Mechatronics
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Lecture – 17
OP-AMP as Signal Conditioner

I welcome you all to this NPTEL online certification course on Mechatronics. Today, we are going to talk about OP-AMP as a Signal Conditioner. In the last lecture, I discussed with you the op-amp its assumptions in the modeling of the op-amp we have seen and we have seen the use of or how can we use the op-amp to amplify a signal with the help of external elements or external resistors rather.

Today, in this lecture, we will talk about how can we manipulate a signal. Manipulation I mean that how can we add the signal, how can we subtract the signal, how can we integrate the signal, how can we differentiate the signal. So, all these and the various other uses of an operational amplifier as a signal conditioning unit we are going to discuss today. I hope you will enjoy this lecture.

So, here we are at this place right now, input signal conditioning and interfacing. First of all, let us look at the adder circuit. That is, I have got two signals and I want to add those signals. So, here what do we do? On the non-inverting side, we ground it, in the inverting side we have the two signals V_1 and V_2 over here.

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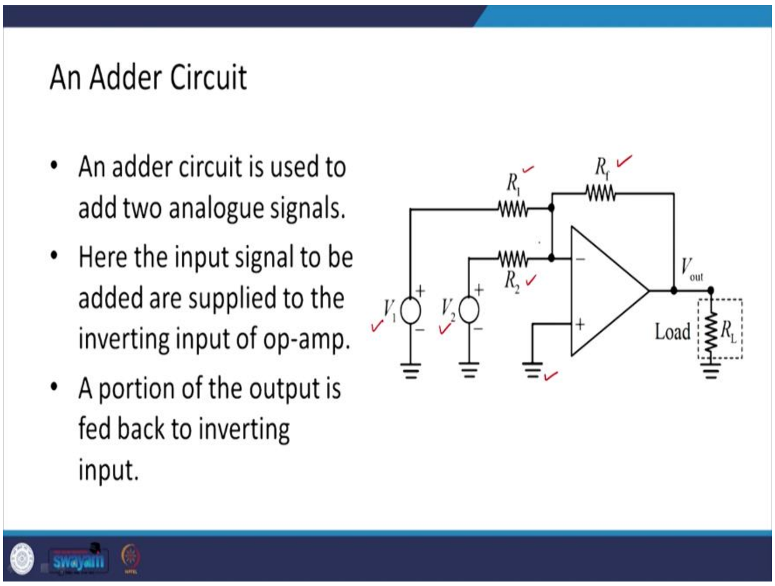

And these are the input side resistances R_1 and R_2, and you have the feedback resistance over here. So, a portion of the output is fed back to the inverting side over here.

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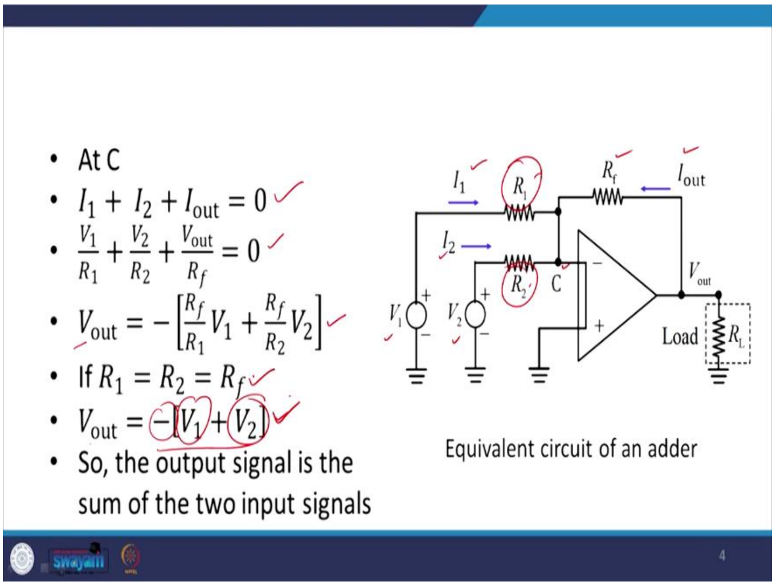

Now, to see it is used at op-amp as the adder of the two signals, let us analyze it.

So, for that purpose, I have drawn the equivalent circuit of an adder. So, these are V_1, V_2, R_1, R_2. This is current through this one I_1, I_2 and this is output current from over here and this is what we are shorting as per the assumptions for the op-amp. At C, we see that if I apply the Kirchhoff current law,

$$I_1 + I_2 + I_{out} = 0$$

$$\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_{out}}{R_f} = 0$$

So, from here I can just write,

$$V_{out} = -[\frac{V_1 R_f}{R_1} + \frac{V_2 R_f}{R_2}$$

Now, if $R_1 = R_2 = R_f$

Then if I put it over here then you can just see,

$$V_{out} = -V_1 + V_2$$

So, I am able, to sum up, these two signals, and although I am getting the signal inverted, so I can use another op-amp, so to correct this inversion, So, but I am able to get the summation of the two signals over here.

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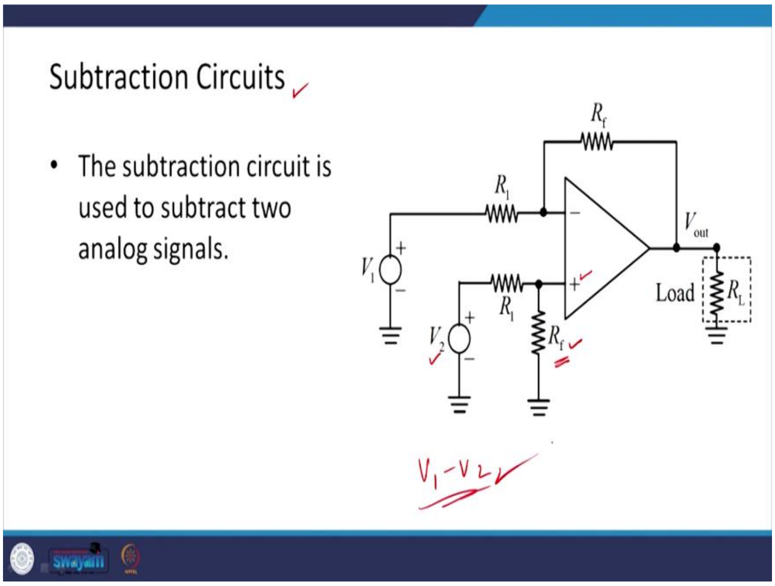

Now, let us look at the use of op-amp for the subtraction of the two signals. So, for the subtraction of the two signals in the previous circuit, we make some modifications over here. So, at the non-inverting terminal, I supply another signal V_2 over here and there is another resistance of the value R_f which is being used over here. So, in this configuration, I can use it for the subtracting purpose that is I will be getting, $(V_1 - V_2)$ from this one.

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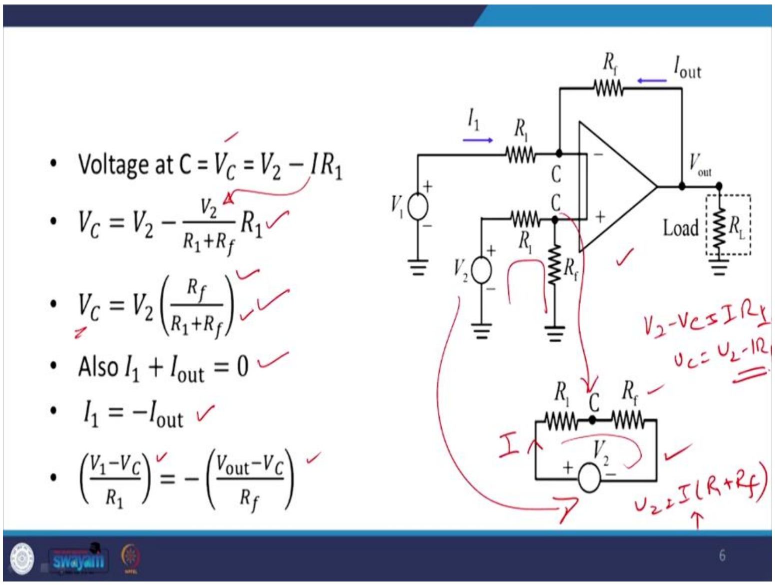

Let us see how this is done. So, again I have put up the equivalent circuit for that, And so, this portion I can analyze over here as you can see. You have R_1, you have R_2, this is point C over here, and this is the V_2 over here. I will come back to it a little late.

So, the voltage at C,

$$V_c = V_2 - IR_1$$

$$V_c = V_2 - \frac{V_2}{R_1 + R_f}R_1$$

$$V_c = V_2(\frac{R_f}{R_1 + R_f})$$

How can I write this I is equal to this one? you can see this equivalent circuit over here. If there is a current I from here then your V_2 is equal to I into $R_1 + R_f$. So, I is V_2 by R_1 plus R_f. So, I have just substituted that I is equal to V_2 by $R_1 + R_f$ into R_1. So, that is there. Moreover this V_c or if I simplify this then what is this? $V_c = V_2$, you have,

$$I_1 = -I_{out}$$

So, this is our equation.

$$\frac{V_1 - V_c}{R_1} = -\frac{V_{out} - V_c}{R_f}$$

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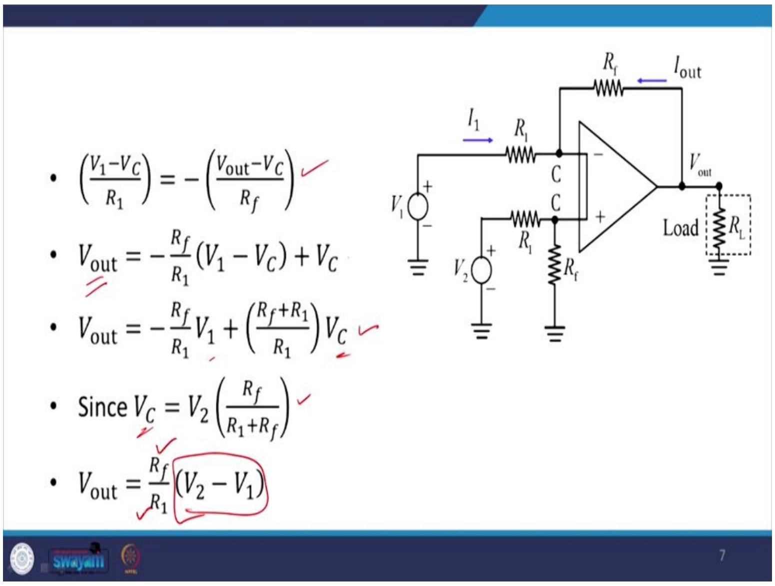

So, from here I can find out,

$$V_{out} = \frac{(V_1 - V_c)R_f}{R_1} + V_c$$

I just simplify this and the V_c have already calculated in the previous slide over here, here this one. So, I substitute it over here, so I get this one.

So, if I substitute this V C over here this is what I am going to get. So, here you can see that what I am having is I am having the difference of these two signals,

$$V_{out} = \frac{(V_2 - V_1)R_f}{R_1}$$

this R_f and R_1 will decide how much I am going to amplify it.

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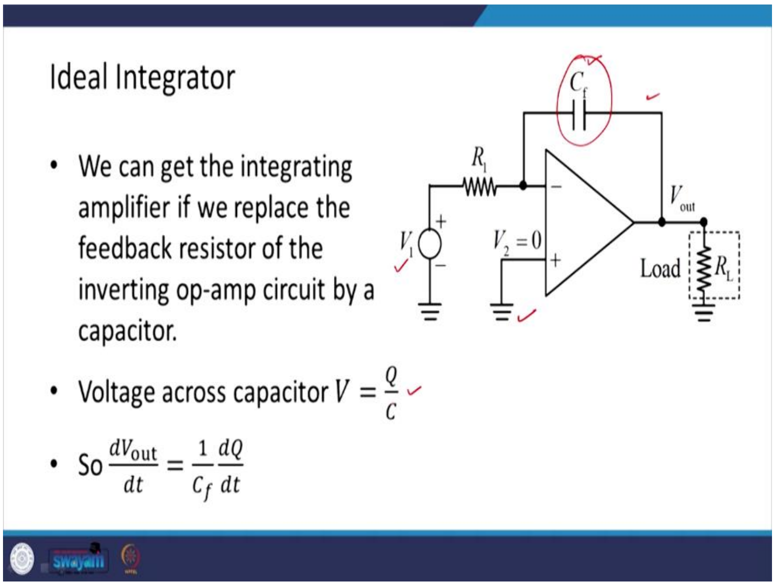

Next, let us see the use of operational amplifier as an integrator. So, for that purpose in the feedback circuit if I replace the feedback resistor with a capacitor of capacitance C_f, here and I have a signal V_1 supplied to the inverting side and the non-inverting side is grounded over here.

So, the voltage across capacitors

$$V=\frac{Q}{C}$$

this is the general equation which we all know, So, from this one, I can write about,

$$\frac{dV_{out}}{dt} = \frac{1}{C_f}\frac{dQ}{dt}$$

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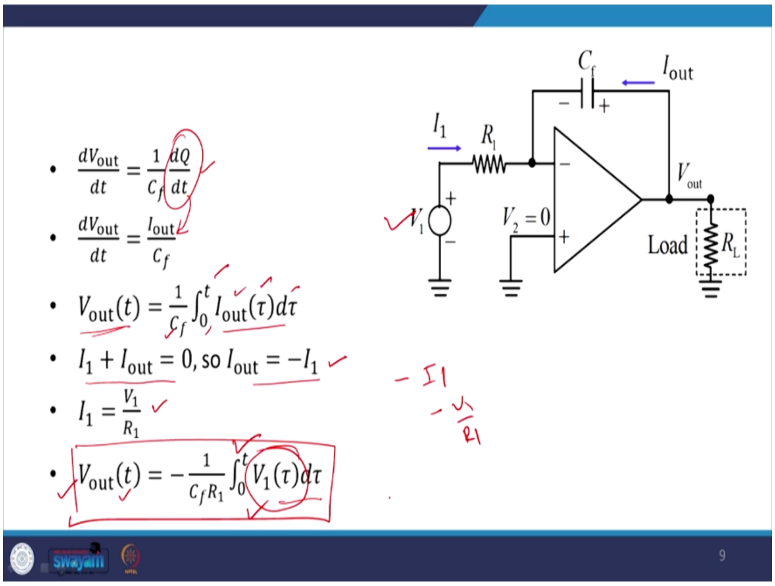

So,

this $\frac{dQ}{dt}$ you know this is I_{out}. So,

$$V_{out}(t) = \frac{1}{C_f}\int_0^t \tau(\tau)d\tau$$

And you see, again from the assumption for the op amp,

$$I_1 + I_{out} = 0$$

$$I_1 = -I_{out}$$

$$I_1 = \frac{V_1}{R_1}$$

So what I get here is,

$$V_{out}(t) = \frac{1}{C_f R_1}\int_0^t V_1(\tau)d\tau$$

So, what we have got is that my input signal that is which was V_1 over here that has been integrated, and this is what I am getting output. So, this way I can use the op-amp as an integrator.

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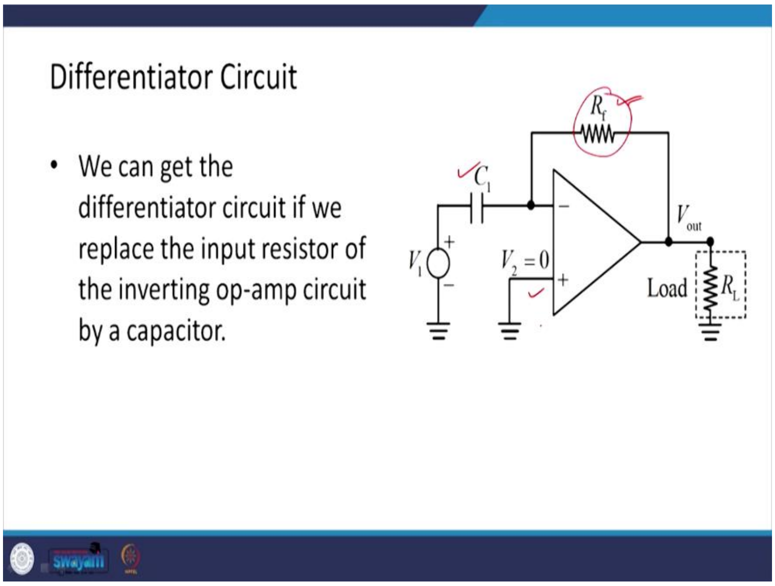

Next let us see the op amp as a differentiator, So, we can get the differentiator circuit. If we replace the input resistor of the inverting op amp circuit by a capacitor as seen in this figure. Rest of the things are same that is you have a feedback path here, with the feedback resistance R_f and this non-inverting side is grounded.

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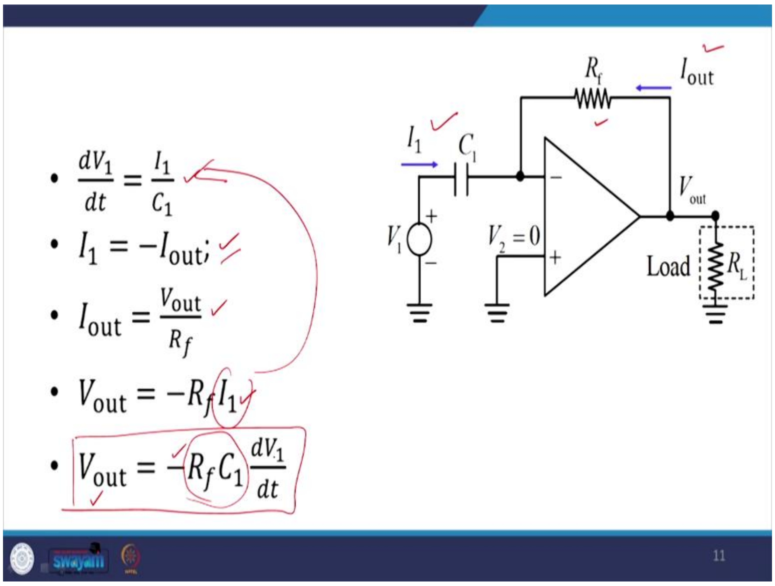

So, if I look at the equivalent circuit over here, this I_1 is the current at the input side, I_{out} is the current at the output side,. So,

$$\frac{dV_1}{dt} = \frac{I_1}{C_1}$$

.So, we have

C_f we already know from our earlier assumption for the op-amp.

$$I_{out} = \frac{V_{out}}{R_f}$$

$$V_{out} = -R_f C_1 \frac{dV_1}{dt}$$

So, here you can see that what we are getting is, my input signal is being getting differentiated and it is multiplied by some factor with an inverting sign over here and that I am getting the output. So, this is how we get the differentiated signal.

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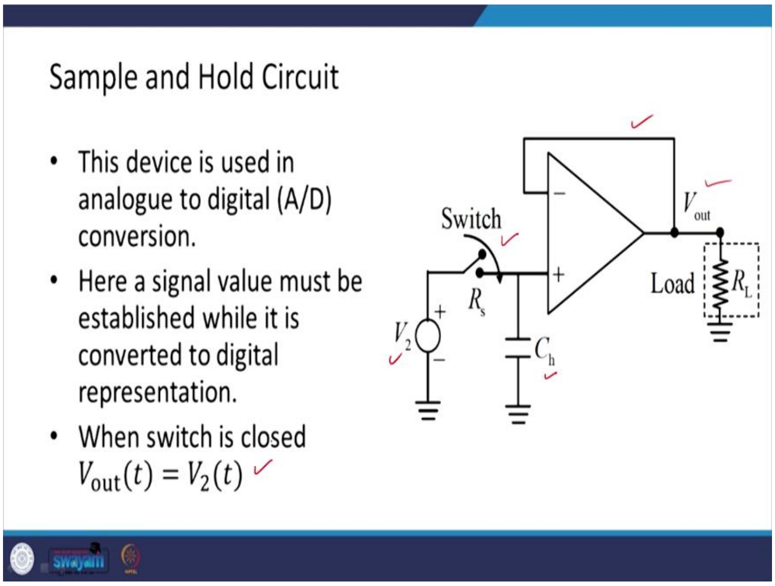

Then, other coming to the other uses of the op-amps, these are used very popularly for as a sample and hold devices. Sampling and holding are required when we are talking about the conversion of analog signal to the digital signal, So, in this, when we are talking about conversion from analog to digital, signal value must be established while it is converted to the digital representation, So, here what is done is that here this is output is connected to the inverting side over here and there is a switch which is used and there is a capacitor with capacitance C_h which is used for holding of the holding purpose, and this is your input side. So, when this switch is closed that time it is used as a buffer, So, whatever output you are getting that is going to be the same as the input. So,

$$V_{out}(t) = V_2(t)$$

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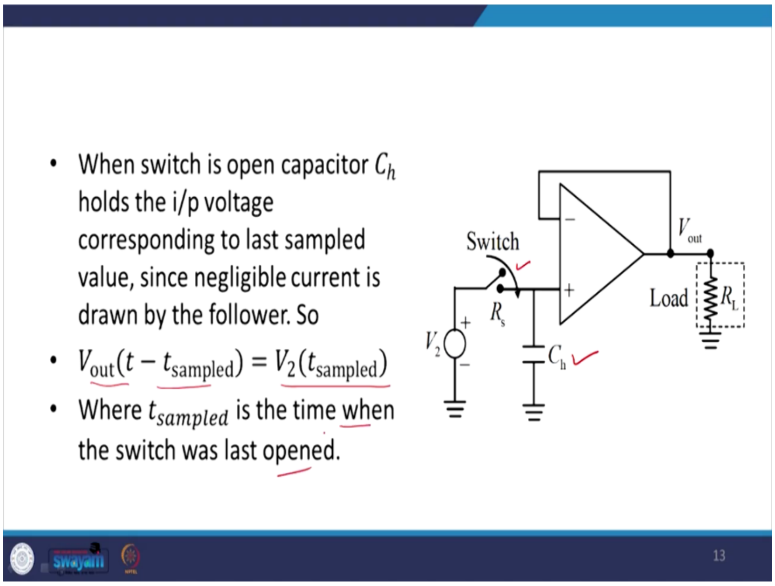

And when the switch is open, this switch is open over here then the capacitor this C_h holds the input voltage corresponding to what? Last sampled value, since negligible current is drawn by the follower. So, the relationship will be what? This,

$$V_{out}(t - t_{sampled}) = V_2(t_{sampled})$$

So, this is what is going to be there, where $t_{sampled}$ is a time when the switch was last opened.

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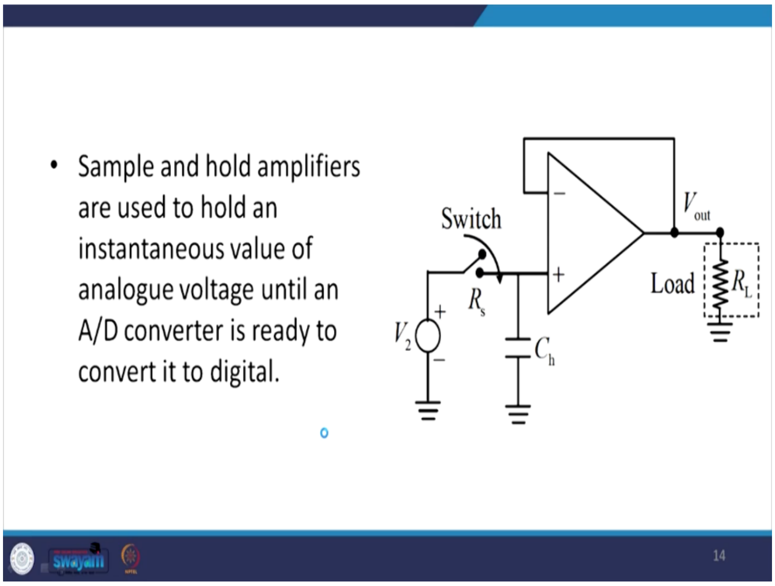

And this sample and hold amplifier are used to hold an instantaneous value of the analog voltage until an A D converter is ready to convert the signal.

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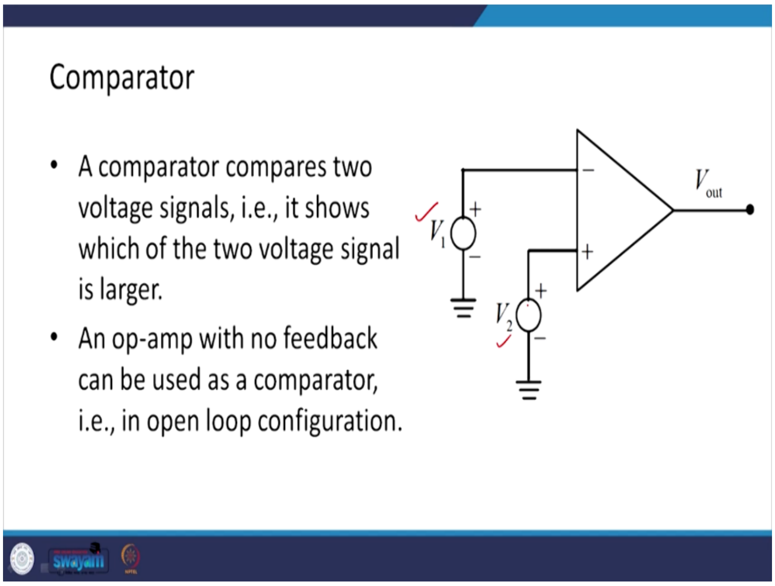

Next purpose or good use of the op amp is as a comparator. So, as the name indicates the comparator compares the two voltage signal. It shows which of the two signal is larger. So, for that purpose what we do is that in the inverting terminal we send one signal, V_1 and in the non-inverting terminal we send another signal of voltage V_2. So and there is no feedback, op amp with no feedback can be used as a comparator. That is, it is in the open-loop configuration since we are not going to have any feedback.

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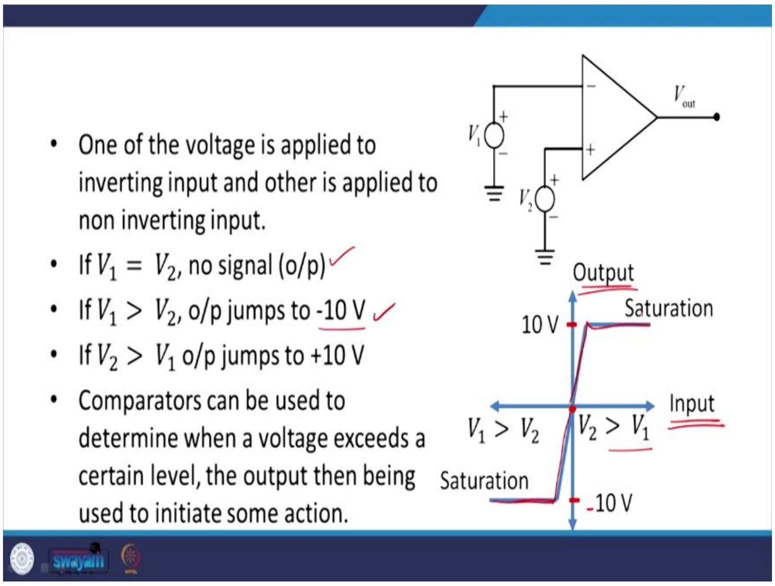

Now, so one of the voltage is applied to the inverting input and the other is applied to the non-inverting as I explained. Now, here there are three things possible. If $V_1 = V_2$ there is no signal, . That is no output is over there. So, you are at this place.

Here I have plotted input versus the output. And if $V_1 > V_2$, then output jumps to a -10 volt range over here. There is saturation over here, so this comes to the -10 volt. And if $V_1 < V_2$, it jumps over here another side, jumps to +10 volts.

So, comparators can be used to determine when a voltage exceeds a certain level that is the output being used to initiate some action in your subsequent circuit.

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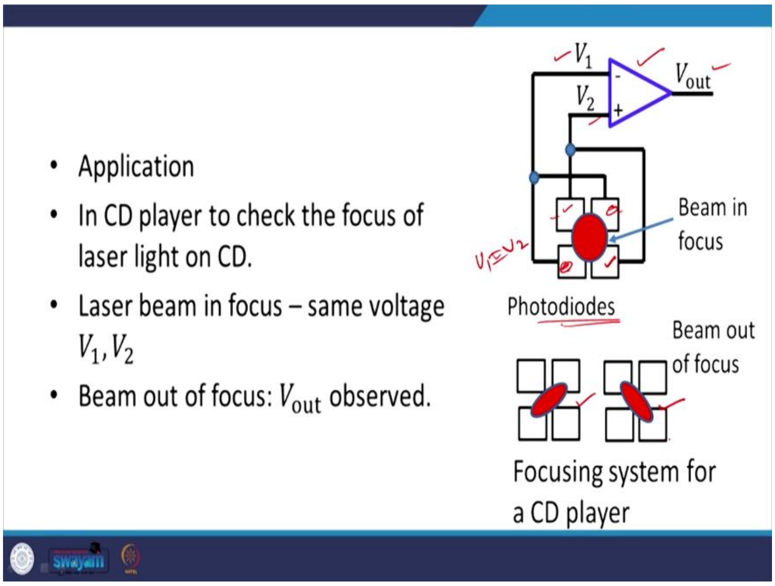

One of the very beautiful application of this is in the CD player to check the focus of the laser light on the CD. So, you have the op amp over here, there are two terminals V_1, V_2, and this is your output side. So, these terminals are connected to the photodiodes over here. These photodiodes are there and V_1 inverting side is connected to this one and this one, whereas the non-inverting side is connected to this, diagonally this one, this one. And here they are connected to this one. Now, when there is a laser beam in perfect focus there is the same voltage. So, V_1 = V_2 you get it from here. So, you do not have any signal. And when there is out of focus either this way or it is this way, you have a certain signal. So, if you have the beam out of focus, then you have a signal. So, this is the application where the comparator is used.

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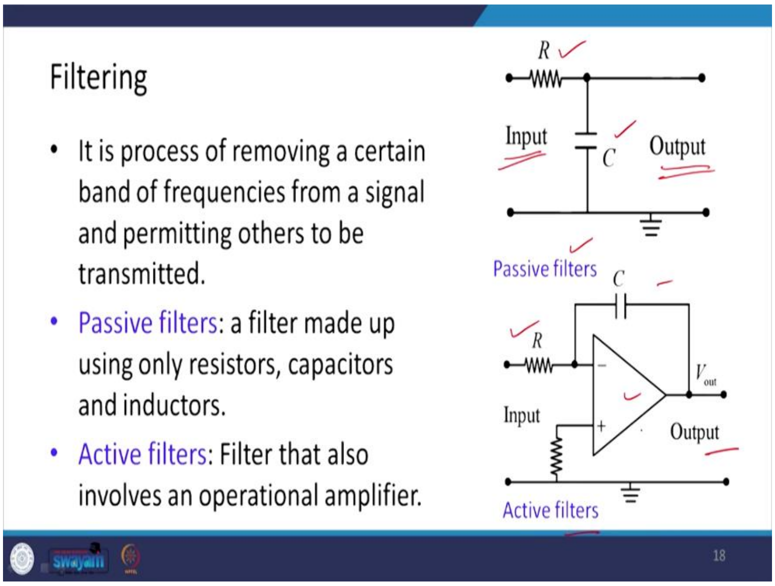

Now, let us look at the filters. Filters are also important device in a mechatronic system for the signal conditioning purposes. It is as the name indicates, it is a process of removing a certain band of frequencies from a signal and permitting other to be transmitted. And these filters could be either active or passive. Passive as a name indicates a filter made up of using resistor, capacitor, inductor, and there is no power source over here. Whereas the active filters are those which involve operational amplifiers and you know that the operational amplifier needs a power supply for them to work. That is why they are called active filters. Here you have the example for the passive filter. You have a resistor, capacitor over here, this is your input side, this is your output side, and here you have the active filter where an op-amp is there. You have a resistor, capacitor, and all.

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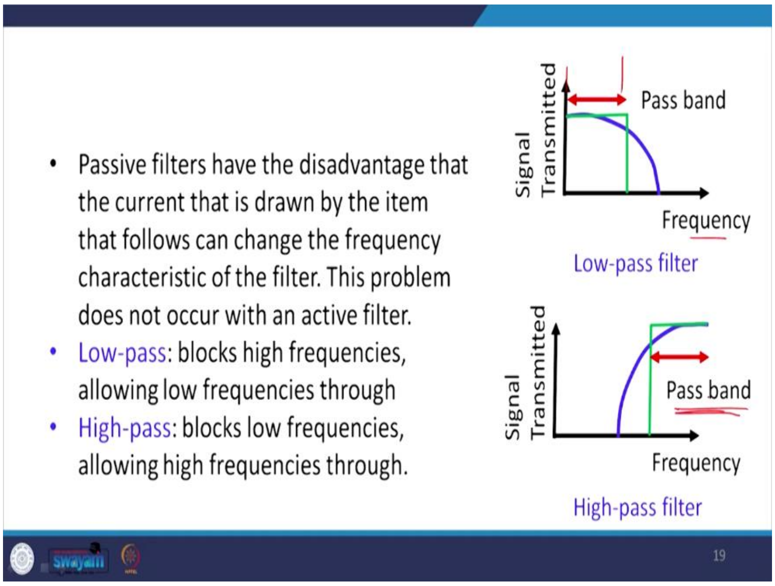

So, let us look at the definition of these filters. Low pass filter as the name indicates they allow the lower frequencies and they block the higher frequencies. So, this signal transmitted and frequency if I am plotting only this range is the allowed one and other higher ranges are blocked. And high pass filter, only the higher signal of a frequency higher than a particular frequency they are allowed, and others are blocked.

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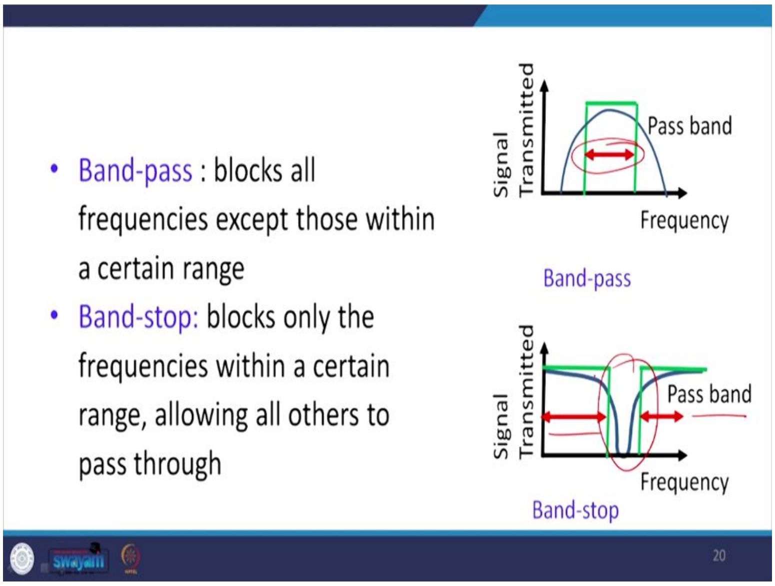

Then you have a band pass filter, where we allow a frequency of a particular band to be passed through, that is the it blocks all frequency except those within this range. And band stop filter blocks only the frequencies within a certain range allowing all other to pass through. So, here this is the pass band, this is the pass band, but frequency of this range is going to be blocked. So, this is what is the band stop filter.

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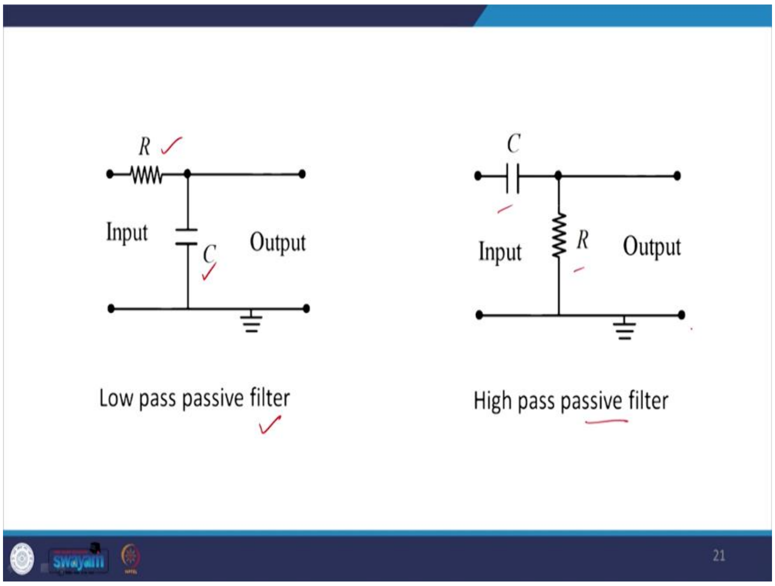

So, the low pass passive filter is this one where you have resistor and capacitor with used in this fashion. And high pass passive filter is this one with capacitor and resistor being used in this fashion.

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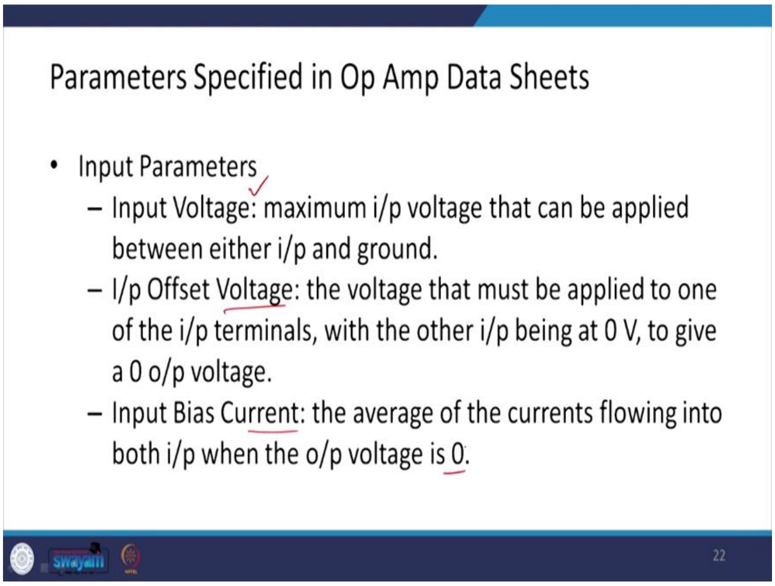

Then, let us look at what are the parameters specified in op-amp data sheet. What are the manufacturer, what all parameters the manufacturer specifies in the data sheet for the op-amp? So, these parameters could be input parameter, output parameter, dynamic parameter, we will look at this. The input parameter first of all is the input voltage. So, it is the maximum input voltage that can be applied between either, input and the ground. So, we have two input ports; inverting and non-inverting. So, between either of that and the ground how much maximum input voltage we can supply.

Then the input offset voltage. The voltage that must be applied to one of the input terminals with the other input being at 0 volt to give a 0 output voltage. So, as I explained in my last lecture about the offset. So, this is how it is defined. Then input bias current, the average of the current flowing into both the input when the output voltage is 0. This is what we call the input bias current.

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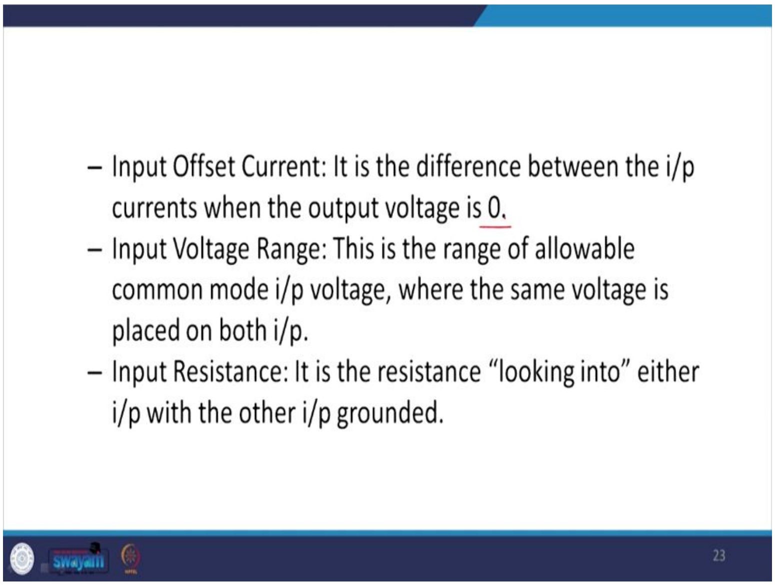

Then input offset current, it is the difference between the input current when the output voltage is 0. Then input voltage range, this is the range of allowable common mode input voltage is where the same voltage is placed in the both the input. Then input resistance, it is the resistance looking into either the input with the other input being grounded. Now, what are the output parameters? These are the output resistance, output circuit current, output voltage swing.

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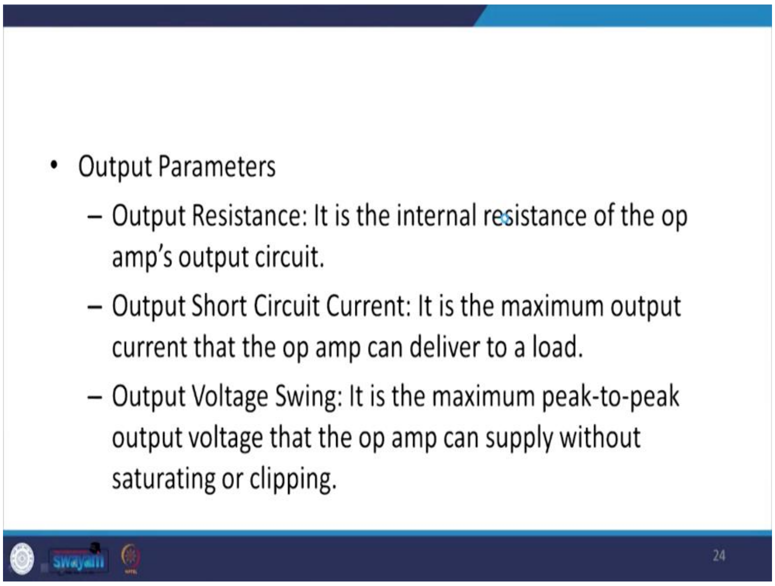

What is the output resistance? It is the internal resistance of the op amp output circuit. And what is the output short circuit current? It is the maximum output current that the op-amp can deliver to a load. And what is the output voltage swing? It is the maximum peak to peak output voltage that the output can supply without saturating or the clipping.

Then, what are the dynamic parameter? So, dynamic parameters are open-loop voltage gain. So, it is the ratio of the output to the differential input voltage of the op-amp without external feedback. As the name indicates, it is an open-loop voltage gain.

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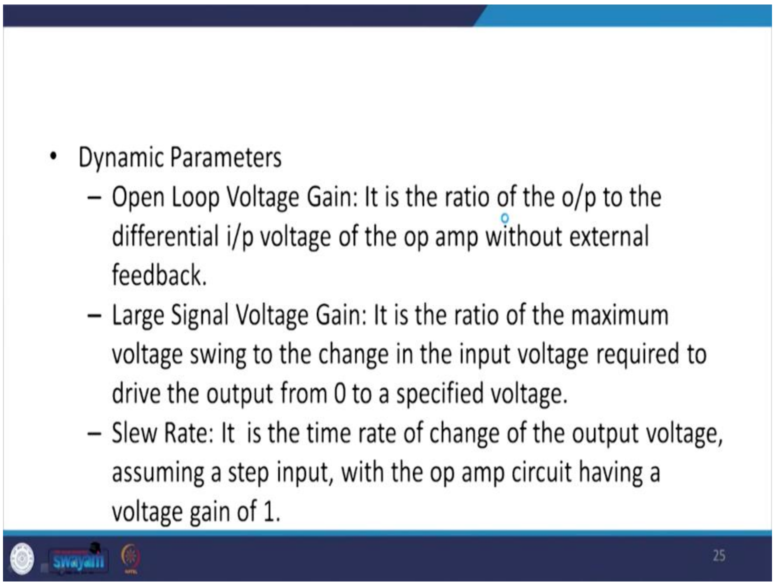

Then, what is the large signal voltage gain? It is the ratio of the maximum voltage swing to the change in the input voltage required to drive the output from 0 to a specific voltage. Then, what is the slew rate? I talked about slew rate in my previous lecture also. It is the time rate of change of the output voltage assuming a step input, with op amp circuit having a voltage gain of 1.

Then, what are the other parameter? There are certain other parameters which are also is specified maximum supply voltage. It is the maximum positive and negative voltage permitted to power the op-amp. Then, what is the supply current? It is the current that the op-amp draws from the power supply. Then, the common-mode rejection ratio is the ratio of the difference mode gain. That is the output gain corresponding to the difference between the input to the common-mode gain that is the output gain when the same voltage is applied to both the inputs and this is usually expressed in terms of decimals.

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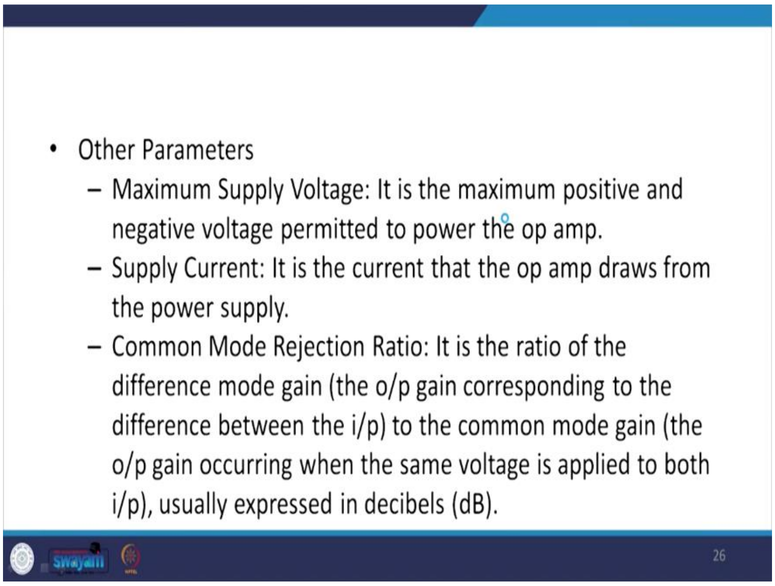

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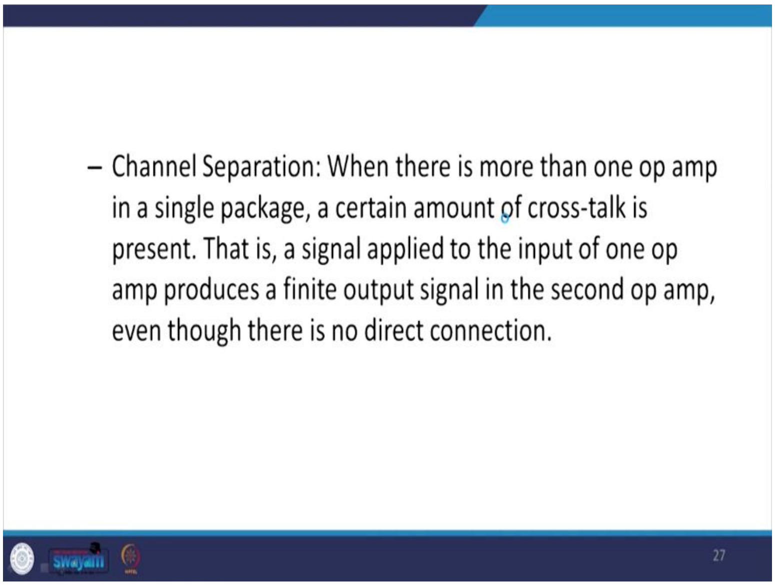

Then, the channel separation. See when there is more than one op amp in a single package, a certain amount of crosstalk is present. And what do you mean by this crosstalk? That is the signal applied to the input of one op amp producing a finite amount of signal to the second op amp even though there is no direct connection between both the op amps. So, this is specified by the channel separation.

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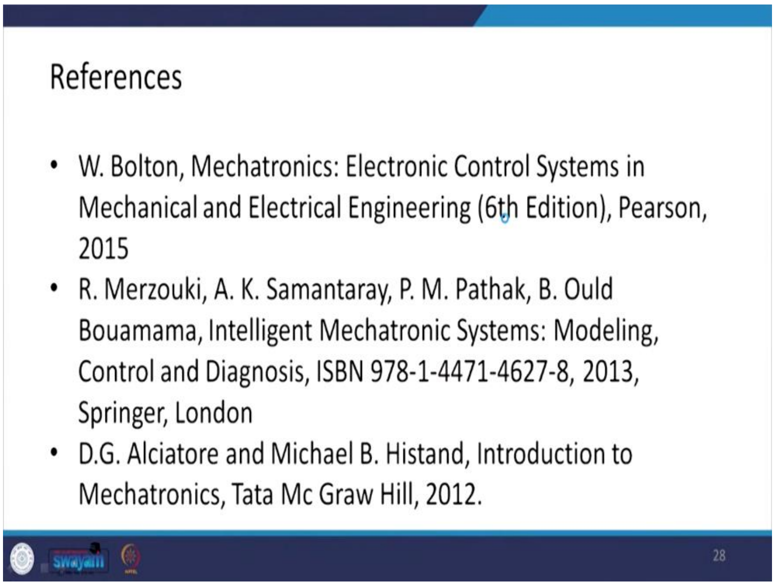

So, these are the further references which I have used in preparing these lectures. So, if you want to read it more please go through these references.

Thank you very much.