Analog Electronic Circuits
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Lecture – 68
Multi -Transistor Amplifiers: Amplifier with Active Load (Contd.) – Numerical Examples (Part A)

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Dear students, so welcome back to our NPTEL online certification course on Analog Electronic Circuit, myself Pradip Mandal from E and EC department of IIT Kharagpur. Today we are going to continue Amplifiers with Active Load we have started this topic and today primarily we will be discussing about Numerical Examples.

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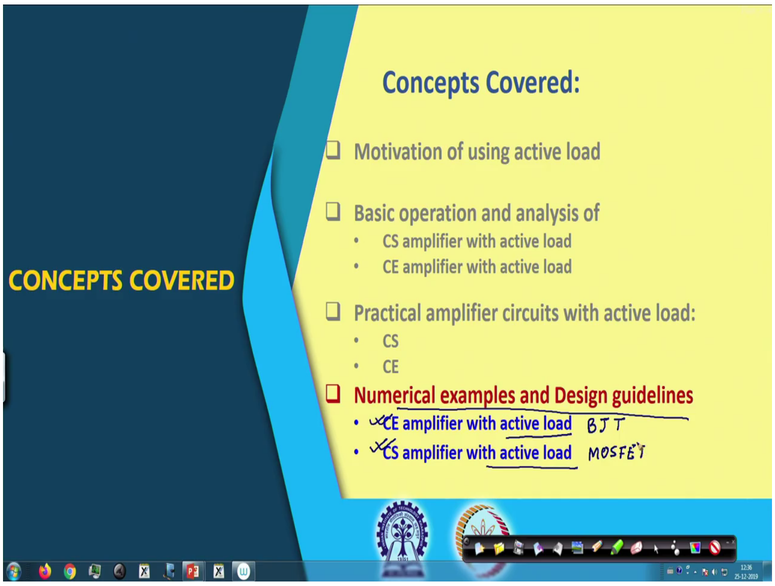

So, the plan for today it is Numerical Examples and inherent design guidelines; while we will be going through the numerical examples we will also be given hint towards how to design a circuit specifically for CE amplifier having active load and then common source amplifier having active load. So, this is BJT version and this is MOSFET version.

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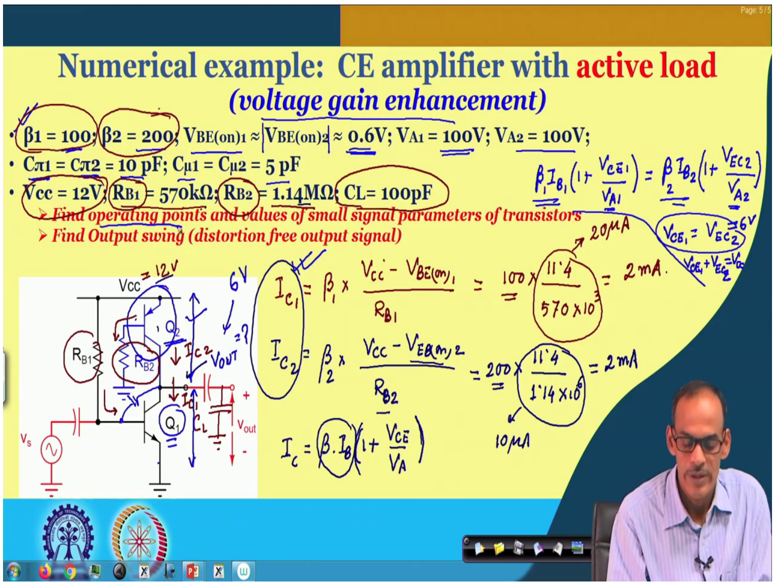

So, let we directly come to the circuit. So, here we do have one example yesterday we have in the previous discussion, we already have mentioned that instead of having a passive load we like to use active load and the purpose of this one we have discussed that to enhance the voltage gain. And here we do have the different parameters of the two transistors for Q 1 beta is 100, for Q 2 beta is 200, just for a change we are taking different value of beta.

And V BE on of transistor 1 it is we are approximating it is 0.6 V EB it should be mod actually V EB of transistor 2 also we are assuming 0.6. The early voltage of transistor 1 it is 100 volt. So, likewise let you consider early voltage for transistor 2 also 100 volt and then the capacitances namely base to emitter C pi 1 for transistor 1 it is 10 pico Farad and likewise for transistor 2 it is 10 pico Farad and then on the other hand base to collector C mu it is 5 pico Farad for both Q 1 and Q 2.

Then also we do have the information about the supply voltage. So, here we consider this is 12 volt and the bias circuits information's are given here. So, R B 1 we have taken 570 kilo ohm and then R B 2 it is 1.14 mega ohm. And we are assuming that in case if we have some load capacitance and it is value it is given here 100 pico Farad.

So, you may have probably you might have observed that the value of the beta of the two transistors they are different. And then to make a balance of that the collector current of transistor 1 and collector current of transistor 2 they should be equal and to do so, to get that what we have done it is that the, base current of transistor 1 and base current of transistor 2 we are making it different.

In fact, it is just compensating that so, to achieve that the value of this R B 2 it is two times of R B 1 just to compensate the beta difference. So, end of it what we are getting here it is collector current of transistor 1 assuming the device it is in active region of operation it is it is beta multiplied by I B and I B it is supply voltage minus V BE on of transistor 1 divided by R B 1 and that is 100 multiplied by.

So, this is 12, this is 0.6 so, that is 11.4 and then R B it is 570 kilo. So, that gives us this part it is 20 microampere multiplied by 100. So, that gives us 2 milliampere. Now on the other hand if you see the transistor 2 it is condition it is to find it is collector current it is equal to it is own beta multiplied by the same supply voltage minus V EB, V CC minus V EB of transistor 2 divided by R B 2 and so, this is beta is 200 and then we do have 11.4 again this part it is the 0.6.

And then in the denominator we do have R B 2 which is 1.14 mega ohm 10 to the power 6 and again this part though it is 10 micro ampere, but after multiplying with it is own beta. So, this is giving us 2 milliampere of current. So, the bias registers base bias registers it is such that they are compensating the beta difference and finally, both I C 1 and I C 2 they are equal.

Note that in this equation we have not considered the effect of early voltage. In fact, we should what we should do it is I C it is equal to beta times I B and then we should multiply with 1 plus V CE divided by the corresponding early voltage. So, since this part beta into I B for both the transistors they are matched then we should directly compare 1 plus V CE divided by V A of the 2 transistors sequel and that eventually gives the output DC voltage here.

So, to get the DC voltage at the output node say V OUT what we can do? we can compare beta 1 I B 1 multiplied by 1 plus V CE of transistor 1 divided by V A of transistor 1 equals to beta I B of transistor 2 multiplied by 1 plus V EC of transistor 2 divided by V A of transistor 2. Now this part and this part we have seen here they are equal. So, now, just by equating this factor what we can get here it is since the early voltage of the 2 transistors they are equal.

So, that gives us V CE 1 equals to V EC 2 and also we know that V CE 1 plus V EC 2 equals to V CC. So, this is V C of transistor 2, this is V CE of transistor 1 that is V CC which is 12 volt and from that we can say that both of them are equal and they are equal to 6 volt. That gives us this output voltage equals to 6 volt and hence we obtain the operating point of the 2 transistors namely so, let me summarize the operating point.

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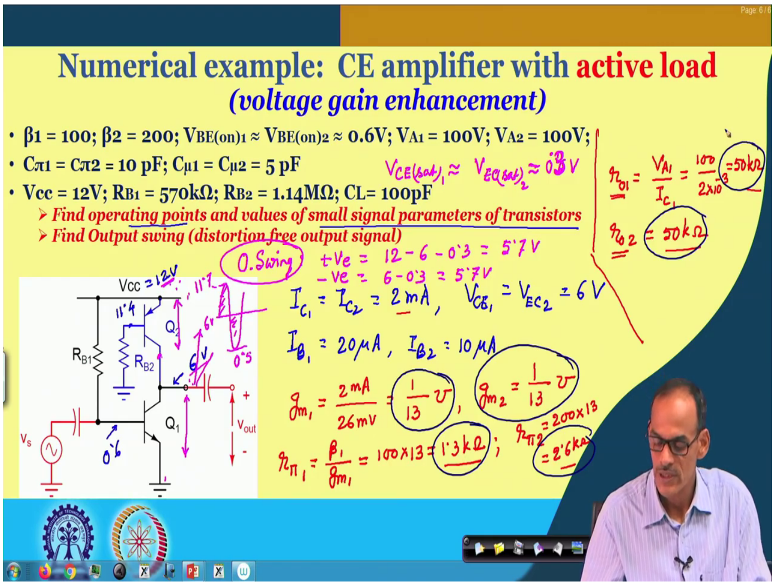

So, we do have I C 1 equals to I C 2 equals to 2 milliampere, V CE 1 equals to V EC 2 equals to 6 volt. And yeah so, the other things we already have obtained namely I B 1 equals to 20 microampere and in I B 2 equals to 10 microampere right. So, since this is 6 volt and this is point 6 volt, this is supply voltage is 12 volt, here the voltage it is 12 minus points 0.6. So, that is 11.4 volt. So, that is the operating point.

So, from that we can calculate the small signal parameters of the transistors namely in a gm say gm of transistor 1 it is I C divided by V T thermal equivalent voltage we can consider that is 26 millivolt. So, this is 2 milli ampere divided by 26 milli volt. So, that is 1 by 13 mole. So, likewise gm 2 it is also equal to 1 by 13 mole ah, then r pi 1 equals to beta of transistor 1 divided by gm of the transistor.

So, that is equal to 100 multiplied by 13 so that is equal to 1.3 kilo ohm. So, likewise it can also find that r pi 2 which is beta 200 and then gm 2 it is 1 by 13. So, that is equal to 2.6 KA. Then r naught, but you have some space here. So, let me utilize this one r naught of transistor 1 which is early voltage of transistor 1 divided by I C. So, this is 100 divided by 2 milli 10 power minus 3. So, that is equal to 50 kilo ohm. So, likewise you can also find that r o 2 equals to 50 kilo ohm alright.

So, that is how we obtained in the small signal parameter of both the transistors and then we can try to find what will be the corresponding gain and so on and so. But before that it is also important to see that if the DC voltage here it is 6 volt if the DC voltage here it is 6 volt, how much is the signal swing we can expect? From positive from this equation point towards the positive side the voltage at the collector it can go as close as the supply voltage in fact, supply voltage minus V CE sat saturation.

And we can assume that V CE sat of both the transistor around say 0.3 V EC of transistor 2 and saturation it is equal to 0.3 volt typically that is what it can be taken sorry 0.3 volt I mean 0.3 volt. So, the we do have a 6 volt DC here and then if we consider this is 12 volt. So, total here it is 6 volt minus 0.3. So, the positive side I should say that output showing in the positive side it is 12 volt minus 6 volt DC minus 0.3. So, that is equal to 5.7 volt.

So, likewise negative side we can say that here we do have 6 volt it can go as low as ground plus 0. 3. So, we can say 6 minus again 0.3. So, that is equal to 5.7 volt. So, output swing wise we can say it is plus minus 5.7 volt, which means that the voltage here it can it can go as high as with respect to 6 volt here. It can go as high as 11.7 volt, likewise lower side it can go as low as 0.3 volt so, that is the good swing.

Now next thing is that, how do we find the small signal gain and so and so, so in the next slide what we can do we are going to draw the small signal equivalent circuit, but to calculate the gain we need to remember these parameters particularly small signal parameters values. So, you have to keep that in mind and then we will be utilizing this parameter value in the calculation of small signal gain and so and so.

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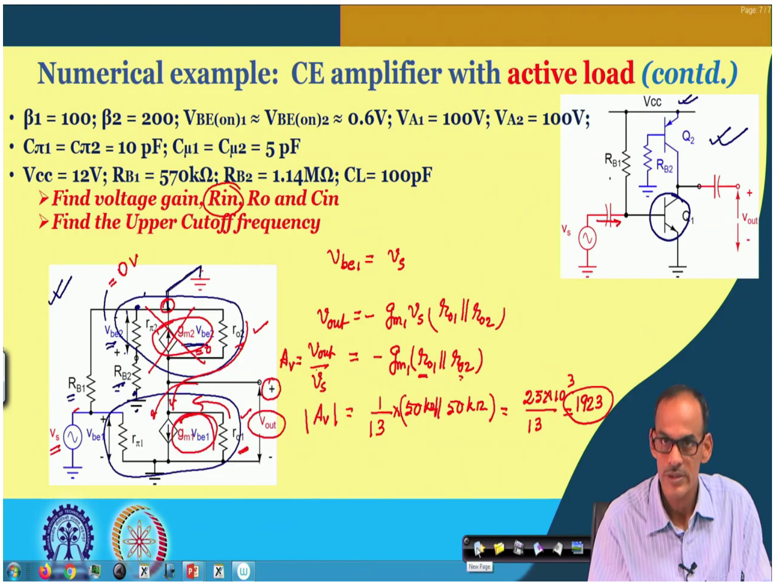

So, in the yeah so, here we do have the circuit it is for our reference it is shown here and the corresponding small signal equivalent circuit it is drawn at this at this place. So, for transistor 1 Q 1 we do have the small signal model drawn here. So, likewise for transistor 2 we do have the small signal model drawn here and then we do have R B 1 here, R B 2 here and this node it is AC ground. So, that is why it is connected to ground.

And note that based on this V be based on this V be we do have gm into V be flowing here. And incidentally this node the R B 2 it is connected to ground and the other side it is also connected to ground and hence we can say that this V be V be 2 equals to 0 volt. So, that gives this portion equals to 0. So, as a result we can ignore this part and then you can find what will be the corresponding V OUT in terms of this input signal say V S.

Now, since we are ignoring source resistance here so, we can say that V be 1 incidentally equals to v s assuming that this capacitor it is successfully bypassing the signal to the base of transistor 1. And then we do have the current flow here gm 1 into V be 1 and that is flowing through r o 2 as well as this r o 1. So, the corresponding v out equals to since the current is flowing in this direction and the polarity of this voltage we are defining like this is positive.

So, the v out it will be minus the current flow gm 1 into v be 1 which is v s then multiplied by the equivalent resistance of this r o 1 and r o 2 which are actually in parallel connection. So, after making the supply node to connected to AC ground these two resistances they are coming in parallel and if you recall that ok. So, this gives us the v out by v s that is the voltage gain A v and it is it is expression is gm 1 into r o 1 into r o 1 in parallel with r o 2.

So, we can say that the voltage gain equals 2 gm 1 it is 1 by 13 and then r o 1 and r o 2 both are 50 k in parallel. So, they are giving us 25 k. So, this is 25 k divided by 13 and that is equal to something like 1900 I made I have done some calculation for you 1923. So, that is this is the gain. Now we can try to calculate the input resistance based on the information available, but let me clear the space yeah.

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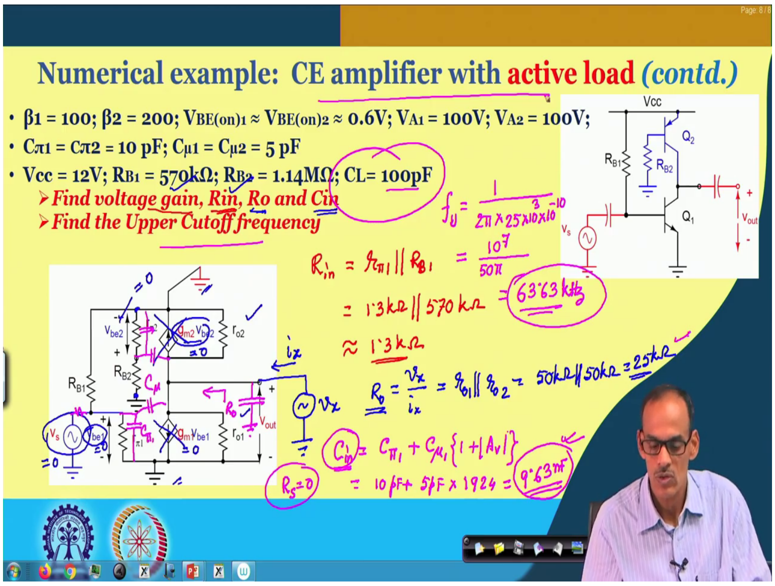

So, input resistance on the other hand it is R in equals to r pi 1 in parallel with R B 1 and you may recall that r pi 1 it is equal to 1.3 k that is in parallel with 570 k. So, you may approximate that this is 1.3 kilo ohm. So, we obtain the voltage gain, we obtain the input resistance. So, next thing is so, this two are done and next thing is that output resistance.

So, to find the output resistance what we have to do? We can stimulate this circuit by a signal called v x and then we can observe the corresponding current here. If the current is i x then you can say that the output resistance R o equals to v x divided by i x. So, that is the methodology we follow to find the port resistance and while we are doing this exercise we have to consider the other sources signal sources at 0.

So, we can say this is equal to 0. So, that makes V be also equals to 0. So, that makes this is also equals to 0 and this source anyway this is 0, we do have ground here, we do have ground here. So, the V be 2 same as in the previous case it is equal to 0. So, that gives this part also equals to 0. So, we do have. So, we do not have this part, we do not have this part, only we do have r o 2 connected to ground here and r o 1 it is also connected to ground here.

In fact, directly we can say that this r out it is equal to r o 1 coming in parallel with r o 2 and both of them are 50 k. So, 50 k two 50 k is in parallel that gives us 25 kilo ohm so that is the output resistance. So, next thing is that the input capacitance. So, while you are talking about the input capacitance we have to consider the C pi and so this is C pi and then this is C mu. So, we do have C mu here and then we do have C pi here and likewise here also we do have, but that is not really contributing anything towards the input capacitance and you may recall that C in it is C pi as is and then C mu of transistor 1 multiplied by 1 plus voltage gain magnitude of the circuit and this one we already have calculated it was 1923 or something we say.

So, C pi it is 10 pico and then C mu it is 5 pico multiplied by 1924. In fact, that gives us something like close to 1 nano Farad close to 1 nano Farad no it is 5 sorry close to 10 nano Farad. So, that is close to 9.63 nano Farad I think I have done the calculation yes. So, this is matching with that yeah. So, this is 9.63 nano Farad and from this information 5.93 nano Farad and then this ok. In case if we have some source resistance then we can calculate the cutoff frequency coming from the C in, but since in this exercise we are considering R S source resistance equals to 0.

So, it is contribution to the cutoff frequency we are not seen ah, instead the upper cutoff frequency it will be decided by the load capacitance here and it is value it is given here 100 pico Farad and the output resistance r o. So, the upper cutoff frequency equals to 1 by 2 pi into output resistance is 25 k 25 into 10 to the power 3 and then we do have 100 pico Farad which is equal to 10 to the power minus 10. In fact, if you calculate this is coming 10 to the power 7 divided by 50 pi and that is coming close to 60 yeah 63. So, that is 63.63 kilo Watt ok.

So, in summary what we can say that the cutoff frequency it is getting reduced gain got increased and output resistance also got increased of course, the input capacitance also got increased. So, to summarize the performance of this CE amplifier with active load probably we can see in the next slide and then we can compare performance of CE amplifier having passive load. So, in the next slide we can see that.

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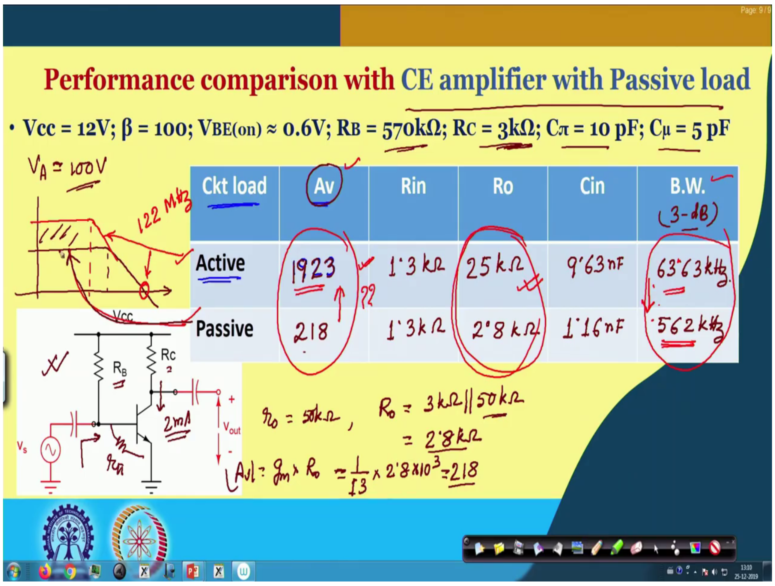

So, here we do have the table to write different parameters namely yeah. So, we do have voltage gain in case circuit load CE amplifier load if it is active load voltage gain what we said is 1923, let me use different colors otherwise it is not visible to you yeah 1923. Input resistance it remains same 1.3 kilo ohm, output resistance it was 25, 50 and 50 in parallel 25 kilo ohm. Then input capacitance it got increased 9.63 nano Farad and 3 d B bandwidth if I say the 3 d B bandwidth or upper cutoff frequency to be more precise ah. So, the upper cutoff frequency it was 63.63 kilo Hertz.

Now if I compare this performance matrices with the performance matrices of CE amplifier having passive load and here we do have the corresponding circuit and to keep the 2 circuits comparable what we have done is that. So, we have taken this R B and the corresponding beta it is such that the collector current here it is 2 milliampere.

So, the corresponding gm and r naught they are essentially same. In fact, early voltage we can consider also V A, for this case it is not so important because we do have the passive load which is dominating and resistance of that passive load it is given 3 kilo ohm. So, R o of this transistor it is 50 kilo ohm and the output resistance so that gives us output resistance of 3 kilo ohm in parallel with 50 kilo ohm. So, that is around 2.8 kilo ohm.

So, the voltage gain voltage gain it is gm 1 or this gm multiplied by this R o. So, that is equals to 1 by 13 multiplied by 2.8 k. So, that is equal to 218, I have done this calculation for you ah. So, yeah so, this is 218. On the other hand input resistance you may say that it is getting dominated by this r pi r pi which is same. So, this remains 1.3 k and output resistance we already have said that 3 k coming in parallel with 50 k for early voltage of 100 volt with collector current of 2 milliampere. So, this is output resistance is 2.8 k.

And then C in C in of course, it depends on the voltage gain. So, since the gain here it is low so, it is expected that the C in is also lower. And we have done this calculation for the same value of this C pi and C mu and that it comes 1.16 nanofarad and the corresponding bandwidth or 3 d B bandwidth here it was 562 kilo Hertz.

Now, if you compare these two and try to see the difference basic difference, the gain it is higher so, almost 10 times higher and the resistance here it is higher. And also the bandwidth if you see this is also close to 10 times higher. In fact, now the bandwidth of the passive load corresponding to the circuit corresponding to passive load it is higher. So, if you if you compare the frequency response for this active load and passive load as it was anticipated.

So, if I say that the frequency response particularly higher side if you see. So, gain it is very decent and then it is having 3 d B bandwidth and then for the active load on the other hand the gain it got increased, but then the bandwidth got decreased. And the increase here from here to here the increase here whatever the factor we do have that is primarily coming from this R o difference and same R o difference it is also creating the same effect here So, here it is getting increased.

So, this factor it is basically the factor by which this gain got increased and the bandwidth got decreased it is same and which is defined by the R o difference. So, if I multiply this gain and then bandwidth that remains same and hence the gain bandwidth product it remains same. In yeah, in my calculation what I have done is that I simply multiplied this gain and this bandwidth and it is coming close to 122 mega Hertz for both the cases.

So, red one is with active load and the dark one it is with passive load. So, that is the comparison of the two amplifiers ok. So, let me take a short break and then I will come back for common source amplifier.