Analog Electronic Circuits
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Lecture - 37
Frequency Response of CE and CS Amplifiers (Part C)

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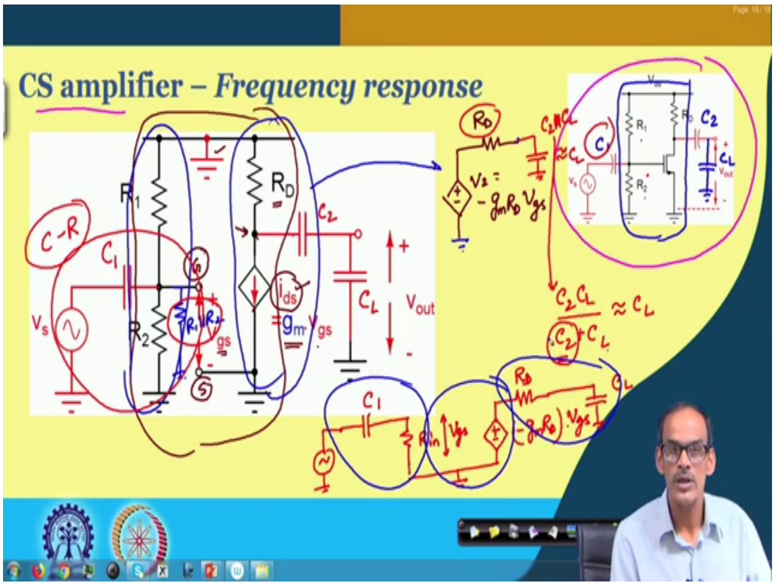

CS amplifier – *Frequency response*

So, welcome back after the short break. And we are talking about Frequency Response of the Amplifier and we have seen that generalized form of a network consists of C-R circuit and R-C circuit and in between we do have an amplifier. Now, let we try to map that model or rather actual circuit mapping to that unified model.

So, say to start with we do have common source amplifier and the circuit is given here. The circuit is given here for your reference and if you see here we do have the main part main amplifier here and then, we are feeding the signal through this capacitor called say C 1. At the output we are observing the signal after removing the DC part through the C 2.

In addition to that, it may have some capacitive load coming from the next subsequent circuit. So, let you call this is C L. Now, if we draw the small signal equivalent circuit after obtaining the quiescent point and other things are defined by R 1, R 2; then, V dd and then R D.

What we obtained in our previous discussion we say that at the middle, at the middle we got the main amplifier circuit and here of course, it is the small signal equivalent circuit; where, V dd it is V dd node, it is AC ground and the transistor it is getting replaced by its small signal model which is voltage dependent current source called small i ds. And its expression it is given by transconductance g m multiplied by the V gs. V g s is the voltage appearing across gate to source of the transistor. So, this is the V g s.

So, based on this V gs, we are getting this current and then that current it is flowing through this R D and then, of course, we are getting a voltage here. Note that still this is not on equivalent, but it can be easily converted into Thevenin equivalent, namely we can make the amplifier which is having a gain of minus g m into R D. So, the voltage here you can say equivalently whatever you say v 2.

So, this voltage here it is minus g m into R D into v gs and of course, the corresponding Thevenin equivalent resistance, it will be same as this R D. So, this part the output port part, it can be translated into this circuit and once you translate this circuit in this form, then we are moving towards our unified model of the amplifier.

Likewise, input side again this two part these two resistors you can translate into equivalent resistance here, which it will be R 1 parallel R 2. So, what we can see here that C 1; this C 1. So, this is the C 1 and then, this R in which is R 1 parallel R 2, they are forming one C-R circuit. This the C-R circuit is getting formed here and then, output resistance which is R D and then this C L along with this C 2 coming in series, they are these two are farming another circuit which is of course, this is R C circuit.

And this capacitor value, it is it is basically C 2 in parallel with C L and its expression it is sorry, this is in series; this is in series. So, its expression it is C 2 into C L divided by C 2 plus C L. Typically, this C L it is much smaller than C 2 rather C 2 is much higher than C L and this part dominates as a result this becomes approximately C L. So, we can say that at the output we do have approximately C L.

So, what we are getting here? It is that the amplifier, it can be translated into that unified model which we have discussed just now, before the short break; where, it is having C 1, then R in and then across this R in the voltage it is v gs and that v gs, it is generating a voltage which is whatever minus g m into R D time times this v g s. And then it is also having the Thevenin equivalent resistance R D and then, we do have the output capacitance approximately same as the C L. And at the input we are giving the stimulus.

So, now as I said that we do have C-R circuit, we do have this is the amplifier part and then, we do have the R C circuit. And from that directly we can say that who are the contributors of the cutoff frequency and the gain. So, in the next slide, I am just summarizing the same information; yes.

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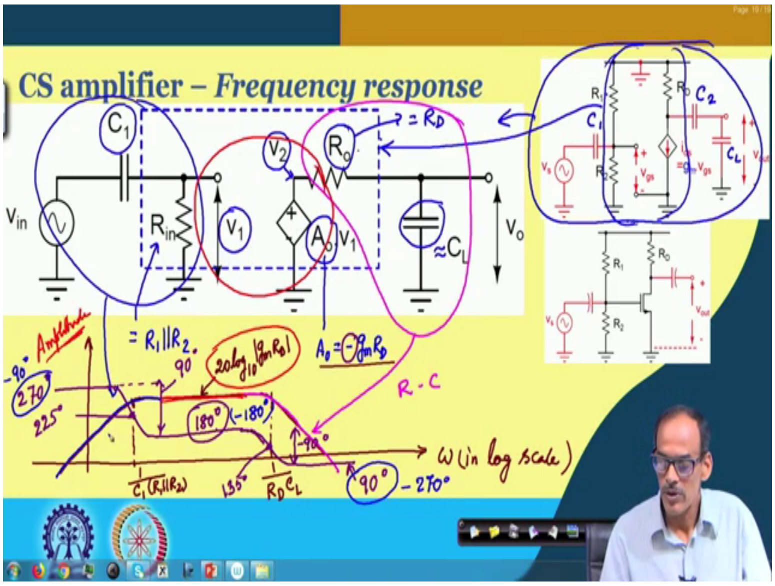

CS amplifier – *Frequency response*

So, what we have for our reference again, I am just keeping this diagram, we just now we have discussed and this circuit we are mapping into this generalized form. We do have the C 1 here. So, this C 1 it is coming here and the middle portion, middle portion particularly this portion, the amplifier portion we are modeling in this form. So, I should say that this amplifier, it is getting modeled into this one which is voltage amplifier, where it is having three important parameter namely R in.

So, R in equals to if I say R 1 and R 2 coming in parallel and then, V gs is basically here we are calling it is V 1 and then V 1 multiplied by A V or A naught that gives us the voltage at this point. So, we can say that this A naught equals to minus g m into R D and then, this R o which is equals to this R D and then, the C L, it is dominating compared to the C 2. So, this capacitor it is approximately the C L.

Now, as we have said that the frequency response now if you are asked to draw the frequency response or the bode plot particularly the gain plot, I think you will be able to do it yourself. Omega in log scale right and then, the mid frequency range the gain it is defined by this A naught. So, if I consider magnitude. So, we do have the gain here and then, the lower cutoff frequency. It is coming from C 1 and that this R in.

So, this frequency, it is 1 by C 1 into R 1 parallel R 2. So, that is the lower cutoff frequency and then, upper cutoff frequency it is defined by this R D. So, if I say this is the upper cutoff frequency which is this R D and C L are defining. So, this is and then gain here it is of course, in d b 20 log base 10 into g m into R D. So, I should say that this as we have discussed before this C-R circuit, it is contributing this part. So, this is C-R part and then the R C part, it is contributing this part. So, this is the R C part and the middle portion which is coming from this part. So, this middle portion, it is coming from this the amplifier.

So, that is how we do get frequency response of the amplifier. Now, if you are asked to plot the phase; phase also ah, so this is gain or magnitude; sometimes it is also referred as amplitude. Now, if you are asked to draw the phase plot, what you can see in the mid frequency range note that we do have a minus sign here. So, as a result in the mid frequency range, the phase it will be; so, we will start from the middle and then as you were.

So, this phase is either you may say that minus 180 degree you are 180 degree. And then, it is having a role of towards this corner frequency and then, it goes a step of 90 degree minus 90 degree. So, this phase, it will be if I consider this is plus 180 degree ah. So, this phase, it will be 90 degree and at this corner frequency, it will be 180 degree minus 45 degree. So, that is 135 degree. On the other hand, here it is the step, it is the other way. So, the phase it rises here and here also it will be having a step of 90 degree phase up. So, this is 90 degree plus.

So, we may say that this is 270 degree at this level and at this point here, it will be this plus 45 degree. So, that is at this point it is 225 degree ok. So, in case if your instead of calling this is plus 180 degree, if you are calling this is minus 180 degree. So, you need to change this one to minus 270 degree and then, this one you need to change to minus 90 degree. But whatever it is. So, we are getting this corresponding gain plot and phase plot easily by using this the unified model of the amplifier. So, similar thing it can be done for the CE amplifier.

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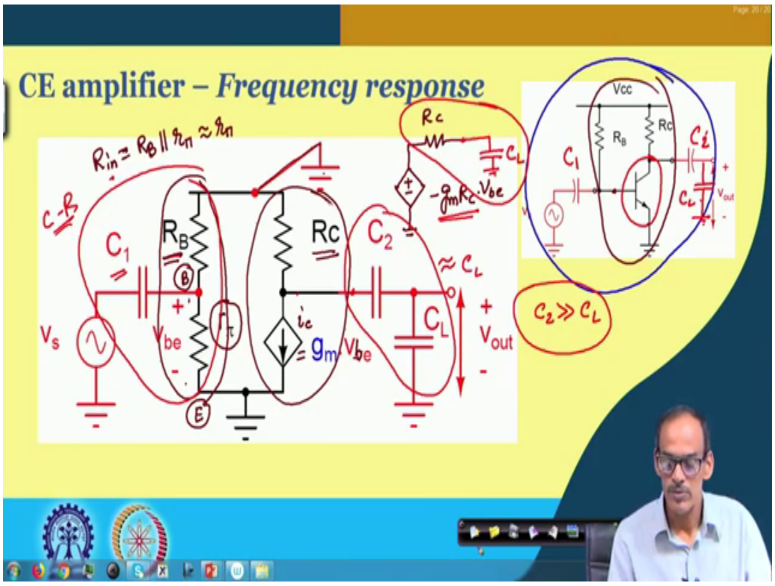

CE amplifier – *Frequency response*

So, let us see what are the things we have done for CE amplifier. As I said that is very similar. So, you may recall the this is the CE amplifier with fixed bias and this middle portion is the main amplifier and it is also having this 2 signal coupling capacitor C 1 and then C 2 alright. And in the middle portion of course, we do have the transistor and the middle portion can be converted into small signal model which consist of this R B. We do have R B there and then we do have R C here and base to emitter junction, we do have r pi this is the.

This is a part of the small signal model of the BJT. And then, we do have the i c; small signal i c equals to g m into V b e, sorry this will be V b e. So, this V b e it is of course, the voltage between this base to emitter terminal or emitter node or voltage across this R pi. So, here again this part it will be straightforward to convert into R in or equivalent input resistance.

So, R in equals to R B in parallel with r pi and typically, this is getting dominated by this r pi. On the other hand, the not on equivalent circuit. So, this is of course, AC ground. So, this not on equivalent circuit we can convert into Thevenin equivalent for our convenience and once you convert this voltage dependent current source into voltage dependent voltage source, what we are getting is this voltage here. It is g m minus g m times R C into this voltage V b e.

And then, Thevenin equivalent resistance of course, this will be same as this R C and similar to our previous discussion as I said that there will be load capacitance coming from the subsequent stage C L. So, the C 2 and C L together they will be giving us giving the load to this circuit and typically, the C 2 it is much higher than C L. So, the series connection of the C 2 and C L together it is approximately with this condition approximately C L. So, at this output node, we do have the C L.

So, similar to the common source amplifier, again here we are getting R C circuit or rather C-R circuit constructed by or consists of the C 1 and R in. In the middle we do have the voltage amplifier, define and it is gain it is defined by g m into R C with a minus sign and then, next one is the R C circuit. So, here again, we can map this amplifier into the unified model to get the frequency response of the overall circuit. So, that is what we are summarizing in the next slide.

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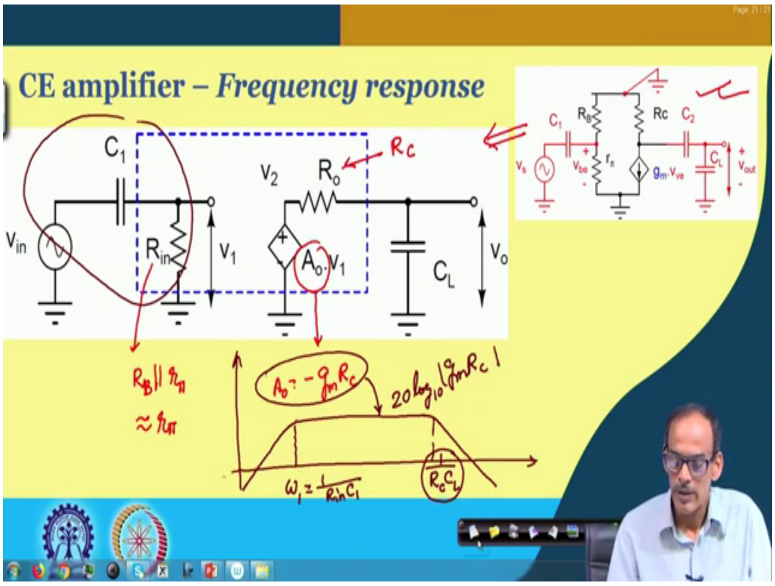

CE amplifier – *Frequency response*

Yes. For your reference again I am keeping this circuit and this circuit it is getting mapped into this unified model and the R in, it is in this case R B in parallel with r pi which is approximately r pi and R o equals to R C and then, A naught is equal to minus g m into R C ok. And here again, the procedure it will be same. If you are asked to draw the bode plot of the entire circuit, what will be getting here it is and the mid frequency range you will get decent gain defined by this A naught and then, the lower cutoff frequency it will be coming from the C-R circuit.

So, the lower cutoff frequency say omega 1, it is 1 by R in into C 1 and the on the other hand, the upper cutoff frequency, it is R C and C L they are defining. So, 1 by R C into C L it is defining the upper cutoff frequency and this is the gain which is 20 log base 10 g m into R C. I think that is the frequency response of the normally used simple voltage amplifier. Now, I must say that few more information that if you recall the so far we are talking about the fixed bias circuit.

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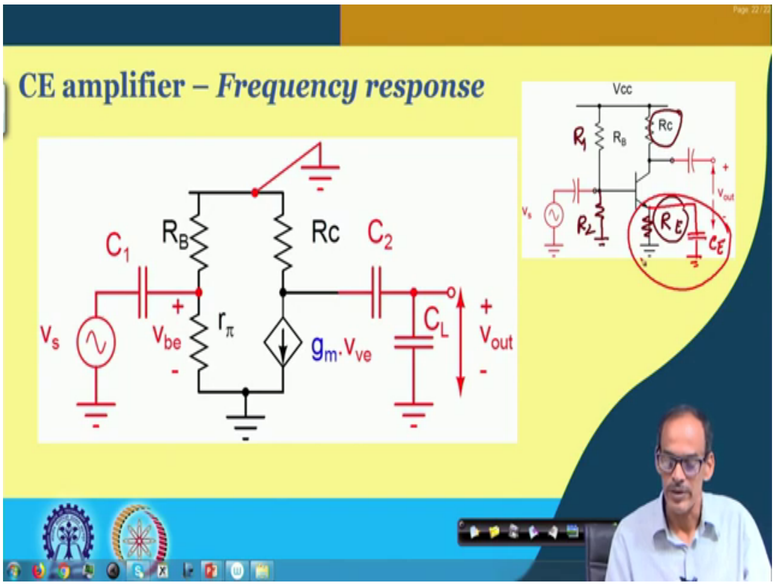

CE amplifier – *Frequency response*

So, in this circuit, we are not having any emitter resistor. And in case if we put emitter resistor here say R E and of course, then I have to put voltage bias here maybe this is R 1 and this is R 2 and so, that gives low gain, the corresponding gain it is simply R C by R E. And to get back the higher gain we need to bypass this R E bias a CE. Now, this CE, it is also having some role to play to define the upper or lower cutoff frequency that can be seen later. So, probably we need to have a dedicated class to discuss about the frequency response of this cell biased common emitter amplifier.

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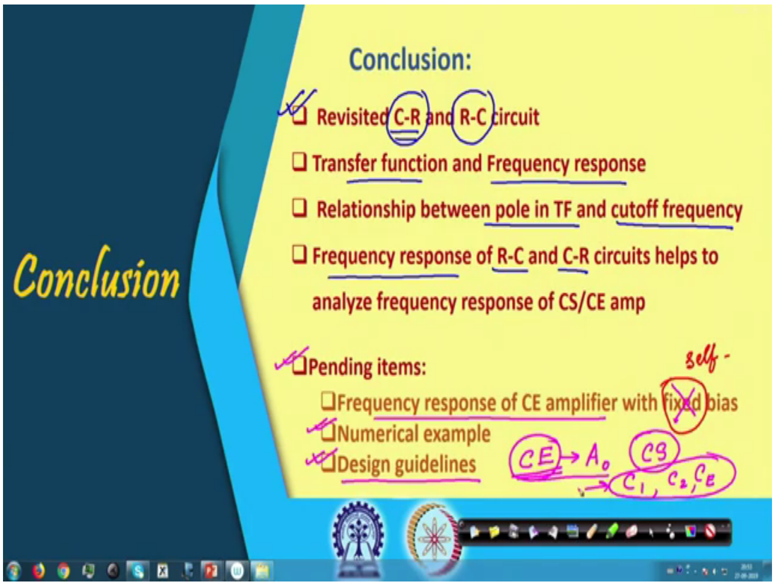

Conclusion

Conclusion:

- ☑ Revisited C-R and R-C circuit
- ☐ Transfer function and Frequency response
- ☐ Relationship between pole in TF and cutoff frequency
- ☐ Frequency response of R-C and C-R circuits helps to analyze frequency response of CS/CE amp

☑ Pending items:

- ☐ Frequency response of CE amplifier with ~~fixed~~ self- bias
- ☑ Numerical example
- ☑ Design guidelines

$CE \rightarrow A_0$ CS

$\rightarrow C_1, C_2, C_E$

So, yeah so, the yeah so, we are all yeah, let me instead of stretching today's class towards the CE amplifier with the cell biased. Let me summarize what are the things we have covered today. Ok, before I forget actually this should be self-bias ok. Anyway, what we have covered today, it is the R C circuit frequency response, we have revisited because this frequency response of R C and C-R circuit, it helps us to get the frequency response of an amplifier.

And what we have seen there with these two examples independently that the transfer function and the frequency response, particularly transfer function in Laplace domain in S domain. And the frequency response while you are changing the frequency in omega along the omega line we have seen that they are definitely they are related. Particularly, which is important thing is that the pole in transfer function in Laplace domain and the cutoff frequency in the frequency the response they are directly related.

So, what we have seen is that we started with simple C-R circuit and then, we have seen that for C-R circuit, the location of the pole defines the lower cutoff frequency of high pass nature. And pole location of R C circuit on the other hand, it defines the cutoff upper cutoff frequency of the low pass filter. And those frequency response, if we combine together along with the middle ideal amplifier, then they are helping us to get the frequency response of common source and common emitter amplifier.

So, in today's discussion that is what the main thing is that how we make use of C-R and R C circuit along with the ideal amplifier to get the frequency response without really going in detail of the analysis or equation. Intuitively, we can say that which are the contributors of the which cutoff frequency and so and so.

Now, the in this module as I say that we need to cover some more things. So, we do have the pending items listed here; the frequency response of CE amplifier having self-bias. So, it required some dedicated class to cover this frequency response and whatever the analysis we have done, we can we can make use of that to find the numerical value of the cutoff frequency of a filter and so and so.

So, we need to cover the numerical examples and then we will be talking about the design guidelines. Note that under this design guidelines, we have talked about design guidelines of CE amplifier for both self-biased as well as fixed bias. But primarily that is related to the mid frequency gain. Cutoff frequency, we have somehow we have touched, but we did not go in detail.

Now, we like to cover similar kind of things for common source amplifier; this thing we need to cover and also the information about the frequency response and the analysis of frequency response of CE and CS amplifier, how they are they will be helping us to find selecting the coupling capacitors namely C 1 and C 2 and CE. They are also in fact, part of the design. So, once you cover the frequency response, then we can revisit the design guidelines of CE amplifier to get rather more appropriate expression of C 1, C 2 and CE.

I think that is all I need to cover in this module ah. So, we will be coming back in the next class with this pending items.

Thank you for listening.