Integrated Circuits and Applications
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AC Applications of Operational Amplifier
Lecture – 05
Precision Half Wave and Full Wave Rectifiers

Ok. In the last lecture we have discussed some of the AC applications of operational amplifiers, but mostly the linear applications. So, in addition to linear applications op-amp can also be used for non-linear applications also. So, this non-linear application uses in addition to op-amp some diodes or transistors also. So, the first the non-linear application of this operational amplifier is precision rectifier. So, you might have studied this conventional rectifier. So, you might have studied this conventional rectifier in your second year.

So, if I take the conventional rectifier we have a single diode, this is input with respect to ground, this is output with respect to ground. If I assume that the cutting voltage or knee voltage of this diode is v_γ , this $v_\gamma = 0.7V$ for silicon and 0.3V for germanium.

So, what will be the operation of this conventional amplifier and what are the its limitations, why you have to go for the precision rectifier. If see here if input voltage v in is less than or equal to the cutting voltage or knee voltage v_γ. So, what happens to diode, diode will be off and the output voltage is $v_o = 0$. If input voltage is greater than v_γ then diode is on. So, output voltage if I take the practical case, this is v_γ, is the voltage across this one, this is plus minus output voltage is this.

So, what will be this KVL, this is minus 2 plus v_i, here this v_γ is plus 2 minus. So, $v_i - v_\gamma - v_o = 0 \Rightarrow v_o = v_i - v_\gamma$. If I neglect this v_γ in case of ideal diode $v_o = v_i$ for ideal case. So, if I take the input and output waveforms of this diode, if this is the input output will be up to v_γ output is 0. So, up to here this is 0, here output is equal to input if I assume the ideal diode, again negative half cycle it is 0.

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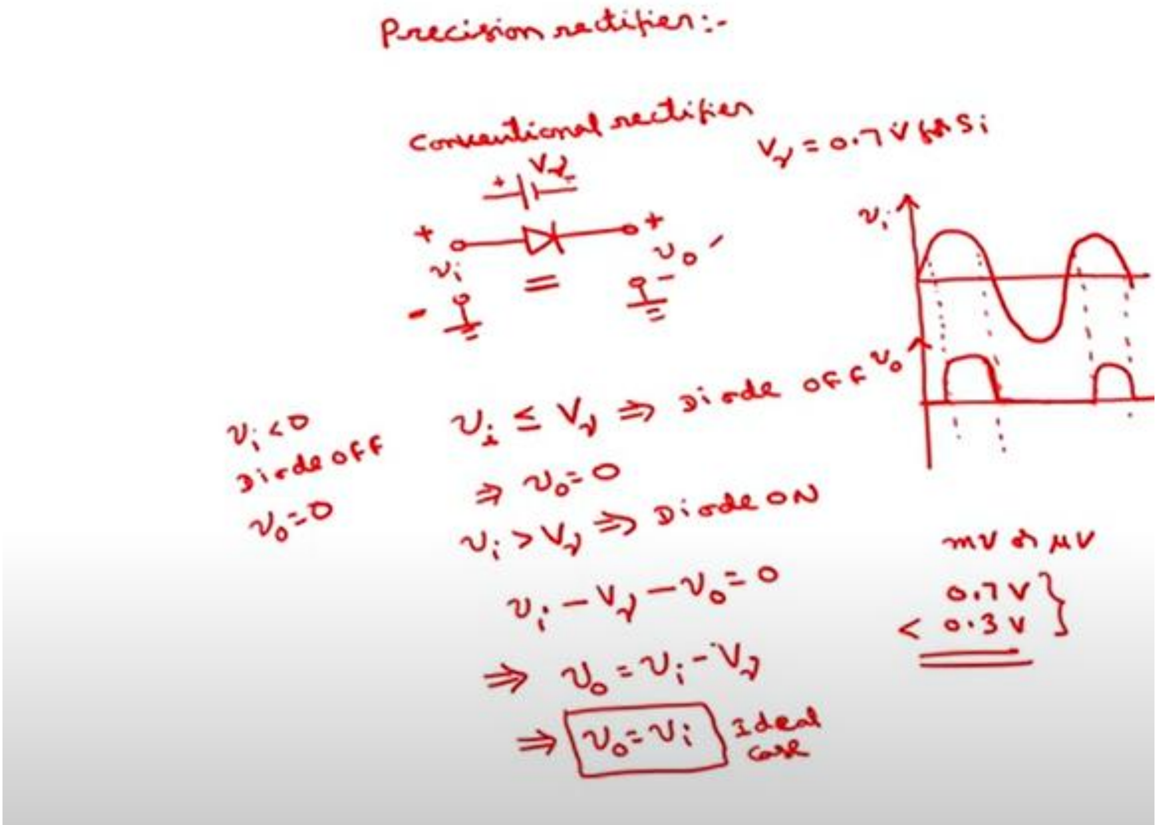

So, negatively reverse bais even if it is $v < 0$, then diode is half and $v_o = 0$. So, here also 0 again when the input is positive greater than v_γ output is input and so on. So, this type of output waveform will get if input is this. So, the drawback of this conventional rectifier is so, this conventional rectifier cannot rectify the signals which is of the order of millivolts or microvolts. So, the minimum voltage that can be rectified by this conventional rectifier is 0.7V for silicon and 0.3V for germanium. The voltages below this it cannot rectify this is the main drawback of conventional rectifier. So, to avoid this limitation we will use a precision rectifier instead of using just simple diode we will use diode along with the operational amplifier. So, the circuit diagram of the precision rectifier is we have operational amplifier, here the input v_A is applied, here diode in feedback path, here internal load resistance across the load will take the output v_o with respect to ground, this v_i with respect to ground.

Let us call this intermediate output as some $v_o{}'$ the final output is v_o ok. Now, if you see the operation of this precision rectifier, let the open loop gain of this amplifier is this is 2×10^5 in case of 741 IC, let us assume this is simply 10^5 gain open loop. Then what happens is if $v_i \leq \frac{v_\gamma}{A_{OL}}$, then what happens what is $v_o{}'$? $v_o' = v_i A_{OL}$, this input voltage into this open loop gain will be the $v_o{}'$. If input $v_i < \frac{v_\gamma}{A_{OL}} \Rightarrow v_o{}' \leq v_\gamma$. Simply what happens to diode? Diode is off.

So, it will acts as a open circuit and what will be the equivalent circuit now? This diode is open circuited and there is a connection from output to input and this is load resistance this is output v_o. This will acts in open loop configuration. So, this current is 0 means this current is 0. So, current is 0 through the R_L means output is 0. On the other hand, if $v_i > \frac{v_\gamma}{A_{OL}}$, then what happens to this $v_o{}' > v_\gamma$ implies diode on.

So, it will acts as short circuit if I assume the ideal diode, you know what will be the equivalent circuit? This is short circuit, this is load resistance, this is the output voltage v_o. This is nothing, but voltage follower which we have discussed in the last lecture. So, output $v_o' = v_i$. So, in summary if $v_i \leq \frac{v_\gamma}{A_{OL}}$ output $v_o = 0$ if $v_i > \frac{v_\gamma}{A_{OL}}$ output $v_o = v_i$. This is basically rectification operation.

If you take the waveforms and this is input waveform v_i and output waveform v_o will be. So, this $\frac{v_o}{A_{OL}}$ is almost negligible because A_{OL} is 10^5 say and v_γ let us assume that this is a silicon diode 0.7V. So, implies what is $\frac{v_\gamma}{A_{OL}} = \frac{0.7}{10^5}$, this is equal to $7\mu V$, it is very very less.

So, your this precision rectifier will be capable of rectifying even a weak signals of the order of micro volts also. So, here this output if $v_i < \frac{v_\gamma}{A_{OL}}$ output is 0, if it is $> \frac{v_\gamma}{A_{OL}}$ output is input. So, this output will be almost same as the input. Of course, this will start it this is of course, $7\mu V$ this is almost negligible this is same as the input. And then for v_o greater than this is same as v_i and for negative half cycle what happens if v_i is negative.

So, this output $v_o{}'$ also negative. If increasing this v_i in the negative direction v_o also increases in the negative direction finally, it will saturate it $-V_{CC}$ because the open loop gain is 10^5. If this v_i is of the order of say for example, 0.12mV, then what will be the output $v_o{}'$? $v_o' = A_{OL} \times v_i$ that is equal to this minus of this, this is minus in negative direction. So, this will be 10^5 times means this is $12V - 0$.

$0.12 \times 10^{-3} \times 10^{5} = 12V$. So, you will get 12V. Any voltage above this 0.12V output will saturate if I assume that V_{CC} of this operational amplifier is 12V plus VCC is 12 volts minus VCC. So, if I increase this $v_i$in the negative direction output is going to saturate.

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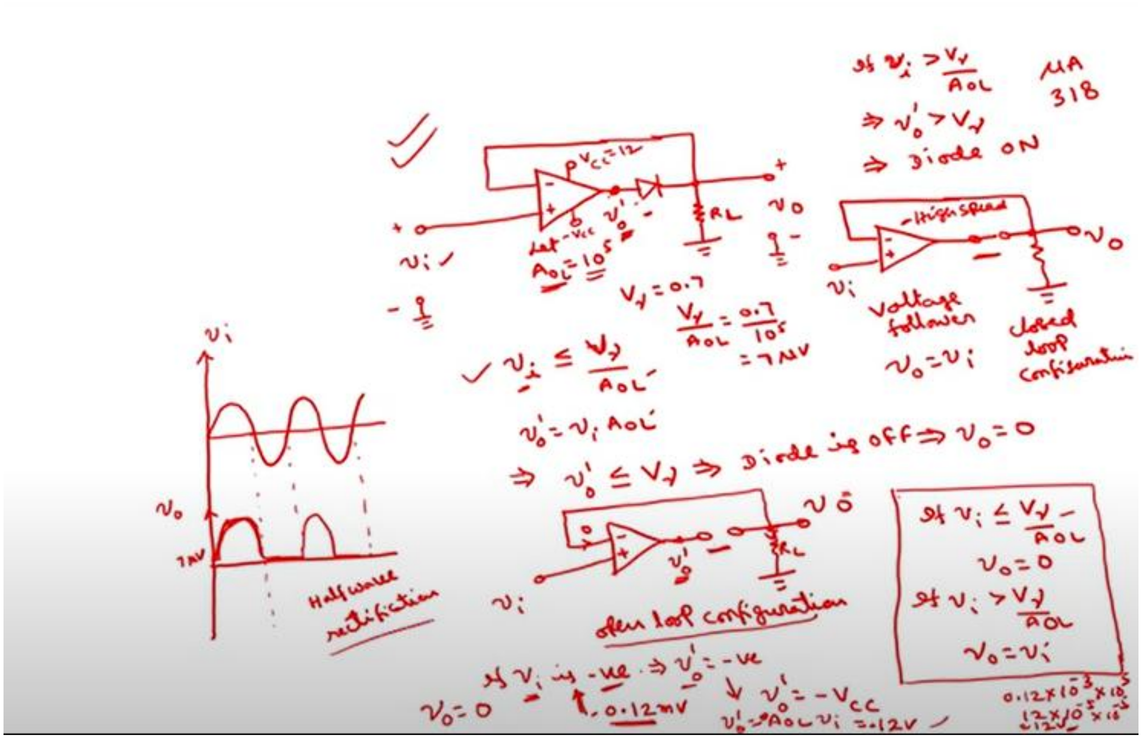

This is one of the drawback of this type of circuit and output will be this output v_o this is about this $v_o{}'$ will saturate, but what about v_o for $v_i < v_o$ is 0. Since, this will acts as a open circuit this is negative value negative value is applied to the anode. So, this will acts as open circuit. So, for negative half cycle this will be 0 for positive half cycle again is same as input negative half cycle 0 and so on. This is of course, this is $7\mu V$ is there that is almost negligible.

So, we will get this is also half wave rectification. So, in this case if $v_i < \frac{v_o}{A_{Ol}}$ this is open loop configuration whereas, this is closed loop configuration. So, this operational amplifier this entire circuit switches between the open loop configuration to closed loop configuration that is why you have to use this operational amplifier which will have high speed. So, normally we will use micro child mu A 318 is the operational amplifier which is high speed. So, one of the drawback of this circuit is as I have told if v_i increases in the negative direction then $v_o{}'$, this $v_o{}'$will saturates of course, v_o=0, but $v_o{}'$ is saturates to the negative value.

So, because of that it will take more response time to reduce this response time instead of using single diode you can use two diodes to perform the half wave rectification. So, this is just two diodes. This is the circuit diagram of another half wave rectifier, but this will be having more response time less response time when compared with the previous circuit thereby this will be having this process the high frequency signals. So, the operation is here again if v_i is positive and this $v_i > 0$. So, we have two diodes D_1 and D_2 now v_i is at the inverting terminal.

So, the voltage here v_o', this v_o will be if $v_i > 0$, this is negative and this voltage is this v_i is positive. So, the voltage to this diode D_1 anode is a positive value which is v_i minus a voltage drop of voltage drop across this R_1. So, this is positive voltage and this is negative voltage. So, this D_1 will be on and for this diode D_2 this anode voltage is negative whereas, the cathode voltage is positive this v_i, is this v_i is here and there will be voltage drop across this R_1 and R_F the remaining voltage will be applied across this point. So, this will be connected to the cathode of this diode D_2.

So, implies D_2 is off. So, what will be the equivalent circuit now? Now, we have this minus this is R_1. So, D_1 is on means this is short circuit and this will be open circuited this is the load resistance this is the output voltage v_o. Here what happens is this because of this short circuit the current that is coming from here this is *i* here no current the entire current flows through the short circuit because the resistance is 0 to the current. So, this part will be R_F part will be removed. So, here there is no current $i = 0$, it is almost acts as a open circuit.

So, this current will be flows through this one. So, output $v_o = 0$, this you can even remove also because there is no current in this path you can remove this. So, output is 0. If v_i is negative that is $v_i < 0$ then what happens this $v_i < 0$. So, negative this point is negative this point v_o' will be positive because this is inverting amplifier.

So, here this is positive this is negative. So, what happens to diode D_1? D_1 will be off because negative voltage to anode and positive voltage to cathode whereas, for D_2 this is also negative voltage this is positive voltage for anode positive and cathode negative. So, D_2 will be on. Now, what will be the equivalent circuit? So, D_1 will be open circuited this will be and D_2 will be short circuited. So, this is basically a inverting amplifier whose output is given by $-\frac{R_F}{R_1} v_i$.

If you choose $R_F = R_1$ implies output $v_o = v_i$. So, for positive half cycle output is 0 for negative half cycle output is equal to input. Now, here because this output v_o' will not saturate because of that. So, the response time of this one is more and can process high frequency signals this is the advantage of this circuit. And if you take the input output waveforms this is input the output v_o will be for positive half cycle is positive half cycle $v_o = 0$.

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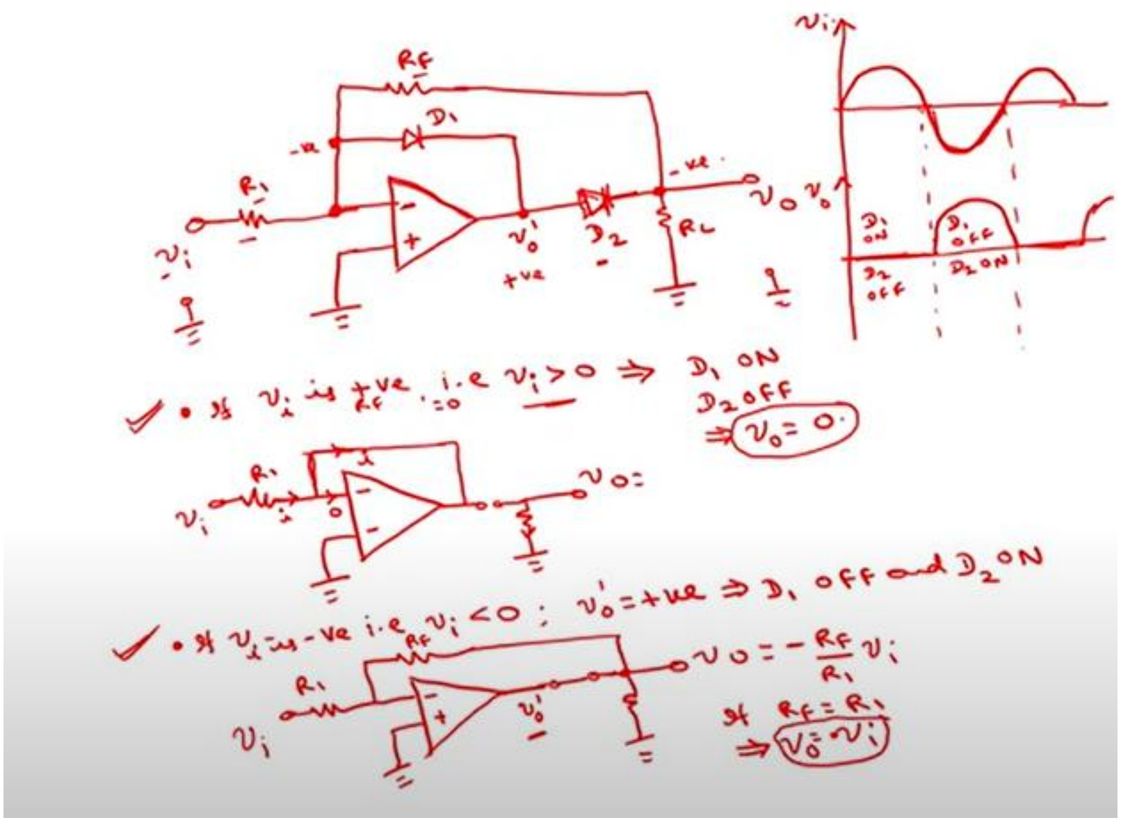

This $v_o = 0$, positive half cycle for negative half cycle $v_o = -v_i$. So, this is already negative and output is equal to $-v_i$. So, this becomes positive minus half minus becomes positive and whereas, for negative 0 and again here positive and so on. Here D_1 is on D_2 off as here D_1 off D_2 on. So, this is also a half wave rectifier, but this is this circuit performs better than the previous circuit because here the response time is less because the output v_o' will not saturate and as a result of that this will process the high frequency signals.

We can also implement the full wave rectifier using diode full wave precision rectifier. So, in circuit diagram of this one is this also uses only two diodes. This is one diode, this is another diode. This totally uses 5 resistors and 2 operational amplifiers. This is the final output v_o this is input v_i .

Let us assume that all the resistors are having equal value RRR. This is operational amplifier A_1 operational amplifier A_2. Now, we can analyze the operation of this full wave rectifier also in similar to half wave rectifier. First, we will consider v_i positive half cycle that is $v_i > 0$. Now, what happens to diodes D_1 and D_2? This is positive.

So, this is positive. There will be some drop across these two resistors whereas, this is inverting amplifier this is negative whereas, this is again this is positive this is also positive. You can see that for diode D_1 anode is positive cathode is negative. So, forward biased therefore, D_1 is on whereas, for D_2 it is reverse anode is connected to negative cathode is connected to positive. So, it is off. So, now, what will be equivalent circuit? D_2 is open circuited D_1 is short circuited assuming the ideal diode this is short circuited this is D_1 and D_2 is open circuited.

So, this part. So, this part this there is no open circuit here. So, we can connect this to the positive terminal of this this is also ground potential this is 0V, this is also 0V this is virtual ground. So, here this path is open circuited. So, this positive terminal will be connected to this positive terminal of will be connected to this resistor to the ground and here we have one more resistor this is connected to negative terminal of half amp and positive terminal is connected to resistance to ground this is another resistance R this is v_o this is called as $v_o{}'$ this is R R R v_i this is the equivalent circuit during the first half cycle or positive half cycle of v_i. So, what is $v_o{}'$? Basically, this is inverting amplifier whose gain is $-\frac{R}{R} = -1$.

So, what is $v_o' = -v_i$ of course, $-\frac{R}{R}$. So, $\frac{R}{R}$ becomes 1 now coming for this circuit this is also another inverting amplifier here this resistance can be neglected because the current is 0 here. So, the voltage across this resistor is also 0. So, you can neglect this normally this resistor will be in practical purposes used for compensating the offset voltages offset currents that we will discuss later we will discussing about the practical half amp characteristics. So, this you can neglect if you neglect this this is again inverting amplifier whose gain is output $v_o' = (-\frac{R}{R})\ v_o'$, but what is v_o', $-v_i$, this is another minus.

So, minus half minus becomes plus. So, simply $v_o = v_i$ during the positive half cycle. Now, what happens during negative half cycle? I will draw on this diagram itself during negative half cycle that is v_i is negative. So, this will be negative now. So, this is also negative this will be negative whereas, this one will be positive because this is inverting amplifier output $v_o{}'$ will be positive. So, for diode D_1 anode is connected to negative cathode is connected to positive.

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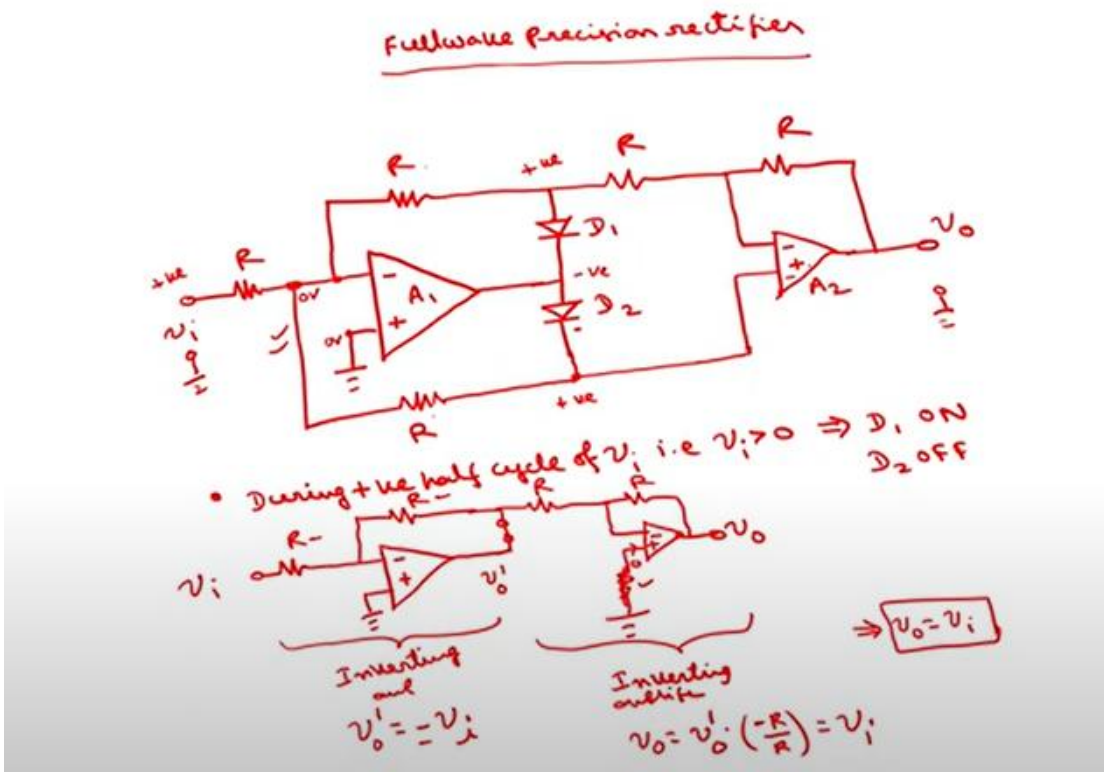

So, off for diode D_2 anode is connected to positive cathode is connected to negative on. So, implies D_1 off and D_2 on for ideal diode D_1 will acts as open circuit D_2 will acts as short circuit. So, the equivalent circuit will be now this will be open circuited. So, this will not be there this will be short circuited this is the equivalent circuit of this full wave rectifier for $v_i < 0$, that is during negative half cycle. So, you can simplify this circuit this circuit can be simplified.

So, you can write this circuit in the simplified manner as this is R this is R and this is also another R is there. Now, this will be connected to this point this is grounded v_i R, this R+R becomes 2 R here. You can see that this is R+R becomes 2 R that will go to the negative terminal of the second op amp here there is no path. So, these two becomes R plus R 2 R this is 2 R and here this part will not be there. So, this will be connected to positive terminal of second operational amplifier and negative terminal is connected to this point.

And, here there is another resistance R this is v_o'. Now, this v_o' if I assume that this is v_o' this current will be this v_o' divided by this R because no current flows through this. And, this current will be no current flows through this one this is this is also v_o' now because voltage at inverting terminal this is short circuited. So, this is this voltage and this voltage will be same.

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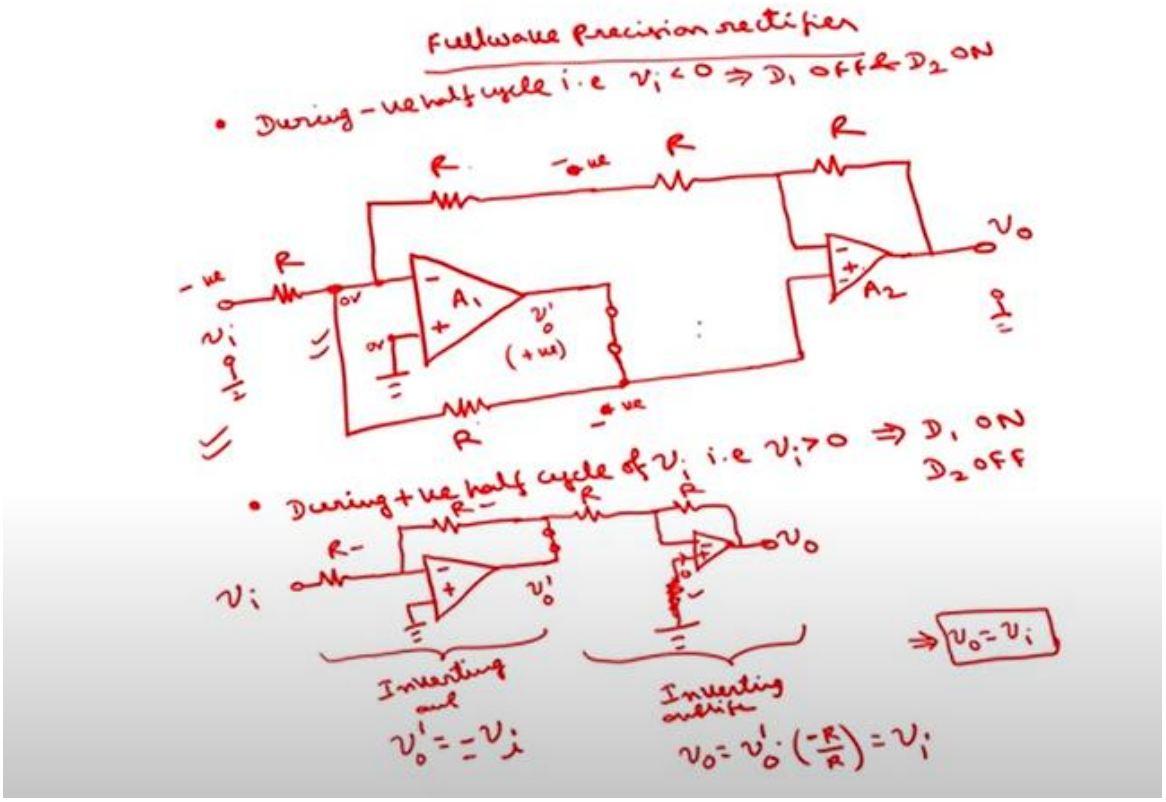

So, this is $v_o{}'$. So, this is v_o between this point and this ground. So, this current will be $\frac{v_o{}'}{2R}$ and this current will be $\frac{v_i}{R}$. So, at this junction you can take these two are short circuited three currents are entering one is $\frac{v_i}{R}$ entering through this is $\frac{v_o{}'}{R}$ this is $\frac{v_o{}'}{2R}$. So, at this point what is KCL is $\frac{v_i}{R} + \frac{v_o{}'}{R} + \frac{v_o{}'}{2R}$ is it clear because this is at $v_o{}'$ voltage and this point is $v_o{}'$ because the voltage at inverting and non inverting terminals are same. So, this is $v_o{}'$ and this is ground 0 this is 0V means this is 0V.

So, in this loop is this is positive to negative. So, this current direction is this one. So, $\frac{v_o{}'}{2R}$ coming for this is ground 0V. So, the current direction is this $\frac{v_i - 0}{R}$ whereas, for this this is 0V this is ground whereas, this point is $v_o{}'$. So, the current direction is $\frac{v_o{}'}{R}$, this is equal to 0. So, if I take 2 R as LCM here this is equal to $2v_i + 2v_o' + v_o' = 0 \Rightarrow v_o' = -\frac{2}{3}v_i$.

Now, coming for this circuit this is a non inverting amplifier this is minus plus this is minus plus in the previous circuit it was minus plus this is minus plus. So, you see inverting amplifier which invert this voltage this is nothing, but v_o' with what is the gain of this one what is $v_o = v_o'(1 + \frac{R}{2R})$,

$v_o = -\frac{2}{3} v_i (1 + \frac{R}{2R})$,

$$v_o = -v_i$$

this is during negative half cycle during positive half cycle $v_o = v_i$ during negative half cycle $v_o = -v_i$. So, you will get now if this is input output will be for positive half cycle same as the input for negative half cycle minus of this.

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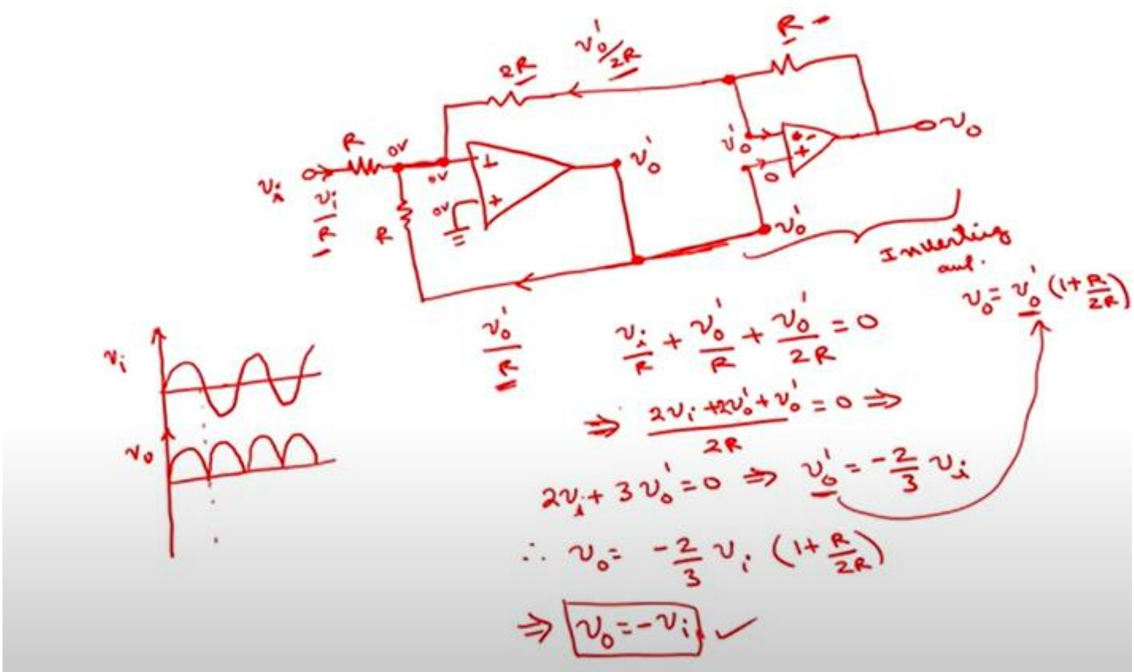

So, this minus means minus minus becomes plus. So, for positive also positive for negative also positive this is full wave rectifier this is the output this is the input this is about the precision full wave rectifier ok. So, we have some other non-linear applications such as clipper, clamper, logarithmic, anti logarithmic amplifier that we will discuss in the next lecture. Thank you.