Analog Electronic Circuits
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Lecture – 29
Common Emitter Amplifier (Contd.)
Numerical Examples (Part B)

Yes, welcome back to our discussion Numerical Examples of CE Amplifier. And, we are discussing about CE amplifier with fixed-bias.

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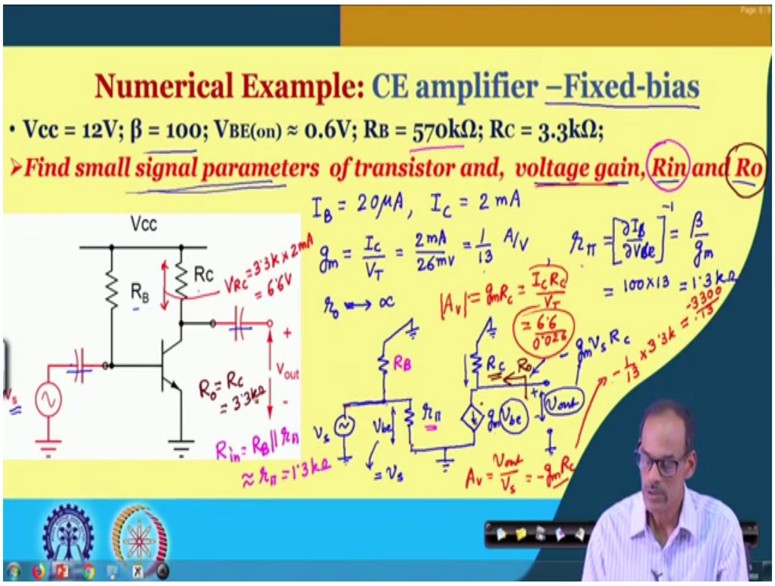

So, what we said is that based on the value of R B and R C. We obtain the base current I B equals to 20 micro ampere and then for the value of beta is equal to 100 the I C equals to 2 milliampere. And then, we are feeding the signal small, signal here and we like to see that what will be the gain of this circuit particularly if the signal frequency it is sufficiently high for considering this capacitors to be short.

So, to get the expression the value of the gain of this circuit as well as input resistance and output resistance, we need to find a small signal parameter of the transistor. Namely, the important parameters are g m, which is I C. We have discussed about this I C divided by thermal equivalent voltage V T. So, this is 2 mill ampere divided by 26 millivolt. So, we can say that this is 1 by 13 and this is 1 by 13 ampere per volt.

And then the other parameter it is the r pi base to emitter small signal resistance which is in fact, defined as reciprocal of change in I B with respect to V be, I should use small V be and this is in fact, this is beta divided by g m. So, in this case g m we already obtained and beta is 100. So, that gives us 100 multiplied by 13. So, that is equal to 1.3 kilo ohms. So, the small signal parameter of the transistors are this.

In fact, we also have one more parameter, but since we did not get any information about the early voltage we may consider this is approximately equal to infinite. So, rather it is going to be very high compared to the R C and the other resistance R B.

So, then what is the voltage gain? So, let us draw the small signal equivalent circuit of the amplifier. What we have it is R B connected to V CC which is AC ground and then at the base we do have the r pi, and then we do have the emitter terminal connected to ground, and then we do have the voltage dependent current source which is g m times, whatever the base emitter voltage we do have here small V be.

And then we do have the R C which is also connected to V CC and then the voltage here it is the V out. So, at the input on the other hand we are given the signal V s. And then incidentally since we are not considering the source resistance the voltage coming here it is V s and this is connected to ground, so from that we can say that V be equals to V s.

So, that gives us this part is also V s, and then since this current is flowing through this resistance then the voltage coming here at this point which is V out equals to minus g m into

V s into R C, so that is the V out. So, from that we can say that the circuit gain voltage gain A v defined as V out by V s equals to minus g m into R C.

And what is its numerical value? So, the value of this gain it is let me use this space here g m it is 1 by 13 and then R C it is 3.3 kilo. In fact, if you see here. So, whatever the value it is; so, I should say that the voltage gain here it is 3300 divided by 13 magnitude wise of course, with a minus sign.

In fact, if you see here the g m and R C we do have another expression of A v, particularly if I consider the magnitude this is g m into R C and g m is I C multiplied by R C divided by V T thermal equivalent voltage. And this R C and I C it is nothing, but the voltage drop across this resistance which is V RC, right, V RC that is equal to 3.3 k multiplied by 2 milliampere. So, that is equal to 6.6 volt.

So, this part it becomes 6.6 volt divided by 26 millivolt 0.026. In fact, that is become same as this one. So, anyway so, that is the value of this voltage gain. And the next one is input resistance. So, the input resistance of this circuit it is R B coming in parallel with r pi. So, we can say that R in equals to R B coming in parallel with r pi. R B here it is quite high compared to this r pi, so we can see that this is approximately r pi which is equal to 1.3 kilo ohms.

And next one is the output resistance. So, the output resistance looking into this circuit, since we do have ideal current source here and this node it is connected to ground, so the moment I make this is ground this is also ground in fact, this current also becoming 0. So, the output resistance R o it is nothing but this R C. So, next one is output resistance which is equal to R C so that is equal to 3.3 kilo ohms, right.

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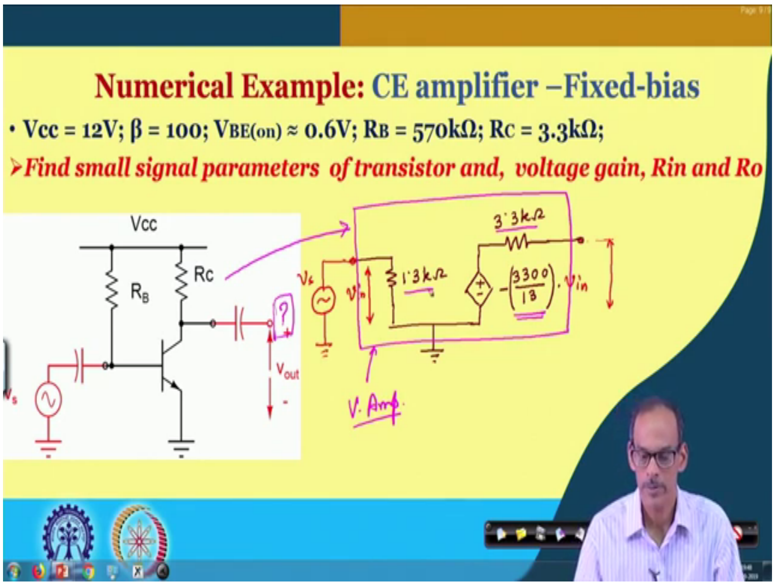

So, if I summarize what we are getting here it is, if we draw the equivalent circuit of the amplifier we do have the input resistance which is 1.3 kilo ohms and then we do have the voltage gain, if I say this is plus and this is minus and then we can say that this is minus how much was it 3300 divided by 1 by 13; sorry.

So, that is the A v multiplied by whatever the V in we do have here V in and at the output we do have the R o which is R C, so that is 3.3 kilo ohms. So, whenever we are feeding the signal at the input port V s and if we are not connecting any load here whatever the voltage you are getting here it is just this multiplied by this V s because the V s is directly coming equal to V in.

So, this is the, this is the I should say voltage amplifier model or it is referred as macro model of this whole amplifier. And this voltage amplifier model it can be used particularly if this circuit is connected to maybe another circuit and then we can find the corresponding model of the subsequent circuit.

So, if we cascade multiple amplifiers together then translating this amplifier into this voltage amplifier model is very important and this voltage amplifier as I said that it is having basic 3 parameters voltage gain, input resistance and output resistance. Now, let me do the similar thing for the CE amplifier with cell biased circuit. So, I do have ok.

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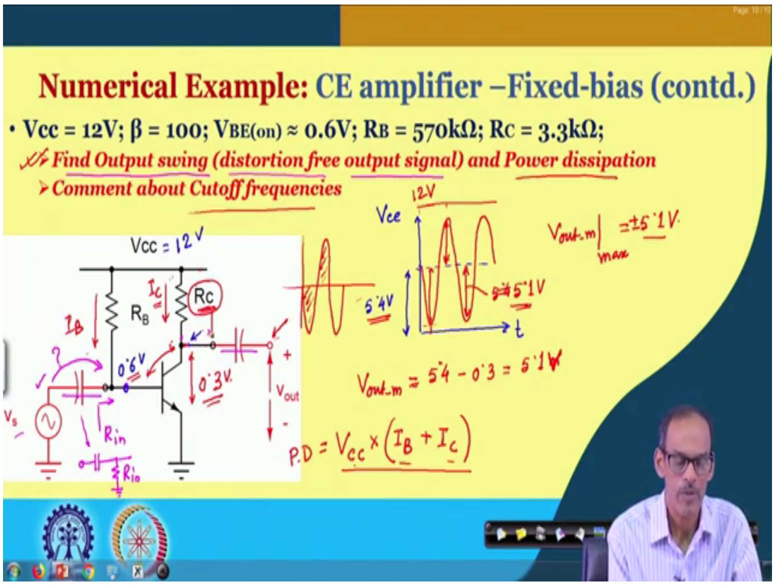

Before I go into cell bias circuit I like to say a few more points about the CE amplifier with fixed bias. So, let me cover that part. So, we are talking about the voltage gain and input resistance and output resistance. What are the other parameters are important for this amplifier?

Next to the amplifier gain I should say that output swing. Output swing means the output signal amplitude, either you may say peak to peak or amplitude which is quote and unquote distortion free. So, in this circuit depending on the operating point here and operating point here while the signal it is riding over the DC we can say that what may be the signal allowed here at the collector node before the transistor it is going out of active region.

Say the voltage here, the voltage here it is let me use different color here voltage. DC voltage here it is around 0.6 and on top of that we do have this signal. However, the signal here it is quite small compared to whatever the signal we are getting here because you already have seen that the gain of the circuit is 3.3, 1000 divided by 13, ok.

So, roughly close to 300 gain 270, around 270 to 300 gain which means that signal amplitude at the output node it is very high. And also we have said that the voltage at this node it is 12 volt minus DC wise, minus 6.6. So, that gives us 5.4. So, the voltage here it is having 5.4.

So, with respect to time the V CE voltage or incidentally that is output voltage it is having a DC which is 5.4 volt and on top of that we do have the sinusoidal signal. So, the sinusoidal signal if it is riding over this DC, it may be taking the transistor towards the edge of the active region. And what is the limiting case here?

If this is 0.6 and if I say that V CE sat it is around 0.3, then the voltage drop here it is lower limit it is 0.3 volt. So, we can say that before the transistor it is going out of active region the amount of signal here it is 5.4 minus this voltage. So, the negative side or we can say that V out, amplitude or magnitude it is equals to 5.4 minus this part which is 0.3.

So, we can say that 5.1 volt, 1 volt rather 1 volt amplitude it can be supported by this circuit. So, this is 5.4 minus 3, so 5.1 volt negative side swing. On the other hand, this voltage it can go theoretical it can go as high as 12 volt and since this DC voltage is 5.4, so positive side it can go even higher than 5.4, in fact, this is the 12 volt level. So, definitely this 5.4 volt it will be well supported.

So, I should say that V out magnitude max equals to minimum of whatever the swing positive side and negative side swing which is 5.1 volt or sometimes it is referred as plus minus 5.1 volt output swing or otherwise you can explicitly say negative side it will be minus 5.1 and then positive side it can go even higher.

Note that DC voltage it is existing here, but whenever we will be seeing the signal here we will be seeing this DC getting blocked, as a result output voltage it will be having only the signal part. So, of course, depending on the limit of the signal handling capacity of this transistor the swing at the output it will be getting restricted. So, that is the output swing of the circuit.

Other point is the power dissipation. While the coefficient current is flowing through the base terminal I B and then the collector current is I C, naturally there will be a power dissipation and the whenever we talk about the power dissipation is basically the V CC multiplied by the these two DC power, I B plus I C.

In fact, it can be shown that since the signal of the, even though the signal it is it may vary this total current, but if I take average of the current it is same as the equation current, as a result the average power it will be simply multiplication of this V CC and I B plus I C.

So, if the circuit is having higher current naturally the power dissipation, power dissipation it will also be higher. So, there may be some application where you like to go for low power application kind of things, then you may have to reduce this collector current and then base current, but of course, to while you will be reducing this current the corresponding resistance you need to increase to achieve the same gain namely as I said the voltage gain is drop across this R C divided by V T.

So, if you are decreasing this current and if you proportionately increase this R C then you can maintain the gain to be remaining constant. However, of course, if R C if you are increasing the corresponding output resistance of the circuit it will be getting increased. So, there is of course, a trade off.

So, this is once the other set of performance parameter. And then also the other thing is that the cutoff frequency. That is the other thing we must say that, so far we are assuming that the signal frequency and the value of the capacitors and then associated resistance and all recess that for the signal frequency the capacitors they are behaving like a short circuit.

But you imagine that if the signal frequency here it is getting smaller and smaller the signal may be having difficulty to come to this node. In other words this C and input resistance of this circuit they are forming one C R circuit. So, the C R circuit, so R is the input resistance and this C, it is this C. So, that is C R circuit that is forming whatever you see the hyper kind of circuit.

As a result depending on the value of this capacitance if you go to lower and lower frequency the available gain starting from this point to this point it will be getting affected. So, in the mid frequency range you may get good gain, but if you consider low frequency side the gain it will be getting affected.

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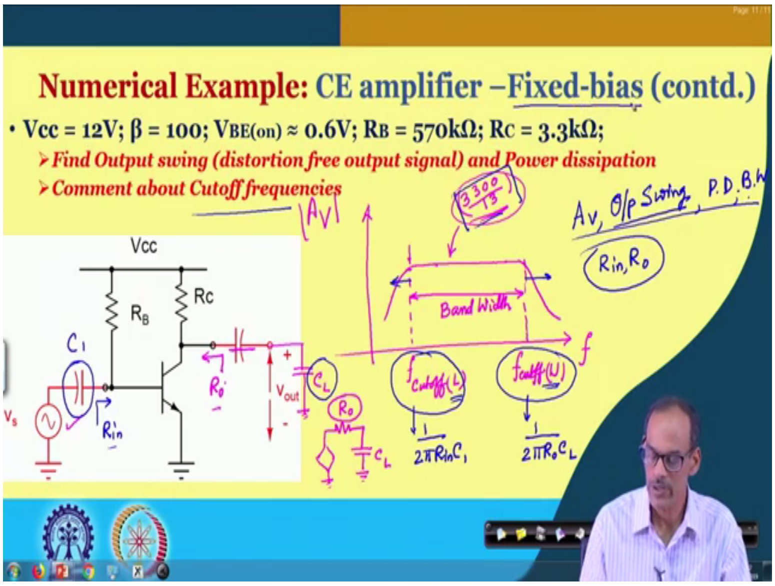

So, let me illustrate differently. So, if you plot the gain, magnitude of the gain, with respect to frequency maybe in the mid frequency range it will be having good gain whatever the gain we talked about say 3300 divided by 13 whatever the value it is.

But then if you go to lower and lower cutoff frequency then there will be degradation of the gain and we may come to a point where the gain it is 1 by root 2 times less than whatever the gain we are getting and then we call this is the cutoff. So, we may say that this is cut off in the lower side or you may say that lower cutoff frequency.

So, likewise if we go to higher and higher frequency the output resistance which is eventually R C, this output resistance in combination with maybe the load capacitance at this node if I call C L, they are forming one R C circuit. Though this circuit is working as a short in higher frequency, but then output resistance and then C L they are forming one R C circuit.

So, R C is, what is it? It is low pass. So, we do have the low per circuit getting formed by this R o and C L. And this R C time constant it will be defining another corner frequency. So, if you go to higher and higher frequency then again the gain it will be dropping by 1 by root 2 times of this middle frequency and then it will be giving another cutoff frequency.

Then this frequency it is referred as cutoff in higher side or upper cutoff frequency. So, the entire frequency range over which the gain is remaining almost constant, this is called the bandwidth of the circuit. So, if the signal frequency it is lying within this one then you can get nice gain like this one. But if the signal frequency it is going beyond this side or beyond this side then since the gain is getting affected, so we may say that the amplifier performance it is getting changed.

So, while we are designing the amplifier not only you have to consider the gain of the circuit, but it is also important to say that, what is the corresponding cutoff frequency, the lower cutoff frequency and the upper cutoff frequency. And the particularly the lower cutoff frequency it is predominantly defined by this one and the input resistance.

So, if I call this is C 1 and this is R in then this corner frequency it is 1 by 2 pi R in into C 1. So, likewise this upper cutoff frequency it is 1 by 2 pi R o multiplied by the load capacitance, whatever the load capacitance we do have here or it may be coming from the next circuit as input capacitance which is working as load for this circuit.

So, these are the other important parameters we must say. To summarize what we said is that the voltage gain is important and then the swing, output swing. So, output swing. So, while we will be defining this output showing it is very important that the question point we should be setting properly so that both positive side as well as negative side it is having equally getting priority, as a result we are getting maximum undistorted amplitude signal.

And then of course, the power dissipation, and then the cutoff frequencies or rather bandwidth. So, the bandwidth these are the important performance parameter. Indirectly, I should say that the bandwidth and R in and R out are related. So, these are the while we will be designing a circuit we must be considering these parameters, right. So, let me as I say that, so far we are talking about fixed bias amplifier, similarly let you consider cell biased.

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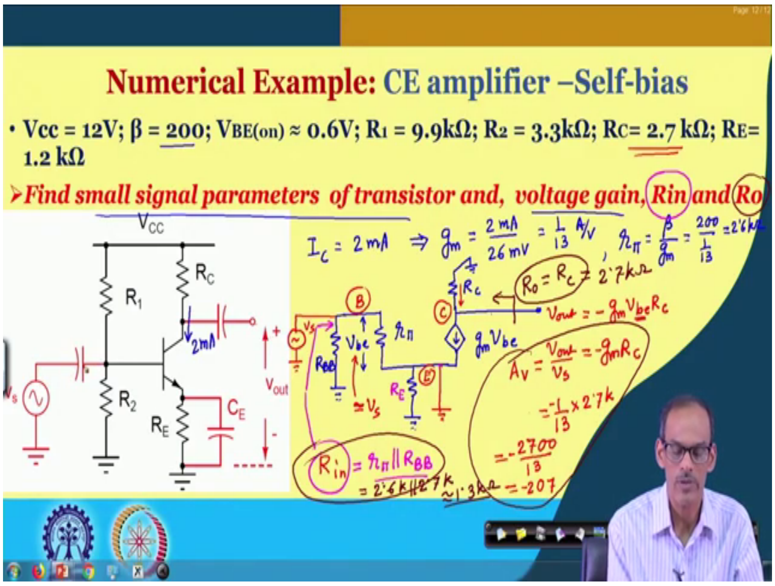

So, here is the numerical example this circuit we have discussed for different reason, namely to check the bias point stability for different values of beta and we have said that the collector current it is I C it is approximately 2 milliampere for this circuit.

So, once we know the collector current then we can find the small signal parameter of the transistor. So, since I C equals to 2 milliampere, so that gives us, that gives us the g m transconductance of the circuit equals to 2 milliampere divided by 26 millivolt which is 1 by 13 ampere per volt. So, it is same as the previous circuit.

And then r pi which is beta divided by g m. So, in this case we do have 200 beta divided by 1 by 13 or so, this is actually 2.6 k, right. So, these are the small signal parameters of the transistor. Now, to find the gain we can and then input and output resistance of the amplifier.

Let me draw the small signal equivalent circuit and so, what we have at the input it is r pi and then we do have the R E, but then R E it is getting shunted by C E. So, we can say that emitter node it is AC ground. And then at the collector to emitter side we do have the voltage dependent current source which is g m into V be where V be is the voltage drop across this R pi.

And then at the collector side we do have the R C connected to DC voltage which is AC ground and this is the output node. And then of course, we do have R 1 parallel R 2 and they are one of them it is connected to V CC another one is connected to ground, but both of them are we can say considered as a C ground. And this is R BB or we can say R 1 parallel R 2 and then we do have the signal source connected through the capacitor which is working as a short.

So, we do have the V s here, we do have the base terminal here, we do have the emitter node here and then the collector node. Now, incidentally say that the emitter node it is getting shunted by C E. So, this V be this is incidentally equal to V s. So, here also the output voltage coming here, since this current is flowing through this R C. So, similar similar to the previous example here also it is g m into V be into R C.

And V b since it is same as R s, so we can say that V out by V s equals to g m into R C and this is what it is the definition of the voltage gain. So, here also we are getting the voltage gain equals to the g m which is 1 by 13. The R C unlike the previous case, so we do have slight different value it is 2.7. So, we do have 2.7 k, so it becomes 2700 divided by 13. So, this is approximately equals to 200 may be how much 208 or something like that 7 roughly, with a minus sign.

So, that is the voltage gain. Likewise, the input resistance it is if I look into this circuit to find the input resistance, what you have to do we need to look into this circuit and whatever the resistance you are finding if we consider this node it is connected to ground. So, R E it is getting shunted. So, this is R E, so this is getting shunted. So, the input resistance it is r pi coming in parallel with R BB, right.

On the other hand, the output resistance if I look into this output port, the output resistance it is equals to R C in absence of R naught. In case if we have say R naught then that r naught it will be coming in parallel with R C. So, we do have this 3 important parameters the voltage gain, and then input resistance and output resistance and this is directly coming 2.7 k and this is r pi it is 2.6 k in parallel with R BB.

So, that was roughly two point around 2.7 k again, so in the order of 1.3 k. So, that is the different parameters of this circuit. Similar to the CE amplifier with cell biased circuit we need to check the output swing and also the cutoff frequency and the values of these cutoff frequency of course, as I say it depends on output resistance and load capacitance, the same way we can calculate.

The output swing on the other hand just to say that, ok. So, let me go to the other slide where I do have the circuit diagram.

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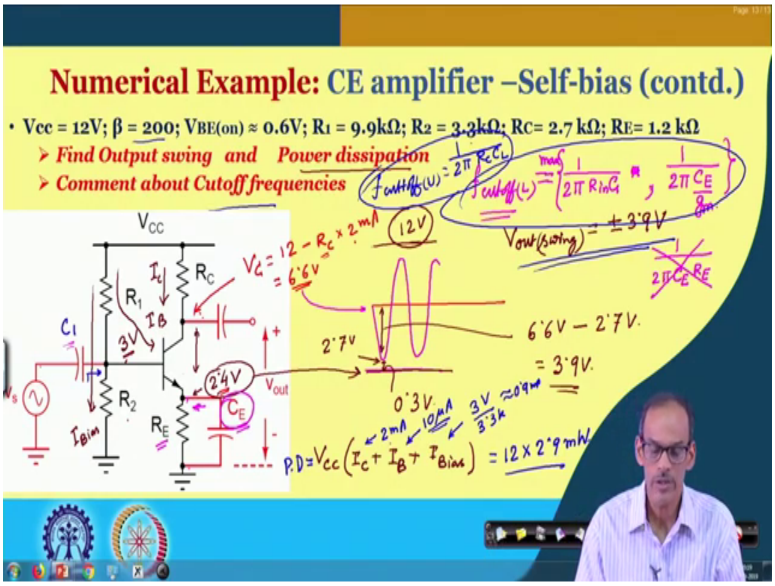

Here what we have analyzed that the voltage at this point it is 3 volt and the voltage here it is 2.4 volt. Note that if we have the CE even though the voltage here it is having AC signal on top of this 3 volt, since the capacitor it is shunting here the voltage 2.4 it will be quite steady. So, the voltage swing of course, we do have at the output node we do have the output voltage which is the collector voltage V C equals to 12 volt minus R C into the 2 milliampere of current.

So, the voltage here it is this part it is 2.7 multiplied by, so this is 2.7 multiplied by 2, so that is 5.4. So, that gives us 12 minus 5.4, so that is 6.6 volt. So, we do have 6.6 volt here and then we do have 2.4 volt here and 3 3 volt here, it is steady. Roughly I should say the signal here it is very weak compared to this one.

So, if I consider this node output node it is having a DC voltage on top of that it is having some AC signal riding like this and the voltage here it is 6.6. The voltage at the emitter on the other hand it is, let me use different color. So, the voltage at the emitter is this one. To keep the transistor it is in active region of operation we require V C sat. So, we require V C sat of say 0.3 volt.

So, the possible swing here possible swing here it is we do have 2.4 here and then plus 3, so the voltage here it is 2.7 volt. So, the possible swing here it is 6.6 volt minus this 2.7. So, this is becoming 3.9 volt. Positive side of course, it can go close to 12 volt. So, positive side we do not have an issue in fact, it can support more than and this 3.9 volt. So, we can see that V out swing without having any distortion it can go plus minus 3.9 volt, ok. So, that is about the swing.

Power dissipation of course, it is having the collector current I C and then also it is having the base current I B. In addition to that it is having a current flowing through this circuit, whatever you say that I bias. So, the power dissipation it will be V CC multiplied by I C plus I B plus this bias current, we can directly say the 3 volt divided by R 2, so the current here it is I bias and each of these terms.

So, this is 2 milliampere, this is 10 micro ampere. In fact, directly you can divide this collector current divided by this beta to get this 10 micro ampere and this current is 3 volt divided by 3.3 k. So, how much? It is close to point 9 milliampere.

So, roughly point 9 milliampere, so it becomes 12. You may ignore this part. So, we do have 12 multiplied by 2.9 milli Watt. And then about the cutoff frequency, as I said that the lower cutoff frequency it will be decided by this C one and then input resistance. So, the lower cutoff frequency, if cutoff L; it is one possibility is that 1 by 2 pi into R in into CE C 1, depending on the value of this C 1. So, this is one possibility.

And also another thing is that depends on how successfully this CE it is bypassing this node and then we will be having another candidate to define this lower cutoff frequency and its value it is, so either maybe this one or 1 by 2 pi into CE divided by g m. Why g m?.

Because the resistance here it is not only this R E, but also the input the emitter resistance of this transistor. So, either you can think that way or probably you can directly write that 1 by 2 pi CE into R E multiplied by the gain of the circuit. So, anyway I will not be let me discuss this one later. But at least we can say that CE also it is having one important role to play to define this lower cutoff frequency and we need to consider and the higher one, max of this two, max of this two.

On the other hand, the upper cutoff frequency if cut off upper that remains same as the previous one 1 by 2 pi output resistance which is R C into C l. So, that is the cutoff frequency and then output swing and then the power dissipation.

So, mostly I have covered important things is that we how do we analyze the circuit. In fact, I do have some more material to cover, but let me see, I will be. In fact, this you can consider as one exercise. In case this CE part, sorry. In case if the CE part if you remove what will happen to this circuit you can find the small signal parameter and then correspondingly the voltage gain as an exercise. You can find what will be the corresponding voltage gain.

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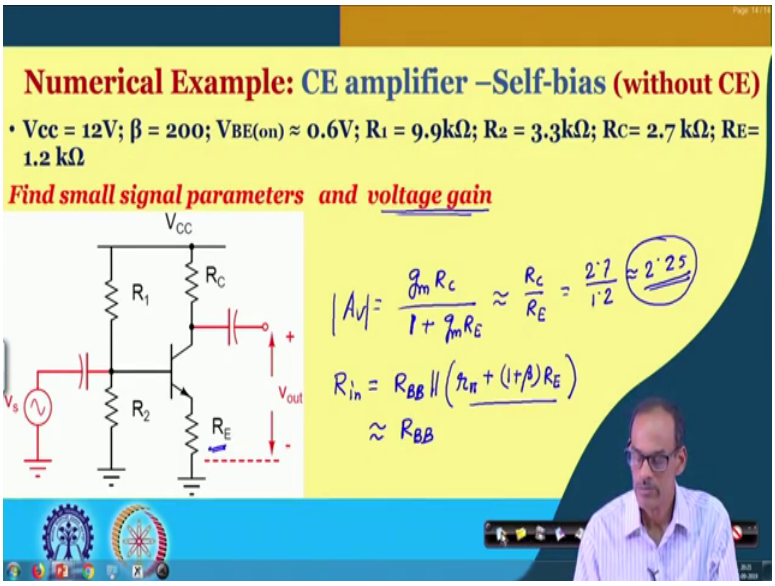

And its expression it is g m into R C divided by 1 plus g m into R E in case C is not there. And this can be well approximated by R C divided by R E. And so, this R C it is how much? Do you have 2.7 divided by 1.2. So, this is of course, it is in the order of two point something, 2.25 or something like that, which means that the important thing is that the gain is very bad.

So, that is what I was telling that the moment we put this R E without CE, the gain of the circuit it will be very poor. And of course, the other thing is input resistance it will be R BB in parallel with r pi in series with one plus beta times R E. So, this is the other change you can see that since it is coming in this beta into R E it is coming in series with r pi, so you may approximate that this is practically this is R BB.

I think the analysis part I have covered, but as I said that he was having different plan we will be covering that detail namely the design guidelines in the next class but let me summarize what are the things we have covered so far.

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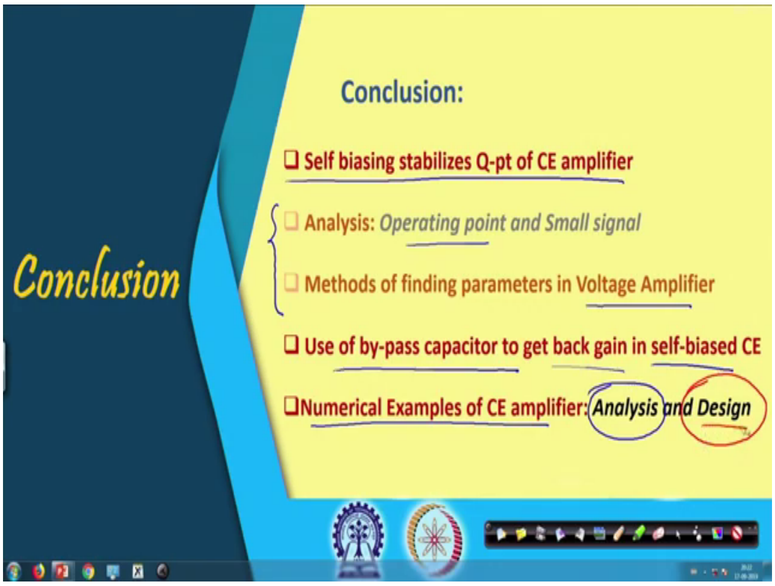

The bias point stability we have covered, both theoretically we have covered in the previous class and today we have numerically cover. This and the theoretical part, analysis and method of finding the input resistance and output resistance we have discussed in the previous class, and today what you have done is that through the numerical problems we have obtained the value of those parameters, and we obtained the operating point, and the voltage gain, input resistance, output resistance and also we learn how we obtain the gain back in the CE amplifier.

So, by using the bypass capacitor how we get the gain back. And then, in the numerical examples primarily we have covered the analysis and this part, the design guidelines part it is remaining. So, I will take this design guidelines part probably in the next class, right. I think that is all I do have.

Thank you.