# Solid State Devices

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**Lecture - 28**

## Bipolar Junction Transistor (Contd…)

This is the 28th lecture of this course and the 3rd lecture on bipolar junction transistors. In the previous lecture we basically explained what transistor action is. We said that transistor action is the transfer of current from one junction which is forward bias to a nearby junction. Now this transfer is complete if this nearby junction which is called the collector junction is very close to the emitter junction as defined by this particular relation $W_B$ is much less than $L_B$. $W_B$ is the width of the base region here that is the distance between the two depletion edges.

And secondly, another condition for the transfer to be complete is that the doping $N_E$ that is the doping in the emitter should be much greater than the doping in the base, this is the relation. So, if these two conditions are satisfied then you will have almost complete transfer of the current from the emitter junction to the collector junction or $I_C$ will be very close to $I_E$. $I_C$ is equal to alpha times $I_E$ where alpha tends to 1. Now what is the condition for this transfer on the bias across the collector junction? What we said is that is this bias is 0 that is the collector base is sorted or if the collector base junction is reverse bias then in both these cases the transfer is almost complete. But if the collector junction is forward bias, that is, if it is like this the p-region positive with respect to the n-region then the transfer is seriously affected and the transistor action therefore is seriously affected. So we must ensure that if you want complete transfer of the current from the emitter to collector this junction should either be zero bias or reverse bias.

For the zero bias case the relation is $I_C$ is equal to alpha times $I_E$ so this is when $V_{BC}$ is equal to 0. $V_{BC}$ is the voltage between base and collector. And $I_C$ is equal to alpha times $I_E$ plus a small current if $V_{BC}$ is greater than 0. That is, the base is positive with respect to collector or collector is reverse bias. So in both these cases you have the complete transfer. This is the only small difference in the reverse bias and zero bias case, this current $I_C$ here.

Now in this lecture we will see how the transistor action can be used for the purpose of amplifying small signals. So the topic in this lecture is small signal amplification. Now let us look at the biasing arrangement for this purpose. The biasing arrangement is as follows. Small signal means the emitter base junction is forward biased and this forward bias is incremented by a small value delta $V_{EB}$.

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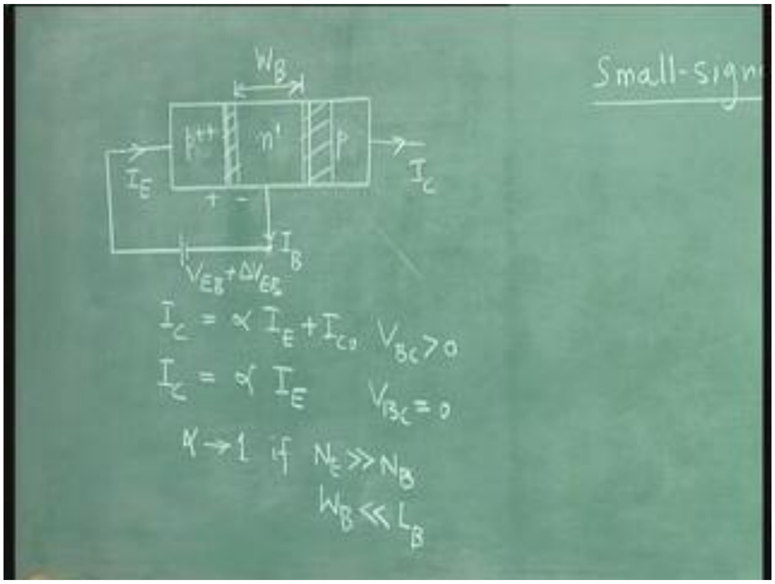


Now as a result of this forward bias change there will be a change in the collector current delta $I_C$. Of course there will be changes in emitter and base currents as well. So, for example, the base current would become $I_B$ plus delta $I_B$ and the emitter current would become $I_E$ plus delta $I_E$. So they are the changes in response to the change in the controlling voltage that is the emitter base voltage. So, the first step of amplification is to relate this change in collector current to the emitter base voltage.

Let us see what is this change delta $I_C$ in the response to delta $V_{EB}$. We can then build up other changes also that is delta $I_B$ and delta $I_E$. And then we will see how this change in collector current can help us to achieve the amplification. Now to begin with we will assume that the collector base junction is zero bias. So here this is shorted so what we will do now is, if you start with the equation $I_C$ is equal to alpha times $I_E$ then we know that delta $I_C$ is equal to alpha times delta $I_E$. This is the first step.

What is delta $I_E$ in response to delta $V_{EB}$ is what we need to see. It can be easily shown that the relation between delta $I_E$ and delta $V_{EB}$ is nothing but the diode relation that is the relation between the current and the voltage across a diode and this can be shown easily as follows. Let us draw the minority carrier distributions in the emitter or base and collector. We are assuming that the base width is very small as compared to the diffusion length $L_B$. So this distribution is almost a straight line as we have pointed out in the previous lecture and this distribution is exponential. So this is emitter this is base and this is collector this is delta $p_E$ and this is delta $n_E$ this is p-type region, this is n-type region and this is again p-type region. So this is the excess minority carrier distribution when the emitter base junction is forward bias and the collector junction is zero bias. We have drawn this in the previous lecture. Using this distribution let us explain the relation between the emitter current and the emitter base voltage.
Now, delta $p_E$ according with the law of the junction can be written as delta $p_E$ is equal to $p_{n0}$ e($V_{EB}$ by $V_t$ minus 1) where the $p_{n0}$ is the equilibrium concentration of minority

carriers in the base region. We can similarly write delta $n_E$ is equal to $n_{p0}$(e($V_{EB}$ by $V_t$ minus 1) where this is equilibrium concentration of minority carriers in the emitter region. Now, we have been using the symbol n suffix p0 also for the electron concentration in the collector under equilibrium. That is minority carrier concentration in the collector because collector is also p-type like the emitter. Now we may therefore think that there can be some confusion.

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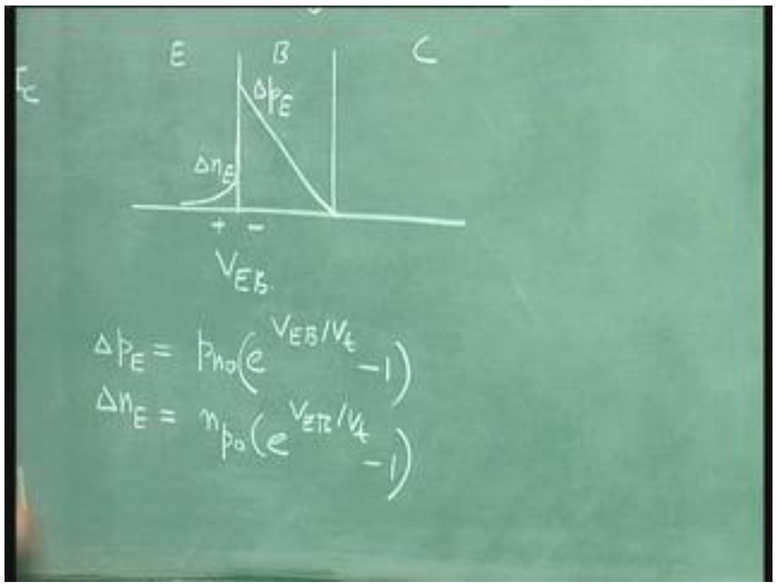


Depending on the context it will be clear whether $n_{p0}$ corresponds to emitter or the collector. For example, here we are talking about delta $n_E$ that is the excess concentration of electrons in the emitter at the depletion edge. Therefore obviously $n_{p0}$ should correspond to emitter. So, depending on the context it will become clear whether $n_{p0}$ is related to the emitter or to the collector. Now, proceeding further how can we write the emitter current in terms of these concentrations? We again follow the PN junction theory and we can write $I_E$ is equal to $I_{Ep}$ plus $I_{En}$ so $I_E$ is the current across this particular emitter junction. $I_{Ep}$ is due to these holes which are injected from emitter into base. And $I_{En}$ is due to these electrons which have been injected into the emitter from the base region.

So we can write $I_{Ep}$ which is q into the diffusion coefficient of the carriers in the base into delta $p_E$ by $W_B$, delta $p_E$ by $W_B$ is nothing but $D_P$ by Dx in the base that is the slope of this line so $W_B$ is this width. Now here we have not shown the depletion edges or rather the depletion layer in the emitter and the collector to avoid complication in the diagram. It is understood that this concentration corresponds to the concentration at the depletion edge. And similarly these other concentration also corresponds to concentration at the depletion edge. So q into $D_B$ into delta $p_E$ by $W_B$ is the current density because of diffusion where $D_B$ is the diffusion coefficient of holes.

Let us explain this nomenclature. We are always going to consider the diffusion coefficient of minority carriers when we talk about the currents in a PN junction.

So we have only one suffix there which shows a region in which the minority carriers are being considered. So, $D_B$ would imply the diffusion coefficient of minority carriers in the base. Now we should multiply this by the area of the emitter to get the current. So this is $I_{Ep}$ in terms of delta $p_E$ that is this current. Similarly we can write $I_{En}$ as area of the emitter into q into diffusion coefficient in the emitter into delta $n_E$ by $L_E$ where $L_E$ is the diffusion length of electrons in the emitter, this an exponential decay so you take the diffusion length of the electrons there. Now, we can combine these relations for delta $p_E$ and delta $n_E$ and then we can write the expression for $I_E$ as $I_E$ is equal to $A_E$ into q[$D_B$ into $p_{n0}$ by $W_B$ plus $D_E$ into $n_{p0}$ by $L_E$] ($eV_{EB}$ by $V_t$ minus 1) because this term will be common for both these terms. Now one can easily recognize that this particular form is nothing but the reverse saturation current of the emitter junction and we will therefore represent this as I suffix E0. This is nothing but the diode law $I_E$ as a function of $V_{EB}$ the exponential and this is a reverse saturation current.

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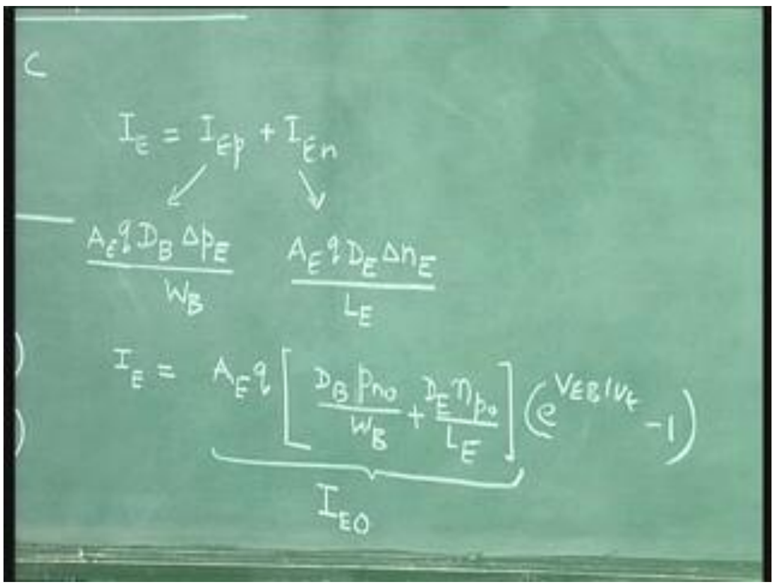


So, as compared to the PN junction theory we have discussed earlier the only difference is that here for this term instead of the diffusion length we are having the width of the particular region. And this is because this is like a short region and therefore the diffusion length in this region is being replaced by $W_B$ that is the width of that region because as we have said in our transistor $W_B$ is much less than $L_B$ for the device to act like a good transistor or to have the efficient transistor action. That is why $L_B$ is being replaced by $W_B$ here and this is the difference. Now we can write this formula $I_E$ is equal to $I_{E0}$ ($eV_{EB}$ by $V_t$ minus 1).

And coming back to our relations here we need to obtain delta $I_C$ which is given by alpha times delta $I_E$ in response to delta $V_{EB}$. So now we can get delta $I_E$ in response to delta $V_B$ using this formula. So we can write delta $I_E$ is equal to $I_{E0}$ ($eV_{EB}$) by $V_t$ by $V_t$ into delta $V_{EB}$ where in if $V_{EB}$ by $V_t$ is more than about three times $V_t$ which will practically be the case ($eV_{EB}$ by $V_t$) is much greater than 1 and therefore $I_{E0}$ $e(V_{EB}$ by $V_t)$ is nothing but $I_E$ itself. So we can write this as approximately equal to $I_E$ into delta $V_{EB}$ by $V_t$.

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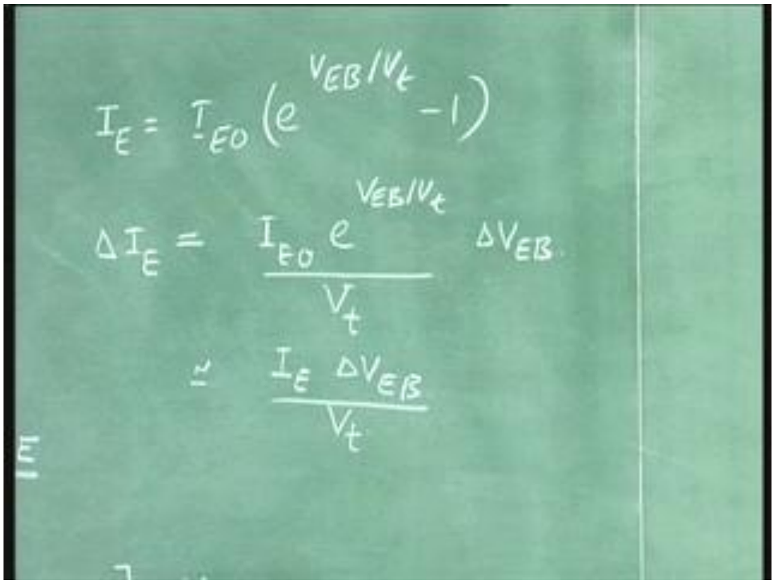


The increment in the emitter current is proportional to the increment in the emitter base voltage and the proportionality constant is $I_E$ by $V_t$. So substituting this relation in this formula here we can write delta $I_C$ is equal to alpha times $I_E$ by $V_t$ into delta $V_{EB}$ where in alpha times is $I_E$ nothing but $I_C$. This can be further simplified to $I_C$ by $V_t$ into delta $V_{EB}$. So delta $I_C$ is nothing but $I_C$ by Vt into delta $V_{EB}$. So increment in the collector current is proportional to the increment in the emitter base voltage. This is a consequence of the exponential dependence of the emitter current on the emitter base voltage. And since most of the emitter current is transfer to the collector the collector current also depend on the exponentially on emitter base voltage. Therefore when you differentiate or when you take the increments you end up getting a linear relation between the increment in the collector current and the increment in the emitter base voltage. This term $I_C$ by $V_t$ has dimensions of 1 by resistance or conductance and therefore we can represent this using a symbol gm and we can write this as gm delta $V_{EB.}$ This $g_m$ is called the transconductance. That is the relation between the increment in the collector current and the increment in the emitter base voltage.

Now, let us see how this increment in the collector current can be used for purposes of amplification. Suppose we pass this current to a resistor R and we try to find out the voltage change across this resistor as compared to the change in the emitter base voltage. Let us try to relate the change in the emitter base voltage to the change in voltage across this resistor R because of the increment in collector delta $I_C$. Now we shall call the increment in the voltage across the resistance as delta $V_0$ that is we shall assume that the voltage across the resistance is the output voltage. The $V_{EB}$ emitter base voltage is the input voltage and voltage across this resistor is the output voltage. So we will denote this as delta $V_0$ and we write delta $V_0$ is equal to R into delta $I_C$.

Now, expressing delta $I_C$ in terms of delta $V_B$ we can write the relation delta $V_0$ by delta $V_{EB}$ as R into $g_m$ where delta $I_C$ is nothing but $g_m$. So delta $V_0$ by delta $V_{EB}$ is simply $R(g_m)$ where $g_m$ is $I_C$ by Vt. Now $I_C$ corresponds to the voltage $V_{EB}$. So, when you make an increment in the emitter base voltage what you find is that there is an increment in the voltage across the resistor which depends on $g_m$ and R. Now, if R into $g_m$ is greater than 1 then we find that we have amplification because delta $V_0$ is more than delta $V_{EB}$. The change in the output voltage is more than the change in the input voltage.

Let us put some typical values and see how much can delta $V_0$ by delta $V_{EB}$ be in practice. Let us assume these values which are typical $I_C$ is equal to 1 mA supposing we set up 1 mA of current in the transistor. Let us take room temperature so $V_t$ is 0.026 volts and let us assume a resistance of 1 kilo ohm. R into $g_m$ is given by 1000 ohms into 1 mA upon 0.026 volts. So ohms into ampere by volts this cancels giving a dimensionless quantity 10 to the power minus 3 and this cancels so 1 by 0.026 that is 1000 by 26. So R times $g_m$ is equal to 1000 by 26 so this is close to 1000 by 25 that is about 40 maybe less than 40 and that maybe around 38 or something. We want just an approximate figure so it is about 40. So you find that the change in the voltage across a resistance is forty times the change in the voltage across the emitter base junction. This is what is meant by amplification.

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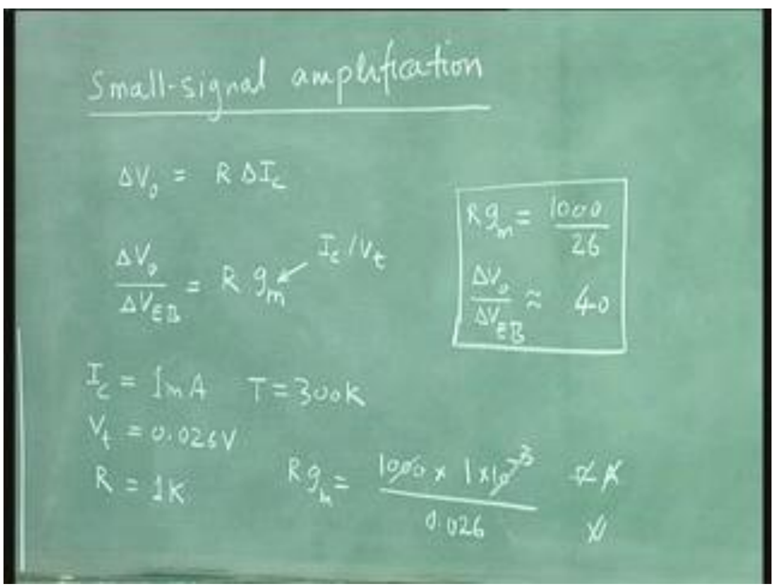


This is what small signal amplification is. So, delta $V_{EB}$ is the input small signal and delta $V_0$ is the output small signal and the ratio between these two small signal voltages is 40 so you are getting voltage amplification here. We emphasize that this amplification is for small signal. So we are not taking the ratio between $V_0$ and $V_{EB}$, this $V_0$ is the voltage across the resistance are because of this current $I_C$ plus delta $I_C$ and $V_B$ is the DC voltage so we are not taking the ratios of the DC current the total current and total voltage. We are taking the ratios of the increment in the voltage across resistor and the increment in the emitter base voltage. This is therefore an incremental picture. This is what is meant by small signal amplification. Now there is one catch here and that is, if you pass this current $I_C$ through the resistor it develops a voltage drop which is like this. Now delta $V_0$ only correspond to $I_C$ so strictly speaking this is $V_0$ plus delta $V_0$. Since we are only concerned about the delta $V_0$ in response to delta $I_C$ we showed as delta $V_0$. So this is the voltage drop because of $I_C$ plus delta $I_C$. Now obviously this voltage drop is going to come here, it appears like this across the junction.

The moment you put a resistance here in this collector to base lead actually your collector base junction has got forward bias by this much amount. And if there is a forward bias across the collector base junction then your transistor action is destroyed. We cannot write $I_C$ is equal to alpha $I_E$ where alpha $I_E$ is very close to 1. Now, that being the case, actually this formulae we have derive are not valid for this particular circuit unless we do something to bring this voltage back to zero bias. If you can bring this voltage across the collector base junction, that is, back to zero bias then all that we have discussed is valid.
Now this is what is important for using the transistor as a small signal amplifier.

One simple way of doing that is you include a battery whose polarity is opposite to that of the battery here. That would mean we must include a battery which is positive on the base side and negative on the collector side. Now you can see that when you go like this then this voltage will compensate this voltage and if you choose this battery to be exactly equal to $V_0$ plus delta $V_0$ then this voltage will return to 0. Let us call this voltage $V_{cc}$ that is c stands for collector. So this is actually a collector voltage between collector and base.
Now if $V_{cc}$ is exactly equal to $V_0$ plus delta $V_0$ then the collector base voltage is zero and then this formula is valid.

Now can you always maintain the $V_{cc}$ is equal to $V_0$ plus delta $V_0$?
Obviously this is not possible because delta $V_{EB}$ means you are changing the emitter base voltage and this is going to change the delta $I_C$ and delta $V_0$. So, as you go on changing your emitter base voltage your delta $V_0$ will change so you have to keep changing your $V_{cc}$ in conformity with the emitter base voltage. So, if $V_{EB}$ for example is a sinusoid your $V_{cc}$ will also have to be a sinusoid of appropriate amplitude because it must compensate this voltage. Now it is obviously not possible, you cannot have a battery whose voltage is going on changing with time, this is practically not possible so what you do?
Now this is where we make use of another result that we obtained in the previous lecture. That is, even if the collector base junction is reverse bias the transistor action is not seriously affected and we can still write $I_C$ is equal to alpha times $I_E$ except that there is going to be a small current $I_{C0}$. But when we take increments delta $I_C$ in response to delta $I_E$ because of delta $V_{EB}$ there will not be any significant change in $I_{C0}$. This current is a reverse current of the collector base junction which is reverse bias.

Once a reverse bias is more than three times $V_t$ any change in the character base reverse bias does not change this $I_{C0}$. And therefore we can still write delta $I_C$ is equal to alpha times delta $I_E$ when we take increments because delta $I_{C0}$ is 0 and if that is the case this formula will still hold even if this is reverse biased. Now, what this means is that we can choose a $V_{cc}$ whose value is such that it compensates this voltage whenever it is maximum. So this $V_{cc}$ is equal to $V_0$ plus delta $V_0$ the maximum value of this. And when this voltage reduces because of change in the emitter base voltage then the junction will get reverse bias to a certain extent. For example, let us take $V_{cc}$ is equal to $V_0$ plus delta $V_0$. Supposing this is what we have chosen and when your delta $V_{EB}$ increment this maximum then this is the voltage and at that point this is zero bias.

Now suppose this voltage becomes $V_{EB}$ and therefore this current becomes $I_C$ and therefore this becomes $V_0$ then you can see that a bias equal to delta $V_0$ will appear here but it would be reverse bias because this voltage is more than this voltage, the bias with this polarity and under that condition this equation will be valid but for incremental purposes same old equation we considered will be valid and therefore our entire analysis will hold. Therefore the moral of the whole story is that you will have to include a power supply in this lead whose magnitude is equal to the maximum voltage drop across the resistor then your emitter base voltage is changing. Now this is the circuit that will behave and it will give you amplification. Is there any effect of reverse bias across a collector on the amplification? We said that as far as this equation is concerned the collector current is equal to alpha times $I_E$ plus $I_{C0}$.

The $I_{C0}$ is the only addition as far as DC is concerned. Now, as far as AC is concerned, that is when you make increments in the currents is the amplification not affected by the presence of a change in reverse bias across the collector base junction? So let us examine this issue in little detail. The effects of reverse bias across the collector base junction. There are two main effects we will show. The first is the following. Now because of the presence of $I_{C0}$ the difficulty is that if the temperature goes on changing which is what can happen in practice then this $I_C$ will be changing with temperature even if you keep your $I_C$ constant by maintaining $V_{EB}$ constant.

Supposing you consider the situation when there are no increments so you have set up a $V_{EB}$ here and as a result you have a current set up in the transistor. Now, for some reason the temperature starts changing, this happens in practice. What are the reasons because of which temperature can change? One reason is that the transistor is dissipating power and this power is dissipated as heat. After all you have voltages and currents in the transistor and obviously the voltage into current that much power is dissipated in the device and that power is dissipated as heat therefore the temperature of the transistor can raise.

Similarly, ambient temperature can rise. The temperature of the room in which you are setting up this device as an amplifier can rise. So because of such reasons temperature can change and in such a case this $I_{C0}$ will change rapidly with temperature. We know that $I_{C0}$ is the reverse saturation current of a PN junction and as we have explained it doubles approximately for around every 8 to 10 degree C rise in temperature for silicon diodes. So, for silicon transistors also similarly $I_{C0}$ will change rapidly with temperature. Now as a result of this the bias point of the transistor under DC conditions can shift which is also called as the quiescent point. So it is the shift in quiescent point with temperature.

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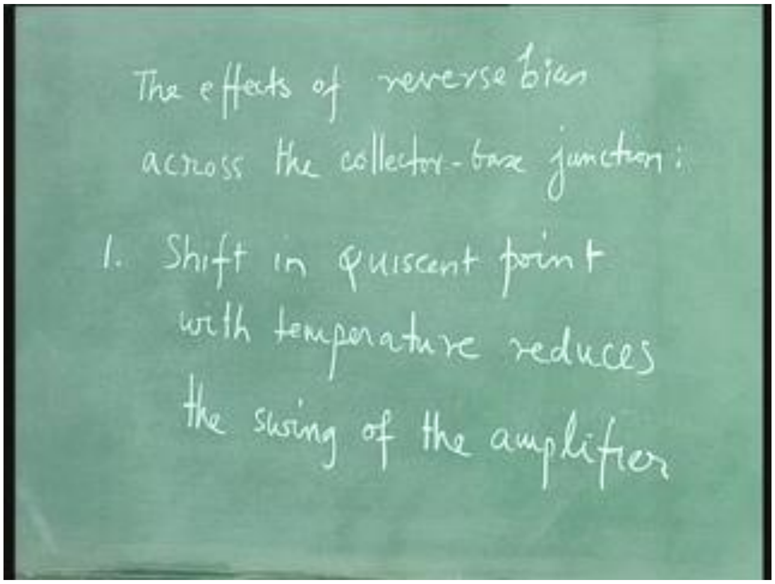


I want to emphasize what is meant by the quiescent point. Quiescent point means the collector current and the collector base voltage when there is no signal when there is no disturbance. The word quiescent means calm. This means the condition when there is no delta $V_{EB}$. When there is no signal you have a certain collector current here and then you have a certain collector base voltage. Both these $I_C$ and $V_{CB}$ is referred to as the quiescent point so what is happening is that when your temperature increases the $I_{C0}$ changes rapidly as a result of which $I_C$ changes because of which $V_0$ changes because of which the $V_{cc}$ minus $V_0$ which is the voltage drop here goes on changing.

What is the effect of that?
The effect is that your swing capacity of the amplifier is reduced. That is the maximum signal amplitude that can be amplified is reduced. What is the maximum signal that you can amplify? This depends on the difference between $V_{cc}$ and $V_0$ when there is no signal. If the $I_C$ is more this voltage drop or $V_0$ is more the difference between this $V_{cc}$ and $V_0$ is less. Therefore you can only increase $V_0$ until it becomes equal to $V_{cc}$. If $V_0$ becomes more than $V_{cc}$ then this will be forward bias and the transistor action will be destroyed. So the difference between $V_{cc}$ and $V_0$ that is the difference between the voltage drop across the resistor and the collector power supply represents the maximum voltage that you can get at the output as result of the signal amplification. So signal voltage that you can get at the output depends on the difference between $V_{cc}$ and voltage drop across R which depends on $I_C$.

If $I_C$ is more and that difference is less then the maximum swing of the amplifier, the maximum input voltage that it can amplify or the maximum output signal voltage you can get is reduced. So shift in quiescent point temperature reduces the swing of the amplifier. This is one effect of the reverse bias across the collector base junction. This is happening because this $I_{C0}$ cannot be control by any means. This is dependent on temperature and this cannot be controlled. And even if I want to maintain $I_E$ constant I cannot control this

$I_{C0}$. So this lack of control of this current that is coming about because of reverse bias is the cause of the shifting quiescent point with temperature.

The next important thing that happens is the reduction in amplification because of what is called base width modulation. Let us understand what is this base width modulation. The base width modulation is the change in $W_B$ with change in $V_{EB}$ or $I_C$ because of change in the depletion width here. The voltage drop across this junction depends on the difference in the voltage of the power supply and the voltage drop across R. When you introduce a signal $V_{EB}$ changes, $I_C$ changes, this voltage changes and this voltage here is changing. So when the amplification is taking place and signal amplification is taking place collector base voltage is changing with time. Therefore the depletion width is also changing with time.

Now because of a change in depletion width the $W_B$ is also changing. So this variation in $W_B$ in the presence of signal is what is called base width modulation. Let us see how the base width modulation can reduce the amplification. When the collector current is at the maximum the difference in these voltages is the minimum here. Therefore the depletion width across the collector junction is small. When the depletion width is small the base width is large. Let us show this effect by exploding this particular portion of the diagram. So we will exaggerate the collector base depletion width for one. This is the collector junction, this is the emitter junction, this is the collector base depletion width. This is emitter p plus plus, n plus and p. So this is the collector depletion width for one reverse bias across the collector base junction.

This is another collector depletion width for another reverse bias across the collector base junction a higher reverse bias. So, when the collector current is more $V_{CB}$ is less so let us say this dotted line corresponds to the current $I_C$ then the solid line depletion-region will correspond to $I_C$ plus delta $I_C$ because when the collector current is more this voltage is more and the difference in this voltage which is this voltage is less so the depletion width is less. So $I_C$ plus delta $I_C$ is solid line, this and $I_C$ is the dotted line. Therefore this is the difference in the width of the base region. So we have not shown the emitter depletion layer here but you can show that. The change in this is small so we are not showing the change here. So this difference from here to here is the base width so this is the delta $W_B$.

Now this is the base width modulation effect. As a result of this base width modulation your amplification will reduce. How do we show that? We know that the change in the base width is going to affect the alpha of the transistor. So, in this particular equation delta $I_C$ is equal to alpha delta $I_E$ is not exactly correct when the base width modulation is present because this assumes that alpha is constant when you make the change. So the correct equation in the presence of base width modulation is delta $I_C$ is equal to alpha delta $I_E$ plus delta alpha $I_E$. Now, depending on this delta alpha your delta $I_C$ in presence of base width modulation can be more or less. For example, if this delta alpha is negative then this term will subtract from this and therefore in the presence of base width modulation your increment in the collector current will be less because of increment in the emitter base voltage.

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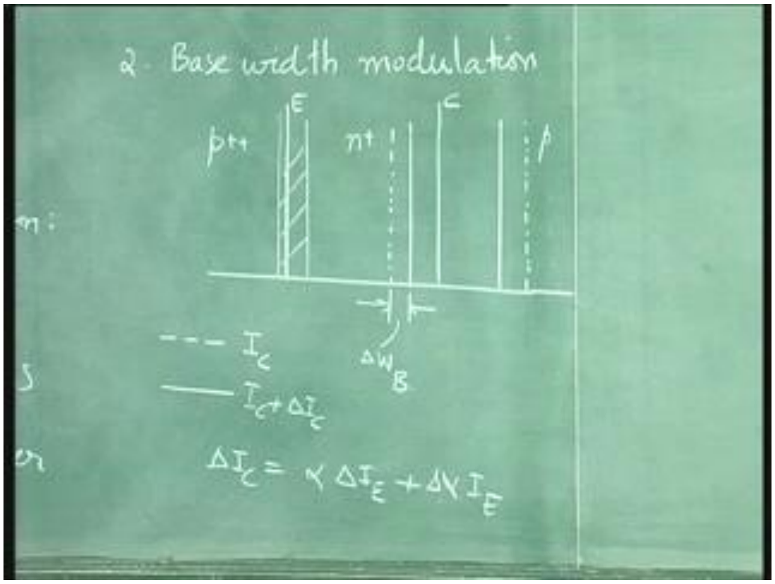


We will exactly show what happens, delta alpha is negative when you increase the collector current the alpha decreases and delta alpha is negative. How do we show that? For this purpose we must derive an equation for alpha. This equation can be derived as follows. The equation for alpha is gamma into b where gamma is injection efficiency and b is base transport factor where gamma is 1 by 1 plus $I_{En}$ by $I_{Ep}$ and B is 1 minus $I_r$ by $I_{Ep}$. The base transport factor b is nothing but $I_{Cp}$ the hole current reaching the collector divided by the hole current injected from the emitter. And that hole current reaching the collector is nothing but the current injected from the base minus the recombination taking place in the base. So, from there we get this relation. Now you can write equations for these terms using the equations for minority carrier concentration.

Now $I_{En}$ by $I_{Ep}$ will depend on delta $n_E$ and delta $p_E$. We can write this as delta $n_E$ into q into DE by $L_E$. I shift this $L_E$ here; $I_{Ep}$ is q delta $p_E$ into $D_B$ by $W_B$. Of course you also have the emitter areas coming both in numerator and denominator. Now this q cancels and $A_E$ cancels and delta $n_E$ by delta $p_E$ we can write in terms of the doping levels. So delta $n_E$ by delta $p_E$ will be in the reverse ratio of the doping in the emitter and base. That is, delta p is inversely proportional to doping here. So doping in the base will come in the numerator and doping in the emitter will come in the denominator. So $I_{En}$ by $I_{Ep}$ is, we can remove this and write it the other way. So, by transferring that information here this is equal to 1 by 1 plus $N_B$ $D_E$ $W_B$ by $N_E$ $D_B$ $L_E$.

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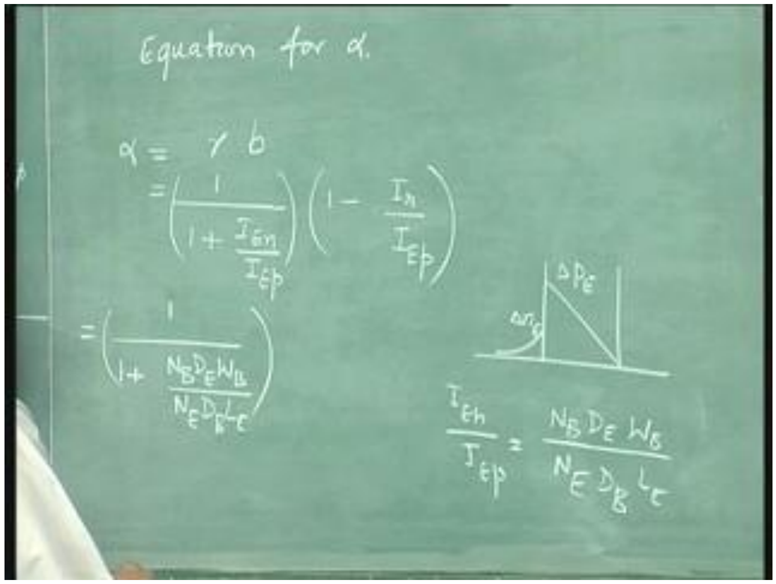


Similarly we can write $I_r$ by $I_{Ep}$. $I_r$ is the recombination current which is related to this area so we can write $I_r$ by $I_{Ep}$ here. Now this area is half of delta $p_E$ into $W_B$ this is the area under the triangle this difference is $W_B$ the base width.

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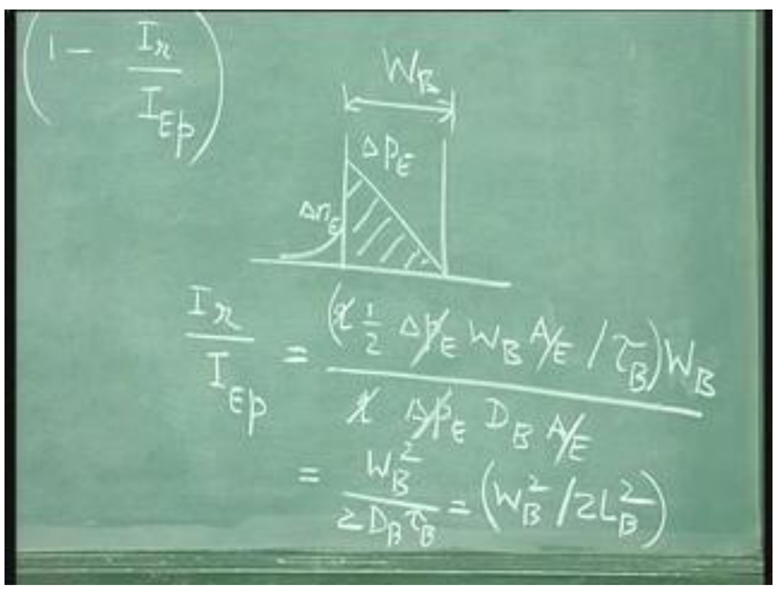


Now this area is multiplied by the charge q multiplied by the area of the emitter $A_E$. So $A_E$ into $W_B$ is the volume and the recombination current will depend on this stored charge divided by the lifetime in this region. Let us call the lifetime in the base region as tau$_B$ so charge by lifetime this is from the law of the junction, it is a recombination in this region.

So divided by $I_{Ep}$ we can rewrite that equation which we wrote for $I_{Ep}$ as Q delta $p_E$ $D_B$ into $W_B$ because the slope of this line is delta P by $W_B$ so this is delta P by $W_B$.

Of course the area of the emitter also comes there. Now we can see that we can cancel this q, we can cancel this delta $p_E$, can cancel this $A_E$ and then this is equal to $W_B$ square by 2 $D_B$ into $tau_B$ which is nothing but $W_B$ square by $2L_B$ square and we got $W_B$ square because of this $W_B$ into $W_B$. So $I_r$ by $I_{EP}$ is $W_B$ square by $2L_B$ square. So we can write this here. This is the expression for alpha and it shows how alpha depends on base width $W_B$. You can clearly see that if $W_B$ is much less than $L_B$ this quantity is negligible and therefore it becomes close to 1.

Similarly, if $W_B$ is much less than $W_B$ and also if the base doping is much less than emitter doping this quantity is very small and again this tends to 1 and that is how alpha tends to 1 for $N_B$ much less than $N_E$ and $W_B$ much less than $W_B$. Now what is important to see from here is that, as your $W_B$ increases your alpha this term will increase and also this hole term will become less and therefore your alpha is going to reduce. So, as $W_B$ increases alpha reduces. Therefore because of increase in $W_B$ the increment in alpha will be negative. So when you increase delta $I_C$ what you have seen is that the collector base voltage reduces which means the depletion width reduces and delta $W_B$ therefore is increasing. So, base width modulation is increased in the base width when your collector current is increasing. And increase in the base width causes alpha to fall. Therefore delta alpha in response to delta $I_C$ will be negative.

So we can write this as alpha delta $I_E$ minus modulus of delta alpha into $I_E$. Now this is a positive quantity subtracting from this quantity and therefore it clearly shows delta $I_C$ is negative. Therefore the increment in the collector current is reduced, it is not negative it is still positive because this is more than this but the increment in the collector current is reduced. Therefore your amplification is affected it is reduced because amplification depends on delta $I_C$. This explains how base width modulation reduces amplification.

We can write this statement as $W_B$ increases alpha falls therefore the base width modulation we will abbreviate as $BW_M$ base width modulation. Therefore $BW_M$ reduces amplification. These are the two effects of the reverse bias. So, base width modulation affects amplification to some extent and also it results in change in the quiescent point width temperature which affects the swing. But for these two effects your gain of the transistor is quite large as we have shown that the voltage gain is large and therefore the device works very well as amplification.

Now please note that it is a small signal amplifier and we are only amplifying small signals. So you are super imposing a small signal over a DC voltage and you are amplifying that small signal or disturbance. Now, if there is amplification then it means there is a power gain. So how can there be gain in power? Your output signal power is more than input signal power. How can this happen because conservation of energy should be there. It is to be understood here that there is an increase in the ac power. If you see the input power of the small signal here and compare that with the small signal output power the output small signal power is more than input small signal power. But this output extra small signal power is coming from the power supply. So what the amplifier is doing is it is converting DC power into ac power that is why it is called an active device. Transistor is called an active device because it converts DC power into ac power. The diagram is something like this. You have a DC power as input you also have an ac power as input. Now you have ac power output.

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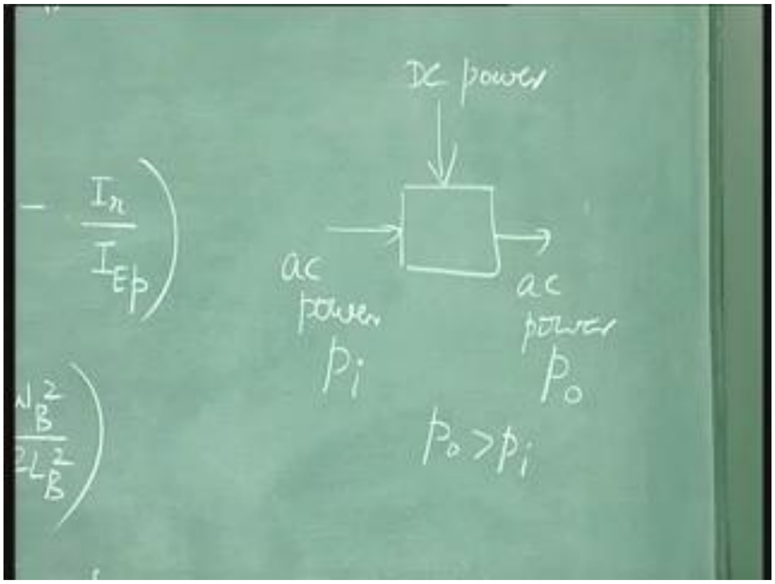


Now this small signal ac power $p_o$ and if this is $p_i$ $p_o$ is greater than $p_i$. But there is this DC power that is coming in. So you are supplying energy from the power supply. And one should not think that you are getting something out of nothing. You are getting ac power amplification but definitely you are supplying DC power and only in the presence of DC power the amplification can take place. So unless you have DC conditions maintained you have $V_{EB}$, $I_C$ and $V_{cc}$ you cannot have this small signal amplification. With this we complete the important application of the transistor action namely small signal amplification. We have explained how you can get the voltage gain. But you can also show how you can get a current gain, and we will see this in the next class.