Analog Electronic Circuits
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Lecture - 27
Common Emitter Amplifier (Contd.) (Part B)

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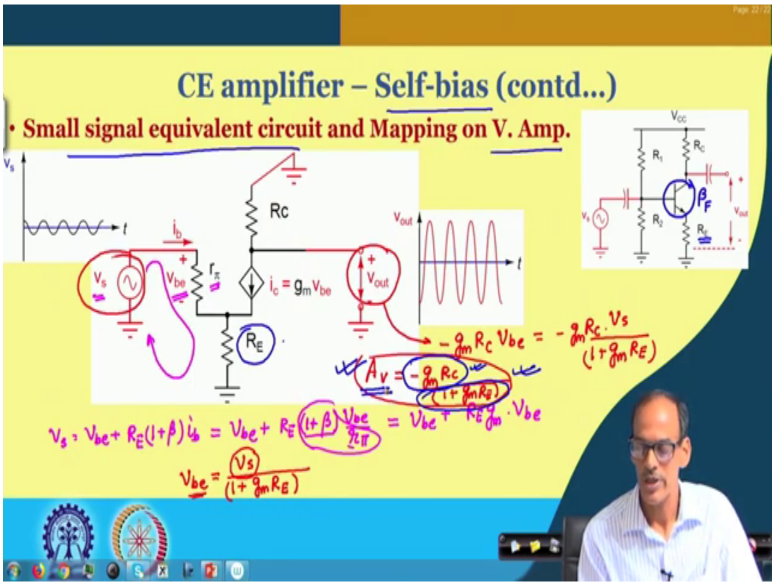

So, welcome back after the short break. So, where we are discussing? We are talking about the small signal equivalent circuit and then we are trying to find the corresponding gain of the circuit.

So, the output voltage as I said that output voltage, it is this one. So, v out equals to minus g m into R C into v be. Now, this v be of course, it is function of V s, but we need to find what is the exact expression of that. So, let me erase whatever the scribbling I have done and start afresh again drop across this R E which is R E times 1 plus beta times i b.

On the other hand, this i b it is; i b it is it can be expressed in terms of v be and r pi alright. So, we can write this as again v be plus R E into 1 plus beta times v be by r pi. In fact, if you see here beta divided by r pi it is nothing, but g m. So, if we drop this 1 and then if we consider this is equal to beta approximately divided by r pi so, this part it becomes g m. So, we can further simplify I am saying that this is v be plus R E into g m into v be. In other words, we may say that v be equals to divided by 1 plus g m into R E.

So, interestingly depending on the value of this R E, we can see that v be it is rather a small fraction of v s. Whatever it is this output voltage we said equals to minus g m R C into v be. So, that becomes minus gm R C into v s divided by 1 plus g m into R E.

So, as a result if I say that what is the gain of this circuit starting from primary source to the primary output, we can say the voltage gain A v equals to minus g m into R C divided by 1 plus g m into R E. So, this is one important parameter of the voltage amplifier out of this circuit.

Now of course, we will be talking about its numerical value and all. But if we; if we recall the if it is fixed by a circuit the expression of the voltage gain, it was only this much. Now, we do have additional factor here which is in fact, degrading the gain of the circuit. We will be talking about that, the circuit of this self-bias circuit because we do have this R E present at the emitter, it is degrading the gain.

In fact, the a purpose more main motivation of putting this R E, it is to stabilize the operating point of the circuit in case if beta is changing. So, you can think of that R E, it is desensitizing the circuit or rather its operating point it is getting desensitized against the variation of this beta. However unfortunately, this is also desensitizing this circuit against input signal and as a result it is making the gain much smaller than whatever the original gain of the C E amplifier potentially can provide.

So, we have to see what we can do for this part, but before that at least to you obtain the expression of the voltage gain and the whenever we are mapping this small signal equivalent circuit on a voltage amplifier model. So, apart from the voltage gain open loop voltage gain, we do have two more important parameters namely input resistance and output resistance of the model.

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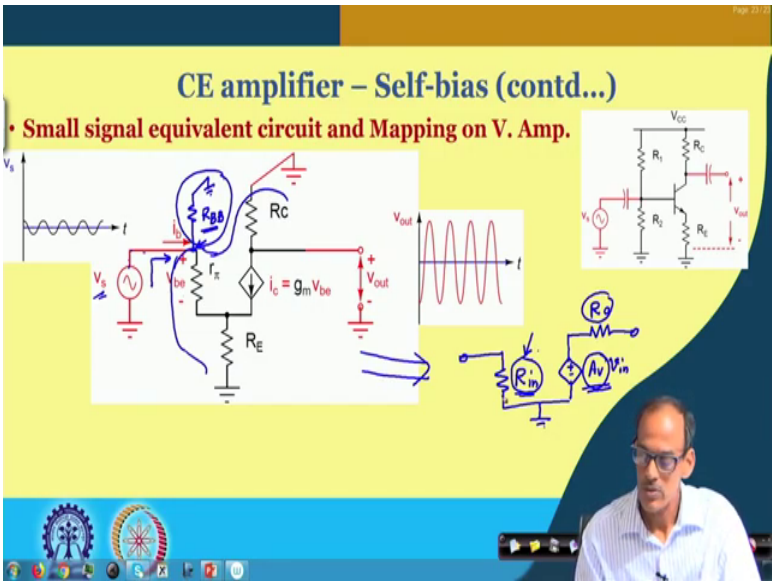

So, you may recall that whenever we are going to map this circuit into voltage amplifier at the input, we do have the equivalent resistance call R in and then also we do have voltage controlled voltage source, namely A V times whatever the v in and then we do have the Thevenin equivalent resistance alright. And so, we obtain this parameter now and we like to get the other two parameters of this model.

By the way, we have ignored this part; this part, if you want you can keep that as well. Many a times we do ignore, but is for practical purposes we may consider this R BB and since this R BB this node the voltage source it is directly coming here and it is a short. So, the voltage at this point of course, it will be same as v s. However, whenever we are talking about input resistance, whatever the input resistance we can see at this input port, it is parallel connection of this R BB and whatever the input resistance coming from the rest of the circuit ok.

So, while we will be talking about input resistance, we may consider this R BB, but while here we are deriving this voltage gain AV, we have ignore because this voltage source it is predominantly defining the voltage at the base node. So, let us find the expression of this input resistance of this circuit. So, I do have another slide for that, yes.

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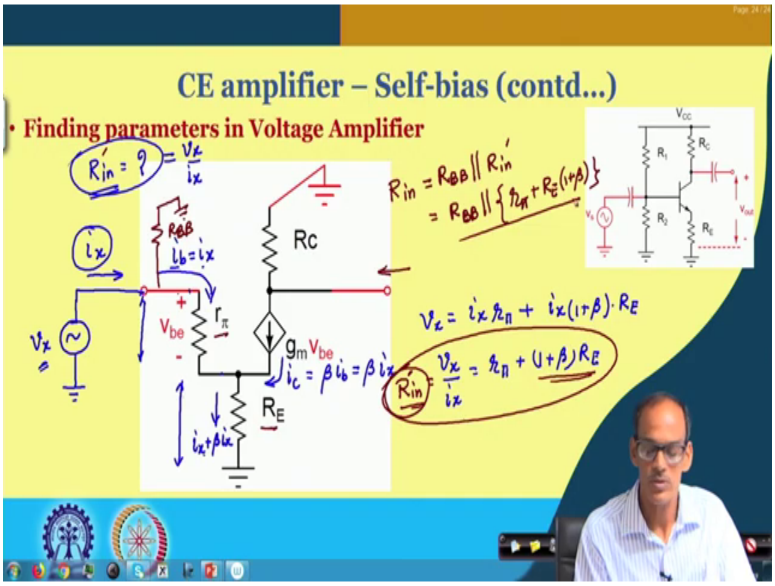

So, what we have? This is the main circuit and whenever we are going to find a small signal parameter. In this case may be R in expression of R in what we will be doing it is as a generalized methodology at the input we will be stimulating the circuit by a known signal source and then we will be monitoring or observing the corresponding current say i x. So, we call this is v x and then we are observing the i x and then ratio of this v x and i x that is giving us the resistance. So, v x by ix is the resistance.

So, one of this v x and i x is the cause and the other one is the effect. So, you may consider say i x is the stimulus and then you can observe the voltage at the base node with respect to ac ground or you may say that we are giving a stimulus called v x and then you are observing the i x. Either way you will be finding the correct expression of the input impedance.

While we are doing this exercise we can keep rest of the circuits in DC operating condition and we will be considering this is the only stimulus. And if I say that this is the v x, we may say that this current it is flowing through this circuit as the base current. So, i b e equals to i x.

And the voltage v x it is again it is having two components; one is the voltage across this r pi which is V bb V be and also the drop across this R E. To simplify what you can do, we may say that if I do have i b which is i x flowing from base to emitter terminal. The current flow on the other hand in the collector terminal it is i c which is beta times the i b which is incidentally, this is beta times i x. So, the total current flowing through this R E it is i x plus beta times i x.

So, we can say that the voltage drop v x equals to v be; v be it is i x times r pi plus i x times 1 plus beta multiplied by R E. So, from that we can say that v x by i x equals to r pi plus 1 plus beta times R E. So, this is what we are defining the input resistance. So, this circuit is its input resistance is this r pi in series with R E, but then R E multiplied by 1 plus beta times.

So, likewise you can find the output impedance of this circuit or output resistance of this circuit. Note that this input resistance we obtained only coming from this part in addition to that we do have the R BB. So, I should say this is only one part of it. So, let me call this is R in dash; R in dash. So, R in dash it is this one and then total input resistance of the voltage amplifier, it will be R BB coming in parallel with in dash which is of course, this is R BB in parallel with r pi plus R E times 1 plus beta.

So, similarly let us analyze the output port and let me see that what is the corresponding expression of the output resistance. I think I do have another slide let me see, no let me do it here itself.

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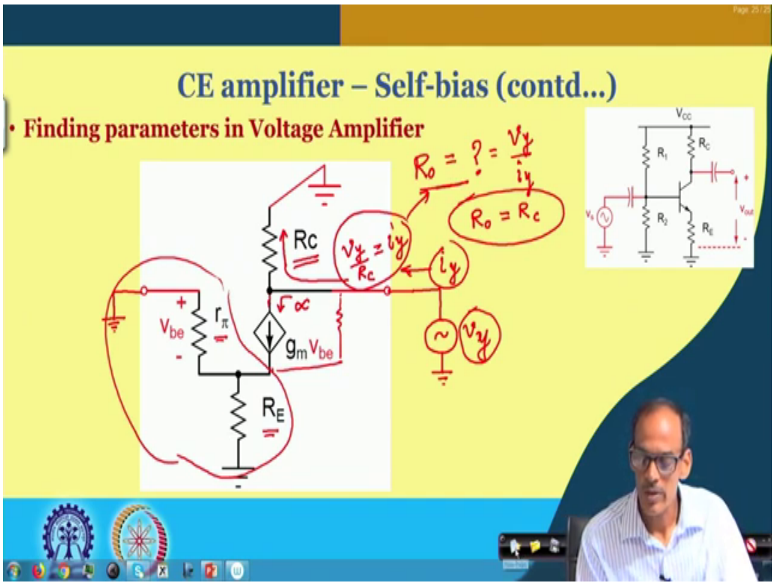

While we will be doing this similar kind of exercise, we need to find as I said that we need to find what will be the output resistance R O of this voltage amplifier, while we are mapping this small signal equivalent circuit into a voltage amplifier. What you have to do? Again we will be stimulating this circuit from this port by say a signal source called v x or say v y and then we can observe the corresponding current let we mark it as say i y.

And while we are doing this exercise we have to keep this signal 0 since it is voltage signal so, we are making this is ground. So, what we are and then if we take the ratio of this v x and i x so, that gives us the output resistance, so v y by i y right. And here whatever you do here in fact, this r pi it is coming in parallel with R E. But since we do have ideal current source here so, these two elements it will be; it will be blocked by this ideal current source because its resistance looking into this circuit it is infinite.

So, at the output port what we have it is only R C remaining. So, if I am applying v y here, the current flow through this circuit it is mainly this is the current. Now, the current of course, that will be v y so, that is v y divided by RC so, that is the i y. So, from that we can say directly that R O equals to R C. Now, this is of course, we are assuming that the conductance here it is 0. Now, if I consider the additional conductance of course, will be having the influence of this part also.

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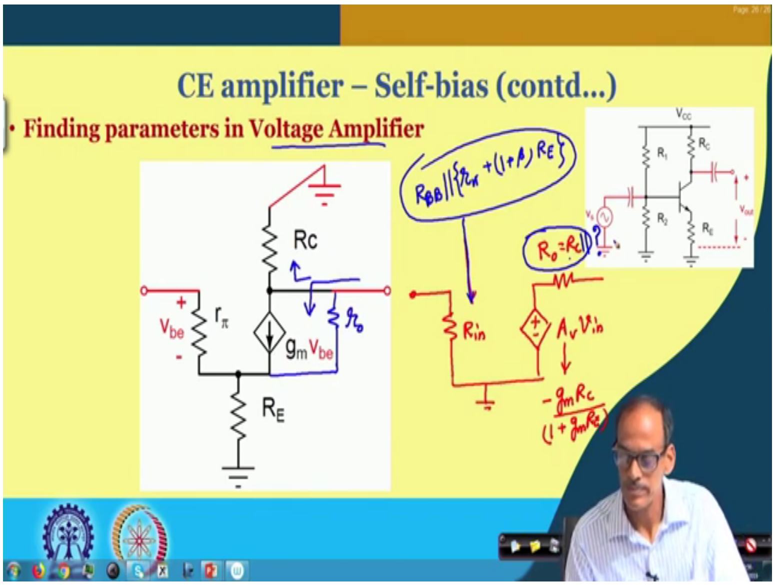

We will see that but so far what we have discussed, it is this amplifier it can be mapped into mapped into the small signal model into a voltage amplifier. And expression of this RO, it is R C this is A V time's v in where A V is g m into R C divided by 1 plus g m into R E with a minus sign and then R in ;R in equals to.

So, if I consider R BB also, so r in equals to R BB in parallel with r pi plus 1 plus beta times R E. Now, yeah, so this is the voltage amplifier model. If we consider as I said that if you consider the resistance here due to early voltage called RO or finite conductance here, then; obviously, I need to consider the resistance of this part coming in parallel with whatever the resistance we can see in lower side.

So, let me discuss about that and that will of course, change the expression of this output resistance. In fact, that will make the output resistance is R C in parallel with some other component. So, let us see what is that component coming here. I think I do have next slide to discuss that, yes.

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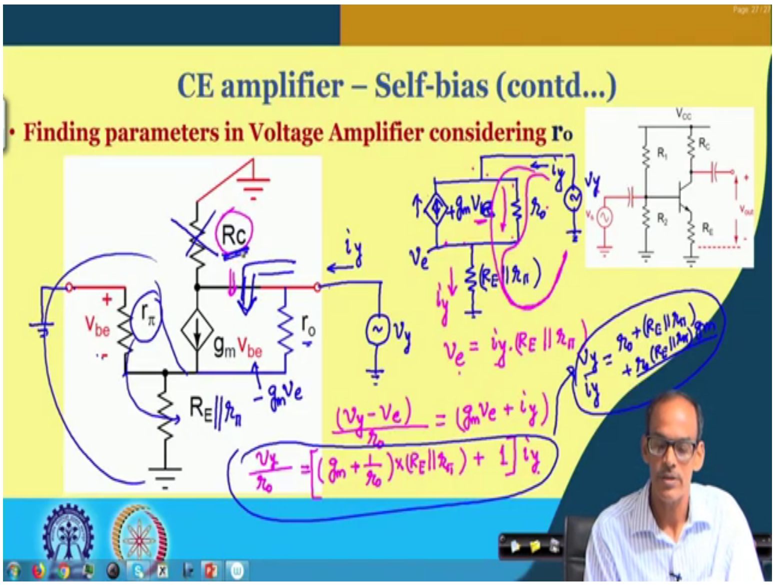

Here again, what we will be doing to find the output resistance in presence of RO, we will be stimulating this circuit by say v y. So, this is we are stimulating and then we are observing this i y and while we are doing this exercise, we have to keep in mind that we have to make this voltage input signal to be 0. And in fact, once you do that this r pi, it is coming in parallel with this. So, you may say that this is coming in parallel with r pi.

So, R E and r pi they are coming in parallel, so that is the representation. And on the other hand since we are doing the exercise to find the output resistance which is of course, parallel connection of this RC and whatever the resistance you are seeing in the lower side. So, for simplicity we may for the time being, we drop this part and let me analyze only this part.

So, if you see this circuit, we may frequently come to this circuit again and again and so, let me draw this circuit as a general one. So, we do have current source here which is g m times whatever you say v be and then we do have the r naught here and then we do have the resistance here.

And incidentally this is v be, so this is minus and this is plus. So, we may call since the base is connected to ground and emitter voltage whatever nonzero voltage, it is having. So, we may say that this v be, you may write this is g m into v e with a minus sign. So, we can probably you can write this v e with a minus sign or we can put the current direction in this other way and then we can say that whatever the current is flowing will; let we call this is i y and the corresponding stimulus here it is v y.

So, since this current is flowing in this direction and of course, since we have changed this direction of the current, we are we need to put the plus sign here. And what is v e? v e is the voltage at this point and this is the resistance R E coming in parallel with r pi.

So, now, if you see this circuit that since we have we are considering only lower part and we are not considering this R C at the moment. So, this i y it is actually flowing through maybe bifurcating and then coming back to this ground. So, the current flow here it is same as this i y.

As a result v e voltage drop voltage at this point, it is i y multiplied by R E in parallel with r pi right. So, that is the voltage here. So, the current flowing on the other hand, it is function of this v e and then current flow through this part of course, it is v y minus this voltage divided by r naught.

So, at this node if you see since this current is coming here and then the current flow here, it is basically summation of this two that must be equal to whatever the current is flowing. So, current flow through this r naught it is having one expression is v y minus v e divided by r naught. And the other expression it is g m into v e plus i y and v e, it is having this expression right.

So, what we can say that v e it since it is function of i y. So, we can take this v right side. So, what we are getting it is v y divided by r naught equals to g m plus 1 by r naught into v e and v e, it is having this expression which is R E in parallel with r pi into i y and also we do have this i y. So, we can say this plus 1 into i y alright.

So, that gives us the v y divided by i y expression and it can be shown that from this one, it can be shown that v y; v y divided by i y equals to r naught plus R E in parallel with r pi plus r naught into R E in parallel with r pi multiplied by g m. So, this resistance whatever the equivalent resistance, it is quite large primarily because of this term. But whatever it is the through this analysis, what we can say that this is the resistance of the lower part then total resistance of course, this will be R C in parallel with that.

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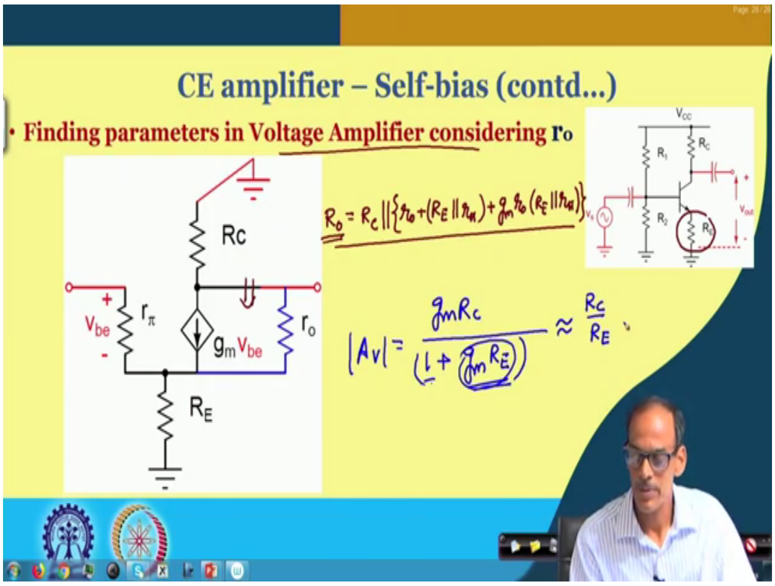

So, let me rewrite whatever I just now have said that output resistance R O which is R C in parallel with whatever the resistance it is coming from this circuit and that resistance it is r o plus R E in parallel with r pi plus g m r naught R E in parallel with r pi and then whole thing it is coming in parallel with R C.

So, that is the this mapping of the CE amplifier with self-bias things onto a voltage amplifier and the corresponding different parameters. Now, what we have said that we are placing this emitter register to make the circuits operating point desensitized against beta variation, but it is making the gain also dropping to a smaller value namely what we say it is that voltage gain A V, it is magnitude wise g m into R C divided by 1 plus g m into R E.

So; obviously, this is not acceptable particularly if R E it is significant and this multiplying this two, it will be quite large and if this may give us a value which is close to R C by R E that is in the order of maybe sometimes it may be less than 10 numerically. So, that is not acceptable. So, we need to unless we address this issue this circuit definitely, we cannot use it. So, let us see how this problem can be addressed.

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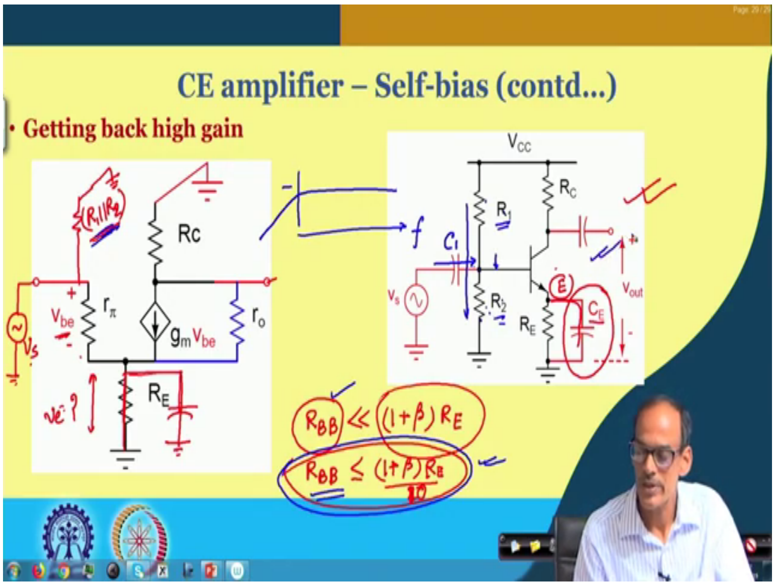

So, what we say that how do you get back gain of the circuit. So, as you can as you have discussed before in that whenever we are feeding the signal here say, v s significant part of that voltage it is getting dropped across this one. And as a result we do have only a small fraction as v be and making this corresponding output voltage very small.

So, if we make this voltage whatever the emitter voltage; if we make 0, then we can then force this v b to be equal to v s and then we can get back the gain. So, we like to make this voltage 0, but then moment we make this is 0 just by hard connection. Again we will be having the issue of the operating point getting sensitive to the beta variation. So, the clever thing is that for dc, we do not want this circuit to be working; but for ac, we want the circuit to be working.

So, as a result we can put a capacitor here and so the what you are looking for is basically this capacitor, it will not be interfering the dc operating point, but then for ac signal this will be making this ground. So, this is the solution of getting the voltage gain back and this is; this is not disturbing the circuit for dc operating point ensuring that the operating point of the circuit it will remain insensitive to beta variation. But for small signal or small signal or high frequency signal, this is working as a short making the emitter node connected to ground and making the this emitter node it is going to be shorted to ground, as a result we can simply shunt it.

So, if you draw the small signal equivalent circuit of this one, it becomes similar to whatever we already have discussed for the fixed bias circuit. By the way we also have this R; R 1 and R 2 coming in parallel and practically, we need to be careful that while we are keeping it similar to the fixed bias. But in this case what we have said is that R BB need to be very small compared to 1 plus beta into R E. So, that is the basic difference remains there even after cunning connecting this CE that R BB should be small compared to very small compared to this one.

Typically to satisfy this condition what we said is that R BB, it will be less than or equal to one-tenth one-tenth of this one into 1 plus beta into R E to get this approximation is getting valid ok. So, that is the sorry this is not two this is ten. So, this is what the practical design guidelines, we follow for this circuit.

So, you may say that smaller this resistance are better. So, can I make this resistance really small or is there any trade off. Of course, if I make this if I want to make this resistance smaller maintaining dc volt same; that means, both of these registers I need to make it smaller and smaller.

One consequence is that of course, there will be a dc current flow here so, that practically increases the power dissipation. But then even more serious problem is that if this resistance is getting smaller and smaller, then this capacitor will be having a difficult time to feed the signal at this node.

In technical terms, you may call that this capacitor and then these two registers coming in parallel call R BB, they do define the lower cutoff frequency of the amplifier. So, far we are talking about the mid frequency range operation and if you go to lower and lower frequency then of course, the gain voltage gain it will be dropping.

So, this lower cutoff frequency, one of the candidate to define this lower cutoff frequency is that this coupling capacitor C 1 and parallel connection of R 1 and R 2. So, we need to be careful that now while you are picking this R BB, we need to satisfy this condition to make sure that circuit is remaining insensitive to beta variation. But at the same time the lower cutoff frequency to keep it low the value of this R 1 parallel R 2 should not be very small.

But whatever it is once we follow all these guidelines the small signal equivalent circuit of this circuit is given there which is essentially very similar to whatever we have seen for fixed bias circuit.

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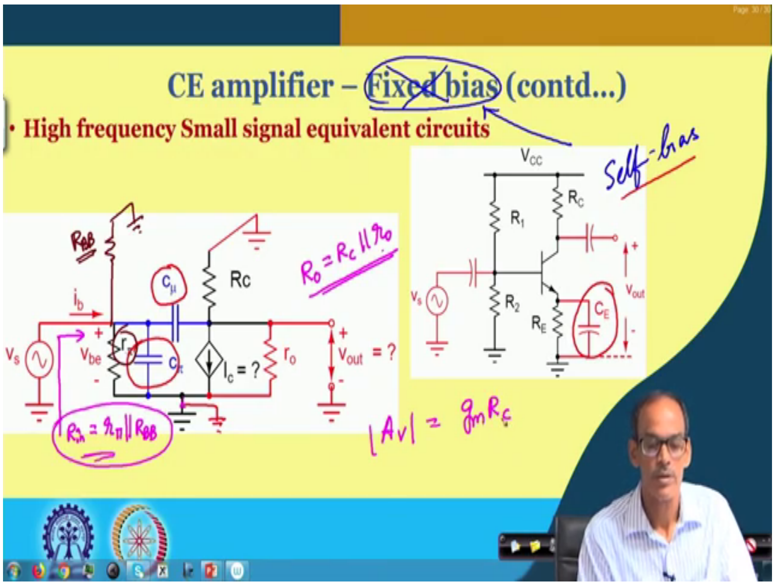

So, for fixed bias as well as the self biased yeah. So, I should say not only for fixed bias, but even for this is self-bias of course. In fact, I should have written this is self-bias instead of writing fixed best.

So, even for this circuit also the small signal equivalent circuit it becomes like this. Primarily this C E, it is making this node ac ground and in addition to whatever the things we have discussed so far ah, the parasitic components namely C mu and C pi they are also coming into play particularly for high frequency applications. So, for high frequency small signal equivalent circuit of for sale by a circuit also, it will be similar. And of course, we can retain this R BB here since R BB unlike fixed bias where R B, it was very high R BB we need to consider. In fact, R BB may be comparable with this r pi.

And once we connect this CE, I must mention that the input resistance input resistance earlier it was r pi in series with 1 plus beta into R E, but then now this input resistance it is r pi only and that of course, coming in parallel with this R BB. So, that makes the small signal input resistance it is becoming smaller that may not be a good thing, but to get the gain back at the cost of this input resistance, we need to ground this one.

And the other consequence is that the output resistance; on the other hand it is R C in parallel with R O. So, we are not having the other big things where we are having R E and so and so because the emitter node it is getting grounded. So, the these are the two changes. Of course, the corresponding voltage gain A V, now it becomes g m into R C.

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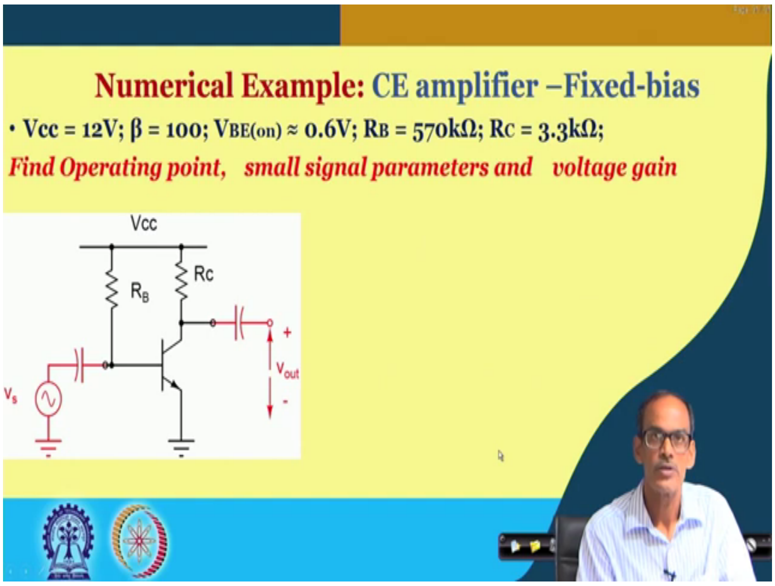

So, we need to discuss some of the numerical problems, but today we are running short of time probably in the next class we will talk about numerical problems from both angles the design wise as well as analysis wise. That is all for now, we will be resuming this class in the next day.

Thank you for listening.