Analog Electronic Circuits
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Lecture – 47
Common Collector And Common Drain Amplifiers (Contd.): Numerical Examples (Part A)

Yeah, dear students, welcome back to NPTEL online certification course on analog electronic circuits. Myself, Pradip Mandal from E and EC department of IIT, Kharagpur. So today, we are going to continue the discussion on Common Collector and Common Drain Amplifiers.

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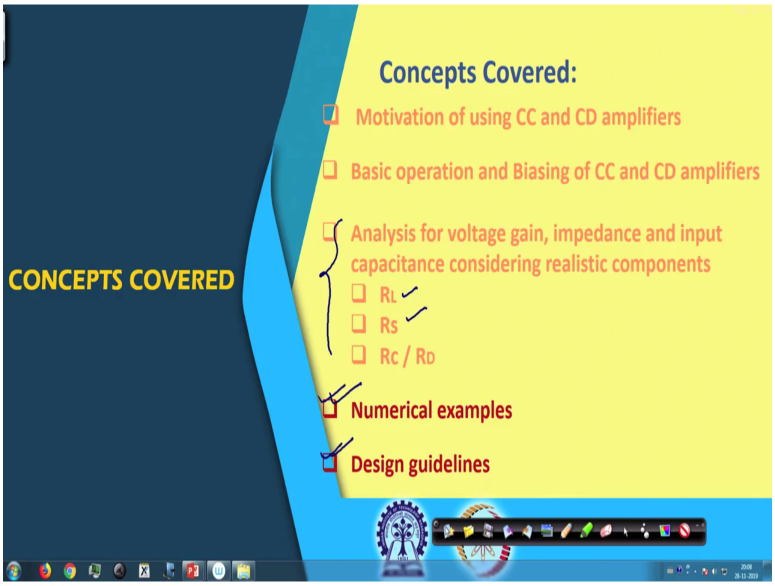

So, the outline of today's presentation, it is given in the next slide. What we are going to do today it is primarily, we will be focusing on numerical examples and design guidelines of common collector and common drain amplifiers.

So, I should say whatever the knowledge we have gathered in our previous discussion namely, the analysis of voltage gain impedance and capacitance of common collector and common drain circuit for ideal situation as well as considering the different parasitics namely, source resistance, load resistance and collector or drain terminal resistances that will also be getting utilized in the numerical examples.

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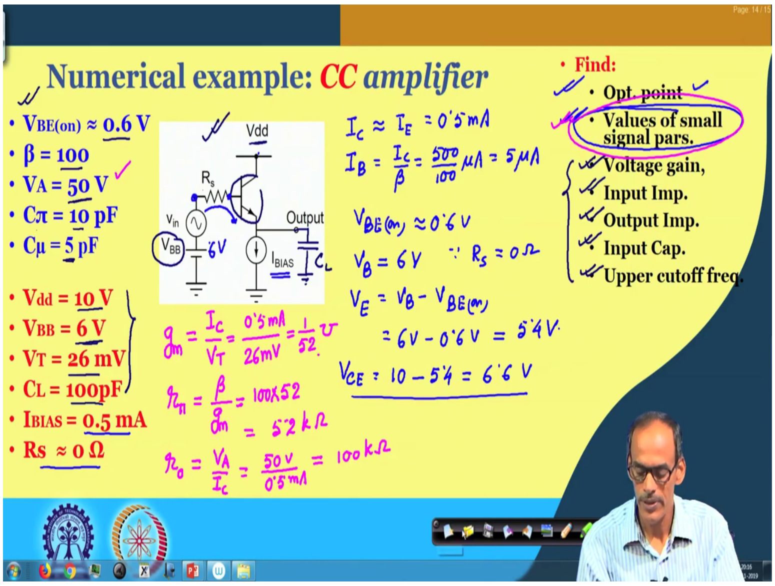


So, let us start with one numerical examples where we do have idealistic bias. So, we do have the common collector amplifier given here; and then we do have the bias circuits, it is given here. In fact, I should say that V BB it is given yeah, so we do have the V BB, it is making a bias at the base terminal and then we do have the DC supply of 10 volt. So, V BB it is given here, it is 6 volt.

And then we assume that the thermal equivalent voltage it is 26 millivolt; then, we are also considering that load capacitance connected at the output node; C L and its value it is say 100 picofarad. So these are the situation, load situation and then the device parameters are given here namely the V BE on it is 0.6 volt; beta of the transistor it is 100, early voltage it is say 50 volt. And then the parasitic capacitances namely the C pi it is 10 picofarad, C mu base 2 collector terminal C mu, it is 5 picofarad.

Now what we need to do it is, as we have discussed earlier, the important parameters are the voltage gain and we are expecting this voltage gain it will be as small as possible; or rather I should say attenuation is as small as possible. So, the voltage gain we are expecting it will be close to 1; input impedance should be as high as possible, output impedance should be as small as possible. Input capacitance also should be as small as possible; and then based on the output impedance and the load capacitance, we can find what is the upper-cut of frequency of the frequency response.

So, these are the things we need to find, these are the final performance matrices, but the intermediate steps are, we need to find the operating point of the transistor or the circuit and then small signal parameters values namely, GM and GD of the transistor.

So, let me start going to the operating point first. So, if I analyze this circuit and if I consider bias current it is, 0.5 milliampere it is given to us. So, we can say that the collector current, it is also approximately equal to the emitter current. So, that is 0.5 milliampere, then the base current quotient current it is I C divided by the beta.

So, that is 500 divided by 100 microampere. So, 5 microampere, then the V BE it is given to us; so, V BE it is approximately 0.6 now, we do have the current is flowing through transistor and we do have 6 volt at the DC coming to the terminal here. So, if I consider drop across this resistance R S that gives us the base voltage.

Now, for this case let us consider the source resistance is very small. So, we can say that the base terminal it is also equals to 6 volt because, the source resistance it is 0. And then the emitter voltage it is the 6 volt, the base voltage minus V BE on; so, that is we do have the 6 volt minus 0.6.

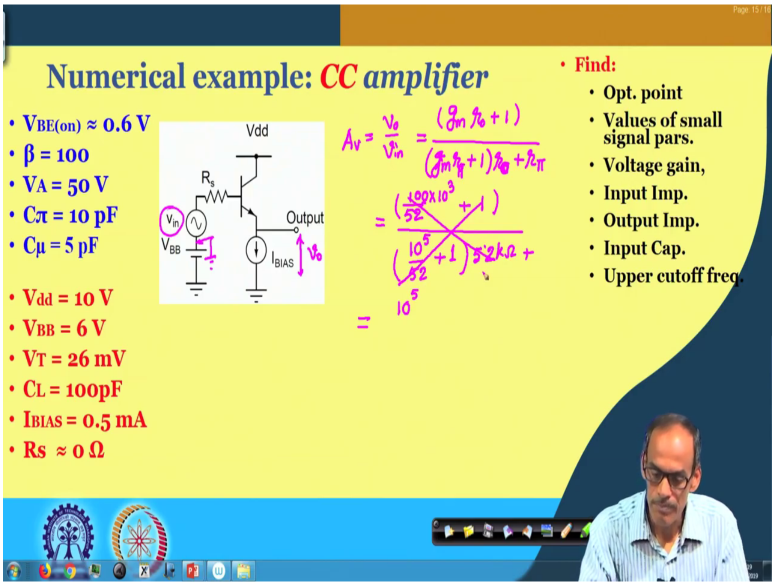
So, the emitter voltage it is 5.4 volt. On the other hand, the collector voltage anyway it is 10 volt V dd. So, we can say that V CE equals to 10 volt at the collector minus the emitter voltage which is 5.4 volt. So, this is 6.6 volt.

So, from this one we can see that the transistor, it is in active region of operation. So, that is that gives us the operating point of the transistor. Now, let us look into the small signal parameters values; namely, GAM and then R pi and then the R DS or rather in this case it is not R DS rather, R naught collected to emitter terminal resistance.

So, let it go one by one small signal parameter; values of small signal parameter. Let we start with GM and you may recall its expression in terms of the quotient current, it is collector current divided by thermal equivalent voltage and collector current it is 0.5, 0.5 milliampere divided by 26 millivolt. So, we can say that this is 1 by 52 ohm or ampere per volt.

And then R pi the base 2 emitter impedance, R pi. So, that is you may recall that this is beta divided by GM. So, it becomes 100 beta multiplied by 1 by GM it is 52 ohms. So, this multiplied by 52 ohms, so that gives us the value of 5.2 kilo ohms. On the other hand, the collector to emitter terminal resistance r naught; which is early voltage V A divided by I C.

Now early voltage it is given as here it is 50 volt divided by 0.5 milliampere. So, that is equal to 100 kiloohms. So now, we obtain the small signal parameters. So, you can recall these numbers; so, we are going to utilize the same space to calculate the voltage gain than then input impedance output impedance and so and so. (Refer Slide Time: 10:11)



So let me C Lear the space and then again. Let me start with the voltage gain, small signal voltage gain A V equals to V O divided by V in; if I say that small signal voltage here it is V O and the voltage coming here it is V in, so for small signal of course, this this terminal it will be AC ground. So, we may see that this is connected to AC ground.

Now, the expression of the voltage gain you may recall for this circuit, it is GM into R naught plus 1 in the numerator, and then in the denominator we do have GM R naught plus 1 into R pi plus R pi right. And just now we have discussed about GM into R naught. So, GM it is 1 by 52 and then R naught it is 100 k right.

So, 100 into 10 to the power 3 plus 1 and in the denominator we will be having this GM into R naught. So, that is equal to whatever, 10 to the power 5 divided by 52 plus 1 multiplied by R pi; that is 5.2 kilo ohms plus this are yeah I think this is this should be R pi and this is R naught anyway yeah. So, let me write this values of this GM into R naught which is 10 to the power 5 divided by no the; let me clear it.

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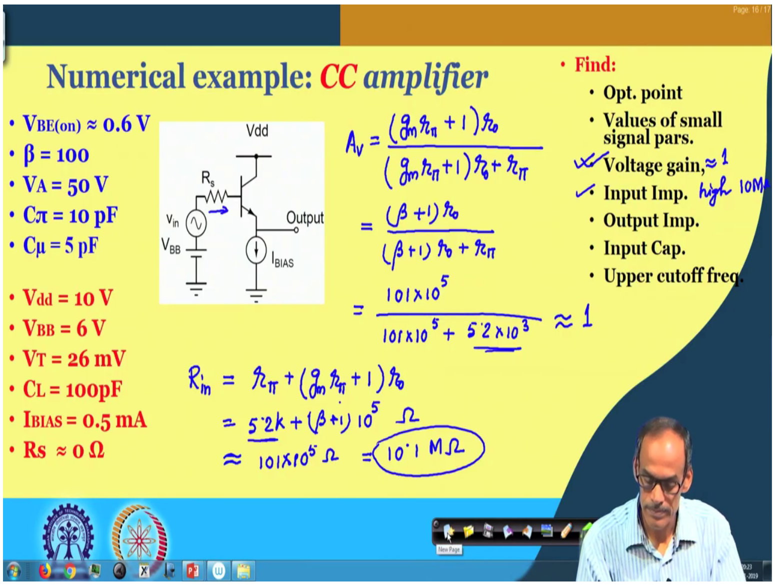

The voltage gain it is A V equals to GM into R pi plus 1 into R naught divided by GM into R pi plus 1 into R naught plus R pi. The other form it was having some any anyway, this this is the correct one. So, now GM into R pi equals to beta plus 1 into R naught; and in the denominator we do have beta plus 1 into R naught plus this R pi.

So, in the numerator we do have beta is 100. So, I should say and then R naught it is what we said is 100 k. So, 101 into 100 k 10 to the power 5 divided by 101 into 10 to the power 5 plus 5.2 k 10 to the power 3. So naturally, you can drop this part and then you may say that this is approximately 1. So, that is what we are expecting the gain it should be 1.

But here, numerically you can say it is really close to 1. And then input resistance of the circuit looking into this circuit; so, what we have it is R in, you may recall from our earlier derivation R in equals to R pi plus GM into R pi plus 1 into R naught right. Because this bias circuit we are assuming it is having ideal situation; so, its conductance is 0. So, this is R pi it is 5.2 k plus GM into R pi it is beta plus 1 into R naught it is, 10 to the power 5. So again, this is equals to, so this is 101 multiplied by and then 10 to the power 5.

So again, this part it will be very small. So, we can directly approximate this by 10, 101 into 10 to the power 5 ohms or what you say, it is 10.1 mega ohms. So, this is quite high. So, the input resistance it is as you said it is very high, and this is approximately 1 this is 10's of mega ohms. Now, coming to the output impedance, so let me again clear it.

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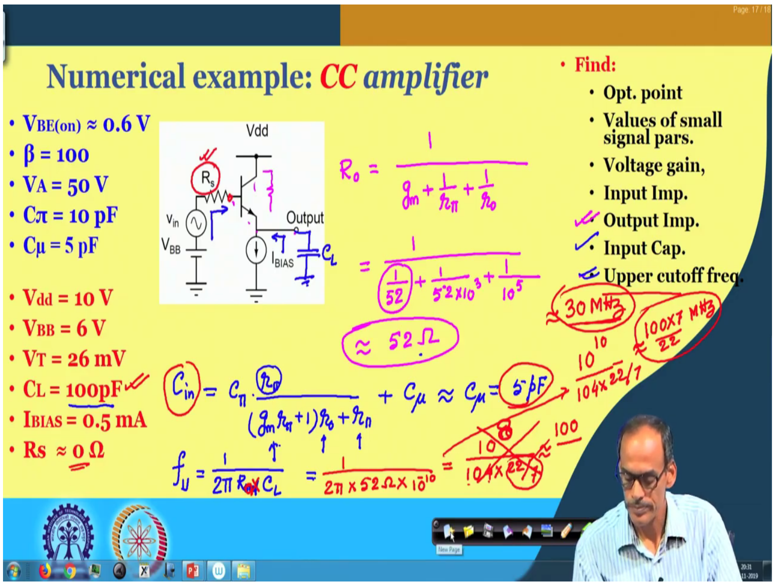

And, let you go for the output impedance. So, output impedance it is looking at the output terminal, what we have it is 1 by conductance at this point. So, we do have conductance here, conductance of the R pi, then R naught and then also the GM part.

So, the output resistance it is 1 divided by all the conductances namely, GM then due to R pi, and then due to R naught alright. So, yeah so, we do have the values here 1 by so, this GM, it is 1 by 5 point rather 52, 1 by 52 plus this R pi it is 1 divided by 5.2 into 10 to the power 3 kilo alright.

And then R naught it is 10. So that is 100 k 10 to the power 5; and again, this is it can be well approximated by this term. So, that gives us 52 ohms. So, that is the output impedance. Now coming to the; so, you can remember this one; you can remember this one for calculating the upper cutoff frequency. So, we will be coming back to that.

Now the input capacitance; so, we do have input capacitance C in looking into this circuit, it is what we said it is C pi multiplied by a very small factor.

So, what was that factor? It was R pi divided by as you may recall. Yeah, so C pi into R pi multiplied by GM into R pi plus 1 into R naught plus R pi. And then C mu as is; so again if you consider this is beta and this is very high. So, compared to that we can see that this is anyway small and this is also small. So, we can approximate that this is C mu and that is equal to 5 picofarad.

So, we do have the output resistance looking into this circuit it is 52 ohm and then we do have the load capacitance here; C L it is 100 picofarad. So, we can say that the upper cutoff frequency now, so this is done. Now the upper cutoff frequency if I say that F u upper cutoff frequency, it is 1 by 2 pi R out or R o into C L. So that is, let me use different color should see R o into C L.

So, we do have 1 by 2 pi into 52 ohms into 10 picofarad. So, that is 10 to the power 10 alright, and so this is 10 to the power minus 10. So, that comes to be 10 to the power 12, 10 to the power 10 divided by approximately or say to be more precise 104 into pi. So, that is 22 by 7.

So, roughly we can see that approximately if I say that this part it is 3 and then this is almost 100. So, that is 10 10 to the power it is now, this is we do have another 100. So, this is 10 to the power 8. So, we do have 100 divided by no.

So, what we have here it is 10 to the power 10 divided by 104 multiplied by 22 divided by 7. So, roughly this is 100 into rather multiplied by 7 divided by 22 mega megahertz yeah. So, it is more or less in the 10's of megahertz. So, rather I should say ; no, I should say close to 30 approximately 30 megahertz.

So, here it is 3 yeah close to 30 megahertz right. So, that gives us some idea that even if say load capacitance it is 100 picofarad, the output, the bandwidth of the circuit coming from the output node it is quite big and we are considering the source resistance is approximately 0.

So, the C in is not having much role to play, but even if I consider practical value of this source resistance since C in is small then, the corresponding bandwidth coming from the from the input pole will also be quite big. So, let us see in the next circuit that if we consider source resistance R S which is say may be having some practical value.

Then you can see what will be the corresponding impact.

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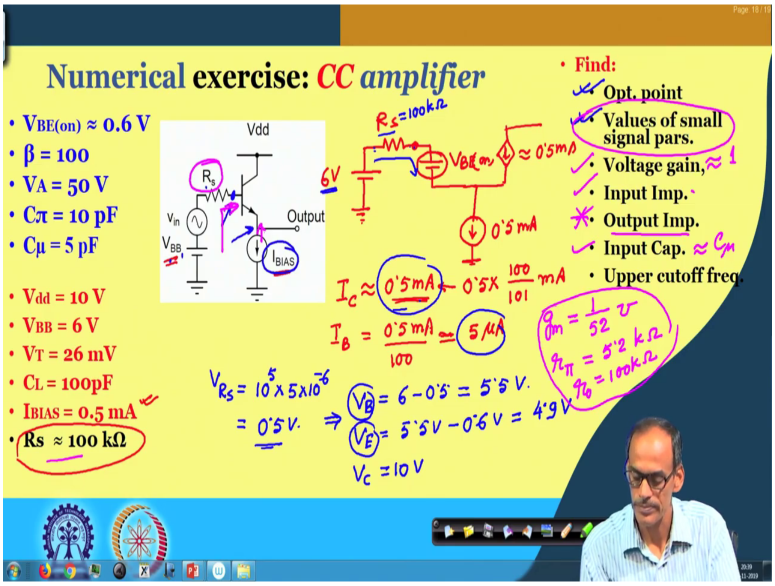

So, in the next slide, it is basically the same circuit except, here we are considering the R S different from different from 100 k. So, if you see this circuit if you analyze this circuit with the bias current of say 0.5 milliampere and then if you try to analyze what will be the operating point.

So, we do have at the base we do have the 6 volt out of this V BB, and then we do have the R S and then base 2 emitter we do have a voltage drop. So, so I should say I am just circling it to indicate that this is representing V BE on. And then we do have the that is the bias current of 0.5 milliampere. And then here we do have the and the collector current, right.

So, this collector current we may approximate that this is also equal to 0.5 milliampere. Now to find the voltage here, what you have to do? So, we can say that I C it is approximately equal to 0.5 milliampere or other to be more precise it will be 0.5 multiplied by beta is 100 divided by beta plus 1 all right.

So that is to be more precise, so I but then we can say that it can be well approximated by 0.5 milliampere; which gives us the base terminal current it is 0.5 milliampere divided by beta, so, that is 100. Again so, this is equal to 5 microampere.

Now once we do have the 5 microampere flowing through this R S; obviously, then there will be finite drop here since it is 100 k, 100 kilo ohm resistance that is quite large. So, we need to see what is the drop across on this resistance.

So, the voltage drop across this R S equals to resistance is 10 to the power 5 and the current is 5 into 10 to the power minus and minus 6. So, that is giving us a voltage drop of 0.5 volt.

So I should say, so, this gives us the base voltage is equal to 6 minus 0.5. So, this is the drop across the resistance R S. So, that gives us 5.5 volt. And then the emitter voltage V E equals to the V B which is 5.5 minus 0.6 V BE on. So that gives us 4.9 volt.

So, we do have the base voltage, we do have the emitter voltage and collector voltage anyway, it is 10 volt. And then base current is here, collector current is also approximately this one. So, that gives us the operating point.

So, note that even though the voltage here it is different from significantly different from 6 volt bias here due to finite value of this source resistance. But since we do have the bias current here it is ideal quote and non-quote ideal of the same value of 0.5 milliampere the collector current and base current hardly gets affected, only thing is that the voltage here and voltage here they are getting changed compared to the previous case.

So anyway, since the collector current is a still remaining 0.5 milliampere so, the small signal parameters on the other hand it is remaining same as the previous one; namely the value of the GM. So, GM it is again it is 1 by 20 52 ampere per volt.

Then R pi it is point 5.2 kilo ohm, and then R naught is equals to 10 to the power 5, so that is 100 kilo ohm right. So, since the small signal parameter it did not change; so, the voltage gain and then input impedance, output impedance they will be remaining unchanged.

In fact, if you see the output impedance there will be a small change we will we will see that, but the voltage gain no need to repeat here. So, again this will be very close to 1, input impedance looking into this circuit it is remaining same. So, this will also be same. So, we will not be considering this calculation.

So, if I consider this is the input impedance looking into the base that is remaining unchanged; but then of course, due to the source resistance R S the output impedance it will be different. So, that probably we can see what is the output impedance.

Input capacitance again, it will be approximately C mu. So, only thing is that let us try to see what is the corresponding output impedance of this circuit in presence of the source resistance R S.

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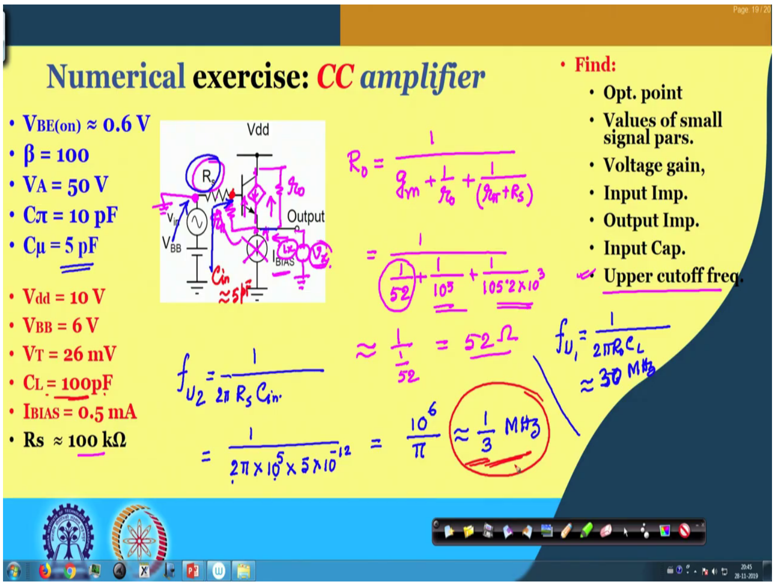

So, let me clear it. So, what we are going to do, we need to see what will be the output resistance. So now, you may recall that at this point if we give a give a stimulus of say V x in the small signal equivalent circuit; then if we try to calculate what is the corresponding I x and of course, this node it will be AC ground.

So, we do have R S and then this R S coming in series with R pi, if I try to sketch the small signal equivalent circuit here and then here we do have the GM part and then we do have the R naught part here. So, looking into the emitter here and if we stimulate the circuit with the V x here ; we will be having 3 current components one is this, then another one is this one which is GM into V x, and then the resistance here.

So, you may recall that we do have the 3 conductances to contribute to I x. So, that gives us a hint that the output resistance it will be 1 divided by all the 3 conducts conductances. One is GM, then 1 by R naught and then 1 divided by R pi plus R S.

Now here, we do have and this is GM it is 1 by 52 and then R naught it is 100 k. So, we do have 100 k here, 10 to the power 5 and then R pi plus R s. So, R s we are taking 100 k. So, this is 1 divided by 105.2 into 10 to the power 3. Again, compared to this term the other terms we can drop. So, it is again it is coming 1 by 1 by 52; that means it is 52 ohms.

So, even though we are connecting this R S; since, we do have the ideal current source and the small signal parameters remains the same, so, the performances of all the circuits it is remaining same. In fact, output the upper cutoff frequency also remains the same.

Only thing is that whenever we are feeding the signal at this point, so, since you are feeding the signal at this point and then we do have the R S and also the input capacitance coming here then we do have one more candidate to define the upper cutoff frequency and that is let me call F u 2 which is coming from R S and the C in. Of course, we have to consider the 2 pi part.

And if you see in this case, the I should say that predominantly this again this since C in it is coming from C mu. So, we can say that this is 1 divided by 2 pi then R S is 10 to the power 5 and then C in it is 5 into 10 to the power minus 12.

So, that gives us 5 and 2 gives 10. So, this is 10 to the power 6, it becomes 10 to the power 6 and then we do have 10 to the power minus 12.

So, that gives us 10 to the power 6 in the numerator divided by pi; and pi is approximately 3. So, we can say that this is approximately one-third megahertz. Whereas, the pole coming from the output node, if i call that is F u 1 which is coming from the output resistance 2 pi R o and then C L.

And this one it we have seen it was approximately 30. In fact, around 28 to something like that; so, 30 megahertz. So the upper cutoff frequency of course, it will be defined by whichever is minimum.

So, I should say that the upper cutoff frequency it is getting changed, but still it is remaining high; primarily, due to the input capacitance here it is it is actually coming from this C mu and its value it is only 5 picofarad.

Now in case if the load capacitance if it is directly connected at this point namely if it is a 100 picofarad; obviously, then this R S and then this C L it would have created the upper cutoff frequency much lower than whatever the 1 by 3 megahertz you are getting here, ok. So, let me take a small break and then we will come back with some more numerical examples.