**Video Course on Electronics**

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**Module No. #02**
**Transistors**
**Lecture No. #03**
**Transistors (contd.)**

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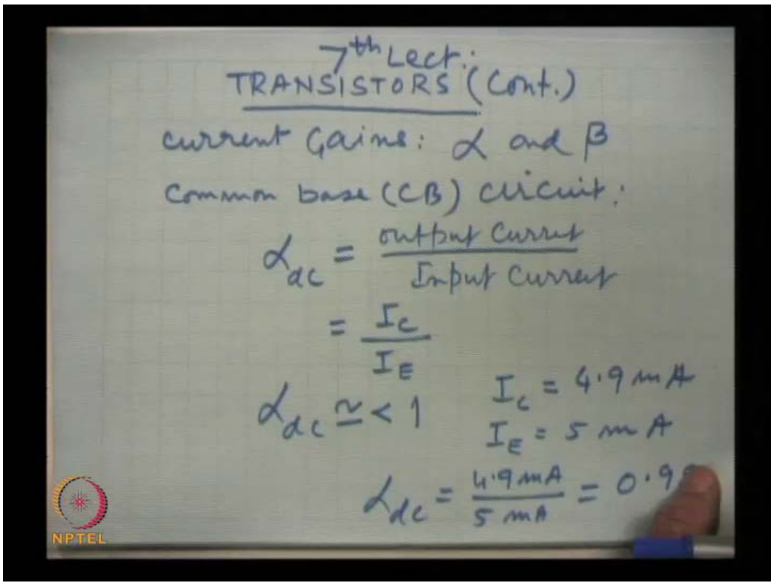


We continue our discussion on transistor. And now we take the two current Gains, which is often encounter with the transistors; the one is called alpha. Alpha is the Current Gain, which is the observed in common base circuit that is CB circuit, and this is defined, because at present, we are considering the dc signals. So, we defined alpha dc is the ratio of as I said earlier that for gain, the fundamental definition remains the same output versus input. When we talk of current gain, then it is output current to input current; and in the CB circuit, common base circuit you will recall that the output current is collector current, in input current is the emitter current. So, always remember that the current gain alpha is for common base circuit, and we defined it is the ratio of collector current to emitter current. We also will recall what we have said earlier that emitter current is slightly higher than collector current. Most of the electrons in n p n transistor, they cross over to the collector region and finally, they are collected, but a small portion of the electrons get recombined in the base region which constitutes, what we called the base current.

So, alpha dc is very close, but less than unity and let us see, as an example, that if I C, the collector current is 4.9 mille Ampere and this is produced by emitter current of 5 mille Ampere, then alpha dc 4.9 mille Ampere divided by 5 mille Ampere. So, this is equal to 0.98 close to one, but less than one and common base circuit is the important case when we talk of the working of transistor and in many other situations. So, alpha dc is the fundamental quantity that we will remember, but it is less than 1. So, in fact in common base there is no Current Gain, in fact, because output current is less than the input current. So, there is a power loss, in fact that is still, because of this ratio is always called as Current Gain, so we call it Current Gain.

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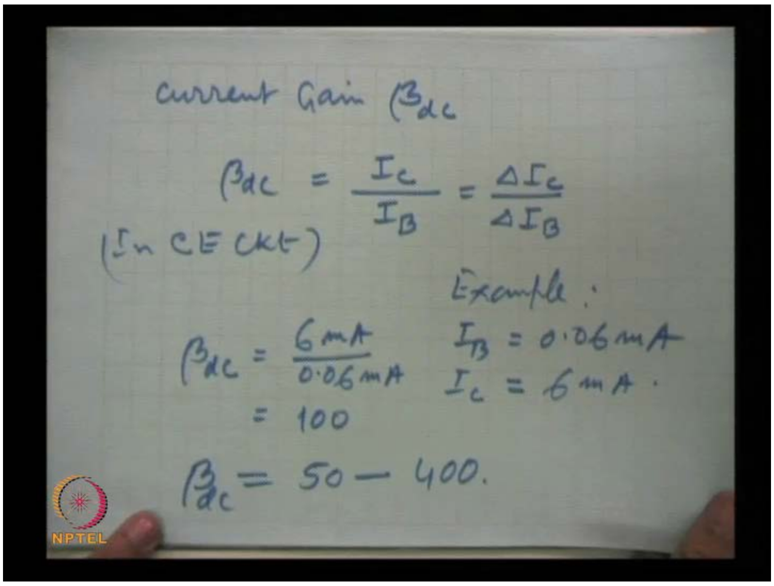


Then there is another Current Gain, which is called beta Current Gain. Beta and is we are discussing the case of dc. So, we call it beta dc and beta dc is the Current Gain in common emitter circuit. Always remember, alpha is the Current Gain in common base circuit and beta is the Current Gain for common emitter circuit and the output current here, again is the collector current and the input current is now, I B the Base Current. Base current is very small in comparison to the collector current therefore, this is very high. This can also will define in terms of the change in delta B delta I B is the change in the base current and if this gives rise to change in the collector current of delta I C, then this ratio, this is actually the way we can define and find out experimentally, the value of current gain beta and so, this is current gain and this is very high. Now, let us take as an example as an example that I B of the say 0.0 6 mille Ampere produces the collector current in common emitter circuit of the order of 6 mille Ampere, then beta dc is equal to 6 mille Ampere divided by 0.0 6 mille ampere so, this is 100. Beta is very high and normally, for the commercially available transistors, we will see that beta is one of the most important parameter for a transistor. In all analysis beta will be there. So, beta in general, varies for all practical transistors in the range say 50 to 400. There is a large number of transistors and they have different parameter similarly, this is the value which goes almost in this range. Then what is the relationship between alpha and beta. If we know one, other can be calculated. So, there has to be relation between alpha and beta.

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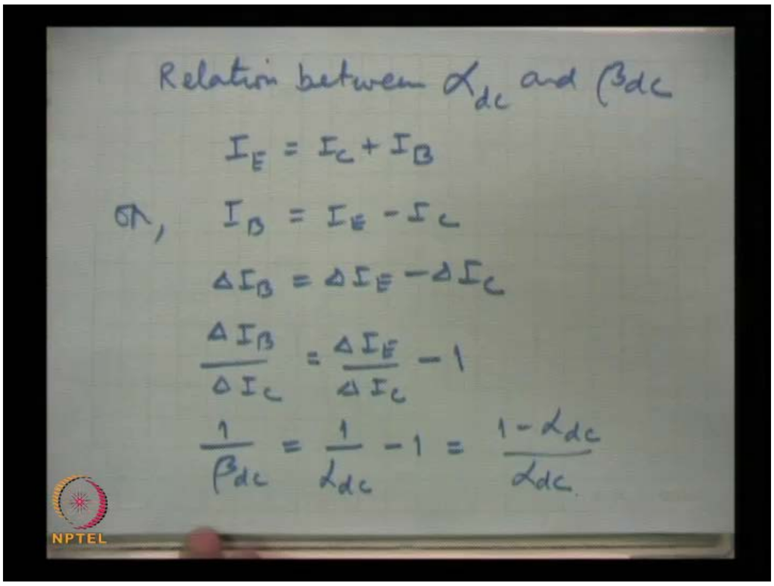


So, we derive this in very simple relation. We can derive it and we write the relation between the Current Gains alpha dc and beta dc. The fundamental equation that how the three currents are related in a transistor, this we know the fundamental relation is I E, is equal to I C plus I B. We will recall that emitter current breaks up into two regions, one is the base region, were some of the electrons get recombine and which are responsible for the base current and the remaining one. See 99 percent electrons they have crossed over to the collector. So, I E is made up of I C and I B and now, this can be written is I B or I B is equal to I E minus I C. If we write in terms of changes, then we can simply write, change in I B is equal to change in I E and change in I C and this can be written as delta I B divided by delta I C. This is equal to delta I E divided by delta I C minus 1. Now, this is inverse of beta dc so, this is 1divided by beta dc and this is inverse of the alpha dc. So, 1 divided by alpha dc minus 1 or this is equal to 1 minus alpha dc divided by alpha d c.

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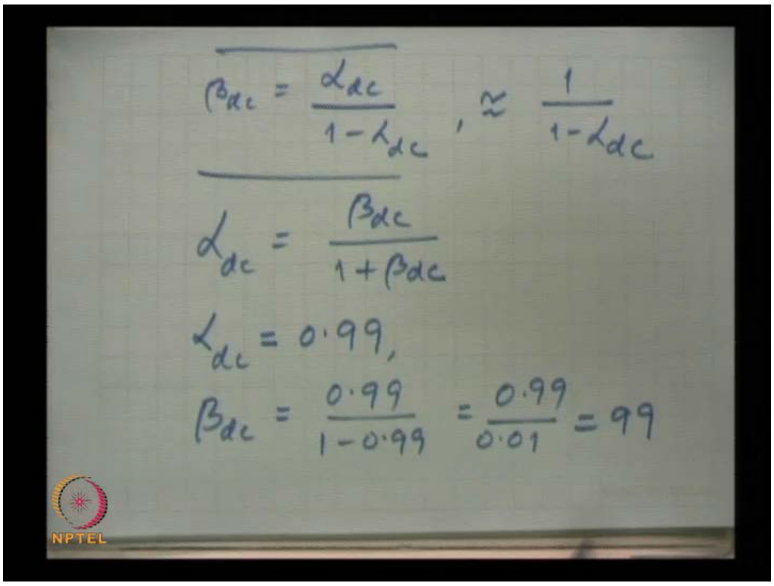


From here, we get the relationship that beta dc is equal to alpha dc divided by 1 minus alpha dc. This is simple relationship which here we use to get the value if alpha is known, beta can be found out or if beta is known, then alpha can be out. From this equation we can write also alpha in terms of beta that is alpha dc is equal to beta dc divided by 1 plus beta dc and hence you are seeing that is will be slightly less than 1.

The values of a… for example, if alpha dc has value of 0.9 9, then using this equation we can get beta dc is equal to 0.9 9 divided by 1 minus 0.9 9 which is equal to 0.9 9 divided by 0.0 1 which is 99. Many times, because this is close to 1 so, beta d c is taken approximately and this is within few percent and the tolerance of few percent is very much expectable in a is accepted in electronic circuit. So, this may be taken as approximately as 1 minus 1 minus alpha dc. If we use this data it will come 100. So, error of just 1 percent, but it may be 2 percent are so in other cases. So, this was about the relationship between the Current Gains. While we have talked about three circuits:

common base circuit, common emitter circuit and common collector circuit. We will study that all these three circuits in details and we will realize that out of these three for various reasons; one reason you have seen here that current gain in common base is very small, but current gain in common emitter is very high. This goes in fewer of common emitter circuit, but there are many more important futures of common emitter circuit. So, common emitter circuit is most widely used. Now, we derive the relation for the current, collector current in the case of CB circuit earlier. Now, we should have a relation of a the output current. What is the total output current in the case of the common emitter circuit and again there are some hidden important points in that.

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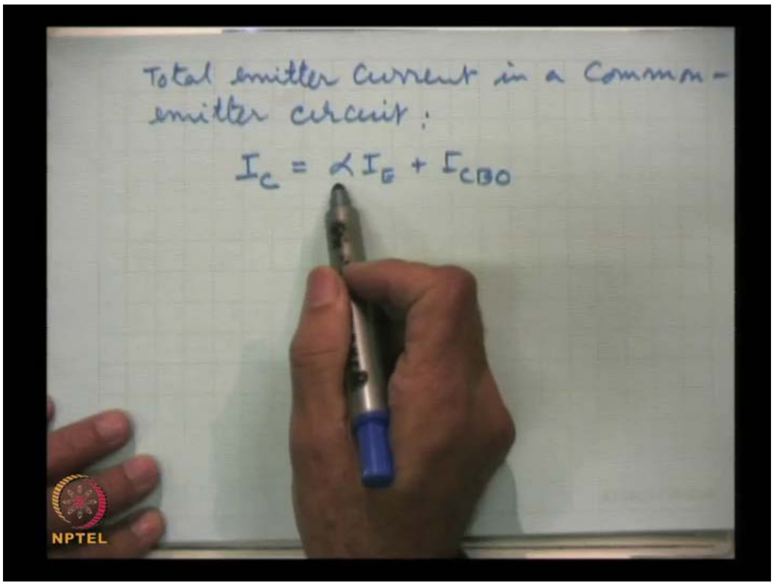


So, this is total emitter current in a common base common emitter circuit. You will remember that we derived we arrive that the expression for total current in common base circuit and this was equal to alpha I E plus I CBO. We said the alpha is the constant and now, we know what this alpha is tens, alpha and alpha dc is one in the same thing. Actually, why we have put dc when a c is proposed on the circuit, for example, we are interested in the amplification of the a c signals so, a c signals will be super imposed over dc.

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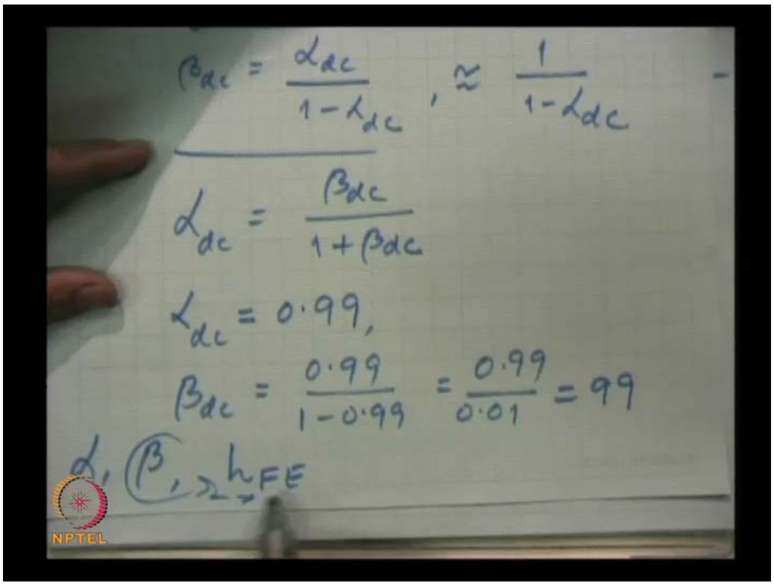


So, then there will be is small variation in these values and that is known as simply beta or alpha and then we talk of h parameters later. Then this is same as h F E beta is same as h F E, this is forward current gain in common emitter circuit. Any way so, alpha we talk that alpha is the current gain.

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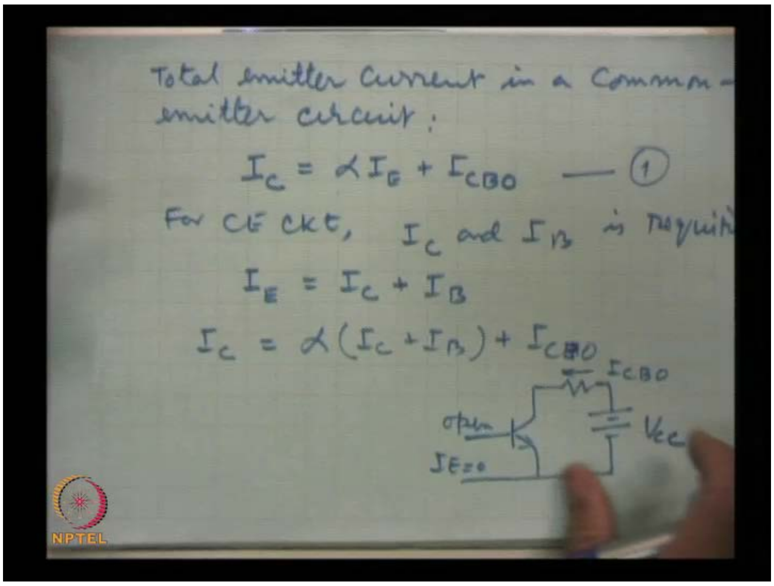


Now, we need a relationship between I C and I B. For CE circuit, a relationship between I C and I B is required is required this we can have in this equation we call it for example, equation 1 we substitute I E equal to I C plus I B we put this here in the first equation, then we get I C equal to alpha I C plus I B plus I CEO I CBO and you will remember this factor was there, because the collector junction is a reverse biased and why we put o, because this is measured when the emitter circuit is open. For example, we can take this arrangement. This is I E is kept 0, this is open and here this is I CBO. When we apply the reverse biased voltage to the collector, then this is the current which will be flowing and we can measure by putting emitter. For example, in series with this circuit so, this is that and now, this equation will continue we further look at it and this can be put in this form.

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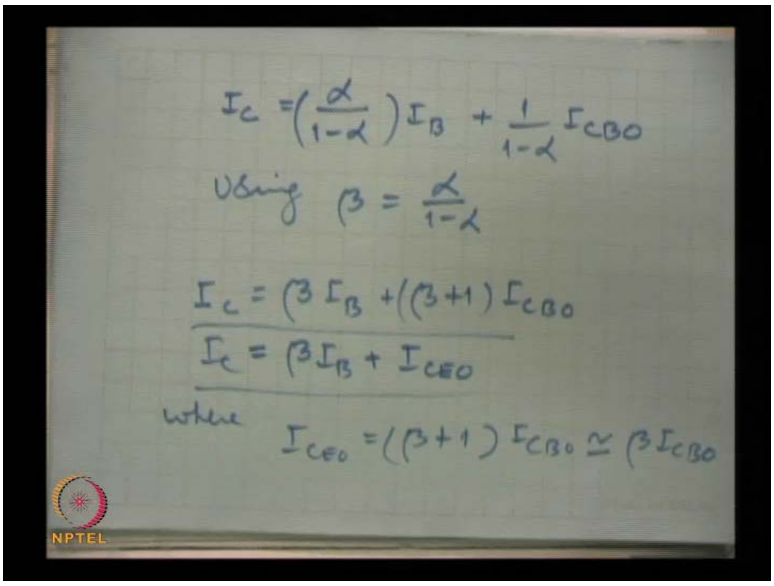


I C is equal to alpha divided by 1 minus alpha into I B plus 1 divided by 1minus alpha into I CBO. Using the relation for beta, beta is alpha divided by 1 minus alpha, then this equation becomes I C equal to beta I B plus beta plus 1into I CBO and this can be written in the form, beta I B plus I CEO, where we have put I CEO for beta plus 1 into I CBO, beta being very high in comparison to unity. So, this 1 can be neglected here. So, this is very closely equal to beta into I CBO. This is something significant that we have talked earlier that the useful current is only this part. This part is a parasite does not play important role, but now, in the common emitter circuit this becomes much higher in this case it was a in the common base circuit it was simply I CBO, but in common emitter circuit which is in the discussion at the movement this is amplified by beta times.

So, this is to be noted and our effect should be to reduce the value of I CBO itself, as much as possible and then there are other corrective measures which we will be talking. So, this is about in the total current in the common emitter circuit. We talked about the fundamentals of transistor and we will process is the alloying process and the diffusion process which are used to fabricate transistors and we have also talked from time to time, about what makes the efficient transistor.

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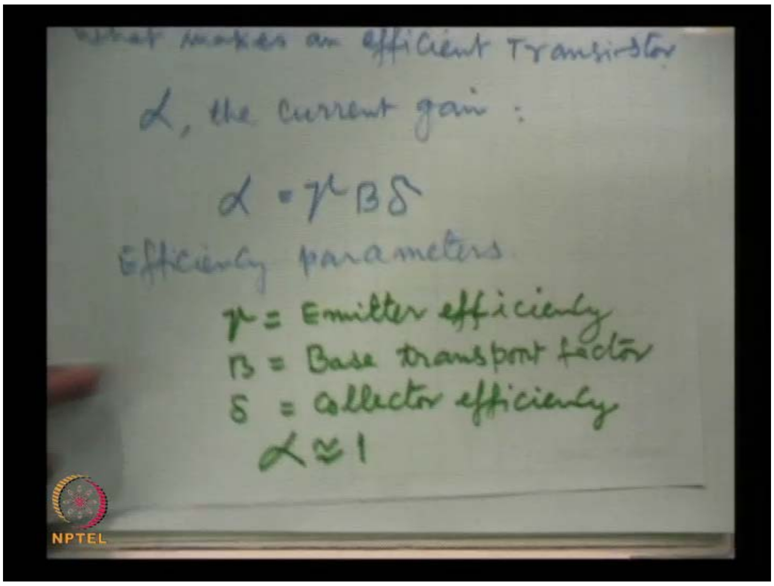


Let us look at this point little in more details that is what makes the efficient transistor. Current Gain alpha is fundamental and all effort should be to make alpha the current gain as you are unity as possible and this depends if they go in greater details, then alpha dependents on three factors. So, alpha is equal to gamma B delta. These are called efficiency parameters efficiency parameters. We will discuss one by one, we are said that alpha should be closed to one that means all these parameters ideally should be unity. Now, what are these here gamma is called Emitter efficiency Emitter efficiency B is called Base transport factor and delta is called collector efficiency. We talk about all these three efficiency parameters one by one. Remember, our objective is to maintain to keep the current gain alpha S close to 1. If possible, and for that will requirement is that all these three parameters individually should be close to unity.

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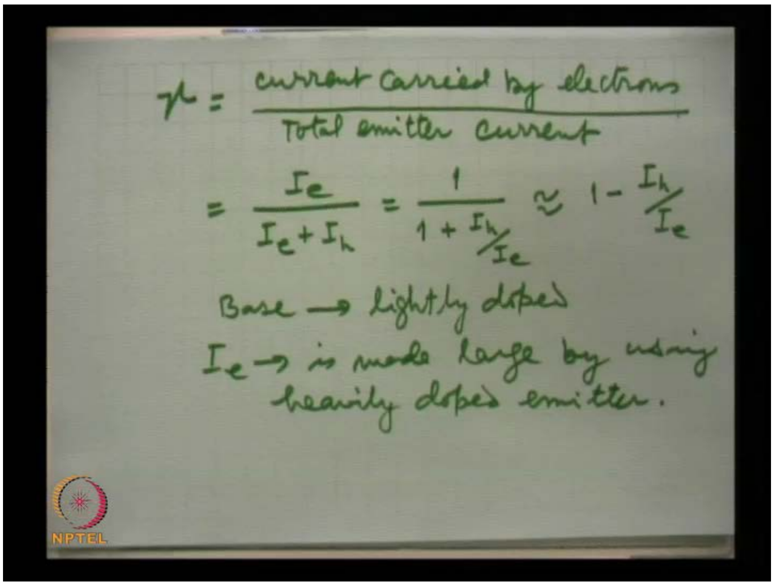


Now, how we define the emitter efficiency that is gamma, emitter efficiency. We have talked about current earlier and we have seen that emitter current has two components. If we talk either of n p n or p n p, but currently we are talking n p n transistor then this is defined as total current current carried by electrons divided by total emitter current and this electron component to the emitter current, we write is I e and total current has two components, the electronic component this we have discussed earlier electronic component and hole component and this can be written is 1 minus 1 plus I h hole component and electronic component and which can be approximately we take up in expand with then this will be 1 minus I h divided by I e.

So, obviously this factor I h divided by I e that means current carried by holes should be less and current carried by electrons should be high and how we achieve in practice that this hole current arises because of diffusion from base region. So, Base region base we keep lightly doped, very lightly doped that will reduce this hole contribution to the current and we increase I e, I e is made large by using heavily doped heavily doped emitter. Now, I am sure you are realizing what was made as a strict meant earlier. If you remember the first lecture and second lecture, then these points were just is stated and it was said that later on things well become clear. So, I am sure now, you realize that why the base was kept low doped, lightly doped and emitter very heavily doped.

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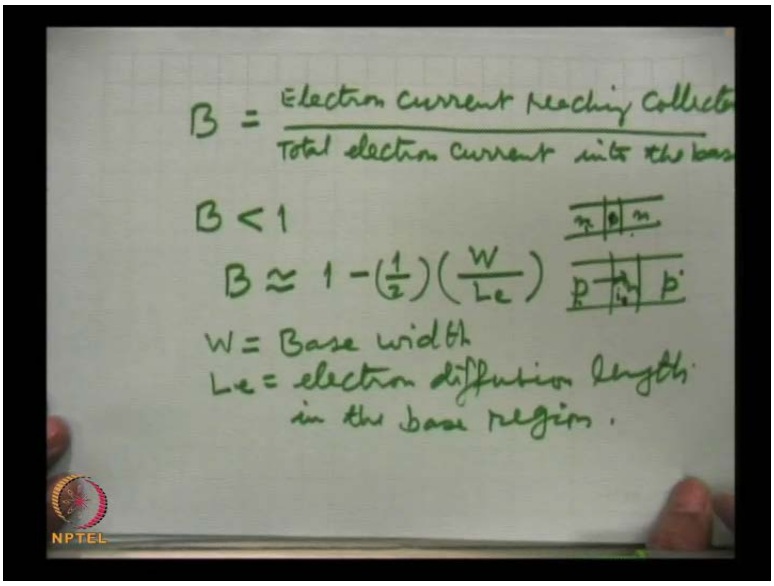


Similarly, the other parameter that is the base transport factor B, base transport factor this is this is this measures that how efficiently the electron current in n p n transistor has been transported to the collector. So, this is defined as the ratio of Electron current electron current reaching collector divided by the total electron current into the base that means the total electron current injected into the base and this beta obviously because of this is reaching collector. This number slightly is smaller because the because there will be recombination. So, obviously this base transport factor B is less than 1, but how we can this is because of the electron loss the recombination in a base and we cannot get rid of that completely. So, how to make this base transport factor close to one that we will see that detailed analysis shows that B is very closely equal to 1 minus half into w divided by L e where, w is depletion with base width not a base weight and L e is the electron diffusion length electron diffusion length in the base region and this base transport factor B to be equal to 1 very closely equal to 1, w has to be low. So, base width we use very small in width. Here this was base; this is n p n end.

Electron diffusion length in the base region should be made high to make this factor is still is smaller and again this is a chip by making base region very lightly doped. The more lightly doped is the region; high will be the electron diffusion minute diffusion. Why transistor is called is minority operator device, because see electron when injected into base they in the p region, they are in minority. If we talk of p n p transistor, p n p then it will be hole diffusion and length in the base region. Now, holes will be injected into base and they will be finally, collected here. So, this is the holes are also in p n p transistor. Holes are in the minority in the n region, n the role of electrons in n p n or holes of holes in the p n p transistor in the base region. They are minority region and this is the more significant part in the transistor operation. So, transistor in bjt bipolar transistor is the minority operator device. It is current operator, everywhere we are talking of current and hence it is a current operator device, minority operator device, if you talk of the electron diffusion length.

This is we are talking electrons in the p base region, which is again here the electrons are minority as in p n p holes in the minority n. So, by making base width low and by diffusing, by using diffusing lightly doped region, we can increase the electron diffusion length making this parameter as a small as possible and hence we will be close to one. The third is that the collector efficiency delta.

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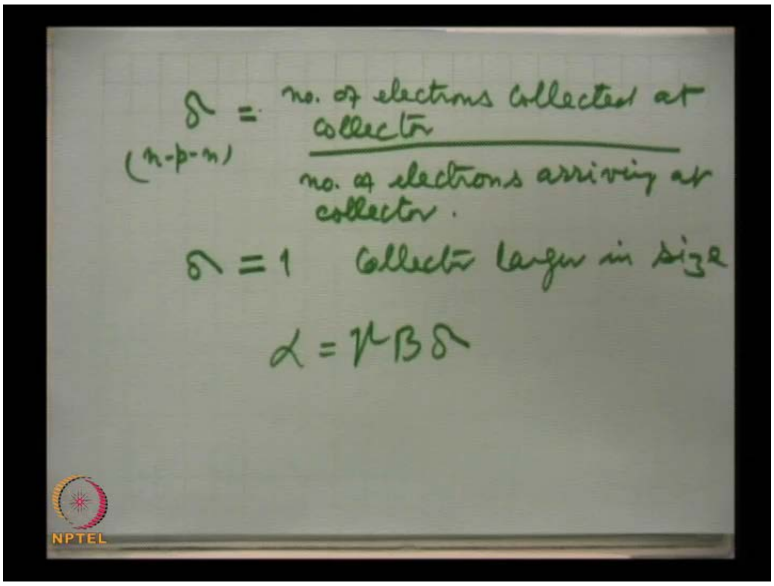


Collector efficiency delta this is again for n p n transistor. This is number of electrons collected at collector divided by the number of the electrons arriving at collector. In almost well design transistor, this collector efficiency is very close to 1. It is equal to 1 and how we get one, because we keep the collector larger in size then base region in the emitter region this was said in the beginning when we talked about the sizes of the three regions.

So, in summary the efficient transistor, the alpha is composed of three component, we are we have talked that this emitter efficiency can be obtain closer to one by making the hole diffusion in n p n transistor less, that means by doping the base lightly. This is the base transport factor and this we have seen this to make it closer to one it meet base width less and diffusion length of electrons that large enough and that is achieved by keeping the base again lightly doped and off course this collector efficiency is a closer always for well design and transistor is equal to 1, because there is no loss of electrons. The size of the collector is kept higher as compare to other. So, this is about how we can make a symbol efficient transistor. Transistor is the electronic device and it is the behavior is governed and then we will decide various uses. The I-V characteristics are important.

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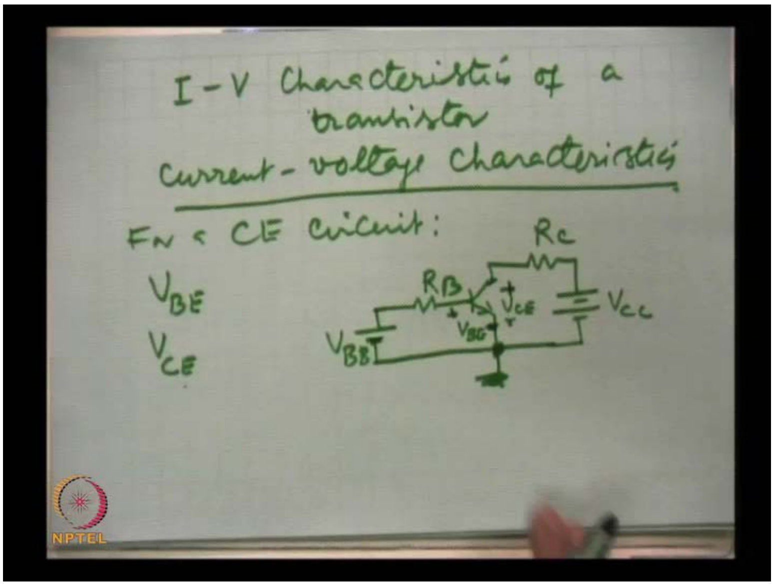


So, I-V characteristics: current-voltage I-V characteristics of a transistor, I-V that is current voltage, Current-voltage characteristics. We are often talking about that common emitter circuit is most widely used common emitter. So, these characteristics, we will be drawing for common emitter circuit in bring out the salient futures of these characteristics. They are not different there are some variations at some point in the common base and common collector circuit, but more or less they remain the same.

So, it is good enough, if we talk about the I-V characteristics, in the common emitter circuit. So, for a CE circuit in the laboratory this can simply be done. We can draw these characteristics and here is a simple circuit. This is a simple circuit to measure current voltage characteristics of the transistor in a common emitter circuit. Here now, we should familiar with the terminology which is used. The collector battery is the represented by V cc, the base emitter battery is represented by V BB. The resistance which is connected to base is written as R B. B is the subscript and this resistance with the collector RC. The voltage drop between base and emitter, emitter is one terminal, often ground it. So, this is the positive voltage drop, this is minus and this is designated as V BE.

Voltage drop between base and emitter similarly, here this is V CE V CE look at the polarity plus, minus and this is the voltage between the collector and emitter. So, let us be familiar with this. Now, there are two sides of the circuit, the input and the output and accordingly, there are input characteristics and output characteristics. Here what I have shown that the input battery has been connected to forward base, the base emitter junction and this battery V cc has been connected such that it will reverse base the collector junction, but we can change, if we change it the other way, we will see what impact it will have.

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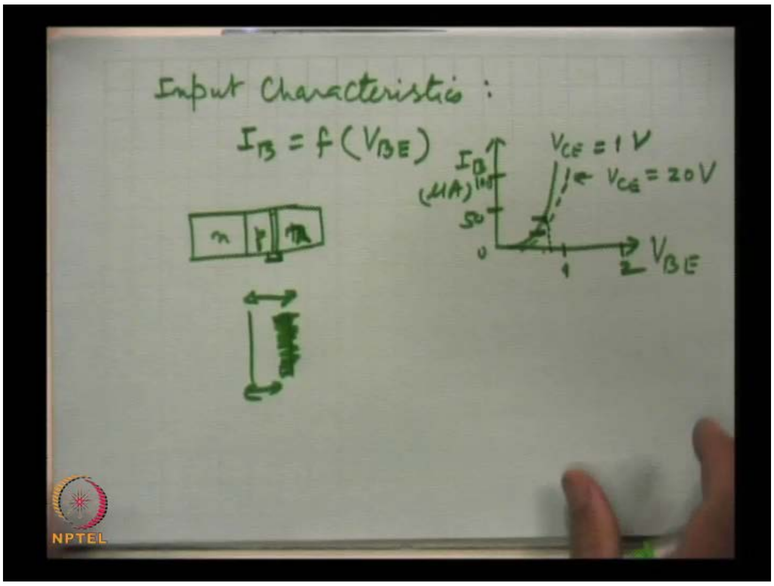


Now, first we talk of the input characteristics; input characteristics for that this is plotted these characteristics are plotted I B as a function of input voltage V E and we can plot and here this is V BE and this is I B and this is normally in Micro Amperes for example, 100, 50, 0. 0, 50 and here it is 100. This is the voltage; this is 1 volt and 2 volt. Now, look here, we can change the base current I B by changing either by changing this voltage and we can plot this is the simply a forward biased junction. Remember that what kind of characteristics we talked, when we talk about the forward biased p n diode.

So, similar kind of this is when we keep V CE that means that output side this voltage, because now, we will discuss that input characteristics are also function of the output voltage will talk that. So, this kept at 1volt, then we change the voltage and we get the current and there is the exponential rise and from here of course, we can find out the input resistance of the circuit. Now, if we change this output voltage say, from 1 volt we make it 20 volt, then there is a some change in these characteristics.

This is for V CE equal to 20 volts. What does it indicate that for the same voltage. Now, the current has fallen, earlier it was this current now, this is current. So, there is the small fall in the base current. Now, this is, because of the fact, the base you know that the depletion width is a function of applied voltage this we have talked and depletion region here, there is the one depletion region and this depletion width will increase, because this junction, collector junction is here. This collector junction is reverse biased. Now, very important point, that the spread will be there and this is spread will be more in less doped base region, because in comparison of the collector this is collector, base is more lightly doped. So, when depletion region broadens, because of we have change the voltage from 1 volt to 20 volts.

Now, there is 20 volt across this. So, this was the base with 1 volt and this depletion region will be more spread in the base region, because this is more lightly doped region. As a result, the base width will fall and hence recombination this is the recombination current, base current is the recombination current, and when base width has fallen from this much to this much, the lesser number of holes will recombine and hence the current will fall. So, that explains input characteristics as the function of the collector emitter junction voltage and then the output characteristics, which are much more important than the input characteristics.

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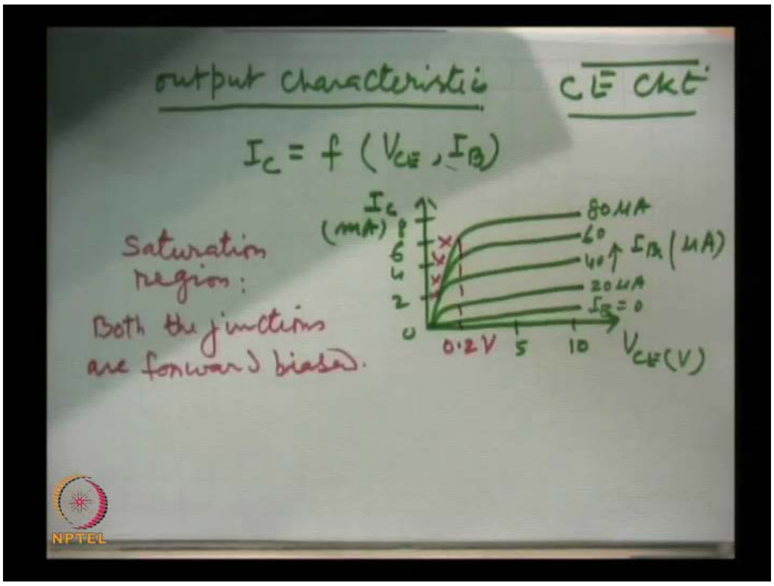


The output characteristics: The output characteristics I C, the collector current, the output current is supposedly function of V CE and of course I B and I want to remained you that we are talking of CE circuit and we can plot this characteristics, they are very important many important parameters which we have been using, they can be calculated, they can be determined this characteristics and these are; we change I B here for different values of I B, we measure first we keep this voltage constant, and we measure the collector current by putting the emitter here and so, then we keep on changing that voltage and we get set of characteristics like this. This is I B. This is for example in mille micro Amperes, this is I C, this is mille Amperes normally, 2 4 6 8 and this is 5 volts, 10 volts and so on. This is V CE in volts and these are the characteristics here. For example, this is I B equal to 0; this is I B equal to 20 micro Ampere, 40 micro Ampere, 60 micro Ampere, 80 micro Ampere and so on. These are output the characteristics.

These characteristics, these can be divided into three different regions. One region is this, this region, left of this and this is called saturation region. Saturation region here I will show you that both junction both the junctions are forward biased. Look here, when this V cc, when this is very small and actually for silicon transistor, this is just point to 2 volts.

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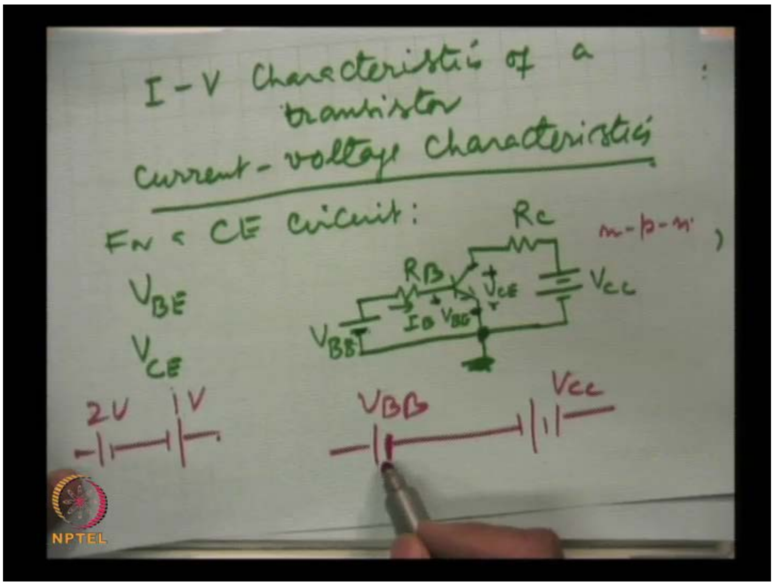


So, when these are the two batteries, this is V BB this is V cc output them just in one line they are in series. If there is very small if there is small then this will be dominating very simple if you take for a example, a 2 volt battery with this polarity two volts and you connect here the 1volt battery with this polarity this is 1volt, then what will be the effective potential difference of the two in this polarity will be dominating. So, this will be like this. So, this is negative and this is the small, this battery will be dominating and hence this is negative, this is n p n transistor.

Collector is n type, when it is gets n battery connection, it becomes forward biased. So, for very small values of this V CE, this battery will forward biased this junction. So, that is why I have mentioned that both the junctions in saturation region or forward biased. This is the region which is to be avoided for amplifying purpose is, because here we have already discussed that current, that the output current does not vary linearly with input current and so, this is to be avoided and totally and to check whether the transistor is in saturation or not there is the condition.

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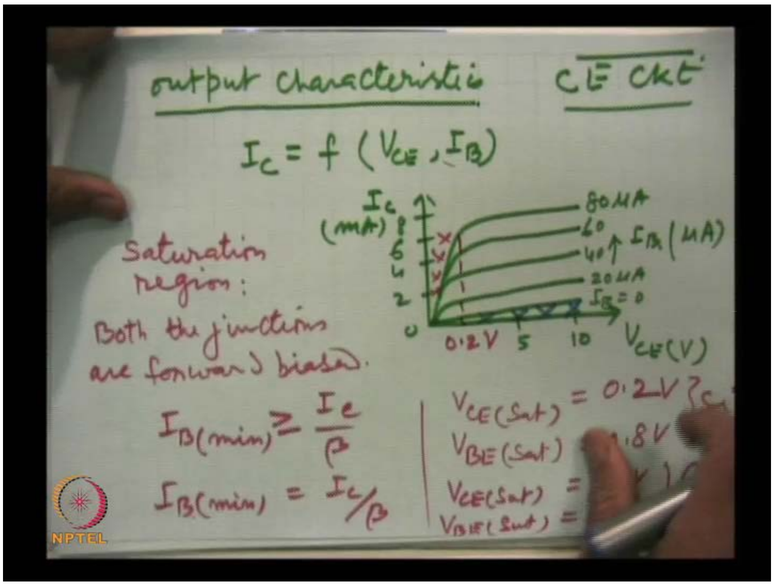


That base current minimum has to be equal to or greater to I C by beta. So, in general we can write the minimum I B, minimum has to be equal to I C by beta. If this condition is satisfied, then because this these this is state is used in digital electronics, and there we will have to see that the transistor is put two saturation. So, then this condition is used for any circuit we can find out the current.

We will take one example, how to find out the currents in a circuit and then this condition can be applied to see whether this is in saturation and the values of saturated voltages, which are also important V CE set in saturation for a silicon device is 0.2 volt and V B E in saturation is 0.8 volts, this is for silicon device; and for germanium V CE set is 0.1 volt and V B E set is 0.3 volts this is for a germanium transistor. Now, we continue with this region this region is called the cut off region. This is the region below I B equal to 0 this is called cut off region.

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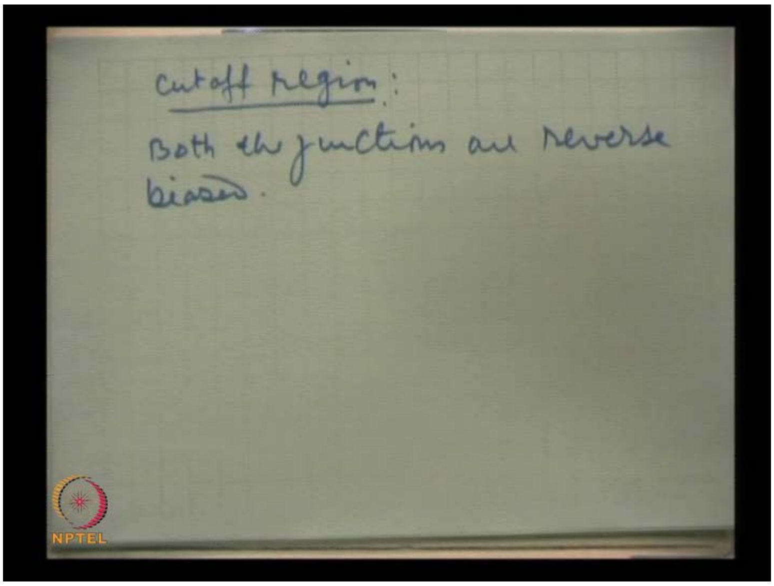


In cut off region, both the junctions are reverse biased, both the junctions are reverse biased how if we want to go, if we want to go below I B equal to 0, we will have to change the polarity here.

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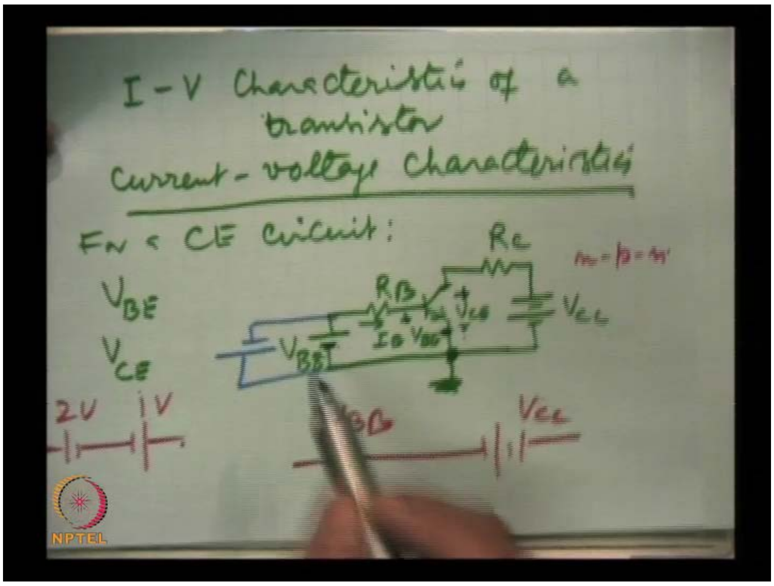


So, once we make it, this is B type base getting negative voltage. So, that junction is reverse biased, and of course the output junction is already reverse biased. So, both junctions are reverse biased. And here these also we have discussed that in amplification purpose is this region also is not to be used. These two regions, the cut off and the saturation region are useful, and are used in digital circuit, when transistor acts as a switch.