Analog Electronic Circuits

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Lecture – 38
Frequency Response of CE and CS Amplifiers (Contd.) (Part A)

Dear students, welcome back to this NPTEL online course on Analog Electronic Circuits. Myself Pradip Mandal from E and EC Department of IIT, Kharagpur. Today, we are going to continue the Frequency Response of Common Emitter and Common Source Amplifier and so it is primarily whatever the remaining topic, it was there we are going to cover today and will be mainly focusing on common emitter amplifier.

So, in the previous day we have discussed about common emitter amplifier with fixed bias and today we are going to discuss more about the self-biased common emitter amplifier.

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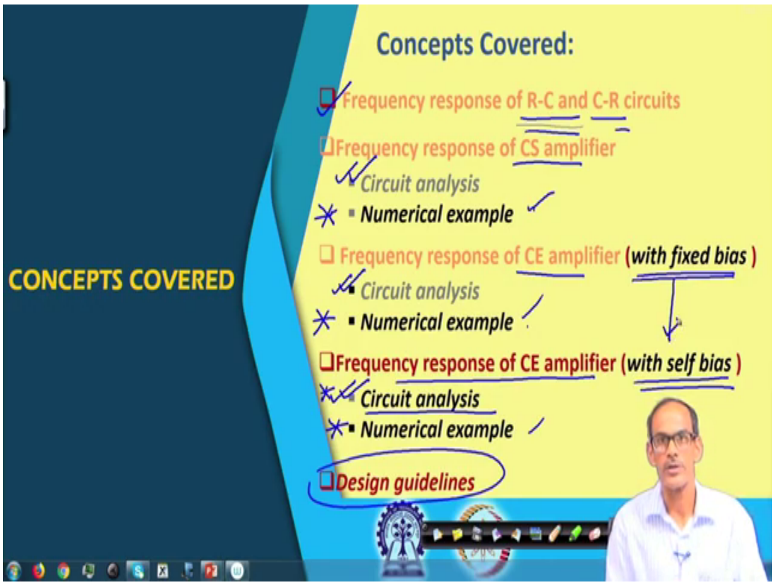

So, what we have today the overall plan; as I said that in the previous week we have discussed about the frequency response of CE amplifier for which we have detail discussion about R-C and C-R circuit and then you know we have discussed about the common source amplifier particularly with circuit analysis.

Numerical portion it was not covered, so today we are going to discuss numerical examples of common source amplifier. Likewise, for common emitter amplifier as I said that for fixed bias we have covered. So, circuit analysis portion it was covered before and today, we will be discussing about some numerical examples. But before that we are going to discuss about the frequency response of common emitter amplifier with self-bias arrangement.

So, we are going to start with the common emitter amplifier with self-biased and its corresponding circuit analysis. And later on of course, we will be going to discuss about numerical examples. From these numerical examples, we will get an idea that how to select the value of different capacitive components in the circuit. In fact, that will help us some design guidelines. In other words, in if say lower cutoff frequency and upper cutoff frequency is given to us, then how do we find that the coupling capacitor and what may be the you know the possible load capacitance, ok.

So, again we are since we are going to start from the previous topic where you have left, so we need to just recapitulate some part of it, particularly the R-C circuit and C-R circuit analysis which it has been deployed for fixed bias circuit and then we will be moving to the common emitter amplifier with self-bias.

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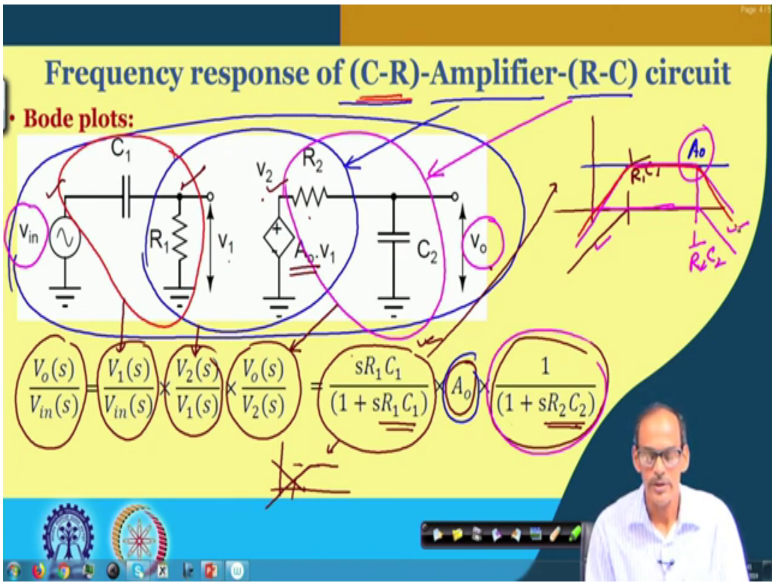

So, in the previous week what we have discussed? It is in case if we have say common in any amplifier which is having say preceded C-R circuit and then followed by the R-C circuit, then the corresponding model of the circuit, it is given here. And what we say it is that this portion, this portion is the amplifier part, and on the other hand this portion the C and R, they are forming the C-R circuit and then on the other side we do have this R and then C 2, R 2 and C 2 it is forming the R-C circuit.

And what we said is to get the overall frequency response starting from the primary input to the primary output what we what you have done is that we obtain the frequency response from this point to this point, and then from this point to this point like V 1 to V 2 and then from V 2 to V o. So, the overall frequency response it is having three parts. So, is one is the frequency response of the C-R part and then frequency response of the main amplifier part and then followed by frequency response of the R-C circuit.

And as we have you may recall that the first part it is C-R circuit frequency response it is having 1 0 at 0 frequency and then 1 pole at 1 by R 1 C 1. So, its transfer function it is given here. The middle portion it is having a voltage gain of A naught. So, A naught it is given here. And then the R-C circuit on the other hand its frequency response it is 1 by 1 plus is R 2, C 2; this is also having a pole at 1 by R 2 C 2.

So, the frequency response what do you obtain, it is this part it was giving us low pass sorry high pass characteristic and this value it was 0. I should say let me let me redraw here. So, this portion it is it was having low pass characteristic sorry high pass characteristic having a cut off frequency it is 1 by R 1 C 1. The middle portion on the other hand, it was having constant gain defined by whatever this A naught and then the C R-C part, it is having a pole and its behavior it was a low pass kind of behavior and combining the high pass, low pass and then all pass, it was giving us the frequency response of the entire system. And note that, the upper cutoff frequency of course, here it is 1 by R 2 C 2. So, overall frequency response we are obtaining is it was like this.

So, this we have discussed in the previous class. And we are going to use the same model for CE amplifier having emitter de-generator namely it is referred as the self-biased CE amplifier.

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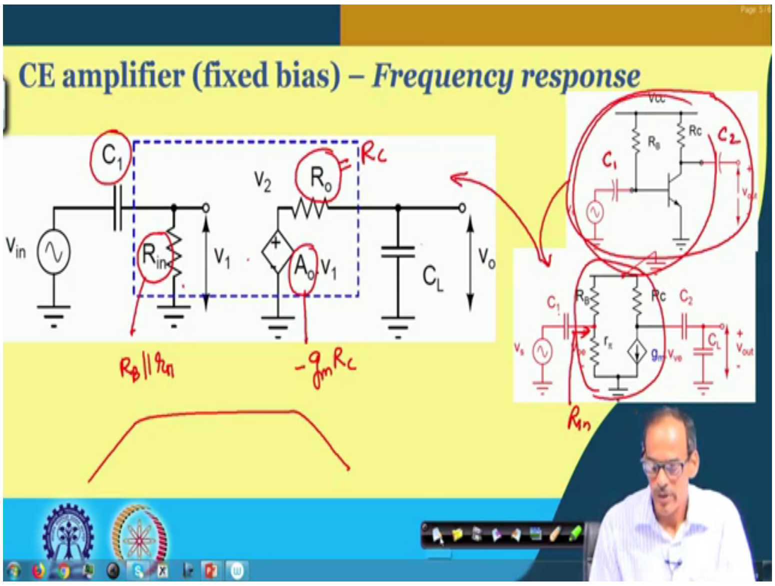

Now, again just for a slight recapitulation; in case, if you recall the fixed bias circuit where this is the circuit diagram given here, which is having coupling capacitor here C 1 and C 2 signal coupling capacitor and then we have drawn the small signal equivalent circuit of the amplifier which is basically the core part.

And then we have translated this circuit into this form namely the input resistance of the core part, R in, it is it was giving us say R 1 and then C 1 it is the capacitor signal coupling capacitor. On the other hand output side, we are having output resistance of this circuit which is equals to R-C, and R in it was R B in parallel with r pi and then it was having the gain which it was minus g m into R-C. So, this circuit frequency response of this circuit, it was obtained by considering its small signal equivalent circuit and then further to further from this it has been mapped onto on this generalized C-R amplifier R-C circuit and then we obtain the corresponding frequency response of DC amplifier.

Now, let us; so, that is what we have discussed in the previous day, now we are going to discuss about CE amplifier having self-biased arrangement.

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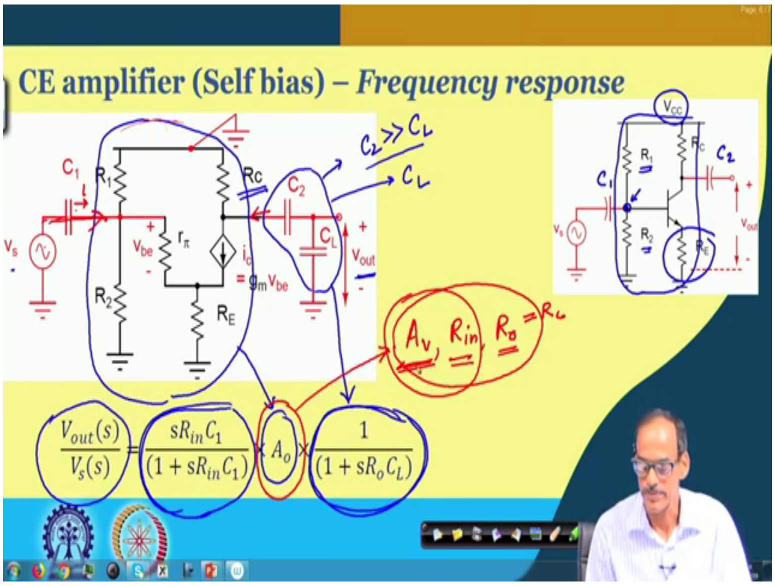

So, you may recall that in this self-biased circuit we do have the emitter resistor and so and also the at the base we do have R 1 and R 2 from this V cc to generate one DC voltage here. And then of course, the signal it was coming here through this signal coupling capacitor C 1, at the output we do have the C 2.

Now, this circuit of course, if we consider the core portion and if we consider its small signal equivalent circuit it is given here. So, this is the small signal equivalent circuit coming from the CE part. And if you, again if you may recall that the overall frequency response V out by V in Laplace domain it is having three basically, three parts one is the C 1 and then input resistance of the amplifier that C-R part and then this amplifier part, and this is the R-C part which is coming from output resistance which is R-C and these two capacitors, they are coming in series and equivalently normally C 2 it is much higher than C L.

So, we can say that this series connection it is giving us, with this condition, it is giving us the net capacitances C L. So, the frequency response of this part it is similar to the previous case namely the CE amplifier with fixed bias. So, we need not to repeat say this part and this part rather we will be giving a focus on the middle portion or you may say that the core portion.

So, let us see what is the analysis of this core portion, and out of this what we are looking for it is the voltage gain whatever A v and then R in and then R out. So, let us now go in detail into this circuit. And to get this parameter, so what we have to do? Let me consider this signal it is directly given to this point and then we like to see what is the corresponding output you are obtaining and if we take the ratio of the two then that gives us the on the voltage gain A v.

And on the other hand, if we stimulate this circuit and then if you observe the corresponding current and then if you take the ratio that will be giving us the input resistance. So, likewise for the output also in this case of course, output resistance is straightforward to say that R-C R o is equal to R-C, but these two parts are a bit involved. So, let us go in detail of this core portion and let we derive the expression on the A v part.

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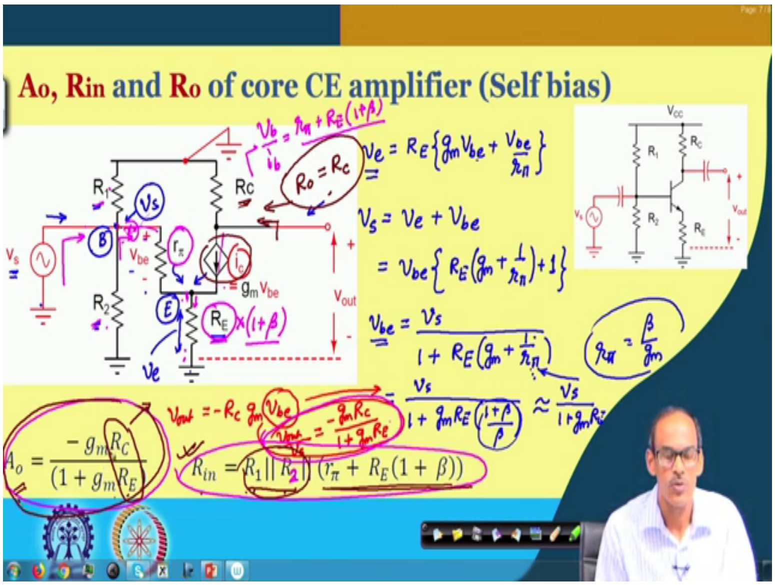

So, yes; so, this is the core part of the circuit and as I said that the signal we are directly feeding here at the input and the output we are observing at this point. Now, what you are doing? That input we are giving at the base node and with respect to ground, but then emitter of the transistor it is not connected to ground rather it is connected to ground through this R E as a result this V s and V be they are not equal but of course, they are related. So, let us try to see how they are related.

It may be noted that since V s we are directly giving here. So, irrespective of this R 1 and R 2, we are getting the signal at this point same as this V s. So, I should say that the signal coming here it is V s. And out of this V s, we do have V be part and also we do have some additional drop here. So, what is this drop? This drop with respect to ground we may call this is V e. So, the V e equals to this R E multiplied by the current and there are two parts of the current flowing through this R E one is i c which is g m into V be and then another one it is V be divided by r pi, V be divided by r pi. So, these two together it is giving us the emitter voltage here.

On the other hand, the V is the total voltage, total voltage here which is equals to V e plus V be. So, we can see that this V s equals to now we do have V be here and what we have it is V be we can take it out. So, we do have R E multiplied by g m plus 1 by r pi plus 1. So, so this gives us the relationship between V be and V s. So, V be equals to V s divided by 1 plus R E multiplied by g m plus 1 by r pi and if you see here this r pi it is equals to beta divided by gm. So, if I put that expression of this r pi here what I will be getting here, it is I will be getting g m here and then divided by beta. So, that gives us V s divided by 1 plus g m into R E multiplied by 1 plus beta divided by beta. Typically, we considered that this beta is much higher than 1, so we can approximate this part this part is equal to 1. So, we can say that this is V s divided by 1 plus g m into R E. So, that is the V be.

Now, V out, on the other hand V out this is R-C multiplied by this i c with a minus sign and i c equals to g m into V be. And then if I if I put the expression of V be here, so this is the V be expression. So, that gives us V out by V s equals to minus g m into R-C divided by 1 plus g m into R E, ok. So, that gives us the gain of the circuit, which means that the mid frequency gain it is basically it is coming from here. So, that is what we have written here. The gain is given here.

So, on the other hand, the input resistance if I see the circuit and if I look into this port and if I want to know what will be the input resistance, input resistance we do have R 1 in parallel with R 2, sorry this will be R 2 and then parallel with whatever the resistance it is coming from this circuit. Earlier we have discussed that this; the resistance looking into this circuit is r pi in series with this emitter resistor multiplied by 1 plus beta, ok. Why beta, 1 plus beta? That is because in case if we are stimulating this circuit with a current i b then current flowing through this collector it is beta times that i b. So, the total current flowing here it is 1 plus beta into i b as a result the drop across this R E it will be i b multiplied by 1 plus beta into R E.

So, if I take the ratio of the voltage here to here and then i b which gives us the input resistance of this circuit. So, there we got this what you say that V b divided by i b equals to r pi plus R E into 1 plus beta. In fact, this is what the resistance it is coming here. So, the total resistance is R 1 parallel R 2 and then in parallel with whatever the resistance we do have.

So, if you see here that is the expression we are giving here. So, to summarize, so what we are obtaining here it is this circuit, this circuit is having voltage gain of a g m into R-C divided by 1 plus g m into R E and then input resistance it is R 1 parallel R 2 and then r pi plus R E into 1 plus beta. And this part, this part depending on the value of this R E we may approximate that this may be given by R-C by R E. Likewise here we can say that R 1 parallel R 2 that dominates over this resistance, so the input resistance may be like this.

And on the other hand, the output resistance looking into the output port what we do get is that R o equals to simply R-C. So, this is also we have done before in some of our lecture, but in case if you have forgotten probably you if you see this circuit since this portion it is ideal current and if we look into this circuit and if you try to see what is the resistance of this entire circuit it will be having only R-C left behind. So, as a result the output resistance it is R-C, input resistance is practically R 1 parallel R 2 and then the input on the other hand the not input the voltage gain it is minus g m into R-C divided by 1 plus g m into R E, ok.

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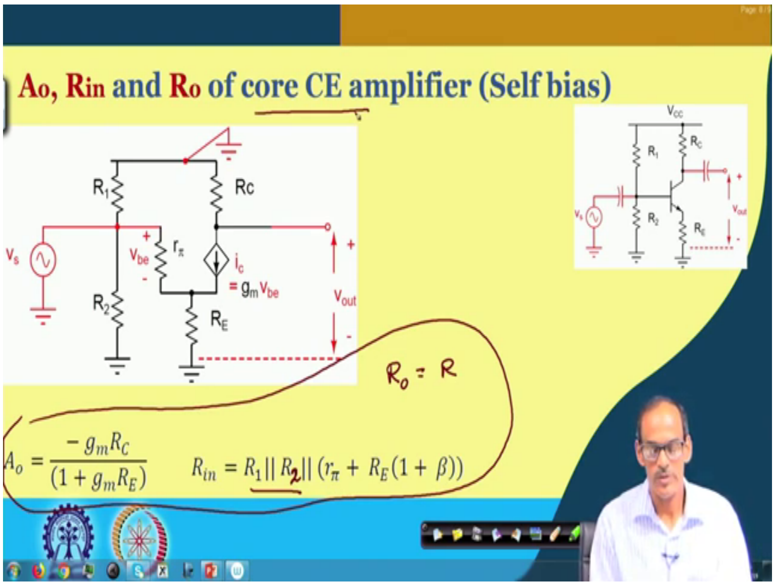

So, what we said here it is this should be R 2 and in addition to that R o equals to R-C. So, this informations these three expressions basically the information about the core CE amplifier, we are going to use to get the frequency response of this entire circuit.

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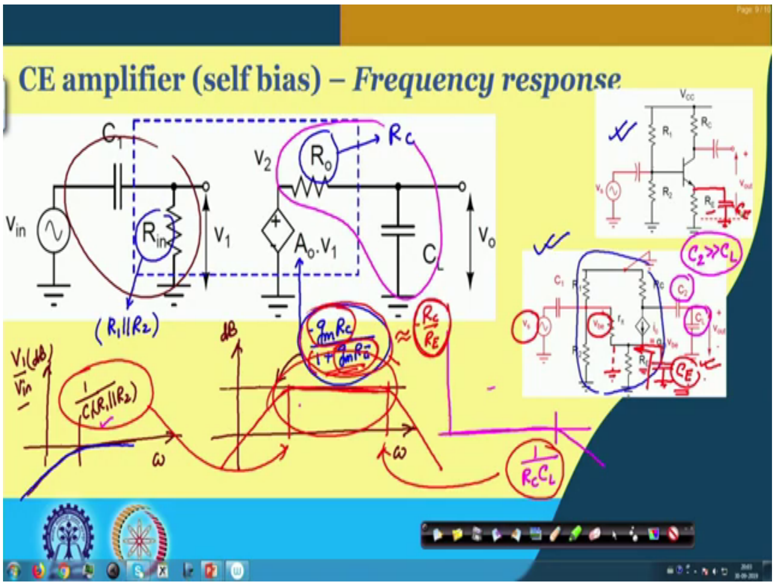

So, then if you see what will be the overall frequency response; now, as we said that this is the this is the small signal circuit where the core portion we have discussed just now and what we have obtained that the gain here, the amplifier gain here it is a g m into R-C divided by 1 plus g m into R E with a minus sign. So, this is the gain A naught.

And input resistance on the other hand, it is it is R 1 parallel R 2 that dominates, R 1 parallel R 2 and on the other hand the output resistance it is equals to R-C. So, to get the frequency response of this CE amplifier with the emitter degenerator, what we can do here it is if you consider the first part this part and as you have said that the frequency response of that it is having high pass nature and the cutoff frequency. Here it is 1 by C 1 and then R 1 parallel R 2, assuming that frequency we are talking about radian per second. So, this is basically V 1 by

V in decibel that means, we have to take log of this ratio and then we have to multiply with 20.

So, it is frequency response of the C-R circuit is it is given here and then middle portion it is, so the middle portion it is basically the amplifier part which is having good gain and the gain here it is coming from this g m into R-C divided by 1 plus g m into R E. May not be very high, of course we have to convert in db a scale. So, and the frequency it is radian per second. And then the right part, the R-C part, it will it will be similar to the previous case it is having the low pass nature and its cutoff frequency it is 1 by R-C into C L. Of course, we are assuming that this C L it is much smaller than C 2. So, that is the assumption. So, we are assuming that C 2 it is much higher than C L.

So, the if I combine now these three graphs together, so what we can get that frequency response will be getting something like this, right. And the lower cutoff frequency it is coming from here and the upper cutoff frequency it is coming from here and mid frequency gain it is obtained from here. So, here again it is very similar to whatever we have seen for CE amplifier in fact, for common source amplifier also. But one thing I must say that because we do have 1 plus g m into R E in the denominator the corresponding gain which is you can say that this is R-C divided by R E all practical purposes, magnitude wise it is very small compared to g m into R-C that CE amplifier with the fixed bias.

And then what we have done is that we to get back the gain we have suggested to use bypass capacitor call CE to bypass these R E, and then in the frequency response it will be definitely it will be having some impact. So, what you are expecting here is that this CE part it will be here and intuitively what we said is that in the mid frequency range this CE it may be completely bypassing this R E making this is AC ground and hence the V be it is it is equal to V s the primary input. And as a result, we say that the gain instead of having this denominator in the denominator 1 plus g m into R E if CE it is bypassing it, so this portion it will be 0. As a result the gain we can get higher. That is what we said by intuition.

But of course, depending on the value of the CE when we will be getting this gain, the high gain with respect to R-C by R E that may vary. So, depending on the value of the CE and probably the effective resistance at this node there will be some cutoff frequency or rather I should say you know the CE will be having direct influence on the frequency response. It cannot go directly here. We prefer to have a smooth gain, but if we are arbitrarily selecting this CE, then we may not get this frequency response. So, what you can do? Now, let me look into the frequency response of this CE amplifier having R E and CE together, and let us try to see what is the corresponding frequency response.

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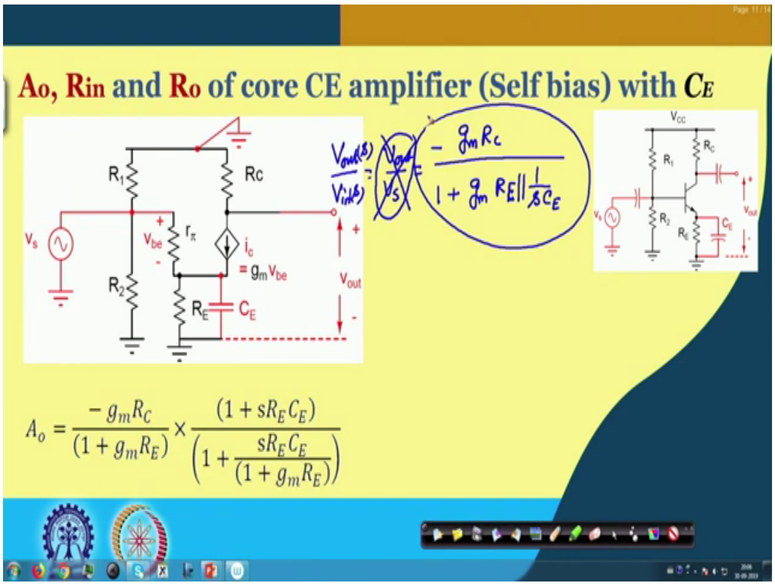

Yes. So, this is the circuit I was referring to. Instead of R E, now we do have R E and CE together. And if you look into the core CE amplifier which is of course, it is the different part compared to the previous case. So, let we focus on this. In fact, if you go back and if you see the previous circuit, sorry, yeah.

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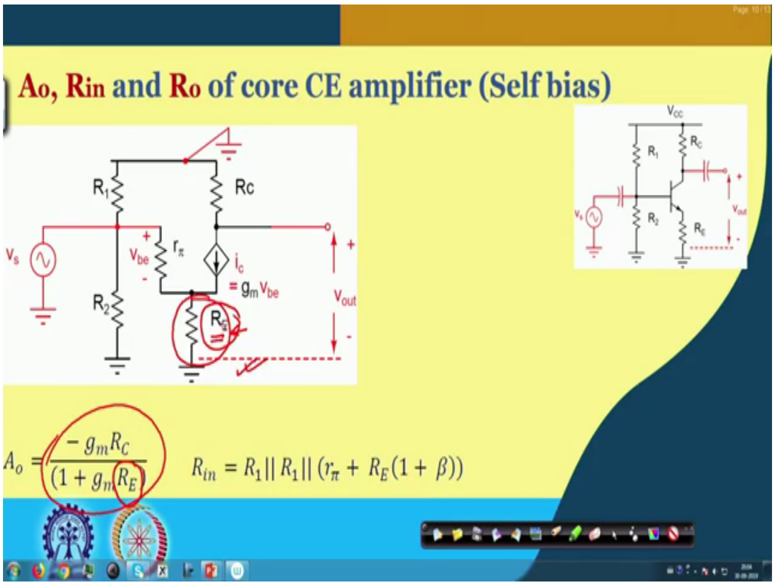

So, if you see here this part this part it is not having the CE part, but then its gain expression we can see that this R E, it is directly coming there. So, whatever the analysis we have done for this circuit, similar kind of analysis we can do by considering this CE in parallel with R E.

So, try to remember that what are the things you have done or at least this is the expression of the voltage gain. So, the same voltage gain or similar kind of expression we will be getting in case if this R E it is shunted by CE. So, what will be; yes. So, from that previous analysis, so what we can say that the voltage gain namely V out by V s, it can be written as minus g m into R-C divided by 1 plus g m into R-C in parallel with CE and its corresponding Laplace domain transfer function, sorry this is R E. R E in parallel with 1 by s into CE.

Of course, now, we are talking about Laplace domain. So, I should use different symbol for this one. I should say rather V out s divided by V in s in Laplace domain instead of the time domain. And then, what we can do that we can simplify this expression and then we can see that it will be having additional pole 0 combinations. So, let me take a short break, and then we will start from here.