Analog Electronic Circuits

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Lecture - 25
Common Emitter Amplifier (Part B)

Welcome back after the short break.

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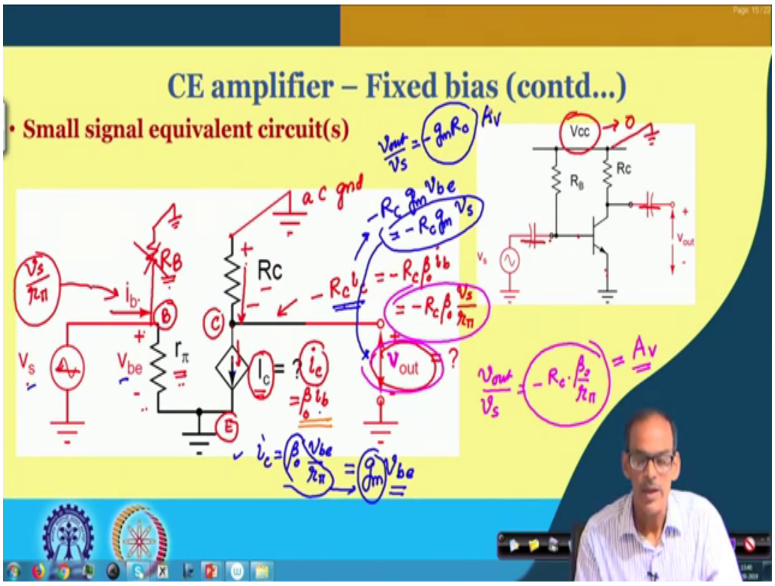

So, we are discussing about the CE amplifier, then we are close to the small signal equivalent circuit. So, large signal analysis we have done and based on the large signal analysis, what we said is the DC voltage here it is fixed.

So, whenever we are going for small signal, first thing is that we will be considering this DC part is 0. And so, we can say that this is AC ground; of course, we do have this ground. Then next thing is that these capacitors are working as a short and whatever the circuit will be having, it is now that we will call the equivalent circuit.

In addition to that base to emitter, we are also having one Vbe on internal DC voltage that also need to be met 0. So, base to emitter what we have it is the r pi. We do have this r pi, then we do have the signal coming here. So, we do have the signal directly coming here.

Along with this r pi of course, we do have RB, R capital B and this is connected to ac ground which means that this RB and this r pi, they are coming in parallel and typically this resistance is very high compared to this one. So, we may ignore this part, we can simply consider this r pi.

And the on the other hand the collector side so, this is the base node, this is the collector side ah. At the collector side, we do have RC which is connected to Vcc which is now ac ground. So, this is ac ground I am using red color ground here just to indicate that this is valid for ac signal only.

And then from collector to emitter we do have the current this IC current, but here again, here it is having the DC part as well as the small signal part. So, we should say that DC part we are dropping it and what we have it is only the small signal part IC.

So, this IC equals to beta into i b and the i b it is whatever the current it is flowing from the signal source into the base. So, this i b if you see here this i b, it is this is V s divided by r pi. So, this is what the i b. Now that i b it is after multiplying with beta, beta naught it is giving us the on the small signal collector current.

That current is flowing through this resistance which is producing a voltage and for it may be noted that the signal here though it can go positive and negative, but for correct polarity and consistency of the input to output signal phases, we need to put a sign.

Say for example, here whenever you are talking about base to emitter voltage, this is signal voltage it can go plus and minus, but then we are putting plus sign here and minus sign here; same thing for polarity of the i b. So, we are considering this is the positive direction of the base current.

Likewise whenever we do have the collector current, this is the positive direction of the collector current with respect to that if the collector current is flowing in this direction the developed voltage here it will be this will be minus and this is plus. So, the voltage coming at this point it is minus R c multiplied by this i c in. So, that is minus R c into beta naught into i b. Further to that we can write this as minus R c beta naught into i b it is vs divided by r pi.

So, that is what the v out. So, we can say that this v out v out expression is this given here. So, this v out expression it is given here. So, from that I can say that v out, I should use this is small v out v out divided by v s equals to minus R c multiplied by beta naught divided by r pi. So in fact, this is nothing, but our voltage gain.

In small signal model, if we map this equivalent circuit into voltage amplifier small signal voltage amplifier, then this is representing as the voltage gain A v. So, we will see that again this A v, but its expression it is given here. Now this small signal equivalent circuit it may be having two ways of representing. The first one just now we are discussing, the other one it is again similar only difference is that let me use a different color to consider that this i c instead of writing in terms of i b. Let me use blue color.

So, instead of using i b we can write i c equals to. In fact, we can write beta naught i b it is v be divided by r pi all right. And so, this v be divided by r pi this parameter, it is of course, it is a small signal parameter we already have discussed earlier. This is gm trans conductance of the transistor multiplied by then this v be. So, this part it is basically the trans conductance of the amplifier. So, in this red color what you have done is that this current, we are writing in terms of i b which means that this current source it is current dependent current source.

On the other hand if I you say, this model then this is voltage dependent current source right. So, this v be it is defining this the current. And then the remaining things; however, it remain same namely the output voltage here, it is minus R c into i c and instead of writing beta into i naught, now I can write this as minus Rc into gm into v be and incidentally this v be, it is same as v s. So, we can write this as minus Rc g m into v s.

Again this is representing the same v out and with this we can say that v out divided by v s equals to minus g m into Rc. This is again the expression of the voltage gain if we are representing this whole circuit as equivalent voltage amplifier.

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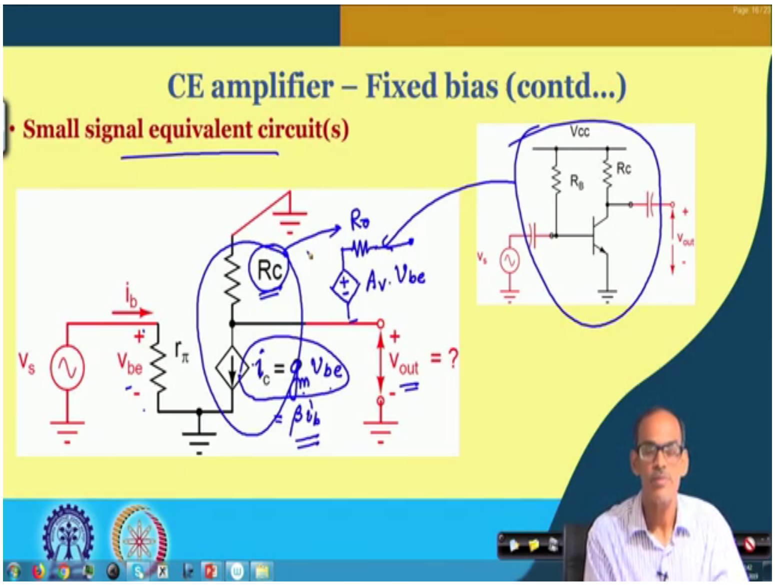

So, I should say that the this circuit we do have while we are mapping this circuit in the form of small signal equivalent circuit, there are so, this circuit whole circuit we are mapping in this form and it is having two ways of writing this small signal i c here; one is in terms of gm v be the other one it is beta times i b.

Now, if we are mapping this circuit in the form of voltage amplifier, we prefer this expression over this one that is because then input we are considering it is input signal we are considering as voltage rather than current. So, maybe in other model while we are considering say the same CE amplifier as current gain current amplifier or maybe impedance amplifier, then we may use say the other model here.

So, if I use say this current source as gm into v be, whatever we will be getting it is equivalent I should say that will be the input signal it is the voltage. Now if I consider this output as voltage; obviously, then this current source along with this Rc, we need to translate this circuit in the form of Thevenin equivalent.

So, once we translate this into Thevenin equivalent model, then only we will be getting the output port as voltage source and we need to map into this normal model the known model which is A v times v in and in this case v in it is basically the v be. And then we do have the output resistance and incidentally this output resistance and this output resistance they are same ok.

So, now, if we map this small signal equivalent circuit into a voltage amplifier, what we are getting it is the following.

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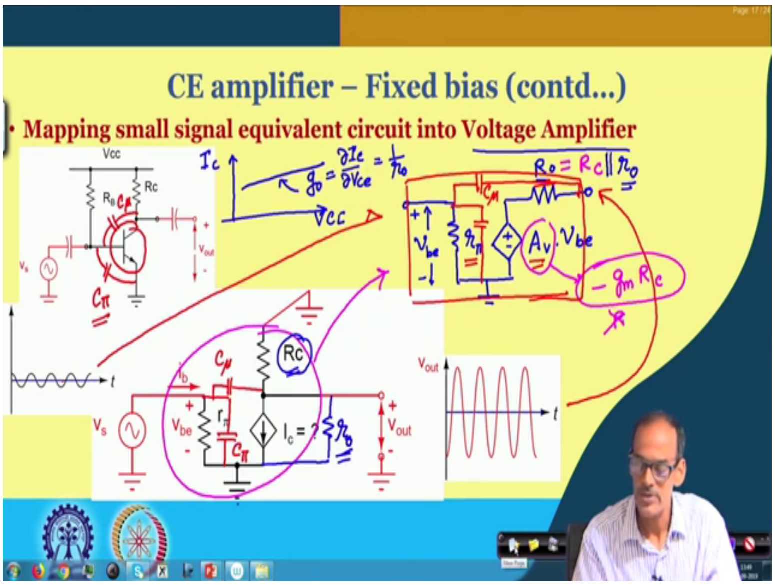

So, we are discussing about the this small signal model. And now if we translate this model in the form of voltage amplifier, what is the voltage amplifier will be getting it is voltage dependent voltage source at the output port and then we do have the output resistance R o. So, voltage dependent voltage source it is A v times the input port voltage

In this case v in it is v be. So, this is plus and this is minus this is connected to ground and then at the input we do have the a r pi. So, the input resistance is r pi of the transistor and at the across this r pi, we do have the v be voltage. So, this is plus and this is minus indicating if this is plus and this is minus the corresponding voltage here this should be in phase.

However we already have discussed that expression of this A expression of the A, it is minus g m into Rc or we also have said that in terms of current. So, for the timing let me stick to this one forget about this one and then output resistance it is same as the Rc.

So, this circuit whatever the circuit, we have discussed here small signal equivalent circuit we can map into this model the voltage amplifier model. Having this three important parameter A V, output resistance and then input resistance here. So, this is input resistances r pi

And at the input of course, we are giving the signal with a 0 voltage here and at the output we are getting the signal all right. So, that is about the how we are mapping the circuit into voltage amplifier. Note that this model, it is valid for low frequency as well as in the mid range frequency.

However, if you go to higher and higher frequency, then the this device may be having this device may be having its own parasitic capacitances from base to collector it may be having one capacitance and then base to collector it is having another capacitance. So, base to collector capacitance, it is referred as C pi and then we do have the C mu.

These are essentially small signal capacitance associated with the BJT. So, if we are considering small signal equivalent circuit and particularly in the high frequency range, then this capacitor and then this capacitor they are again popping up and we need to consider them. So, we need to consider this C pi and then C mu ok.

Then of course, we can consider their equivalent circuit here which is having the C pi and then C mu. Note that C mu need to be connected to this point not this point ok. So, in addition to that I must say that so far, we are ignoring the early voltage effect namely the dependency of the collector current on the V ce we are ignoring.

But in case if we want to consider whatever the dependency, it is having slight whatever positive slope in the active region and this slope will be represented by finite conductance called g naught which is defined as change in I c with respect to change in V ce.

And this is called small signal reciprocal of small signal output resistance R O. So, if you consider this resistance or this finite slope, what will be getting here it is that one resistance here which is either you can write in the form of conductance or resistance R O and so, this resistance since it is coming in parallel with RC.

And as this is connected to ground, this is also connected to ground. So, the output resistance R O, it will be rather RC in parallel with small R o. So, this represents the complete model of the c e amplifier small signal model of the CE amplifier which is valid for low frequency as well as high frequency. And of course, in the low frequency region ah, then the c pi and c mu they are effected to be very negligible and also this typically this r naught it is quite high compared to R c. So, we may still consider this is R c.

But once we replace this passive element by active element which may be having output resistance comparable with this and then we must have to consider this r naught.

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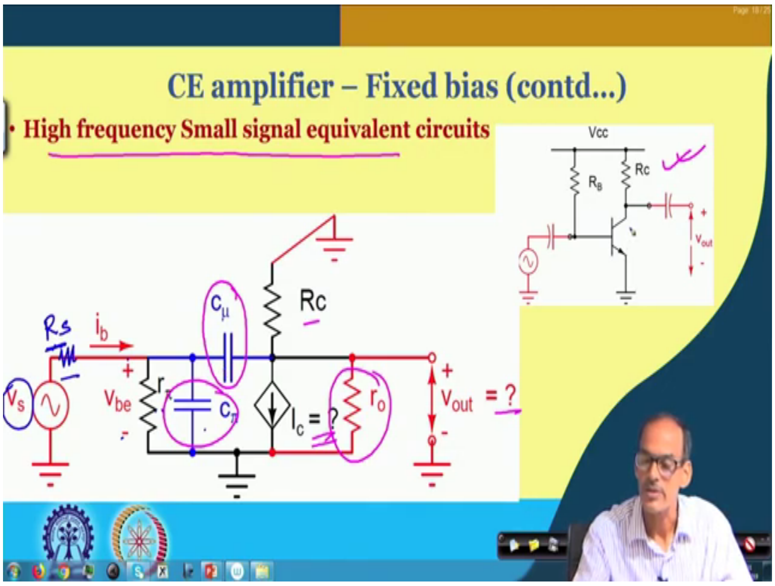

So, to avoid this so much of clumsy things, let me go to the next slide where I have the clear diagram of the small signal model. So, what we have as I said that the in the small signal model we do have r pi and then RC which is the output resistance and so and so, and then we do have this resistance this capacitance and this capacitance, they are getting added up and also to take care of the early voltage effect we do have r naught.

So, this small signal model, it is referred as high frequency a small signal equivalent circuit of the CE amplifier. So, this derivation we already have said. So, nothing to discuss about that and in case I must say one thing, I must add one thing that this in case the source resistance is having source signal source is having source resistance R s, then this voltage need not be same as this one.

So, then we may have to consider this R s and then r pi to consider this voltage and once you go to higher and higher frequency this R s in combination with r pi and then C pi also effect of C mu, you may call it as equivalent input capacitance all of them are going to contribute to define the cutoff frequency of the amplifier.

So, this capacitors are they will be playing important role to define the bandwidth of the circuit. So, whenever the situation comes, we will discuss that in detail. Now let us see or lest let me highlight one issue of this fixed bias CE amplifier is having particularly the operating point it is sensitive to beta of the transistor.

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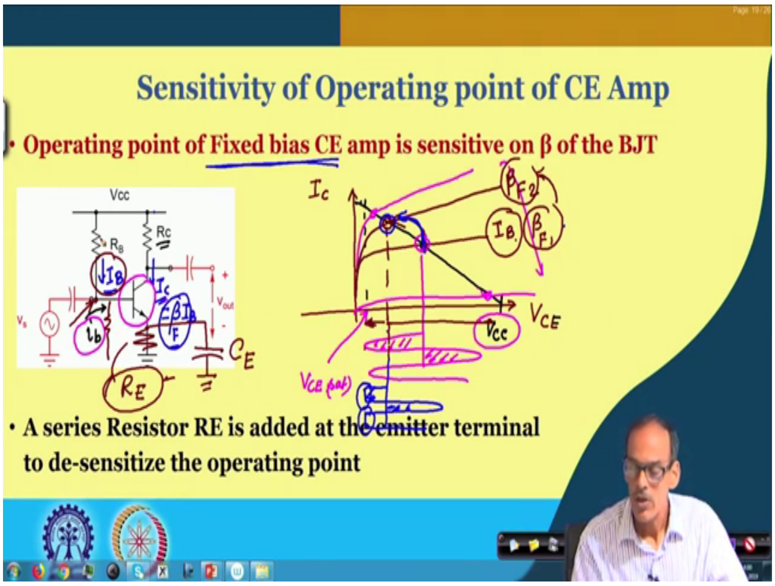

So, then to let me use a different slide to discuss that point. Sensitivity of operating point as I said sensitivity of operating point of the CE amplifier particularly if it is fixed bias. So, if it is fixed bias namely the I B, it if it is decided by this R B and V be one and V cc then the collector current I C which is beta times I B.

So, as a result if I fix this I B and then if I replace this transistor by another one having different value of this beta f, definitely the corresponding I C, it will be getting changed. So, what will be the consequence? To explain that, let me go back to our previous method of finding operating point of the circuit. So, where do we is to draw this I C versus V CE. So, we used to draw I C versus V CE characteristic curve for a given value of I B.

So, I B it is fixed and then also we do, we used to draw the load line. So, is to draw the load line defined by this RC and V CC. So, this node this point it is V CC and so, these two together it was giving the operating point there.

Now typically we like to avoid of course, this point as well as the saturation point and whenever it is to give a signal here, we are adding the I B as a result this total I B, we are expecting that if the signal is present, then it will be going up and down like this one. And as a result this the crossing point of the device characteristic and the load line they used to, it is to move from here to here and as a result it was products in the output voltage.

So, if this operating point is properly set, then if the in presence of I B the I C maybe it is changing over this range and this the meeting point, it was shifting from this point to this point and as a result it was giving the output signal.

And to get a very good swing we want this operating point should be middle of this range. What is this range, which is defined by upper side it is defined by supply voltage V CC and lower side it is defined by the limit of the active region which is referred as V CE set; V CE set saturation.

So, we like to keep this operating point middle. So, that both the lower as well as the upper swing of the signal is to get a good one. Now if you see that in case suppose, we are fixing this R B which is deciding this i b and then if you replace this transistor having different beta.

So, then what it be it would be happening is that this line for the same I B because of different beta it may be getting shifted here.

So, this beta if it is say beta F2 from beta F1, then the q point, now it is getting shifted from here to here. And if the q point it is coming here; obviously, the signal swing if you see this side it will be very much limited. This side it may be getting extended, but since this lower side it is getting limited, then if you apply the signal the signal limit it will be decided by the lower one out of these two limits.

So, as a result if the beta is getting changed from the previous value to this new one, the I C characteristic it is getting shifted here. And then the operating point since it is coming here so, that may create the signal and getting distorted towards the lower side. So, if you still continue giving the same amplitude signal for this operating point so, what we are expecting that, then the corresponding output signal let me draw here. It will be getting huge distortion and this side it may be like this.

So, this distortion of course, for analog circuit it is not acceptable. So, that creates the main problem the change of this beta, it may be due to various region. In case if you want to replace this transistor by another one and you do not know the beta, then it may create problem and to get the same value of the beta using which you have obtained this operating point may not be practically a good solution.

The other problem are which is the typical problem, it is that this beta it is a strong function of temperature. So, in case if the junction temperature of this BJT is increasing this beta, it may increase as a result this operating point it may be going up there. And that may affect the q point operating point of the circuit drastically which is referred as thermal runaway problem.

Why is it called runaway problem? If I C it is increasing due to increase of beta maybe that is due to originally due to increase of temperature and if the I C is increasing and then that may increase the power dissipation of the in the junction and that may further increase the temperature and then that may lead to again increase the beta. As a result it is having cumulative effect to increase the beta and on this q point of the circuit it may it may go towards the saturation limit or active region limit.

So, this problem can be as I said that this is a problem which is referred as the thermal run away problem for C E amplifier particularly if it is fixed bias. So, what is the solution for this is we can add a series register at the emitter. So, if you add one series resistor called R E and then instead of fixing this current probably we can try to fix the voltage here by different means and then we can the we will be seeing that the operating point will be having a better stability.

So, that gives us something called from now voltage bias with emitter degenerated. So, this R E it is referred as emitter degenerated which desensitize the operating point of the circuit, but of course, will be discussing the topic later. But since we are desensitizing the circuit by placing this R E that will that also a affect the gain of the circuit. Now to get back the gain, we need to connect one bypass capacitor.

So, this is this will be discussed in the next day, but just to give a hint that yes C E amplifier with fixed bias it is one good amplifier, but it is having this issue need to be addressed differently and we will see that how this node it will be biased in the form of voltage namely by using a potential divider, those things will be covered in the next class.

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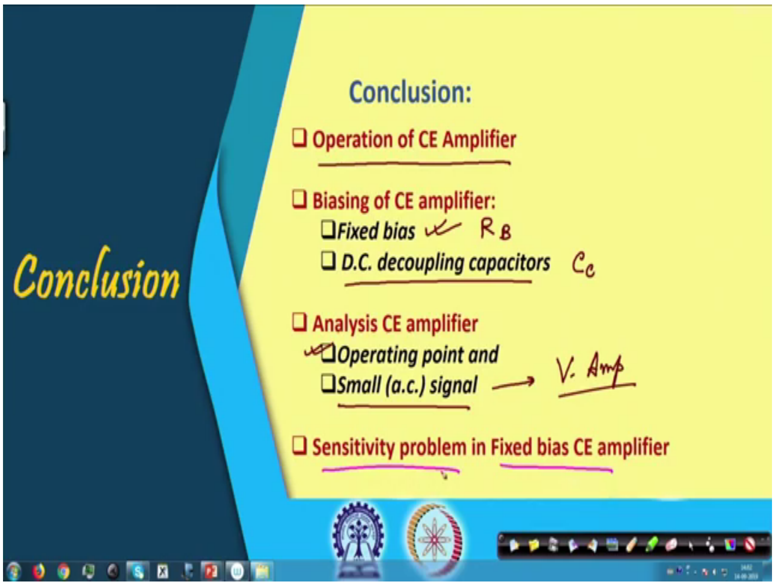

So, what we have discussed today let me summarize. We have started with simple operation of the CE amplifier rather earlier whatever the knowledge we already have gathered that we have discussed. And then we have discussed the biasing of the CE amplifier namely how we define the operating point of the circuit by connecting a base register called fixed bias register R B at the base.

And then we put a DC decoupling capacitor to feed the signal. So, in combination with R B and a capacitor C called coupling capacitor C C to feed the signal, we obtain the appropriate arrangement of the circuit. And then we have analyzed the operating point little detail by considering the input port situation and then output port situation for large signal and then we have discussed about the small signal equivalent circuit.

And then we map that equivalent circuit into a voltage amplifier. At least as I said that typically CE amplifier it is considered as a voltage amplifier. So, that is what we have done. We have mapped into voltage amplifier.

And then finally, we have discussed about the issue for which is existing for fixed by a CE amplifier namely the operating point is sensitive to beta of the transistor and that will be that need to be addressed by different means. So, that will be our next topic of our discussion. I think we are end of it.

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Thank you for listening.