Analog Circuits

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Week -01
Module - 03
OP-AMPs

Hello, welcome to another module of this course analog circuits. So the past module we had covered the concepts of poles and zeros, in this module we will be covering the concept of opamp and with this we will be starting our formal course on the analog circuits.

Opamp is a very basic circuit that is used to introduce many of the concepts used in analog circuit design, the reason being opamp is a very simplified version of more complicated devices like MOSFET's or BJT's, it is a linear device which unlike other devices like MOSFET or BJT's which are not inherently linear so it is easy to understand it is easy to introduce the concepts of analog circuits using an opamp.

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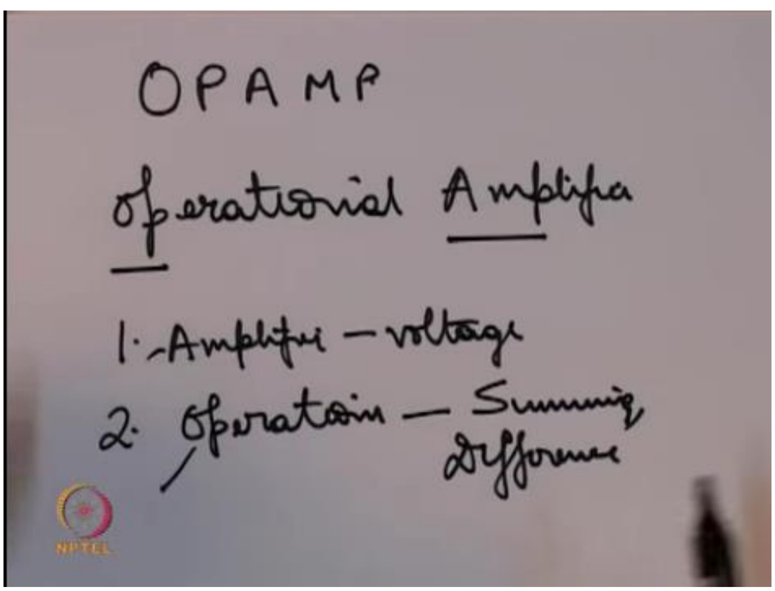

So let us see what is an opamp? An operational amplifier is called an opamp by taking the first two letters or operation and the first three letters of the word amplifier, so why is it called an operational amplifier? The reason it is called an operational amplifier, because number one it is an amplifier voltage specifically a voltage amplifier that is if you have a low value voltage at the input it can produce a higher value voltage at the output and secondly it is used to perform operations various operations like summing, difference and many other operations that we shall see in this course.

As we proceed along this module so that is why it is called an operational amplifier that is it can perform operations and it is an amplifier that is a very simple definition of opamp. Now but now let us see the properties of an opamp before going on to the properties of an opamp we have actual opamps that can be bought on the market, but these opamps are not that can be purchased from any vendor these are not the so called ideal opamp they are real opamp. So to begin with we should start with an ideal opamp

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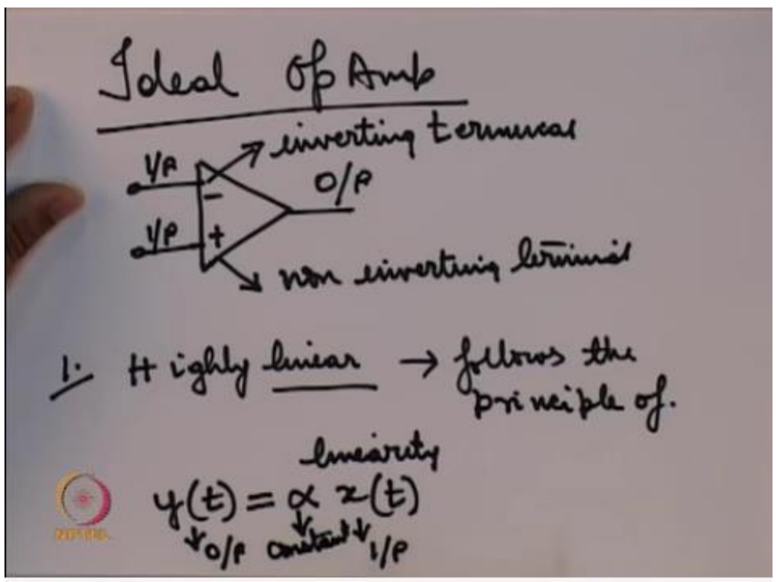

So what is an ideal opamp? An ideal opamp is represented by this circuit, this is the circuit you (()) (03:13) it has three terminals and output and two input terminals, one input terminal is labeled by a minus sign the other input terminal is labeled by a plus sign, the one which is labeled by a minus sign is called an inverting input or the inverting terminal the one labeled by the positive sign is called a non inverting terminal.

But an ideal opamp it has some properties number one it is highly linear, what do you mean by the term linear? So the first property is that opamp is highly linear device, now what do you mean by this term linear? When I say linear it means follows the principle of linearity and what is the principle of linearity? That suppose you have your output represented as yt then yt will be proportional to the input xt so xt is the input yt is the output and alpha is a constant if this relationship holds in any system then such a system is said to be linear.

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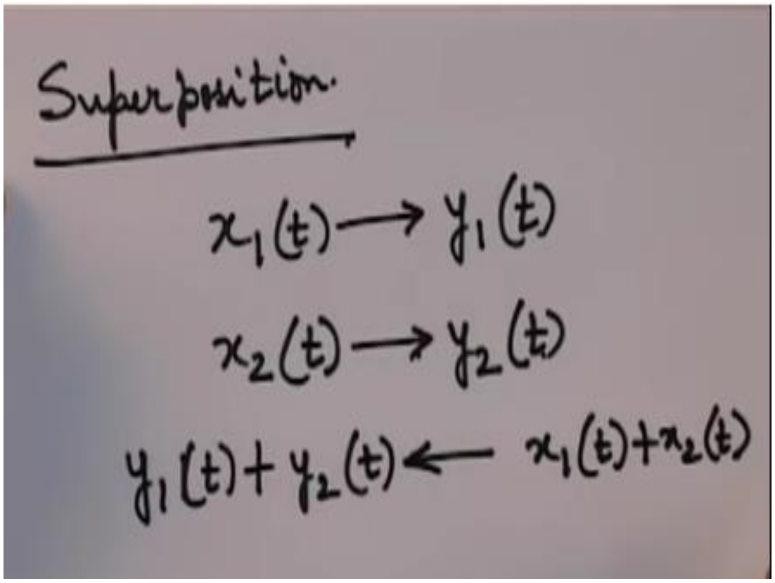

In addition to this there is one more property which has to be such satisfied for a system to be called linear, which is superposition. It is if x1t is the one input and x2t is another input and suppose due to this x1t I have an output y1t and due to this x2t I have an output y2t then y1t+y2t should be the output produced when my input is x1t+x2t that is not only should the output be proportional to the input but also the sum of the outputs produced by individual inputs should also be proportional to the sum of the individual inputs. So these are 2 principles that have to be followed for a system to be called linear.

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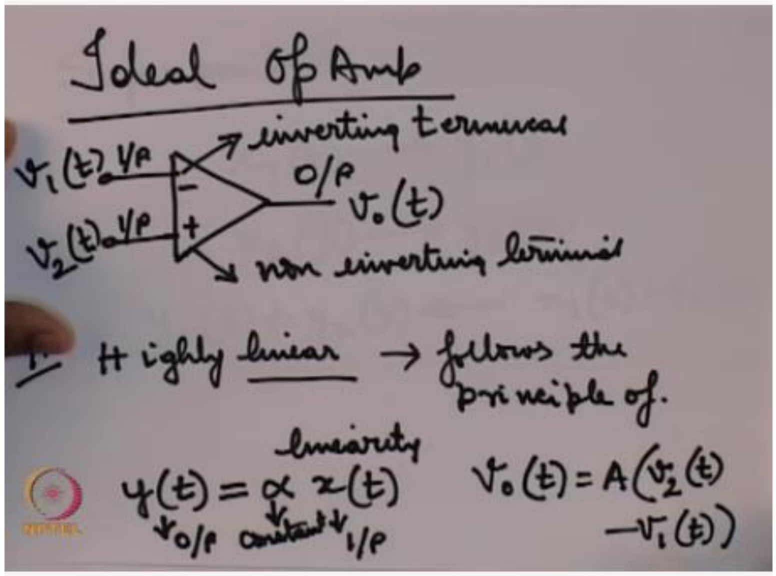

So it is highly when I say that an opamp is highly linear, what it means is that when I say that an ideal opamp is highly linear, it means that this relationship is followed. So if we have an output say let us say I call that Vot and say my input here is V1T input non inverting input is V2T then VoT should be equal to V2T-V1, okay and in addition it should also satisfy this condition so it is highly linear.

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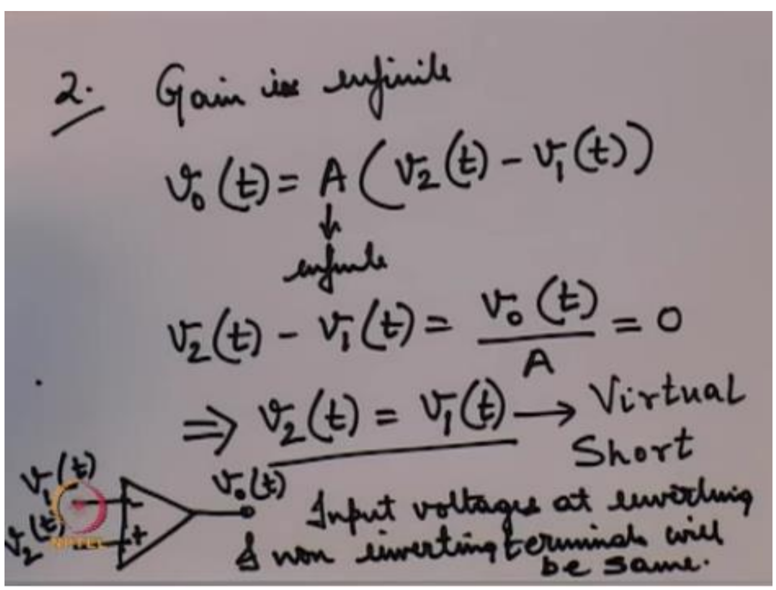

Then, what are the other properties? Gain is infinite, so gain is infinite means let us go back to that relationship v or t is equal to A v2t-v1t, so this gain A is infinite if it is infinite then you know this might be a little counterintuitive that if A is infinite and obviously Vo should always been find another way of looking at the same problem is let us see that happens to v2t-v1t, that is equal to vot upon it since A is infinite therefore we can say that this is always equal to 0 which in turn implies that v2t is always equal to v1t.

Now this condition, I can redraw my opamp is called a virtual short, virtual short means these 2 terminals the inverting and non inverting terminal the input voltages to the inverting and non inverting terminal for an ideal opamp will always be 0. It is input voltage is at inverting and non inverting terminals will be same this is known as virtual show.

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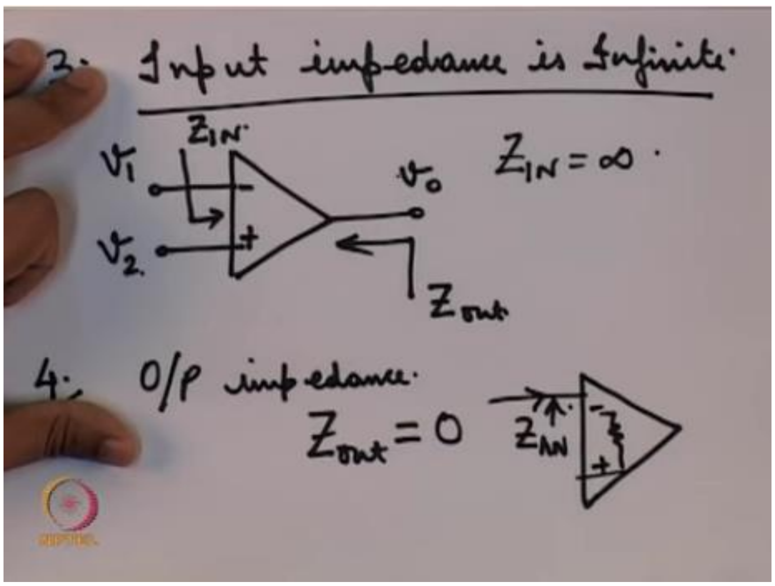

And this now yet another property of the opamp is so once again we have our opamp inverting, non-inverting output. Now if you calculate the input impedance Zin, Zin is always equal to infinity and the fourth point is output impedance that is Z out is equal to 0 now I do not want to delve into the details of this input and output impedance right now but just I will mention that for a voltage amplifier say and how amplifier is a voltage amplifier?

Then ideally the input impedance should always be high, why because if there is some input impedance then some finite input impedance or low value of input impedance then there will be a current flowing through the impedance or in other words if we if you just want to show.

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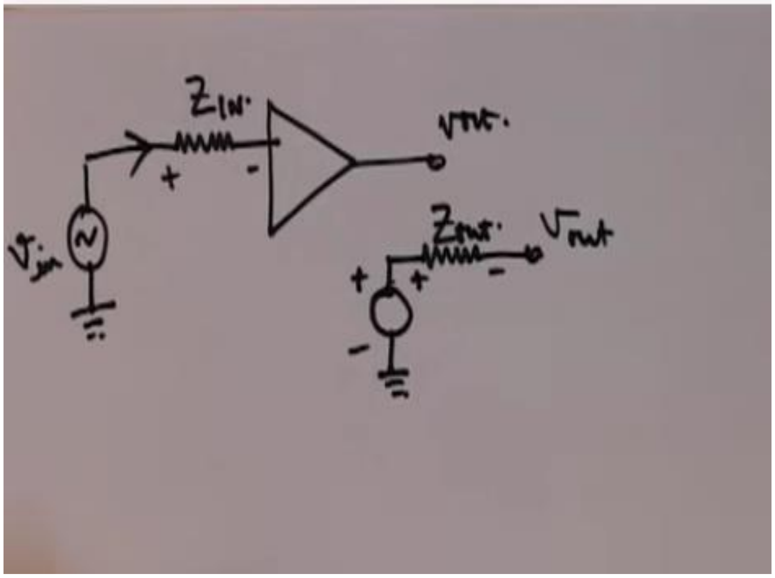

Say, we have an amplifier whose input impedance is given like this, so if you have a source here a voltage source now if Zin is not infinite then there will be a finite current flowing through this input impedance, because of which there will be a voltage drop and therefore at the input of the voltage amplifier the full be in that is the input voltage will not appear conversely for the output impedance.

Suppose you have voltage as the output, this voltage source represents the output voltage with the series impedance Zout. Now here if Zout is non 0 or even high, what happens is the output voltage before appearing at Vout will undergo a potential rock due to this Zout and hence the total output voltage that was supposed to go to the output does not appear, so this was just a digression about why input impedance on output impedance of a voltage amplifier should be high very high and very low respectively.

So another property of this ideal opamp is that the output impedance should be very low input impedance should be very high then the another important property of the ideal opamp is 0 DC offset, now as we shall see later on we shall study this offset voltage phenomenon in some detail later on.

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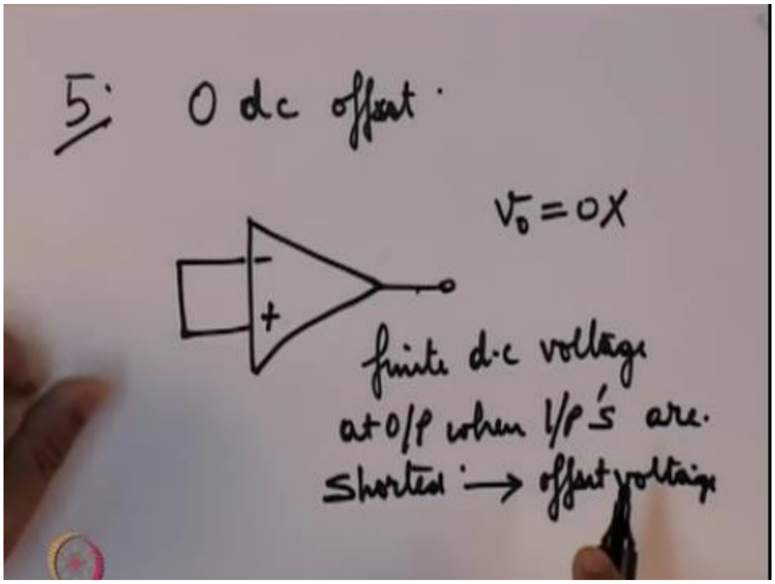

But for now, if this is an opamp and if you short the inputs then obviously both the inputs are at the same value which is also the case from what you are short but in some real opamps where the gain is not infinity what happens is when you short the 2 inputs vo which should have been 0 is not that you get some finite value finite DC voltage at the output this finite so a finite DC voltage at output when inputs are shortened this finite DC voltage is knows as offset voltage and is undesirable, so for an ideal opamp we have 0 DC voltage 0 DC offset.

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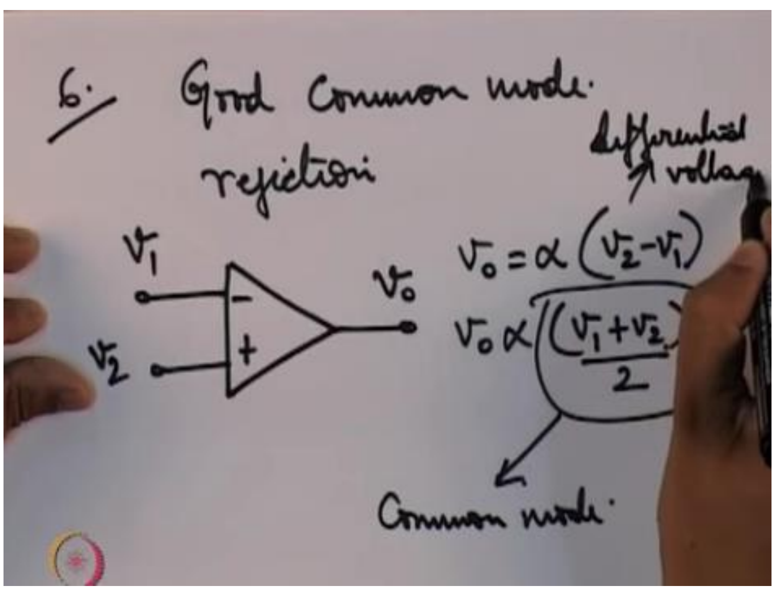

The second last property of an opamp is that good common mode rejection, so common mode out at the output means suppose you have 2 inputs now your output should always be proportional ideally to the difference between the 2 voltages isn't it, that is what you want but sometimes what we see is output, there is a component and output which is proportional to the average of the inputs so this average of the inputs is known as common mode and is undesirable.

We ideally want no component at the output should be proportional the common mode voltage and therefore an ideal opamp should have very good common mode rejection by rejection I means it should totally reject this component and the entire output should only be proportional to the difference or differential voltage one another property that and I that is desirable in an ideal opamp is the frequency response.

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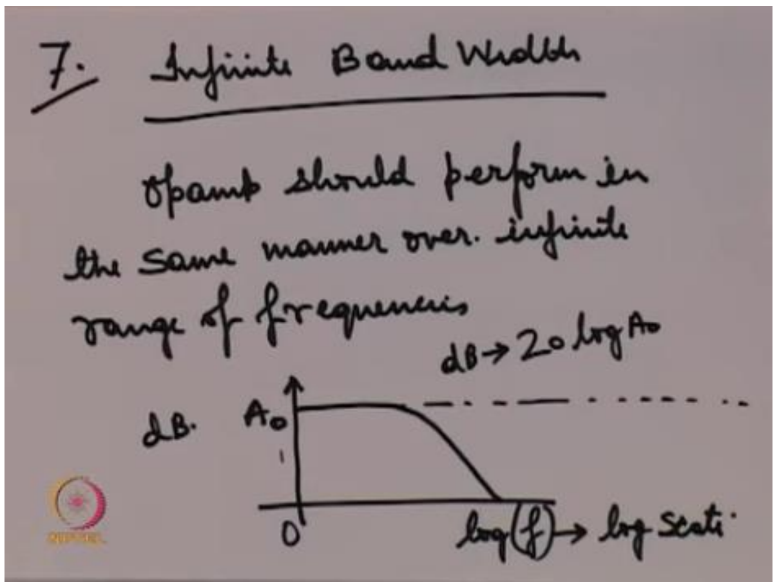

That is opamp should perform in the same manner over infinite range of frequencies, usually amplifiers act like a low pass filter, so there is a DC gain which is usually high and then slowly the gain meters of as the frequency increases, so this is on a log scale this frequency A is plotted on log scale that is this is log of F on the X axis and this is in DB, so decibel means 20 log of A0 DB this is the formula for converting from absolute magnitude too deep.

So this has been plotted this amplitude has been our output amplitude has been plotted in DB, this X axis the frequency is on a log scale this is the usual pattern that we see that the amplifier does not perform the same way over all frequencies. If A0 is the output amplitude at D0 frequency or DC, we will see that as we keep on increasing the frequency the output gradually decreases, but in an ideal opamp that will not happen in an ideal opamp.

We will assume that our frequency response is like this good remains A0, if this is the output at DC, A0 will continue to be the value over all frequency ranges now one property that I mentioned is actually derive able from another property.

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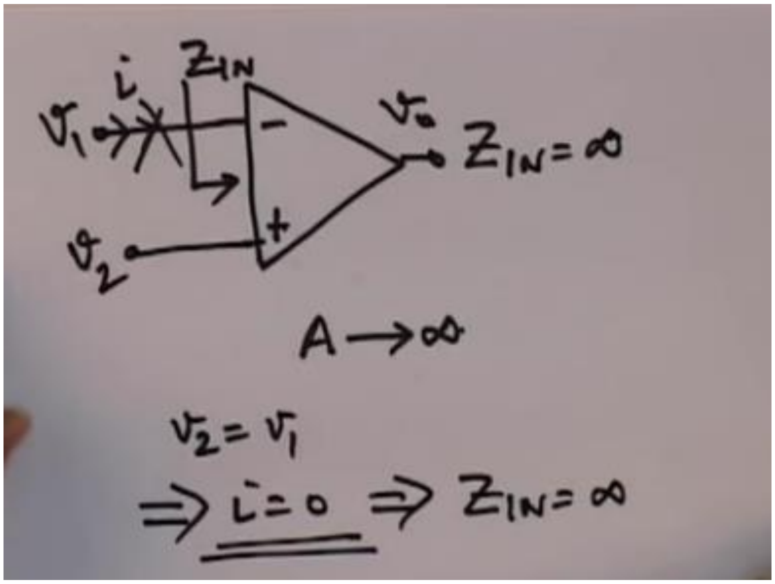

For example, I said that the input impedance of an ideal opamp should be infinity, this can be derived from the another property that is the gain is infinity. So we know that V2 is equal to V1 and if V2 is equal to V1 then we can also say that there is no current flowing, why because since both the terminals are the same potential therefore there cannot be a current flowing between V1 and V2 terminals and therefore if so this implies that current i is equal to 0 and from this since i is equal to 0 this implies that input impedance is equal to infinity.

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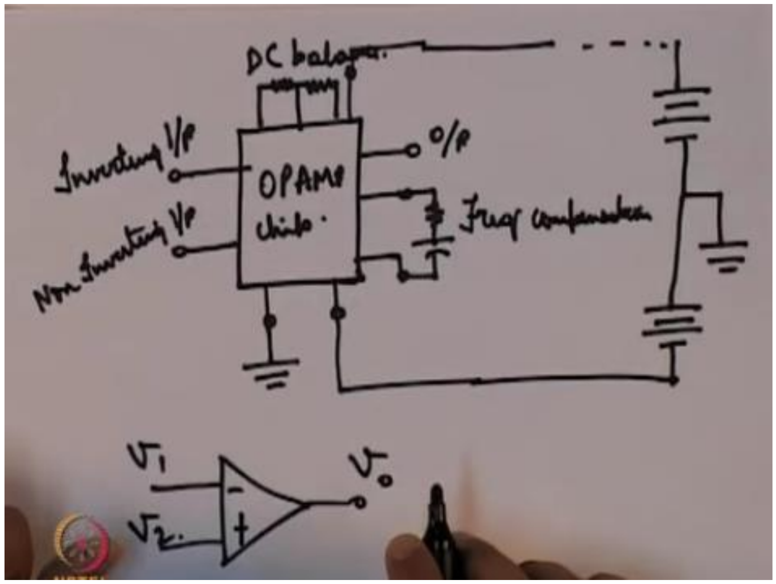

A normal opamp that you buy from the market you can purchase various opamps that are available, the chip that you the opamp is actually in the form of a chip and one possible chip in one chip that I know of has a layout of the various spins, like this so this is a opamp chip these are the this is the inverting input it the non inverting input this is the output.

So far these agree with the circuit that we have drawn so this is vo v1 v2 in addition to that there is also the power supply because the opamp is after all an active device and if we will need a DC power supply for its operation. So 2 terminals one for the positive and one for the negative terminal of the power supply then there is frequency compensation some chips which are where you can connect some external elements like inductors, capacitors or resistance to compensate for the frequency response.

As I said an opamp a real opamp will have its gain decreasing with increasing frequency or we might want to compensate or we might want to change the response for stability of the amplifier, so for all those purposes some additional pins have been provided where you can connect some external resistance capacitance or inductors to change the frequency response characteristic of the opamp then there is a DC balance something's dedicated for DC balance of the opamp.

So DC balance means the offset voltage that is a problem or as we shall see later, there is also something called offset current so to compensate for them we have some provisions for pins where properly designed external resistors can be connected to reduce those offset voltages and offset currents usually for an ideal opamp.

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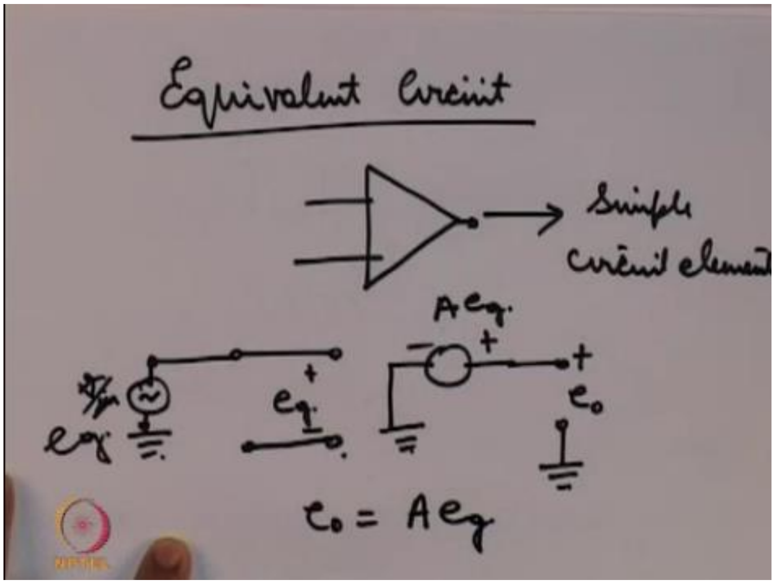

We can draw a simple equivalent diagram so equivalent circuit, now what is an equivalent circuit? An equivalent circuit is a circuit where a somewhat complicated circuit is represented in terms of simple circuit elements it gives a better visualization of this circuit so if you have an opamp the inside of this opamp is like a black box, but if we threw an equivalent circuit we can get a little bit more information about what is going on inside.

So an opamp for an ideal opamp the equivalent circuit is something like this you so this is the equivalent circuit as we can see the input voltage is directly fed without any impedance connected between the terminal, so on impedance connected means the input is an opamp basically opamp means in input impedances infinite and the output we have a voltage source.

This is a dependent voltage source whose value which is proportional to the input voltage EG instead of V in we can write this also as eg and this AG basically appears at the output as easy row there is no the output impedance is 0 so no impedance is connected and we have e0 is equal to A times eg, so this is the equivalent representation of a ideal opamp.

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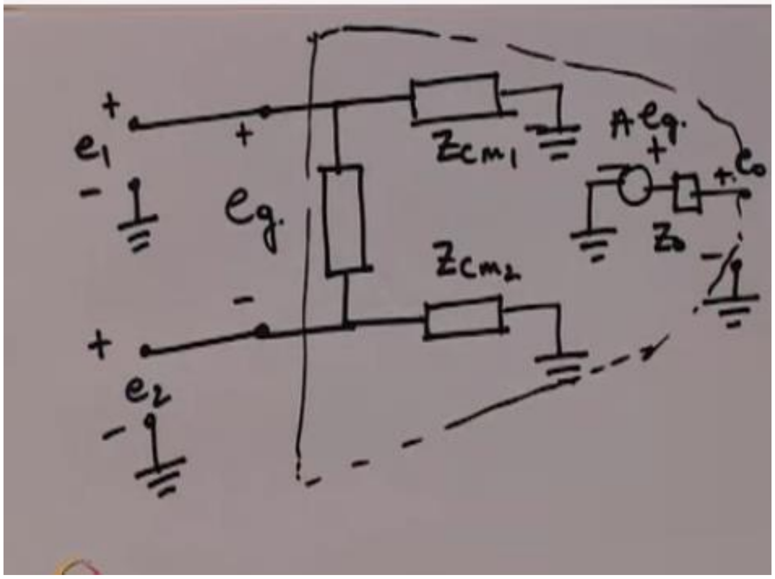

Now for a real opamp we have a somewhat more complicated representation like this, so the opamp itself is this whole block. So, in this lecture we covered the basics of an ideal opamp we saw its properties and also its equivalent circuit, of course the properties of the of an ideal opamp are ideal in the sense that they cannot be actually realizable.

But we will see that if we start our design with an ideal opamp we can achieve a number of circuits which though you used ideal opamp can be very closely realized with real opamp as well and of course since they are made using ideal opamp when we actually implement them using practical opamp there will be some shortcoming and we shall study them but ideal opamp gives a good template from where to design a number of circuits and that we will cover in the next module, thank you.