Analog Electronic Circuits
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Lecture – 70
Single- Ended vs. Differential Signaling and Basic Model of a Differential Amplifier

Yeah dear student, so welcome back to our NPTEL online certification course on Analog Electronic Circuits. And myself Pradip Mandal from E and EC department of IIT Kharagpur. Today's topic of discussion it is Single Ended and Differential signaling and Basic model of differential amplifier. So, let us see where we stand today compare to our overall plan.

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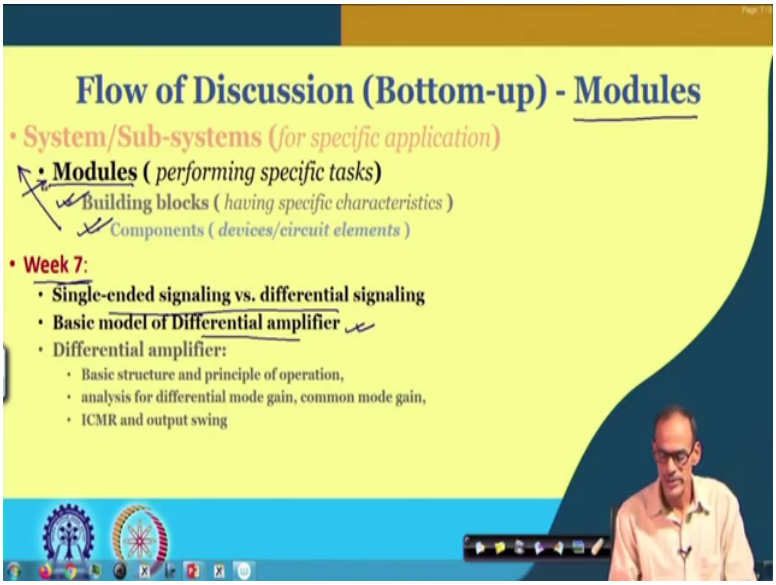

So, we are in module 7 in fact, we are about to start this module and so the main topic as I said that we will be discussing about single ended versus differential signaling and the basic model of differential amplifier. And if you see the overall flow we have completed

components. In fact, we also have completed building blocks in the previous class and we are in the we are just beginning the modules.

So, in fact we may consider this differential amplifier it is one module depending on the context it may be considered a building block also, but the depth at which will be going in this course we can consider differential amplifier as a module.

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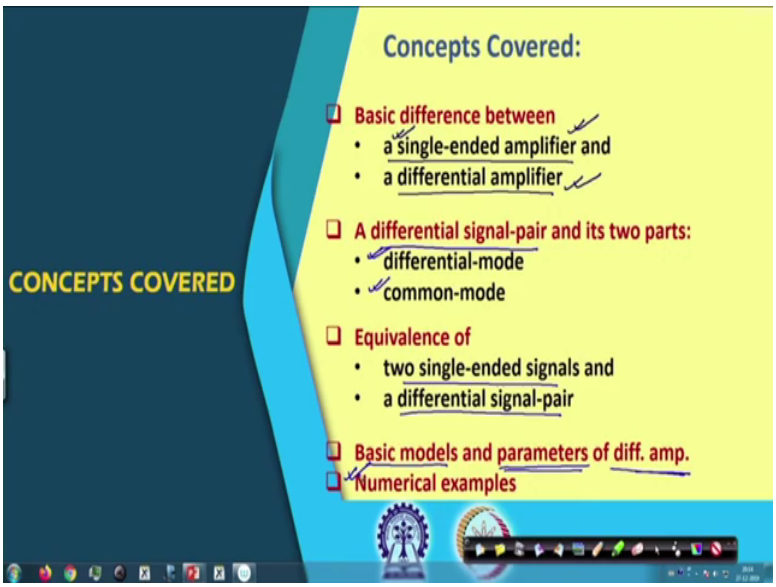

So, we are as I said that we are just starting this modules and today's topic of discussion it is entering into differential amplifier. So, what are the concepts we will be covering here? The basic difference between a single ended amplifier and a differential amplifier. In fact so far whatever the amplifier we have discussed whether it is voltage mode or current mode primarily it is single ended amplifier. And we are going to start differential amplifier.

So, naturally we need to understand the basic difference of these two kinds of amplifiers, and also we need to understand the how we activate the circuit. Particularly if it is single ended amplifier; the way we feed the signal it is quite different or rather for differential amplifier I should say the way we feed the signal it is quite different compared to whatever we have done for single ended amplifier.

So, we need to have fair understanding or we need to be comfortable of discussing about differential signal pair and then individual signal which we call single ended signal. So, we will be talking about what are the different two components are there in a differential signal pair. Namely differential mode signal and then common mode signal and then when do you call say two single ended signal individual signal they are equivalent to a pair of signal, namely representing a differential signal.

And then we shall discuss about basic model of differential amplifier and we shall discuss and introduce basic parameter of a differential amplifier. If time permits then we may also go into numerical examples. So, to start with let we go back to single ended amplifier and its basic operation.

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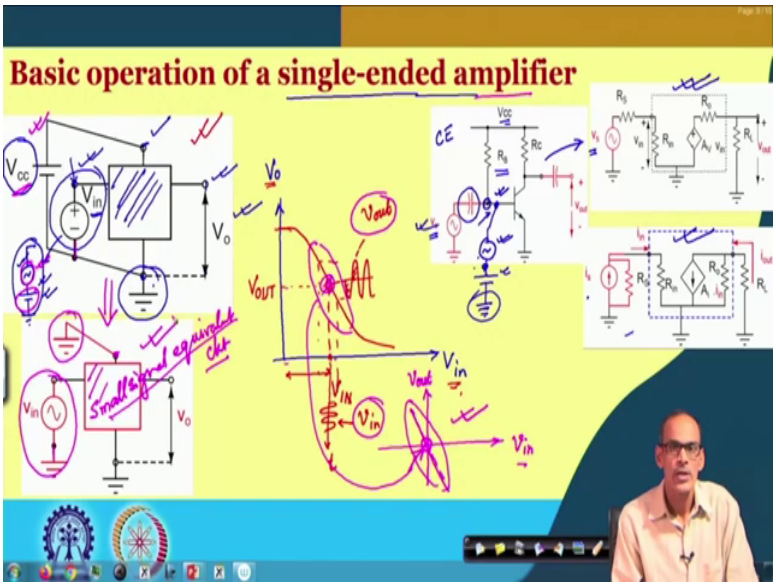

So, the basic operation of single ended amplifier as I said that we do have the main amplifier, the circuit it is getting activated by a DC source called V cc or V dd. So, with respect to ground we are putting a DC voltage here and then we do have one more port where we are feeding signal called V in. The signal need not be always voltage it can be current also.

So, the signal whatever whether it is voltage or current we do have a different port for the signal 2 feed into the circuit. Likewise for signal at the output we do have another port the output port for the signal. And if you have observed carefully that both this input as well as this output, if they are voltage we are comparing the signal with respect to the common terminal called ground.

Now, this V in it may be having 2 parts namely a sinusoidal part and a meaningful DC. In fact, if we have the DC power having positive supply and ground then most of the cases this DC

part is essential for proper operation of the electronic circuit here. Now, how do we feed the signal? We may be having different arrangement namely we can generate this DC voltage or DC current by some circuit and then we can feed the signal part through a signal coupling capacitor.

As you can see here the CE amplifier we have seen this circuit quite often. And we do have a DC bias here the DC bias it is coming from R B from the supply and then we do have the signal source which is getting couple to the input port through this signal coupling capacitor.

So, in general you may say that at this point we are feeding this signal along with either a DC voltage you may think of or you may consider it is a current, but whatever it is this is the signal primarily this signal it is we are giving with respect to common node maybe having a DC voltage, but the signal it is with respect to common node. And the way we are giving this signal it is referred as single ended signaling.

So, we do have a signal one terminal of the signal port connected to the input here, the other terminal of the input port it is connected to DC voltage or you may say that signal wise it is connected to ground. Now, this amplifier may be having a model in the form of a voltage amplifier or in the form of current amplifier. So, whatever the discussion will be having now it is applicable for both current mode signal as well as voltage mode signal, but then without loss of generality we may focus on voltage mode amplifier.

So, in our subsequent discussions we will be assuming that signal it is in the form of voltage both at the input port as well as output port. But most of the discussions subsequent discussions we will be having it is applicable for current mode amplifier also. So, what we have here as we understand the basic operation wise for single ended amplifier basic operation wise; we feed the signal at the input port and then we observed the signal at the output port. And then based on the input to output transfer characteristic namely, if I plot say V o with respect to V in both V o and V in is having DC as well as the signal component.

And suppose it is having say characteristic input to output transfer characteristics is something like this ok. And then what we are doing is that at the input we are giving a meaningful DC

called say V capital IN and then with respect to this DC we are applying a sinusoidal signal or signal; which is changing with time. And the corresponding observation at the output port we do have maybe a DC voltage which is meaningful DC voltage and then with respect to that DC we are getting sinusoidal signal. So, we may be having the signal coming at the output it is like this.

So, this part what we call it is small v small in or it is called small signal input and whatever the signal we do have with respect to this quotient point we call this is small v small out. So, in this circuit if we plot the V o with respect to V in we got input to output transfer characteristic. On the other hand if we keep our operating point fixed, and then if we consider some linear segment of this transfer characteristic curve and then if you plot the small v out namely the output signal with respect to small v in then we do get the input to output characteristic, but now we do have the signal.

So, we do have only signal into our discussion or in our consideration. So, now, small v out versus small v in and it is having a linear segment of this characteristic curve which is coming here. And then circuit wise what we have seen that to get this relationship input signal to output signal relationship, what we do; we translate the actual circuit into equivalent circuit what we call small signal equivalent circuit.

And sometimes we may call it is linearized circuit and then also the DC sources namely DC voltages, DC currents we do suppress that is because the operating point which is having non zero value of V in and V out that is getting mapped into origin of a this new transfer characteristic. Which means that we are intentionally dropping the DC part or in technical terms we may say that, this node it is AC ground and also if this V in it is having DC part and the signal part. Then we are keeping only the signal part and then DC part we are dropping which means that we do have at the input we do have only the signal part with respect to AC ground

So, the actual circuit we are replacing by a small signal equivalent circuit or we may called linearized circuit. So, for single ended amplifier we have done this exercise extensively and for differential amplifier also we will do this exercise. But for our comparison of basic operation

of single ended amplifier and a differential amplifier let we let we discuss in this domain. What we mean is that a small signal equivalent circuit domain or linearized domain ok.

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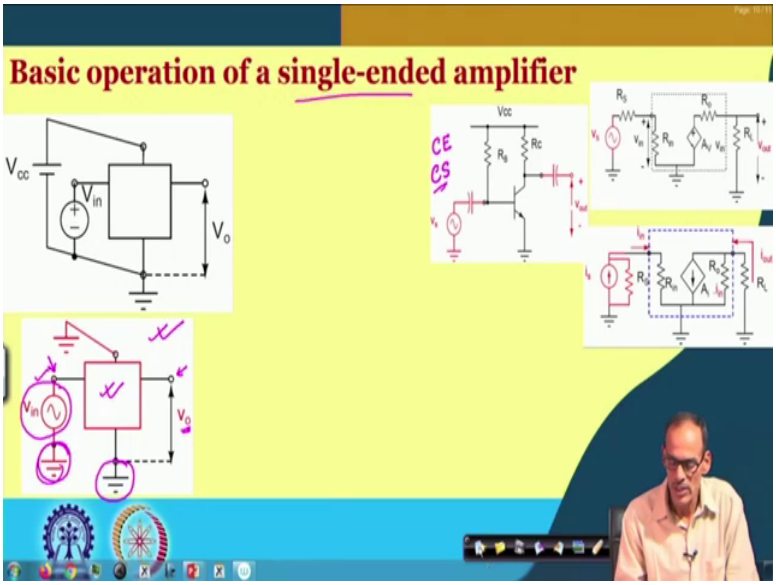

So, now we do have the small signal equivalent circuit here and here the input signal we are giving with respect to AC ground and output also we are observing this output voltage with respect to ground or AC ground. And since the signal at both the terminals we are comparing with respect to common terminal. So, we can say effectively we do have the signal terminal is only 1. So, that is why it is called single ended signaling and the corresponding amplifier it is referred as single ended amplifier.

So, whether it is CE amplifier or whether it is common source amplifier whatever the amplifier we have discussed, so far all of them you can say that they do have a nature of single ended

amplifier. Now, we are going to discuss a different types of amplifier called different CL amplifier.

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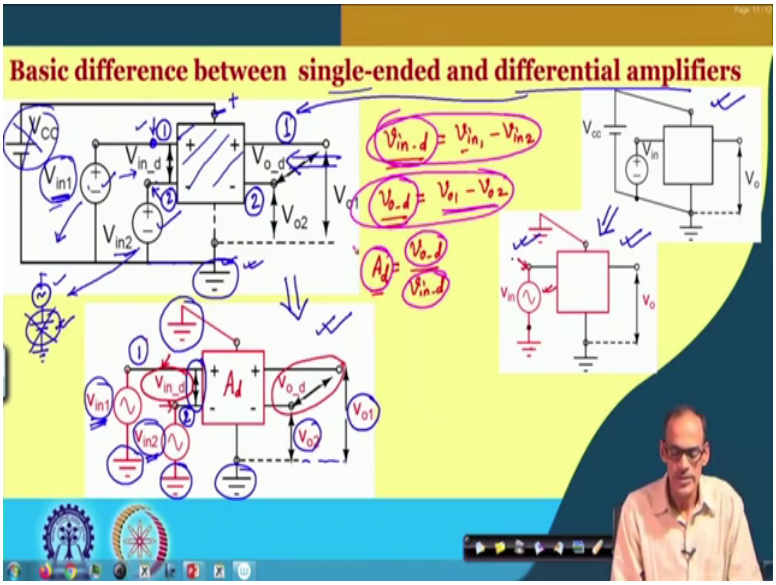

So, let us see what is the basic difference of the 2 kinds of circuit. So, for your reference we are keeping this; we are keeping this single ended amplifier and the corresponding small signal model here and now here we do have the differential amplifier. So, we do have the differential amplifier circuit here. So, the main circuit it is here and similar to single ended amplifier we are giving the power from a DC source at the power port.

So, we do have positive supply port and then we do have the common port or ground port and then we do have the input signal port. So, this is the input signal port, now here instead of having only one signal we do have two terminals; one is say one terminal is here to feed a

signal called V in1 and then we do have one more terminal called this is for signal V in2. So, at the input port we do have a pair of terminals apart from this ground.

So, individually you may say that individually V in can be treated as a signal here at terminal 1 with respect to this common node. So, likewise the other signal V in2 we are feeding at terminal 2 with respect to this common terminal. And at the output similarly for the output signal here also the output port it is having 2 terminals or 2 signal point apart from the common terminal. So, we do have say terminal 1 at the output port and then terminal 2.

Now, if you consider the in generalized case both V in1 and V in2 maybe having their signal part or small signal part along with a meaningful DC. Similar, to a single ended amplifier both V in1 as well as V in2. So, both of them are accompanying a DC; this DC part typically for both the signals they are equal, but not necessarily they should be equal.

Now, as I said that will for comparison of this differential amplifier and single ended amplifier. Let you consider its small signal equivalent circuit or linearized model and then let you compare with respect to whatever the small signal equivalent circuit or linearized model we do have for single ended amplifier. So, similar to single ended amplifier here once we linearize the circuit, we are dropping this DC part namely we are making this is AC ground. And likewise here also for both the signals we are dropping this DC part and the signals we are given with respect to ground.

So, both the small v in signal at terminal 1 it is given with respect to AC ground likewise v in2 small v in2 it is applied at terminal 2 with respect to AC ground. So, signal wise we do have a pair of signal; one is V in1, another is V in2. So, likewise at the output we do have a pair of signal one is V o1 and then V o2 both are with respect to the common terminal.

Now, what is the difference then compared to the single ended amplifier and this differential amplifier? The signal for this differential amplifier when you say signal what we what we consider as signal it is the difference of the signal we do have minus this signal or to be more precise V in d which is V in d which is defined as V in1 minus V in2 so this is the input signal.

Unlike the case for single ended amplifier where we consider voltage here with respect to ground. So, likewise when you consider output we consider difference of these 2 voltages as the main output. So, V o differential which is defined as V o1 minus V o2 and when I say this is a differential amplifier having a gain of say A d; which means that this A d it is essentially representing the relationship between this V o d and V in d right. It is it is not really representing the relationship between say V in1 and V o1 in the form of single ended.

Rather it considers the difference of these 2 signal as the main signal. So, likewise for the output also difference of this V o1 and V o2 it is it is considered as the main signal. And then ratio of the 2 signals it is defined as the gain of the circuit ok. So, that is the basic difference.

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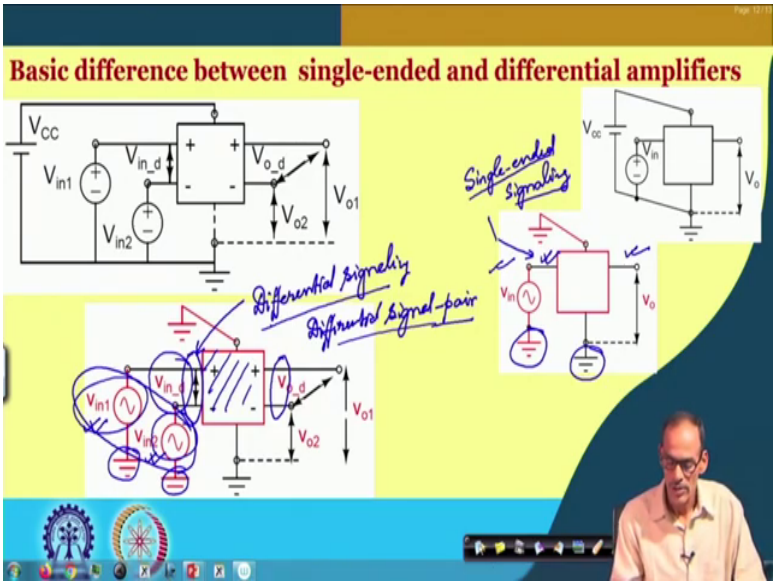

Now, what we have seen that if I again come back and compare whenever we will be talking about the main differential amplifier its input port it is differential output port it is differential.

On the other hand for common mode sorry single ended amplifier we do have; we do have single input and then single output and they are with respect to ground. So, this kind of signal it is referred as differential signaling versus whatever the signaling we are doing here it is single ended signaling.

So, we need to we are quite comfortable with single ended signaling and we need to make our self comfortable with differential signalling. And also we need to say that you can consider that v in1 and v in2 both are they can be considered as individual signal. So, whenever we are talking about say differential signaling it is essentially it is having a differential signal pair right.

So, we do have this signal and this signal together and they together it is representing this v in d right. So, it must be having some relationship or meaningful relationship of between say differential signal pair and 2 single ended signals ok. So, let us see what is the relationship between these 2 kinds of representation of the signal.

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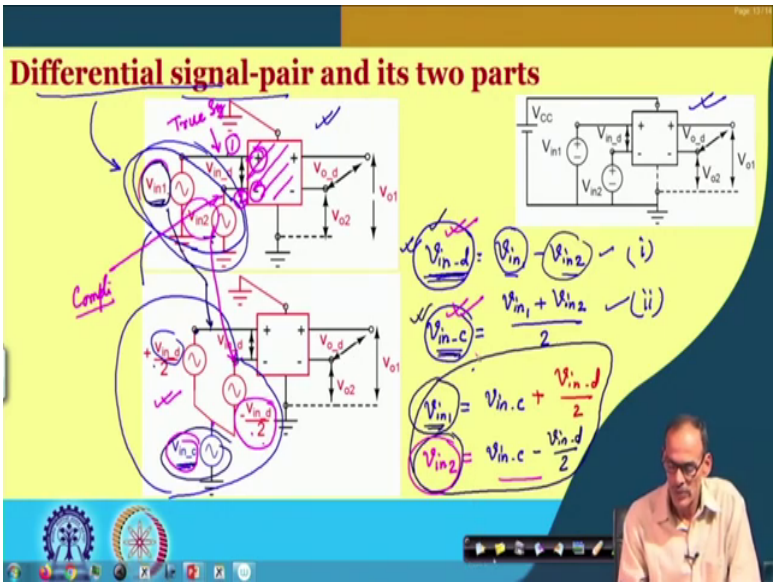

So, if you see we will be talking about the relationship, but we need to also understand that here we do have the small signal; here we do have the small signal equivalent circuit, coming out of the differential amplifier. And here we do have a pair of signal and we call it is differential signal pair. And we already have said that v in d v in d it is equal to v in1 minus v in2 right.

And also if you see that; if you take the common of this 2 signal so that means, v in1 plus in2 by 2 which you can say average of these 2 signal that is also another signal of course, it is different from the main signal, but that signal it is considered as the common mode signal.

So, we can say that whenever we do have a differential signal pair actually it is having 2 components; one is the differential mode component, another one is the common mode component. In fact, if you see here since it is these two equations are linear equations in case if

we have this information namely; for a differential signal pair if we have the information of this differential part and the common mode part then we can get the individual signal.

So in fact, if we have individual signal we can get the differential part and common mode part. And then alternatively you can represent this signaling in this form and this is in terms of the common mode component and the differential component. So, let us try to see that, but before that if I you say this equation 1 and equation 2 what we can get it is a v in 1 you yourself can find that v in1 it is having 2 parts one is v in c plus plus v in d by 2. On the other hand the other part or the other signal V in2 the second signal it is again it is having the common mode part namely v in c part and we do have the minus v in d by 2.

So, this is mathematically saying that if we have these 2 components given to us from that we can get the individual signal. So, circuit wise on the other hand you can say that if we have say v in1 and V in2 we can calculate this v in d and v in c. And then we can represent this signaling in this form, what we have here it is this signal it is V in1. And if you see this v in1 it is v in c plus v in d by 2 so the signal coming here it is matching with this v in1. On the other hand if you see the other signal the signal at this point and it is supposed to be representing this V in2 and the signal here it is V in c which is common and then we do have minus V in d by 2.

So, the signal coming here it is v in c minus v in d by 2 that is nothing, but the v in 2. So, we can say that we do have whenever we do have say differential amplifier and then invariably we will be stimulating the circuit with a differential signal pair may be signal 1 and signal 2 and then these two signal if we can bundle them together and we can represent the information in the form of differential part and common mode part and circuit wise this is how we can represent.

In fact, the signal which is going to the positive input or something later we will be discussing about that the meaning of that. It is referred as noninverting input and this one is inverting input. The signal we are feeding at the noninverting input it may be considered as something

called true signal and the signal we are feeding at the other terminal it is called complimentary signal.

So, these are the two terminologies we may frequently use so true signal it is basically we are representing this v in1 and then complimentary part it is v in2. Now, as I said that if we have this common mode part and differential part then individual signal we can translate. So, we can say that if we have one differential signal pair that can be translated into single ended a paired signal.

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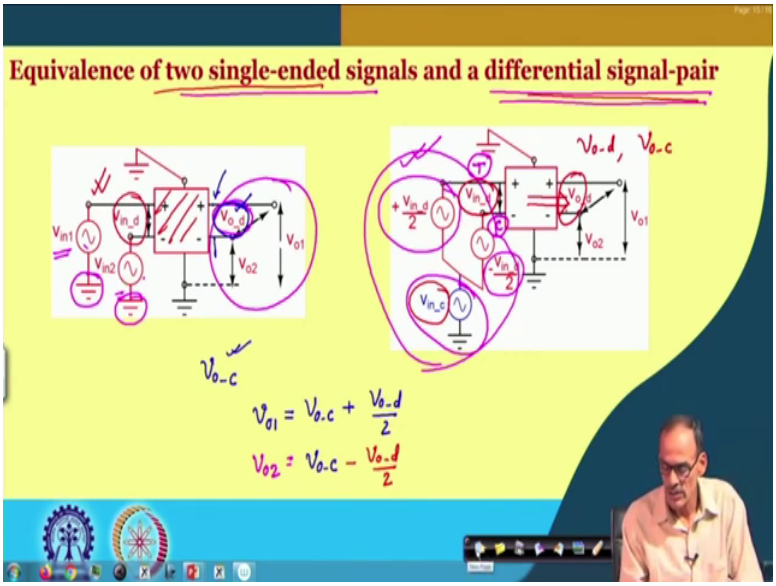

So the two ways of representation it can go back and forth while will be analysing the circuit. So, again let we try to make our self comfortable and try to ah understand that when do we called two single ended signals are together equivalent to a differential signal pair. So, similar to the previous discussion here we do have two individual signals or two single ended signal,

both of them are with respect to common node and they are getting represented here by a differential signal pair.

In fact, whenever we will be talking about differential signal pair instead of considering two single ended signal invariably we will be representing the information in this form. Namely the it will be having a common part called v in c or the common mode v c and then we will also be having a differential part; half of the differential part it will be going to the true terminal and negative half of the signal it will be going to the complimentary terminal.

So, that is that is how we can say that we can always make the equivalence. So, whenever you are talking about the equivalents for the input port. In fact, this is also valid for the output port. So, if you see the output port and if I know what is the differential output signal say v o d and also if I know the average of these two signals; average of these two signal and if I say the average of the signal is v o c then using this v o d.

And v o c we can express we can express the individual output signal. Namely v o1 equals to v o c plus v o d by 2, the other signal v o2 equals to v o c minus minus v o d by 2. Now, the natural question is that suppose we do have 2 way of representing the signal; one is a pair of two single ended signal another; one is a differential signal pair namely in the form of common mode component and differential component. And then which one we should follow which convention we should follow while we will be discussing the differential amplifier.

Now, the answer to that why we are going for this convention is that this circuit differential amplifier it its response to v in d and v in c it is different. And whatever the whatever the signal we are getting at the output port. In fact, whatever the signal we are getting at the output port namely v o d and v o c; they do have nice linear relationship with v in d and v in c, but not with the individual signal ok.

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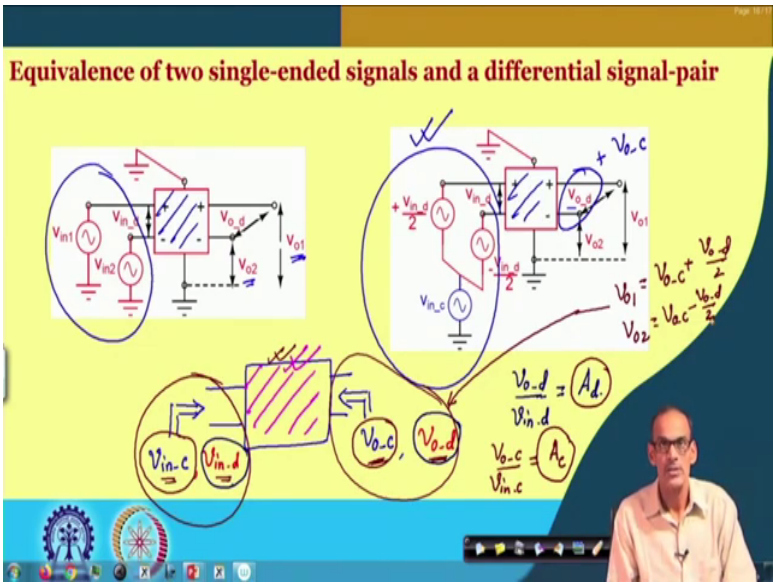

So, I think it will be clear in the next discussion. So, as the summary of this slide is that in case if we have two ways of representing the differential signal. Namely one is this way the other one is this way and if we are dealing with differential amplifier then we prefer this kind of representation.

In fact, same way whenever we are considering the output before we go into the single ended information single ended signal pair we will be considering the signal here in terms of v o d and v o c. So, whenever we do have a differential amplifier then at the input signal wise we will be considering that signal in the form of v in c and v in d. Likewise whenever we will be talking about the output port and whenever we will be observing the signal here the signal will be representing in the form of the common mode part and the differential part.

And this block the differential amplifier in fact once it is getting linearized. So, if I consider this linearized model then this circuit it can be characterized by considering linear relationship among these quantities. Namely if I consider v o d and v in d and if I take the ratio of the two namely, v o d divided by V in d that represents something called differential gain.

So, likewise when you consider the other two quantities namely v o c and v in c and if I take the ratio v o c divided by v in c. So, that is defining another parameter called common mode gain. So, this gives you an idea that whenever we will be characterizing this circuit in terms of this two important parameter or called gain of the circuit then it is always better to represent the signal in the form of v in d and v in c.

So, likewise at the output also whenever we will be talking about the signal we prefer to use this convention rather than individual signal. And once you get this and these two components namely common mode and differential component, then these two together we can use to represent v o1 as I said that v o1 it is v o c plus v o d by 2 and v o2 equals to v o c minus v o d by 2 all right ok. So, we will be going further discussion towards that, but let me take a short break and then we will come back.