Analog Electronic Circuits
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Lecture – 28
Common Emitter Amplifier (Contd.) Numerical Examples (Part A)

Dear students, welcome back to NPTEL online course on Analog Electronic Circuit. Myself Pradip Mandal from E and EC Department of IIT, Kharagpur. So, this is a continuation of our previous topic Common Emitter Amplifier. And, in the previous class, what we have discussed about the relevant theories and today, we are going to discuss more detail of some numerical problems.

So, I guess during this numerical problem solution some of your doubts it might get clearer. So, as I said that primarily we will be focusing on common emitter amplifier. And, it is having two basic biasing schemes namely the fixed bias and cell bias, and we have discussed about the disadvantage of each of them and then advantages and all. So, through the numerical problems, so, we shall address the limitation as well as the advantages of the two circuits as well.

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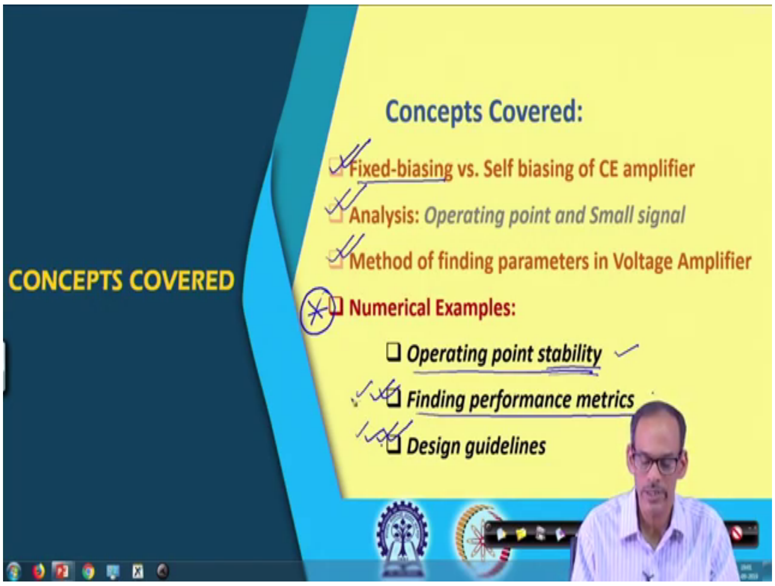

So, the overall plan we do have here it is as I said that the previous two rather theoretical things we already have discussed namely the biasing schemes and then analysis, what are the theoretical analysis we do follow, and then method of finding the parameters in the voltage amplifier where we like to map the circuit and on to and today we are going to discuss more about this numerical examples of CE amplifier.

So, first one it is we will be talking about the bias point stability where we shall demonstrate that fixed bias CE amplifier it is having a major issue in case if the beta of the transistor it is getting changed. And, it may requires it may requires the redesign of the circuit in case if the beta of the transistor is getting changed.

On the other hand, whenever it is sale biased CE amplifier the operating point is pretty stable and now we will see that if we vary the beta the collector current hardly changes. And, then after that we shall find the performance parameters of CE amplifier having both the schemes biasing schemes namely fixed bias as well as cell biased and then we shall discuss about what are the design guidelines we will be having.

Note that while we will be talking about the performance evaluation of a given circuit which means that we are assuming somebody has given a design and our main task is to find the gain and the input resistance and output resistance and so and so. Whereas, in the third one whenever we will be talking about the third one there will be discussing about suppose, we do have some requirement of gain and say supply voltage is given to us and then how do we design the circuit, how do we find the values of different components.

So, these two items are of course, complementing each other and of course, we need to understand that how to do the analysis first. And, then of course, once we are reaching to next level of maturity then for a given requirement we should be in a position to decide how to pick the value of the different components right. So, on the as I said the first point is that how do we demonstrate the bias point stability or instability for the two biasing schemes.

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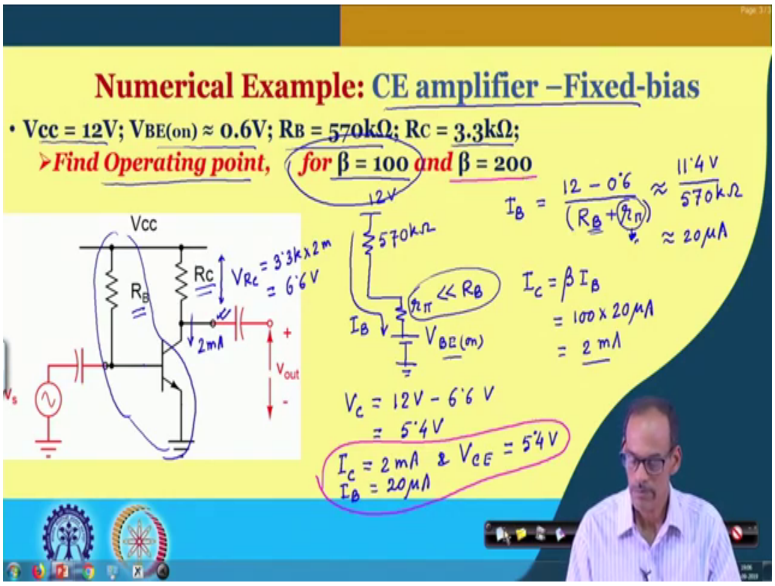

So, here what we have it is CE amplifier having fixed bias. So, we do have fixed bias, the R B is given here and here we are starting with the design which is of course, it is a proper design at least it is a proper design for beta is equal to 100. Supply voltage it is 12 volt and base to emitter on voltage approximately 0.6, this is true for silicon BJT and then this R B it is given to us say 470 kilo ohms, and then on the collector resistance R C it is 3.3 kilo ohms.

Now, here let us try to find the operating point for beta is equal to 100. So, how do we proceed? First of all we can consider the input port and we can replace the base to emitter junction by it is corresponding equivalent circuit namely the r pi and in series with V BE on. So, we do have the V BE on here which we are given that this is around 0.6, we do have the supply voltage 12 volt and then we do have 570 kilo ohms and this is r pi. And, later we will show that this value of this r pi it is very small compared to this R B.

So, we may ignore this part for simplicity and then what we are getting is that the current flowing through this circuit is the DC base current I B. So, the I B equals to 12 minus V BE on which is 0.6 divided by R B. So, we are ignoring this r pi of course, but strictly speaking we do have R B plus r pi. So, we can approximate that this is 11.4 volt divided by 570 kilo ohms.

So, we are getting this is by ignoring this part. So, we are considering this is very small compared to the other term. So, this approximation involves that this we are ignoring. So, the base current we are getting it is 20 micro ampere. So, the corresponding collector current which is beta times I B. So, this is equal to 100 multiplied by 20 micro ampere. So, that gives us 2 milli ampere.

Now, once you have the collector current it is 2 milli ampere DC current the drop across this R C let you call this is V voltage drop across R C. So, that is equal to 3.3 k multiplied by 2 milli. So, that gives us 6.6 volt. So, the voltage coming at this node it is V C equals to 12 volt V CC minus 6.6. So, that gives us 5.4 volt.

So, the operating point of the transistor namely I C equals to as I said 2 milli ampere and then V C and V C or V CE since emitter is connected to ground so, this is equal to 5.4 volt and base current of course, we can say that I B equals to 20 micro ampere. So, that is what we get for beta is equal to 10. So, please remember that this operating point and we will see that what will happen if we change this beta to 200.

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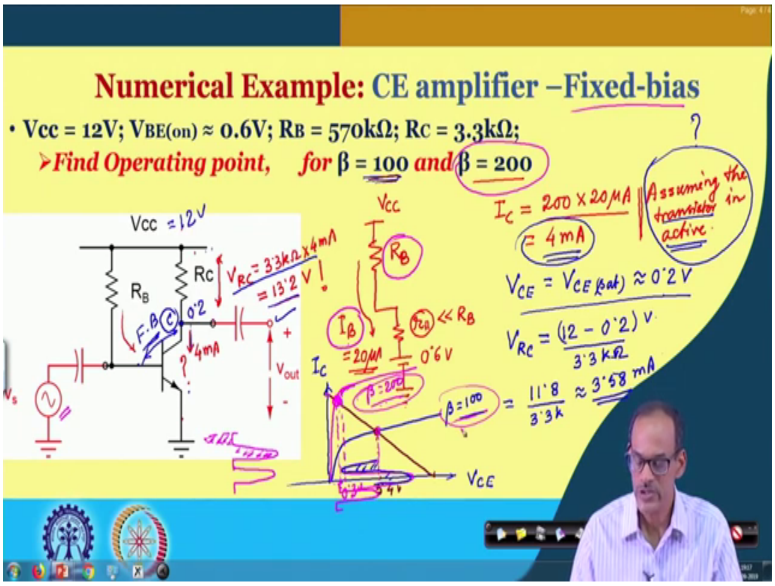

So, let me recalculate whole thing for beta is equal to 200. So, what we have here it is let me use a different color here, maybe I can use red color. So, again we can consider the input port circuit containing R B connected to V CC and then we do have the V BE which is around 0.6 volt and again in this case we are finding that I B; I B it is same as the previous case namely 20 micro ampere ignoring of course, this r pi with respect to R B.

But, then since the beta is 200 the corresponding collector current this is very important that collector current it becomes 200 multiplied by 20 microampere assuming the transistor it is in active region of operation. This is very important. We assume this assuming the transistor in active region. Previous case, we have seen that V C voltage it was 5.4. So, it was supporting this assumption, but in this case incidentally it is not. So, we will see that.

In case it has to support this 4 milli ampere of current, the drop across this resistance in case this is 4 milli ampere, then the drop across this V R C is 3.3 k multiplied by 4 milli ampere. So, that requires in fact, 12 13.2 volt. So, this is of course, it is surprising because we do have 12 volt supply here, we do you have a ground here. If the drop here it is 13.2 volt, then what is the drop across this resistance. So, that becomes impractical.

So, naturally this is a question mark. So, this is also question mark. So, practically what happens is that once this current it demand is more the voltage drop across this R C if it is getting higher rather close to the supply voltage of 12 volt making this collector voltage and it is sufficiently low enough, and then base to collector junction it gets forward biased.

As a result if the base to collector junction it is getting forward bias the V CE voltage it will be very close to ground, of course it will not be negative and you may say that V CE it is going to it is limit; normally referred as V CE sat and it may be in the order of few hundreds of milli volts. So, let you consider this is say 0.2 volt.

And, if the device it is forced into to this saturation region so, then the V CE equals to 0.2 volt and then of course, if this is 0.2 volt then drop across this R C instead of 13.2 actually V RC is equal to 12 volt minus 0.2 volt divided by 3.3 kilo ohms. So, that means, this is how much 11.8 divided by 3.3 k. So, that gives us maybe 3.5 I made some calculation for you. So, it was 13 3.57 something approximately 8 milli ampere.

So, instead of 4 milli ampere actually the current is practically the current is this one and most important thing is that the transistors this transistor enters into deep into the saturation region and the consequence is that the gain from base to collector it will be much different much smaller. So, later probably we will discuss about that, but just to say that to keep the gain it is good we need to keep the transistor it is in active region which is failing.

In fact, you may recall the methodology of finding the operating point. So, if we plot the I C versus V CE characteristic curve for the transistor. So, what is happening is for beta is equal to 100 the device characteristic it was like this and then the load line load line it was this one and we got nice operating point and the V C it was 5.4 volt.

So, this is for beta is equal to 100. So, we may say that this is beta equal to 100 and this is now if we change this beta if the device is getting replaced by another one having different beta then the corresponding device characteristic it is shooting out. So, this is for beta is equal to 200 and making this device the transistor it is deep into the saturation region.

So, this boundary of the active region actually it is 0.3 sometimes it is also considered it is 0.2. Basically, the voltage across this collector to emitter port is very small. So, we can say that the operating point got changed from this point to this point. So, that makes this fixed bias CE amplifier it is its operating point it is very sensitive to this beta.

So, you may say that yes, beta also change from 100 to 200 is it somewhat abnormal? No, it can be it may have even wider range the beta can go even higher or it can go even lower than 100. So, it is in the normal range of this beta. But, then if the operating point it is going here from here earlier if the operating point it was here for a given meaningful input here, the output voltage probably we are obtaining having a nice signal swing.

But, sorry let me use a different color consistent color. So, for beta is equal to 100 we are getting nice signal swing at the output. So, we are getting nice signal here. On the other hand, if we have say beta is equal to 200 since the operating point got shifted here. So, we are expecting that output it will be almost it is getting saturated here and only one side.

So, let me redraw in this case. The output voltage it goes heavy distortion at this point. So, this part it is this part it is properly sinusoidal, but ideally it is supposed to be this part also sinusoidal, but this entire portion is getting removed because the operating point it is towards the in fact, outside of the active region. So, as a result we cannot use this circuit. So, only one possible thing is that if the beta is changing to 200 for some reason probably the only option is remaining is that we need to adjust this I B to 100 microampere by changing this R B.

Now, this may not be practical particularly if we consider thermal runaway problem where the beta may be continuously changing with temperature. So, the next thing next as I said the solution is that cell bias.

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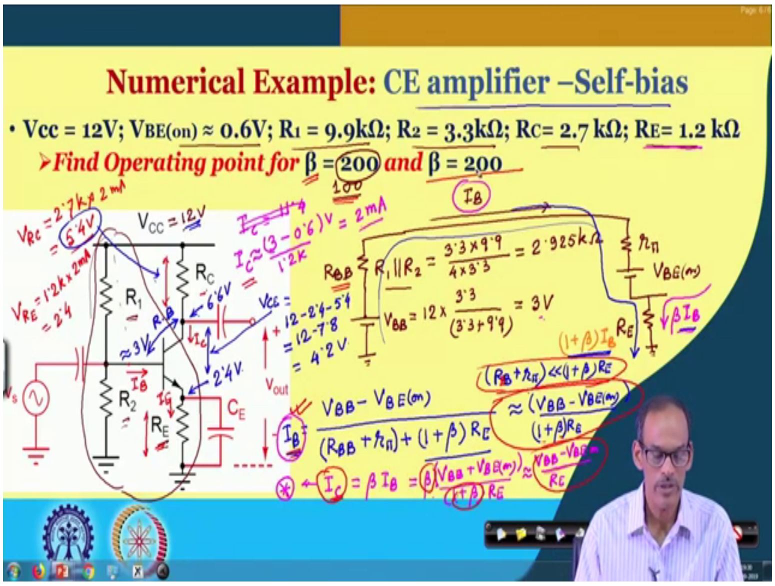

So, let us see that cell bias circuit and the same situation if we consider namely we consider two values of beta and then we will see the changes of operating point of the cell bias circuit ok. For consistency let me consider this is mistake. So, we should consider this is 100, beta is equal to 100. So, let you consider beta is equal to 100 and for that let me calculate what is the operating point.

Now, here also let me consider the input port we do have R 1 and R 2 and their values are given here R 1 and R 2 supply voltage here it is 12 volt and V B on it is approximately 0.6 and then we do have the R C and R E also.

So, once you consider say the input port what kind of circuit we do have it is probably we can translate this part this part by it is equivalent circuit namely V BB. So, we can say that V BB which is the Thevenin equivalent voltage coming here from this 12 volt and the potential divider R 1 and R 2. So, incidentally this is 12 multiplied by 3.3 divided by 3.3 plus 9.9 and that becomes 3 volt.

And, then we do have the Thevenin equivalent resistance which is R 1 in parallel with R 2 and what is the value here? It is 3.3 multiplied by 9.9 divided by 4 into 3.3. Why 4? I just consider summation on this one, but whatever it is, it is coming around 2 point I think I made some calculation for you 2.925 kilo ohm. So, that is the we call this is R BB and with that we do have the diode.

So, we can draw it is equivalent circuit having R pi and then V BE on and then we do have the emitter register R E. And, note that while the I B current it is flowing through this circuit we are expecting the current flow through this R E it is not only this I B let me is a different color. So, not only this I B it is flowing through this circuit, but also we do have beta times this I B coming from the collector side. So, this is beta times I B is also flowing.

So, we do have I B here plus beta times I B. As a result the current flowing through this circuit it is 1 plus beta times I B. So, that is the current is flowing. Now, in this circuit if you see if we analyze to find the expression on the collector current it is what we have it is V BB minus V BE on divided by R BB plus r pi plus 1 plus beta times R E. So, that is the expression of I B.

So, if you analyze this loop and then if we consider this current is 1 plus beta times whatever this current so, even though this beta times I B current is coming from the collector side we can simplify this analysis to get the expression of I B. Now, this can be well approximated by considering that this is dominating over these two elements.

So, if I consider this approximation if I consider R RB plus r pi is much smaller than one plus beta times R E. Then we with this approximation we can say that this is V BB minus V BE on divided by 1 plus beta times R E. In fact, further to that probably we can drop this one with respect to beta, but whatever it is we are getting this expression of this I B and from that we can say that the collector current which is beta times I B which is V BE plus V BE on divided by 1 plus beta times R E multiplied by beta.

So, if I ignore this one and then I can cancel these two beta, so, this we can approximate by considering only this V BB minus V BE on divided by R E. So, that gives us this collector current equals to. So, let me use the space. So, the collector current it is 12 volt minus 0.6. So, that is 11.4 sorry V BB, V BB we do have 3 volt.

So, we do have collector current I C equals to 3 volt minus 0.6 divided by R E which is in this case it is given as 1.2 k. So, of course, this is approximation and it is 2 milli ampere. In fact, the design wise we said the value of this R E it is such that this 2 milli ampere current is consistent with the previous circuit.

Now, here note that since in this expression let me use a different color here in this expression of this I C since this part and this part it is getting cancelled. And, then expression here after this cancellation it is becoming almost independent of beta, but of course, there are two approximation one is 1 plus beta we are approximating as beta and also we do have this approximation. So, V BB..

Now, so, if these two approximations are consistent then we can say that this collector current it is quote and unquote independent of beta and in fact, the same analysis it can be done for this beta also and with this two approximation again we can say that the collector current it is approximately equal to 2 milli ampere.

So, what is the conclusion is that even if the beta is changing from 100 to 200 and as long as this is valid, then we can say that collector current is not changing. But, note that the base current base current of course, it is function of beta. So, what is happening internally that because we are placing this R E and the voltage here it is approximately getting 3 volt by ignoring the drop across this R BB the current flow here it is maintained to be close to 2 milli ampere or another I C it is very close to 2 milli ampere and the I B on the other hand it is getting self adjusting.

So, this equation if you see here this equation on the other hand equation of this I B if beta is changing I B it is proportionately getting decrease, maintaining the collector current independent of beta. So, that is the catch. So, here we are saying that the collector current is 2 milli ampere.

So, the drop across this resistance it is R C it is 2.7. So, the drop across this is V RC equals to 2.7 k multiplied by 2 milli ampere. So, that gives us 5.4 volt. And, the drop across this R E on the other hand V RE approximately equal to 1.2 k multiplied by 2 milli ampere approximately.

So, we are considering this I E and I C they are approximately equal. So, this is becoming 2.4 volt. So, what we have here it is to find the operating point the voltage DC voltage here it is 2.4 volt and the drop here it is; drop here it is 5.4 and we do have 12 volt. So, the V CE voltage that gives us this V C voltage equals to 12 volt minus 2.4 minus 5.4. So, that is equal to 7.8 here and then we do have 12 minus 7.8. So, that gives us 4.2 volt.

So, V C is 4.2 volt and the voltage of course, here it is. So, the voltage here it is approximately 3 volt and the voltage here it is 12 minus 5.4. So, that is how much, it is 6.6 volt. So, that ensure that this junction it is getting reverse bias. So, the transistor also it is remaining in a active region.

So, that demonstrate that the CE amplifier with cell biased circuit the operating point is not changing. In fact, it is even though beta is changing from 100 to 200 still it is approximately remaining same.

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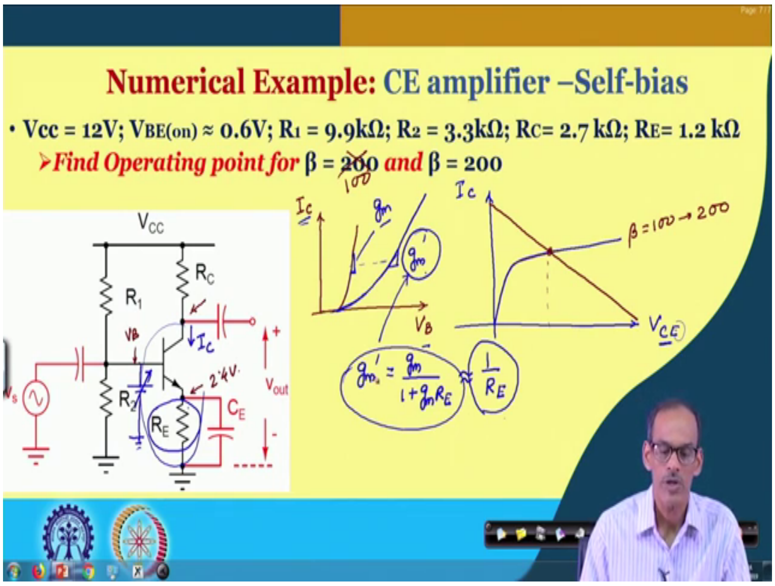

Intuitively or pictorially rather what you can say that the if we draw the I C versus V CE characteristic curve, even for different beta we can say that this characteristic curve almost remains the same. And, in fact, I should not say this is V CE rather I should drop this part and then I should draw only the I C versus V CE, but whatever it is let me complete what I like to discuss here. So, this is the load line.

So, even though beta is changing from 100 to 200, this characteristic curve almost remaining there, and not only that the voltage here also it is remaining close to 3 volt minus 0.6. So, that is 2.4 volt approximately and the voltage here it is whatever it is. And, however, if I draw the voltage sorry I C versus V B not V BE, but V B voltage at this point.

So, instead of exponential characteristic curve actually we are getting this curve getting shifted to something like this. So, if I apply a voltage here to illustrate that if I apply voltage and if I vary this voltage and then if I observe the corresponding collector current because we do have R E present here, this exponential characteristic curve instead of exponential it becomes almost flat.

And, in fact, if we see the slope here which is g m change in I C with respect to base voltage and then if I see the corresponding g m here the changed one if I call this is g m dash it is much smaller than this g m. And, it can be shown that this g m actually it is much smaller. In fact, in the previous class we already have discussed that transconductance of the circuit in case if we do have this R E it becomes if I call g m dashed it is g m divided by 1 plus g m into R E and this is approximately 1 by R E.

So, the transconductance of the circuit if though it remains g m, but if I consider if the transistor it is degenerated by R E the corresponding g m it is getting changed to this one. As a result gain of the circuit it was dropping. We will discuss that in the numerical problem.

So, what we have discussed that we have demonstrated the stability of the operating point, now we will be coming to calculate the gain and the other parameter of the voltage amplifier for the two examples namely cell biased as well as the fixed bias.

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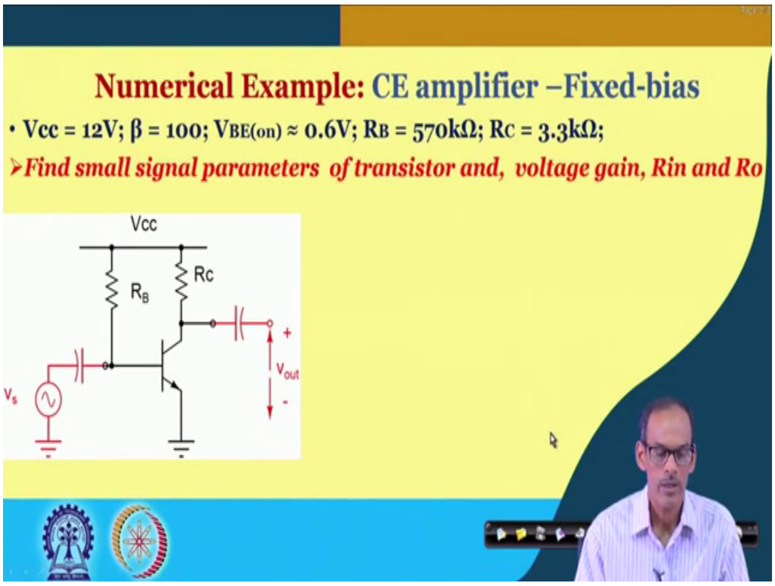

So, we will be going to discuss this one, but let me take a small break then we will come back.