# Microelectronics: Devices to Circuits
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## Lecture - 50
## Ideal Operation Amplifier and Its Terminals

Hello and welcome to the NPTEL online certification course on Microelectronics Devices to Circuits. Today we will start with a new chapter, or a new section as per the syllabus and the chapter is on operational amplifiers and its terminals. So the name of the module is ideal operational amplifiers and its terminals. What we will be doing in this module is the following.

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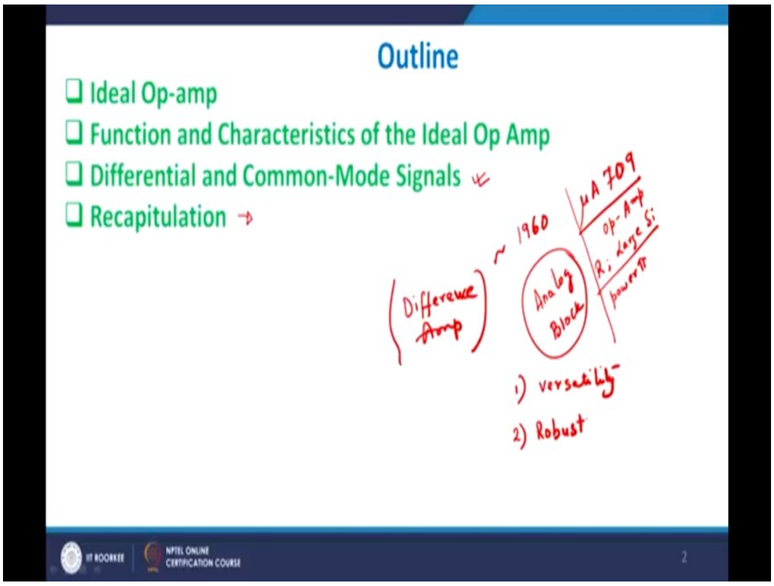

**Outline**

- ☐ Ideal Op-amp
- ☐ Function and Characteristics of the Ideal Op Amp
- ☐ Differential and Common-Mode Signals
- ☐ Recapitulation

We will look into what is known as an ideal Op-Amp, when we say Op-Amp, we mean to say operational amplifiers and we will see why is it named so. We will look into the function and characteristics of an ideal operational amplifier. Then we will be looking into the differential and common mode signal here, right? And then we will come to non-inverting inverting mode and then we will finally recapitulate our discussion.

And now way back in 1960's or around 50's and 60's, you had the first operational amplifier been designed which was in IC form, in so, it approximately in 1960's or 65's. You had this your operational amplifier which was named as μA709. So this was a first sort of an operational amplifier which was designed. It consists of large number of resistors. It consists large silicon area, right. And the silicon area was typically very large in this case.

As a result, it also consumed very high power. So the power was also very high, right. And this was in the analog block available tome. So it was basically an analog block and as I discussed with you, this analog block did consume large amount of power, but this was the first time we are able to look into the operational amplifier. What is the operational amplifier basically means? It primarily means that it senses the difference between two voltages and then amplifies it to have a output voltage, which is just a difference of the two voltages.

So I, if I have got two voltages maybe sine wave, 2 sine waves and then we subtract the 2 and then multiply with the fixed gain value 'A' and that is what output is all about. So that is the reason it is also referred to as a difference amplifier, right. It is also referred to as a difference amplifier. Why difference? Because it is actually trying to look into the difference of 2 voltage sources and trying to find out the output voltage depending on the difference of the 2 voltage sources.

Now, the idea was why it became famous? Or operational amplifier was used quite often in large amount of instrumentation design, was first of all it is versatility, right. Versatility so, the first reason why it became very famous was versatility, and the reason why it was so versatile is that you put this operational amplifier anywhere within the structure, whenever you have an analog signal or for that matter even if digital signal is available to you, but primarily 90 percent of the cases, analog signals. You can do large amount of computation in analog domain using operational amplifier, right.

So you can add 2 signals. You can subtract 2 signals. You can do multiplication of 2 signals. You can do cascading of 2 signals so on and so forth. So this was not possible earlier, remember. It was possible through a bipolar technology, but operational amplifier through bipolar technology is also available to us and the gains are relatively very high. So you get a large gain and you also get a versatility and you can use this across many signals, signal domains.

The second thing is its robustness. It is quite robust, in the sense that the offsets or the variabilities are very very low in this case. So if you have designed a Op-Amp which is say working with an amplification of 100 then you will be 100 percent sure or you will be pretty sure that the gain is fixed at 100, irrespective of the ambient, irrespective of the variations in the parameters of the devices used in the operation amplifier. It is almost fixed at approximately 100, right.

So it is two advantages, it's versatility and it is very robust in design. That was the reason Op-Amp is still very very important in IC whenever you are, you are using it in specially analog and mixed signal blocks of your VLSR design.

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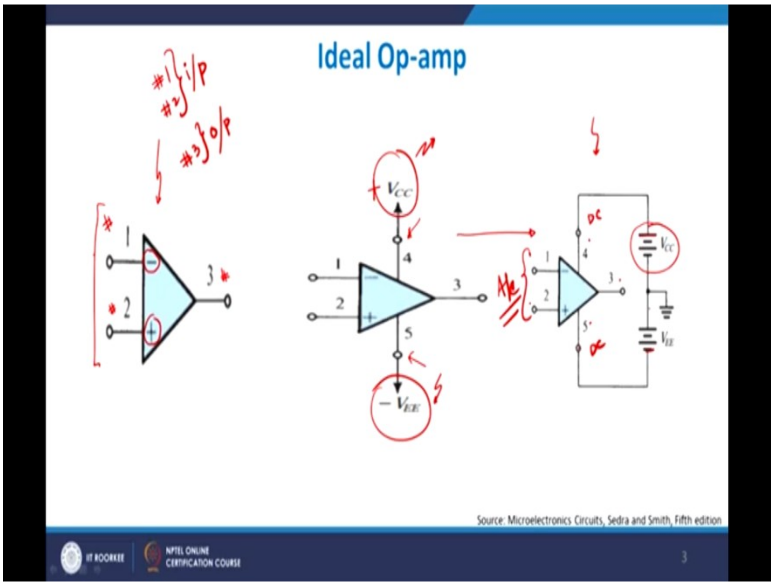

Ideal Op-amp

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

Let me show you how an ideal operational amplifier looks like. Ideally for a user, the ideal operational amplifiers look like this, which is this one and it has got 3 terminals here. Terminal number 1, so this is terminal number 1, right. This is terminal number 2 here and this is a terminal number 3. So there are 3 terminals and there is a specific sign to the first terminal minus. Specific sign to the second terminal plus, and you have an output here which is $V_{out}$. So, this is your output terminal.

So, terminal number 1 and terminal number 2 are basically your input terminals, right. And terminal number 3 is your output terminal. So, it is physically a 3 terminal structure where in the first two terminals 1 and 2 are basically your input terminals and structure 3 is output terminal here.

Now, since this is active device obviously it is operational amplifiers are made up of differential amplifiers that you possibly be knowing also or maybe I can give you a extra talk on that, but these are internally they are made up of difference amplifiers, differential amplifiers which we have already studied on our earlier modules.

So, you require an external power source to drive these operational amplifiers. And this is where this fourth and fifth terminal comes into picture. We generally do not show these terminals or we do not show whenever, whenever drawing an operational amplifier, we do not show it but typically these remain there and this is given as plus $V_{CC}$ here and a minus $V_{EE}$ here. So, I have a plus $V_{CC}$ here and I have a minus $V_{EE}$ at this particular point. Obviously, this is third terminal which is available to you.

Now therefore, I can therefore correlate this to this terminal, that terminal 4 is biased in this in this manner such that the positive terminal of $V_{CC}$ is connected here and the negative terminal of $V_{EE}$ is connected to terminal number 5. So I have got therefore typically at this stage understanding purposes, 1, 2, 3, 4 and 5. 4 and 5 are primarily DC biases. 1, 2 are input and 3 is the output.

Now, if you look very carefully across this network which you see here, these are the DC biases which you apply and here you apply the AC signal, right. So sort of a mixed signal approaches here, but DC biases is done in order to or in order to make those transistors or a bipolar transistor or even a MOSFET in the active region of operation so that they start behaving like a current source and you do have a large gain available with you. So this is the basic structure of an operational amplifier and basic structure looks like this in a real sense.

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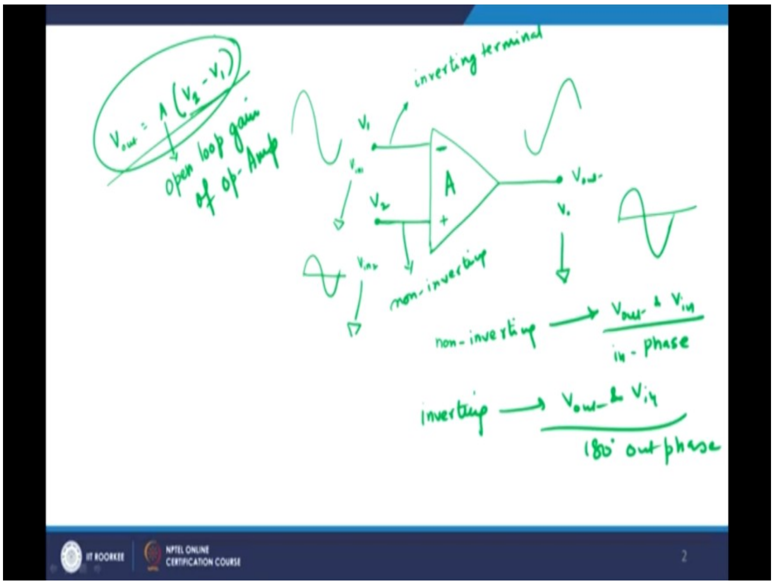

So, let me show to you or let me give you an idea of what the idea is. The idea is something like this. So if I have got a as I discussed with you that I have a operational amplifier like this, right. And I have got negative and positive, so this is your this and this your this. This terminal, negative terminal is referred to as an inverting terminal, inverting terminal. And this is referred to as a non-inverting terminal.

Inverting terminal primarily means that any signal you give here right, will be inverted or will have a 180 degree phase shift between input and output, output where? Terminal number 3. So this is your output, $V_{out}$ and this is always measured with respective ground. So all of these measurements, so this is a $V_{out}$. So all these measurements which you do here, this is with respect so so this is $V_{in1}$ let us suppose again with respect to ground. And then you have $V_{in2}$ here, again with respect to ground. So all are with respect to ground here.

And whatever signal you give on a inverting terminal here will appear as 180 degree phase shift. So if you have got something like this it it will appear something like this in the output side. Whereas in the non-inverting terminal if you give like this it output will be something like this, right and you have to ensure that, so they they will be in phase. So if I talk of non-inverting terminal, non-inverting inverting then I will have $V_{out}$ and $V_{in}$ are in phase, right, in phase. And if you have got inverting terminal then $V_{out}$ and $V_{in}$ will be 180 degree out phase this is quite important.

And therefore, and therefore, let us suppose this is suppose, this is $V_1$ and this is $V_2$, then my output looks like $V_{out}$ or say $V_{out}$ in this case will look like A multiplied by $V_2$ minus $V_1$. This will be the general equation of an ideal operational amplifier. Now you see, it is $V_2$ minus $V_1$ why? Because it is connected to the inverting terminal. So whatever input you give, it will be always phase shifted by 180 degree whereas $V_2$ is basically my inverting terminal.

Now, when I so, so whatever signal I am giving, is the difference between the 2 signals, is basically my output multiplied by A. A is referred to as open loop gain of operational amplifier. So, A is defined as the open loop gain of the operational amplifier which means that A, basically this is the gain of the differential amplifier which is there within the operational amplifier, right. And therefore, you get $V_{out}$ to be equals to A times $V_2$ minus $V_1$, right and this is what general scheme of things appears here.

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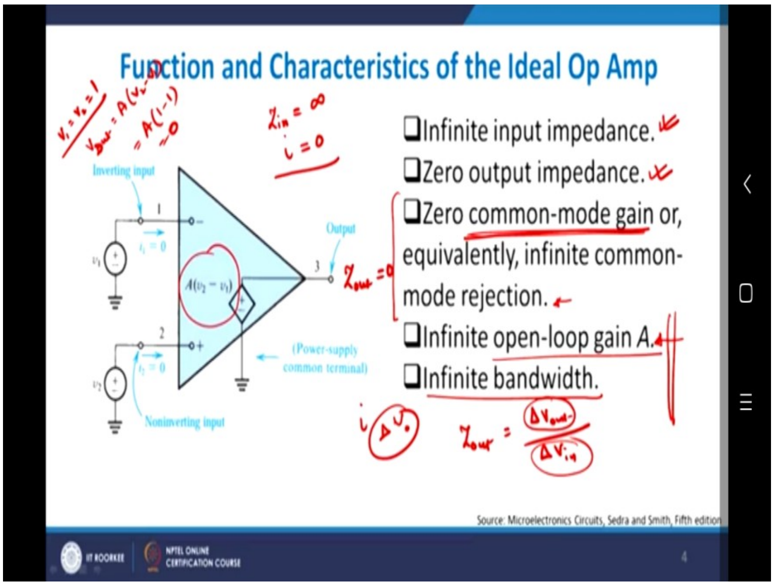
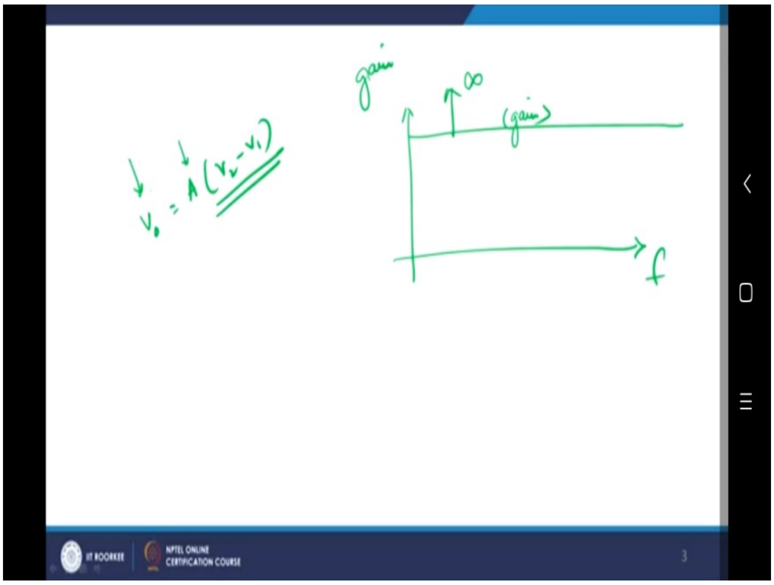


Function and Characteristics of the Ideal Op Amp

- ❑Infinite input impedance.
- ❑Zero output impedance.
- ❑Zero common-mode gain or, equivalently, infinite common-mode rejection.
- ❑Infinite open-loop gain A.
- ❑Infinite bandwidth.

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition



Now, what you see in this case is that if you look, now let us draw it’s appropriate circuit diagram its equivalent circuit diagram. So if you see here, I have an inverting terminal. I have a non-inverting terminal. It has been seen that the inverting, that the input of my input of my Op Amp is having $Z_{in}$ which is input impedance to be ideally infinite which mean that the current is actually equals to 0. So, no current is entering into the terminal of Op Amp, right. And you can understand from your basic theory also.

See if you remember from your differential amplifier that 2 inputs are towards the gate, remember. The gate of the MOSFET, right. The gate of the MOSFET, automatically, if you remember has got a very very high input impedance because there is an oxide layer and therefore, it is a dielectric. And that is the reason you do not have any current flowing through the gate side, right. Almost 0 current, which means that the input impedance is relatively very high. In ideal Op Amp the input impedance should be infinitely high which means that your voltage remains fixed, right and your current is almost 0.

Whereas in the output side your $Z_{out}$, will be equal to 0 in an ideal case. Which means that you can draw nay current you want to do, right. You can draw any current and and typically your voltage will remain fixed. Or otherwise or otherwise the current will remain fixed and you can vary any voltage which you want $\Delta V_{out}$. So how I will define my $Z_{out}$? $Z_{out}$ is defined as $\Delta V_{out}$ by $\Delta V_{in}$, right $\Delta V_{in}$, which means that if which means that $\Delta V_{out}$ should be equals to 0, which means that I should not see a change in the voltage with change in current.

So I can do, I can do a large variation in the current in the output domain, but my voltage across the terminal 3 and ground should remain fixed and therefore, that is my 0 output impedance which you see here. I will come to this point just now but let us concentrate here, that open loop gain for ideal operational amplifier is infinitely high

and it's infinite bandwidth, both of this treatments are for ideal operational amplifier.

Which means that if you are able to plot, if you plot gain versus gain versus omega or frequency for operational amplifier, right, it will look something like this, for ideal case it will be infinitely bandwidth and the gain is always fixed and the gain is always fixed and very high gain, infinite gain. So this will be around infinite, right and that is what is happening here.

Now you see here, within the blue triangle which is a schematic of the Op Amp this is the voltage which you will see, A times $V_2$ minus $V_1$. So it is a voltage source here and therefore, the output is given as A $V_2$ minus $V_1$ for all practical purposes. We come to this one now. See, it tells me that common mode gain is 0 which means that if any signal which is common to terminal 1 and 2 will always be rejected. So if I have $V_1$ equals to say equals to $V_2$ equals to 1 volt then of course ideally my $V_3$ or $V_{out}$ will be equals to A times $V_2$ minus $V_1$ and therefore, A times 1 minus 1 will give you 0.

So my $V_{out}$ will be equals to 0, which means that any signal which is common to both the terminals will be automatically rejected or will not be accepted or gain will be almost equals to 0. This is known as a common mode gain. Common mode, why? Because you are giving a common signal to both the inputs of your operational amplifier and therefore they are gain, right. And therefore, and therefore so, common mode gain is high.

Now, but my differential gain is relatively high. Why differential gain? Because differential gain by definition if you see is $V_{out}$ is equals to A times $V_2$ minus $V_1$. This is your differential gain. The difference between the 2 signal gets amplified by a large value which is infinitely large in ideal case and therefore this will be infinity large. But we will see that it does not, it will never be infinity, it will have some values associated with it, can you tell me why it will not be infinity? Can you think about it why it will not be infinity even if your A is infinity?

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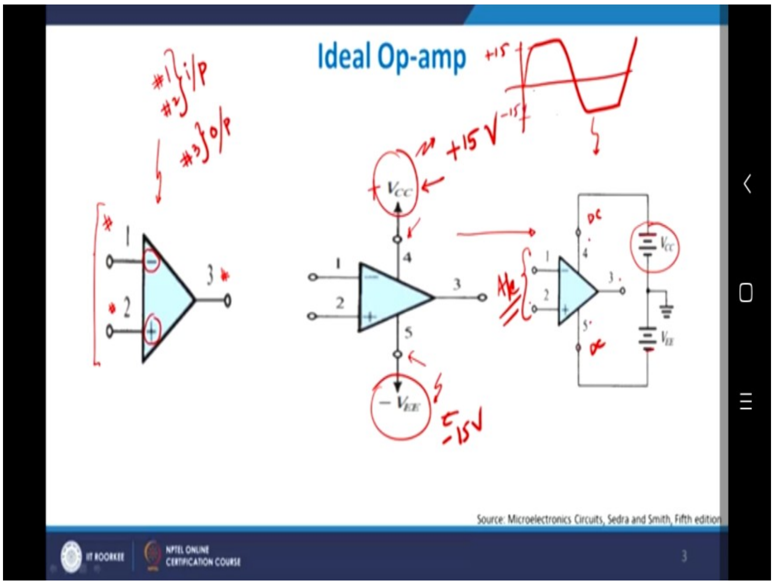

## Ideal Op-amp

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

The reason is see I discussed with you just now that in the previous slide that this is limited by plus $V_{CC}$ and minus $V_{CC}$. So if your plus $V_{CC}$ is plus 15 and let us suppose this is minus 15 volts right. You do anything you want to do, the $V_{out}$ value cannot exceed plus 15 in the positive cycle and cannot exceed minus 15 in the negative cycle because these are limited by the power supply here. And if it crosses there will be clipping.

And therefore, what you can see is if the, if typically the A value is large you will expect to see something like this. Clips. So it will clipping at plus 15 here and it will clip at minus 15 here. And so your distortion will take place. And therefore, an ideal Op Amp has got a 0 common mode common mode gain and has got a large infinite gain with with you, right.

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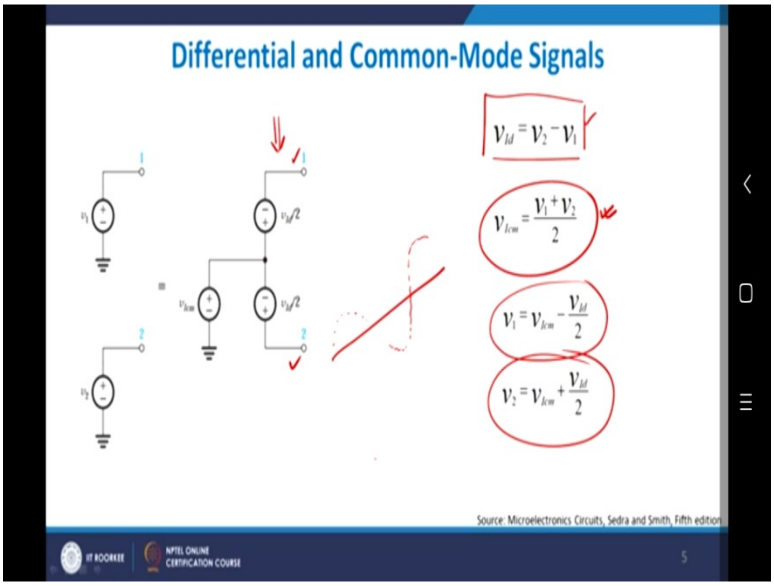

## Differential and Common-Mode Signals

$$\boxed{v_{Id} = v_2 - v_1}$$

$$v_{Icm} = \frac{v_1 + v_2}{2}$$

$$v_1 = v_{Icm} - \frac{v_{Id}}{2}$$

$$v_2 = v_{Icm} + \frac{v_{Id}}{2}$$

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

So, let me come to the next case and explain to you the differential and common mode signals so I said differential signal $V_{Id}$ will be given as the difference of the 2 signals $V_2$ minus $V_1$ whereas common mode signal is given as the average of the 2 signal, $V_1$ plus $V_2$ by 2, right. So, what is common mode signal? Common mode signal as you can see here is basically a DC bias which is given to or even a AC bias which is given to both, common to both the both the terminals, inverting and non-inverting terminal of my design. You will ask me why is it given?

Well, this is given very simply because that you want to bias it in the active region, both the MOS devices, remember. So, you need to give an external bias which will try to do it, that plus we will see later on that has to do with the noise of the source also. So I get $V_{Icm}$ is equal to $V_1$ plus $V_2$ by 2. Therefore, if you just place it and do some manipulation here, I get I get this V1 equals to VIcm minus $V_{Id}$ by 2 and I get $V_2$ to be equal to $V_{Icm}$ plus $V_{Id}$ by 2. So, I have $V_{Icm}$ and then the voltage goes up $V_{Id}$ by 2 and it goes down by $V_{Id}$ by 2 so on and so forth, right. So this is the output voltage which you see or the input voltage what you see right.

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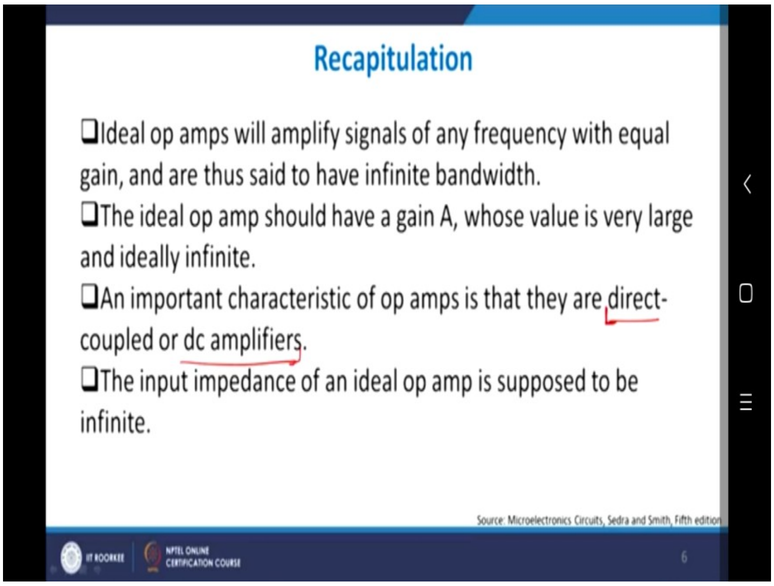

## Recapitulation

- ❑Ideal op amps will amplify signals of any frequency with equal gain, and are thus said to have infinite bandwidth.
- ❑The ideal op amp should have a gain A, whose value is very large and ideally infinite.
- ❑An important characteristic of op amps is that they are direct-coupled or dc amplifiers.
- ❑The input impedance of an ideal op amp is supposed to be infinite.

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

So, let me recapitulate what we learn and then we will go for negative and inverting terminal, inverting terminal, non-inverting terminal in the general sense. So ideal Op Amps will have infinite bandwidth, large gains, A will be also infinitely large. These these are basically input impedances are relatively very high. $Z_{in}$ equals to infinity and output impedances is 0, in reality. These are again a direct coupled or DC amplifiers, we will discuss this later on when time permits, but these are known as Direct coupled or DC amplifiers, right.

Because they are able to able to amplify signals which have very very low frequency signals. So even at a very low frequency good good amplification is available when you do an operational amplifier design, right.

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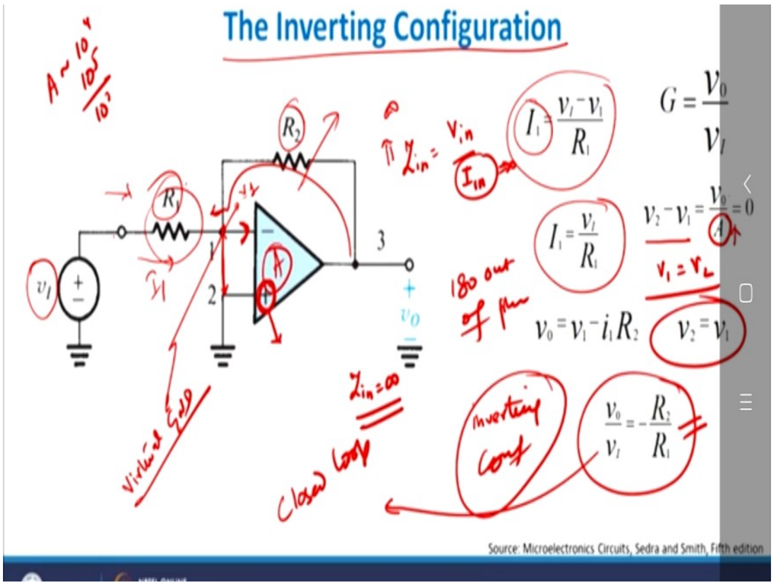

The Inverting Configuration

$G = \frac{v_O}{v_I}$

$I_1 = \frac{v_I - v_1}{R_1}$

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

$v_2 - v_1 = \frac{v_O}{A} = 0$

$v_1 = v_2$

$v_O = v_1 - i_1 R_2$

$v_2 = v_1$

$\frac{v_O}{v_I} = -\frac{R_2}{R_1}$

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

With this knowledge, let me come to very important configurations now which means that Op Amp by itself has got no use until and unless you do have a supporting configuration to to help it. For example, this is the first configuration which we will be studying and known as inverting configuration. As a result, what we will see later on is that this configuration helps you to invert an signal, analog signal. So if I have a sine wave, I will actually get automatically I will get a sine wave, 180 degree sine wave and I can change the gain of the output wave form also.

So how it is done? It is done in this manner. My this positive is grounded. My inverting, non-inverting terminal is grounded here and the inverting terminal is connected across R1 and R2 and through this thing, they connected to the Vout value here. Now the current flowing through this R I1 will be equals to V1 minus V2, Vi minus V1 which is the voltage, this is V1. So, Vi minus V1 by R1 will be the voltage which is the current flowing through this R, I1, right.

And similarly I1 can be written as Vi by R1. Why? Because you see, it is quite interesting that this concept of virtual ground that in a operational amplifier since my Z in equals to infinity, right. Voltage at arm number 2 arm number 1 sorry, here, will try to actually equalize itself to arm number 2 because remember Zin was defined as Vin by I-in, right. Now I told you input impedance is infinitely high so I-in equals to 0. 0 means this will go to infinity and Z in equals to 0.

Similarly, I can also define it in this manner that my V so that is the reason infinity large bandwidth, but this point, point number 1 is also referred to as a virtual ground.

Why is it referred to as a virtual ground is that, if you remember a ground is a place where you will have high currents and low voltages. Because low voltage, because you are grounding it to the ground. High current because since it is grounded, it is a 0 potential, all the current will flow through it.

Here interestingly, 1 will follow 2 so its voltage will be around ground so its very very low voltage, but there will be no current flowing through into this. Because its a high impedance node. So therefore, they are referred to as a virtual ground, right. So, though they are grounded, though their voltage is 0, but you do not get any current into it or out of it and therefore they are known as they are referred to as this thing.

Similarly, so therefore if I have infinitely a large value I get $V_2$ minus $V_1$ equals to $V_0$ by A right, because $V_0$ was equals to A into $V_2$ minus $V_1$. I took it denominator, A is infinitely large so I get $V_2$ equals to $V_1$ which means that $V_1$ equals $V_2$. That was what was talking about. That whatever voltage is there at terminal 2, terminal 1 also starts to go towards that voltage right. This is because of an infinitely large value of amplification open loop gain of operational amplifier.

With this knowledge I do a small derivation and get $V_0$ by $V_i$ equals to minus $R_2$ by $R_1$ right, minus $R_2$ by $R_1$. Now this is known as an inverting configuration, inverting configuration. Why inverting? Because you have a negative sign here, which means that the input and output will be 180 degree out of phase, out of phase right. And its now this is referred to, this is referred to as a closed loop gain. Closed loop why? Because now your loop has been closed by $R_2$ and $R_1$. Open loop when you open it up, we define it open loop gain. That will be just the amplifier gain which you see here. Which means that the closed loop gain will be relatively much smaller as compared to an open loop gain.

Typically A is of the order of 10 to the power 4, 10 to power 5 maybe or 10 to the power 3000 volt by volt. Whereas this might be very very low, maybe 100 or maybe 10, 20 whatever.

So, what we have done is that using this negative feedback concept, we have actually reduced the gain, right but my gain is more stable and it does not depend upon the open loop gain of the operational amplifier which I am using here. That is the major advantage. So therefore, by simply changing the value of $R_2$ and $R_1$ you will have various value of the output voltages in the case of the inverting configuration.

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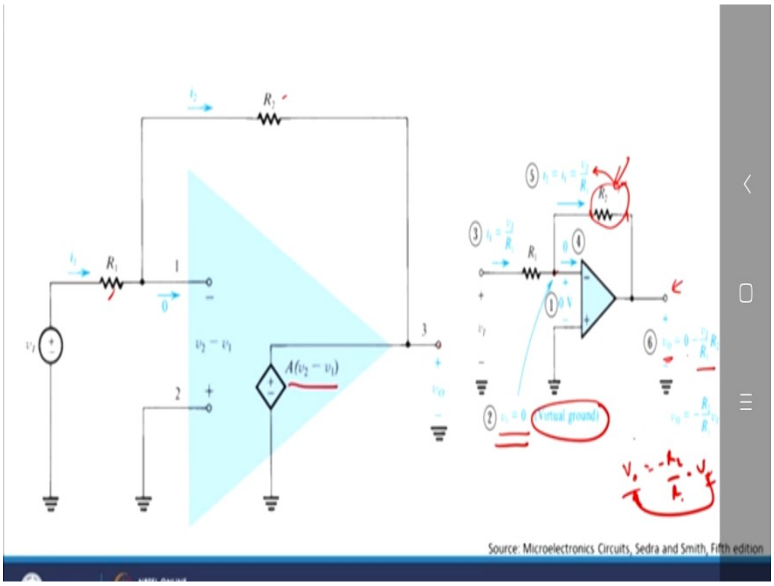

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

In inverting configuration let me show you the corresponding your corresponding circuit diagram. This is the equivalent circuit diagram which is there with us and therefore I can show it you that in this case for example I can write down that say this is your $R_1$, $R_2$ and therefore this is the voltage difference $V_2$ minus $V_1$ because they are inverting and non-inverting terminal. You multiply A into $V_2$ minus $V_1$ and you get 3 here.

Now therefore, as I discussed with you $V_1$ is approximately equals to 0 because it is a virtual ground and therefore, the current flowing here is $V_i$ by $R_1$ and the same current will trough $R_2$ because there is no other path for the current to flow down. And therefore, at this output terminal I get, output will be equals to 0 minus, why 0? Because this is grounded and therefore 0 minus the voltage drop here will be nothing but minus times $V_i$ by $R_1$ into $R_2$. Because this is the current, current multiplied by this resistance will give you the voltage drop here. And that must be equals to $V_{out}$.

So $V_{out}$ I get equals to minus $R_2$ by $R_1$ into, so $V_{out}$ equals to minus $R_2$ by $R_1$ into $V_1$. So if I take $V_i$ down here as a denominator, I get minus $R_2$ by $R_1$ as my explanations. So that is the reason why we get virtual ground in in in a detailed manner right. And we get typical virtual ground here.

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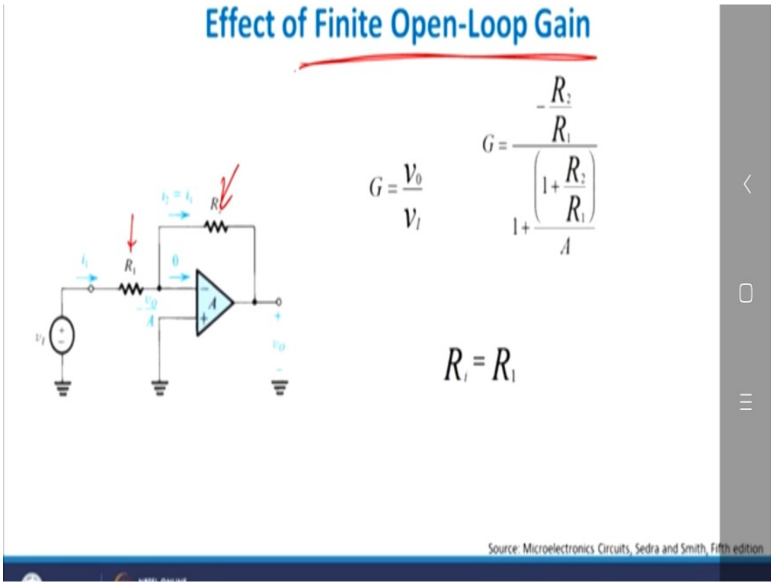

Effect of Finite Open-Loop Gain

$$G = \frac{v_O}{v_I}$$

$$G = \frac{-\frac{R_2}{R_1}}{1+\frac{\left(1+\frac{R_2}{R_1}\right)}{A}}$$

$$R_i = R_1$$

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

Now the second aspect is that, let me see, effect of a finite open loop gain, which means that till now when we when we are dealing with your operational amplifier per say, we were looking into the fact that, we were assuming that the gain is infinitely large when in reality not true. Whenever we have a closed loop gain, for example a feedback loop here, $R_2$ is feeding back into the input side, you do have a finite open loop gain. So your open loop gain is not infinitely large, right. And I get finite open loop gain. So let me see, let me explain to you how do I how do I get finite open loop gain.

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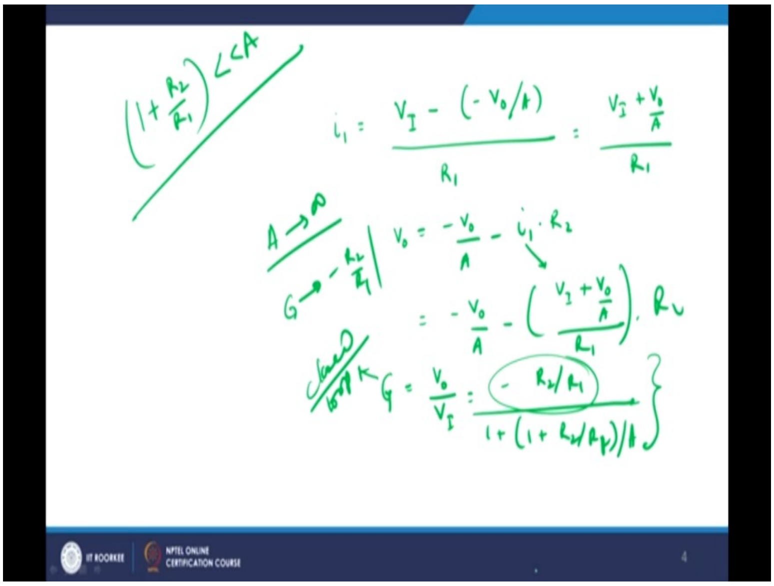

$$\left(1+\frac{R_2}{R_1}\right) << A$$

$$i_1 = \frac{V_I - (-V_0/A)}{R_1} = \frac{V_I + \frac{V_0}{A}}{R_1}$$

$A \to \infty$

$G \to -\frac{R_2}{R_1}$

$$V_0 = -\frac{V_0}{A} - i_1 \cdot R_2$$

$$= -\frac{V_0}{A} - \left(\frac{V_I + \frac{V_0}{A}}{R_1}\right) \cdot R_2$$

closed loop

$$G = \frac{V_0}{V_I} = \frac{-R_2/R_1}{1+(1+R_2/R_1)/A}$$

So I get current $i_1$ equals to $V_I$ right minus minus $V_0$ by A. Why $V_0$ by A? By $R_1$. $V_0$ by A is output voltage by A will give you the difference in the input voltage. So, $V_I$ minus that by $R_1$ is the current. So, I get $V_I$ plus $V_o$ by A by $R_1$ equals to $i_1$. This $i_1$ flows through $R_2$, $R_1$ and $R_2$, the same current is flowing. So I get $V_0$ equals to minus $V_0$ by A minus $i_1$ into $R_2$, right.

And therefore, I get minus $V_0$ by A minus of $V_I$ plus $V_0$ by A divided by $R_1$ into $R_2$, just I have replaced $i_1$ by this one. If we do a small so gain which is the closed loop gain, I get $V_0$ by $V_I$ equals minus $R_2$ by $R_1$ divided by 1 plus 1 plus $R_2$ by $R_1$, right, $R_2$ by $R_1$ divided by A. This gives you the value of G. Now as A tends to infinity or very large value, this quantity goes to 0 and G tens to minus $R_2$ by $R_1$.

So you see, from this formula or from this definition I can achieve a infinite open loop gain if A is infinitely large, I get my closed loop, this is my closed loop gain. G is my closed loop gain. Closed loop gain, will be equal to minus $R_2$ by $R_1$, right. So the condition, therefore the condition is 1 plus $R_2$ by $R_1$, this should be as small as compared to A. When this is as, so A if it is very large you automatically get this into consideration, right. So this is the effect of finite loop gain, so I get $R_i$ equals to $R_1$ right.

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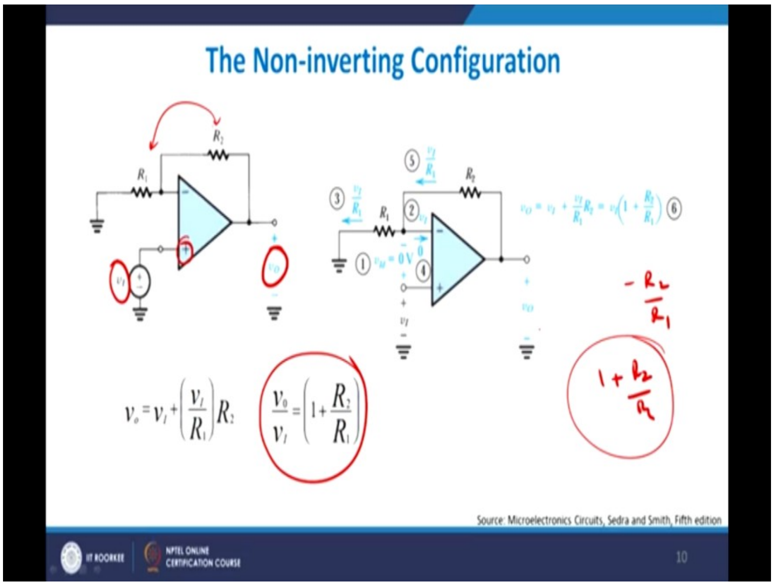

## The Non-inverting Configuration

$$v_o = v_I + \left(\frac{v_I}{R_1}\right)R_2 \qquad \frac{v_O}{v_I} = \left(1+\frac{R_2}{R_1}\right)$$

$1+\frac{R_2}{R_1}$

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

Let me come to the, if you understood inverting and non-inverting is just the just the just the complimentary of that, so non-inverting configuration will come. In non-inverting what we do, we apply the signal to the non-inverting mode, but we have the same configuration of the closed loop gain and $R_1$ and $R_2$ are here. So, if you solve it, am not doing it on the class, am not doing in the module. If you solve it, I get $V_0$ by $V_i$ equal to 1 plus $R_2$ by $R_1$.

So what are you getting in the inverting mode was minus $R_2$ by $R_1$, here you are getting 1 plus $R_2$ by $R_1$, and with the positive sign. With the positive sign, primarily means that they are in phase. So this $V_i$ and this $V_o$, this $V_i$ and this $V_o$ will be in phase in all respects, right.

We can do small derivation to get these value of $V_o$ and $V_i$. They are very simple straight-forward. I would expect you to do it if you know what is a Kirchoff's law and how you know, you solve a Kirchoff's law. So I get 1 plus $R_2$ by $R_1$ as the gain for this case, right and that is what you, what the gain which you get in this case, right and that is what we get for all practical purposes.

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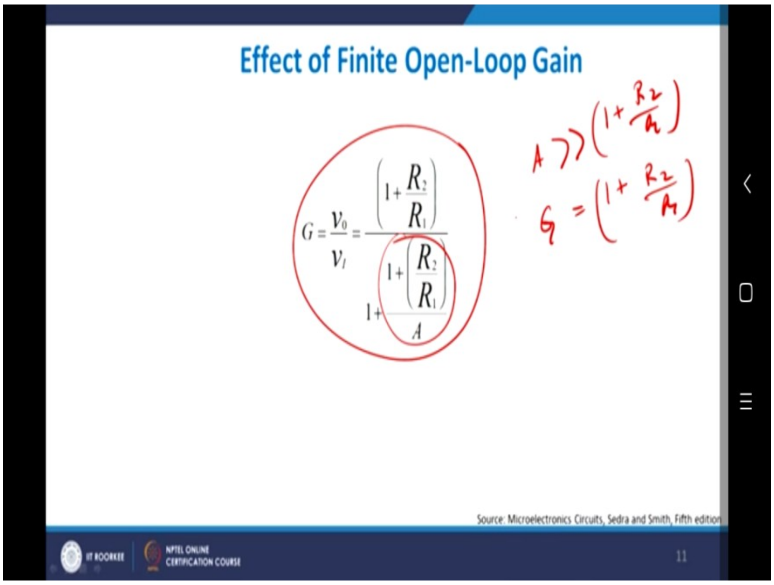

## Effect of Finite Open-Loop Gain

$$G = \frac{v_0}{v_I} = \frac{\left(1+\frac{R_2}{R_1}\right)}{1+\frac{1+\left(\frac{R_2}{R_1}\right)}{A}}$$

$$A >> \left(1+\frac{R_2}{R_1}\right)$$

$$G = \left(1+\frac{R_2}{R_1}\right)$$

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

Again, if you take a finite open open loop gain in case of a non-inverting terminal, I get this into consideration that I get gain equals to $V_0$ by $V_I$, 1 plus $R_2$ by $R_1$ upon 1 plus $R_2$ by $R_1$ by A, 1 plus of this one. So in this case also if A is very large, sorry if A is very large as compared to 1 plus $R_2$ by $R_1$, then what you get is that that this automatically vanishes and I get open loop gain, closed loop gain to be equals to 1 plus $R_2$ by $R_1$.

So in both the cases, you do have, if your amplification factor is very high you can afford to have almost 0 gain in the closed loop configuration, right, and it only depends upon the resistors. The ratio of the resistors. So you change the value of $R_2$

and $R_1$ and you can get variable resistance, a variable gain with respect to your requirements, right. And that is what an important part is.

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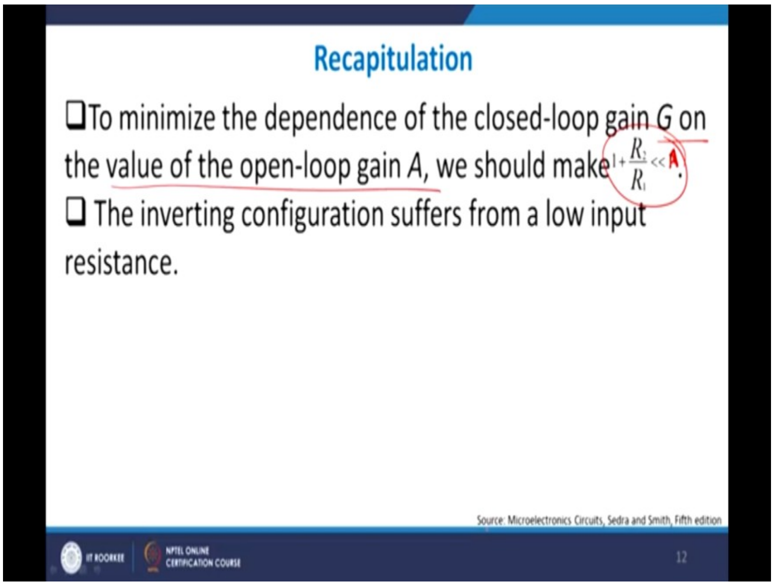

## Recapitulation

- ☐ To minimize the dependence of the closed-loop gain $G$ on the value of the open-loop gain $A$, we should make $1+\frac{R_2}{R_1} \ll A$.
- ☐ The inverting configuration suffers from a low input resistance.

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

So, let me recapitulate what we learnt from this small module which we discussed now, is that to minimize the dependence of closed loop gain on the value of open loop gain we should make 1 plus $R_2$ by $R_1$ much smaller than A actually, it should be smaller than A here. Much smaller than A right. And the inverting configuration suffers from low input impedance so inverting configuration has a problem, we did not discuss this but we will come to this in the next module. That they suffer from a low input resistances. So input resistances are pretty small in the case of inverting configurations, right.

When we meet time, we will take care of voltage follower networks and then we will look into Op Amp as an integrator, as an differentiator, and we will look into as a waited summer. So all these 4 or 5 configurations we will finish in the next turn so that we are able to have Op Amp as a circuit element for the purpose of amplification, right and that is an important phase.

So this module takes care most of, this and the subsequent module will take care of the analog design and then we will revisit the combinational logical design at the last part of our module, right. Thanks a lot for your patient hearing and thanks a lot.