Analog Electronic Circuits
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Lecture – 39
Frequency Response of CE and CS Amplifiers (Contd.) (Part B)

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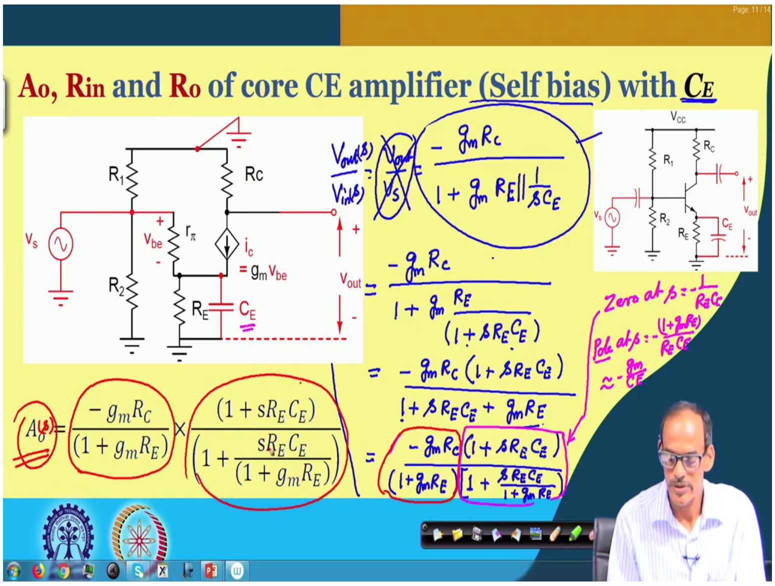

Welcome back after the short break and what we are discussing so far that, the C E amplifier with the with self-biased arrangement with C E, that bypass capacitor C E in parallel with R E. And what we said is that input to output gain, it is having this expression and let we rearrange this expression and let us see how it looks like, maybe it is having some meaningful expression.

So, this is denominator part it is 1 plus g m into R E and then we do have 1 plus s into R E into C E. And if we further rearrange and what we will be getting the this factor we can take into the numerator. So, numerator part it will be g m into R C multiplied by 1 plus s into R E C E divided by. So, this factor it is getting multiplied here. So, we do have 1 plus s into R E C E plus g m into R E.

Now, this is independent of frequency, this is also independent of frequency; we can take together. So, 1 plus g m into R E you can take them together. And then if you take it as 1 plus g m into R E as a factor. So, what we are getting in the denominator it will be seen; but let me write the numerator part 1 g m into R C multiplied by 1 plus s into R E into C E divided by 1 plus g m into R E. So, we are taken together; and then if we take this factor as out, we do have 1 plus s into R E C E divided by 1 plus g m into R E.

So, what we have here it is; one part is this one, which is independent of s, independent of the frequency and then we do have the other part, it is dependent on frequency. In fact, if you recall that, this part it is same as the previous case when the C E was not there. And due to the C E, then we do have this additional part and note that it is having a zero at s is equal to minus 1 by R E and into C E and also a pole at s is equal to minus 1 plus g m into R E divided by R E into C E.

In fact, you may approximate this location of the pole. So, pole location it can be approximated by considering this part it is dominating and R E part it is getting cancelled and then you may say that, this is g m into C E. So, what we like to say here it is, this is what we have written and that the expression of the gain voltage gain; it is not only this part, rather it is having a frequency dependent part. So, since it is having pole zero, I think it is better to go a little deeper into the frequency response of this A naught itself.

Now, instead of telling this is A naught, I should say A naught s which is function of frequency. So, let us try to sketch the bode plot of this gain; unlike the previous case, this portion it is in got change.

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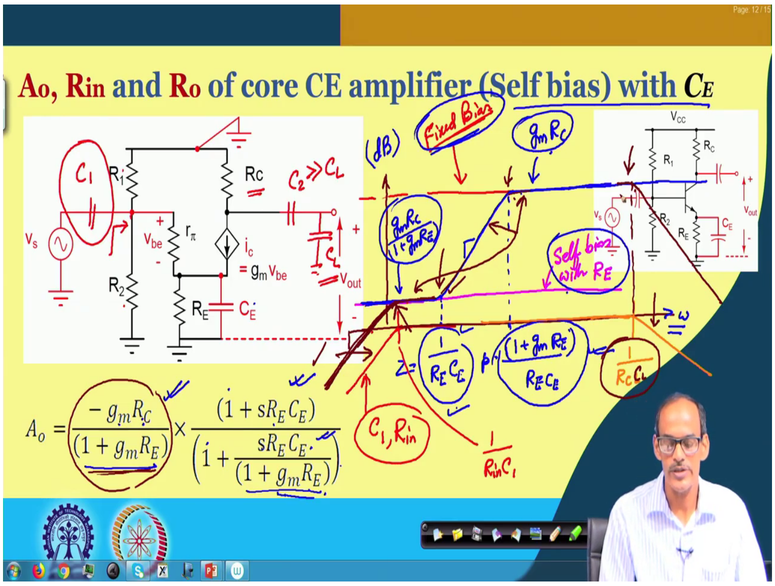

So, let me clear and then let me try to plot the gain or magnitude plot of this A naught. So, A naught is having; of course, we do have low frequency gain something like this and which is assuming that this part it is more than 1. So, we can see that it is above 0 dB. So, it is having a gain like this. So, which is coming from this part and then we do have one 0 here. So, ones with it is having a 0, then it is frequency dependent part it will be changed and it will be linearly increasing. So, the corner frequency here, it is 1 by R E into C E.

And then once you see the denominator part and at some higher frequency, which is 1 plus g m into R E divided by R E into C E and that point we do have here pole. And once you have this pole we can say that the variation of this gain with frequency, it got compensated by this pole. So, mathematically we can say that once we have this part dominating over one and this part dominating over this one; then s and this s they are getting cancelled, then we do have R

E and C E this part is also getting cancelled, and then 1 plus g m into R E that is also getting cancelled with this.

So, what we have here it is g m into R C. So, in conclusion what we said is that, the gain here it is basically g m into R C and the gain here it is g m into R C divided by 1 plus g m into R E. And location of this the pole here, which is 1 by I should not say 1; this is rather let me write this is 1 plus g m into R E divided by R E into C E. So, if you see the this expression and this expression, they are differing by this factor 1 plus g m into R E. In fact, if you see since this is bode plot and then omega it is in log scale and y axis is also in dB; that means the data got converted into log.

So, you can see that ratio of this and this is consistent with the ratio of the location of the pole and location of the zero. So, at this point we do have a zero and then we do have a pole. So, anyway and beyond this point of course, the gain it is continued to be remaining constant. Earlier, now if we recall if it is say fixed bias, where the gain it was g m into R C. So, there the gain it was like this, it was continuing like this. So, this is again for C E amplifier with fixed bias.

And on the other hand if it is if we have say self-biased, and if we do have only R E; then the corresponding gain it was continuing like this So, this is self-bias and with R E only. On the other hand if we have self bias, but then we do have both R E and C E; then in the low frequency before the C E it is really showing its effect, before this 0 frequency, it was matching with the gain of this self-bias circuit with R E. And beyond this point then it is having a changeover starting. And then once it is reaching to this point, then it is catching up with the gain of the fixed bias.

So, the self-bias circuit with C E it is having both the behavior; one is for self-biased with only R E at low frequency. But then if you consider sufficiently high frequency, then the corresponding gain it is matching with the fixed bias. And of course, this will be appearing in the frequency response and in addition to if I consider the coupling capacitor here and then the C L here; of course their corresponding effect it will be obtained by considering their the high pass behavior coming from C 1 and R in, and then low pass behavior coming from R o and C L.

So, if I consider this part, effect of that part depending on the input resistance of the circuit which may be R 1 R 2 coming in parallel and then rest of the things. So, depending on that we may be having seen a low pass behavior sorry high pass behavior; and if we say that this kind of high pass behavior it is coming from C 1 and R in of the amplifier, and the corresponding cutoff frequency it is in fact, 1 by R in into C 1. And on the other hand if I consider say C 2 which is sufficiently high compared to C L, then this R C and the C L it is showing the low pass behavior.

And let me consider the low pass behavior, it will be somewhere here. So, it is having low pass behavior, but then it is cutoff frequency it is sufficiently high and the cutoff frequency it is coming from R C and then C L. So, if I combined say this part and then the blue part, which is having three component and then we combine this one; what will be getting here it is, the overall frequency response it starts from here and then it goes with this blue line. Since this is 0 dB for the passive circuits and then it is going here and then again at high frequency, this 1 by R C into this C L. So, this part it is coming there.

So, the entire circuit, frequency response it is having a behavior like this. So, what are the; what are the different poles and zeros are there; this at this point we do have, this is a indication that it is having a pole at high frequency and then also it is having a pole at this frequency. Then we do have a zero at this frequency, then we do have a pole here at this frequency coming from C 1 and R in and also it is starting from a slope of 20 dB per decade; so that means, it is having a zero at zero frequency.

So, it is having one zero at zero frequency, we do have another zero here and then the three poles. So, that is how the frequency response of this entire C E amplifier with R E and C E looks like.

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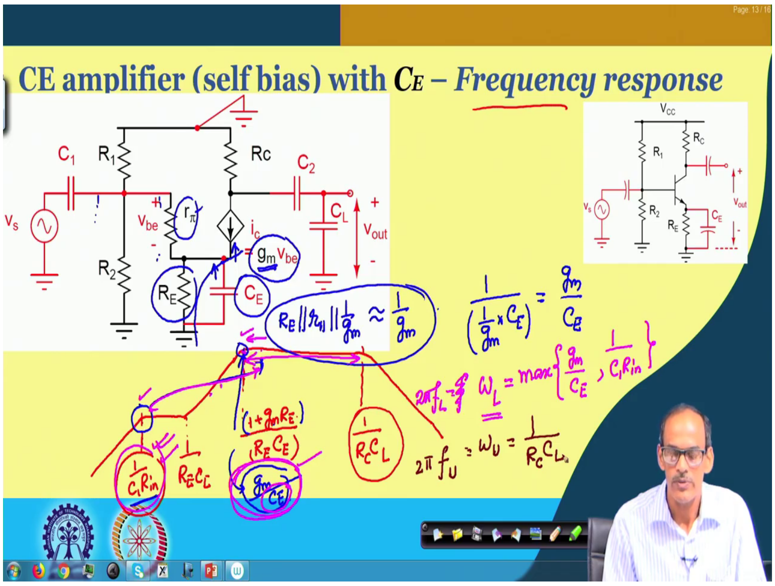

In fact, I was having different slightly explained, but we already have discussed this part. Again just to summarize here, the frequency response of this entire circuit; it is having a pole here coming from C 1 and R in and then it is having zero here, which is coming from R E and C E and. So, this is 1 by C 1 and R in.

And then we do have frequency here which is 1 by I should not say 1 by; 1 plus g m into R E divided by R E C E. And then we do have high frequency pole, which is coming from 1 by R C and C L. So, that is the frequency response of the C E amplifier. Now one additional information I like to say here; while say this part it is indicating that it is location of this pole it is depending on one R C time constant, likewise this zero it is another no it is coming from another time R C time constant and so is for the high frequency pole.

Whereas for this case I do have a different kinds of expression; but it is having a meaning, in case if you approximate that the numerator part it is practically g m into R E. So, this expression of the, this cutoff frequency it becomes g m divided by C E. So, what does it mean is that, whenever the C E it is looking into this node; the effective resistance it is saying, here it is not only this R E and then r pi, but most important thing is that we do have an one active device here.

So, if you are applying a voltage here that, voltage it is directly appearing as V be or V eb and that is making a huge current flow because of this g m. So, the net resistance seen by this C E, it is I should say that R E in parallel with whatever the r pi we do have; in case if I consider this is connected to ground and then in parallel with 1 by g m. So, this is getting dominated by 1 by g m. So, the corresponding R C time constant is basically this resistance and then C E.

So, as a result whatever the corresponding pole we are saying, it is 1 by g m into and this C E. So, this time constant and that gives us g m divided by C E. So, this C E in combination with the equivalent impedance coming from this active device which is 1 by g m; it is giving us the corresponding corner frequency. Now, in case if the depending on the value of this of course, C 1 and R in; it is possible that this corner frequency it may exceed this corner frequency.

But most of the time what we do, we take the value of this C E sufficiently high, so that this corner frequency it is not exceeding this one. That is because, you may remember that our main purpose is to get an amplifier having a good gain. So, this is our main frequency band and if we are having higher band, it is better most of the time. And so, if one of them it is you know exceeding the other one; whichever is lying on the right side that defines the lower cutoff frequency.

In this case the lower cutoff frequency it is defined by this; but in case if we take a value of C 1 very small and in case if it is crossing this point and then this may be; this may be defining the corner frequency. So, typically we try to see that value of this C E it will be taken sufficiently large, so that in the optimum case we may say that, these two corner frequencies they are coinciding. So, depending on in case if it is exceeding this point; of course, it will be having the behavior of the frequency response, it will be slightly different.

But nevertheless I should say that, I do have to define the lower cutoff frequency, I do have two candidates; so one is g m divided by C E, another one is 1 by R 1 R in and C 1. And whichever is higher, I should say that is the lower cutoff frequency. So, what we are saying is that, let me write in terms of omega lower cutoff frequency if I say omega L. So, that is equals to max of these two candidates; one is g m divided by C E, the other one it is 1 by C 1 R in.

So, whichever is higher that defines the lower cutoff frequency. Of course, we can convert this into hertz. So, this is 2 pi f L. On the other hand on the upper cutoff frequency there is no ambiguity. So, 2 pi f u which is omega u. So, that is coming from 1 by R o which is R C and then C L. I think that is completes the analysis part of the C E amplifier and in a common source amplifier frequency response. Let us see some of the numerical examples.

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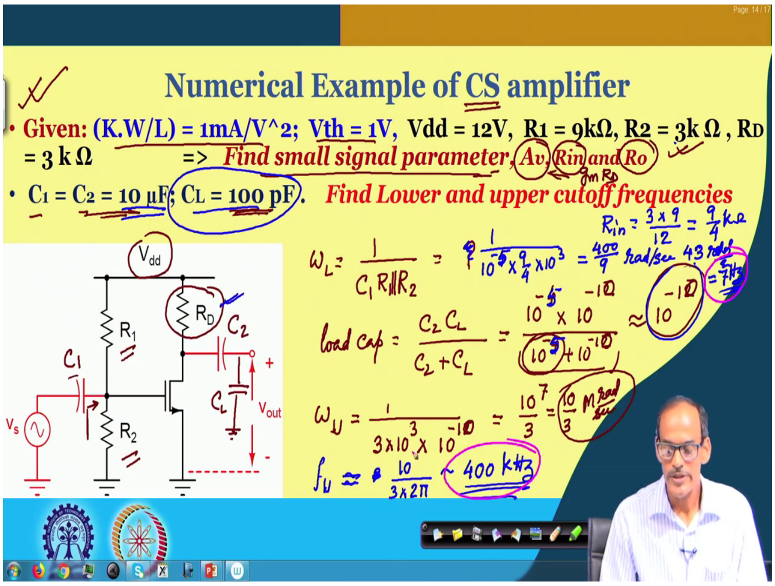

So, here we do have this C common source amplifier, CS amplifier and this part we already have done; namely if the device parameter K multiplied by W by L, it is given to us; then threshold voltage is given to us, supply voltage it is if it is given to us, and then bias elements are given to us. From that what we have obtained is that, we obtain the DC operating point, and then small signal parameter namely g m and R naught in case lambda is given; but anyway here lambda is not given, so at least small signal parameter wise it was g m.

And from that g m we obtained this voltage gain A v, which is g m into R D. And then input resistance we obtain here it is primarily R 1 parallel R 2, and then output resistance we obtain same as this R D. So, this part we have done before. Now today in addition to that in case if we have these two capacitors value and also the C L is given to us. So, this is C 1, this is C 2, and then we can find what will be the corresponding R in and then we can find what will be the cutoff frequency, lower cutoff frequency.

So, in this case what will be the lower cutoff frequency? Omega L equals to 1 by C 1 into R 1 parallel R 2. So, whatever the value it is we are getting, we can calculate ourself. And likewise since C 2 is much higher than C L. So, we can say that this series connection, C L it is connected here. So, the series connection of C L and C 2 it is giving us the load capacitance, which is load cap is equal to C 2 multiplied by C L divided by C 2 plus C L.

Now, you see this value here it is the C 2 it is 10 power minus 4, and then C L it is 100 picofarad 10 power minus 12 divided by 10 power minus 4 plus 10 power minus 12. So, this is what we say that, the denominator part it is dominated by this. So, we can easily write that this is 10 power minus 12, right. And so, the upper cutoff frequency omega u it is equal to 1 by the C L and this R D; and R D it is given to us this is 3 k, 3 into 10 to the power 3. And then C L it is 10 to the power minus 12, no sorry we do have 100 pico, 10 to the power 10 sorry 10 to the power 10 anyway.

So, this is becoming 10 to the power 7 divided by 3 or we can say that, 10 divided by 3 mega radian per second, ok. And we can convert this in terms of the in terms of Hertz and what will be getting is that; f u it will be in the order of few 100's of kilo Hertz. So, that is 10 divided by 3 into 2 pi; so roughly it maybe 400 something, 400 something kilo Hertz, ok.

Whenever you are talking about C L, it may be coming from maybe next stage or maybe from measuring probe capacitance or instrument. Typically in a hardware lab we have seen that, the C L it is in this order somewhere 30 to 100 picofarad. So, that with that C L and this practical value of this R D, you may get this upper cutoff frequencies like this.

Lower one what we have it is R 1 and R 2, if they are in parallel. So, that is how much? This is R in equals to 3 into 9 divided by 12. So, that is 9 divided by 4, right. So, this is 1 by C 1, it is again 10 to the power minus 4 and then R in, it is 9 by 4 k 10 to the power 3, right. And so, that gives us how much; this is no this is what we said is it 10 microfarad sorry, this will be

10 to the power minus 5, earlier we have written minus 4, anyway it is still this approximation is valid.

So, we do have. So, this is 400 divided by 9 radian per second. And so, this is how much? Around whatever 40 maybe 40 less than 45. So, maybe 43 radian per second and divided by 2 pi. So, if I divide by 2 pi roughly because 6, so that is becoming around 7 Hertz. So, that gives you some idea that what may be a typical value of the lower and upper cutoff frequency of this common source amplifier.

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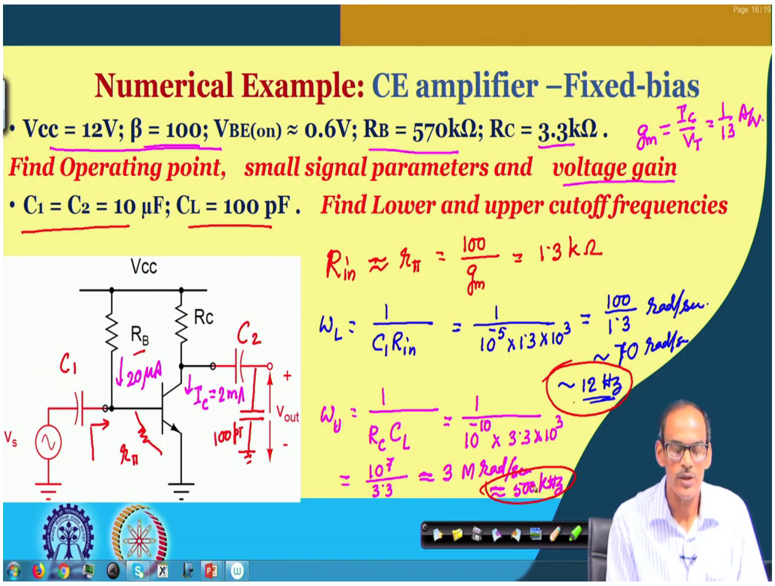

So, likewise you can consider say C E amplifier also. So, again for this circuit we have done the mid frequency range analysis; namely by considering supply voltage and then R B we obtain the base current. And then from the beta we obtain the collector current; it was you may recall that it was 2 milliampere current or you can calculate here I b equals to 20 microampere. And from that we obtain g m it was I c divided by V T. So, that was 1 by 13 ampere per volt. And so, from that we obtain the gain, which is g m into R C and R C it is 3.3 k.

So, we got something around 240 gain. Now similar to the previous example here, so we do have this additional information. So, C 1 and C 2 it is given to as say 10 micro farad, and we do have the C L here which is a 100 picofarad. And then input resistance of this circuit it is R B in parallel with whatever you say r pi and r pi. So, I should say R in equals to all practical purposes it is r pi which is beta divided by g m. So, that is 1.3 kilo ohm and then the lower cutoff frequency it is 1 omega L equals to 1 by C 1 R in.

So, that is one divided by 10 power minus 5 into 1.3 into 10 power 3, so that gives us 100 divided by 1.3 radian per second. So, roughly you can say that this is how much around 70 in the range of 70 around 70 to 80 radian per second. And if you convert into Hertz, then it will be in the order of maybe it around 12 Hertz all right. And on the other hand the upper cutoff frequency, it is omega U equals to 1 by R C into the C L; C L it is dominating with respect to C 2. So, this is equal to R C we do have 3.3.

So, C L it is 10 power minus 10 farad multiplied by 3.3 k 10 power 3. So, that is equal to 10 power 7 divided by 3.3. So, that is becoming how much, this is around 3 roughly 3 mega radian per second, and in Hertz that is in the order of 500 kilo Hertz. So, that is what the typical you know lower and upper cutoff frequency. So, in case if you are doing lab experiment with whatever the components it is given to us; then you will be getting the lower and upper cutoff frequency of this circuit.

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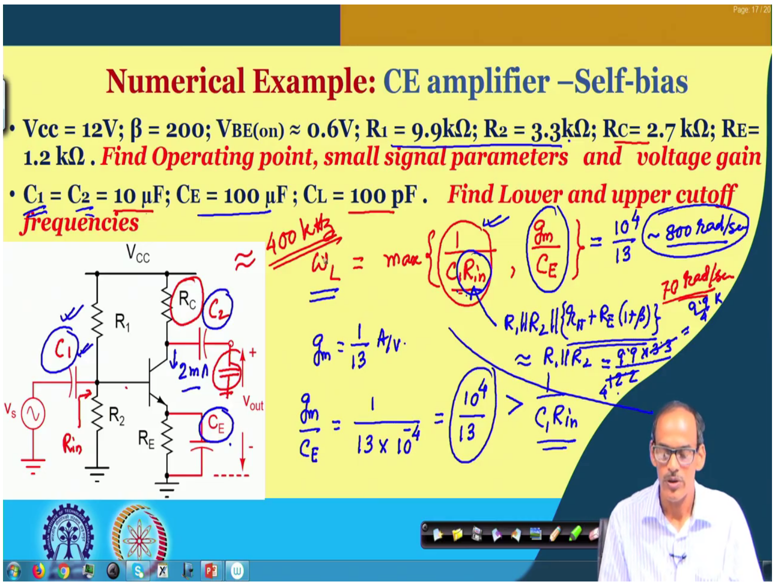

So, likewise if you consider the C amplifier having R E and C E and if we have the similar kind of value of this R, or rather R 1 R 2 it is given such that the current here it is similar namely 2 milli ampere of I c. And then here we do have the C 1 and C 2 similar to the previous case 10 micro farad and C L also it is given to us, it is a 100 picofarad. And depending on the value of this R in of course, you will be getting the input resistance.

And of course, as I say that for the lower cutoff frequency omega L, we do have two candidates to define the lower cutoff frequency; one is 1 by C 1 and R in and the other one it is g m divided by C E. Now, if you see that previous case if we consider that R in equals to r pi, ok. So, of course, there will be a doubt that, why we consider r pi; but for the time being let you consider if it is in this R in is equal to r pi. And there we have seen that the lower cutoff frequency it was coming from this part, it was around 70 radian per second around this value.

Now let us calculate numerical value of this g m divided by C E part; g m it is for I c equals to 2 milliampere this is 1 by 13 ampere per volt. And C E it is given here, so the g m divided by C E. So, that is it is becoming 1 by 13 into, C E it is 100 microfarad, so that is 10 power minus 4. And this is becoming how much, this is rather 10 power 4 divided by 13.

So, what you can see here it is this is definitely higher than 1 by C 1 into R in. And so, as a result while in this case, practically then this becomes 10 power 4 divided by 13. And its value it will be somewhere in the close to 1 k, may be around 800 radian per second. And in case this is the situation then, actually we should have considered this R in equals to R 1 parallel R 2 in parallel with r pi plus R E into 1 plus beta.

And since this part it is higher than this one, so then R in it is approximately equal to R 1 parallel R 2. And if you see this R 1 parallel R 2, earlier we have discussed it is value it was, no we have not discussed. So, we have to consider these two in parallel and since we do have 3.3 k here and 9.9 k, so what will be getting here, it is 9.9 k multiplied by 3.3 k divided by 12.2. So, if I cancel this part it will be 4 so. In fact, this is becoming 9.9 divided by 4; 9.9 divided by 4 k.

So, if I consider even say 9.9 and divided by 4 k, and C 1 it is 10 microfarad; then also the g m divided by C E it is becoming dominant. But of course, in case if you are picking say this value, this C 1 it is say maybe 1 microfarad; then of course, the candidate to define the lower cutoff frequency, it will be the first one, ok. So, most of the time what you do that, this value of this capacitor it is almost 10 to maybe a few, 10 times higher than this one or rather sometimes it may be even 100 times higher than this one C 1. On the other hand C 2 normally we take same as this C 1.

Now this numerical examples as I say that, indirectly it is giving you some idea that what may be the typical value of this C 1 and C 2 to get the whatever we have discussed that lower cutoff frequency and upper cutoff frequency, right. And upper cutoff frequency of course, again it is coming from this R C and C L and R C it is it was in the similar value or at least it is a order of magnitude it is similar to the previous example.

So, the upper cutoff frequency again it will be in the order of around few 100 of kilo Hertz. So, that gives you some idea that what may be the practical value of those lower and upper cutoff frequency you can get, or the frequency response you do gain.

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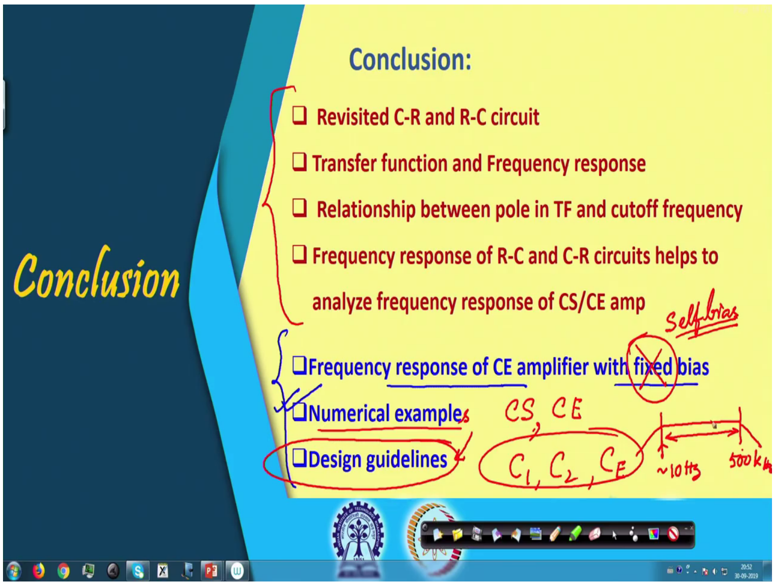

So, what we have covered today, let us let me summarize that, today and previous day. So, the first part, this part we already have discussed before, and today we have covered this part. The frequency response of the C E amplifier having fixed bias, and when you say fixed bias it may be only with R E or R E in parallel with C E. And then we have discussed about numerical examples for common source amplifier, common emitter amplifier with two category two types; one is fixed bias, another is the self-biased, sorry this is self-bias.

Today we have discussed the self-bias, but not the fixed bias, this is the type of. So, we have covered the numerical examples for common source, common emitter with and without C E and R E and then that gives us indirectly some design guidelines. So, later on if we find sometime, probably we may revisit to this design guidelines; but for the time being at least we got some idea that what may be the value of this C 1, C 2 and C E to get meaningful upper and lower cutoff frequency, so that the mid frequency range it will be sufficiently wide.

And as we say that, this is in the order of say or roughly 50 kilo Hertz and this is in the range of maybe 10's of Hertz. So, that gives us one amplifier which is definitely suitable for audio kind of application. I think that is all we do have.

Thank you for listening.