EXPERIMENT – 2.2
NON-LINEAR OP-AMP CIRCUITS

2.2.1 OBJECTIVE

a. To study the operation of 741 op-amp as *comparator*.

b. To study the operation of *active diode* circuits (*precisions circuits*) using op-amps, such as *half-wave rectifier, clipper, clamper* and *peak detector circuits*.

2.2.2 HARDWARE REQUIRED

a. Power supply : Dual variable regulated low voltage DC source

b. Equipments : AFO, CRO and DMM

c. Resistors :

d. Capacitors :

e. Semiconductor : Diode 1N4002 and op-amp μA741

f. Miscellaneous : Bread board and wires

2.2.3 PRE-LAB QUESTIONS

1. A certain op-amp has an open-loop gain of 200,000. The maximum saturated output levels of this particular device are $\pm$ 14V when the dc supply voltages are $\pm$15V. If a differential voltage of 0.5m V_{rms} is applied between the inputs, what is the peak-to-peak value of the output?

2. Sketch the output voltage waveform for each circuit in fig.(a) with respect to the input. Show voltage levels. Assume the maximum output levels of the op-amp are $\pm$12V.

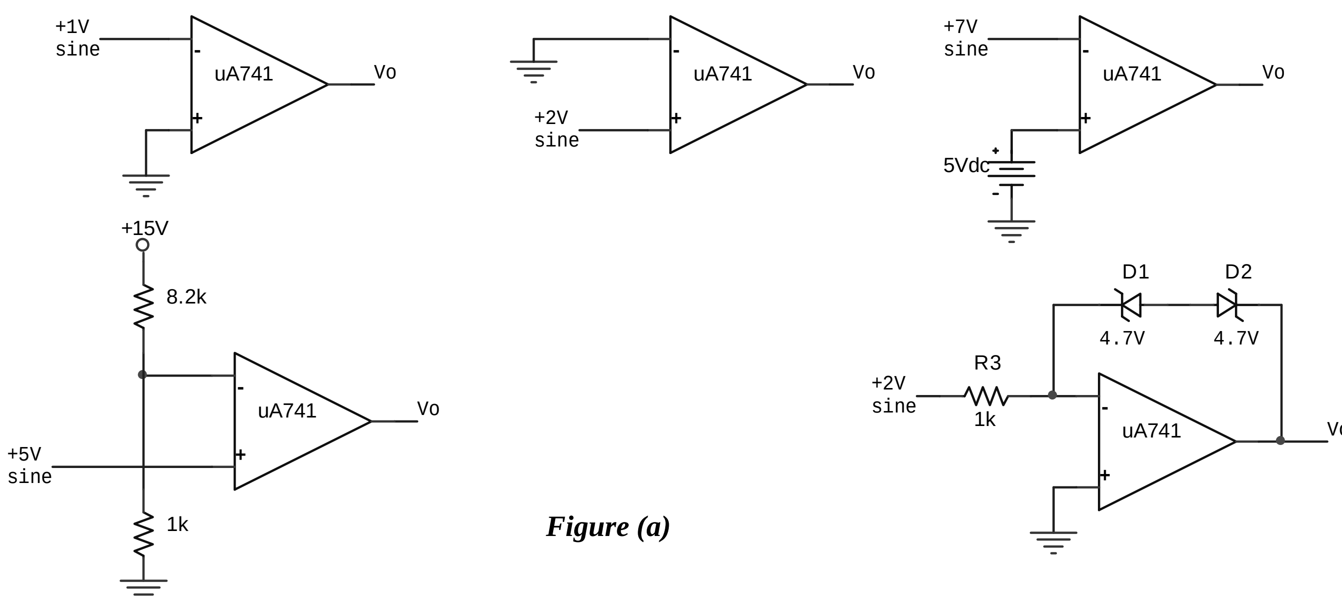


Figure (a)

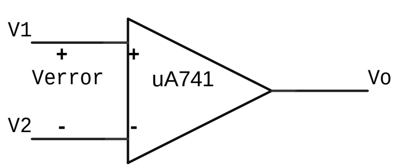
3. For a positive clipper circuit, draw the output waveform if V_{in} is a $5V_P$ sine wave at 100Hz and $V_{ref} = +2V$.
4. For a negative clipper circuit, draw the output waveform if V_{in} is a $5V_P$ sine wave at 100Hz and $V_{ref} = -2V$.
5. For a precision HWR, draw the output waveform if V_{in} is a 300mV peak sine wave at 1KHz.
6. For the peak clamper circuit, draw the output voltage wave form if $V_{in} = 50mV_{PP}$ sine wave at 1000 Hz and (a) $V_{ref} = 25mV$. (b) $V_{ref} = -25mV$.

2.2.4 THEORY

The use of op-amps can improve the performance of a wide variety of signal processing circuits. In rectifier circuits, the cut-in voltage drop that occurs with an ordinary semiconductor diode can be eliminated to give precision rectification waveforms can be limited and clamped at precise levels when op-amps are employed in clipping and clamping circuits. The error with peak detectors can also be minimized by the use of the op-amps.

2.2.4.1 Comparator

The simplest way to use an op-amp is open loop (no feedback resistors), as shown in figure 2-2-1(a). Because of the high gain of the op-amp, the slightest error voltage (typically in μV) produced maximum output swing. For instance, when V_1 is greater than V_2, the error voltage is positive and the output voltage goes to its maximum positive value ($+V_{sat}$), typically 1 to 2V less than the supply voltage. On the other hand, if V_1 is less than V_2, the output voltage swings to its maximum negative value ($-V_{sat}$).



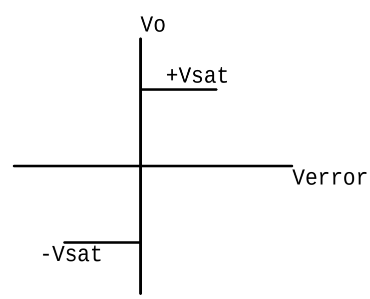


Fig 2-2-1(a) *Comparator* *(b) input/output characteristics*

Fig. 2-2-1 (b) summarizes the action. A positive error voltage drives the output to $+V_{sat}$. A negative error voltage produces $-V_{sat}$ when an op-amp is used like this, it is called a comparator because all it can do is compare V_1 to V_2, producing a saturated positive or negative output, depending on whether V_1 is greater or less than V_2.

Basic comparator

A comparator, as its name implies, compares a signal voltage on one input of op-amp with a known voltage called the reference voltage on the other input. Fig. 2-2-2 (a) shows an op-amp comparator used as a *voltage level detector*.

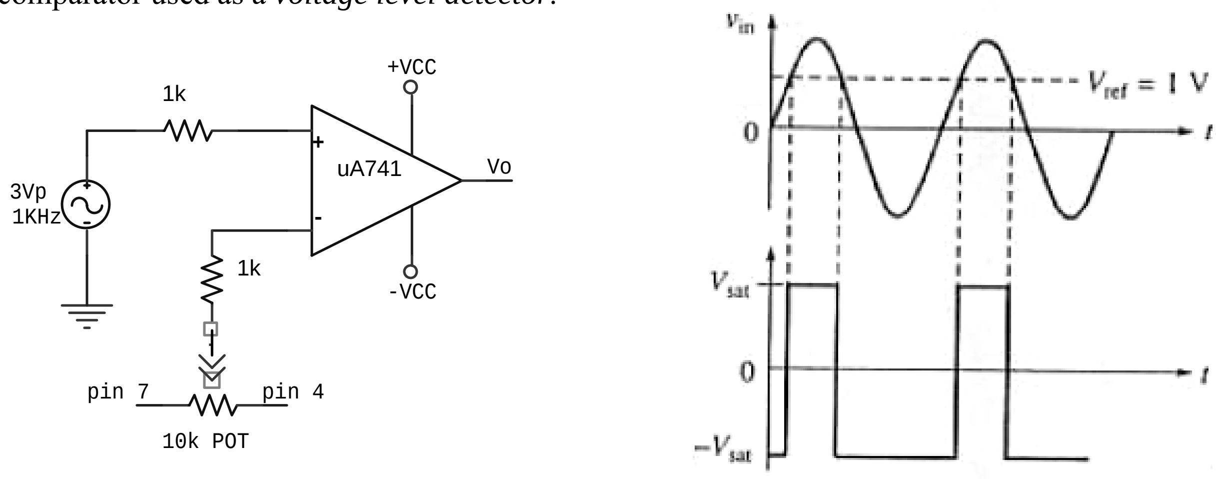


Fig 2-2-2(a) *Basic non-inverting comparator, (b) input and output waveforms*

Let us say that a fixed reference voltage V_{ref} of +1V is applied to the inverting input and the other time varying signal voltage V_{in} is applied to the non-inverting input. Because of this arrangement, the circuit is of non-inverting type. When V_{in} is less than V_{ref}, the output voltage V_O is $-V_{sat}$ because the voltage at the inverting input is higher than V_{in} is greater than non-inverting input. On the other hand, when V_{in} is greater than V_{ref}, Vo goes to $+V_{sat}$. This V_O changes from one level to another level whenever $V_{in} = V_{ref}$ as shown in fig. 2.2.2 (b). At any given time, the circuit shows whether V_{in} is greater than or less than V_{ref}. The circuit is hence called a *Voltage level detector*.

Use of comparators

The comparators are interface circuits between analog and digital domains, converting a continuous linear analog signal into a two-state digital signal. Comparators are used in circuits such as

- Digital interfacing
- Schmitt triggers
- Discriminators
- Voltage level detectors
- Oscillators, etc.

2-2-4-2 Active half wave rectifier

Op-amps can enhance the performance of diode circuits. For one thing, the op-amp can eliminate the effect of diode offset voltage, allowing us to rectify, peak-detect, clip, and clamp low-level signals (those with amplitudes smaller than the offset voltage). And because of their buffering action op-amps can eliminate the effects of source and load on diode circuits. Circuits that combine op-amps and diodes are called active diode circuits. Fig. 2-2-3 (a) shows an active HWR, with gain.

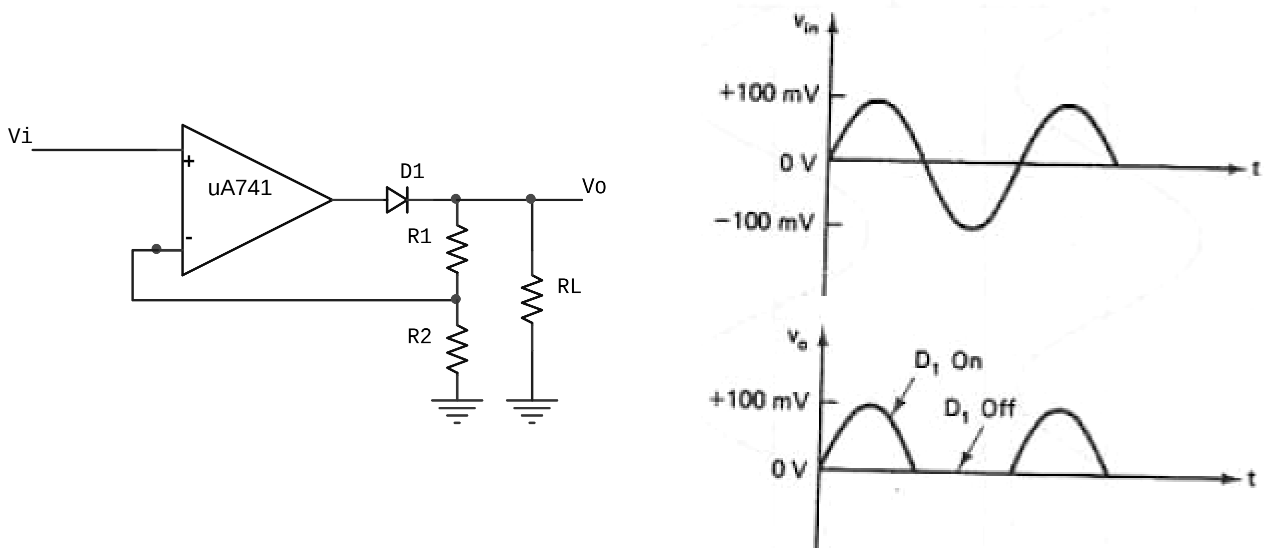


Fig 2-2-3(a) *Active HWR, (b) input and output waveforms*

When the input signal goes positive, the op-amp goes positive and turns on the diode. The circuit then acts as a conventional non-inverting amplifier, and the positive half-cycle appears across the load resistor. On the other hand, when the input goes negative, the op-amp output goes negative and turns off the diode. Since the diode is open, no voltage appears across the load resistor. This is why the final output is almost a perfect half-wave signal.

The high gain of the op-amp virtually eliminates the effect of offset voltage. For instance, if the offset voltage equals 0.7V and open-loop gain is 100,000, the input that just turns on the diode is

$$V_{in} = \frac{0.7V}{100{,}000} = 7\mu V.$$

When the input is greater than 7μV, the diode turns on and the circuit acts like a voltage follower. The effect is equivalent to reducing the offset voltage by a factor of A.

The active HWR is useful with low-level signals. For instance, if we want to measure sinusoidal voltages in the millivolt region, we can add a milliammeter in series with R_L with the proper value of R_L, we can calibrate the meter to indicate rms millivolts.

2-2-4-3 Active clipper

Clipper is a circuit that is used to clip off (remove) a certain portion of the input signal to obtain a desired output wave shape. In op-amp clipper circuits, a rectified diode ma be used to clip off certain parts of the input signal. Fig. 2-2-4 (a) shows an active positive clipper, a circuit that removes positive parts of the input signal. The clipping level is determined by the reference voltage V_{ref}.

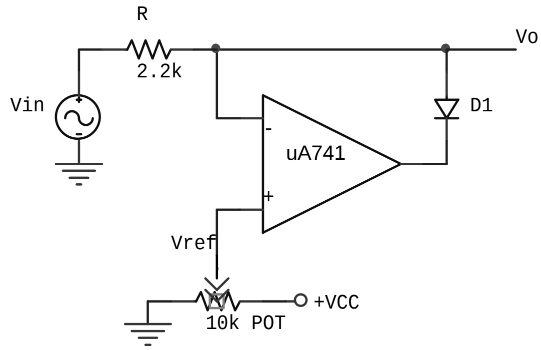
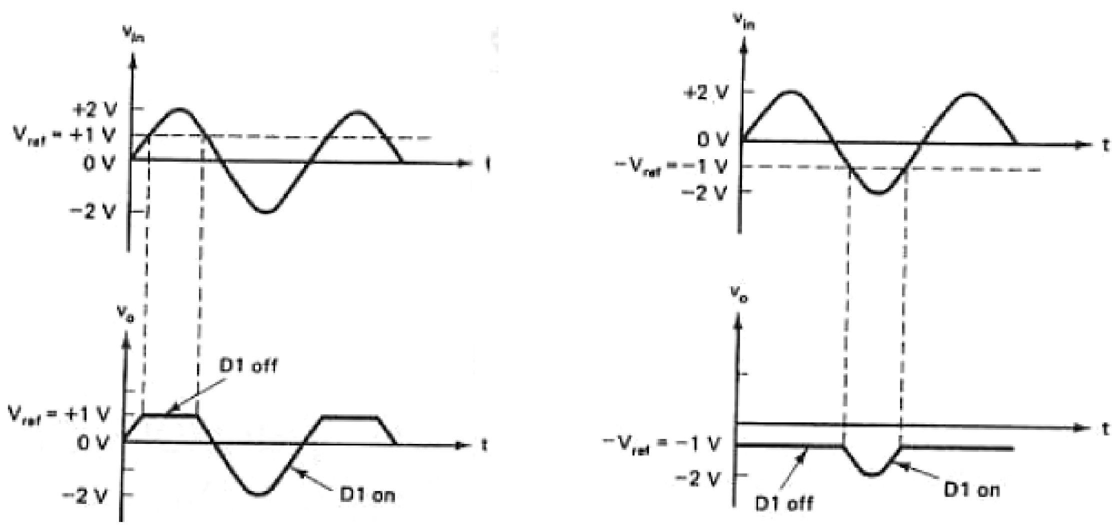


Fig 2-2-4(a) *Active Limiter*



(b) (c)

Fig 2-2-4 *(b) input & output waveforms with +V_{ref}, (c) input & output waveforms with -V_{ref}*

With the wiper all the way to the left, V_{ref} is o and the non-inverting input is grounded. When V_{in} goes positive, the error voltage drives the op-amp output negative and turns on the diode. This means the final output V_O is 0 (same as V_{ref}) for any positive value of V_{in}.

When V_{in} goes negative, the op-amp output is positive, which turns off the diode and opens the loop. When this happens, the final output V_O is free to follow the negative half cycle of the input voltage. This is why the negative half cycle appears at the output. To change the clipping level, all we do is adjust V_{ref} as needed.

2-2-4-4 Active clamper

In clamper circuits, a predetermined dc level is added to the input voltage. In other words, the output is clamped to a desired dc level. If the clamped dc level is positive, the clamper is called a *positive clamper*. On the other hand, if the clamped dc level is negative, it is called a *negative clamper*. The other equivalent terms for clamper are *dc inserter or dc restorer*.

A clamper circuit with a variable dc level is shown in fig. 2-2-5 (a). Here the input wave form is clamped at $+V_{ref}$ and hence the circuit is called a positive clamper.

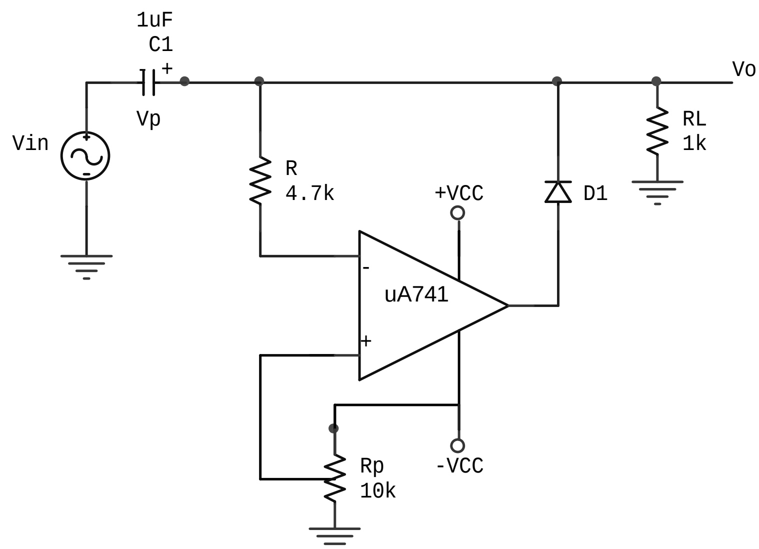
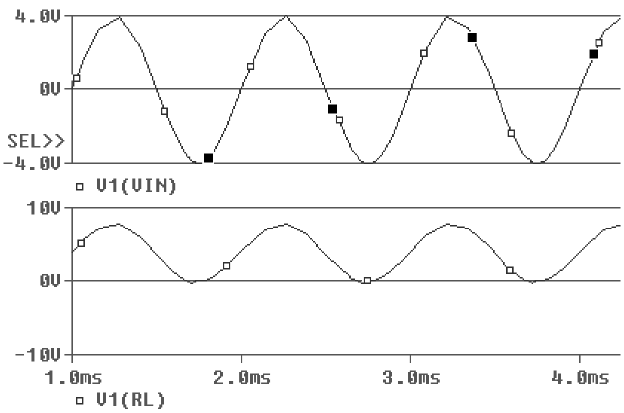
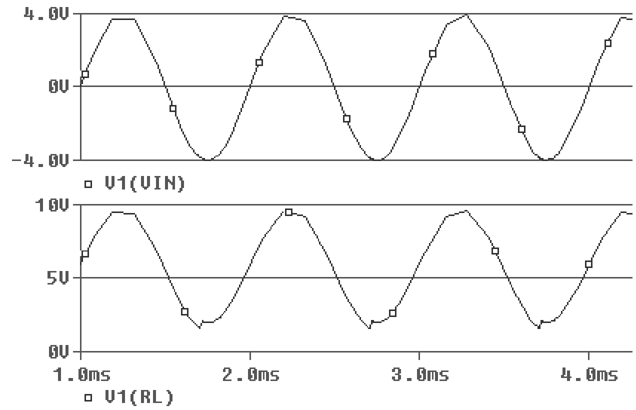


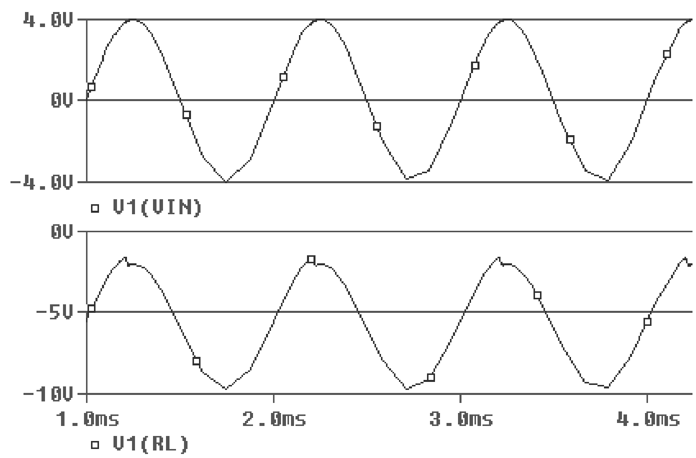
Fig 2-2-5(a) *Peak clamper circuit*

The output voltage of the clamper is a net result of ac and dc input voltages applied to the inverting and non-inverting input terminals respectively. Therefore, to understand the circuit operation, each input must be considered separately. First, consider V_{ref} at the non-inverting input. Since this voltage is positive, is $+V_O$ is positive, which forward biases diode D1. This closes the feedback loop and the op-amp operates as a voltage follower. This is possible because C_1 is an open circuit for dc voltage. Therefore $V_O = V_{ref}$. As for as voltage V_{in} at the inverting input is concerned during its negative half-cycle D1 conducts, charging C_1 to the negative peak value of the V_P. However, during the positive half-cycle of V_{in} diode D1 is reverse biased and hence the voltage V_P across the capacitor acquired during the negative half-cycle is retained. Since this voltage V_P is in series with the positive peak voltage V_P, the output peak voltage $V_O=2V_P$. Thus the net output is $V_{ref}+V_P$, so the negative peak of $2V_P$ is at V_{ref}. For precision clamping $C_1R_d<<T/2$, where R_d is the forward resistance of the diode D1 (100Ω typically) and T is the time period of V_{in}. The input and output wave forms are shown in fig. 2-2-5(b)





(i) ***(ii)***



(iii)

Fig 2-2-5(b) *Input and output waveforms (i) with V_{ref}=0V, (ii) with +V_{ref}, (iii) with -V_{ref}*

Resistor R is used to protect the op-amp against excessive discharge currents from capacitor C_1 especially when the dc supply voltages are switched off. Negative clamping at a negative voltage is accomplished by reversing diode D1 and using the negative reference voltage $-V_{ref}$ as shown in figure 2-2-5(c).

2-2-4-5 Peak Detector Circuit

Square, triangular, saw-tooth and pulse waves are typical examples of non-sinusoidal wave forms. A conventional ac voltmeter cannot be used to measure the rms value of the pure sine wave. One possible solution for this problem is to measure the peak values of the non-sinusoidal wave forms. Fig.2-2-6(a) shows a peak detector that measures the positive peak values of the input.

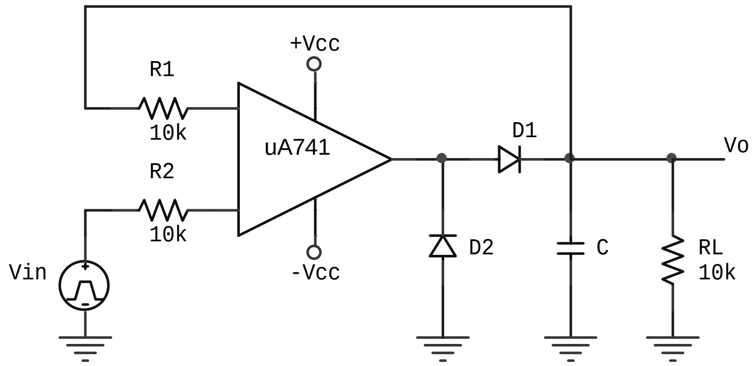


Fig 2-2-6(a) *Peak detector*

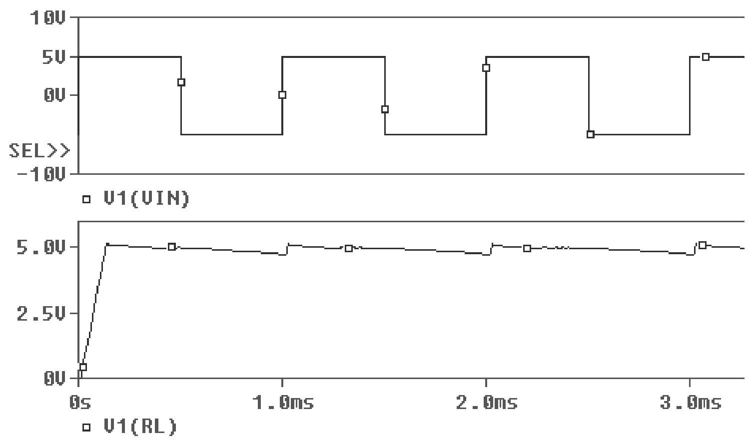


Fig 2-2-6(b) *Input and output waveforms*

During the positive half-cycle of V_{in}, the output of the op-amp drives D1 on charging capacitor C to the positive peak value V_P of the input voltage V_{in}. Thus when D1 is forward biased, the op-amp acts as a voltage follower. On the other hand, during the negative half-cycle of the V_{in}, the diode D1 is reverse biased, and the voltage across C is retained. The only discharge path for C is through R_L since the input bias current is negligible. For proper operation of the circuit, the charging time constant (CR_d) and the discharge time constant (CR_L) must satisfy the following conditions

$$CR_d << T/10 \text{ and } CR_L \geq 10T$$

where R_d is the forward resistance of the diode, R_L is the load resistor and T is the time period of the input waveform V_{in} The wave form for a square wave input is shown in fig.2-2-6(b)

For a very small R_L, a voltage follower is connected between C and R_L. The diode D2 conducts during the negative half-cycle of V_{in}, thus preventing the op-amp from going into saturation.

2-2-5 EXPERIMENT

Use op-amp dc power supply voltages of $\pm$ 15V.

(1) Basic comparator

1.1 Design a voltage level detector as shown in fig.2-2-2 (a) to detect a voltage level of 1V in a sinusoidal input voltage. Consider R=1kΩ. Use 1N4002 diodes. Assemble the circuit.

1.2 Feed sinusoidal input of amplitude $3V_P$ and frequency 1KHz. Adjust the 10K POT so that V_{ref}=+1V.

1.3 Using a CRO observe the input and output waveforms simultaneously. Tabulate your readings in table 2-2-1

1.4 Plot the input and output voltages on the same scale.

(2) Active HWR

2.1 Design an active half-wave rectifier as shown in fig.2-2-3 (a) for a gain of -4.7. Choose the appropriate resistor values of R_1 and R_2. Consider R_L = 10kΩ. Use 1N4002 diodes. Assemble the circuit.

2.2 Feed sinusoidal input of amplitude $200mV_{PP}$ and frequency 100Hz.

2.3 Using a CRO observe the input and output voltages simultaneously. Determine the amplitude and frequency of the output voltage. Increase the frequency of the input signal till distortion appears in the output. Record this frequency in table 2-2-2.

2.4 Plot the input and output voltages on the same scale.

(3) Active clipper

3.1 Assemble the clipping circuit as shown in fig. 2-2-4 (a) with R=2.2kΩ. Use 1N4002 diode.

3.2 Feed $3V_P$, 1 KHz sinusoidal input. Observe the input and output voltages on a CRO.

3.3 Look at the output signal while turning the potentiometer through its entire range.

3.4 Record your readings in table 2-2-3 for a desired clipping level. Plot the input and output voltages on the same scale.

(4) Active clamper

4.1 Design a positive clamping circuit with clamping level at zero as shown in fig. 2-2-5 (a). Note that V_{ref} = 0V. Consider C_1 = 0.1μF, R = 4.7 KΩ and R_L = 10 KΩ. Use 1N4002 diode. Assemble the circuit.

4.2 Feed $5V_{PP}$, 10 KHz sinusoidal input.

4.3 Using a CRO observe the input and output voltages simultaneously. Determine the clamping levels of the output voltage. Tabulate your readings in table 2-2-4.

4.4 Plot the input and output voltages on the same scale.

(5) Peak detector

5.1 Assemble the peak detector circuit as shown in fig. 2.2.6 (a). Assume R_1=R_2=R_L=10kΩ and C=1μF. Use 1N4002 diode.

5.2 Feed $5V_P$, 1 KHz square input.

5.3 Using a DMM, measure and record the dc output value in table 2-2-5.

V_{ref} =

Particulars	Amplitude	Time Period	Frequency
Input Voltage			
Output Voltage			

Table 2-2-1 *Basic Comparator*

Particulars	Amplitude	Time Period	Frequency
Input Voltage			
Output Voltage			

Table 2-2-2 *Active Half-wave Rectifier*

Clipping Level =

Particulars	Amplitude	Time Period	Frequency
Input Voltage			
Output Voltage			

Table 2-2-3 *Active Clipper*

Clamping level =

Particulars	Amplitude	Time Period	Frequency
Input Voltage			
Output Voltage			

Table 2-2-4 *Active Clamper*

Particulars	Magnitude
Peak Value of AC Input voltage	
Output DC Voltage across capacitor	

Table 2-2-5 *Peak Detector*

2.2.6 POST LAB QUESTIONS

1. The circuit of fig. 2-2-2(a) can be called *"go-no go detector"*. Explain why it is called so?
2. In the fig. 2-2-2 (a), if the POT is adjusted for V_{ref} = -1V, what would be the output?
3. Set V_{ref} = 0V in fig. 2-2-2 (a) to make a zero crossing detector observe the output waveform and record your comments.
4. If the diode is reversed in fig. 2-2-3 (a), what would the output voltage be?
5. If the diode is reversed in fig. 2-2-4 (a), what would the output be like?
6. Is this circuit of problem 5 a positive or negative clipper?
7. If the diode is reversed in fig. 2-2-5(a), what would be the output?
8. If the diode is reversed in fig. 2-2-6(a), what would be the output?