Video Course on Electronics

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Lecture No. # 08

Module No. # 02

Transistors

We were discussing the I-V characteristics of a transistor we are taking n p n transistor in the circuit and the characteristics are basically identical with slight differences in for CB circuit, CE circuit and CC circuit and because for various reasons common emitter circuit is a most widely used. So, we are taking the characteristics of the series circuit.

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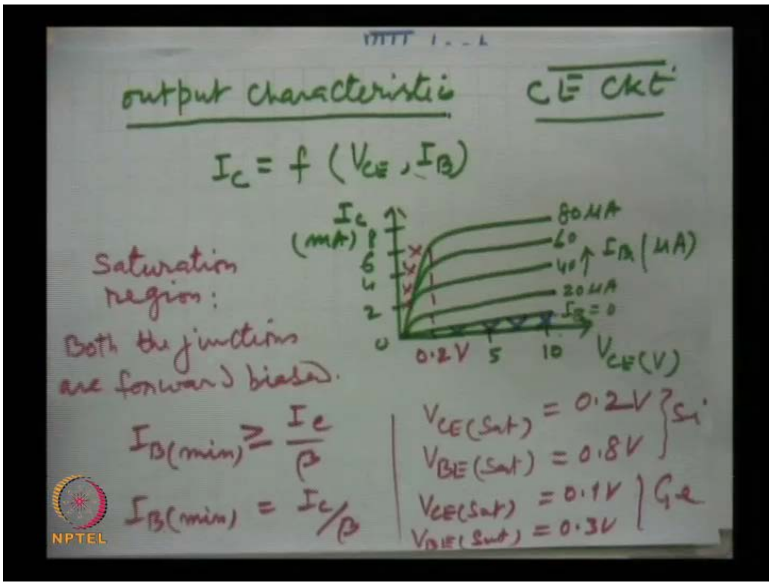

We said earlier that these characteristics can be divided into three parts. We discussed the saturation region in which both junctions are forward biased, emitter junction as well as collector junction is that the both are forward biased and this is the cut off region to go below I B equal to 0 that is in the other direction we will have to change the polarity of this.

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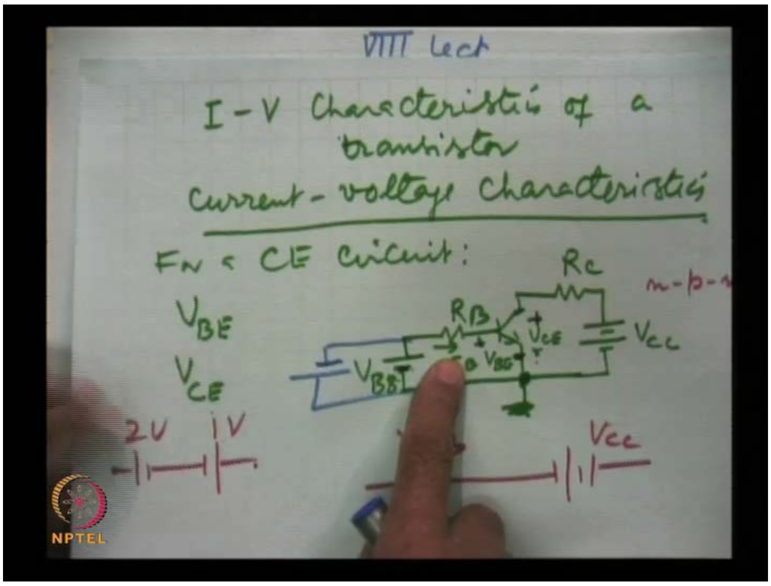

As it is shown here and this will make even this is the p type base connected to the negative terminal of the battery. So, even input junction is reverse biased. So this region is called cutoff region, where both the junctions are reversed bias. And, as I have said that, saturation region and cutoff region they represent two states, quite different states and they are very useful for digital circuits in which the transistor is used as the switch. Now, the third region that is above I-V equal to zero and on the right side of this saturation region, this is called the active region.

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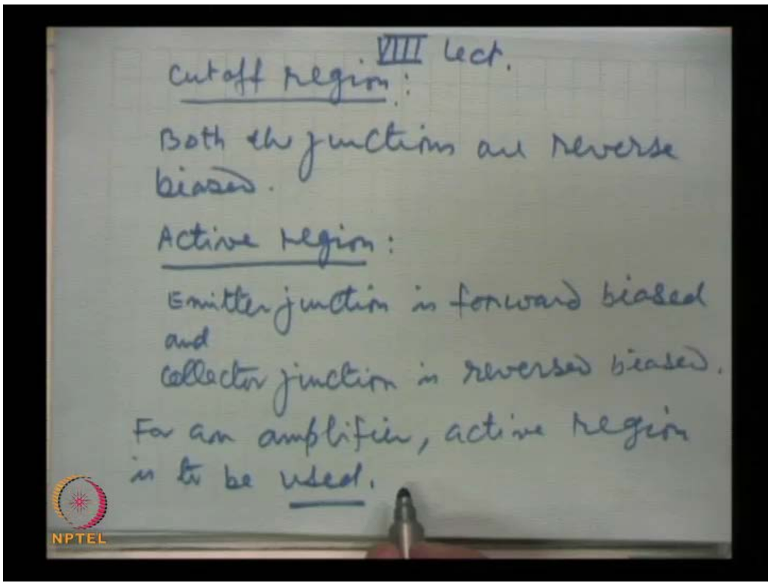

In active region, this is called active region, most useful. Active region, is where the emitter junction is forward biased and collector junction is reversed biased emitter junction is forward biased and collector junction is reversed biased. And this is the polarity, ,which we use where we want to use the transistor as a amplifying device so actually, active region is a very important for the amplifying for amplifier circuit.

Now here if we will notice that as been increased the input current the output current is changing for larger values of input current corresponding output current is high. This is what is expected in the amplifying circuit that, output current should vary proportionally to the input current only the magnitude should change. Here we have seen that, these magnitude is in mille amperes while this is in micro amperes so, this is definitely a amplified output. In fact, we can find out several useful parameters from here. So, active region emitter junction is forward biased, collector junction is reversed biased. For amplifier for an amplifier the active region is to be used.

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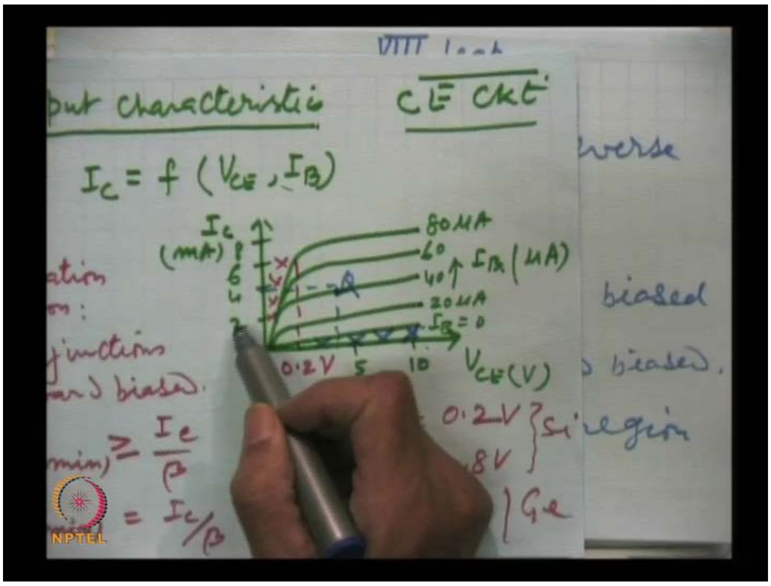

At the moment, we are talking about the DC but, as I have said in amplifier our purpose is not to just amplify the input signal but, a AC signal because, whether the arbitral sound or the radio frequencies signals these are all AC signals of different frequencies. For audible frequencies these are in kilo hertz but, radio frequencies can be very high. So, our purpose is will be to amplify a AC signal. Now, once we fix a circuit and fix in the sense that, what is the DC output current? and what is the corresponding input current? This is to be chosen for the circuit then over that, we have to super impose the AC signal.

So, choosing the AC output current, DC output current and input current, this is called Q point, we will talk in details about this choosing the operating point in the next section. So, when we have chosen the input current for example, in this case equal to forty micro ampere and the corresponding output current will be roughly four mille meter for this particular transistor for which these characteristics had been drawn. Now, when we apply the AC signal that will change that will this input current will vary and correspondingly the output current will vary.

Now, in low part of the cycle, when the AC is super imposed over these DC, the operating point that, low part the signal should go beyond the active region on either side that means, it should remain within this prescribed region. Here the because, any portion which falls if by round choice it touches or it comes in the saturation region the output will be distorted. Because, that much part will not appear in the output so, output will be a distorted signal, that we have to avoid. Same thing will happen if the signal loops in the cut of region because, in cutoff region the net output current will not be the function of net input current. So, that will be distorted.

Hence signal will super imposed is still for the hole cycle the operation should continue to remain within active region. Now, these characteristics prove very useful. One is, if we are asked to find the current gain beta for the circuit, we can find from here we take any input current in how much is the corresponding or we change the input current by this much amount how much the collector current change.

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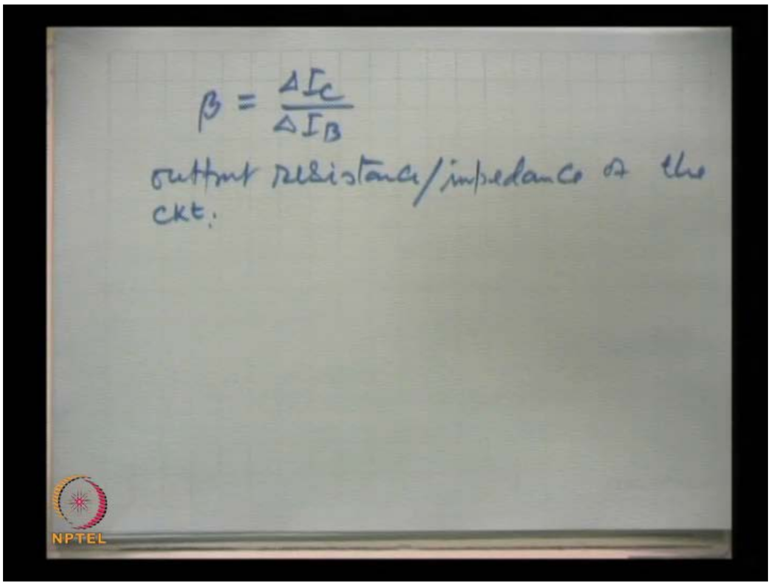

Then we can find from these output characteristics that, beta will be equal to change broadly the collector current by change in the base current, this we can find out. Also because, these two quantities they parted to the output circuit hence, the slow is totally that will give the output impedance or output resistance of the circuit. From the slope of this curves we can find the output impedance resistance. Output resistance or output impedance of the circuit, that can be easily been determined from these characteristics.

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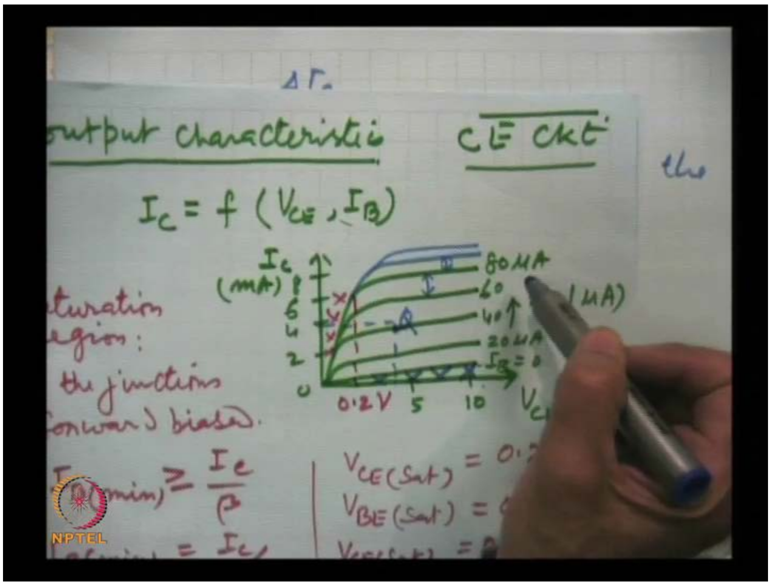

Few more points we note down from these characteristics is that, if we look these regions actually here the this is the cordoning of this characteristics. For example, for next twenty degree rise, this may be like this where this will have a less space as compared to this. Now this is to be explained. So, two points I explain number one, when we increase the base current then, while there is a cordoning of this curves. This is this cordoning arises because, this is high injection.

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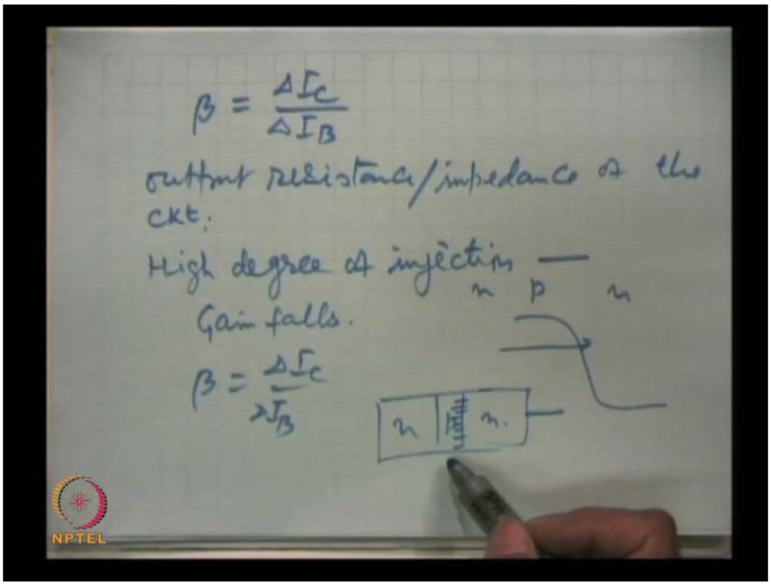

High injection, when the input current is very high it is called, high degree of injection. The lot of charge carriers will be injected into the base as a result of this the gain gain falls gain falls and gain is for example, beta change in I-C by change in I-B if this falls then, the ratio will be less and this will not change corresponding to that. Here, the gain has falling and so is this not much as it was here because of high injection. So, they have come closer, this is one reason. Other point is a actually we have said that, these collector junction is reverse bias, if we look at the that potential energy diagram this is n p n then, this is reverse bias.

All the electrons which are crossing the based region, they are collected here. So, what we have said earlier that, should amount that the output current should be independent of this reverse voltage, this is true towards the large extent but, not hundred percent. There is a slight there is finite that curve that means, there is a slope and they are not exactly flat. This is because, when we increase when we increase this reverse voltage here when this reverse voltage is increased as I have discussed earlier that, there will be a broadening of the depletion width because, this is very lightly doped so, more penetration of a the depletion region will be in the base region.

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Hence ,that lesser number of electrons will recombine giving rise to slightly higher value of a collector current because of that, we with that rise in the this reverse bias voltage, that is why if there is a slight rise in the current with voltage had it been totally independent then, this curve should have been totally flat but, I had shown that there is a sum as slope and that is because of, what we call the base width modulation with the rise of reverse voltage, the depletion width falls with the rise of the reverse bias depletion width falls so, lesser number of charge carrier will recombine and the current will slightly rise so, that explains these characteristics.

We can get the current gain, we can get the output impedance from this circuit from the slope itself. These are very useful characteristics so, that covers the input and output characteristics of the transistor. The significant thing which we have said is that, the output characteristics which are more important that, they can be divided into three parts. The saturation part, the cut off part, and the active region. The saturation and cutoff regions are used when we design digital circuits, and transistor is been used in the two states. One is the conducting state, the other is the non conducting state.

This is what in actual switch we have giving in simple electrical switch the you know up and down in one case, there is a high conduction through the switch in the other case, there is high insulation so, this is equivalent to that. But, for amplifying purposes we have to use the active region and we should choose the operating point properly so that, over the whole AC cycle that no where this signal goes near the saturation region or the cutoff region. We will talk more about this operating point soon.Now, having said so much we now talk about some features, which are important in designing a circuit in handling the currents and voltages in a circuit, and we have broadly not talked about these points here.

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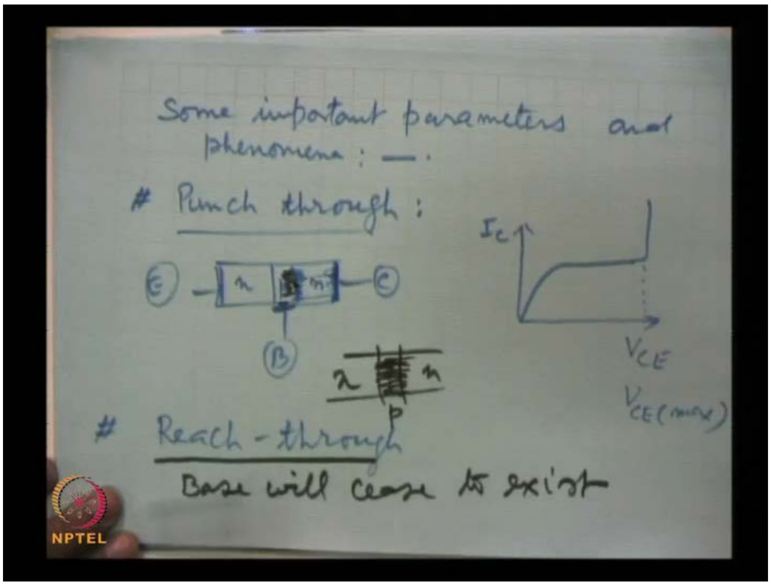

So, some important parameters in phenomena first is, punch through punch through if we keep on increasing the reverse voltage, the situation may come these dimensions are where is know this whole dimension of the transistor is a fraction of a mille meter or is around a mille meter which contains three regions the emitter region, the base region, and the collector region then, there are many contacts this makes our transistor. If we go on increasing this voltage how our output characteristics will change?

These output characteristics for very large values of the reverse voltage at the output I just take out of the several curves I pick up one and this will happen this way, this is V CE, this is I C and this is the normal curve normal operation it is suppose to be restricted operation should be restricted to this region but, if we keep on increasing then, the depletion width keep on increasing in the situation become that, we will find that the collector current will rise suddenly. This is the break down actually break down.

We are not suppose this is prescribed what is the value of V CE max for each number? this is provided by the manufacture so, this is called punch through that means, the depletion region is almost touching the collector electrode and the transistor action transistor action which is fundamental for the transistor continues till we have the three regions the emitter region, the base region, and the collector region. When the voltage at the collector junction goes beyond the certain limit then, there will be sudden rise in the collector current and this is known as punch through.In which the depletion region has spread to such an extent, that it is almost touching the collector electrode this is punch through.

The manufacturers prescribe the value of this V CE max maximum which we are suppose to absorb. The second point is, also related with this depletion width that is reach through reach through this is because, base region is already very small, very thin, and this is lightly doped. So, when this voltage is not large enough yet but, still large enough so that, the penetration of depletion region is there and that this depletion touches almost the emitter region that means, base will cease to exist.

You follow here, this is the base because, this is lightly doped so, low spread of the depletion region will be in the base region and there this situation become and this depletion region almost touches the emitter when this happens transistor again stops working and this is known as reach through process.

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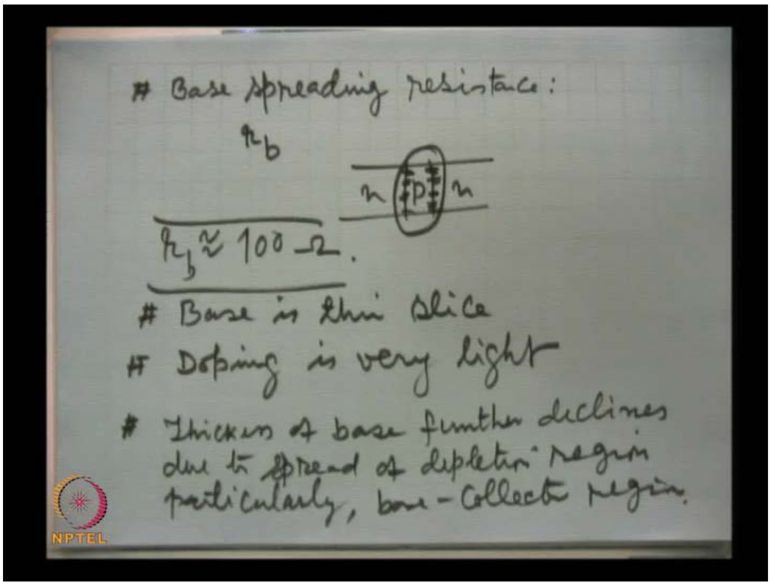

Third is, in this category base spreading resistance base spreading resistance it is written by r b. Base, this is base it is a thin region, it becomes thinner because of the spread of the two depletion regions it is thin and then it becomes thinner because of the spread of the depletion region. The doping level is also very light very lightly doped region. Hence, it offers a resistance and resistance to the passing currents, that is known as base spreading resistance. The value of this base spreading resistance r v is of the order of hundred volts.

I hope you have understood what is the meaning of base spreading resistance? what gives rise to base spreading resistance? Base spreading resistance comes from the two factors that, the base is narrow. It is a very small thin slice and doping is low so three factors contribute to this. The base is thin slice so, the dimensions are very small. Doping is very light. What does doping do? By doping we change the resistivity of the semi conductor so, it is directly related with the doping level and doping is kept very low in the in the base region for the reasons which we have discussed what are the requirements for a efficient transistor?

Third point which contributes to this is that, the basis thin and thickness of base further declaims due to the spread of depletion region particularly from the the base collector region. So, these are the three factors which contribute to this base resistance, basic spreading resistance which is of the order of hundred ohms or so. In many analysis, we will disregarded we can neglected considering other points but, there are situations as we will see where this resistance cannot be neglected? So, base spreading resistance.

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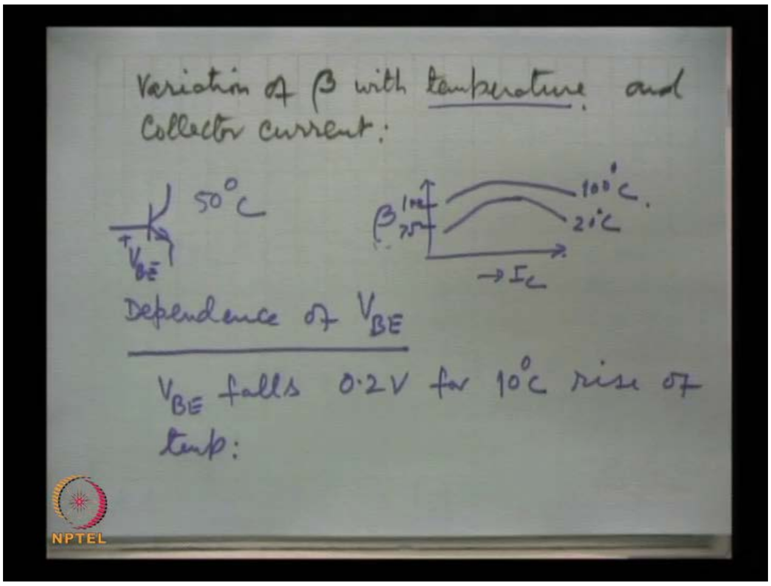

And then, next point is variation of beta, the current gain with temperature and the collector current collector current. Beta is one of the most significant parameter for a transistor this we have been repeatedly saying because, beta represents the current gain in a common emitter circuit and common emitter 99 percent circuits are common emitter circuit. Common base circuits have very few application and common collector is of course, have sometimes used but, most widely used circuit is common emitter and beta is connected with the common emitter circuit which is the current gain so let us see how does it vary with a temperature and collector current

With collector current, this is beta, this is collector current I C. Initially beta increases attains a constant value and then falls and this fall is as I have said we when we try to explain the cordoning of this output characteristics that, high injection when very high injection of charge carriers is there from the emitter then collector is unable to handle them as efficiently as in this region. So, a there is a fall in the value of beta in this fall may be significant this if it is hundred, this may be seventy five or even low. So, this is how the current gain and beta varies with the collector current the output current.

Another variation is with respect to temperature. Transistor contains semiconductors, which are very sensitive for current the temperature variations. Because of that, there is a chain if this is the plot, at a temperature say at 20 degree centigrade then about hundred or so this variation will be like this. Current gain beta changes with collector current output current and it also changes with change in resistor change in temperature, with rise in temperature beta increases.

Now, I have been very frequently talking about the changes in temperature. Let me made this point clear here that, temperature n p n temperatures we know in winter and summer it changes. Changes of the order of 50 degrees or quite common, plus when we change the place in Kashmir area, in hill areas, in Himalayas, in Himachal Pradesh, in winter the temperatures and temperatures in summer in the hill there is a drastic variation so, that is why in all operations temperature variation is important.

Another point which contributes, when we are talking about a circuit and says concealed in a box. For example, then because of various currents in voltages and components like a transformer, the other devices there is heat generation, that heat changes the environment of the device under which it is operating, you must have seen that, your TV sat, your radio sat, your casket after say use of a say 15-20 minutes, if you touch it from outside it has become hot it has gain certain temperature 20-30 degree rise because of, those electrical operations., it is quite natural.

So, temperature is a significant parameter in all these variation. Then finally in this category, we talk dependence of this voltage base emitter junction, here if this was then this voltage this also varies with temperature for the same reasons, that semiconductor the resistivity falls with the temperature so, with the rise of temperature V BE also falls and it has been calculated absorbed experimentally that roughly, V BE falls at the rate of 0.2 volts for every ten degrees rise, for you it is sufficient to remember that, temperature also changes the voltage drop which occurs between base and emitter junction. So, this are these are certain parameters which we will be making use.

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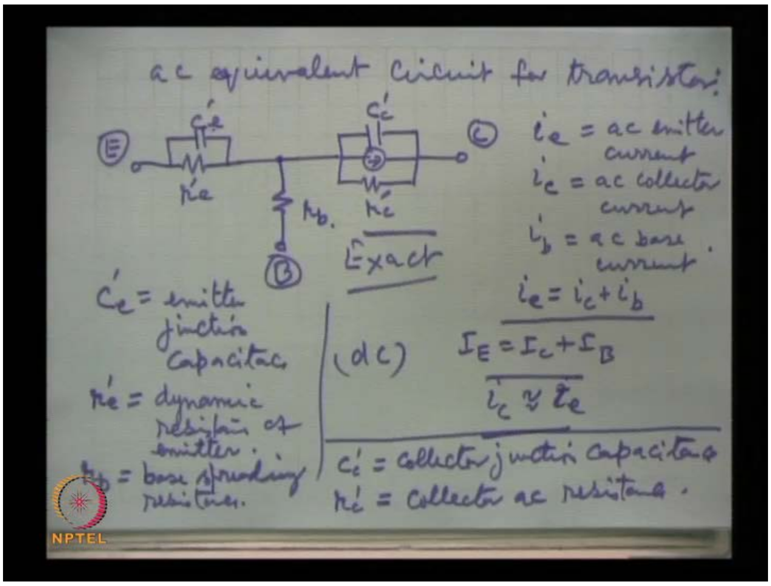

Now, we go for another thing very important AC equivalent circuit for transistor. What is the equivalent circuit? and why do we need this two points? Let me make very clear at the start. The transistor which we have been discussing, this is used for example, in a amplifying circuit, we have to analyze the circuit. Trialing error is not the best policy a circuit designer will prefer to have a model and what are the requirements which we expect from the circuit? and that will fix different circuit elements which are to be used what is the amount of current? what is the amount of voltage? which resistances are to be used in the circuit? that you should know so there is there should be a way to analyses the circuit.

AC equivalent circuit, why AC? Because, in amplifiers we are interested in amplifying AC signals so, AC equivalent circuit is required. Now, what is this actual equivalent circuit? and then, we will come to certain simplifications which are possible under certain situations and then, we will see that how these derived equivalent circuits can be used for the analysis, what is the analysis? we should be able to calculate what will be the voltage gain in the circuit? what should be, what will be the input impedance? what will be the output impedance? what is power gain? what is the current gain in the circuit? all this will be possible through proper analysis.

A proper analysis needs a proper equivalent circuit so, that is why we have to talk about this. Now, this is the circuit. Now, we are talking of AC equivalent circuit so, there will be AC input current with this small letter and a small this alphabet I we note AC emitter current. Similarly, there will be AC collector current and AC base current and that relationship holds that, this has the DC emitter current was divided into two parts one is goes to the recombination in the base region this gives rise to base current and the other gives the collector current that continue similarly, this AC emitter current will be split in the two in this relation is still holds.

As, we have written for DC case, I E I C plus I B this is for DC direct current. For AC case, we can write a similar relation so, this is still holds. In many situations as we will see that, in transistor analysis because, the base component is a at least two orders of magnitude is smaller than this. So, in many situations I C will be equal to I E, this we will see when we come to this point. Here, this is base, this is collector, and this is a emitter. Now here, this is r b.

What are these components? Let me first try to explain the C e prime this is the emitter junction capacitance emitter junction capacitance, r e prime this is the dynamic resistance of emitter, r b base spread we just talked about the base spread, base spreading resistance, C c this is collector junction collector junction capacitance, and this is r c prime r c prime is the collector AC resistance. So, this is emitter junction capacitance, collector junction capacitance, this is dynamic emitter resistance, this is the effective collector a c resistance, and this is the base spreading resistance.

So, if any circuit in any circuit if the transistor is replaced by this equivalent model this is exact model, this is exact. Then, we should be able to compute the properties of a interest. But, we can simplify this here, we can simplify this and the simplified equivalent circuit which we will be using is this.

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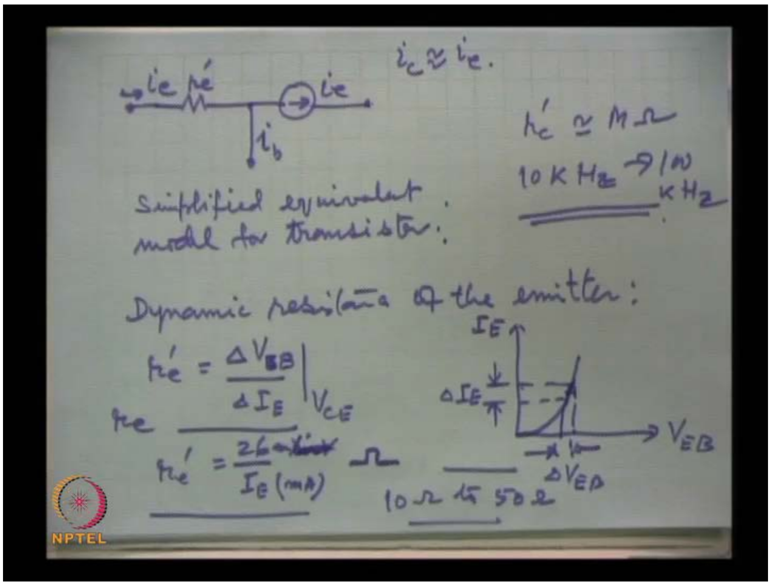

This is the simplified model for transistor. Here, we have dropped for example, these this resistance the collector resistance collector junction is a reverse bias junction and r c is to the tune of , in mega ohms in mega ohms very high resistance because, it is in parallel so this can be taken almost as open. Similarly, this capacitance this two capacitances can be dropped when the operation is limited in frequency that means, up to few tens of kilo hertz or say up to hundred kilo hertz. We can the impedances often by this capacitances are very high because, they are in parallel so, they can be neglected.

So, as long as our operation is limited to this range which of course, again is not varying a rigid because, it varies from transistor to transistor. There are transistors which will go still higher in frequency but, normally we will be using them in this range for that, this simplified model is good enough. Here, this is these are the currents I C, I E, and I B. I C is equal to I E and this resistance how we get dynamic resistance that, I can show you that, how practically we can get the value of this emitter dynamic resistance.

Dynamic of the emitter, experimentally we can find it from this input characteristics input characteristics of the transistor at a fixed value we know that, this is the characteristic, this is I E, and this is V EB, the voltage between the emitter and base this is the how the current exponentially increases. Here, we take the operating points and were here and we take the changes, this much change in this voltage V EB changes the current by this amount. The ratio of the two gives you, r e prime E B we can write actually V B at a fixed value of V CE this is, how the dynamic resistance of emitter is defined, it is written either as r e prime or many times it is written just as r e.

Instead of base, instead of determined experimentally we can find out by, simple equation it can be shown that, r e prime is equal to twenty six mille volts, when I E the emitter current DC emitter current is in mille amperes. So, this is most widely used expression for finding the dynamic emitter resistance, twenty six divided by I E the emitter DC emitter current when, DC emitter current is expressed in mille volts then, this gives the resistance in the resistance in mille ohms this is I am sorry this is also in mille volts this is also in mille volts. So, we get the resistance in ohms, this resistance varies from ten ohm to fifty ohms. So, this is about the model, we will use this model.

Let us take the example that, how we can find out the three currents in a circuit in a three currents are the collector current, the emitter current, and the base current.

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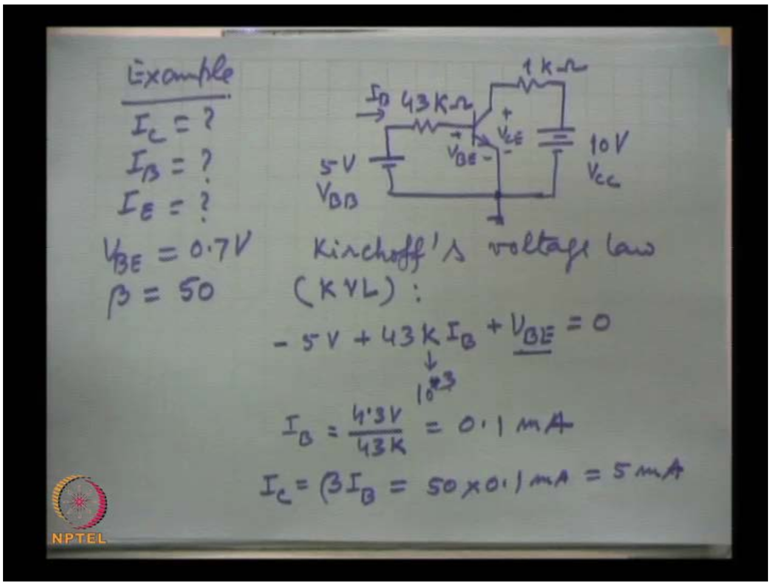

Let us consider this simple circuit, this is an example for example, we have seen here, that to find out the value of this dynamic resistance, we need the value of emitter current. So, I am taking a general example to demonstrate that, how simple it is to calculate the three currents I C, I B, and I E in a circuit. When some parameters are given and what is given is that, in this circuit V BE is 0.7 volts, and also given that beta the transistor current gain is say fifty and we have to find out the value of these three currents.

Then, there is another point which needs and enforces is this example illustrate that, what are the kind of resistances which are to be used in a small circuit, in a small loop over circuit, in a small signal circuits with which we are mostly concern. What are the battery voltages? what are the resistances? So, this is the reason behind this example. Now, if we apply kirchoffs voltage law popularly known as, KVL kirchoffs voltage law which is the summation of voltages in the closed loop. If we write the equation then, we will get this is the summation.

Here there is a current I B so, the voltage drop here is forty three K is actually I can write I can replace this with ten to power minus three but, when we take the resistances in kilo ohms often they are left like that and then the currents will be in mille amperes, if we take it in ohms if we I replace it ten to power multiply by ten to power three then, the currents will be in ampere and because, ampere is a large current normally we will encounter with mille ampere current so, this is good enough to take to maintain this in the kilo ohms. So, this equation is to be solved for I V here five volts and forty three K I B and this is given as 0.7 volts so, we substitute and we get I B equal to 44.3 volts divided by forty three K and that gives 0.1 mille amperes so, base current is 0.1 mille ampere.

I C we can find out, I C we know is beta times I B because, beta was defined as the ratio of these two currents output current by the input current. So, here we can use this relation in this form very widely used in a transistor circuits and this is fifty into 0.1 mille ampere so, this is equal to five mille ampere.

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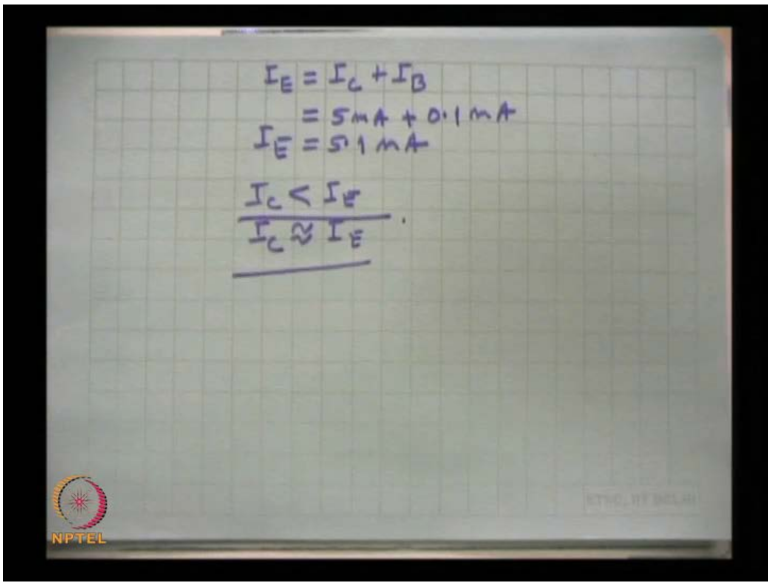

The I E for the determination of I E we use the relation I C plus I B, we have found out this two currents we can get the value of emitter current this is five mille amperes plus 0.1 mille ampere, that gives you I E the emitter current to be 5.1 mille ampere. This further shows that I C was five mille ampere so, I C is always less than I E but, they are very close this is 5.1, this is five. So, our assumption which we will be very frequently use and the analysis of the circuits, this is valid.

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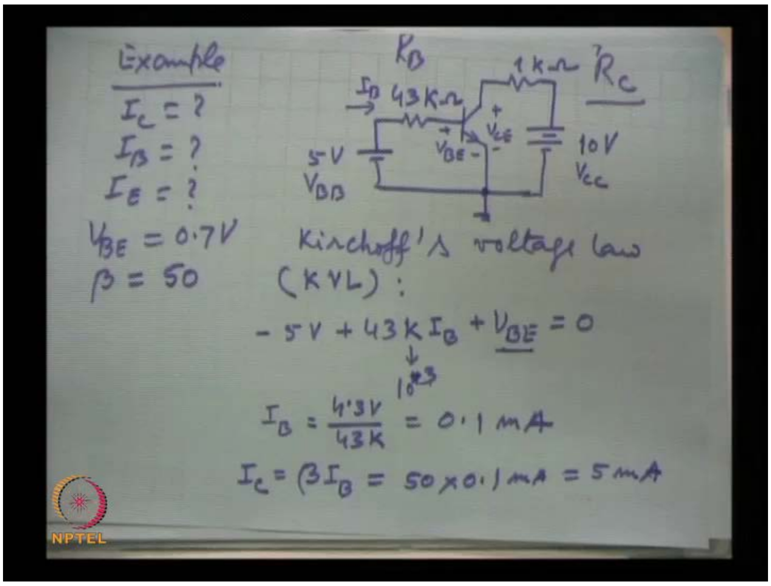

So, I have taken this example to illustrate few things often we will be required to calculate the currents so, how to calculate the currents in a circuit and then another purpose was to show you that, what kind of resistance is? what is the order of resistances? which we have to use in transistor circuits so here, the this was the base resistance noted normally written as R B, this was the collector resistance with the collector which is written as R C, and what are the batteries which are used in the circuit? So, I am sure that, it has added to your knowledge and how to handle the circuit this is simply one example we have taking.

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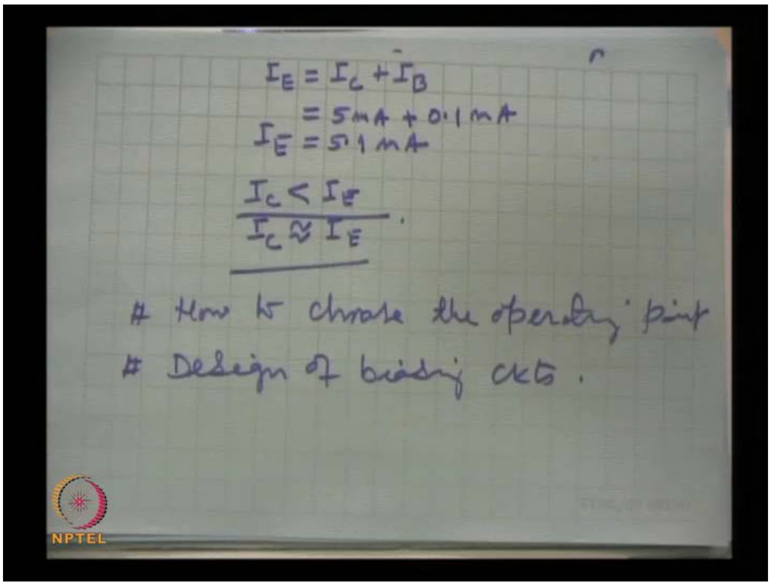

The next thing which we will be considering, how to choose the operating point? how to choose how to choose the operating point and what is the meaning of operating point? that we will see and then, design of biasing circuits. So far, we have been using very primitive approach for example, here I have used two batteries and soon, when we take this two topics we will see that, single battery will do the job and then, what are the points? what are the features? what are the considerations in choosing a appropriate operating point? That, we will have to see in the next lecture.