Analog Electronic Circuits
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Lecture – 40
Frequency Response Of CE/ CS Amplifiers Considering High Frequency Models Of BJT And MOSFET (Part A)

So, dear students so, we will come back to our NPTEL online certification course on Analog Electronic Circuits, myself Pradip Mandal from E and EC Department of IIT Kharagpur. Today's topic of discussion it is Frequency Response of CE CS Amplifiers Common Emitter and Common Source Amplifiers Considering High Frequency Model of BJT and MOSFET.

In fact, we already have started about this frequency response of CE amplifier and CS amplifiers, but there we did not consider capacitances associated with the MOS transistor itself. So, today's discussion it is a we will see what will be the impact of the capacitances associated with the devices the transistors on its frequency response particularly for common emitter and common source amplifier.

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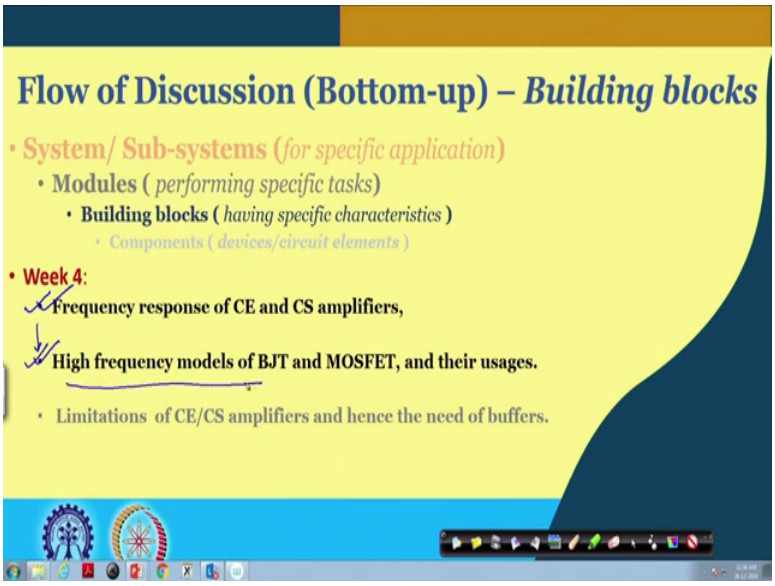

Compared to our overall flow and overall plan where we stand today it is we are in module 4 we have done quite an extent about the frequency response of common emitter and common source amplifier. Today we will be extending that for frequency response considering high frequency model of BJT and MOSFET transistor.

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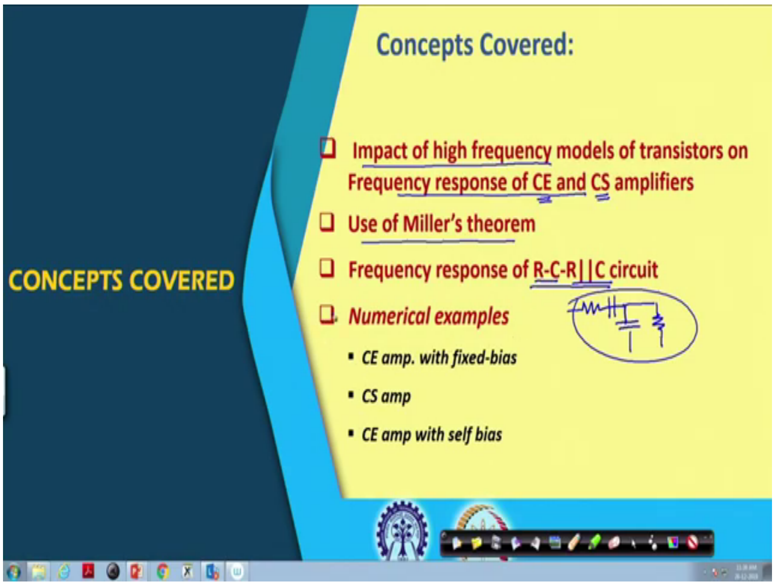

So, the concepts we are planning to cover today is the following. First of all we like to; we like to highlight the points that the impact of the high frequency response on the frequency response of CE and CS amplifiers and then we will see that there is a need of some theory, proposed by Miller called Miller's theorem.

And then we shall use that Miller's theorem to calculate effective capacitance associated with the transistor in the frequency response and then we shall see the need of a frequency response analysis for a special kind of circuit namely R-C followed by R and C in parallel. So, this frequency response of this kind of circuit we have not discussed.

We have discussed only R-C and CR circuit, but here whenever we will be talking about the equivalent circuit of common emitter and common source amplifier, containing the capacitance is coming from the transistor, then we will see that there is a need of a R-C circuit followed by CR circuit. So, that is what we have to consider. So, we will be having R-C and then R and C in parallel. So, this kind of circuit we have to consider and then after that we will be talking about some numerical examples. So, this is what the overall plan.

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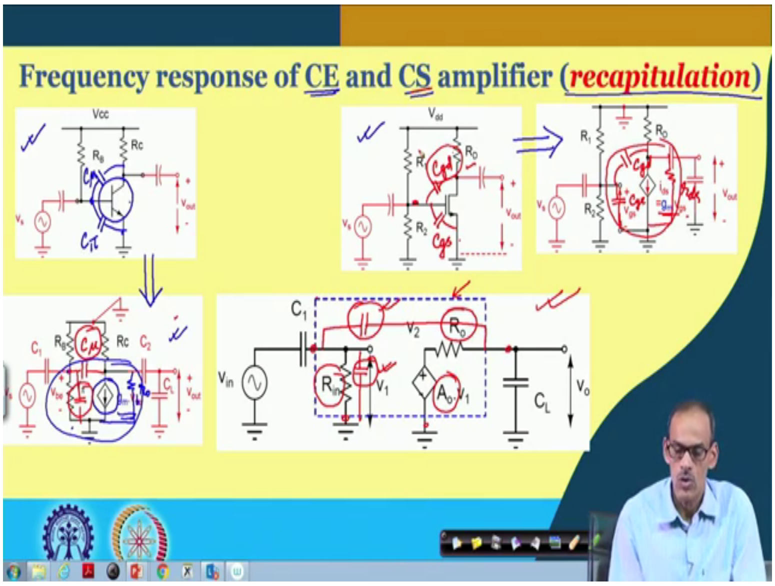

So, let we look back what is the frequency response we have discussed for common source and a common emitter amplifier. So, this is a recapitulation as I say recapitulation of whatever we have discussed so far. So, here we do have the CE amplifier and here is the corresponding small signal equivalent circuit for that.

And so, likewise here we do have the common source amplifier and its corresponding small signal equivalent circuit is given here. So, note that in this model in this small signal equivalent circuit, for this transistor we do have r pi from base to emitter terminal and then we do have gm into V be. In fact, this will be V be.

So, this current source it is basically voltage dependent current source in addition to that we may consider ro, but whatever the model we have considered so, far it does not include the inherent capacitances associated with this transistor namely base to emitter terminal capacitance called C pi and then base to collector terminal capacitance called C mu. So, if you consider these two capacitances in this equivalent circuit, we are expecting we will be having a C mu part here and then C pi part here.

So, likewise if you see the common source amplifier, here in the model of the MOS transistor we do have the voltage dependent current source gm into Vgs and then we may consider from here rds, but so far we have not considered inherent capacitances of the MOS transistor namely gate to source capacitance Cgs and then Cgd. So, if I consider that Cgs and Cgd what we are expecting that we will be having Cgd here and then Cgs here.

Now, if I consider generalized model and here we do have the generalized model of the two amplifiers namely common emitter amplifier and common source amplifier. So, what you can see that the dotted portion is the macro model or the voltage source or other voltage amplifier where we do have this is the input port and then this is the output port within that we do have output resistance, input resistance and then also the voltage gain.

Now, if I consider the C pi C mu what we are expecting that from say input to output node there will be one capacitance. So, likewise from input to ground there will be another capacitance. Now, this capacitance input port capacitance for Ce amplifier it represents primarily the C pi part and if it is a common source amplifier, then this capacitor represents Cgs part on the other hand the input to output port bridging capacitance this one it is representing C mu for common emitter amplifier and then Cgd for common source amplifier ok.

So, in summary so far we have discussed these two small signal equivalent circuit and they are we have seen the frequency response now in our present discussion, we need to consider two more capacitances in our discussion and that will lead to a frequency response particularly for high frequency behavior.

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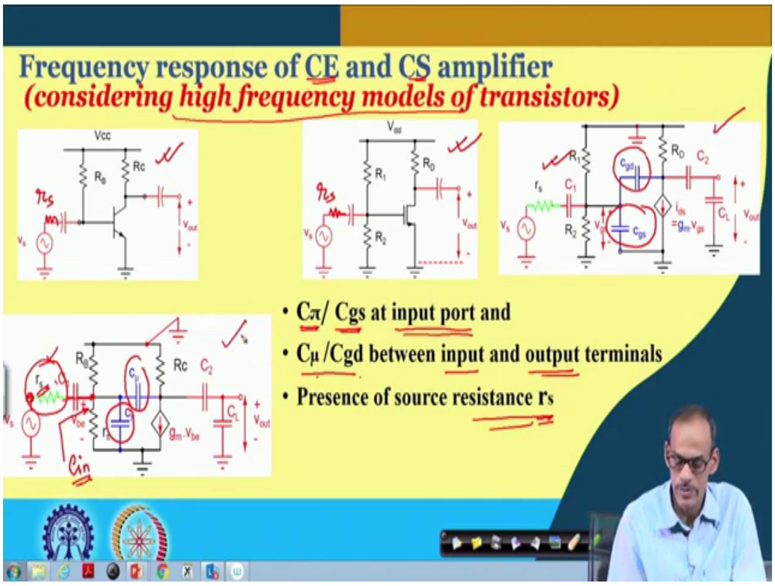

So, what we have to consider now, it is given here as I said just now we need to consider C pi and C mu for common emitter amplifier. Likewise, here we need to consider Cgs and Cgd for common source amplifier. So, this C pi or Cgd depending on whether we are talking about common emitter or common source amplifier, that increases the input capacitance or that contributes to input port capacitance and then we do have C mu or Cgd it is the bridging capacity capacitance between input and output terminal.

Now, we also consider since so, this Cpi and C mu effectively they are providing input capacitance, input parallel capacitance called say C in to see its effect it is also we consider the source resistance R s. Of course, if I do not consider source resistance even if you consider say input capacitance, in the frequency response it will not be having any effect because the signal applied at the primary input, it will be directly coming to the input port of the amplifier.

On the other hand if I am having this rs if I consider the source resistance rs and then in presence of C in, I will be expecting one rc circuit and naturally that will affect that will change the frequency response of the amplifier. So, while we will be talking about the frequency response considering high frequency model, we do consider this non zero value of this rs, rs here and rs are here so we will consider the source is having rs here and this source is also having source resistance rs.

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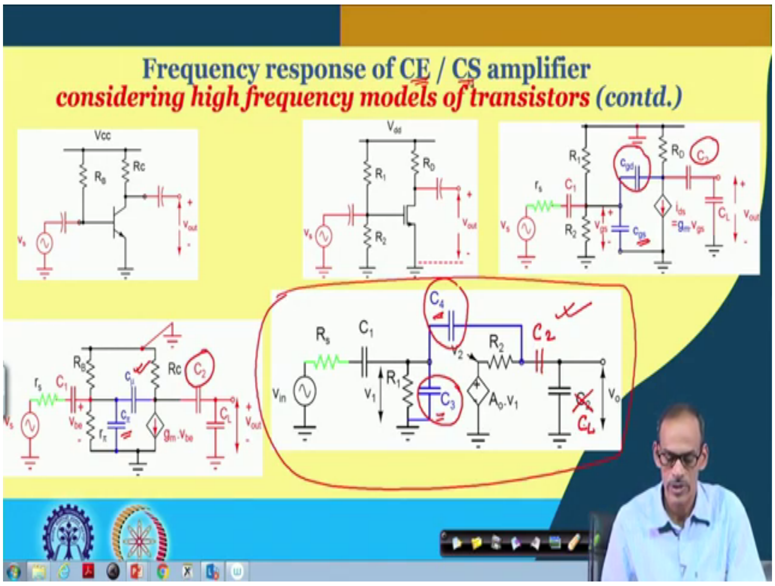

So, if I consider this model and this model together we do have generalized model which is given here. So, we do have C 3. C 3 representing either C mu sorry C pi or Cgs likewise, C 4 it is representing C mu or Cgd depending on Ce or Cs amplifier. So, I should say this is the generalized model of the amplifier whether it is common emitter or common source that can be analyzed by considering this circuit.

So, here while we will be talking about the frequency response, what we can see that impact of these two capacitances we have to consider. And in this frequency response of course, I have committed a small mistake in this circuit we should be having C 2 here. So, this is the C 2 and this additional capacitance. So, whatever the capacitance you are putting here that is basically the C L instead of C 2 it is CL ok.

So, now our task is to find the frequency response of this equivalent amplifier representing both common emitter and common source amplifier. So, to analyze this circuit let we try to see that, what are the additional things we have to do.

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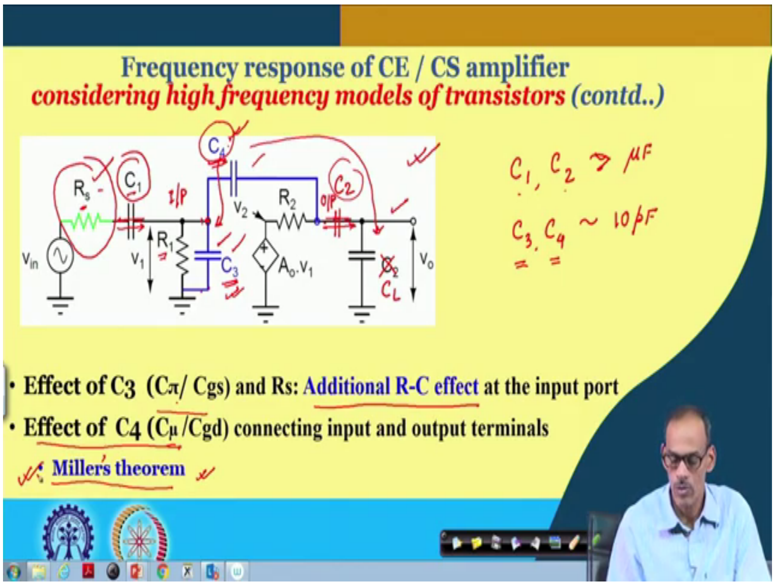

So, if you see carefully in this circuit as I said again I have repeated this mistake, we should be having C 2 here and then this should be CL. Now, as I said that this C 3, C 3 it is the input port capacitance and this input port capacitance, it is forming RC circuit with this Rs and whatever the equivalent parallel capacitance. So, do have. So, it is introducing additional RC effect at the input port earlier in absence of say Rs and R 3 we used to consider only C 1 and R 1 to get the frequency response.

Now, we do have this resistive element and this capacitive element. In fact, we also have this capacitive element, but before we translate this capacitive element we need to be careful that C 4 it is connected between the input port of the amplifier and the output port of the amplifier.

So, we need a special treatment to translate this C 4 in terms of or into two equivalent element one is at the input port and another one it is at the output port either you can consider here or here. Now, I must say that this splitting of this C 4 capacitance a one for input port another is for output port, it is normally done by a theory proposed by Miller which is commonly known as Miller's theorem.

So, before we go into the detail analysis let me go through this Miller's theorem first and then we split this C 4 into these two equivalent component and then we will be going for the frequency response of the amplifier right. So, and the other point I like to mention is that whenever we will be talking about the frequency response considering say r pi sorry C pi and C mu or Cgs and Cgd we may consider that whenever these capacitors are prominent the C 1 and then C 2 they may be successfully allowing the signal to go through this.

So, for simplicity whenever we will be talking about the effect of C 3 and C 4 we may short this one. So, that you have to keep in mind mainly because the typical value of say C 1 and C 2 if you see, this these capacitors maybe having higher than microfarad. On the other hand typical value of say C 3 and C 4 they may be in the range of 10 picofarad ok.

So, naturally the frequency range over which we will be considering the effect of C 3 and C 4 there you may consider that C 1 and C 2 effectively they are simply shorting their two terminals. So, now, we like to go into this Miller's theorem and try to see what is it and how we split the input to output bridging capacitance into two parts; one is for input port another is for the output port.

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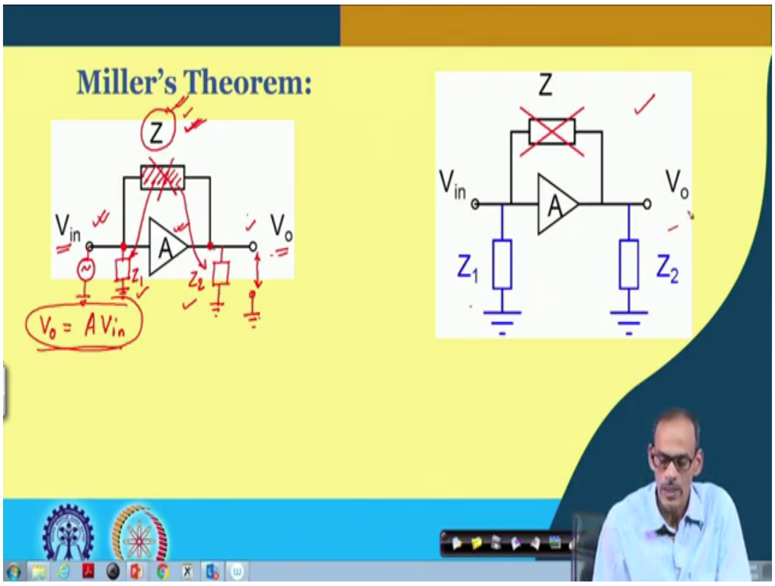

Now in general here suppose we do have one amplifier and let me consider the signal at the input it is voltage. So, likewise we do have output signal also in the form of voltage and then we do have that mean amplifier A, which means that V o equals to A times V right. So, the signal it is going from left to right. So, we do have input port and then we do have the output.

So, you may say whenever you are talking about V o we are considering the voltage at this terminal with respect to common terminal called ground likewise at the input we are feeding the signal V in with respect to the common terminal. Now, we do have this bridging element. So, in general it may be resistive, it may be inductive or it may be capacitive or it may be combination of that but whatever it is, this element it is bridging the input port and output port.

Now this input port to output port relationship signal relationship can be represented by this one excluding this Z element the bridging element. Now, in presence of this Z that makes the analysis a little complicative. So, a better approach and efficient approach is to split this capacitor sorry I should say this Z element into two equivalent element; one is for the input port, which is connected with respect to common node ground and let me call this is Z 1 and since the other terminal it is connected to the output port we also need to consider its effect before we remove it and let we call this is Z 2.

So, we can say that effect of Z it is getting captured by the Z 1 and Z 2. So, we can see once it is getting translated into the its equivalent parts then you can remove this one. So, that is what your this diagram it is representing that we are splitting the bridging element into two equivalent parts called Z 1 and Z 2 one for input port another is for the output port.

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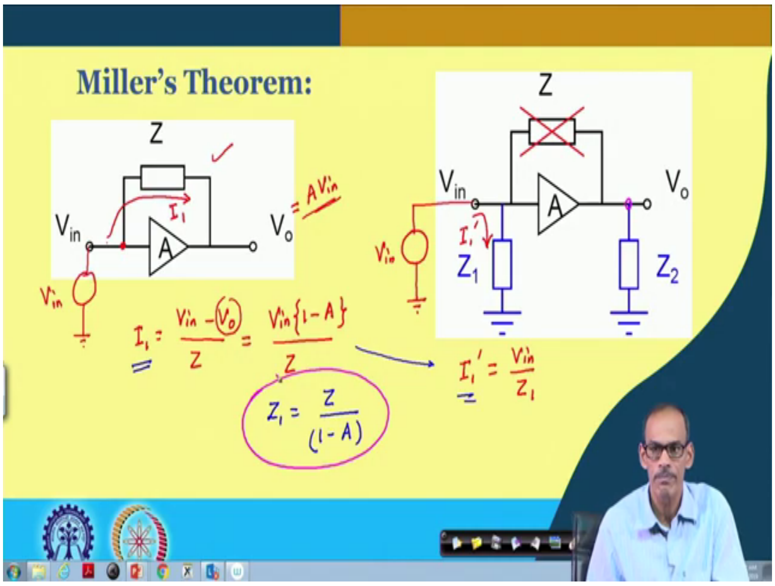

Now, when do I say that they are equivalent? So, first of all if we feed a signal V in, then if I call that these two circuits are equivalent and then if you feed the same signal V in, then the condition for this circuit and this circuit should be same which means that if I am feeding a voltage here and then whatever the current supposed to be flowing through this element, that should be seen for this circuit also.

Now, for this circuit the current or the if I call say this is I 1. So, for this case the current expression I 1 it is equal to V in minus V o divided by the impedance Z. Now, we also know that V o equals to A times V in. So, this can be written as V in multiplied by 1 minus A. So, by replacing this V o by expression we are getting V in divided by Z.

Now, on the other hand if you see in this case and if I call this current it is say I 1 dash. So, I 1 dashed we can write this is equal to V in divided by Z 1. Now, to claim that these two circuits are equivalent we have to equate these two currents or these two currents should be equal and so, we can say if I equate these two, what we are getting here it is Z 1 equals to Z divided by 1 minus A right.

So, likewise if I say that these two circuits are equivalent for the output port, then similar kind of things we can do for the output port. So, please try to remember this relationship Z 1 is equal to Z divided by 1 minus A.

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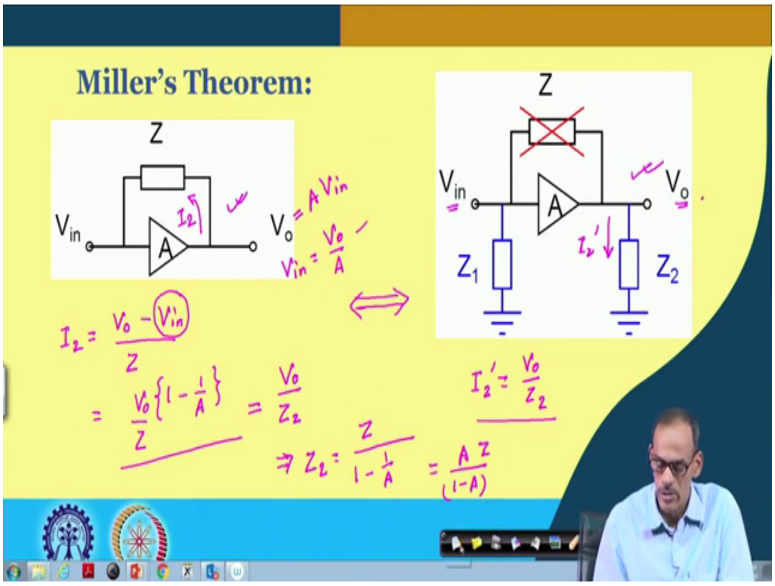

So, then if I consider a output port and if I stimulate this circuit by say V x or instead of calling say V x say this Vo. So, if I say that this V o if it is coming here. So, let us not stimulate sorry. Let us not stimulate suppose we are applying V in and then we do have V o here and if the voltage here it is V o the current run through this circuit, it is say if I call I 2 dashed.

So, I 2 dashed it is equal to V o divided by Z 2. On the other hand the current flowing through this circuit, if I call it is I 2 and in this case I 2 equals to V o minus V in divided by Z and we know that V o equals to A times V in. In other words we can write V in equals to V divided by A. So, this V in you can replace by this expression. So, what we are getting here it is V o multiplied by 1 minus 1 by A divided by Z.

Again if I say that these two circuits are equivalent for this output port, then we can say that this current and this current expression they should be equal. So, if I equate this with V o divided by Z 2. So, that gives us the expression of Z 2 equals to Z divided by 1 minus 1 by A or you can say that this is equal to A divided by 1 minus A into Z.

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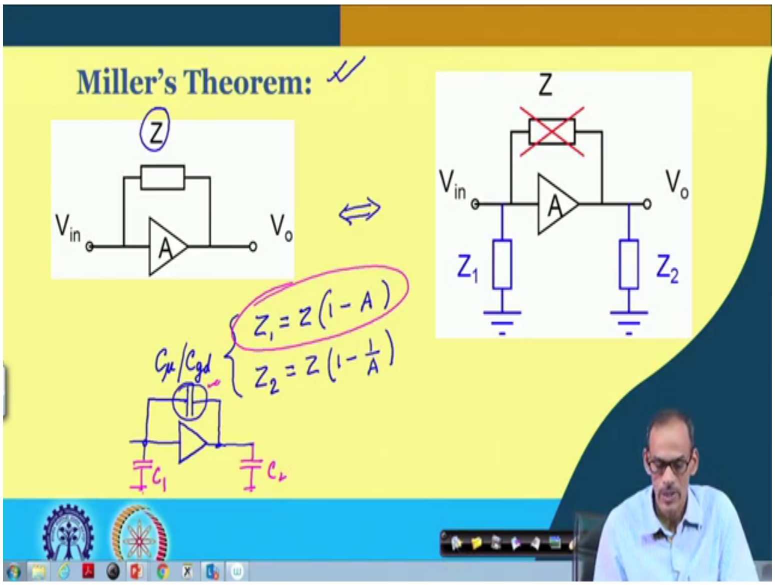

So, in summary these two circuits it will be claimed as equivalent provided the Z 1 equals to Z multiplied by 1 minus A and then Z 2 equals to Z into 1 minus 1 by A right. So, and so, this is what the whatever it is called Miller's theorem and as I said that this Z it may be capacitive, it may be the inductive or it may be resistive element or it may be combination.

Now, in our application in our today's discussion we do have one amplifier and then we do have input to output bridging capacitance either it may be C mu or it may be Cgd depending on CE or CS amplifier and then we can try to see what will be this capacitance it can be splitted into two parts one for the input port another is for the output port ok.

So, the in the next slide we consider a special case of this Z and we consider this C and then we will try to find what will be the corresponding equivalent capacitance, we do have a here and here.

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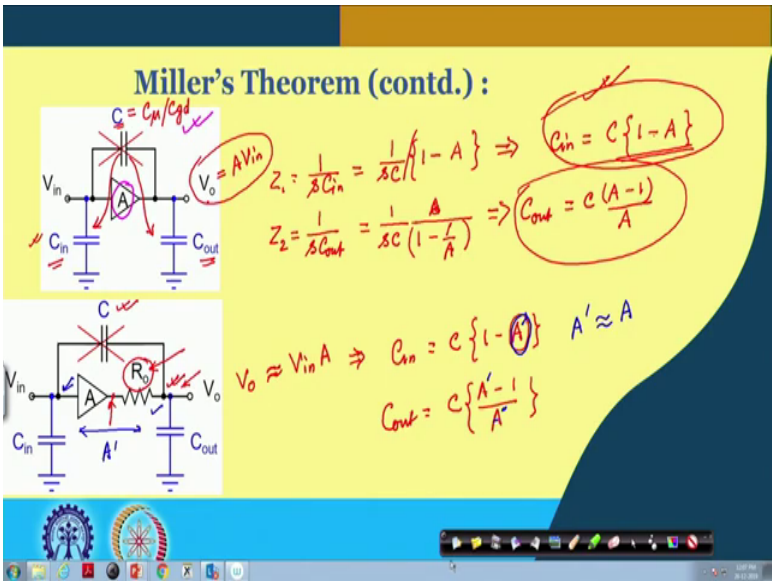

So, here we do have the circuit of our discussion namely we do have this amplifier and its gain it is a and we do have the C it may be as I said it may be C mu or a Cgd that you call it a C and this capacitor it can be replaced by its equivalent two parts. One is for input port another is for the output port and how do we say that this is the equivalent? So, the impedance of this capacitance which is 1 by s into C in should be equal to 1 by s into C multiplied by 1 minus A.

Sorry, this is divided by; this is divided by. Now if I rearrange this equation what we are getting here it is C in equals to C multiplied by 1 minus A. Note that here this whenever we are defining this A we consider V o is equal to A times V in. Now, in case if A is having minus sign so; that means, this part it will be getting plus. So, that you have to keep in mind whenever we will be talking about the actual circuit. On the other hand the 1 by s C out so, that is the you see Z 2.

So, this was Z 1 this is Z 2. So, this is equal to 1 by s into C into A divided by or I should say this is multiplied by 1 minus 1 by A right ok. So that gives us C out equals to C multiplied by A minus 1 divided by A. In fact, ok. So, these two equation it will be used for our analysis and this is valid even if you consider the finite output resistance. So, in this case of course, the bridging element it is not connected here instead it is connected after the resistors, because this may be part of the model of the amplifier.

So, we can say this is the terminal equivalent resistance of the amplifier output port right. So, even for this circuit if I consider the signal coming here and the signal coming here they are almost equal. So, if I say that even though we do have this resistance, if I say that this V o it is practically V in multiplied by A. So, then also we can use this relationship namely C in equals to C multiplied by 1 minus A and C out equals to C into A minus 1 divided by A.

Now, in case if you want to really consider this R o then this A part. So, this A part should be replaced by whatever the gain you get from this point to this point. So, in case the corresponding gain from here to here it is A dashed, then this A should be replaced by A dashed this A should also be replaced by this A dashed right. So, depending on the situation we may consider this A dashed or we may say that A dashed it is approximately equal to A. So, this is the Miller's theorem it will be used in our frequency response analysis ok.

So, let me take a break and then we will come back for continuing this topic.