Analog Electronic Circuits
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Lecture - 42
Frequency Response Of CE/CS Amplifliers Considering High Frequency Models of BJT and MOSFET (Part C)

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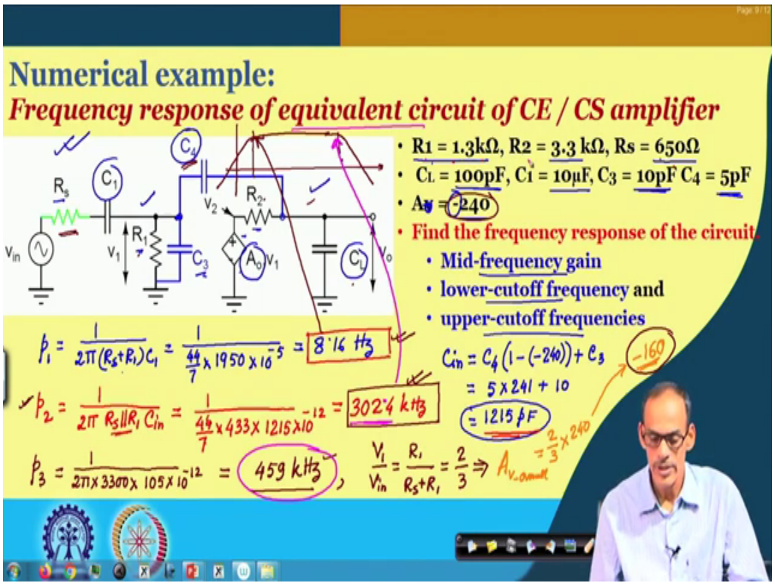

Welcome back after the short break. So, we are going to discuss about numerical example, and the circuit it is still that equivalent circuit we do have and what we are. So, we do have the generalized equivalent circuit, but then also we do have additional information namely the value of different components, R 1 this input resistance is 1.3 k, then R 2 output resistance it is a 3.3 k and then let you consider source resistance 650 ohm that is also a typical value one possible value of typical signal source.

And then the load capacitance C L 100 picofarad, C 1 it is given here it is say 10 microfarad and then C 3 which is one of the element contributing to input capacitance it is say 10 picofarad, C 4 the Miller effected capacitance the capacitor which is breezing the input and output terminal of the circuit is 5 picofarad. And let you consider this voltage gain A v or A naught in this case we are denoting this by A naught which is a 240 with a minus sign.

So, that means, actually this is minus and this is plus. So, anyway with this information let we try to get the frequency response and particularly containing the mid frequency gain and then lower cutoff frequency and then upper cutoff frequency. So, how do we proceed? First of all this resistance directly given there, but then need to calculate the input capacitance.

So, to start with let we calculate C in and C in equals to C 4 multiplied by 1 minus minus of 240, then plus C 3. So, we do have 5 here and then multiplied by 241 plus 10. So, that gives us how much; we do have 1215, 1215 picofarad, yes. So, we do have the C in is given here, with this C in we can calculate the location of the second pole and let we calculate the first pole first. So, p 1 which is defined by if I express this in the unit of Hertz then we have to consider 2 pi. So, 2 pi multiplied by R s plus R 1 into C 1, so this is equal to 1 by 44 by 7.

C s it is 650 and then R 1, R 1 it is 1.3 k, so that is 1950 this resistance and then C 1 it is 10 microfarad which means 10 to the power minus 5. And if you calculate it, I have done this calculation for you. So, what you will get it is 8.16 Hertz, right. So, you got the lower cutoff frequency is this one and then we can get the second pole p 2 which is coming from again R s and R 1 in parallel and since it is in Hertz.

So, we have to consider 2 pi, so 2 pi R s in parallel with R 1 into C in and the value of the C in it is given here. So, this becomes 1 by 44 divided by 7 into this resistance, these two resistances in parallel, so we do have 650 and 1.3 k it is coming close to 400. In fact, to be more precise it is 433.3 ohm and then C in it is 1215 into 10 to the power minus 12. And if you do this calculation what you will be getting it is close to 300 and to be more precise 302.4 kilo Hertz.

So, we do have the second pole it is given here 302 kilo Hertz. Now, you can also calculate the third pole p 3 which is coming from R 2 and then output resistance. So, p 3 it is 1 by 2 pi into R 2 it is 3.3 k, so you have 3300 ohms and then output resistance it is when you have C L equals to 100 picofarad and then the C 4 it is almost coming as is, so we can see roughly 105 picofarad 10 to the power minus 12. So, if you do this calculation what you will be getting it is 459, in my calculation that is what I obtain 459 kilo Hertz.

And as I said that since this is higher. So, the upper cutoff frequency it will be decided by p 2 and lower cutoff frequency it will be coming from this one. And also to get the mid frequency gain, so mid frequency again it is of course, this multiplied by whatever the attenuation coming from these two elements. So, what is that attenuation? So, I should say V 1 divided by V in mid frequency range equals to R 1 divided by R s plus R 1 and R 1 it is 2.3 this is 0.65 kilo, so that is equal to 2 by 3 and that gives us the overall gain, let me use different color. So, overall gain, A v overall, so that is equal to two-third multiplied by 240 with a minus sign and this is equal to 160, right.

So, we should say that the overall frequency response of this circuit, it is something like this. So, I do have some space here. So, let me utilize this space. So, mid frequency gain it is given here, maybe we can convert that into dB and then we do have the lower cutoff frequency here and then upper cutoff frequency. So, the lower cutoff frequency it is 8.16 and then the upper cutoff frequency it is this one and this is because this is lower than the p 3 part.

Now, let we go to a one axial circuit. So, as I say that this is equivalent circuit and of course, the value we have picked up here it is very close to whatever the equivalent circuit we get out of actual circuit, but for you to get a feel of that let me consider one practical circuit.

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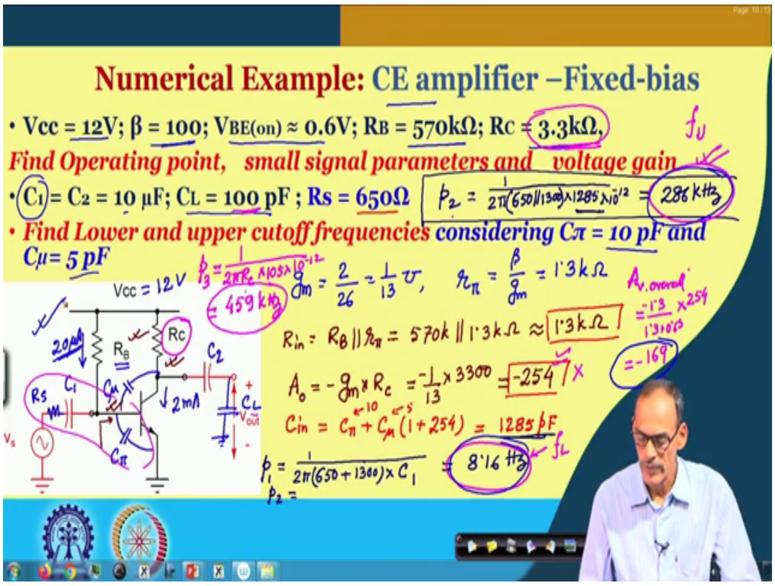

So, in the next slide we do have CE amplifier having fixed bias arrangement and different components of, so different components of these bias as well as the other value the capacitors and all it is given here. So, R B, R B it is 570 kilo ohm, supply voltage it is 12 volt and then V BE on it is approximately 0.6. So, that gives the base current equals to 20 microampere.

Earlier we have done this calculation and with multiplying with beta we do get the collector current it is 2 milli ampere, question collector current is 2 milli ampere. So, that gives us the g m equals to 2 milli divided by 26 millivolt. So, this is equal to 1 by 13 mho. And in r pi, r pi of the transistor which is beta divided by g m, so that is 100 divided by g m is 1 by 13 that means, 13 into 100, so that is equal to 1.3 kilo ohm.

And then we have C 1, C 1 it is given here. So, this is C 1, C 2 it is also equals to same 10 microfarad. And then we can connect a C L here, and this C L it is given equals to 100 picofarad. In addition to that we are assuming that we do have a source resistance R s to see the effect of this C pi and C in. So, C pi it is given in 10 picofarad and then we do have the C mu it is given us 5 picofarad.

So, from that let we and of course, the R C it is given here. So, from this parameter, so we can probably we can try to find the voltage gain, and then input capacitance, input resistance and so and so. So, first of all input resistance R in which is equal to R B in parallel with the input resistance coming out of the device, so that is r pi. And this is equal to 570 k in parallel with only 1.3 kilo ohm. So, you can approximate this by considering 1.3 kilo ohm, it is dominating. So, that gives us the input resistance.

Now, before we calculate the input capacitance, so we need to know what will be the gain from this point to this point and that gain if I call say A naught equals to g m into R c, and so this is equal to 1 by 13 into 3.3 k 3300. So, that is becoming equal to close to whatever earlier we obtain or earlier we have taken, but to be more precise I think it is 254, of course, with a minus sign. So, the voltage gain here it is minus 254, input resistance it is 1.3 k and then we can calculate the input capacitance, C in equals to C pi as is plus 5 picofarad C mu into whatever 1 plus 254.

So, if I put the value here it is 10 and then value here it is 5, so that gives us 10 plus 5 into 255. So, that is giving us 1285 picofarad capacitance, ok. So, now, we can calculate by considering this R s, we can calculate the pole location of the pole. So, let you consider first pole p 1 which is equal to 1 by 2 pi into R s which is 650 plus R in equals to 1300 multiplied by this C 1. In fact, this calculation we already have done for the previous example and that gives us 8.16 Hertz.

On the other hand, we can calculate p 2, p 2 also it will be very similar. So, let me use this space here to calculate p 2. So, the expression of p 2 it is 1 by 2 pi 5 sorry 650 in parallel with 1300 multiplied by C in, so that is 1285 picofarad 10 to the power minus 12. So, with this, so this is again this part it is coming whatever 433 and with that what we get of course, this capacitance it is slightly different and this gives us 286 kilo Hertz.

Now, if I calculate the third pole namely the pole coming from the output resistance which is R C and then the C L, and R C it is given here. So, the third pole, let me use this space. To calculate the third pole which is 1 by 2 pi into output resistance which is R C and then output capacitance which is 100 and then also C mu coming there, so that is 105 picofarad. In fact, if we calculate this what we can get by putting the value of this R C equals to 459 kilo Hertz.

Now, if I compare the p 2 and p 3 since p 2 it is lower, so p 2 defines the upper cutoff frequency f U. And then of course, p 1 it is defining the lower cutoff frequency f L. And then the gain overall gain, of course it will be this multiplied by; this multiplied by whatever the attenuation coming out of R s and R in. So, the overall gain A v overall equals to, so this is equal to 1.3 divided by 1.3 plus 0.65, in fact, that is two-third multiplied by this 254 of course, with a minus sign and that is becoming close to minus 169.

So, in summary the mid frequency gain it is 169, lower cutoff frequency it is 8.16 Hertz and then upper cutoff frequency it is 286. So, that is the overall frequency response or the common emitter amplifier given here. Now, we can similar kind of exercise you can try for common source amplifier.

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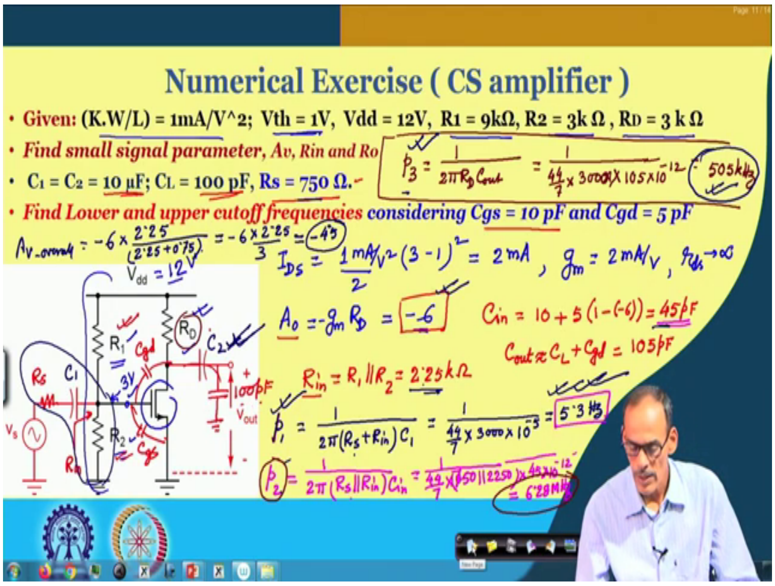

So, again this circuit is very similar, but we need to be careful here that g m of this transistor MOS transistor, since it is much lower than g m of b j t, so we are expecting the gain here it will be much lower and then we can see what is its consequence in the frequency response.

So, here we do have the value of different bias elements namely R 1 and R 2 are given here, 9 k and 3 k respectively. We do have the supply voltage 12 volt. And then for this device parameters are given here namely transconductance factor it is 1 milli ampere per volt square, threshold voltage it is 1 volt and then R D the passive load it is 3 k.

Now, if I analyze say this part to find the voltage here, since it is 9 and since it is 3 the voltage coming here it is 3 volt from this 12 volt, right. And once we have the gate voltage 3 volt and threshold voltage is 1 then we can say that this I D D equals to this 1 milli ampere per volt square by 2 into 3 minus 1 V gs minus V th square, so that is equal to 2 milli ampere.

In fact, with this we can also get g m of the transistor it is 2 milli ampere per volt. Earlier we have done this calculation, and we can assume that the lambda is very small. So, we can say that r naught or r ds is very high, we may consider this as very high. So, the voltage gain voltage gain from gate to drain of this amplifier it is g m into R D with a minus sign and that is equal to 6. So, we got voltage gain from here to here it is only 6.

Now, we can calculate the input capacitance using this information. So, we do have voltage gain it is only 6, so the C in, so the C in part it is we do have C gs which is 10 picofarad and then C gd 5 multiplied by 1 minus minus 6. So, that gives us 45 picofarad only. And on the other hand, if we connect the C L here which is 100 picofarad given here and if this is 10 micro farad, so effectively these two together it is giving us 100 picofarad and of course, we have to consider effect of C gd and this is C gs, so effect of C gd it is coming here almost as is.

So, we can say that C out it is equal to C L plus C gd approximately, right and so that is we can see it is equal to 105 picofarad. Now, based on this information of course, we need to know the input resistance here R in and gate to source resistance of coming out of the device it is very high. So, input resistance it is coming from the bias circuit only and also we consider the source resistance to get the effect of C in and the source resistance it is given here it is 750.

So, R in now it is R 1 in parallel with R 2, so that is equal to 2.5 kilo ohm. So, we do have R in is equal to 2.25 kilo ohm, then R s is 750. So, the first pole, let me use different color here. First pole p 1 coming due to series connection of R s and R in and C 1, C 1 it is here C 2 it is here So, this is 2 pi, then R s in series with R in multiplied by C 1. So, that is equal to 44 by 7 into we do have together series connection of R s and R in this is actually 3 k, 3 k and then C 1 it is 10 to the power minus 5.

So, that gives us the lower cutoff frequency of this circuit it is even lower than the previous case. So, this is equal to 5.3 Hertz only. So, we got the lower cutoff frequency it is coming here. Then p 2, if you consider p 2 which is 1 by 2 pi then R s in parallel with R in and then multiplied by C in and C in it is only 45 picofarad, so this is equal to 1 by 44 by 7 into. So, these two coming in parallel, so that gives us let me check in my calculation.

So, this is R s is equal to point or let us say 750 in parallel with 2250 and then 45 picofarad. In fact, this is becoming quite high particularly the capacitance, it is low this is equal to 6.28 mega Hertz. So, note that the value of this capacitance it is higher, sorry the lower that makes this p 2 it is higher.

Now, let me also calculate p 3 which is coming from R D the output resistance here let me use this space here, ok. So, we do have 2 pi here and then R D and then C out. In fact, if you consider the corresponding numerical value here, so this is 44 by 7 into R D it is 3 k and then C out it is, so this is 3 k sorry. C out it is 105 picofarad and in fact, this is becoming 505 kilo Hertz.

Now, this is the case where what we are getting is that this frequency it is lower than this one. So, naturally the upper cutoff frequency it will be decided by p 3 of course, the lower cutoff frequency it will be decided by p 1, ok. So, this is the; this is the example where I was talking about that this p 2 it is not defining the upper cutoff frequency, it is rather p 3 the output node pole it is still defining the upper cutoff frequency.

And then what is the mid frequency gain? We do have the gain of 6, that need to be multiplied by the attenuation coming from R s and R in and the attenuation there it is of course, that is 0.75 and we do have the input resistance it is 2.25. So, overall gain A v overall equals to we do have minus 6 multiplied by 2.25 divided by 2.25 plus 0.75. So, this part it is becoming 3 and. So, this is minus 6 into 2.25 divided by 3, so that gives us minus 4.5. So, the mid frequency gain it is only 4.5 and the lower cutoff frequency it is 5.3 Hertz, upper cutoff frequency it is 505 kilo Hertz, ok.

So, anyway we know that this circuit will be having low gain, but the exercise here what you have seen here it is because of the low gain the input capacitance, it is not so high. As a result the upper cutoff frequencies it is still getting decided by the pole coming from R D and C L or output capacitance. Now, we can do probably one more exercise which is cell biased, but I suggest that probably you can try it out to solve this problem.

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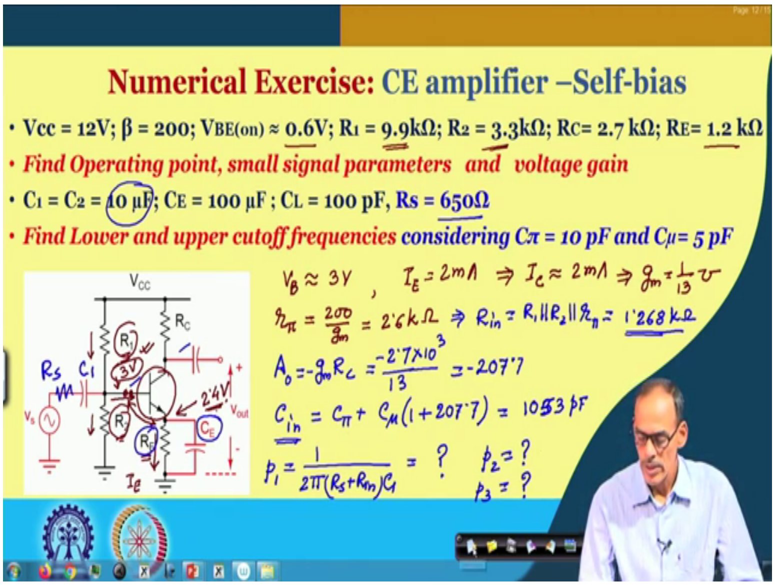

So, I will be giving little hint to solve this problem. First of all here again we shall try to find the operating point of the transistor. So, if you consider R 1 of 9.9 k and R 2 it is 3.3 k. Again, the voltage coming here it is 3 volt. So, we do have the value of this resistance it is 9.9 k and we do have 3.3 k, so that gives us 3 volt here. And with this 3 volt if you consider that we do have the base to emitter voltage drop of 0.6, in fact, that gives us this voltage equals to 2.4 volt.

Now, of course, we are assuming that while the base node it is connected here and then the base current it is flowing here we are assuming that this voltage the base voltage it is not changing. And in this case it is valid because the internal current here through this register R 1 and R 2 before we connect this base terminal it was much higher than the anticipated base current. So, even after connecting this base terminal we can see that the V B still it is very close to 3 volt, right.

So, once we have 3 volt here then if we reduce this drop of point 6 then we do have 2.4 volt coming at the emitter. And then if we consider R E which is 1.2 k that gives us the emitter current I E equals to 2.4 divided by 1.2 which means that the I E is equal to 2 milli ampere. And we can also approximate that this I C is also equal to same, so that is also 2 milli ampere. And then from that you can calculate g m which is 1 by 13 mho, then we can calculate r pi which is 200 beta is 200 divided by g m. So, that is 1 by 13, so that is equal to 2.6 kilo ohm.

Now, the input, so that gives us the input resistance R in equals to R 1 in parallel with R 2 in parallel with r pi. Probably, you can check I think in my calculation it was coming 1.268 kilo ohm and the voltage gain of course, the internal circuit voltage gain from base to collector A naught which is g m into R C assuming that this emitter register it is successfully bypassed by this capacitor C E. So, this it becomes R C we do have 2.7 and then g m it is 1 by 13, so that gives us a gain. So, this is k of course, multiplied by 1000. So, this gain it is coming close to 200, in fact, 2.7.7 with a minus sign.

And using this you can calculate what is the input capacitance, namely C pi plus C mu into 1 plus 207.7. I think in my calculation I was getting close to 1 nanofarad, in fact, 1053 picofarad, right. So, using this information of say C in and then R in you can calculate what will be the p 1 by considering the source resistance R s which is given here. So, p 1 again you can calculate this is equal to 2 pi R s plus R in multiplied by C 1 and C 1 it is given here it is 10 microfarad.

So, you can find the value of this one. Likewise you can calculate p 2 and then you can calculate p 3. So, I will not be doing this one, probably, you can simply try it out and get the corresponding solution.

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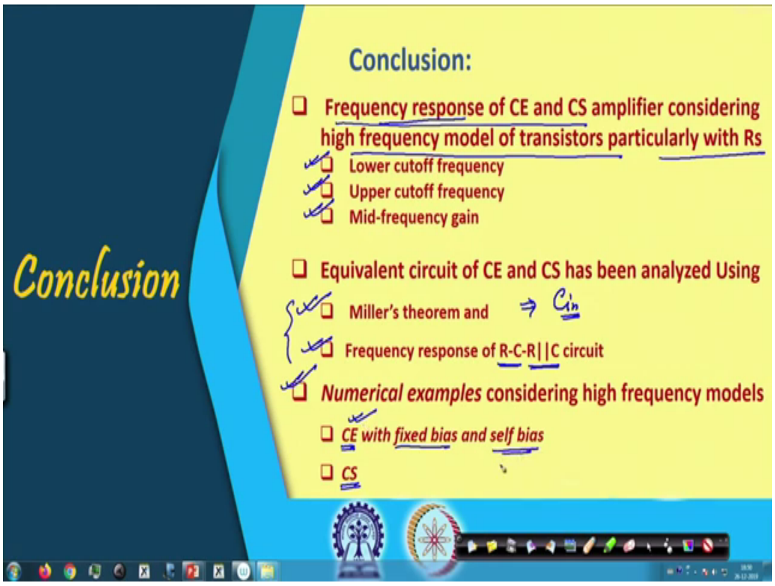

So, in summary what we have so far we have covered it is. So, in this module what we have covered here it is basically we have considered high frequency model of transistor and particularly in presence of source resistance R s, what is its impact on the frequency response of common emitter and common source amplifiers. And what you have seen primarily, it is the change of the lower cutoff frequency and upper cutoff frequency and also the mid frequency gain.

So, this is the main thing we have done and that has been done by properly calculating the input capacitance for which we have considered Miller's theorem. So, we have touched upon the basic Miller's theorem and then we have seen that that theorem it was helping us to calculate the input capacitance C in which primarily it was defining the upper cutoff frequency. And then, also to get the overall frequency response we also have analyzed R C followed by R C in parallel circuit and we obtain the corresponding frequency response.

So, these two underlying theory it was helping us to get the frequency response of the CE and CS amplifier. So, we started with analysis and then the expression of the poles and all. And later in the third part of it we have considered numerical examples and particularly for common emitter amplifier with fixed bias and common source amplifier in detail, and we have given a hint of how to do similar kind of you know analysis for common emitter amplifier having self-bias arrangement. I think that is all I do have.

Thank you for listening.