**Analog Electronic Circuits**
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**Lecture - 22**
**Linear Models of Amplifiers (Part A)**

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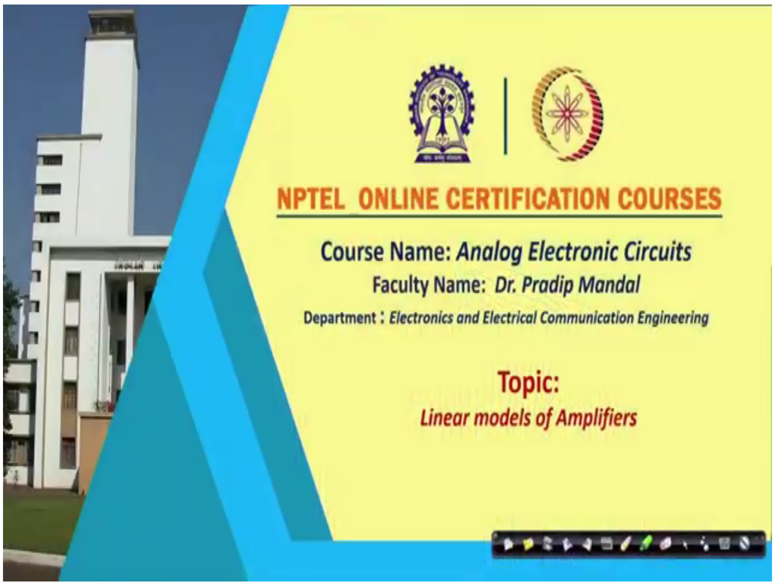


Dear students, welcome back to this NPTEL course on Analog Electronic Circuits and today we are going to cover the topic of Linear Models of Amplifiers. So, in fact if you see, we already have covered few topics and today actually we are in the first day of 3rd week. So, let see what where do we stand today, compared to our overall plan.

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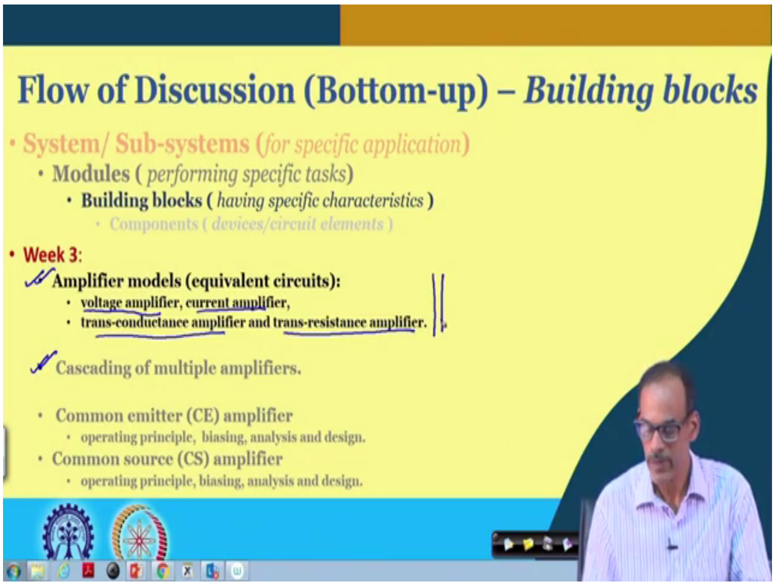


This 3rd week we are planning to cover amplifier models and followed by cascading multiple amplifier stages; and then followed by CE amplifier, common emitter amplifier and common source amplifier. And under this topic of amplifier models what you are going to cover it is; the voltage amplifier, current amplifier and trans-conductance amplifier and trans-resistance or trans-impedance amplifier.

So, these are essentially simplified model of the different types of voltage amplifier. Today we are going to discuss with simple example and we will cover the purpose and the little detail of the model different, these four models.

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Now, what are the concepts we are going to cover today? It is, basically as I said that the model of voltage amplifier, then model of current amplifier, model of trans-conductance amplifier and trans-impedance amplifier.

So, primarily we will be discussing more detail of these two topics and whatever the idea we will be gaining from that, we will be extending to the other two types of amplifiers quickly. So, let see the voltage amplifier and let we start with two simple examples of voltage amplifiers.

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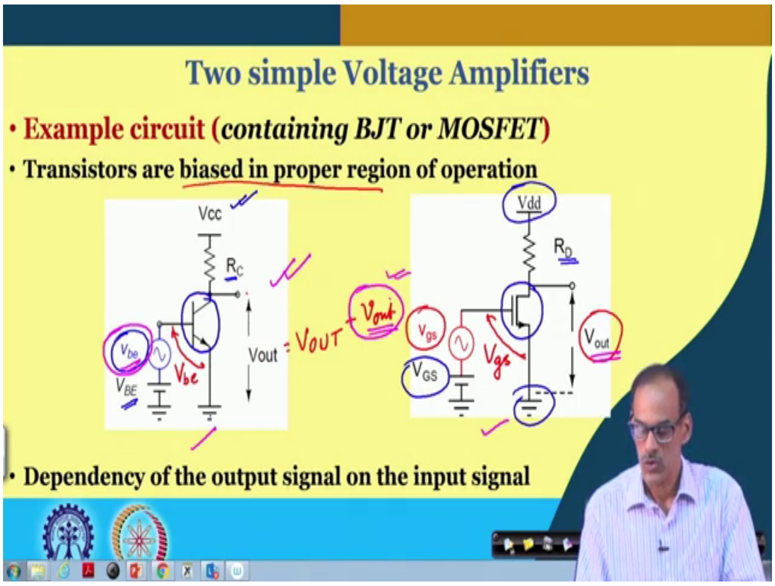


Say for example, the first one it is; it consist of BJT, second one it is having a MOS transistor. And for each of the cases what we have here it is, the DC voltage source and then of course the ground and along with the biasing element registered. The transistor it is in this case the BJT is kept in the active region of operation with the help of V B E, the DC voltage here.

And then on top of the DC voltage we do have the small signal current call small V b e. And on the other hand here for the transistor having the MOSFET, it is again it is having a DC voltage source and then of course the ground, main ground and then we do have the biasing register call R D connected to the drain of the transistor. And then at the gate, we are applying a DC voltage call capital V capital G S on top of this DC voltage we are applying a small signal.

So, the if you see the voltage here along with this V g s; the voltage here we are applying is, it is having a DC part as well as the small signal part. So, we can see capital V small g s. So, likewise for the BJT circuit on the other hand we do have the V b e, namely capital V small b e. And it produces a voltage here at the output, which is having a DC part and DC part called I capital out plus small signal part called small v out. So, same thing here also, it is having a DC part and the small signal part.

So, whenever we are going for say model or linearization basically what you do; as I said that the transistor we are keeping in the appropriate region of operation, and then after that we try to find what is the relationship between the applied voltage here to whatever the corresponding output we are getting. So, in our main operation the DC conditions are kept intact, only the small signal part changes with time and then the corresponding effect we observe here.

So, since the DC parts we are not changing what we can think of that; we can probably simplify the circuit, which supposed to represent the relationship between this output and this V b e. Rather dependency of this signal output with respect to the input signal here; same thing for the circuit amplifier having the MOSFET transistor.

So, since the procedure it will be same for this circuit and this circuit and let you concentrate only one of them; let you concentrate only on this circuit in the next slide and let us see what is the linearized model or the voltage amplifier model. So, the same circuit we are going to discuss here.

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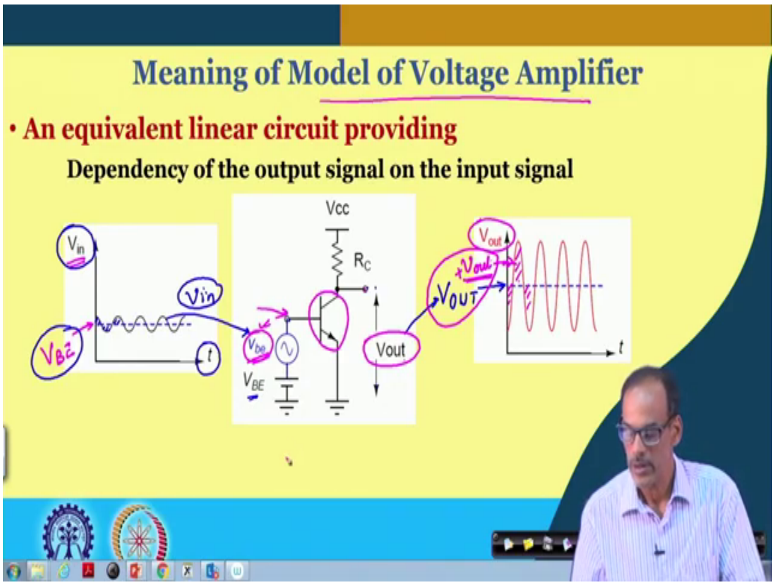


What we have here as I said that, we do have the basic amplifier and at the input we are having a DC voltage, on top of that we do have we are applying a small signal. So, if you observe the voltage here and if we call this is V in to the circuit; it is having a DC part here which is capital V B E and then on top of that we do have the small signal part. So, you may say that the small signal part is given here, and that small signal part is the small V b e or you may call this is small v in.

So these two together; the DC part and the small signal part together they are representing the total or instantaneous voltage which is of course, a function of time. And the consequences of whatever the voltage you are applying here; if you observe at the output, if you are keeping the DC voltage only, then at the output will be getting a DC voltage.

So, this DC voltage it is given here, we may call this is capital V capital OUT. So, that is one part of this V OUT. And now if we are applying the small signal at the input here, the corresponding effect here it will be coming; which is shown by this variation of the output voltage with respect to time.

So, if the input here it is sinusoidal, we are expecting that output will also be sinusoidal. And this sinusoidal part it is referred as small signal and it is referred as small V out. So, these two together capital V OUT and small v out together, they are representing the instantaneous output. So, whatever we are seeing here it is essentially the instantaneous output for the given instantaneous input.

Now, whenever you are talking about modelling of voltage amplifier what does it mean is; we like to change the circuit, whole circuit by an equivalent circuit or you can say equivalent linear circuit, which primarily correlates the small signal output with respect to whatever the small signal input we are giving. So, that is what the meaning of the voltage amplifier.

So, whatever the sinusoidal part we are applying here to what are the sinusoidal part we are observing here; that is what it is getting represented by the voltage amplifier. So, let we go little detail of that, but before that just to summarize what I said here in the next slide.

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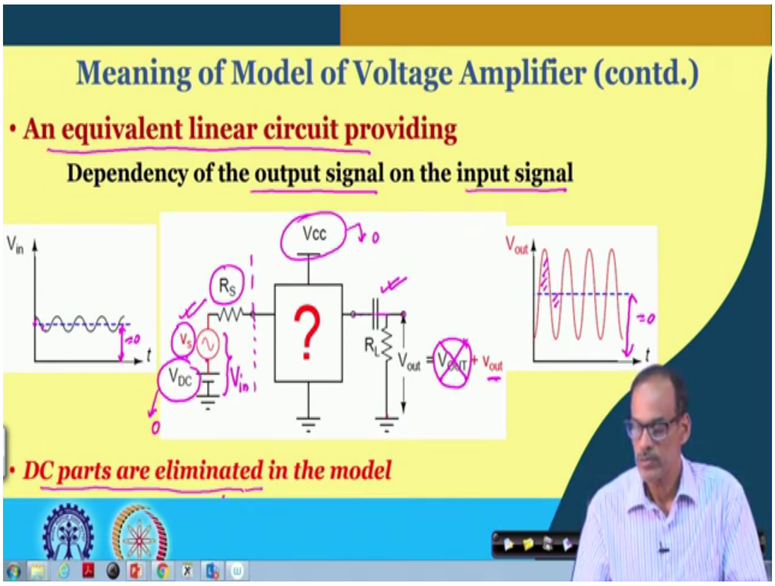


So, what we mean by the voltage amplifier? It is an equivalent linear circuit and it is main purpose is to provide the dependency of output signal on the input signal. So, dependency of this output signal on the whatever the input signal we are applying that supposed to be captured by this one.

And as I said that with progress of time this DC part we are not changing. So, we can probably eliminate the DC part in the simplified model to make the circuit simple enough or probably the analysis we can make it simpler.

So, in general you might have observed that at the input, now we are not calling it is V b e; rather in general we are calling this is the signal source V s having a DC part. So, these two together we may call this is capital V in and then this voltage source may be having a Thevenin equivalent resistance call R S or the source resistance.

So, we are stimulating the circuit with this kind of arrangement and at the output what you are observing is that the voltage across the output point with respect to the common node and we are placing one capacitor to remove the DC part. In fact, once we place this capacitor, this DC part it is getting eliminated.

So, naturally whenever you are talking about voltage amplifier, we are not concerned about the DC part or the rather we are simplifying the circuit just to keep the focus to find the relationship between the small signal input to the small signal output. So, the DC part we are eliminating.

So, as you can expect that we can drop this part to 0, we can drop this part also to 0 in the small signal model. And of course, while you are talking about the signal changing with time; so we can assume that this capacitor it is also working as a short from this point to this point.

So, what we can say here it is the DC part, after eliminating the DC part, of course with appropriate meaning of the circuit namely keeping the circuit in the appropriate region of operation. The simplified model must be expression the relationship between this signal source or whatever the input voltage you do have to this output, ok.

So, the simplified model as I said that this DC part we need to drop to 0 and here also this DC part, equivalently this DC part is also going to be 0. So, we can say that DC parts not only in the circuit it is getting to be 0; but our focus is also on that, namely the signal and making the DC part 0.

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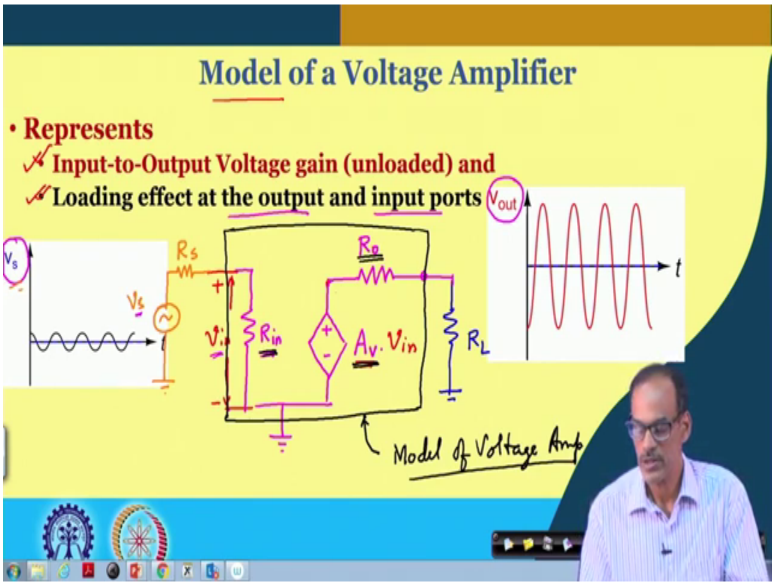


So, we may say that to again to summarize what we said is; that we like to get the input to output signal relationship primarily. So, this is the say, you may say that input signal and this is the corresponding output. So, the input signal of course, it may be coming from the signal source it need not be same. And since we are expressing this output in terms of the input signal, we the simplified model must capture one basic element called voltage dependent voltage source, ok.

So, we may say that this is representing the output voltage with respect to the common node. And this is, in fact if you are not putting any load to the output; this supposed to be representing the gain of the circuit. So, let we call A v is the voltage gain of the circuit. So, A v multiplied by V in; if I call the input voltage is V in. So, A v multiplied by V in is giving the voltage here. So, this is the first element, input to output voltage gain, so A v is that voltage gain.

Now, what are the other elements we require? Note that the basic purpose of having this model of the voltage amplifier is that to simplify the circuit; but at the same time it must represent whatever the necessary information we are looking for. So, apart from the game next thing is that, the loading effect at the output port and the input port. So, whenever we are talking about the loading effect at the at the output port; which means that, the moment we connect load to the output of the circuit, so naturally the output voltage signal it may not be remaining the same. In fact, theoretically it will not be remaining same.

Now, how do we capture the variation of the output voltage based on the load? So, if I connect a load at the output; say for example, I am connecting one load say R L. Probably this R L it is not changing the DC operating point of the circuit; namely we do have a DC blocking capacitor. And then if the moment if I connect this node here, obviously, I will be getting the same output voltage. So, this is the output voltage.

So, naturally just by having this voltage dependent voltage source is not representing the main amplifier. So, I do have the input port here and V in is the voltage at the input port, that is how it is defined. So, I should say this is to be two port network; at the input we are giving a voltage and at the output we are observing the corresponding effect called V out.

Now, as I was mentioning that how do we capture the loading effect and so, what we can do it is, we can put a resistance here. In fact, you can think of that; since at the output port we are considering signal in the form of voltage, naturally we may be expecting one Thevenin equivalent resistance. And let you call this is R o, output resistance of the amplifier at the output node.

So, that takes care of the loading effect at the output port. Likewise the input port; in case say I do have a signal source which is maybe getting loaded with the circuit, yeah let me use this color. So, I may be having a signal source called V s as we are saying here. So, V s is here and the moment we connect the signal source to the input port or the amplifier; depending on the source resistance and the internal behaviour of the circuit, the input voltage coming to the circuit namely V in need not be same as the V s.

So, again once I connect this one whatever the reduced voltage you will be getting at the input port to capture that, we need to put one element here. So, I should say, I must say that we need to put one element called say input impedance or input resistance, if we can simplify it.

So, this input resistance and whatever the external source resistance we do have, they are forming one potential divider. So, the voltage coming at the input port of the amplifier which is V in, definitely it will be lower version of this V s. So, we can say by keeping this input resistance here, I can consider the loading effect at the input port. So, likewise by keeping this R o at the output port, I can consider the loading effect at the output port.

So, I do have basically three important entities in the circuit; one is the voltage amplifier, sorry voltage gain A v; then output resistance which is representing the loading effect at the output port; and then other one is the input resistance R in to take care of the loading effect at the input port.

So, the circuits here what you can see, it is the small signal model of the voltage amplifier or you can say that it is a model of the voltage amplifier, so model of voltage amplifier, ok. So, what we are doing is that; so let me summarize what we said here.

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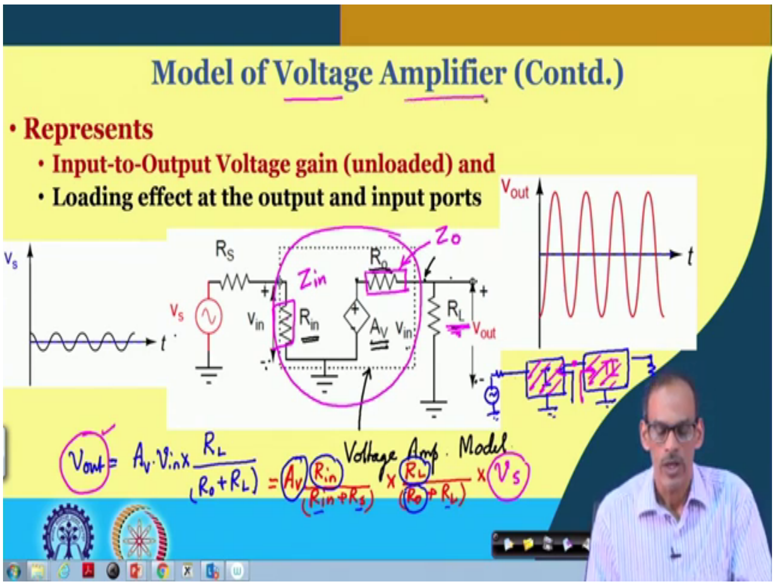


So, this is what the same thing we have discussed, we do have the model, we do have the model of the amplifier; namely the voltage model, voltage amplifier rather, voltage amplifier model. So, what it represents is basically the input to output relationship. And as I said again to summarize the, it is having three important parameters called input resistance, voltage gain and the output resistance.

So in fact, if we are applying one input signal here V s and if you like to know what will be the corresponding V out; first of all A V it will be giving us the gain from this point, the input port to the unloaded output. Why do I call it is unloaded? In case if this R L is in finite, then there will not be any current flow; so the voltage coming here it will be same as the internal voltage, which is A v times V in.

So, if I am not conducting any R L, whatever the gain I will be getting at the output port with respect to input port is solely captured by A v. So, that is why this A v it is referred as open out unloaded voltage gain or open output voltage gain. On the other hand the moment I can need this R L; the available voltage here it will be the voltage here which is A v into V in, multiplied by this attenuation, all right.

So, the V out, now if I say that what will be the V out; let me consider this V out equals to this A v A v times V in multiplied by R L divided by R o plus R L. Now again this V in it is not same as V s. So, if you see, if I write this V s, sorry V in terms of V s what I will be getting here it is; A v and then R in divided by R in plus R s multiplied by R L divided by R o plus R L multiplied by that V s, let me use this color V s.

So, this simple model it is helping us to find the input V s to final output voltage. And it involves the, as I said that important parameters of the amplifier it is; it is having the unloaded voltage gain, it involves the input resistance along with this source resistance R s and also includes the R o along with this R L. So, I should say these three parameters are sufficient to represent a voltage amplifier, all right.

Now likewise, so at least we understand that the simple model is good enough to capture the behaviour of the amplifier, main behaviour; namely the linearized behaviour. And probably then we can cascade not only this load and the source resistance here; probably we can have multiple stages of voltage amplifier or you may have multiple voltage amplifiers, they may be cascaded one to each and so and so.

And then at the input of course, we may be having the primary source. And then at the output we can put the corresponding load resistance. And so, the output resistance of this amplifier one, so output resistance looking into this output port. And input resistance or the second stage or second amplifier looking into it is input port, they may be providing the loading effect.

So, the loading effect it is not only just coming from the primary port element namely R L and R s, but also whenever we are cascading say multiple voltage amplifiers together, then the output resistance of one stage and input resistance of the other stage together they are providing loading effect at this middle point.

So, that is how I should say that if we are having a circuit having many stages of amplifiers. Then you can probably each of the those amplifier stages, you can represent by the simple simplified model. And then you can probably cascade each of these simplified model together to get the overall gain or overall transfer function of the circuit.

Now, I must add few things; one is this load need not be always resistive, likewise this resistance, input resistance need not be only resistive, it may be having reactive components also. But the basic model, namely it will be having three elements, it will be there. And in case each of these elements are having reactive part also; so in that case, we may consider in general it is a complex entity and we may call this is output impedance call 0. So, likewise this element instead of calling R in, we may call it is Z in,

And so, that is one point and the second point is that, whenever we do have fairly complex system, we may not be having always voltage amplifier; we may be having some other amplifiers. So, that is what I said that, in this discussion we will be having model of not only voltage amplifier but also the current amplifier and maybe other kinds of things.

So, depending on the signal type here, this signal if it is current and likewise the output signal it is current; then we can think of the corresponding model it must be different from this model that is called the model of current amplifier, ok. So, let me take a short break and then I will come back.

Thank you.