Analog Electronic Circuits

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Lecture – 74
Single - Ended Vs. Differential Signaling and Basic Model of a Differential Amplifier (Contd.)

Yeah. So, dear students welcome back after the break.

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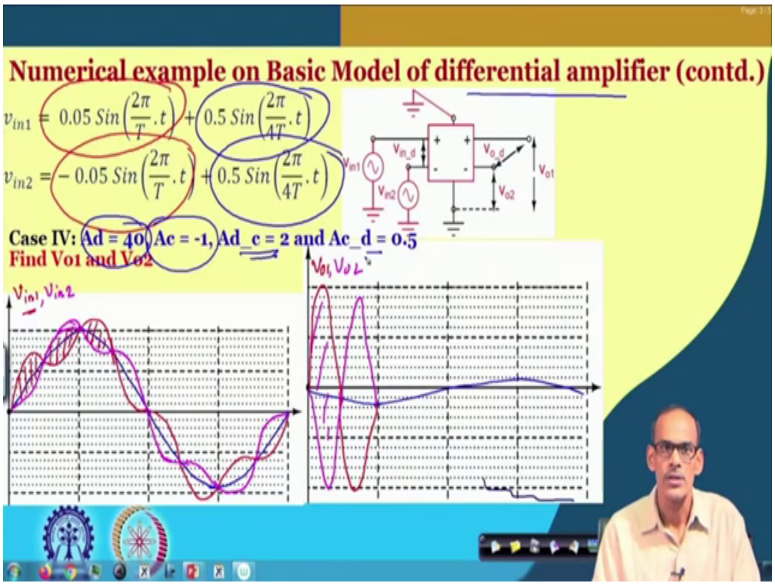

So, what we are talking about the basic characteristic of differential amplifier. And what we said is that its main purpose is to suppress the common mode signal, which is unwanted quote and unquote unwanted. And then along with that to appreciate the differential part the differential signal namely if you consider the two input signal.

This is the shaded portion is the differential signal and the blue line here it is the common mode unwanted signal. And this is what we do expect at the output vo 1 and then vo 2. So, vo 2 and what we do get is primarily vo 1 and vo 2; it was almost I should say amplified version of the individual signal namely the differential part of the individual signal. And what we said is that the common mode part it got suppressed.

So, the blue part it got suppressed and the differential part it got amplified. So, the and of course, it depends on the relative value of the differential mode gain and the common mode gain and the other parameter. Now next thing is that what we will be looking for is what may be the basic purpose of using this differential amplifier or what is its need, what is its application in actual scenario?

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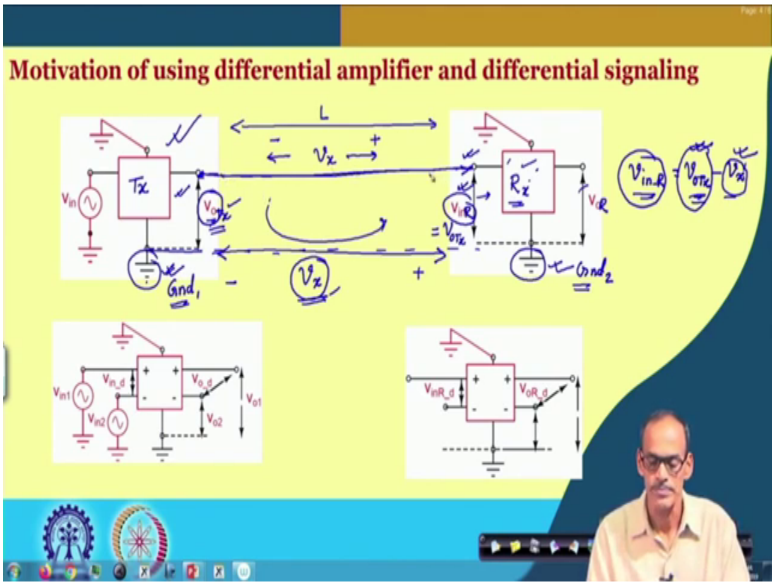

So, in the next slide, we will be talking about the basic need of the differential amplifier. So, suppose we do have single ended amplifier. So, we do have this is one single ended amplifier. And it is producing a signal V out and since it is single ended this V out it is with respect to its common node. And let you call this is the transmitting circuit and then we do have a receiving circuit.

So, we are expecting that this output it is getting connected to the receiver input and assuming that this connection it is long. So, ideally we whenever we are producing signal from the transmitting end it produces a voltage with respect to its common node. Likewise whenever the receiver it is receiving the signal at its input, it is comparing this voltage with respect to its own ground. And ideally we want these two grounds are same and if these two grounds are same then this v out of the transmitter say V o T x is directly coming here.

And then we can say that the V in r is exactly equal to v o T x transmitter. So, then the signal received by the receiver is not having any issue and then of course, based on its own characteristic it is providing its corresponding output V o R. Now the problem starts whenever the spacing between these two blocks; it is quite large. And if there is a chance that this ground of the transmitter circuit and ground of the receiver circuit, if they are not equal maybe average wise they are equal.

But instantaneously if there is any variation, then the received signal by the second unit. And the transmitted signal from the first unit they will be they will be different. Say for example, if we have some voltage here. And if we consider the voltage difference between these two it is a vx; assuming this is plus and this is minus. So, now, if I consider this line, it is directly carrying the signal and if I consider kvl through this loop.

So, from this you can say that either this way or this way. So, we can say that v in R equals to v in. So, our vo transmitter T x minus this vx. So, this vx entity in case if it is unknown, then we can see that at the receiving end whatever the signal we are receiving even though the signal it is coming from here to here without any problem. But then because of the this ground and this ground may be instantaneously they are different.

And if it is having a difference of vx then the difference of the two ground it is appearing as input signal which means that the receiver it is not only receiving the transmitted signal, but also it is receiving, the voltage difference it may be referred as ground noise or ground difference; many a times depending on this length depending on this spacing. The difference of these two ground voltage may be quite different. And many there may be even practical cases where this ground difference; it may be comparable with the transmitted signal if not higher than this. So in fact, there may be a situation, where the ground difference may be even higher than the signal quantity naturally the received signal it is we should say it is not only noisy probably.

It the receiver may be having difficulty to properly identify whatever the signal it has been transmitted from the transmitting end. So, that creates the major problem of course, in case if we have say same amount of voltage difference in this line also. Then of course, this this voltage difference and voltage difference may get canceled, but in general we cannot say that the ground difference and the signal difference they will be same.

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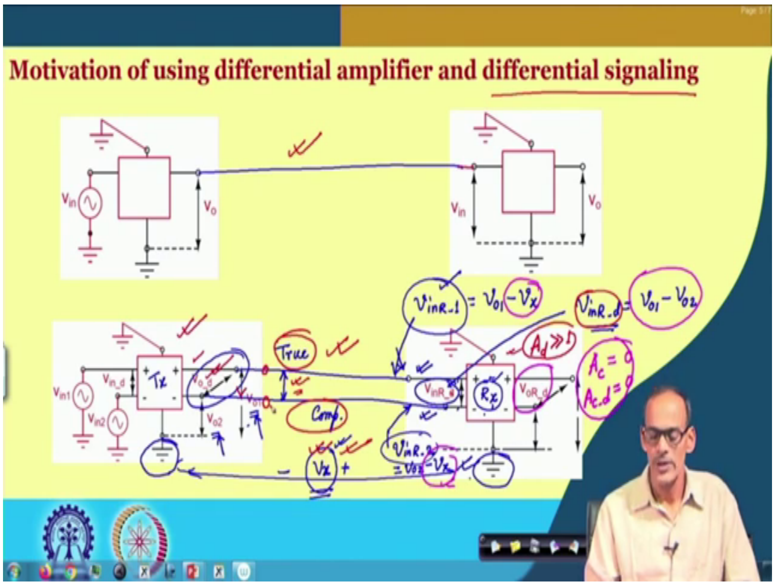

Then how to solve this problem, instead of sending the single signal instead of sending say this kind of single signal, what we can do? We can send the signal which is referred as true signal and its complementary signal.

So, the voltage difference between this two now it may be considered as the main signal. So, whenever this transmitter it is produced a signal, it is the signal it is essentially the difference of this two terminal voltage. Or I should say that V o 1 minus V o 2 is the main signal.

And at the other end whenever the receiver it is trying to pick up the signal and trying to detect the signal,it considers that voltage difference at this terminal with respect to the complimentary line is treated as a received signal. Now in case if this ground and this ground it is having a difference then you may say that V o 1 and V o 2 may be having different voltages with respect to this ground. In other words this line and this line, may be having not only this signal volt differential signal, but whatever the common difference we do have called V x that may be appearing at this terminal; terminal 1 as well as terminal 2. And since both the terminals are experiencing the same V x in same phase,, we can say that the receiver it will be seeing this V x as common mode signal.

So, the signal received at this point, if I call say v in R 1. So, that is equal to v o 1 minus v x vx is the voltage here that is the ground difference. So, likewise if you consider the voltage here this is v in R 2. So, that is equal to vo 2 minus vx. Now whenever this receiver it is trying to detect the signal, it takes the difference of v in R 1 and v in R 2.

And the differential voltage here which is referred as a v in R d, which is the difference of v in R 1 minus v in R 2; that is v o 1 minus v o 2. So, if this receiver it is essentially amplifying or sensing the differential input, then this receiver it will not be getting disturbed by this common voltage difference between the two grounds. So, of course, this is possible only when the receiver it is having capability to completely suppress this common part. Namely minus v x part, then only we can say that the output of the receiver it is completely independent of this v x.

And that can be achieved by considering common mode gain A c equals to 0 and also common mode to differential gain is also equal to 0. And then this differential part probably, we can amplify by considering a good differential gain A d. So, we can say that this A d if it is much higher than 1, then we can say that the received signal is getting amplified. Or even if it is a comparable with 1, at least we can say that unwanted signal it is suppressed; and then differential signal which is the transmitted signal coming from the other end it is properly getting received.

So, this is what the the basic motivation of going for differential amplifier. And the kind of signal coupling in this case it is referred as differential signaling versus whatever the signal coupling we have done here it is referred as single ended signaling. So, many of the high-speed application, where this transmitted signal due to various reasons, this transmitted signal it is typically it is very small its voltage showing it is very small. And in that case the ground difference may be quite significant it may be even higher than the signal here.

And for such situation this mechanism called differential signaling it is very essential for proper communication of the signal from one end to the other end. And in nowadays for many of our devices attached with computer we might have seen that the cables are differential in nature. So, the transmitter one end device of this cable is transmitter which sends the signal in differential form and the other end we do have the receiver that receives the signal in differential form. And the whenever we say differential signal it is essentially it is having two signal lines; one is true signal another one is the complementary signal.

So, that gives you the motivation of going for differential amplifier. Apart from this of course, common very common application of differential amplifier and age-old application of differential amplifier I should say is op amp operational amplifier.

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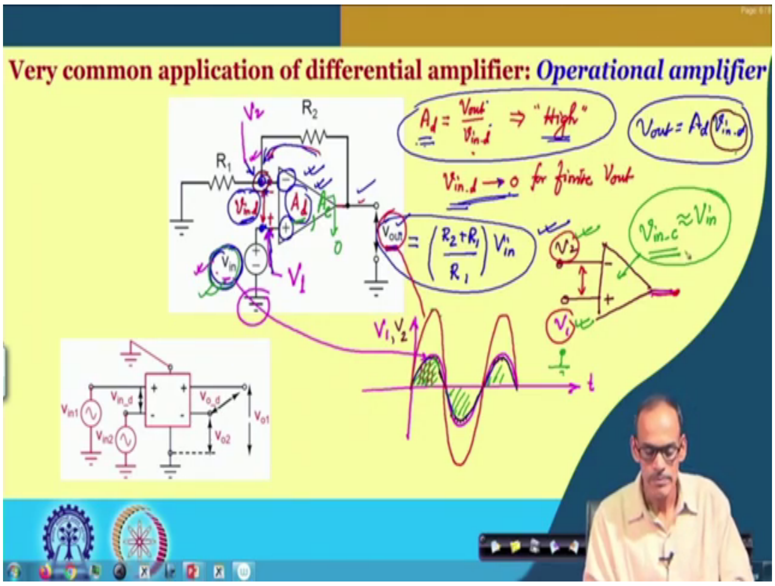

So, let us see why we require differential amplifier for this op amp implementation. Suppose here we do have say op amp having a gain of say A or in fact, strictly speaking it is a differential gain A d. And it is defined by its output vo divided by this differential input v in d.

So, for v in d this is plus and this is minus. So, I should say that gain of the op-amp A d it is defined by v out by this v in d. You might have observed that its input port it is differential, but then output port it is single ended. We will come back to this kind of configuration, but at least let me try to appreciate that its input port it is differential in nature and why we look for such kind of things.

Now, if the op amp gain A it is very high. So, if I say that this is very high quote and unquote very high, then what you can say for finite value of v out the v in d it is very small. And we can see that this v in d approaches to 0 for finite v out right. And of course, this is this is possible if the feedback in this circuit it is having a negative feedback, then only it is possible. So, later we will be talking about the importance of having negative feedback and the polarity of inverting and non-inverting terminal. But for the time being let me consider that since this differential mode gain it is very high that makes this v in d approaching to 0; making the two inputs; one is here, another is here two input terminal of the different the op-amp.

It is virtually equal or I should say they are close to each other very close to each other and you may say that they are virtually following each other. So, if the voltage here it is v in controlled by this v in then if we consider this is v in and also if I consider input current is 0 ; from that we can say that v out it is equal to R 2 plus R 1 divided by R 1 into V in.

I suppose you may be knowing this relationship and here the basic assumption is that the gain is very high and the differential input here it is approaching to 0 ok, that is fine. And based on this equation we can consider this circuit is an amplifier. So, whatever the voltage you are applying here, amplified version of the voltage it is coming to the output and so and so on. But you might have observed that this circuit this op amp, it is receiving a signal here of course, it is having differential input though it is expected to be very small.

But that is the signal after multiplying with A d it is producing V out right ; because the definition of A d is given here and from that we can say that v out v out is equal to A d times v in d right and so, I should say that it is amplifying differential input and then it is producing the corresponding output.

In addition, if you observe say voltage at this terminal which is referred as non inverting input so, this terminal with respect to ground of course, it is having a voltage V in. So, likewise if you observe this voltage this voltage is also very close to this V in. So, if you consider the voltage at this point called say V 1 and then this is V 2 and then also we do have V in. So, if we are applying say v in with respect to time of course, V in and V 1 they are same. So, I can say V 1 it is also same as V in; then the V 2, it is very close to that.

So, V 2 it is very close to that, but of course, there may be a small difference, but that small difference is good enough; because once we multiply that signal with an A d differential gain.

So, this differential part little difference that difference is essentially the v in d. So, after that is getting multiplied by A d it produces the corresponding output right and this is the this is the final output this is V out. So, we can say that V in, we are applying here and then we are getting the red color one. And also because of the negative feedback the black one this black one is essentially this voltage.

So, if I see this circuit independently. So, we can say that op amp, it is receiving two signals; one at its non-inverting input another one it is at the inverting input and these two signals they are very close to each other. So, we do have v 2 here and then we do have v 1 here and these two voltages they are very close to each other. And then this output of course, we are expecting this output primarily it is the it is amplified version on this differential. And with progress of time of course, if you see this voltage and this voltage they do have a big common signal. If you see here, if I take average of these two signal, it is having a big common mode signal.

So, with respect to ground both V 1 and V 2 they do have very big common mode signal which is almost equal to whatever V in we are applying. So, this amplifier it is facing its v in c, it is very close to whatever the input voltage you are applying. And this input voltage this common mode input voltage we are expecting that it should not really affect the output; rather this output should be coming only from the difference of the two signal right.

So, this circuit we also look for you know one apart from the differential mode gain it should be high we also look for another parameter called common mode gain. It should be as small as possible; otherwise this red colored signal it will not be solely dependent on v in d it may also be getting affected by v in c.

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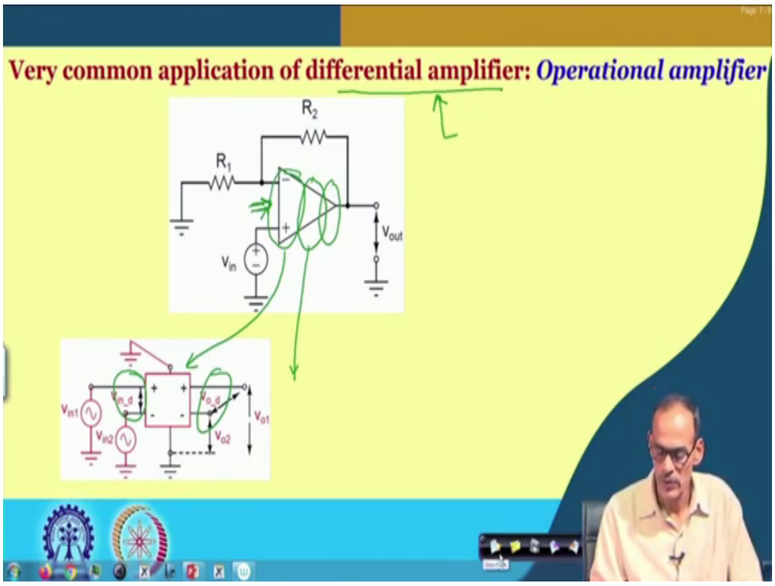

So, to summarize within the within the op amp within the op amp at least it is having a circuit that is the first part the port if you see it is differential. In fact, if you see inside of this, it may be having multiple stages and the first stage it is differential amplifier.

Second stage may be having similar to differential amplifier, but it is I should say special or some variants of differential amplifier and so and so. So, this is also another very common application of differential amplifier where it receives the signal in the form of differential signal it produces a differential output. So, we should say that we need to have good understanding of this differential amplifier and its corresponding implementation.

Now, there may be different variants of differential amplifier. So, in the next slide let we see different variants of different amplifier. So, we already have discussed about the fully differential amplifier.

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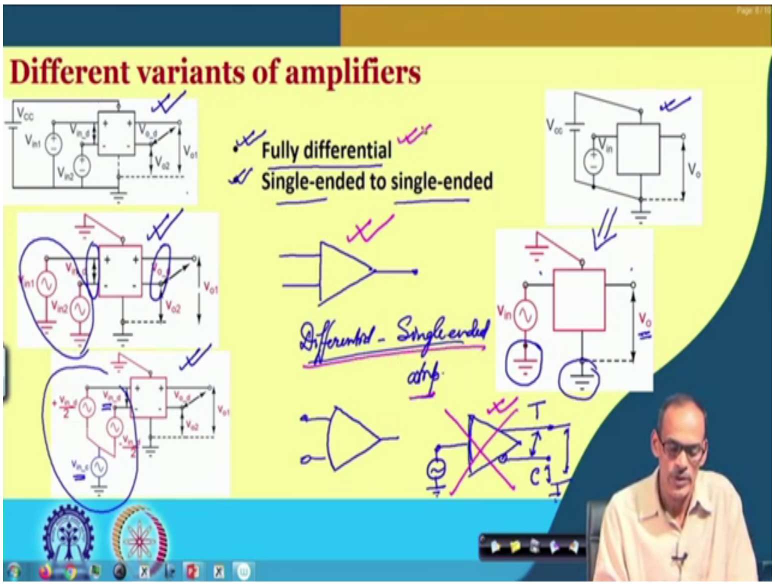

So, here this is the circuit or block diagram of that, here we do have the corresponding linearized model. And here we do have different representation or different way of representing its input signal; namely in terms of the common mode part and the differential part.

Likewise we also are quite familiar with single ended to single ended amplifier. So, here we do have the main circuit and here we do have the corresponding linearized model. The input it is input signal it is with respect to common node ground and output also it is with respect to ground. Now apart from this two we do have one more variants of amplifier you might have seen for this circuit both the input port and output port they are differential.

So, that is why this circuit actually it is referred as fully differential whereas, for this case both input and output their single ended. So, it is it is referred as single ended amplifier. The third possibility is that the input can be differential and the output can be single ended which is referred as differential to single ended. So, in fact, whenever we talk about say op amp op amp it is also one kind of differential to single ended amplifier right

What is the other possibility? The other possibility is that there may be the input port may be single ended and then output port it can be differential in nature. So, this is referred as single ended to differential amplifier ; where this is the true signal and this is the complimentary signal input it is with respect to ground. This output it may be with respect to ground common ground, but we do have a pair of signal where difference of these two voltages is carrying the main information.

So, this is a special kind of circuit in this course we will not be discussing about single ended to differential amplifier, but definitely we will be frequently talking about differential to single ended amplifier. So, it is better to better to see the difference of the difference of this this differential to single ended amplifier with respect to fully differential amplifier.

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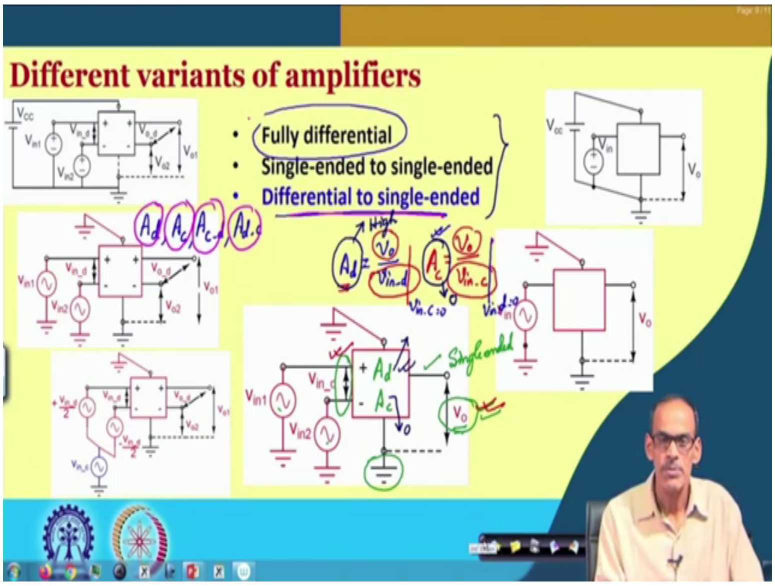

So, in the next slide we are going to give a little hint how this differential to single ended amplifier it is really different. So, if I consider fully differential amplifier, here as I said that there are four basic performance matrices; namely differential mode gain common mode gain and then common mode to differential gain and then differential to common mode gain.

So, these are the four basic performance parameters for fully differential amplifier. Now if you see on the other hand whenever you are talking about differential to single ended amplifier; since the output port since this is single ended. So, the signal here it is with respect to ground. So, then the signal it is a signal there is no you know separation of this the common mode and differential part of the signal. So, naturally whenever we will be talking about gain of this circuit it may be differential input to output gain.

And then the other one is that the common mode input to output gain. So, it is having essentially two parameters A d and A c and for this case A d and A c, they are defined as A d it is vo divided by v in d and the corresponding the other one is common mode gain which is vo divided by v in c. So, you might have observed that at the input since it is differential signaling differential port, we do have differential part and the common mode part we can treat them separately.

But at the output it is single ended signal. So, we do have only one signal. So, whenever we are defining this A d we are assuming that the v in c equals to 0. So, likewise whenever we are talking about A c we are assuming that the corresponding differential part at the input a v in d equals to 0. So, of course, the other basic characteristic namely for proper operation of this circuit, we want this differential mode gain it should be as high as possible. And for good differential amplifier differential to single ended amplifier we want this should be as small as possible.

So, ideally we want A c should be 0 and this should be as high as possible ok. So, these are the three variants of amplifiers. And as I said that while our discussion it is with voltage amplifier similar kind of you know variants are also possible, if we consider the signal in the form of current. In fact, the signal can be mixed namely at the inputs say signal may be voltage at the output the signal can be current and so and so.

But whatever the circuit we considered, everywhere we do have the possibilities of this kind of different variants of the amplifier. So, whether it is current mode or voltage mode or mixed mode and of course, apart from this three the other variant; namely single ended to differential amplifier we are not going to discuss in this course right. So, now, when and where to use this different kind of circuit? So, let us try to see where we considered which circuit and keeping in mind that the basic purpose of differential amplifier is to suppress the unwanted part namely the common mode part.

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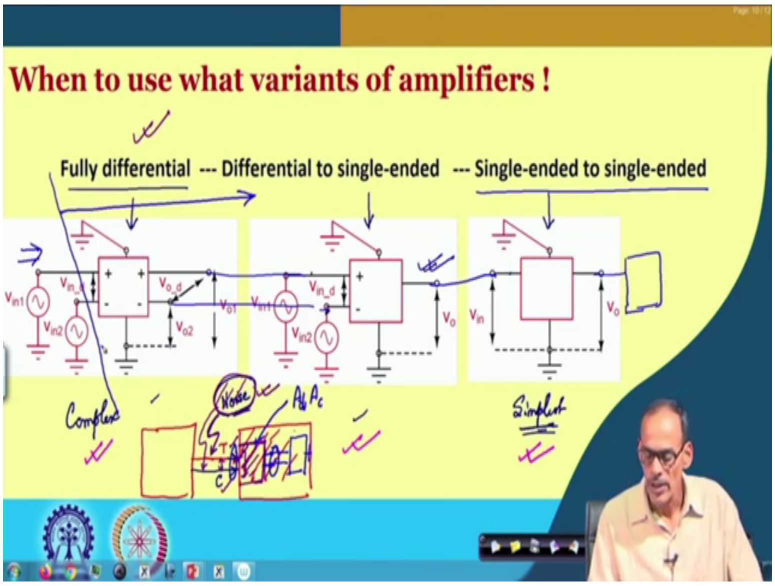

So, if you see this chain, we do have we do have say fully differential amplifier. So, this is fully differential amplifier, followed by differential to single ended amplifier. So, its input port it is differential, but then its output port it is single ended and then followed by single ended to single ended amplifier. In fact, if you see this circuit as you can guess that since the input it is single ended, among these three this is the simplest one in in realization. And this is most complex one this is in between.

So, if we have some task, which can be performed by the simplest version then unnecessarily will not be going for a differential circuit. On the other hand if it is really not possible to perform some task by single ended to single ended amplifier, then we do invite either fully differential or differential to single ended.

So, unless otherwise it is needed we will not be going for fully differential. So, the natural question is that when do we look for this differential amplifier? In case if we have say one system, if we have a system and we do have say different blocks of some system; from outside we are receiving a signal from another probably another system. Then; obviously, this connection in this connection there is a scope of getting the signal interfered by some other environments. Or we may say that the signal may get affected by some other interferer called noise.

So, for such cases whenever the signal it is coming with some interference and if this noise is really alarming. So, then we prefer to use differential signaling here having a true signal. Having a true signal path and along with that we do have a complimentary signal. Now how it helps in case we do have this some noise unwanted noise is coming there. And this noise it may be interfering the true signal path as well as the complimentary signal path in same way which means that whatever the noise this noise it is coming in the true signal as and complimentary signal in the same way.

So, the received signal if you see here, the noise can be received as like a common mode signal. And the difference of these two signal these two line voltages that can be treated as the main signal which is differential. So, whenever we do have some block here which is first interfacing with the external world we like to keep particularly whenever we are receiving sensitive signal. And in case if it is getting affected by noise then we like to keep the first block at least its port is differential in nature.

And if this block it is getting realized by say fully differential, probably that may give signal where this noise part it may get significantly suppressed. Of course, it depends on what is the what is the differential mode gain and the common mode gain of this this circuit. But whenever we are seeing the output probably the quality of the signal here, it will be much better compared to the signal here because here the noise is getting suppressed. And if we are happy with the quality probably you can subsequent block we can put as single ended.

So, probably then we can convert this differential into single ended and then the subsequent block it can be single ended. So, as you can anticipate that whenever we are receiving signal from outside, we do consider it is fully differential signaling. And then once it is going inside the system we do convert into single ended and subsequently we can keep the signal in single ended form. So, this is the boundary of the system and this is the inside of the system.

So, as you are going inside the system for simplicity, we keep the single ended blocks more and more there and only at the interface we keep the port as differential. So, that gives you some idea that where and when we should use what kind of amplifier what kind of configuration.

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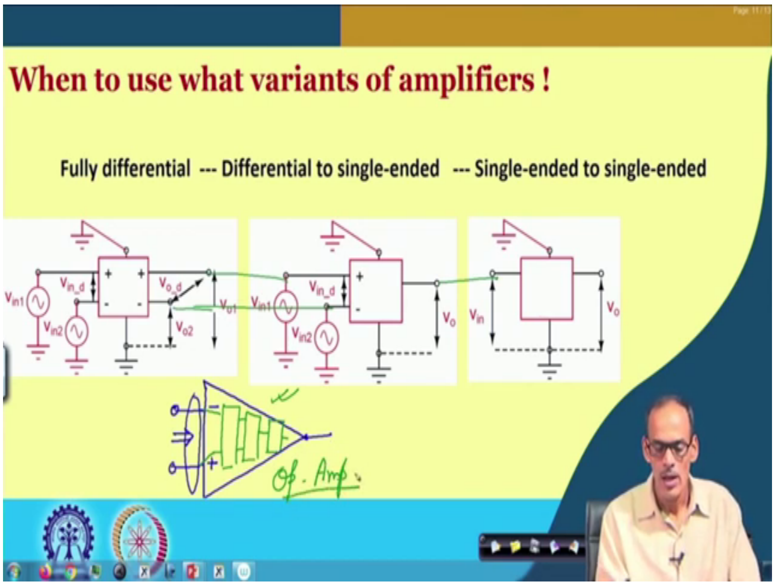

In fact, if you see the op amp there also in op amp also if you see its input port where we do have the inverting terminal and non-inverting terminal.

So, we are expecting that whatever the signal it will be received by this block, it will be having significant amount of common mode. In fact, that the common mode signal; it can be even higher than the differential signal. So, naturally the first block if you see this first block it is differential to differential and then one say the common mode part it is getting suppressed. Then probably the next block it converts the differential signal into single ended signal and then subsequent blocks are a single ended.

So, we can say that this chain this kind of chain it is quite common in this kind of circuit called op amp operational amplifier.

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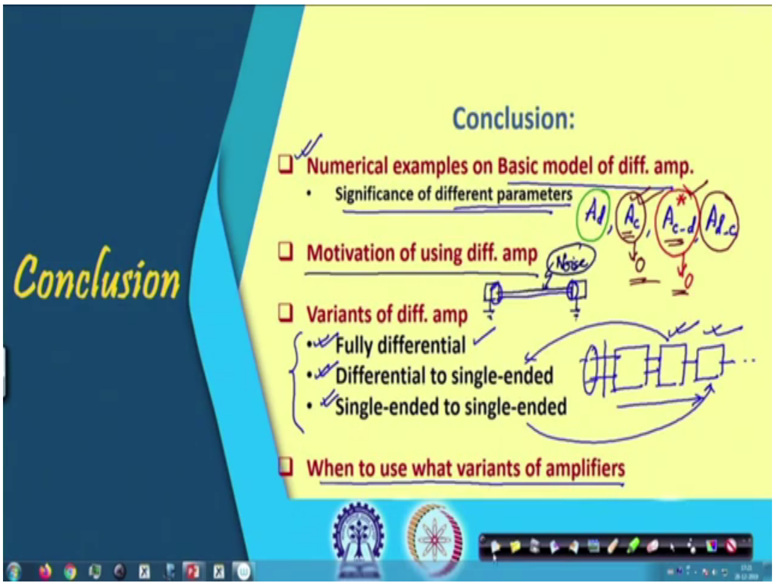

I think that is all we like to cover and so, let me conclude whatever the whatever the topics we have covered today in. So, first of all we started with numerical examples, numerical examples on basic model of differential amplifier. And then there what we have discussed is that significance or importance of different performance parameter; namely differential mode gain, common mode gain, then common mode to differential gain and then differential to common mode gain. And what we have said is that this is this is definitely we want it should be as high as possible.

But most vital thing is that this parameter should be as low as possible. And so, this is the having this is having the highest priority and then in addition to that to improve the signal quality we have also want it should be low. And probably we want this should also be low, but definitely these two parts, which are essential parameter indicating that how much the elimination of unwanted signals are performed by differential amplifier. So, that need to be taken care. So, we want these two parameter should be as low as possible.

So, whenever we will be implementing a differential amplifier we have to pay good at good attention to achieve this. And then, we also have then discussed about the motivation of using differential amplifier we are all we do use. Particularly whenever we like to send very sensitive signal from one device to another device they are far apart. And in case if their grounds are not really maintained equal. And or in case if some possibilities of having noise corrupting the signal; then we do go for differential signaling namely sending both true signal and complementary signal. And that says that we require a differential circuit here and differential circuit here.

So, while we have discussed we with the basic discussion we started with fully differential amplifier, we also have introduced something called differential to single ended amplifier. So, that as you are progressing towards the system that signal seen, it is getting converted from differential to single ended and subsequently it remains single ended. So, this single ended is important because that simplifies the circuit, but then we require this basic chain to convert the differential signal into single ended form.

So, we do have fully differential amplifier, we do have then differential to single ended amplifier and then we do have the subsequent stages are single ended to single ended amplifier. We also have just touched upon that when to use what variants of amplifiers; namely if I consider this three variants of amplifiers. We have discussed about when to use which block. I think now we are well set to go for implementation of differential amplifier. So, in our next class, we will be talking about implementation of differential amplifier. So, that is all to share in this lecture.

Thank you for listening.