltd., 2021, Sixth Edition ISBN 978-8122472127.
2. Sergio Franco, -Design with Operational Amplifiers and Analog Integrated Circuits, 4th Edition, Tata Mc Graw-Hill, 2016

REFERENCE BOOKS

1. A. Ramakant A. Gayakwad, -Operational Amplifiers and Linear IC, 4th Edition, Prentice Hall / Pearson Education, 2015
2. B. S.Salivahanan & V.S. Kanchana Bhaskaran, -Linear Integrated Circuits, TMH,3rd Edition, 2018

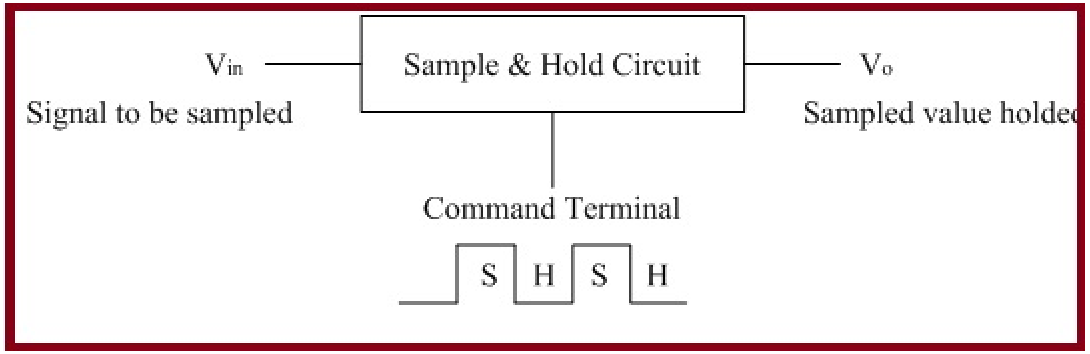
Useful Links

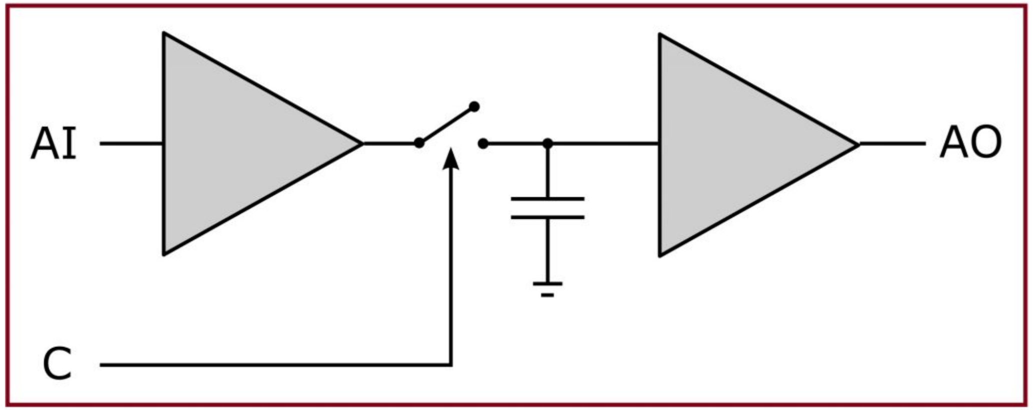
1. https://nptel.ac.in/courses/108/108/108108111/
2. https://nptel.ac.in/courses/117/107/117107094/
3. https://onlinecourses.nptel.ac.in/noc20_ee13/preview

M_III: Non-Linear Applications of Op-Amp

- S/H Circuits,
- Comparators,
- Schmitt triggers,
- Waveform generators,
- Precision Rectifiers,
- Clippers and Clampers

Sample and Hold (S/H) Circuits

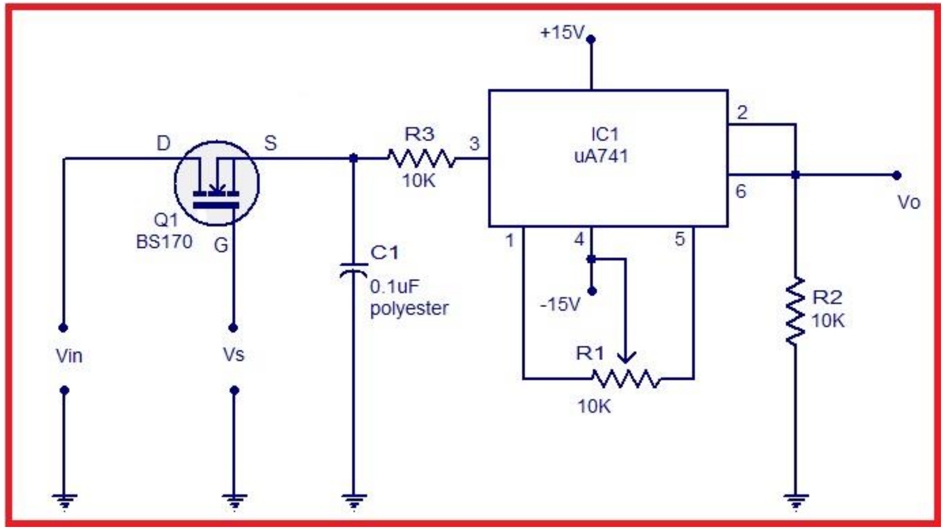


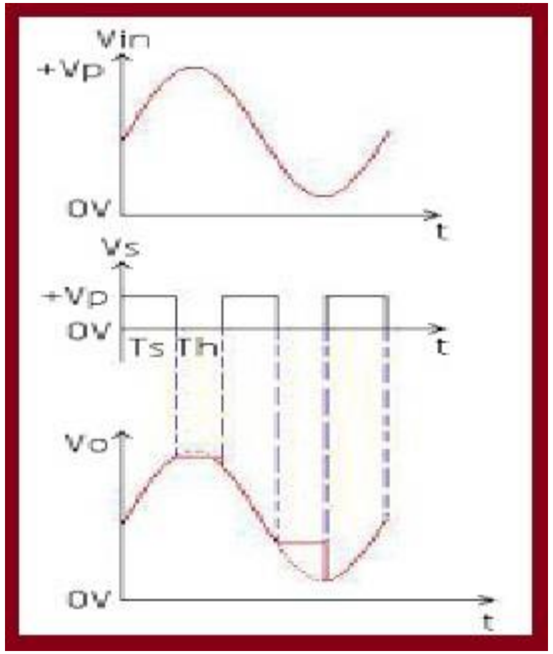


- a sample and hold circuit is one which samples an analog input signal and holds onto its last sampled value until the input is sampled again when singled by the command/control signal;
  - Generally, the sampling time is between 1µs-14 µs while the holding time is any value as necessary in the application
  - Holding of the sampled value is facilitates the circuit or system following the S/H to have the necessary time to process it.
- Sample and hold circuits are commonly used in: ADCs; DACs; communication circuits; PWM circuits and so on.
- The capacitor is the core of sample and hold circuit.

S/H Circuit & its Operation

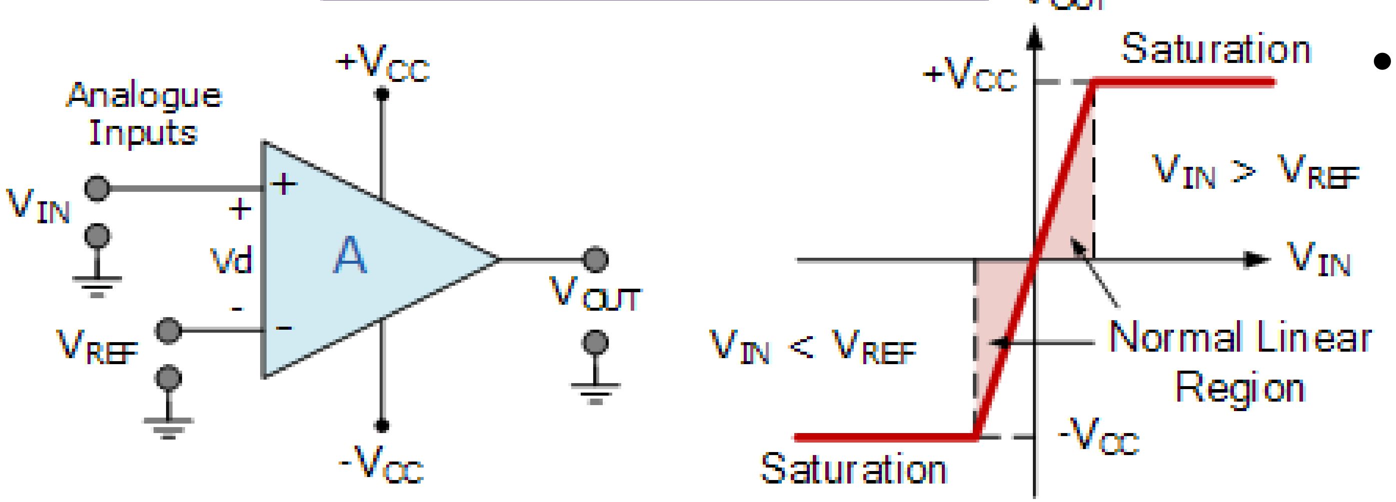
- the N-channel Enhancement MOSFET is used as a switch
  - ➢ The drain terminal receives input voltage (Vin) and
  - ➢ gate terminal receives control/ Command voltage (Vs)
  - ➢ When the control voltage
    - ✓ is +ve (part of the control pulse), the MOSFET will be in activated state as a closed switch;
    - ✓ otherwise the switch is open.
- Whenever switch is closed,
  - ➢ the analog input through its drain is fed to the capacitor; which, gets charged to it's peak value (the sample mode)
- When the switch is released (open),
  - ➢ then the capacitor discontinues charging; hence, due to the high input impedance op-amp, the capacitor will keep the charge & "v" as-is SINCE it cannot get discharged (the hold mode)





OPAMP Comparator

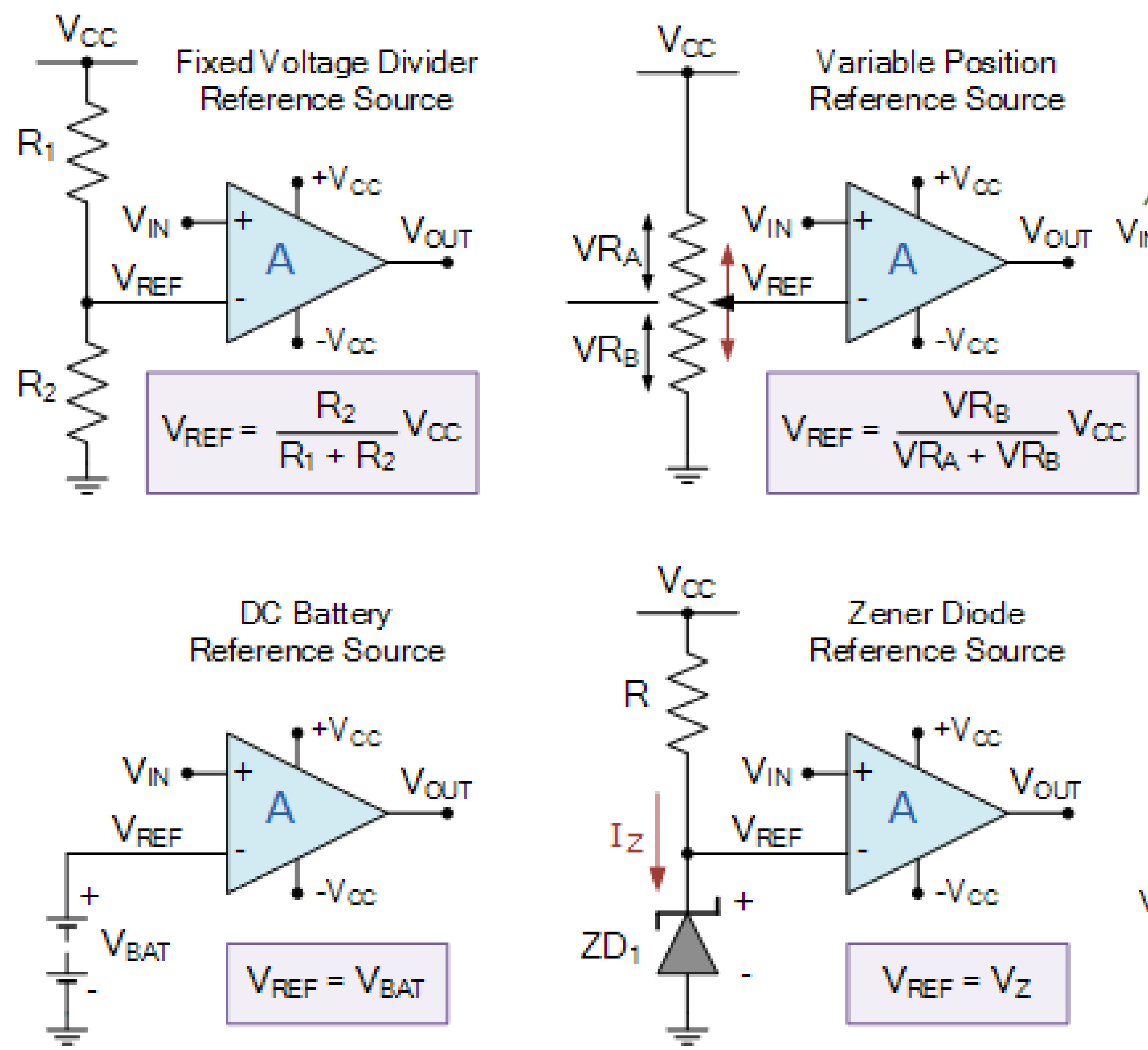
If $V_{IN} > V_{REF}$ then $V_{OUT} = +V_{CC}$
If $V_{IN} < V_{REF}$ then $V_{OUT} = -V_{CC}$



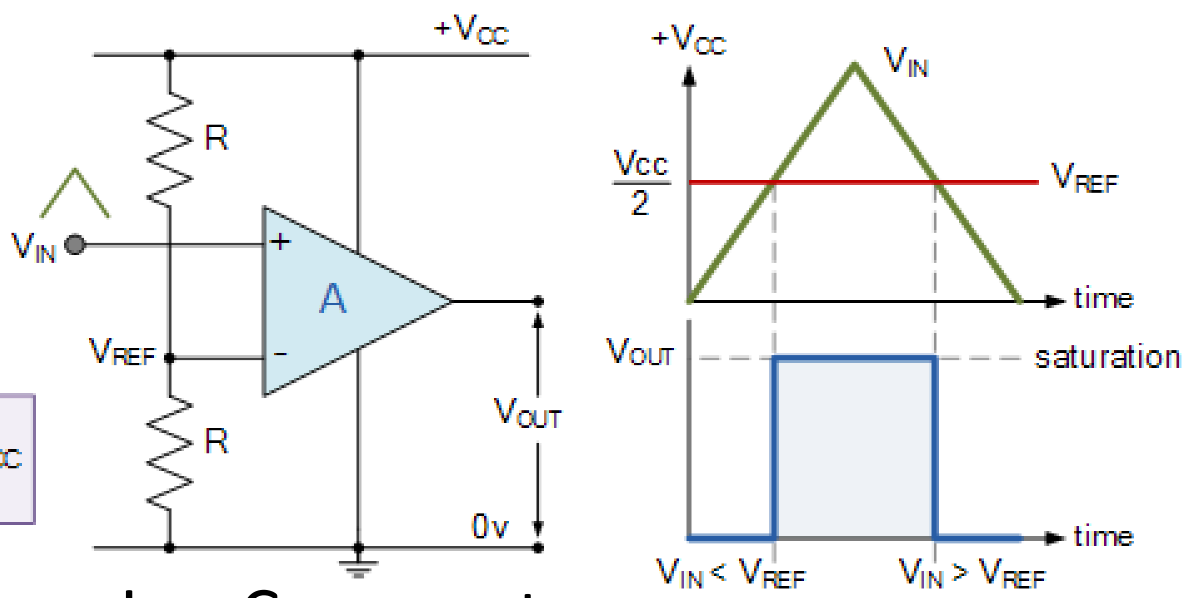
- As the non-inverting (positive) input V_{IN} of the comparator < the inverting (negative) input V_{REF}, the output will be LOW
- increase the input voltage, V_{IN} so that its value is greater than the reference voltage V_{REF} on the inverting input, the output voltage rapidly switches HIGH

- If the input voltage V_{IN} reduces again, once it is slightly < the reference voltage, V_{REF}, the OPAMP's output switches back to its negative saturation voltage ($-V_{CC}$) acting as <u>a threshold detector</u>

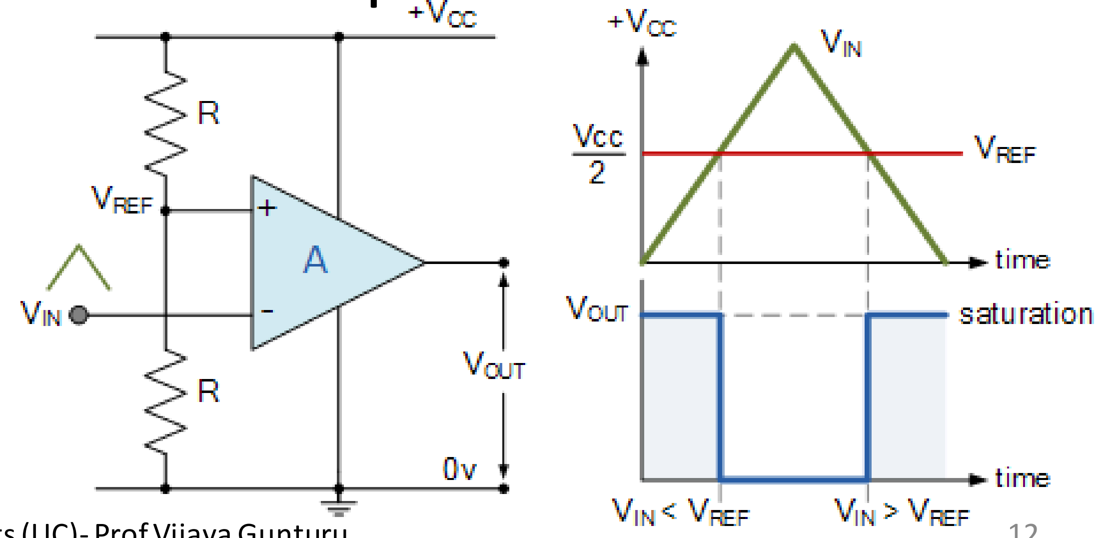
Comparator Reference Voltages



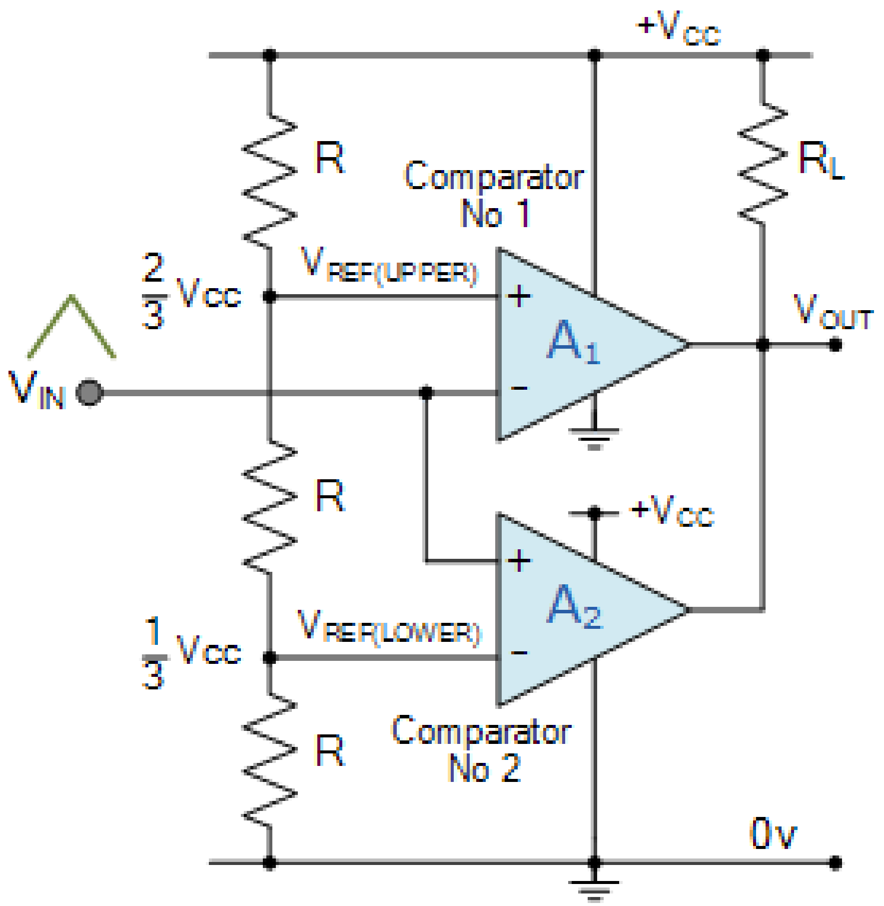
Non-Inv. Comparator

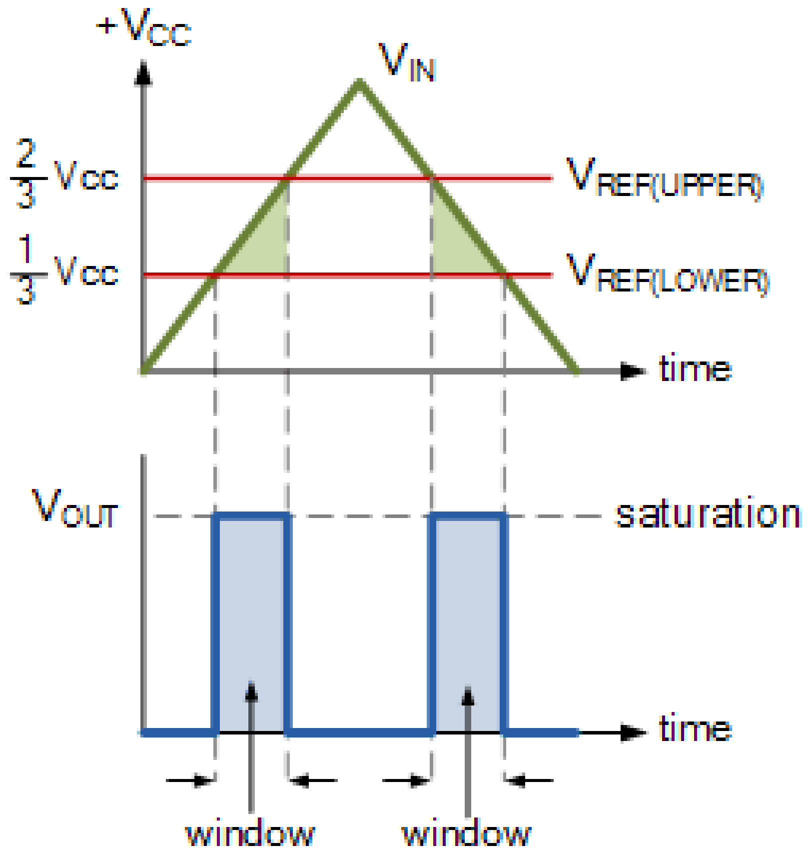


Inv. Comparator



Window Comparator

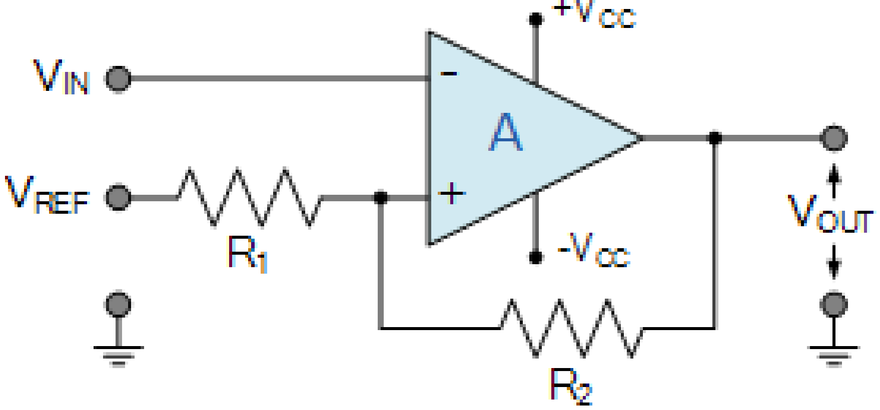


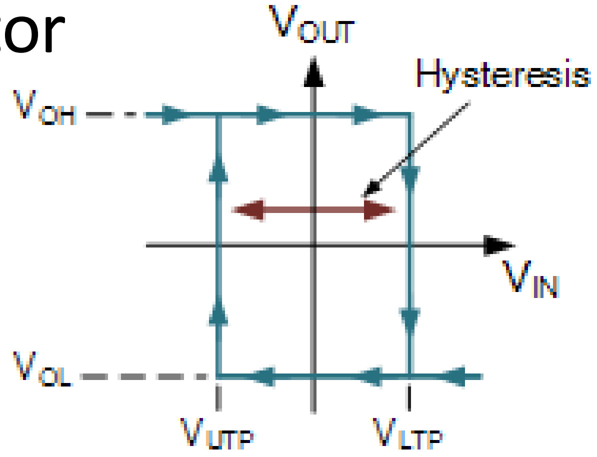


OPAMP Comparator with Positive Feedback

- operational amplifiers can be configured to operate as comparators in their open-loop mode, and this is fine if the input signal varies rapidly or is not too noisy.
- However if the input signal, V_{IN} is slow to change or electrical noise is present, then the op-amp comparator may oscillate switching its output back and forth between the two saturation states, +Vcc and -Vcc as the input signal hovers around the reference voltage, V_{REF} level.
- One way to overcome this problem and to avoid the op-amp from oscillating is to provide positive feedback around the comparator

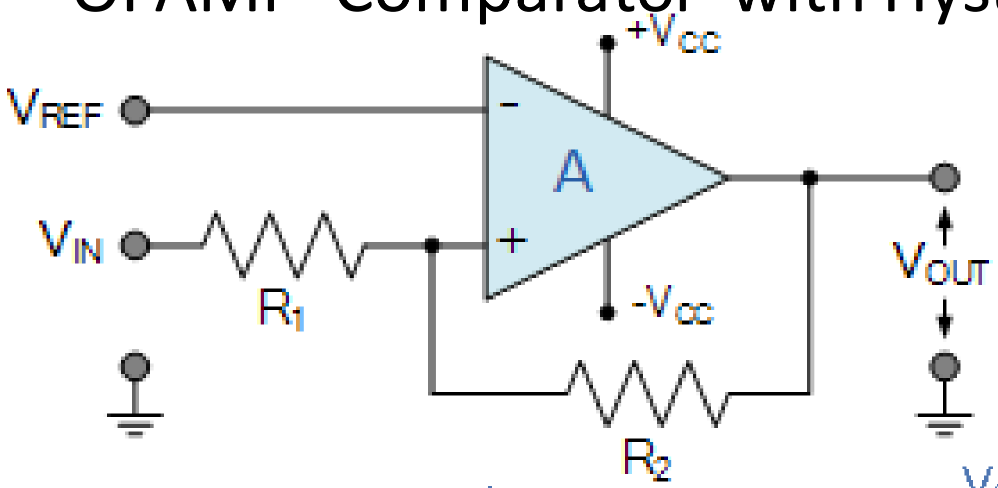
Inverting OPAMP Comparator

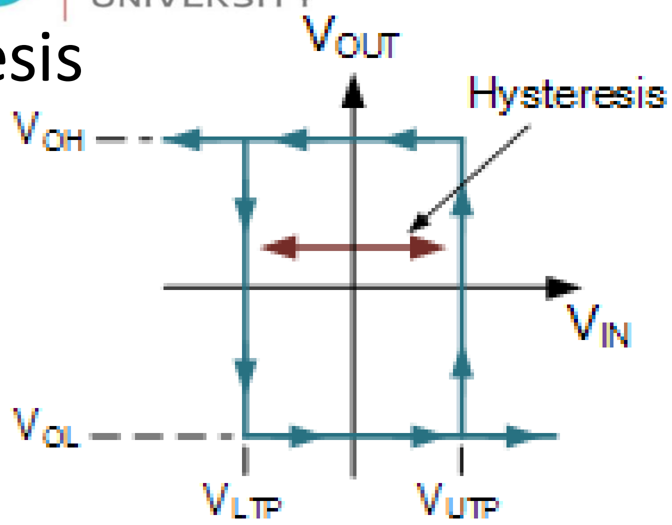




- The use of +ve feedback around an OPAMP comparator means that once the output is triggered into saturation at either level, there must be a significant change to the input signal V_{IN} before the output switches back to the original saturation point.
- This difference between the two switching points is called hysteresis producing what is commonly called a Schmitt trigger circuit.
- Consider the inverting comparator circuit shown

Non-inverting
OPAMP Comparator with Hysteresis





$$\beta = \frac{R_1}{R_1 + R_2} = \frac{10k\Omega}{10k\Omega + 90k\Omega} = 0.1$$

$$UTP = \left(\frac{R_1}{R_1 + R_2}\right)\times(+Vcc) = +\beta Vcc$$

$$\therefore\ UTP = 0.1\times(+10) = +1.0V$$

$$LTP = \left(\frac{R_1}{R_1 + R_2}\right)\times(-Vcc) = -\beta Vcc$$

$$\therefore\ LTP = 0.1\times(-10) = -1.0V$$

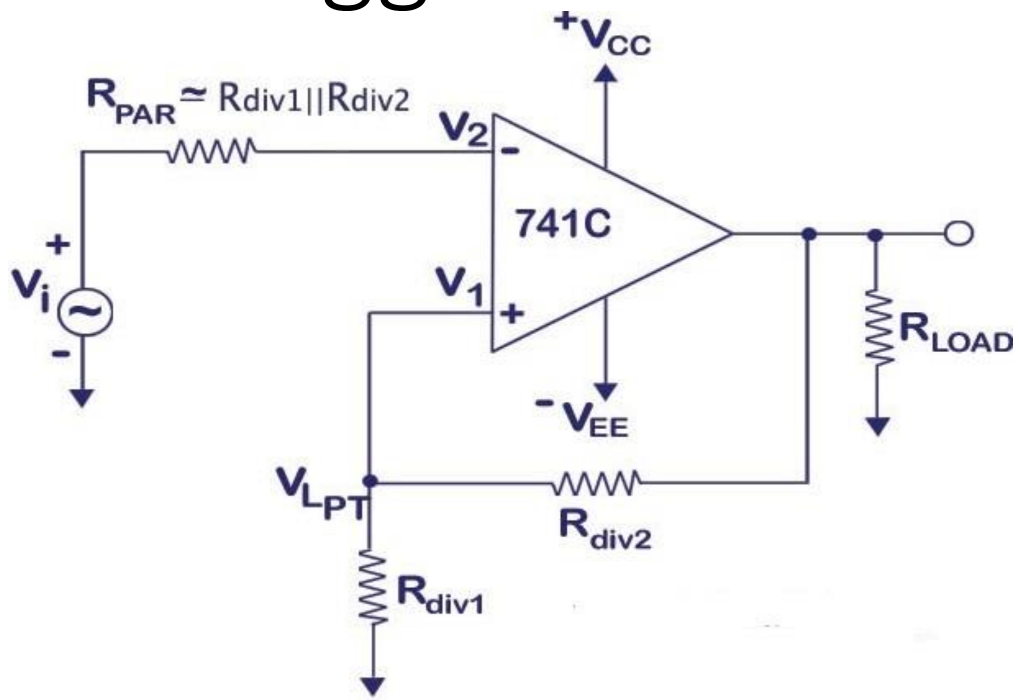
$$V_{(HYS)} = UTP - LTP$$

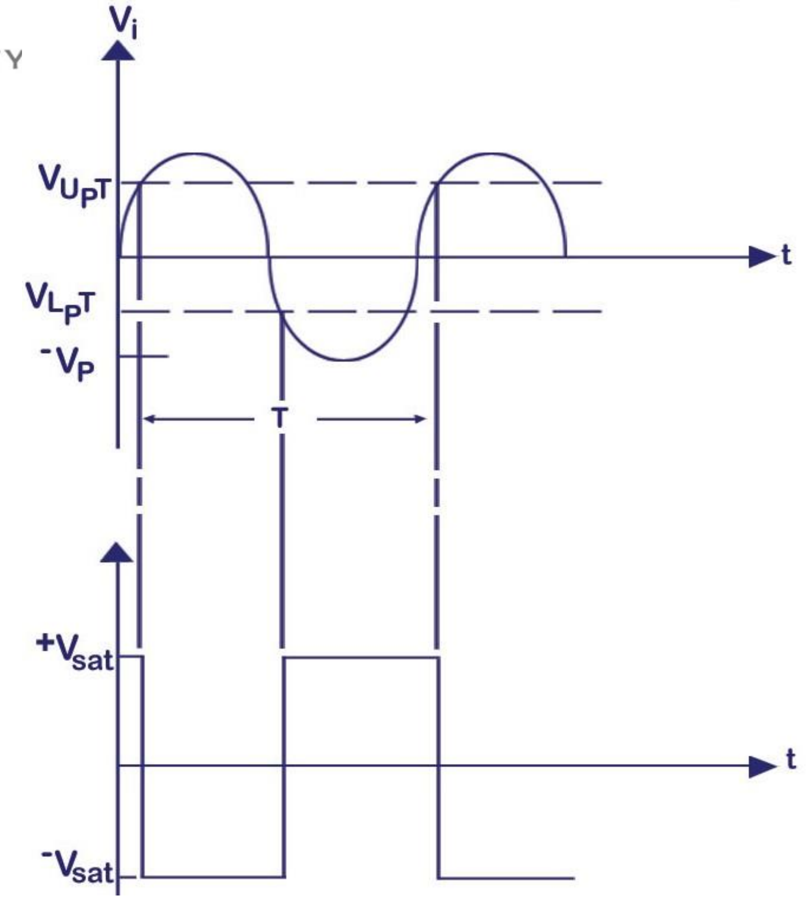
$$V_{(HYS)} = +\beta Vcc - (-\beta Vcc) = 1.0V - (-1.0V) = 2.0V$$

$$\text{also: } V_{(HYS)} = 2\beta Vcc = 2\times 0.1\times 10 = 2.0V$$

- The LM324 OPAMP IC can be worked as a comparator.
  - ➢ It has 4 independent operational amplifiers on a single chip.
  - ➢ It's a Low Power Quad OPAMP and it has
    - ✓ high stability, bandwidth and was designed to operate from a single power supply over a wide range of voltages

Schmitt Trigger



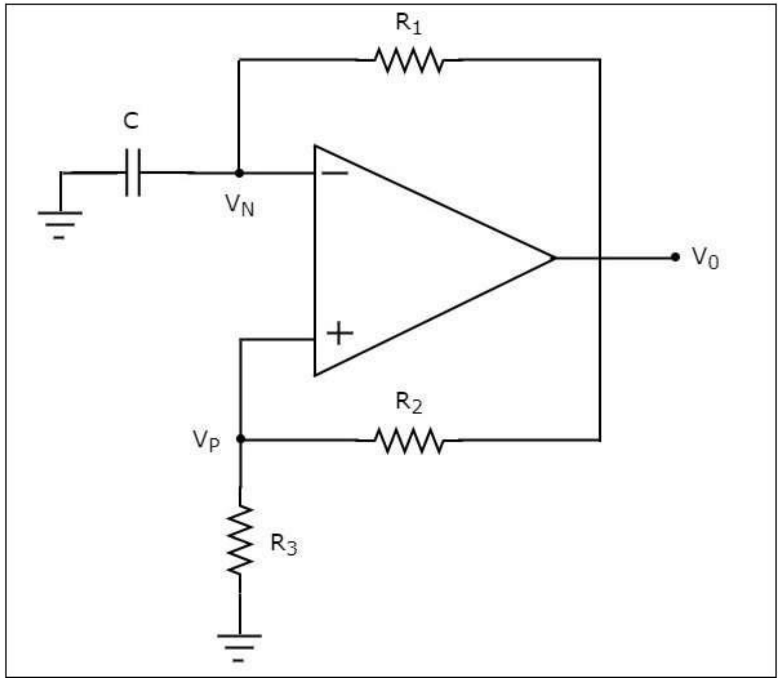


- Regenerative comparator circuit
- removes the difficulties in a zero-crossing detector circuit due to low frequency signals and input noise voltages
- It is basically an inverting comparator circuit with a positive feedback
- The purpose of the Schmitt trigger is to convert any regular or irregular shaped input waveform into a square wave output voltage or pulse. Thus, it can also be called a squaring circuit

Operation of Schmitt Trigger

- a voltage divider with resistors Rdiv1 and Rdiv2 is set in the positive feedback of the 741 IC op-amp.
- The same values of Rdiv1 and Rdiv2 are used to get the resistance value Rpar = Rdiv1||Rdiv2 which is connected in series with the input voltage.
- Rpar is used to minimize the offset problems. The voltage across R1 is fedback to the non-inverting input.
- The input voltage V_i triggers or changes the state of output V_{out} every time it exceeds its voltage levels above a certain threshold value called Upper Threshold Voltage (V_{upt}) and Lower Threshold Voltage (V_{lpt})

Square wave generator

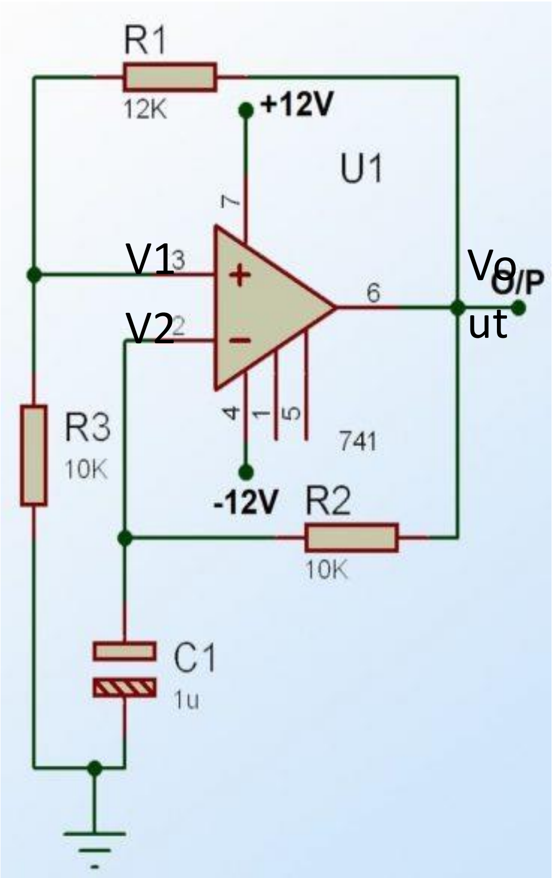


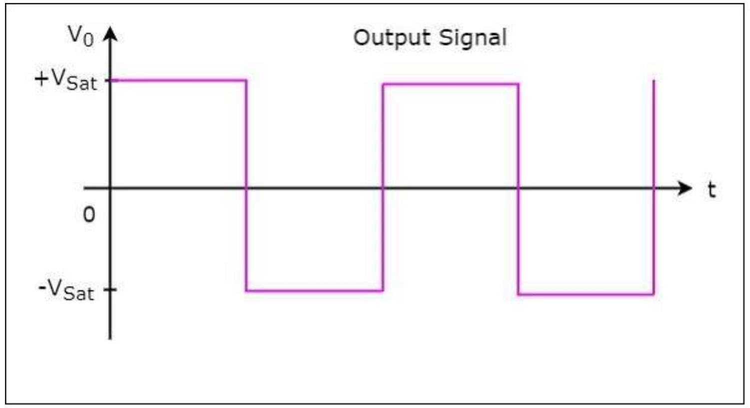
- in the circuit diagram shown, the resistor R1 is connected between the inverting input terminal of the op-amp and its output of op-amp. So, the resistor R1 is used in the negative feedback.
- Similarly, the resistor R2 is connected between the noninverting input terminal of the op-amp and its output. So, the resistor R2 is used in the positive feedback path.
- A capacitor C is connected between the inverting input terminal of the op-amp and ground. So, the voltage across capacitor C will be the input voltage at this inverting terminal of op-amp.
- Similarly, a resistor R3 is connected between the non-inverting input terminal of the op-amp and ground. So, the voltage across resistor R3 will be the input voltage at this non-inverting terminal of the op-amp

- Assume, there is no charge stored in the capacitor initially. Then, the voltage present at the inverting terminal of the op-amp is zero volts. But, there is some offset voltage at non-inverting terminal of op-amp. Due to this, the value present at the output of above circuit will be +Vsat Now, the capacitor C starts charging through a resistor R1. The value present at the output of the above circuit will change to −Vsat , when the voltage across the capacitor C reaches just greater than the voltage (positive value) across resistor R3
- The capacitor C starts discharging through a resistor R1 , when the output of above circuit is −Vsat . The value present at the output of above circuit will change to +Vsat ,when the voltage across capacitor C reaches just less than (more negative) the voltage (negative value) across resistor R3.

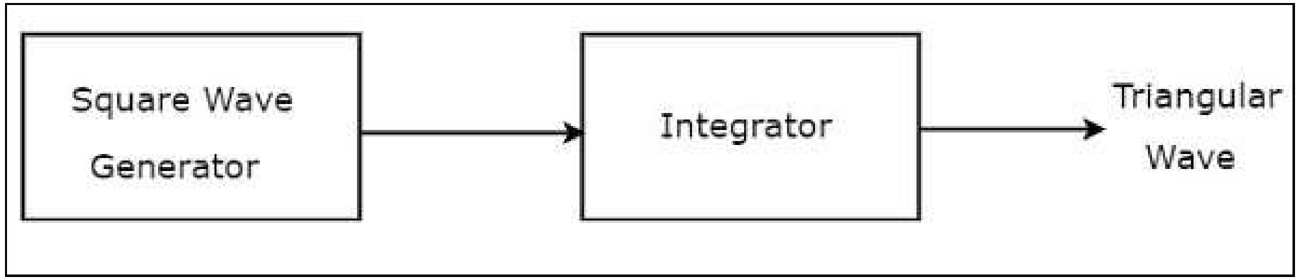
Square Wave Generator

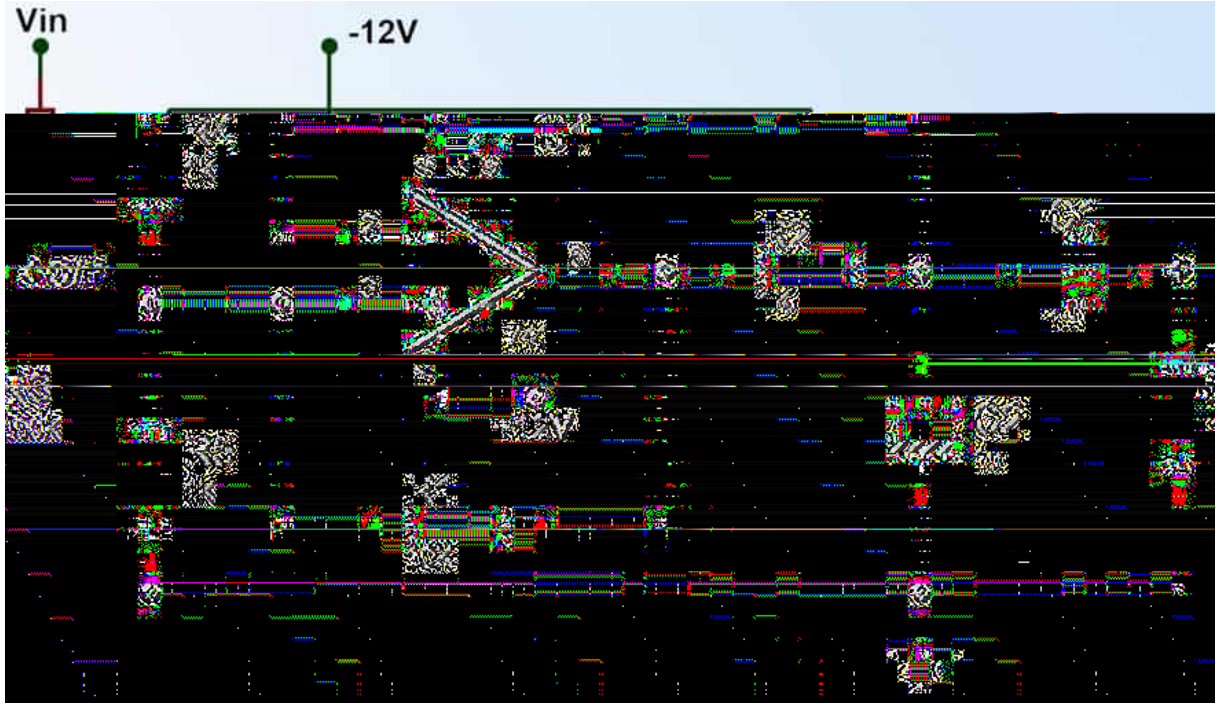
- At the initial state when the capacitor is fully discharged, the voltage V_2 = zero; so, $(V_{in}) = V_1 - V_2$;
- When V_{in} is +ve the output is also positive & the capacitor starts to charge through resistor R_2 towards positive saturation voltage until $V_1 = V_2$;
- When the voltage at the capacitor (V_2) increases slightly more than the differential voltage V_1; Negative $V_{in} = V_1 - V_2$ ($V_2 > V_1$); so, Then the output will be switched from positive saturation voltage to negative saturation voltage.
  - Thus, capacitor starts to discharge now through resistor R_2 because V_2 becomes greater than V_{out}
- Again, after reaching V_2 slightly less than V_1 the output will again switch to positive saturation voltage.
- This process repeats again and again as a result square wave is generated





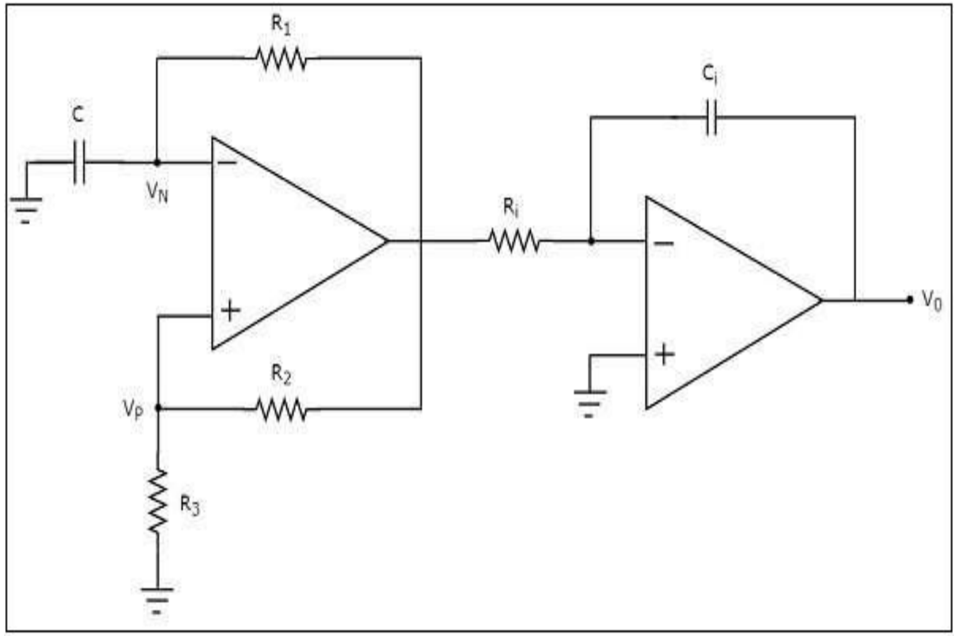
Triangular wave Generator



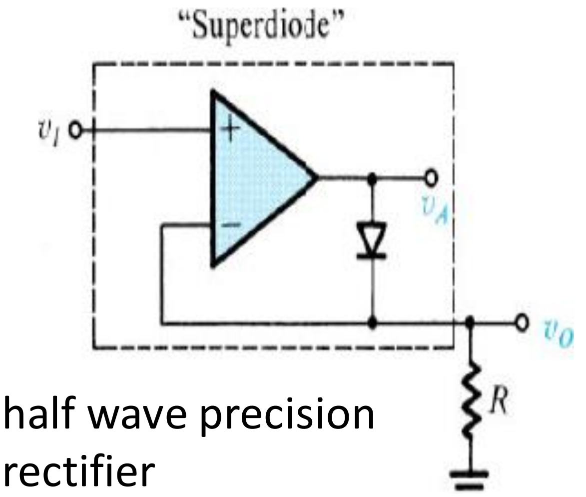


- assume that the capacitor is discharged. This makes the inverting input terminal at a voltage lower compared to the non-inverting input terminal; half the Vsupply from the resistor divider network
- The output will go high till the capacitor voltage goes above half Vsupply. At this point, the voltage at the inverting input is greater than the non-inverting input.
- Afterward, the output will go low and discharge the capacitor.
- Simultaneously, the 10K resistor acts as hysteresis.
- When the output goes low, the voltage divider has a 1K and a 10K in parallel, which decreases the overall resistance and reduces the reference (Vref) voltage.
- The values of the hysteresis resistor which is 10K and the resistor divider network both can be changed to increase or decrease the frequency

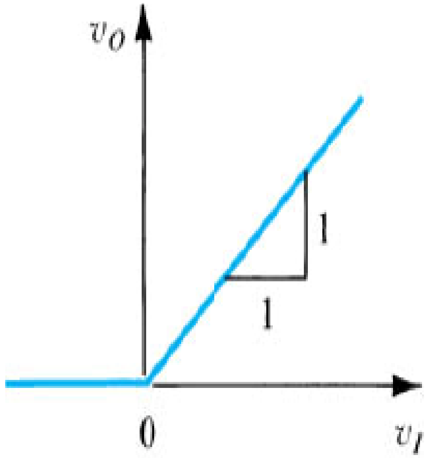
Triangular wave generator



Precision Rectifiers

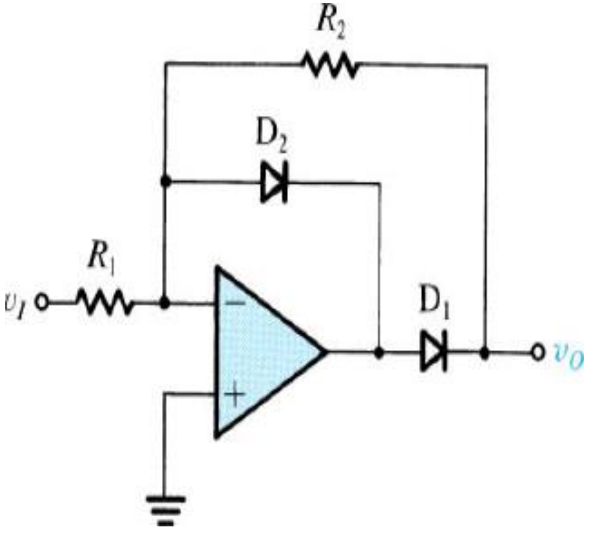


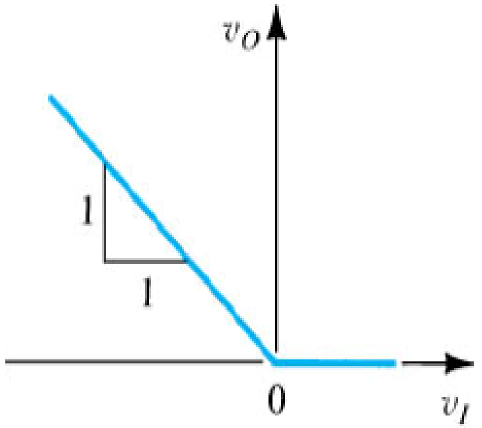
half wave precision rectifier



- Super Diode concept: diode in the feedback loop effectively cancels the forward voltage drop of the diode; thus, making the cut-in voltage to be too low or zero.
- Limitations: Low Speed;
- the inverting input follows the positive half of the input signal almost perfectly; When the input signal becomes negative, the op amp has no feedback at all, so the output pin of the op amp swings negative as far as it can.
- When the input signal becomes positive again, the op amp's output voltage will take a finite time to swing back to zero

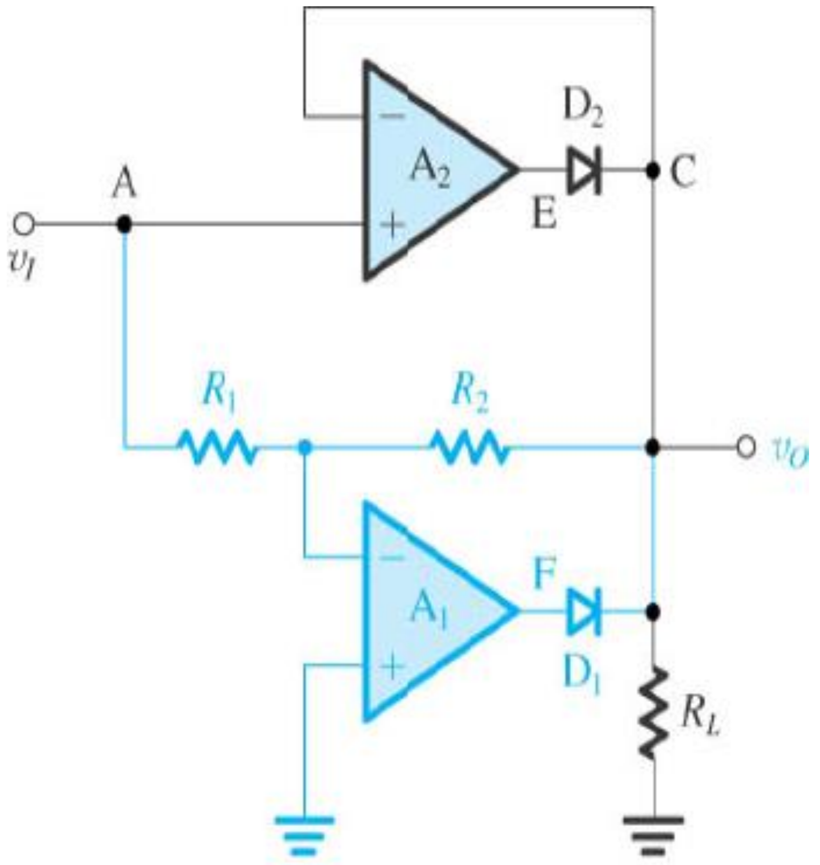
Precision Rectifier (continued)

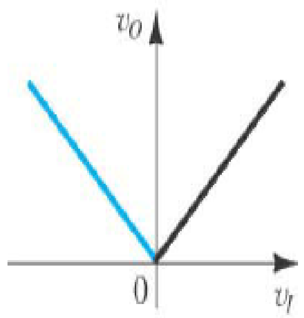


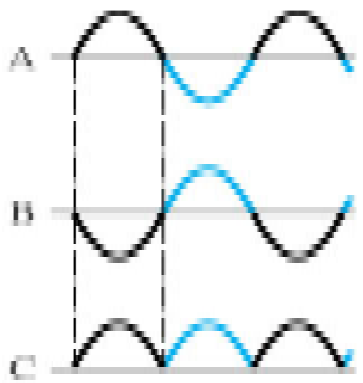


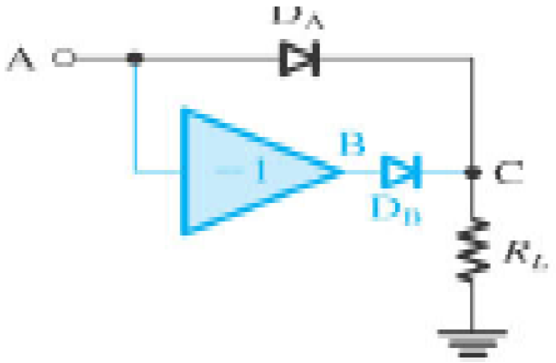
- The circuit accepts an incoming waveform & inverts it.
  - However, only the positive-going portions of the output waveform, which correspond to the negative-going portions of the input signal, actually reach the output.
- The direct feedback diode shunts any negative-going output back to the "-" input directly, preventing it from being reproduced. The slight voltage drop across the diode itself is blocked from the output by the second diode.
- D1 allows positive-going output voltage to reach the output.

Precision Rectifier – Full wave







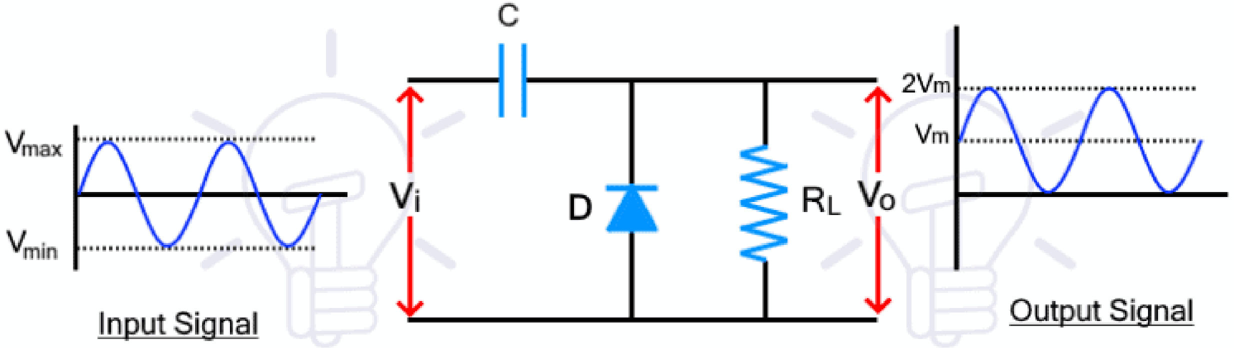


- LHS the basic circuit: Replace DA with a super-diode and the diode DB and the inverting amplifier with the inverting precision half-wave rectifier to get the precision full wave rectifier in the following page

Clippers and Clampers

- A clipper is an electronic circuit that produces an output by removing a part of the input above or below a reference value
- Applications: Wave shaping circuits are commonly employ clipping and clamping and they are used
  - ➢ in digital computers and
  - ➢ In communication such as TV and FM receiver
- The diode works as an ideal diode (switch) because
  - ➢ when ON, the voltage drop across the diode is divided by the open loop gain of the op-amp;
  - ➢ When off (reverse biased) the diode is an open circuit.
- In an op-amp clamper circuits, however a predetermined dc level is deliberately inserted in the o/p volt.
  - ➢ the clamper is sometimes also called as a dc inverter

Diode Clampers (without use of OPAMP)



Positive Clamper

- In a positive clamper circuit, the input waveform is shifted upward above the 0v reference line.

  During the positive half cycle, the diode is reverse biased; therefore, the input signal appears at the output as it is.

  - At this point, the capacitor is not charged and
  - there is no clamping. Therefore, the output at this half cycle is not considered.

- During the next negative half cycle, the diode becomes forward biased and it starts to conduct, at this half cycle, the capacitor charges up to the peak input voltage VM with inverse polarity.
- During the next positive half cycle, the diode is reverse biased and it does not conduct. Due to this, the capacitor starts to discharge. The capacitor discharge adds to the input signal which appears at the output as the summation of both voltages which reaches up to 2VM. This is how the signal level is shifted above the 0v line.
- Biased positive clamper: a voltage source is employed to further shift the input signal waveform. the positive biasing further shifts up the waveform while the negative biasing lower down the waveform by the amount of the biasing voltage

Clippers: Positive or Negative

- Positive Clipper

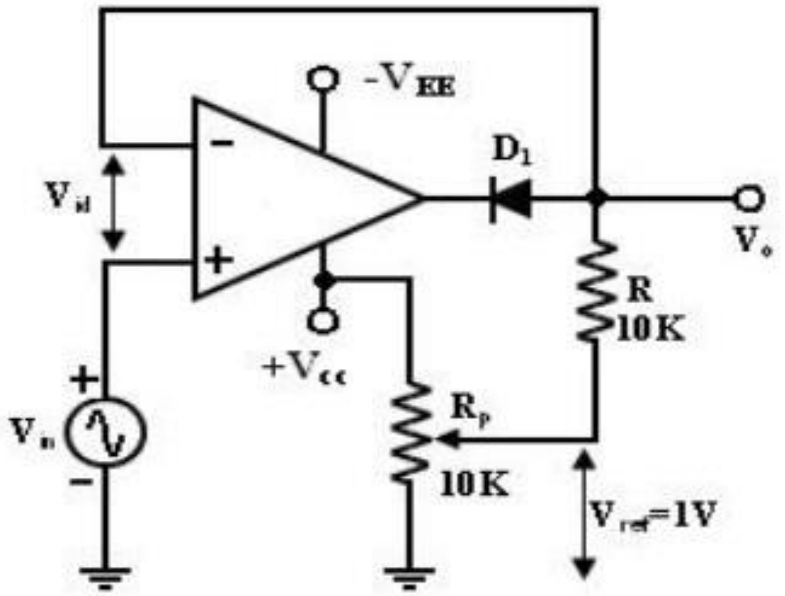


Fig. 2.44 Positive Clipper

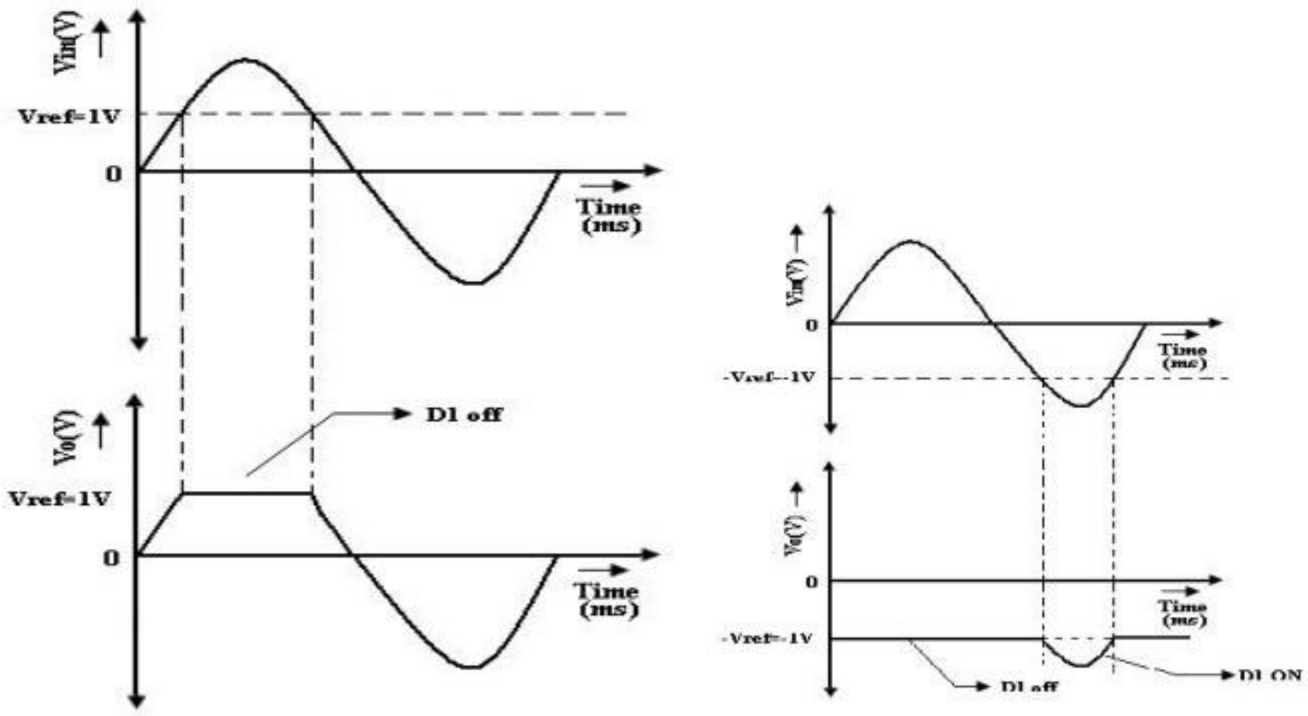


Fig 2.45 Positive clipper input output waveforms

Clampers

- Positive and Negative clampers
  - First consider the input voltage Vref at the positive input.
  - Since this voltage is positive Vo is also positive, which forward biases the diode D1 (indicated with, R_F). This closes the feedback loop and the opamp operates as a voltage follower.
  - This is possible because C_1 is an open circuit for dc voltage. Therefore, Vo=+Vref.
  - As far as voltage V_{in} at the negative input is concerned, during its negative half cycle, diode D1 conducts, charging C_1 to the negative peak value of Vp.
  - However, during the positive half cycle of V_{in} diode D_1 is reverse biased; hence, the voltage Vp across the capacitor acquired during the negative half cycle is retained.
  - Since this voltage Vp is in series with the positive peak voltage Vp, the output voltage Vo=2Vp.

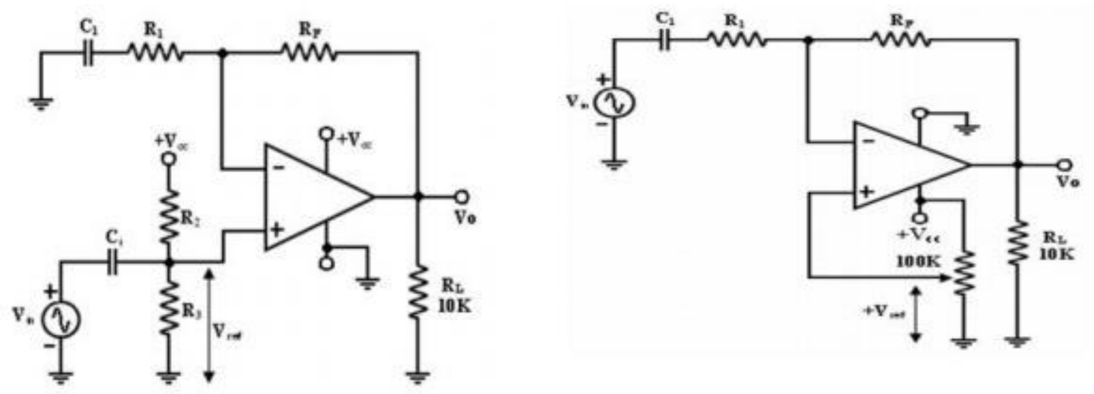


Fig.2.48 Positive –Negative campers

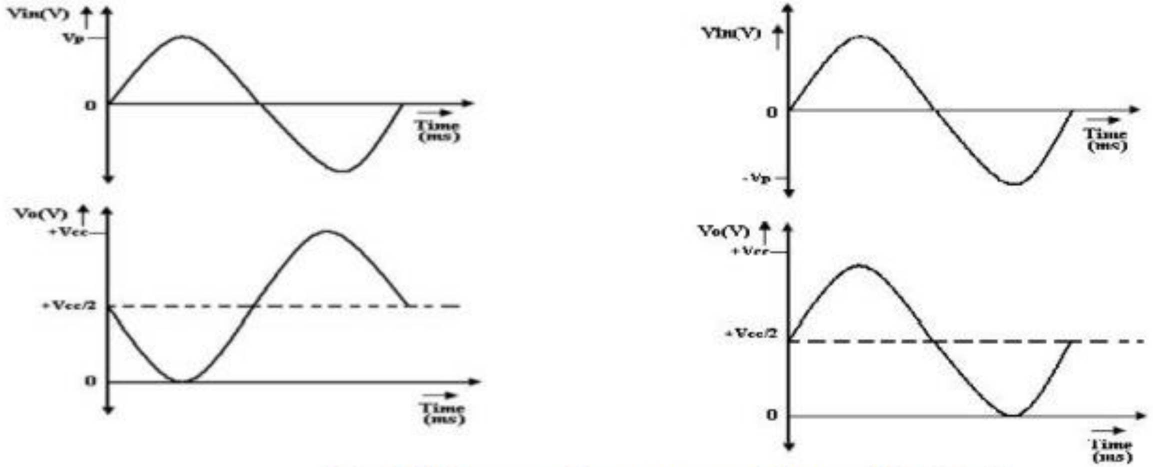
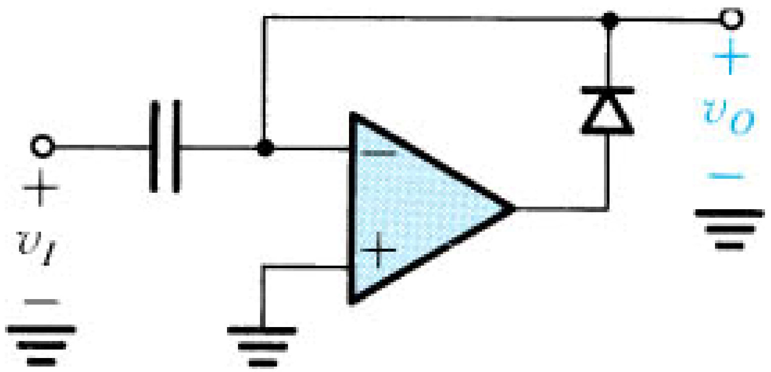


Fig.2.49 Input and output waveform with +Vref

Precision Clamping Circuit



- By replacing the diode in the usual clamping circuit with a superdiode the precision clamp is obtained.

Additional References

- https://circuitdigest.com/tutorial/frequency-compensation-of-op-amp
- Comparators:
  - https://www.electronics-tutorials.ws/opamp/op-amp-comparator.html
- Waveform Generators
  - https://www.tutorialspoint.com/linear_integrated_circuits_applications/linear_integrated_circuits_applications_waveform_generators.htm
- Clippers and Clampers using OPAMP
  - https://www.brainkart.com/article/Clipper-and-clipper-using-Operational-Amplifier_36014/
- Unit III Practice Problems/ Questions
- https://www.brainkart.com/article/Important-Questions-and-Answers--Linear-Integrated-Circuits---Applications-of-Operational-Amplifier_36017/