Analog Electronic Circuits
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Lecture - 26
Common Emitter Amplifier (contd.)
(Part A)

Dear students, welcome back to our NPTEL course on Analog Electronic Circuits; myself Pradip Mandal from E and EC department of IIT Kharagpur. So, we are going to continue our previous topic namely the Common Emitter Amplifier, we have started this topic in the previous class and we are going to continue on the same thing.

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So, what are the plan we do have it is in the previous class we have discussed about the CE amplifier with fixed bias. And, today we will be going little detail of another kind of bias called self bias and in the previous discussion we already have cleared that fixed bias it is having some stability issue, particularly the operating point stability issue which is resolved by this self biasing that is what we will be discussing in detail.

Then subsequently we will be discussing about the self biased CE amplifier and then its corresponding analysis having two parts. One is the DC operating point analysis and then small signal analysis which is eventually giving us small signal equivalent circuit of CE amplifier having self bias. And, then subsequently we will be talking about the mapping of the small signal equivalent circuit of CE amplifier on a voltage amplifier.

And, then in typical voltage amplifier it is having three important parameters; how those parameters can be obtained in the small signal equivalent circuit as a methodology we will be discussing as well as this example. And, then subsequently we will be discussing about two numerical examples. So, under the numerical examples we will be having analysis for a given design, we will do the analysis to find the numerical value of gain and operating point of course.

And, then we will be giving some design guidelines for achieving some performance of an amplifier. So, this is what we will be covering today. So, let us talk about the biasing scheme and then let me compare the two biasing scheme.

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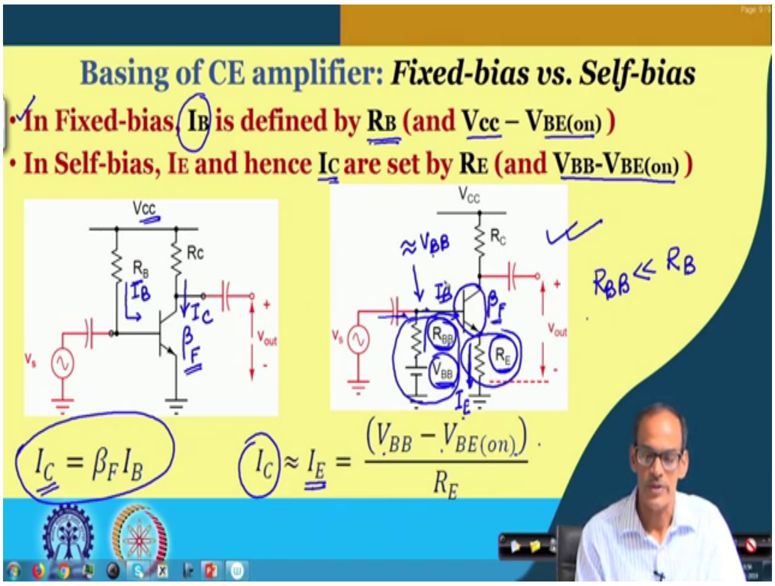

So, as we have discussed that this is the; this is the fixed bias kind of circuit and here what we have done it is the base current, base terminal current particularly the DC current I B it is decided by the V CC and then V BE on and this R B. So, in fixed bias circuit the base current it is well defined by the base register called R B and then supply voltage minus base to emitter diode on voltage.

So, once say this base current is defined and that is fixed then the corresponding collector current of the transistor it can be obtained by simply multiplying this I B with the beta F of the transistor. So, what we have discussed that since I C it is a direct function of the beta F there may be a situation, in case if the beta of the transistor it is changing then the collector current directly getting affected.

And, if the collector current is getting affected the drop across this resistance as a result the collector to emitter voltage of the transistor that may vary. So, we can say that operating point of the transistor it was getting heavily affected by variation of the beta of the transistor. In contrast to that we are going to discuss about this circuit which is referred as self bias.

And, in this self by us what we have it is this emitter register we are connecting in series with emitter to the ground. And, on the other hand at the base we prefer to give a DC voltage rather of course, we do not want from this voltage should be ideally a DC voltage because we like to feed the signal here.

So, but then the voltage here DC voltage here we want predominantly define in other words we want this Thevenin equivalent resistance of this bias circuit should be as small as possible in terms of the bias stability. So, even if we consider practical value of V BB this sorry R BB it is much smaller than whatever R B we do have.

So, we can say that the R BB in the self based circuit it is much smaller than the R B of the fixed bias circuit. So, we can say that even if say the base current is flowing through this circuit I B it is flowing through this circuit the drop across this R BB it is very small. As a result we may say that this voltage it is approximately V BB, now once this voltage DC voltage it is remaining almost constant then V BB minus the V CE the base to emitter on voltage.

So, V BB minus V BE on divided by the whatever this R E that defines the current flow here. So, in other words we can say that this emitter current I E in the self biased circuit it is defined by this voltage difference and then divided by R E. So, if R I E it is independent quote and unquote independent of this the beta of the transistor.

So, naturally the collector current it is also quote and unquote independent of the beta F. So, in this circuit in the self bias circuit in contrast to the fixed bias the emitter current V BB minus V BE on divided by R E. So, that is this current and we can approximate if the beta is very high we can approximate that the collector current is very close to that.

So, in this expression since beta is not there; so, we can say that the collector current is quote and unquote independent of beta of the transistor so, that is the main purpose here. In other words so, based on our requirement if we fix the value of this R E and then V BB assuming that R BB it is very small, then the collector current it is almost decided. As a result the DC operating point of the transistor it is almost fixed. So, that is the main advantage here. So, let us see what may be the analysis of this circuit to compare these two circuits performance.

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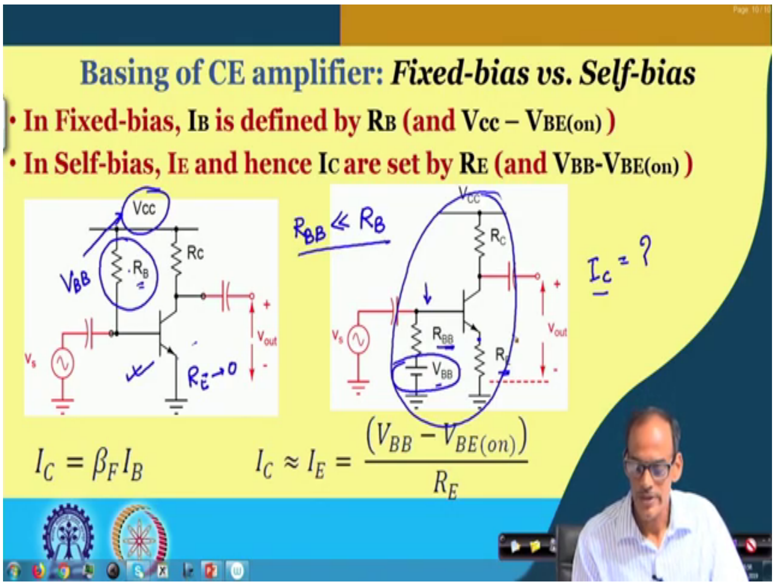

In fact, if you see it carefully what can be seen here that V BB you may consider as a special case it is V CC and R BB it is similar to R B. However, as I said that in this circuit R BB it is much smaller than R B and that can be obtained because we are adding this emitter register R E.

So, in contrast to over this circuit where emitter is connected to ground. So, we do have the flexibility to change this voltage and predominantly we can say that this circuit is more like a voltage bias rather than current bias what we are seeing in the fixed circuit.

But, nevertheless we may consider that this circuit is more generalized and the self bias circuit it may be treated as in general it may be treated as a special case where you may say that R E it is going to 0. And, then V BB is going to be equal to V CC and whatever the R B is there. So, to compare the expression of the collector current in the two circuits probably we can analyze the circuit and we can find the expression of I C.

And, then we can probably the through equation we can compare the collector current expression in there in the two circuits. Namely, in the fixed bias circuit the collector current it will be having lot of dependency on the beta of the transistor whereas, for self bias circuit the dependency it will be less. So, let us see the analysis of this circuit here.

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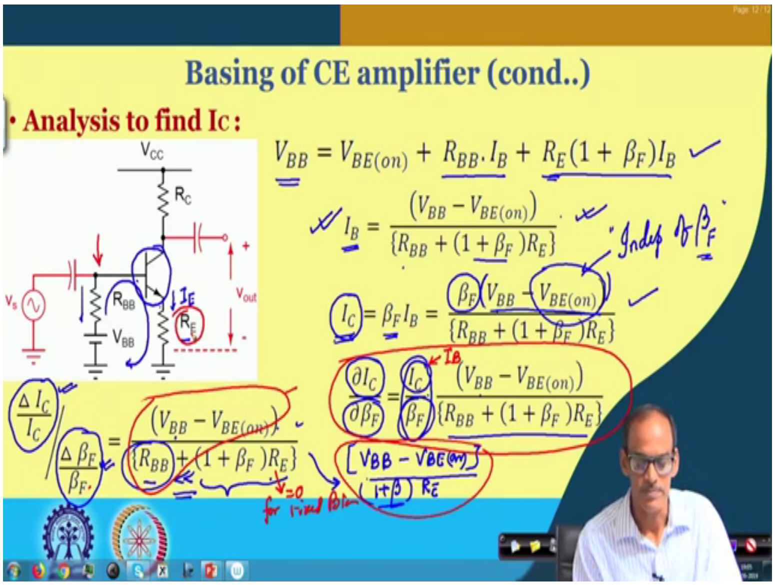

So, in the next slide we are going to analyze this circuit in detail. So, what we have here it is we do have the same circuit we have discussed we do have V BB. Now, if I consider say this loop, this loop then we can say V BB equals to V BE on plus drop across this resistance which is R BB multiplied by I B plus the drop across this emitter register R E. And the drop here it is of course, the resistance multiplied by the emitter current I E.

And, I E it is 1 plus beta of the transistor times I B so, this is the drop across this R E. So, if we rearrange this equation to get the expression of I B, now by taking this I B left side and what we are getting here it is I B equals to V BB minus V BE on divided by R BB plus 1 plus beta into R E. Note that here there is no approximation.

So, here as I said that if we consider two special cases, the same equation will be helping us to find the expression of the base current. Now, if I am having this base current we can get the collector current by multiplying with beta of the transistor. So, the expression of the collector current is given here, it is same as this part along with multiplying with this beta.

Now, if we like to see what will be the variation of this collector current with variation of beta, we can take partial derivative of this equation with respect to beta. And, if we assume that this part, this V BB on it is quote and unquote independent quote and unquote independent of beta F though it is not theoretically exactly correct, but practically that is quite consistent. Particularly, since we are not looking at V BE independently rather we are observing V BB minus V BE on.

So, even if it is having some variation, but if I consider V BB minus V BE on variation with respect to beta that can be ignored. So, if I assume that this part is remaining constant and then if I take partial derivative with this I C with respect to beta F what we are getting here it is V BB minus V BE on divided by this denominator.

Note that here this part it is I B; so, the expression of this I B it has been used here to make a to get a nice form. But, in this form what you can see if we further analyze if I take the change in collector current divided by the collector current; that means, fractional change in collector current divided by change in beta divided by beta.

So, we can say that fractional change in collector current divided away divided by fractional change in beta that is having this expression which is V BB minus V BE on divided by R BB plus 1 plus beta into R E. So, if we assume that this part, this part it is much higher than this part.

So, if I consider this R BB it is much smaller then we can say that this is V BB minus V BE on; so, divided by 1 plus beta into R E. Now, due to this 1 plus beta coming on the denominator, this is since it is inversely proportional with beta F under this condition of course, then we can say that sensitivity of the collector current change with respect to beta F it will be quite small.

On the other hand the same equation; same equation if I consider R E equals to 0; so, if I consider this is on the other hand if I consider for the fixed bias where this R E equals to 0 for fixed bias. And, for that the dependency of the collector current with respect to beta F or fractional change in collector current divided by fractional change in beta F it is only this one.

So, as a result you can see that this part it will be quite significant compared to this one which is the fixed bias case. So, or directly maybe you can use this equation and then you can compare the two circuits namely. So, we do have we can replace this part by I B and then we can say that it is having strong dependency on beta F. So, anyway so, what we like to say here it is we like to bias this circuit in terms of voltage.

And, we like to place this emitter register to get the better stability of the operating point; particularly if we are changing the transistor by another one having different beta or may be due to the thermal runaway if the beta is changing, this circuit it will be having a better stability.

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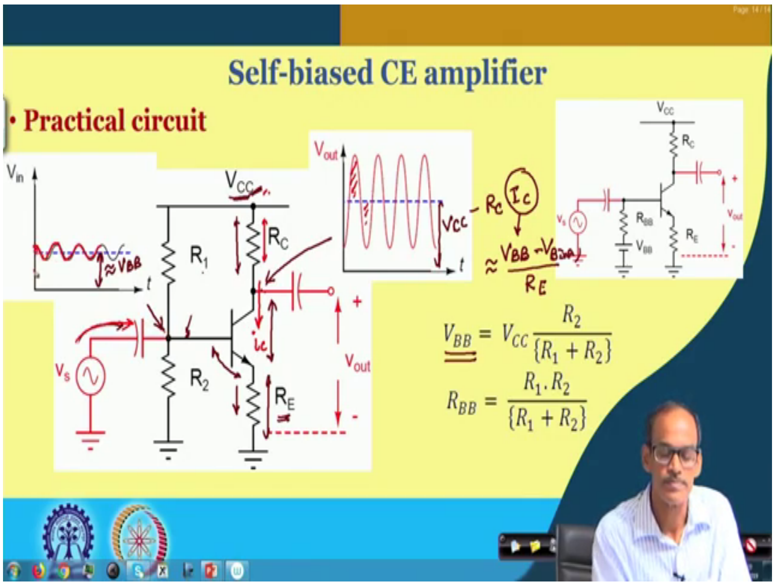

Now, what is the practical circuit let us see. So, this is what the practical circuit you can see that instead of having independent voltage at the bias voltage at the base what we have here it is potential divider from V CC by this R 1 and R 2. So, the voltage coming here if I consider Thevenin equivalent voltage source of this one along with the V CC what we can get is V BB it becomes V CC multiplied by R 2 divided by R 1 plus R 2.

And, then Thevenin equivalent resistance R BB what we have drawn in the previous circuit R BB it is parallel connection of this R 1 and R 2 or you can say R 1 multiplied by R 2 divided by R 1 plus R 2; so, that is the expression of R BB. So, as I said that this is the practical implementation of this self bias and of course, we do have the R E part emitter register that connected here.

So, the typically this circuit is quite popular and then we do use this emitter register to avoid the thermal runaway problem or the dependency of the coefficient point on the beta. Now, in this circuit similar to fixed bias the voltage at this point it is having a DC voltage defined by this R 1 and R 2 and then V CC. Practically, this V BB it is defining this DC voltage and then on top of that we are feeding the AC signal through this coupling capacitor. So, we do have the AC signal riding over there. So, we do have the ac signal riding over this one. So, the voltage here it is having a DC voltage and then on top of that we do have the signal.

Now, at the output similar to the previous case the it is also having a DC voltage level. So, this DC voltage level at this point particularly at this point it is having the drop across this R E plus whatever the V C voltage you do have or we may say that V CC minus the drop across this resistance that gives the this DC voltage. So, we can say this DC voltage it is V CC minus R C into I C. And, then to get the I C we have discussed that once this voltage it is given here then that minus V BE on.

So, that divided by R E that gives the emitter current and that actually it gives the approximately the collector current. So, I C you may say that this is approximately equal to V BB minus V BE on and divided by this R E so, that is the emitter current; so, approximately you can consider. So, that is how we are getting DC voltage and once we have the AC signal at the base coming from the signal source naturally this is also having the small signal current I C along with the DC current.

And, as a result it is also producing a drop across this resistance and hence we do have the signal at the output. Only thing is that since we are subtracting from the DC voltage this drop across the R C we are subtracting from the V CC. So, the signal here it is having 180 degree phase difference with respect to whatever the signal we do have. So, in this circuit let me go a little detail of analyzing the input part and the output part namely the input port.

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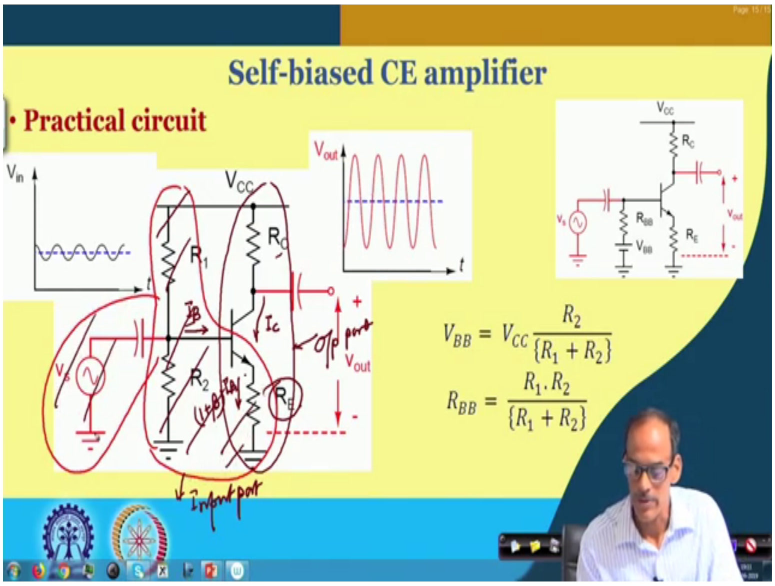

So, if I consider input port is this one DC wise, in addition to that we do have the signal. And, the output port we do have on the other hand consist of on the collector register, transistor and also this emitter register. So, you need to see that this emitter register it is part of the input, input port as well as the output port as well as the output port.

So, in the input port while we will be analyzing we need to be careful when whenever we will be talking about the I B current; we need to see how much the current actually it is flowing. In fact, the current here it is not only I B it is flowing through this one, but also the I C. So, whenever we are writing say I B here the current here it will it is 1 plus beta times I B; so, that we need to be careful.

So, and then of course, then we will be talking about the small signal thing. So, let us see the input port circuit what we are discussing here along with the signal part.

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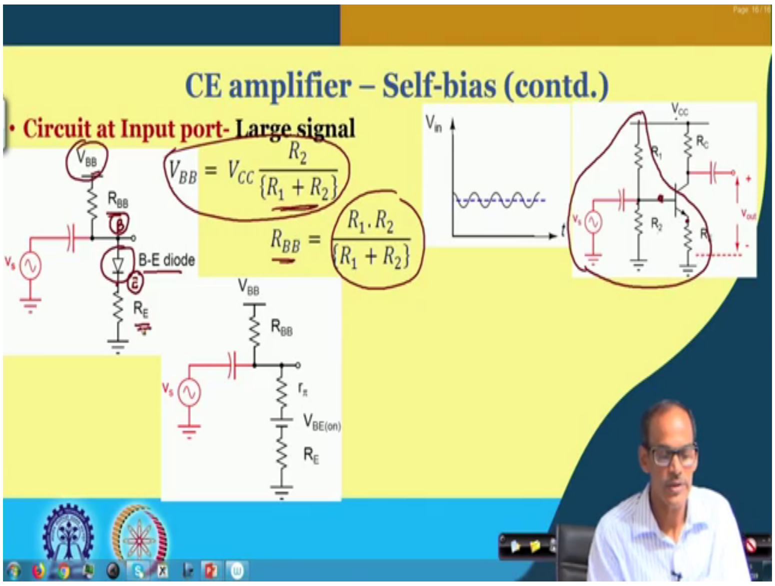

So, at the input port what we have here it is the so, this is the; this is the circuit we are talking about, let me mark it here. So, at the input port we are talking about this one. So, we do have the R 1 and R 2 coming in parallel to give us the R BB. So, R BB which is parallel connection of the R 1 and R 2 and then V BB it is the voltage Thevenin equivalent voltage coming from V CC and R R 1 and R 2 together.

So, we do have V BB it is having the expression earlier we have discussed about that V CC multiplied by R 2 divided by R 1 plus R 2. So, then out of the transistor from base to emitter we do have the base emitter diode and then at the emitter node. So, this is the base node and this is the emitter node and at the emitter node we are having this emitter resistor.

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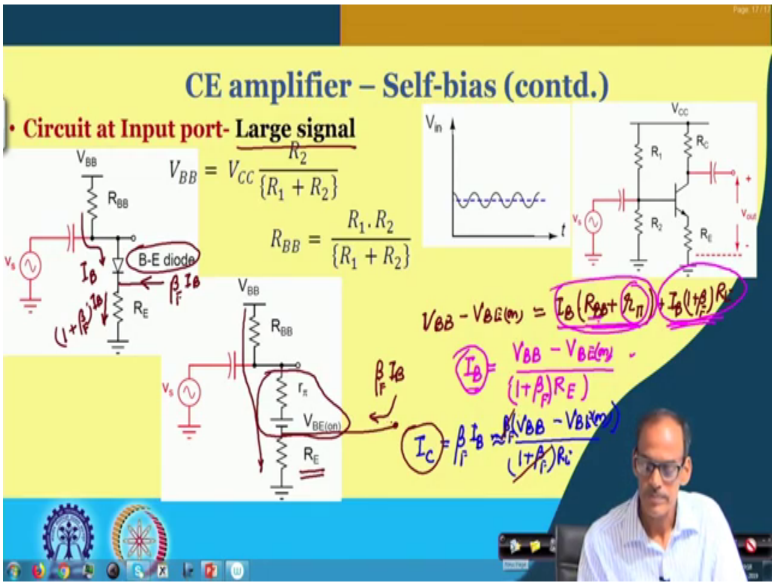

Now, at the emitter of course, we do have the; we do have the additional current flowing into this. So, whenever we will be talking about I B it is flowing here, we need to consider that I C also which is beta times I B as a result the current flowing through this part it is 1 plus beta times I B. So, if it is DC current will be talking about 1 plus beta F times I B.

Now, if I consider if I replace this diode base emitter diode by its equivalent circuit shown here. So, which is parallel connection of the V BE on voltage and then small r pi and again this node we need to consider that collector current is coming here which is beta times I B.

So, now, if we analyze; if we analyze this circuit if we analyze this circuit what we can get here it is the I B. So, rather V BB minus V BE on equals to I B times R BB plus r pi and then plus I B multiplied by 1 plus beta times R E. So, here we may or may not be able to sorry I need to consider this is R BB.

So, in this case we may or may not be able to ignore this R pi in this case. So, we may have to consider this entire portion, but if we consider say drop across these two resistances; since R BB it is much smaller than the R E part then typically compared to this part we may ignore this part. So, we may say that I B equals to V BB minus V BE on divided by 1 plus beta F into R E.

In fact, in our previous analysis we have ignored this part compared to this one, but even if you consider this whole thing these two together it can be ignored compared to this part. So, as a result what is the expression of the current I B we are getting? It is V BB minus V BE 1 divided by 1 plus beta into R E. So, large signal analysis if we do then we can find the corresponding base current, whenever we will be talking about some numerical example we will see that this current it will be very small.

And, once we get this beta I B then the collector current it is I C equals to beta F into I B. So, that we can approximate that V BB minus V BE on divided by 1 plus beta F into R E and then whole thing multiplied by beta F. So, we may ignore we may ignore this one part and then we may cancel this part and this part.

So, that gives us the collector current it is independent of beta F; so, that is what again we are converging to the same point. So, that is what we do, the input port we do this large signal analysis. Only thing as I said that we need to be careful that this R E it is also taking the current of the output port. Now, from this circuit after getting the large signal current probably we can do the small signal analysis.

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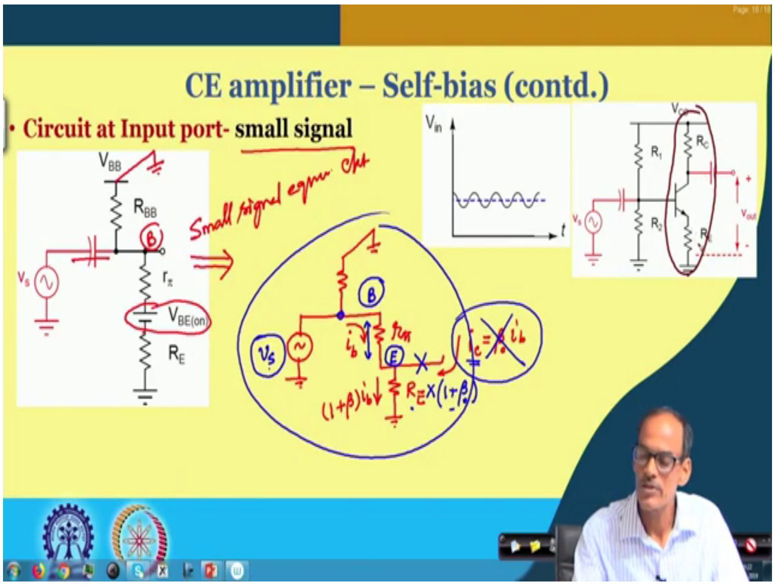

So, I do have a different slide for that. In fact, the same circuit we are drawing here, but what we are talking about; we are going to talk about the small signal analysis. So, once we have this entire circuit and we like to see what will be the corresponding small signal equivalent circuit; equivalent circuit.

What you have to do here we have to make it AC ground, we have to drop this part and then we have to short it. So, what we have it is we do have a signal source shorted to the base node. So, this is the base node this is of course, the emitter node. And, then we do have the AC ground and then we can keep this R pi and then we do have the R E, but again we need to be careful that we also have the collector current to be considered.

So, if I say collector current is I C that is also flowing to this R E. So, if we have say this current we do have say small i b. So, this collector current it is beta times beta naught times i

b. So, as a result the current flowing through this circuit it is 1 plus beta times i b into R E; so, that is the drop.

So, probably you may drop this current source, you may drop this part and then instead you may simply say that this registered it is getting multiplied by 1 plus beta naught of the transistor. And so, then we may you may forget about this part, you may say that the resistance is getting increased; so, that what normally it is followed.

But, whatever the way you feel we need to be careful that we need to consider this collector current or probably the emitter register we need to consider its amplified version of the emitter register. Now, this V s it is coming here and it is going to the base terminal. Note, that this is emitter terminal so; obviously, V s it is not same as V BE as it was for fixed bias.

It is rather having a voltage drop here which is called base to emitter voltage different from this V s. Now, let us look into the output side. So, whenever we will be talking about the small signal equivalent circuit, we must consider this analysis. So, while will be going to the small signal equivalent circuit for the entire emitter amplifier common emitter amplifier then we have to consider this circuit. So, will be coming back, but for the time being let we consider the output port. And, again for this output port what we have it is emitter register it is common.

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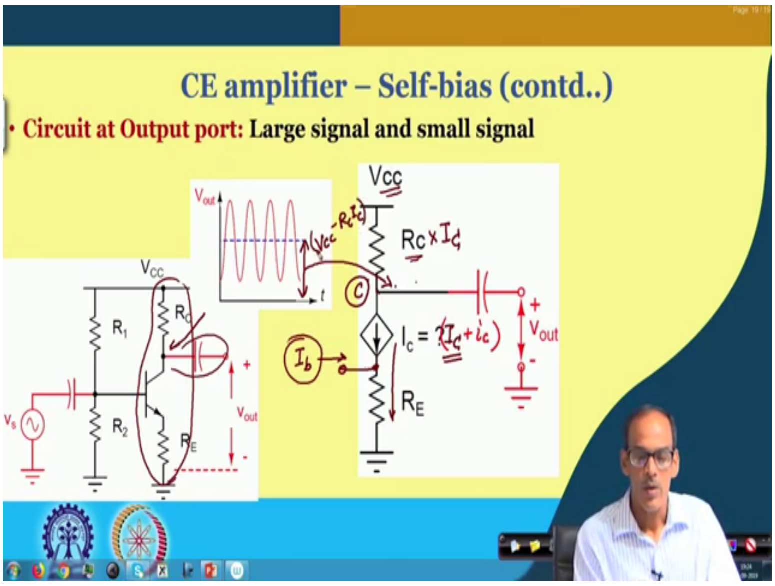

So, let me go to the; so, here again we do have the large signal and a small signal notion. And, here we do have the; here we do have the actual circuit and at this point we do have the voltage shown here and we are going to talk about at this circuit along with this DC decoupling capacitor.

So, what we have at the collector? We do have the R C, collector resistor connected to the V CC and then collector to emitter we do have the current. And if it is of course, it is having a DC current I capital C plus in case if it is having small signal small i c also.

But, whatever it is this entire current it is flowing through this emitter register and in addition to that at this node the base current is also coming. However, this base current it is small compared to this collector current. So, we may or may not ignore this part that we can see, but that this is what the output port.

And, once to find the DC operating point one say I C it is known by analyzing the input port then you can say that current is flowing here. And, the DC voltage coming here which is V CC minus R C multiplied by this I capital C; so, that is the DC voltage coming here.

So, the voltage at the output node or the collector node rather it is V CC minus this drop; so, this is V CC minus R C into I capital C. Now, once you obtain the DC voltage here let us look into the small signal part.

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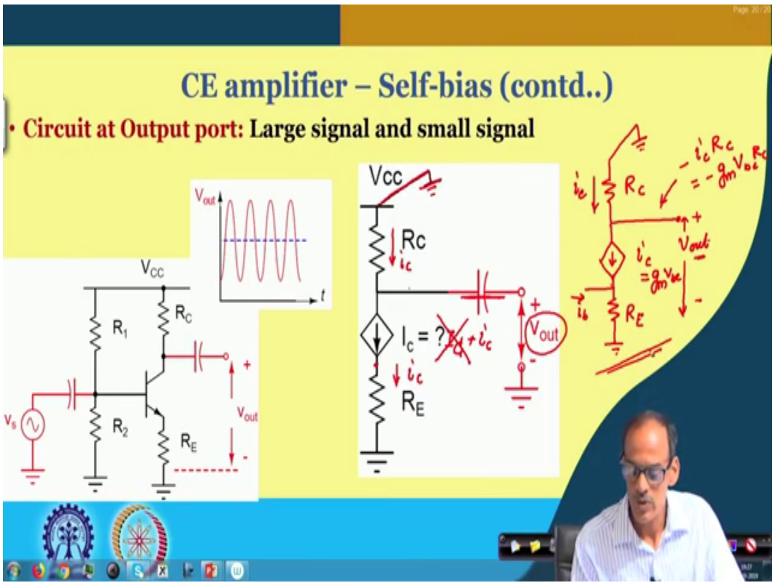

And similar to the input port here again for small signal what are the things we will be doing, it is the this terminal will be will be considering AC ground. So, this is AC ground and here this DC part it will be removed. So, though it is having total current is I capital C plus small i c, but this will be dropped and whatever the current it will be flowing through this one it is only small i c; so, this is also small i c. And, the corresponding capacitor here of course, it will be getting shorted.

So, whatever the voltage small signal voltage you are getting that will be called small signal output voltage, while we are dropping this DC part. So, if I draw the small signal equivalent circuit, we do have the R C connected to AC ground and then we do have the small signal current, small i c. And, then at the emitter we do have the R E maybe we can think of the base current coming here i b and then at the output we can say this is the open circuit output signal.

So, this i c of course, we may be having a different expression. One of them it is i c equals to transconductance of the transistor multiplied by base to emitter voltage and since this is ideal current source; so, we may to find this output voltage we may prefer to see how much the drop across this register is appearing while small signal current i c it is flowing.

So, the output voltage at this point output rather signal it is minus i c into R C which is of course, this is equal to minus g m into V BE into R C. So, while we will be combining this small signal equivalent circuit at the output port and small signal equivalent circuit at the input port, then we can get the combined small signal equivalent circuit.

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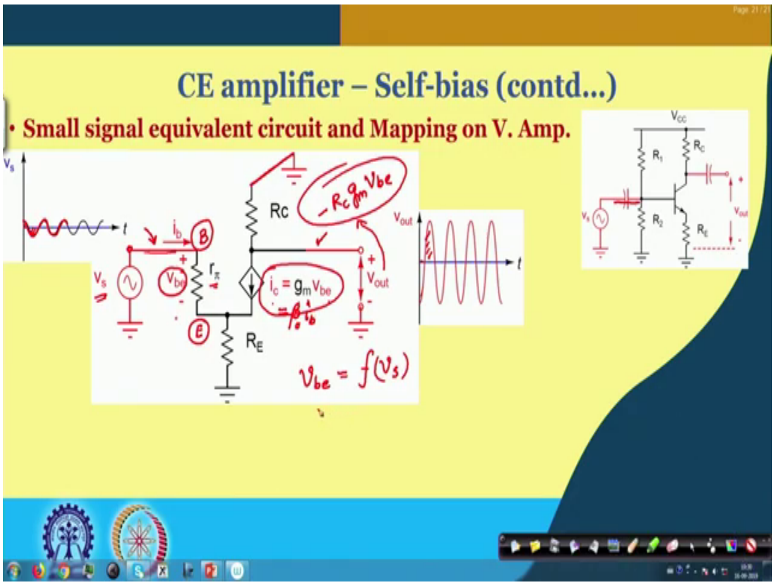

So, let us see what you are going to get here yes. So, we do have this small signal equivalent circuit shown here, where now if you see at the collector side we are making AC ground first thing. The capacitor here we are shorting; so, that is what we are doing and then the collector current it is having only the small signal collector current, small i c which is g m times V be.

And, the V be it is the voltage drop between the base terminal and the emitter terminal ok. So, this is the voltage drop across you can say that this is drop across R pi; so, of course, we are giving the signal here. So, the voltage coming at this point in this circuit since we are eliminating the DC we do have plus and minus kind of signal and the output here we are removing the DC.

So, we are getting the only the signal part and in this illustration as I said that the signal here it is in opposite phase of the input signal that is because of the voltage coming here it is minus

R C into g m into V be. Now, if you see here this V be of course, it is not same as V s; so, this is not V s.

So, since the V be it is not same as V s, it is rather only a part of it we need to do the detailed analysis of the circuit. Now, we are going to take a small break, but just to after we come back we need to find what will be the relationship between this V be and the V s. So, V be as function of V s and while we will be doing this we may use this important relation that this i c we may say that this is g m into V be or, we may say that this is beta times i b.

Anyway we will come back and we will be having little more discussion to find the output voltage.