Analog Electronic Circuits
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Lecture - 23
Linear Models Of Amplifiers (Part B)

Welcome back after the short break. So, before the break we are talking about the Model of Voltage Amplifier. And, as I have given a hint that the amplifier need not be always voltage amplifier.

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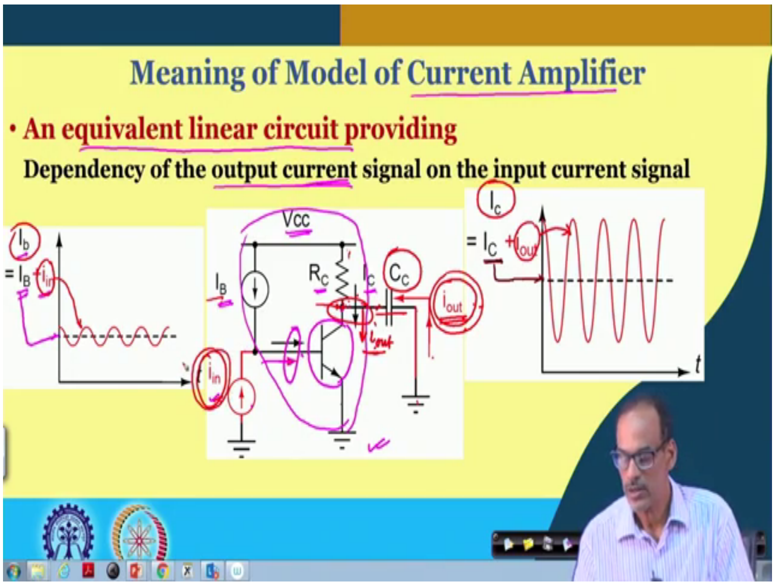

Meaning of Model of Current Amplifier

- An equivalent linear circuit providing

Dependency of the output current signal on the input current signal

There may be based on the signal at the input and signal at the output we may be having different types of amplifiers. So, let us talk about other kinds of amplifier called current amplifier. And, whenever we are talking about current amplifier similar to voltage amplifier, what does it mean is that, it is an equivalent linear circuit, which provides dependency of the output signal output current signal on the input current signal.

So, note that the output signal and input signal both are current and that is why you we call this is current amplifier. So, similar to the previous case here we do have one example having this is also amplifier having 1 BJT. And, as you can see here, what are the things we do have is the BJT is at the center place, and then it is having a DC bias through the R c, we are giving proper voltage at the collector of the transistor.

And, then we do have a DC current at the base which is providing a meaningful bias to the base of the transistor. Either you can think of this V B it is sitting the V B or on the on DC base current, but whatever it is this is also providing one bias in condition. And, depending on this I B and beta of the transistor we may having a if the device it is in active region of operation, we may be having this collector current DC collector current.

So, this DC collector current is flowing through this R c providing a voltage draw ensure and most likely that even after deducting this drop the V cc it is sufficiently high. So, that it is based to collector junction it is reverse bias. Namely keeping the device it is in active region of operation. So, there is the main part here. So, the main part it is here including the bias.

And, all and then if we feed the signal in the form of current at the base as we are seeing here. And, depending on the current here we are expecting this current to the flowing. Note that in simplistic model here we are showing this is signal current, which means that it is average it is 0.

And, need not be sinusoidal, but sinusoidal things we may consider as one special case. So, at the base of the transistor what you can say that the base current to the transistor it is having two components. Namely the capital I, capital B, the DC part, and also the time varying part which is shown here. So, it is having a DC part here and the time varying part.

So, the time varying part is given here. So, these two together they are giving the total base current. So, as a result the current flowing through the collector it is also having two components; one is the DC part and the small signal part.

Now, if you are observing the voltage at the collector without making any connection here, then you may see the voltage is changing there, but in case if we are looking for this circuit as a current amplifier, then at the output we like to extract the signal in the form of current. So, what we do?

We like to short this output node to ground and then we like to extract the entire signal, but while you are doing this, we have to make sure that the output node it is not really or other the collector node it should not get shorted to DC ground. And, hence we need to put one DC blocking capacitor or it is referred as AC coupling capacitor.

So, for time varying signal, whether it is current or voltage whatever you say, that we can think of this capacitor is essentially working as a shot. So, the current whatever the current will be observing here is the variable part of this the collector current. So, we may call this is a small i small out.

So, the collector current here we can say the total current here; it is having a DC part. So, it is having a DC part here sorry, it is having a DC part here. So, the DC part it is capital I capital C, and then it is having the on top of that it is having the small signal part ok. So, in case if we are not connecting anything here actually this I C it will be flowing here or a small I out will be flowing here, but you in case if you want to extract the signal, you need to connect to AC ground through this capacitor to extract this entire current.

So, naturally the voltage here ideally by making this connection it will not change. And, then you can say that whatever the current it is flowing, the signal current it is flowing it will not flow through this register. So, the current whatever we obtain here, which is referred as the short circuit current or it is called unloaded current I must say it is unloaded current. Since, the signal here it is current form. So, to get the entire current you must short this 2 AC ground to extract the entire current.

For voltage signal we like to keep the output node open whereas, for current signal at the output node we must sort it to AC ground. So, anyway so, this is what the amplifier overall amplifier as I said that at the input we are giving say DC current here and along with the signal current. And, at the output what we obtain here it is a DC part and a small signal part, but then whenever we like to see this circuit as an amplifier the signal amplifier, then our main focus is that this is the input and this is the corresponding output.

So, whenever you are talking about the model of the current amplifier, similar to voltage amplifier. What we are looking for it is simplified equivalent circuit, which must represents this entire circuit, in terms of finding the relationship between this final output to the this input ok. So, what we have said here, let me again summarize in the next slide I think I do have the next slide to summarize.

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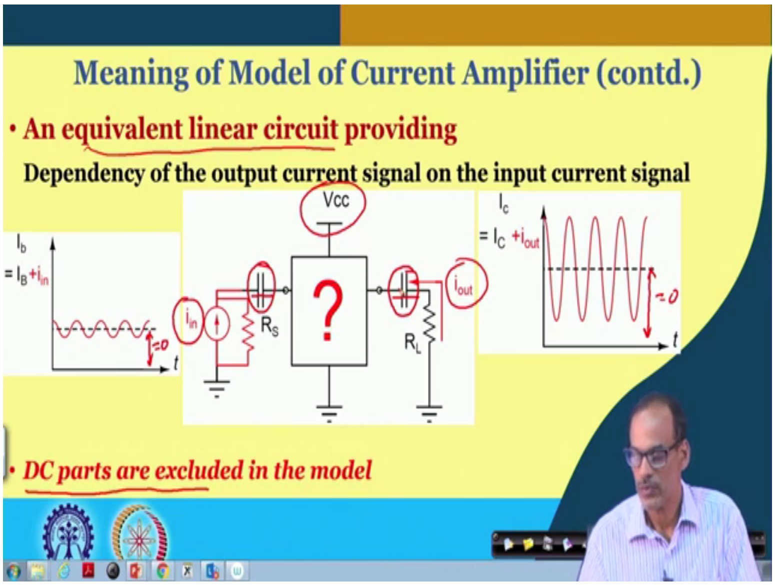

Meaning of Model of Current Amplifier (contd.)

- An equivalent linear circuit providing

Dependency of the output current signal on the input current signal

- DC parts are excluded in the model

Yes. So, whenever we are talking about the model of amplifier. So, what we are referring to it is so, we are basically referring to one equivalent linearize circuit, which is representing the entire circuit to find the input to output relationship, input to output relationship. So, what may be the corresponding circuit here, that is what we are going to say it is the model of the amplifier.

So, similar to the voltage amplifier here again we like to remove the DC part, we like to exclude the DC part and the model to simplify the circuit. So, we will be definitely excluding this part and also to avoid DC current we are or I should say that we are feeding the signal only through coupling capacitor. Likewise while we are extracting the signal we are putting a DC blocking capacitor here at the output port.

So, we are assuming that these arrangements are there. So, for in the model; however, since we are focusing on the signal which is having sufficiently high frequency for which this capacitor it is working as a short, this is also working as a short. So, this as I said that this DC part need to be made 0. So, likewise the DC part we are making it to 0 by putting this capacitor. Now, to again to see what are the basic elements are there in the current amplifier let me focus, let me start with a fresh slide.

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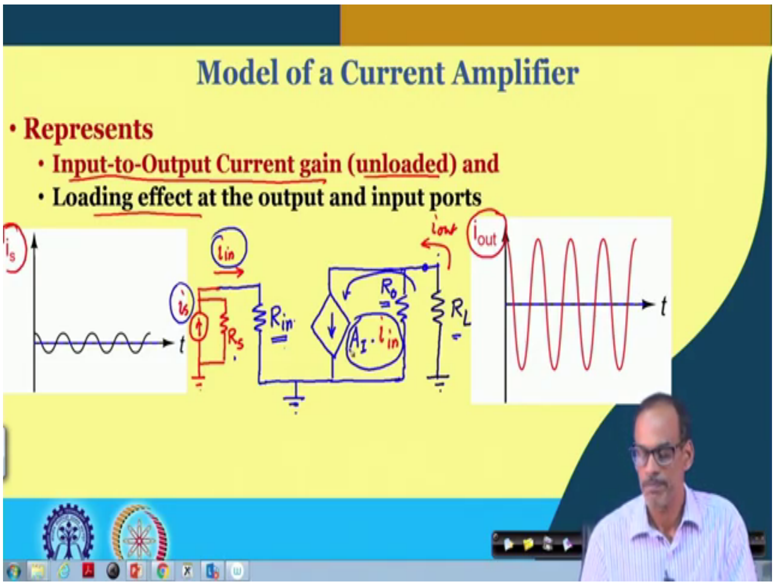

Model of a Current Amplifier

- Represents
  - Input-to-Output Current gain (unloaded) and
  - Loading effect at the output and input ports

So, what we are going to do in the current amplifier model, it is we like to get the relationship between the primary input call the source current to the primary output. And, the model, whatever the model we are going to discuss here it must be having input to output current game and it should be unloaded current gain.

So, the first element of the model we are expecting that, we must be having a current dependent current source. So, if I say that the gain of this amplifier it is a A I. So, the output current unloaded current should be A I times the input current i in. So, that is the current here, which is the unloaded current.

And, then similar to the voltage amplifier and what is i in is whatever the current is entering to the circuit, entering to the circuit. So, the circuit may be having elemental like say, having one element which is having some finite conductance or finite input resistance, but whatever it is as long as i in is entering here. And, then we are getting the corresponding output here and the output it is in the form of current.

Now, this element A I as I said this is the first parameter or first element of this model. The other 2 elements supposed to capture the loading effect at the output port and input port. Now, the moment we connect to load at the output instead of directly shorting in. So, if I am having a finite resistance at the output so, it is expected that the practically the current flowing through the circuit may not be same as the internal current.

So, whatever the current will be seeing here call i out need not be the total current what we are getting here. In other words the we must add one we must add one non zero conductance to this element in parallel with this current depending current source.

So, either we may say that this conductance is G naught or you can write in terms of resistance call R naught. And, the output port of course, it is here. So, the moment we connect this R L; obviously, then the total current it will be getting bifurcated one part it will be flowing through this R L and another part it will be flowing through this R o. So, these 2 currents so, this current and this i out together it is giving the internal current, which is of course, it is what we call it is unloaded current.

When, I say unloaded current, which means that R L is equal to 0. If, I make this R L is equal to 0 for a finite value of R o, then we can say that the current flowing here, it will be same as this one, because the drop across this resistance if this is 0 then this is 0 so, the drop across this R o it is 0. So, the current here it will be 0. So, then i out it will be entirely same as the internal current A I multiplied by i in.

So, again what I said is that this R o represents the practical loading effect in the circuit. So, if we are having load resistance R L, which is non-zero, then whatever the reduced current will be seen that reduce current it will be again it can be calculated by considering this R out.

So, same thing at the input side the input resistance ideally we want this input resistance to be 0, but practically when you consider circuit and if we are stimulating the circuit by a signal current. And, so if I say that this is i s and if I directly feed this current to the circuit, it the internal current i in or the current going to the circuit need not be same as this i s, which means that along with this i s.

Practically if it is having some conductance and this conductance either we can call it is G s the source conductance or we can write in terms of resistance say R s. And, the moment we connect it here the it is not that entire current it will be flowing here, that is because this R in practically it is nonzero.

So, the moment I connect practical value of R in or nonzero value of this R in, the current i in it is coming to the circuit it will be only a fraction of this i s. Of course, depending on the relative value of this R s and R in, this i in it will be significant part or maybe small part of it, but whatever it is this i in it is producing the internal current A I times i in. So, what we have, what we have seen here, again I am showing in different slide to summarize whatever we have discussed the about the model.

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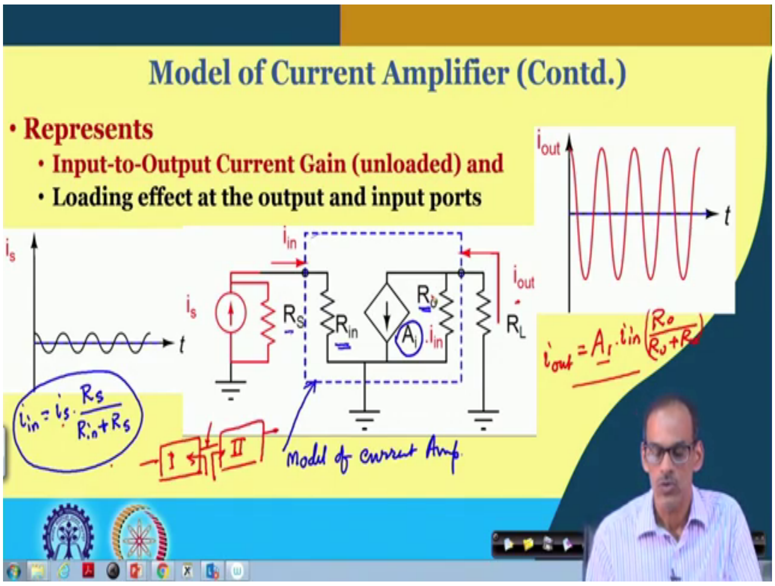

Model of Current Amplifier (Contd.)

- Represents
  - Input-to-Output Current Gain (unloaded) and
  - Loading effect at the output and input ports

$i_{in} = i_s \cdot \frac{R_s}{R_{in}+R_s}$

$i_{out} = A_I \cdot i_{in} \left(\frac{R_o}{R_o+R_L}\right)$

Model of current Amp.

So, the current amplifier model it is shown here by this dotted line. So, this is what the current amplifier model. So, this is the model of the current amplifier. And, then as I said that it is having 3 important parameters namely the unloaded current gain A I, which gives the internal output current, after multiplying with i in..

Then other element is that R o which is representing the loading effect at the output port and then R in, which is representing the loading effect of the circuit, whenever we do have this nonzero conductance. Namely, R s if it is finite, then whatever the bifurcation it will be happening that will be getting represented by this R in.

So, if you look into say this input port the i in it is as I said that it will be. So, we can write that i in equals to. So, whatever the i s we do have multiplied by the this parallel resistance it is developing the voltage divided by R in is the current or simply you can say that R s divided by R in plus R s.

So, we can say at the input we do have the loading effect getting captured by this R in. So, likewise at the output whenever we are talking about the output port, at the output port we do have the output current i out, it will be internal unloaded voltage A i times i in multiplied by R o divided by R o plus R L. So, again so, these two important equations they are representing the loading effect.

So, by considering these two loading effects along with this A i you can find what will be this i out and i s relationship. So, in case if we have a circuit which is having multiple stages, each of the stages if we can break into as current amplifier, then each of these amplifier stages you can model by this circuit. So, we can have say one current amplifier followed by another current amplifier and then maybe the primary input and primary output.

So, the output port parameter of the first stage along with the input port parameter of the next stage together again it will be producing one loading effect. So, everywhere wherever you are making connection from one stage to another stage or maybe feeding the signal or you are connecting the load everywhere you will be having the loading effect. And, this R in and R o they are playing important role to capture this loading effect. So, that is about the current amplifier.

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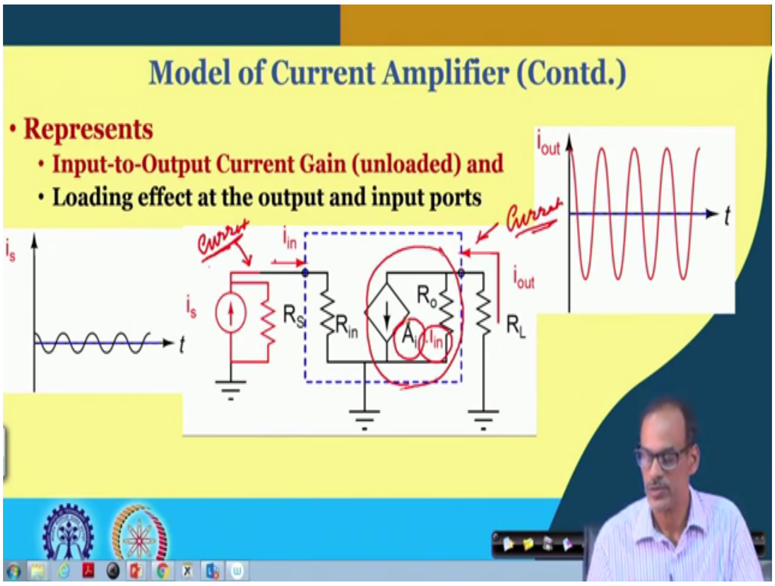

Model of Current Amplifier (Contd.)

- Represents
  - Input-to-Output Current Gain (unloaded) and
  - Loading effect at the output and input ports

So, the as we said that we have discussed about voltage amplifier and then also we have discussed about the current amplifier and you might have seen that, whenever you are talking about say current amplifier the signal here it is current, and the signal here it is current.

But, there may be a practical situation where we cannot say that signal always be of same nature. In case say input is say current and output is voltage, then what kind of model will be using or say, if the input is voltage and output is current then what kind of model we will be using. So, based on the signal type here, if it is voltage and then current will be having one kind of amplifier or third kind of amplifier.

And, likewise if I am having the input is input signal is current and then output signal it is in the voltage form then we will be having the fourth kind of amplifier. So, utilizing this port nature, namely if the signal here it is current, we are representing this the output port in the form of not an equivalent circuit on the other hand if it is voltage then we are representing this by Thevenin equivalent circuit.

So, depending on this signal type either we can have the Norton equivalent or Thevenin equivalent, but then depending on the signal here the controlling elements it may be current or voltage. So, based on whether it is current or voltage we can have different parameters here. So, let us see that the other two types of the amplifiers and their corresponding model.

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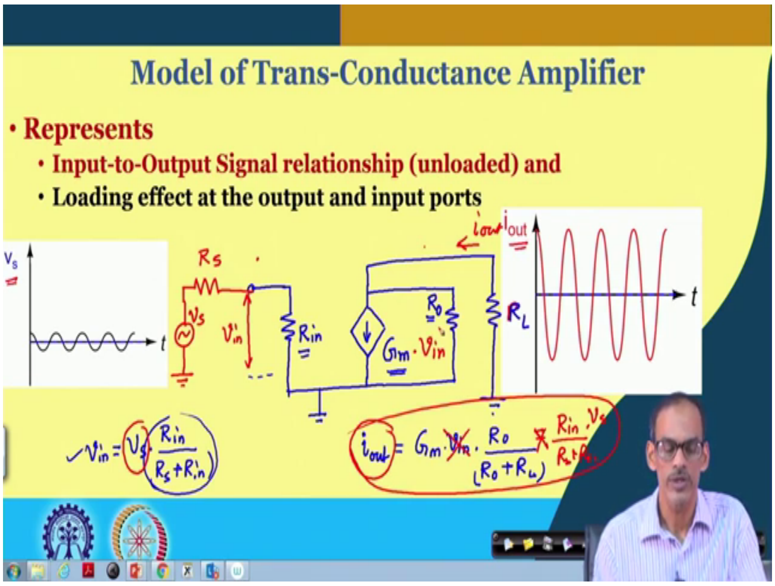

Model of Trans-Conductance Amplifier

- **Represents**
  - **Input-to-Output Signal relationship (unloaded) and**
  - **Loading effect at the output and input ports**

$$v'_{in} = v_s \cdot \frac{R_{in}}{R_s + R'_{in}}$$

$$i_{out} = G_m \cdot \cancel{v_{in}} \cdot \frac{R_o}{(R_o + R_L)} \times \frac{R_{in} \cdot v_s}{R_s + R_{in}}$$

So, suppose you do have this situation like this. At the input you do have the signal in the form of voltage and then at the output you do have the signal in the form of current. So, as the signal at the output it is current. So, we are expecting that the in the model, it should be not an equivalent is not it. So, we will be having a current source, but then it will not be current dependent current source, because the signal here it is a voltage rather it will be voltage dependent current source.

So, since it is relating the input voltage to output current. So, we call this is conductance and it is representing mutual relationship from input port to output port. So, we denote this parameter by capital G m call Trans conductance, then multiplied by of course, the corresponding signal. So, what is the signal? It will be v in; v in is the signal appearing at the input port of the circuit. So, we may call this is v in and the v in is basically the input port voltage.

And, so since it is not an equivalent to take care of the loading effect as you might have seen for the current amplifier we like to put one finite conducting element. And, it is conductance you may write in terms of G conductance or you can for simplicity you can write the resistance R naught. And, at the input again to take care of the loading effect at the input port we may have a finite input resistance.

So, note that if this R in is higher it is better, in case if the signal it is in voltage. So, anyway we do have these three elements; one is the Trans conductance of this amplifier, output resistance and then input resistance. And, of course, at the input we are feeding the signal in the form of voltage. And, this voltage source may be having it is finite resistance call the source resistance R s and, this is of course, the v s.

And, here again you can see that R s and R in together it will be creating a potential division of v s to produce this v in. So, likewise at the output side in case if we are connecting a load here instead of directly shorting to ground to see the corresponding signal output. So, the i out here, it will not be entirely this internal current in state there will be some potential division.

So, there will be potential division or rather I should not say potential current division between this R o and R L. So, here in this case we can say that i out it will be G m times v in multiplied by R o divided by R o plus R L. So, this is again taking care of the loading effect.

So, likewise at the input side the v in it will be v s multiplied by R in divided by R s plus R in.

So, here again we do have the this factor to take care of the loading effect. Now, if I combine these two equation we can find the relationship between this the i out and the v s. So, we can say that i out it will be let me use this space i out it will be ok. So, if I replace this part by it is expression in terms of v s. So, I do have R in divided by R s plus R in into v s. So, that gives us the overall gain of the circuit capturing the loading effect at both the ports.

So, likewise if the signal if the signal it is at the input port it is say current, if this is current and this is voltage, then we can again model the circuit and differently of course, but since the output it will be voltage, then the output port it will be Thevenin equivalent. So, let us see that model in the next slide.

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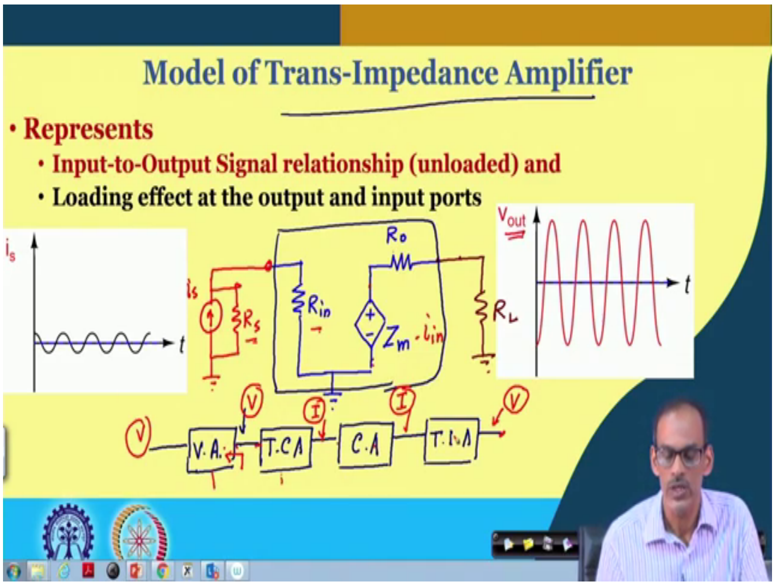

Model of Trans-Impedance Amplifier

- **Represents**
  - **Input-to-Output Signal relationship (unloaded) and**
  - **Loading effect at the output and input ports**

So, here as I said that the output it is voltage. So, the output port, output port it will be the Thevenin equivalent. So, we do have Thevenin equivalent. This is dependent voltage source and also it is having Thevenin equivalent resistance call R o and this dependent voltage source, it is it depends on the current.

So, what we write here the parameter it is actually it is impedance and since it is correlating the output port to input port we call Z m mutual impedance or it is called Trans impedance. And, this Trans impedance multiplied by the whatever the current it will be having at the input port.

So, i in times Z m it produces a voltage here, which is referred as the unloaded internal voltage. And, at the input again to take care of the loading effect, we are having finite resistance call R in. And, in case if we are connecting say load at the output say R L, the voltage here it will be reduced version of this voltage. So, likewise at the input of course, it is current source. So, we will be having a signal current here say i s and it is having a finite conductance say R s.

So, again this R s and R in they are providing the loading affected the input port and then R o it is along with this R L finite value of R L, it is providing the loading effect at the output port. So, the model what we are seeing here, basically this part is the Trans impedance model of the Trans impedance amplifier.

So, now we are having 4 basic models or different types of amplifiers based on the signal type. So, if we are having one amplifier having multiple stages and these stages need not be only one type of amplifier say for example, this is a voltage amplifier ok. And, then we do have say Trans conductance amplifier, trans conductance amplifier ok. And, then you may be having say current amplifier ok and, then we may have say, Trans impedance amplifier.

Note that while we are connecting it the signals are consistent. So, if you see here since it is voltage amplifier the volt the produces a signal here in the form of voltage. So, the signal here it is voltage and the Trans conductance amplifier it is also expecting input as voltage. So, they are consistent.

And, here the output of the Trans conductance amplifier it is current and I do have current amplifier. So, the current amplifier is expecting signal in the form of current. So, then there is no problem. And, here we do have the signal coming from the current amplifier is of course, in current form and then we do have the Trans impedance amplifier, which is of course, producing the signal in the form of voltage.

So, we do have here it is the signal it is in the form of voltage final it is coming to the voltage and it is going through different other modes of signals. So, that is why we can we may have a chain of amplifiers having each of the stages are of different types of amplifiers.

Now, the natural question is that, in case if the signal here and signal expected signal to the next stage if they are not consistent, then what do you do? Luckily each of the stages they do have their own practical output impedance or output conductance element and you can nicely convert the output port model into appropriate model. Namely, Thevenin equivalent model you can convert into Norton equivalent and vice versa.

So, those kind of after seeing what kind of amplifier it is cascaded to you may have to adopt those things, but as a individual building blocks, we do have this kind of 4 basic model they are sufficient. And, each of those models are having primarily 3 elements.

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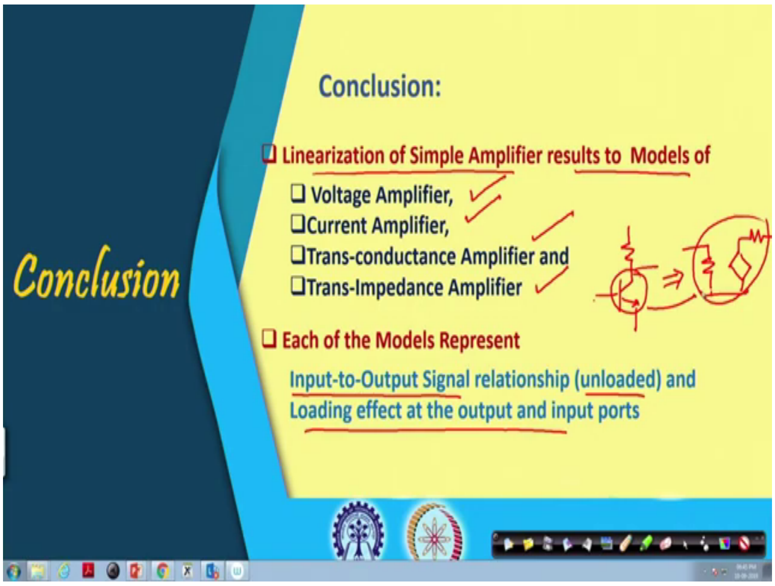

Conclusion

Conclusion:

- ☐ Linearization of Simple Amplifier results to Models of
  - ☐ Voltage Amplifier, ✓
  - ☐ Current Amplifier, ✓
  - ☐ Trans-conductance Amplifier and ✓
  - ☐ Trans-Impedance Amplifier ✓
- ☐ Each of the Models Represent

  Input-to-Output Signal relationship (unloaded) and Loading effect at the output and input ports

I think, let us summarize what we have discussed in the today's class. Primarily we have discussed about the linearization of amplifier, namely simple amplifier and that results to models or the amplifier. Depending on the signal type we do have voltage amplifier, we do have current amplifier, Trans conductance amplifier and trans impedance amplifier.

And, each of these types of amplifiers what we are doing is we are simplifying the circuit, into one equivalent circuit. The circuit is simple enough it is simple enough, but it is also it is sufficient to capture whatever the information we are looking for. Namely, it represents the input to output a signal relationship, whether it is voltage gain or current gain or a Trans conductance and trans impedance particularly in unloaded condition. And, also it is having the other 2 parameters namely output resistance and input resistance or maybe output conductance and so, to capture the loading effect when you considered practical circuit.

So, I think these models are pretty handy when will whenever we will be having fairly more complex circuit what we will be doing is that this basic models we have to keep in mind. So, whenever we do have one amplifier we must always try to translate this circuit in this form. Namely, whenever we do this amplifier we need to say suppose this is voltage amplifier, then how do we find the basic three elements, namely the open loop voltage gain output resistance and input resistance.

So, that will be the exercise we will be performing whenever we will be going to the actual circuit and converting that into the corresponding model. I think that is all I do have.

Thank you for listening.