Basic Electronics
Prof. Dr. Chitralekha Mahanta
Department of Electronics and Communication Engineering
Indian Institute of Technology, Guwahati

Module: 2 Bipolar Junction Transistors
Lecture-10
Transistor as a switch

In the last classes we have discussed about the BJT being applied as an amplifier. The amplification of a weak signal is done by a BJT and we have discussed in detail the analysis for the amplification or using the BJT as an amplifier. Apart from using the BJT as an amplifier we have other use also for a BJT and that is a switch. That is the transistor can be operated as a switch also. Transistor is used as a switch means that it can be used for opening or closing of a circuit and when the transistor is operated in this manner then it is not used in its active mode of operation but it is used in saturation mode and cut-off mode of operation because we know that the transistor is having three modes of operation active, saturation and cut-off and in the active mode of operation the transistor is mostly used as an amplifier.

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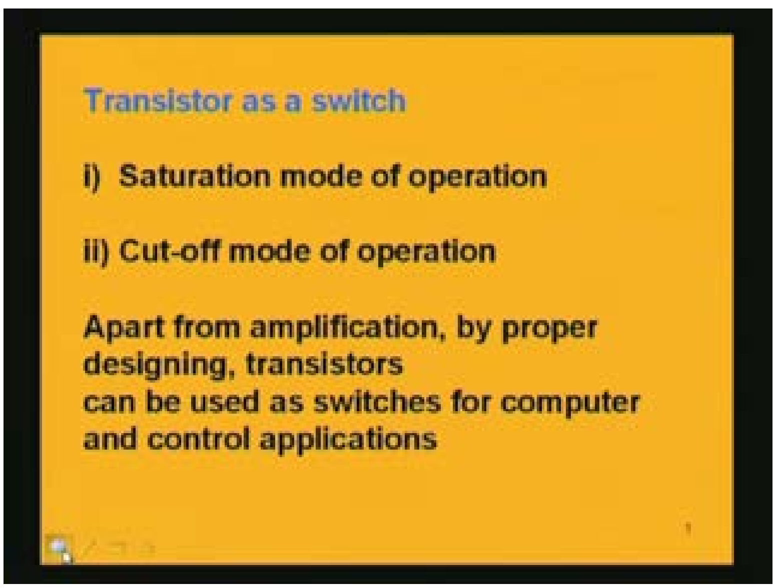

But for some specific applications as in a switch we use the other two modes of operation which are the saturation and the cut-off modes. Today we will discuss about these 2 modes of operation and see how the transistor uses these 2 modes for being applied as a switch. The application of transistor as a switch has found use in many areas like computers. In control applications the BJT is used as a switch and one typical example where a BJT is used as a switch in digital circuits, is in an inverter. Inverter is a device where the output will be just the inverted form of the input. For example if we give a low input at the inverter then the output will be high and if the input is high then output of the inverter will be low. The circuit for that inverter is as shown in this circuit. Here the BJT common emitter is used and the resistances in the collector as well as in the base are R_C, and R_B and V_{CC} is the biasing voltage. In this case we are taking 5 volt V_{CC} and the values of the R_C and R_B are 0.7 k ohm and 50 k ohm. This is a very simple example and the beta value for this common emitter transistor is 125.

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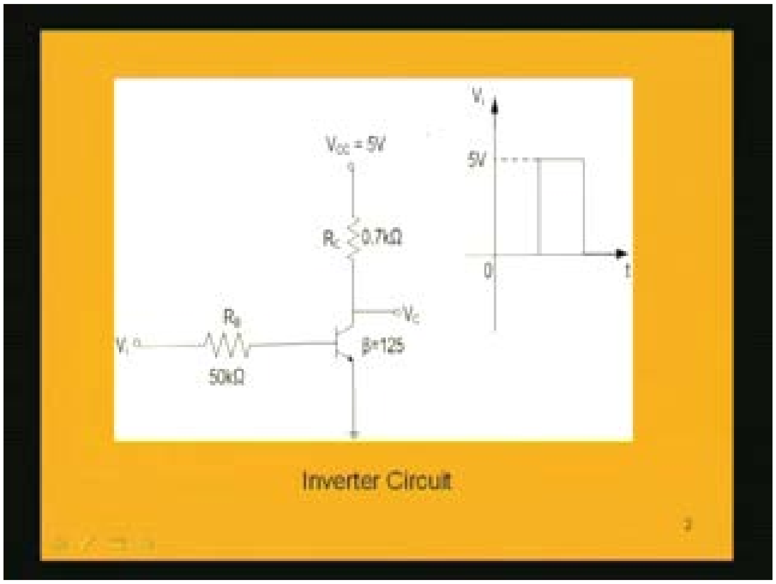

Input is V_i that is being applied to this transistor amplifier and the output at the collector side is V_C which is nothing but V_{CE} because here emitter is grounded. The voltage between collector emitter is the voltage with respect to ground at the output side. The input to this transistor circuit here is given as shown here. It is between 0 and 5 volt which is given at the input. Mind it that we do not have a DC biasing voltage here but we are using a signal varying between 0 and 5 volt at the input of this transistor. We will see what will happen to the voltage at collector? When you have voltage zero, V_i zero what will be the output at collector; what will be V_c and when the voltage is 5 volt what will be the output V_c that we have to find out. For this particular example with these typical values let us see what will be the output voltage at collector and to see that we have to again revisit the characteristic of the transistor.

Let us recall the output characteristics of a common emitter transistor. We know that in a common emitter output characteristic when the voltage V_{CC} that is given is equal to the voltage at one extreme point of the characteristic curve and the other extreme point of the collector current that we have are joined by a straight line we get the load line.

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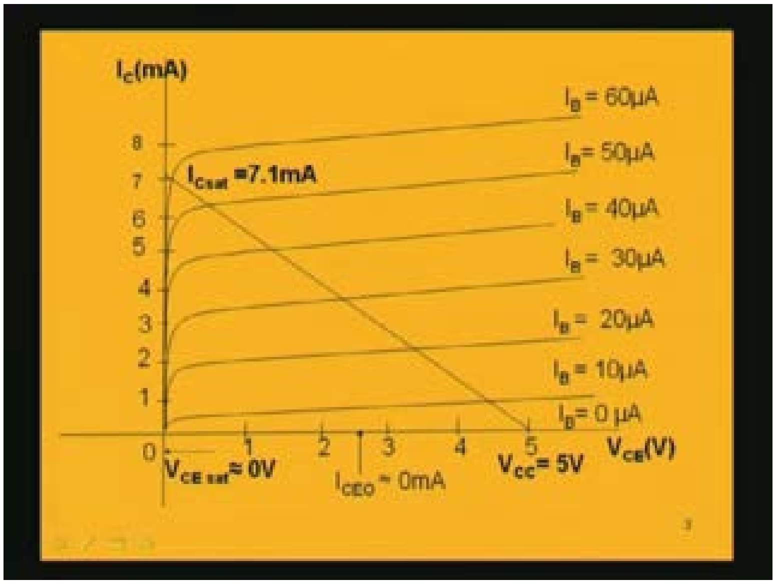

For this particular example let us find the load line and draw it on the characteristic curve. For that we have here the voltage V_{CE} equal to V_{CC} minus I_CR_C. When I_C equal to zero, V_{CE} is equal to V_{CC} and that will be equal to 5 volts, one extreme point of the load line and when V_{CE} equal to zero we get I_C equal to V_{CC} by R_C the other extreme point of the load line. In this particular example the value of I_{Cmax} will be equal to V_{CC} by R_C. V_{CC} is equal to 5 volt, R_C is equal to 0.7 k. That will give 7.1 milliampere. That is the value of the saturation current I_{Csat} and when I_C equal to zero V_{CE} maximum value will be 5 volt V_{CC} value here. We are joining these two points and this is the load line for this particular example. In this plot we are now having the output characteristics, the curves for different values of the base current. Base current is from zero onwards, so we are plotting for I_B is equal to 0, for I_B equal to 10 microampere, 20 microampere like that and the values of I_C in milliampere are on the y-axis. It is assumed here that the saturation voltage $V_{CE\ sat}$ is almost equal to zero.

Practically the V_{CE} saturation is the saturation value of the collector to emitter and that is around 0.1 or 0.2. That means it is a very small value. For simple analysis we are assuming that V_{CE} saturation is equal to zero volt. That is when we have I_C saturation flowing, maximum collector current then V_{CE} is equal to zero and the cut-off value of current, I_{CEO}, this current is actually the reverse saturation current when the base current is zero. That is base current I_B is zero. We know that the value of I_C is actually beta times of I_B plus beta plus 1 into I_{CBO}. But if we make this I_B equal to zero we have I_C equal to beta times of I_B plus beta plus 1 into I_{CBO}. If I_B is equal to zero I_C is equal to actually beta plus 1 into I_{CBO}. I_{CBO} means the reverse saturation current I_{CO}. But for simplicity we are assuming that this part is zero for I_B is equal to zero. When the base current is zero, the reverse saturation current is very small. So this part is also almost equal to zero. That is why we are writing I_{CEO} equal to zero milliampere when I_B is equal to zero and that is shown by this axis itself.

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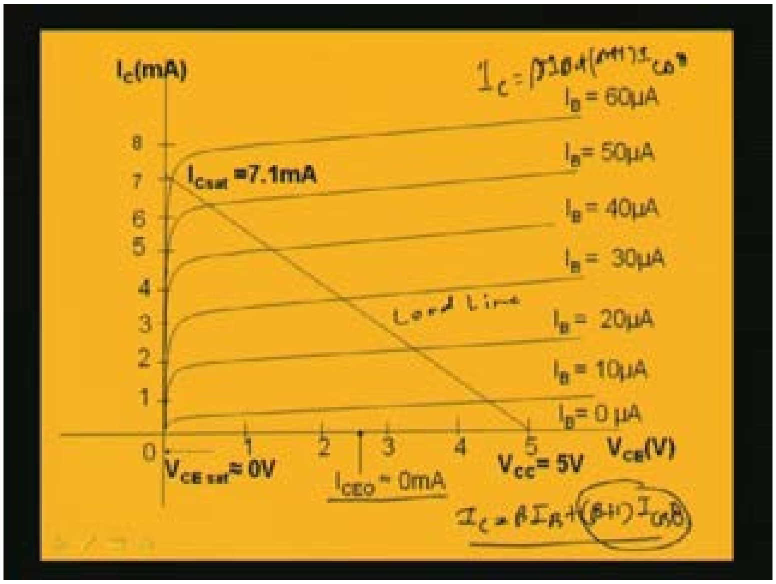

That is why this I_{CEO} is equal to zero when I_B is equal to zero. With this knowledge let us proceed to see the circuit again. The current that flows in the circuit under saturation condition is I_C saturation which is 7.1 milliampere.

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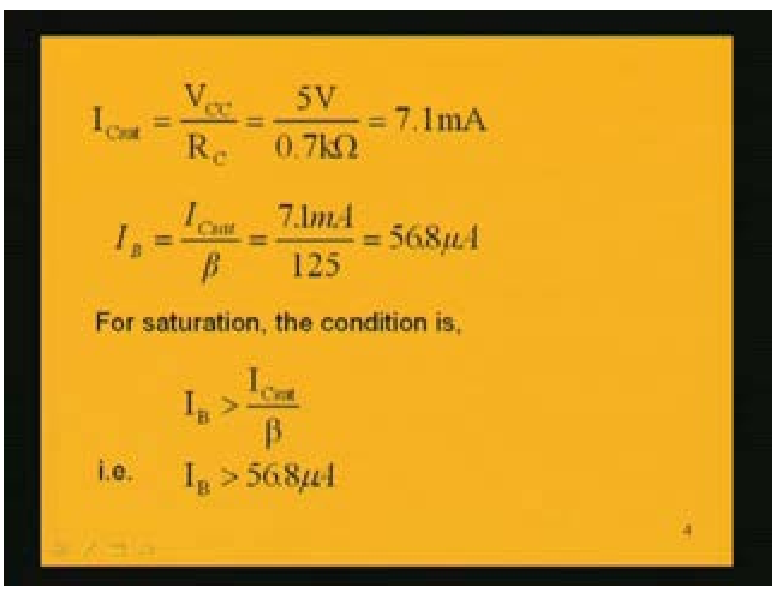

That is the maximum value of the collector current under saturation and correspondingly the value of the base current will be I_C by beta and I_C is equal to 7.1 milliampere saturation current divided by beta. For this particular example beta is 125; that gives 56.8 microampere. If I_B is equal to 56.8 microampere or more the condition of the transistor is in saturation because we can see here that this is the peak value or maximum value that the collector current can have in this circuit when V_{CE} is equal to zero. That is equal to 7.1 milliampere and for that collector current what will be the corresponding base current for which this collector current flows? That is 56.8 microampere. If base current is increased beyond 56.8 microampere then the transistor will be into saturation. It will be over driven and the saturation condition will occur. Beyond this I_B is equal to 56.8 microampere the transistor will achieve the saturation condition and when the transistor is in saturation we know that the collector to emitter voltage will be zero. For saturation to happen the condition is that the base current is more than I_C saturation by beta or 56.8 microampere in this particular example. If we give an input voltage and adjust the resistance in the transistor, R_B, R_C, etc such that the base current becomes more than 56.8 microampere then the transistor will be driven into saturation and then the voltage which will be at the output or collector, V_C will be equal to zero.

In this particular example what we are applying is a voltage between 0 and 5 volt input voltage. What will happen when you have 5 voltage input? Let us consider the case when input voltage is 5 volt because it can be 0 or 5. It is a pulse. It can have two values 0 or 5 volt. It is a digital type of voltage. If this input voltage is 5 volt in this circuit, we have to find out the voltage which will be at V_C or at the collector. When the voltage at the input is 5 volt then what will be the base current? That can be found out by applying Kirchoff's voltage law; V_i minus V_{BE} divided R_B which is 50 kilo ohm. What will be this base current? Base current is equal to V_i minus V base to emitter voltage divided by R_B. Putting the values of this in the equation we can find out the base current.

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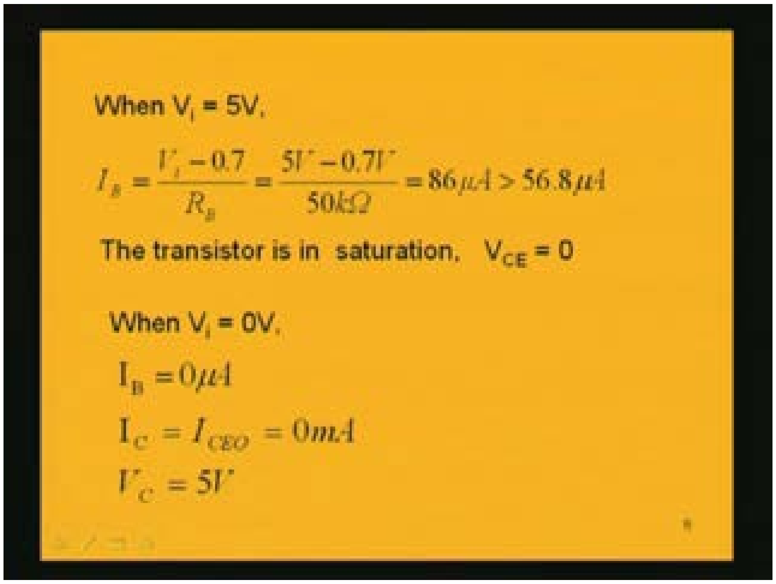

5 is the input voltage minus 0.7 volt typically is the value for V_{BE} for a silicon transistor, we are assuming, that divided by 50 kilo ohm is the resistance R_B. That gives 86 microampere. 86 microampere base current is flowing when you have input voltage 5 volt. That is well above the value of I_B which is required for saturation because saturation requires I_B value of 56.8 microampere. Whatever we are getting here I_B is much greater

than 56.8 microampere. The transistor is driven into saturation. The output voltage V_{CE} or the voltage at the collector V_C will be equal to zero. When you have an input 5 volt output becomes zero.

Let us examine the other condition when we will have voltage V_i is equal to zero volt and for that here if input voltage is equal to zero volt then the base current will be zero. If we look into the circuit if this is zero the emitter is grounded which is also zero. So the emitter base junction is not forward biased which is the condition for the transistor being ON. We do not have the emitter base forward biased. In this particular example it is NPN. So we must have a higher voltage with respect to and that means we must have base voltage greater than the voltage at the emitter which is not happening because if V_i is equal to zero volt, this is zero and this is zero. Both are same, so we are not having base at a higher potential than this emitter. Because this is an NPN transistor, we must have forward biasing which is not met and that is why there will not be flow of base current. Base current is zero, the transistor is not ON; it is OFF. When base current is zero then collector current is only the reverse saturation current and here we have assumed that the reverse saturation current is also zero and that is why we are getting at the output the voltage which is equal to 5 volt because output voltage is equal to V_{CC} minus I_C into R_C. I_C is equal to zero since I_B is equal to zero. So we are getting V_C equal to V_{CC} that is equal to 5 volt. When input voltage is zero volt, we are getting at the output 5 volt.

If we compare the two voltages, input and output voltages V_i and V_C then we get a plot like this. When you have input voltage zero, the collector voltage is 5 volt. When the input voltage is 5, the voltage at the collector becomes zero. It is just inverting. If it is low it becomes high, if it is high it becomes low and this is the action of an inverter. Actually this is the symbol of an inverter.

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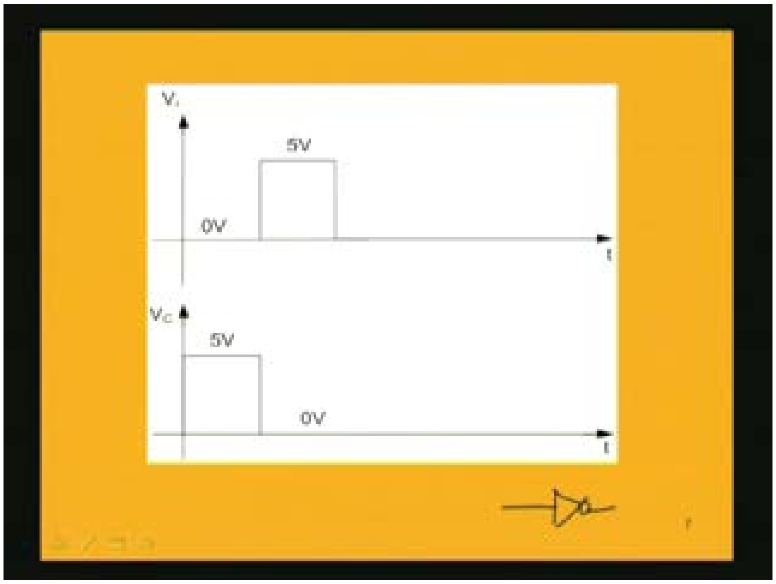

If it is zero at the input, output will be 1. If it is 1 at the input, output will be zero. This is a digital device and in digital circuits the voltage is in between two levels and it is typically between 0 and 5 volt. That is why in this example we have actually analyzed the circuit of an inverter and we have seen that here the transistor is operating in two modes. One is in saturation mode and the other mode is a cut-off mode and when the transistor is ON, this is in the saturation mode and we are getting at the output the collector voltage which is equal to zero. But when it is in the cut-off mode, the transistor is in cut-off means we are having the output voltage equal to the voltage which is equal to 5 volt and this is the cut-off mode of operation. So in between saturation and cut-off the transistor is operating and if we also look into the transistor when it is operating in saturation and when it is operating in cut-off we can see that these actions are nothing but the actions of a switch because again if we consider the transistor and their saturation this is the transistor symbol. Here we are using a common emitter transistor.

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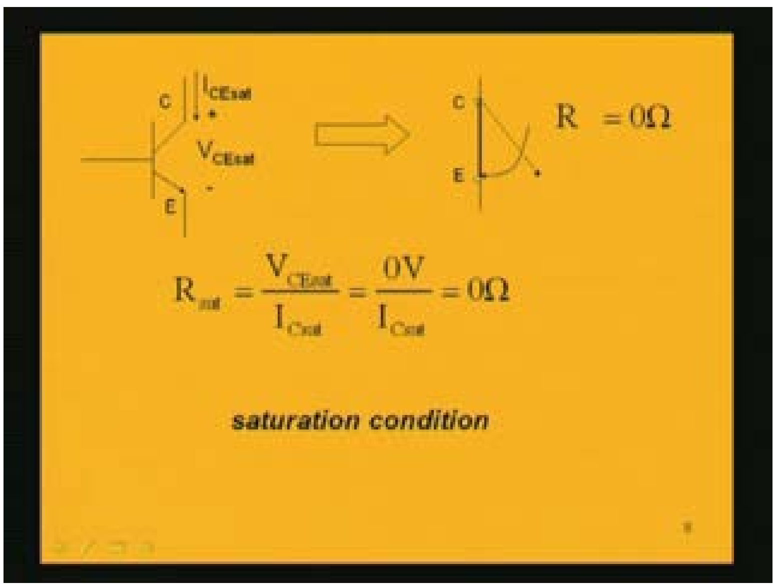

The condition when it is operating in saturation then V_C saturation which we have seen that is almost equal to zero and practically this value may be either 0.1 or 0.2 but very, very small; so we are assuming almost equal to zero and the current flowing in the transistor under saturation is I_{Csat}. Equivalently we can express it as a switch between collector and emitter because it is like a short between collector and emitter; as if it is being shorted by a switch and what will be the resistance from collector to emitter? The resistance between these two points or two terminals, collector and emitter is nothing but the voltage divided by the current and voltage between collector and emitter is V_{CEsat} and the current flowing from collector to emitter is the saturation current I_{CEsat} and this V_{CEsat} is equal to zero volt, I_{Csat} has a high value. But it does not matter because in the numerator if it is zero, resistance becomes zero. The resistance of this part between collector and emitter is zero ohm. If the resistance is zero ohm, it is like a short and this is the action of a switch. A switch is ON means the current flows without any resistance or zero resistance as if the collector to emitter part is being closed by a switch which happens under saturation. This is the saturation condition. That is why we can equivalently say that this is working as a switch which is ON. The switch is ON means it is in the saturation.

In the other condition when it is in cut-off, then the voltage between collector and emitter is V_{CC} which in this particular case is 5 volt and the current which flows in the collector is I_{CEO} and we have assumed it and this is practically correct that it is almost equal to zero milliampere. What will be the resistance between the two points, collector and emitter? That will be equal to 5 by zero, almost infinity. That is infinite resistance is offered by this part between collector and emitter when it is in the cut-off mode of operation.

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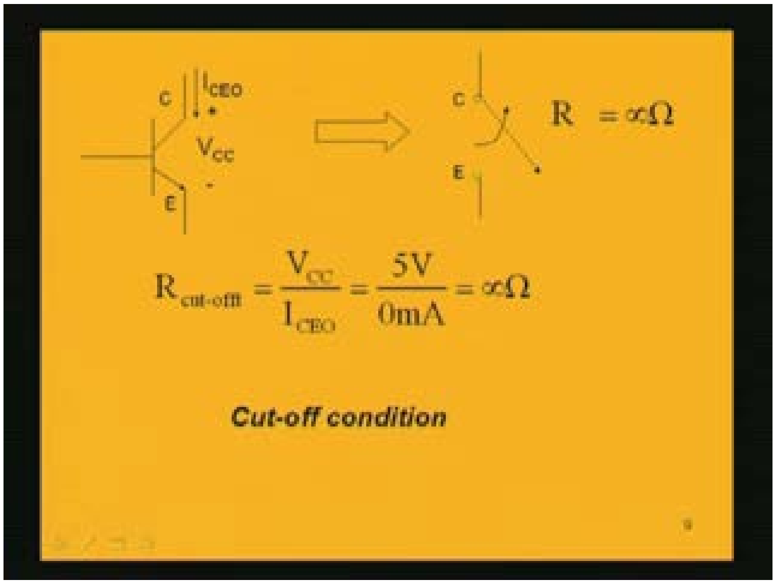

The switch is now open because we do not have any current; zero current is flowing and the resistance between these two points, collector and emitter is infinite. Infinite resistance is being offered by this part between collector and emitter. There is no current and it is like an open switch. That is why under cut-off condition the transistor can be well assumed to behave like an open switch. This analysis now shows us that we can use the transistor in these two modes of operation of saturation and cut-off to close a switch ON or close a switch OFF. For example if the values of this saturation voltage $V_{CE\ sat}$ is not zero, even if it is a few order of say some 0.1 or 0.2 volt then also the resistance which will be offered will be almost like zero. It will be very small value because I_C saturation is a high value. This whole quantity will be almost equal to zero. Even if it is not zero it will be very small and in the other when there is cut-off, in reality this I_{CEO} even if it is not zero milliampere, it is say 10 microampere it can be because it is in the microampere order only still this value of resistance will be very high. So it is almost like infinite that we are assuming. Even in practical case if you do not have zero saturation voltage or zero reverse saturation current then also the analysis will not be different because the resistance value will be almost in the same order.

Let us again discuss another circuit.

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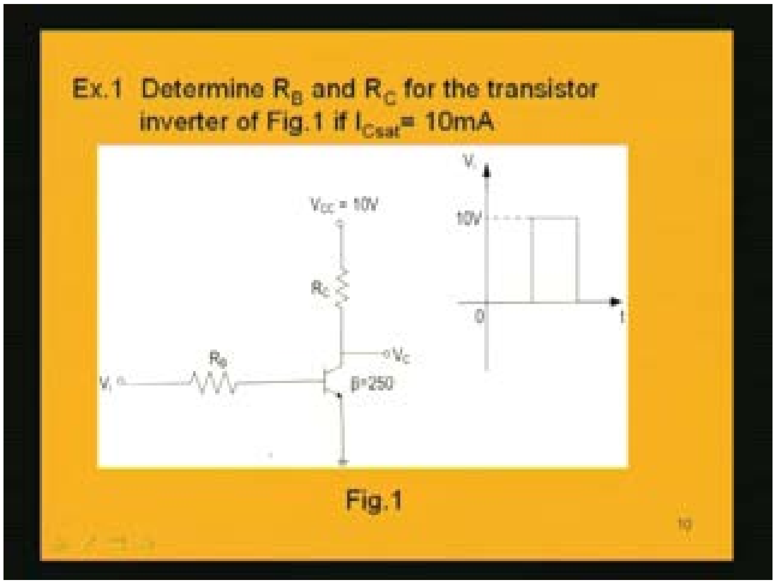

This is the same circuit, which we have discussed now which is used for saturation and cut-off and let us try to see if this amplifier circuit is also acting as a switch. In this example we are taking V_{CC} is equal to 10 volt and the resistances R_B and R_C are not known. We have to determine the value of resistance R_B as well as resistance R_C for this transistor inverter if the collector saturation current that is I_{Csat} is given as 10 milliampere and the input voltage is between zero and 10 volt as is shown. In this case what will be the value of R_B and R_C that we have to design? For solving that as we are given that the I_{Csat} is 10 milliampere we can find the expression for I_C. What is I_C in this particular configuration? I_C is V_{CC} minus V_{CE} divided by R_C. That is generally the expression for the collector current. Under saturation what will happen?

Let us draw the circuit again. In the solution for this example, we have V_{CC} given as 10 volt and we have R_C, which is not known. We have to design this R_C value. This is a common emitter transistor. This is NPN as per the symbol and we have a resistance at the base which is R_B and input voltage is given as V_i and emitter is grounded. This is the circuit and we are given beta which is equal to 250. Beta value is 250 and the input voltage is between zero and 10 volt. Initially it is zero and then it becomes 10 after some time. This is the input voltage across time and $V_i(t)$. What is this saturation current $I_{C\ sat}$? That saturation current can be found from this equation for I_C which is nothing but V_{CC} minus I_C into R_C divided by V_{CC} minus I_C into R_C minus V_{CE} is equal to zero. That is the original expression or the Kirchoff's voltage law being applied in the output circuit. But for the case when you will find out I_C saturation, that can found out when V_C is equal to zero. Make V_C is equal to zero. Then $I_{C\ sat}$ is obtained which is equal to V_{CC} by R_C.

In this particular case we know $I_{C\ sat}$. This is given as 10 milliampere. $I_{C\ sat}$ is 10 milliampere and what will be the R_C? That has to be found out first. R_C equal to V_{CC} by

I_{Csat}. V_{CC} is equal to 10 volt. $I_{C\ sat}$ is given as 10 milliampere. That means 1 k ohm is the collector saturation current that is $I_{C\ sat}$.

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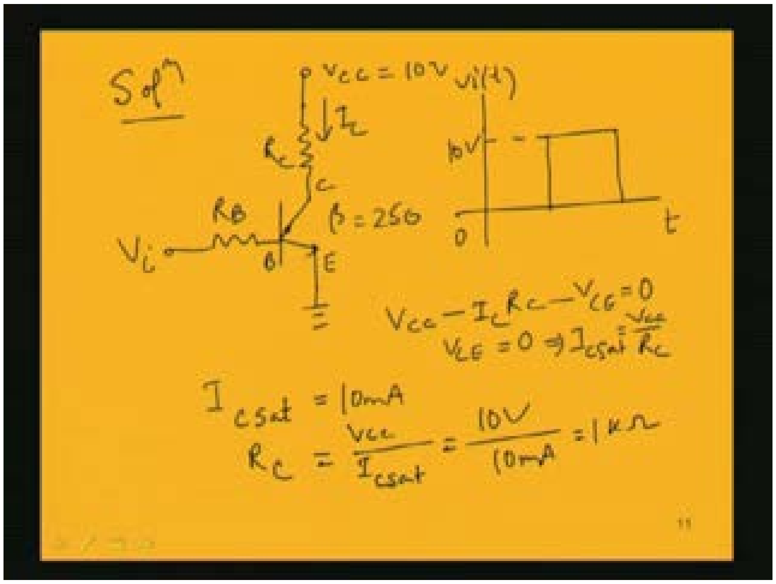

If we know this $I_{C\ sat}$ we can find out what is I_B for that particular $I_{C\ sat}$ and that is $I_{C\ sat}$ divided by beta. Beta is given as 250. So 10 milliampere by 250; that comes to around 40 microampere. This is the value of the I_B for which the saturation occurs. If I_B is above this value then the transistor will be driven into saturation. Now we have to have a condition where I_B is greater than 40 microampere to ensure saturation. Here as we have to design R_B for ensuring saturation, let us assume a saturation current of I_B which should be more than 40 microampere and conveniently let us choose I_B is equal to 60 microampere. I am choosing a value higher than 40 microampere and that range I am taking as 20 microampere. It is higher than 40 for our convenience. To ensure saturation I must have a value of I_B conveniently higher and that value I am choosing as 60 microampere which will ensure saturation.

If I_B I have chosen to have 60 microampere what will be the corresponding value of R_B? That I can find out. In this circuit this is the I_B. What is I_B Kirchoff's voltage law being applied in this input circuit? V_i minus V_{BE} divided by R_B is I_B. I_B is V_i minus V_{BE} divided by R_B. We do not know R_B. We have to design R_B and we are designing for a value of I_B is equal to 60 microampere. For this case what will be the value of R_B? R_B is equal to V_i minus V_{BE} divided by I_B and V_i is 10 volt when saturation will occur. 10 volt is given because voltage is between zero and 10. Zero will make it cut-off and 10 volt may drive into saturation. We are considering saturation and that should be 10 volt input voltage and typical value of V_B is 0.7. We are taking that divided by I_B, which I am choosing as 60 micro ampere; so 60 into 10 to the power of -6 actually if you consider it in ampere. Finally we will get a value of 155 kilo ohm.

155 kilo ohm R_B value is obtained for a value of I_B chosen to be 60 microampere. But as we are designing the circuit, practically when we design the circuit it is better to take tough standard value of resistances because the resistances which we will have practically in the laboratory or real environment are actually having some standard values and that is why it is better to choose standard values while designing because then our design will correspond to the actual design that can be done in the lab environment. Although we are getting for this particular value of 60 microampere a value of resistance R_B which is 155 kilo ampere, let us take a standard value of 150 k because 150 k can be obtained in the lab easily. We take R_B equal to150 k as the standard value which is readily available.

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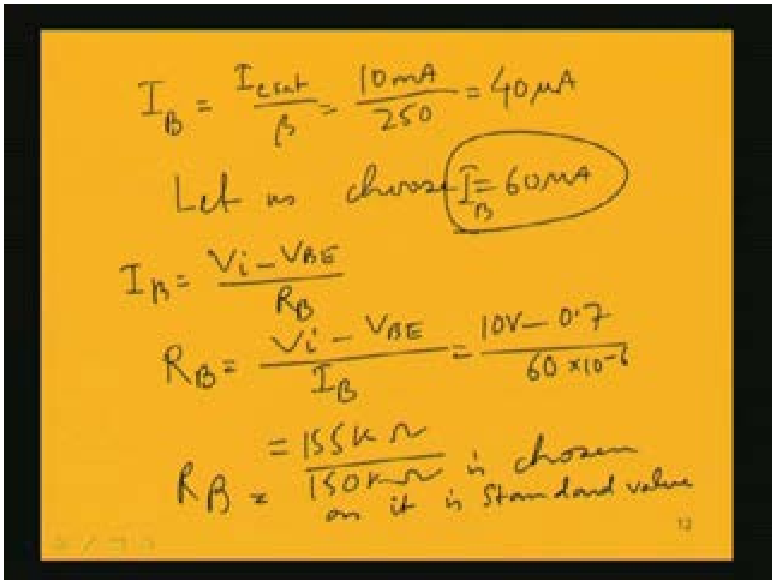

For this R_B is equal to 150 k, we can cross verify whether we are getting the saturation condition or not because then what will be I_B? I_B is V_i minus 0.7 divided by R_B and for this particular value of resistance which is 150 k we are having 10 volt. That value of I_B comes to 62 microampere and so it is well in saturation because saturation requires that the value of the I_B current should be 40 microampere or more. 62 microampere is greater than 40 microampere which we got initially as a condition for saturation. So saturation is guaranteed in this design, saturation is ensured. In this design we have designed R_B to be 150 k and R_C was designed to have 1 kilo ohm value.

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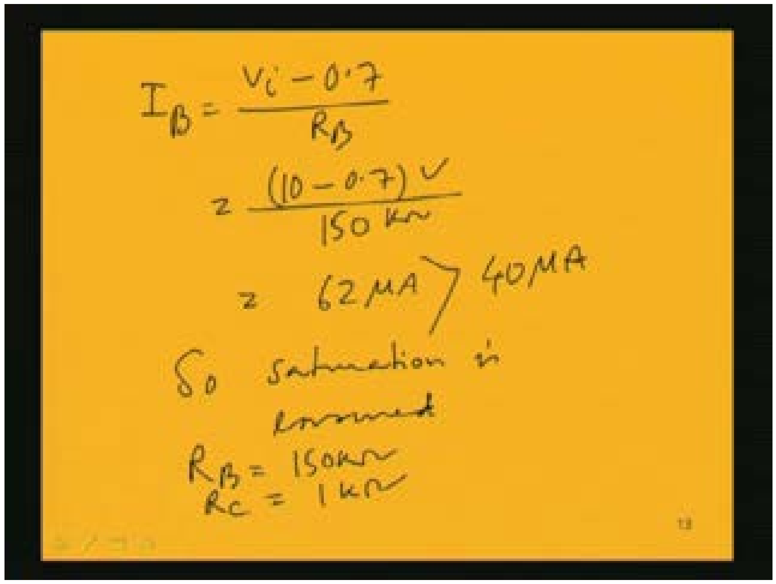

This design example shows how to get the values of R_B and R_C if we want to design a transistor as a switch. We have earlier discussed about the transistor as an amplifier and we also have seen that the capacitances which are present in the circuit do affect the gains. In relation to that let us do one example. We have to find out in this circuit the lower cut-off frequency for the amplifier.

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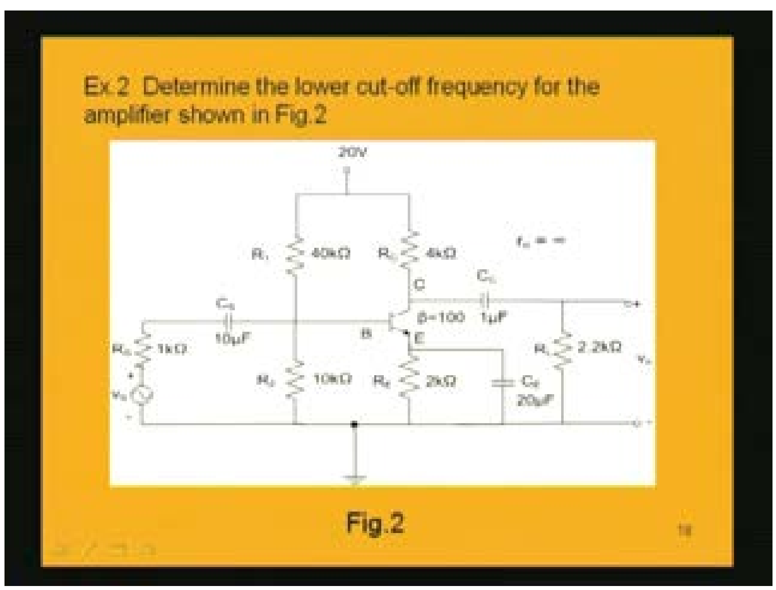

I am going back to the amplifier again and I want to do an example which has all the capacitances and we have to find out what will be the lower cut-off frequency for this amplifier.

In order to solve such problems first thing is to draw the equivalent circuit and a small signal model. If we now draw this equivalent circuit for this amplifier considering all the capacitances then in the low frequency region, as we have earlier discussed, the capacitances which will exist will be the coupling capacitor and the emitter by pass capacitor and the transition capacitance or junction capacitances of the transistor junctions. This will have no effect in the low frequency region. They will affect only in the high frequency region. In order to find out the lower cut-off frequency we have to consider only those coupling as well as the emitter by pass capacitors. Let us draw this equivalent circuit in the small signal model. We will have the resistance in series with the applied voltage signal V_S. If you look into this transistor amplifier, coupling capacitors are C_S, C_C and the emitter by pass capacitor is C_E. Others which are present in the mid frequency zone are the potential divider biasing circuit having the resistance R_1 and R_2, R_C is the collector resistance and R_E is the emitter resistance; load resistance is already there which are existing in the mid frequency also.

But in the low frequency region we have to consider the capacitances extra which are affecting. The capacitances C_S will be there. Then the resistance R_B I am writing for R_1 parallel R_2. In the small signal model you have these two resistances in parallel and the transistor is having the resistance between emitter and base which is beta plus 1 into r_e and the emitter is having resistance R_E and the capacitance which is by passing it is C_E and the output side is having the current source, beta I_B which is the collector current. In this direction collector current will flow and there will be resistance in the collector which is R_C. There is a capacitance which is coupling the collector which is C_C and R_L is the load resistance. The output voltage is V_O, input voltage at this point is V_i. The emitter is grounded through resistance R_E and R_C.

In this case, base current I_B is flowing in this direction; this is collector current. In order to know the lower cut-off frequency, we have seen in the earlier classes that we have to consider one by one the cut-off frequencies. Again in this small signal analysis in order to find out R_E, the resistance between emitter and base we have to again consider this equivalent circuit because r_e is nothing but 26 millivolt divided by capital I capital E, I_E. This is the DC current.

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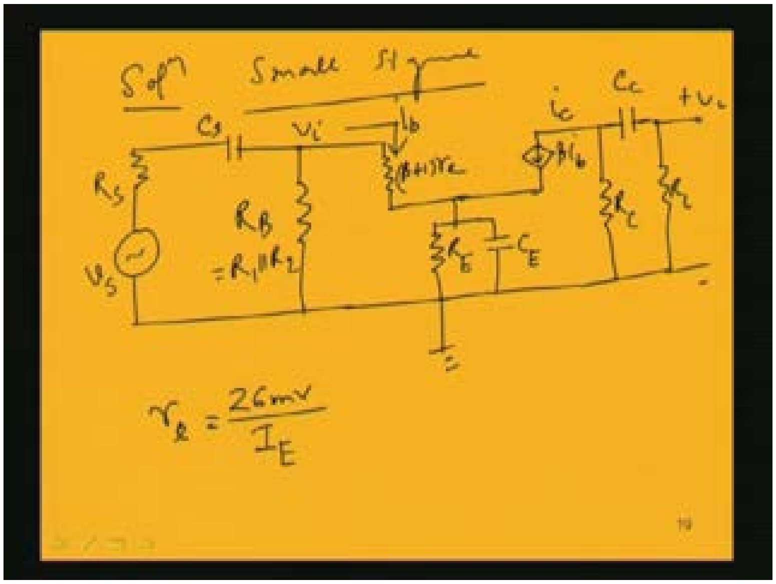

In order to know the DC current we have to again draw the DC equivalent circuit. If we consider the DC equivalent circuit we will be left with V_{CC} which is 20 volt and R_1, R_2 and R_E, R_C. This is R_1, this is R_2, R_C, R_E with the corresponding values of R_1 40 k ohm, R_2 is 10 kilo ohm, R_C is equal to 4 kilo ohm and R_E is equal to 2 kilo ohm. This is the DC equivalent circuit and in order to simplify the circuit what we have earlier done is that we are drawing the Thevenin's equivalent for the base circuit. That will give us a simplified circuit which can be drawn like this. This is the Thevenin's voltage; we have to find out Thevenin's voltage. From the base to ground the circuit will have a resistance R_B and this will be R_E, R_C and V_{CC}. Beta value is given as 100. We have to find out what is Thevenin's voltage and Thevenin's equivalent resistance and we know that Thevenin's voltage is equal to the voltage across R_2. Between base and this ground we have to find out the voltage and that is equal to V_{CC} into R_2 by R_1 plus R_2. V_{CC} is 20 volt, R_2 is equal to 10 k by 10 plus 40. If we do this calculation we are having 4 volt.

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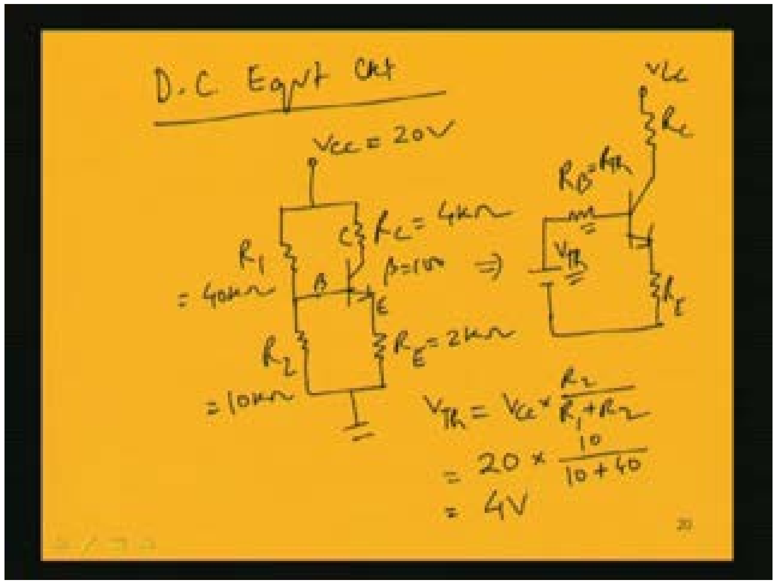

This 4 volt is the Thevenin's voltage and similarly we can find out what is R_B that is our Thevenin's voltage, which is the parallel combination between R_1 and R_2. It's equal to R_1 into R_2 divided by R_1 plus R_2. Putting the values of R_1 and R_2 we get 40 into 10 by 40 plus 10 and that gives 8 k. If we know this R Thevenin and V Thevenin and replace in the circuit we are getting 4 volt is V Thevenin and R_B is equal to 8 kilo ohm. Others are as it is. R_E is equal to 2 k, beta is equal to 100 and R_C will be there which is equal to 4 k; V_{CC} is 20 volt. In this circuit we can find out the base current, we can find out the emitter current; if required we can find out I_C also.

What we require is emitter current in order to know small r small e. For that if we write down the expression for I_B in this loop V Thevenin minus I_B R_B minus V_{BE}, base to emitter voltage minus beta plus 1 I_B into R_E is equal to zero. That is expression for I_E. Putting the values of the voltage and resistance and the other things we can find out the value of the base current. So 4 into I_B taken common, R_B we have found out is 8, 100 is the value of beta into R_E is 2 k minus 0.7. From this the value of I_B will be equal to 0.0157 milliampere.

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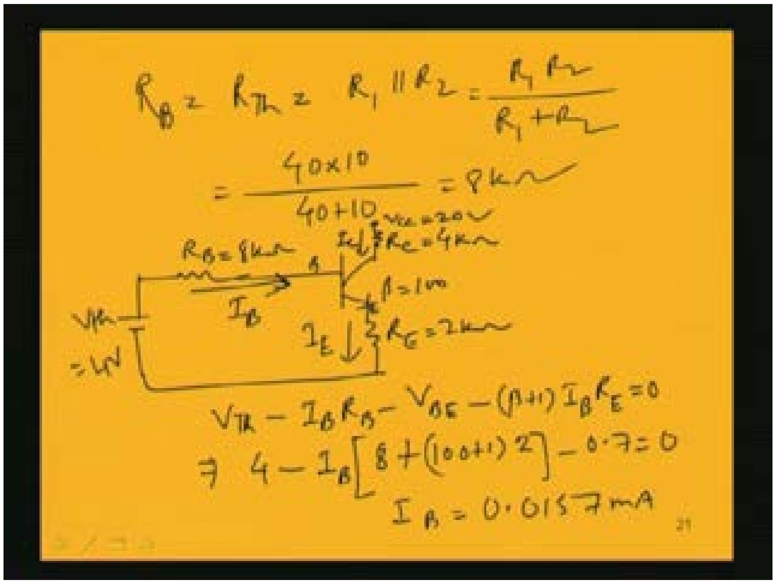

If B is this much we can find out what is I_E. It is beta plus 1 into I_B. Beta is 100; 100 plus 1 into I_B is equal to 0.0157 we have found out. This is equal to 1.586 milliampere. Once we know I_E we can find out r_e. It is equal to 26 millivolt by I_E. 26 millivolt by 1.586 milliampere and that comes to around 16.39 ohm.

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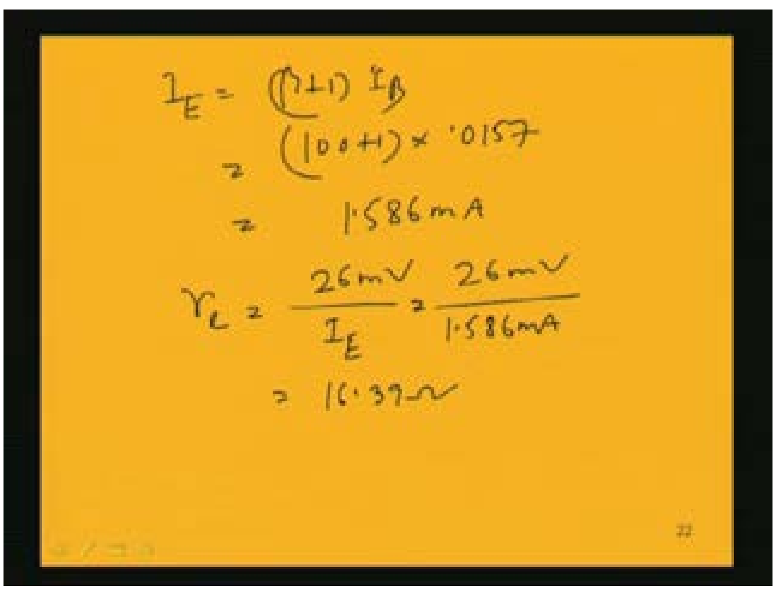

So 16.39 ohm is the value of resistance r_e. If we know this now we can find out all other required things in the small signal model because if we see here the small signal model, this was the only unknown, others we have found out. In order to know the lower cut-off frequencies, we have to first find out the input resistance R_{in}. Looking into the circuit

from the input terminals what will be the input resistance? R_B parallel beta plus 1 r_e in mid band region. This is in the mid band region because in the mid band region a capacitancy will be short circuiting and so this will be bypassed. You are left with R_B parallel beta plus 1 r_e. Let us find that out.

We will first consider mid band region and find out R_{in} which is R_B parallel beta plus 1 r_e. R_B is found out which is equal to 8 kilo ohm parallel 1.655 is the value of beta plus 1 r_e because beta plus 1 r_e is nothing but 100 plus 1 into r_e; r_e value you have found to be 16.369. This value comes to 1.655 kilo ohm. Putting this here if we take this parallel combination, 8 into 1.655 by 8 plus 1.655, this is the value of R_{in} in mid band, 1.371 kilo ohm.

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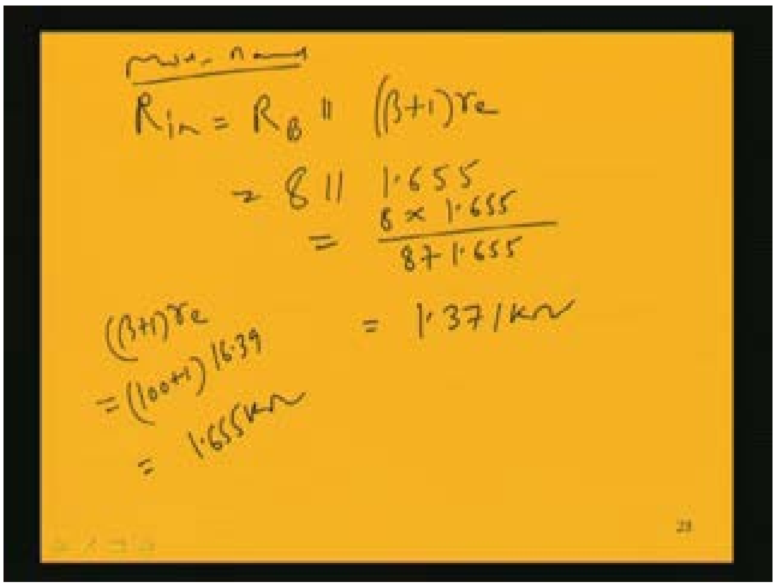

If this R_{in} is known we can now find out the lower cut-off frequency for all the capacitances. Then we will decide which one is the final lower cut-off frequency. Considering the C_S first that is the capacitance in series at the input with the source resistance, what is the lower cut-off frequency? f_{LCS} means low cut-off frequency due to C_S. That we have analyzed earlier and we have seen that this is 1 by 2 pi R effective into C_S and R effective for C_S is R_S plus R_{in}. If we look from the capacitor C_S and find the effective resistance then we have in this circuit R_S plus input resistance because input resistance will be the resistance for this input circuit. If we look from this capacitor we have R_S and other one is R_{in}. R_{in} is the input resistance for this transistor amplifier. Effective resistance is that much and so we replace here by R_S plus R_{in} into C_S and that is equal to 1 by 2 pi R_S is given as 1; I think R_S is 1 in this circuit. If R_S is 1 k, R_{in} we have found to be equal to 1.371 and be careful about the units. These are in kilo ohms. So let us multiply by 10 to the power 3 and what is C_S? In this circuit of the amplifier C_S value is 10 micro Farad. 10 micro Farad we will replace here; 10 into 10 to the power -6, as it is micro Farad.

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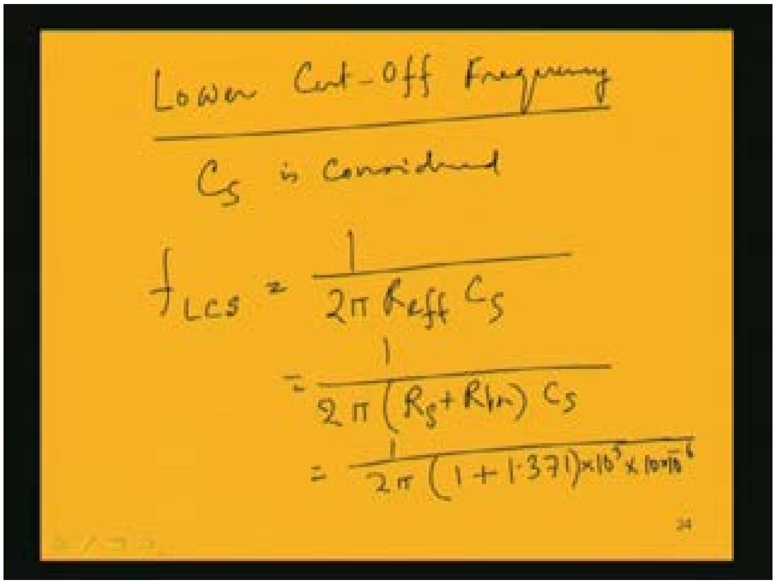

The whole calculation if you do you will be getting the lower cut-off frequency due to C_S as 6.71 Hertz. This is the lower cut-off frequency due to C_S only. If you consider the lower cut-off frequency due to C_C, f_{LCC} we have to find out. That is equal to 1 by 2 pi into effective resistance due to C_C into capacitance C_C. What is the effective resistance due to C_C? In order to find that let us look into the amplifier circuit from C_C. In the small signal analysis look from C_C this coupling capacitor and find out the effective resistance which is actually series resistance between R_C and R_L. In between R_C and R_L, the series resistance is the effective resistance seen by the coupling capacitor. We will replace here R effective which is equal to R_C plus R_L into CC. Putting these values we get R_C value is given as 4 k and R_L is 2.2; but these are in kilo ohm and C_C value is 1. You can look into the amplifier again and find out what values are given. C_C is 1 micro Farad, R_L is 2.2 k and R_C is equal to 4 k. Putting these values here we find the lower cut-off frequency due to C_C.

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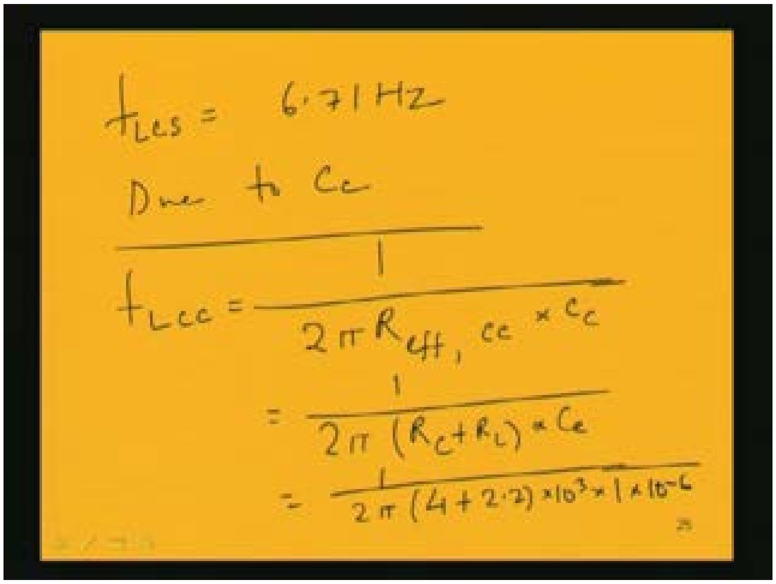

Finally we get f_{LCC} equal to 25.67 Hertz. What will be the other lower cut-off frequency that is due to C_E? Let us find out the lower cut-off frequency due to C_E. Again the lower cut-off frequency due to C_E is 1 by 2 pi effective resistance looked from C_E. Let us denote that by R_{eff} C_E into C_E. We will replace C_E value. What is the effective resistance due to C_E? If we look into the circuit or we have already earlier found out that the effective resistance due to C_E is nothing but the value of R_E parallel small r_e plus R_B parallel R_S divided by beta plus 1 and this derivation we have already done earlier. So we will replace this value of R effective resistance which is equal to R_E parallel small r_e plus capital R_B parallel capital R_S divided by beta plus 1.

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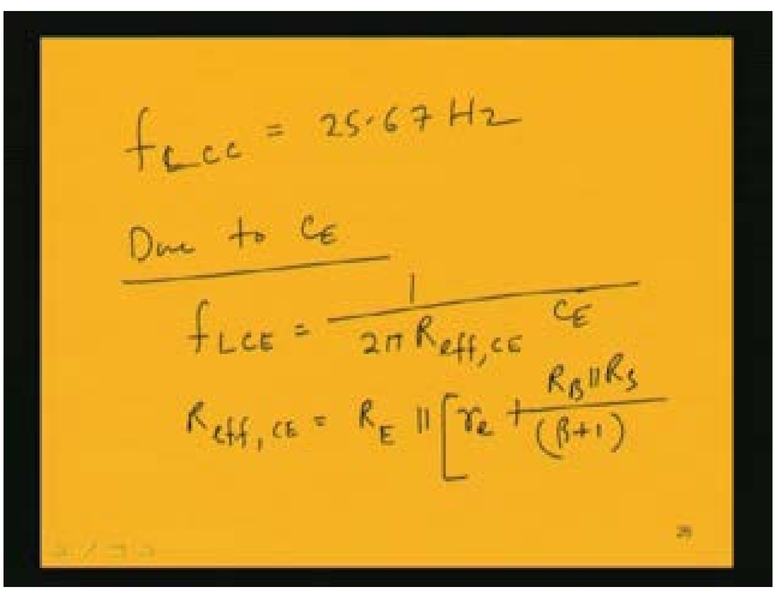

Putting all these values we get R effective resistance is equal to R_E capital is 2 kilo ohm that is 2 into 10 to the power 3 parallel the value of r_e we have found out to be 16.39; I am writing all R in ohm. That is why I am giving 16.39 plus parallel between R_B and R_S which is 8 and 1; so parallel between 8 and 1 and divided by beta plus 1. Beta plus 1 is 100 plus 1 and this will be multiplied by 10 to the power 3. You can check this calculation and verify. This will be finally equal to 2 into 10 to the power 3 parallel the whole value to the right hand side of this parallel will be 25.2 ohm. The parallel combination between these two will be 2 into 10 to the power 3 into 25.2 by 2 into 10 to the power 3 plus 25.2 and that comes to 24.89 ohm.

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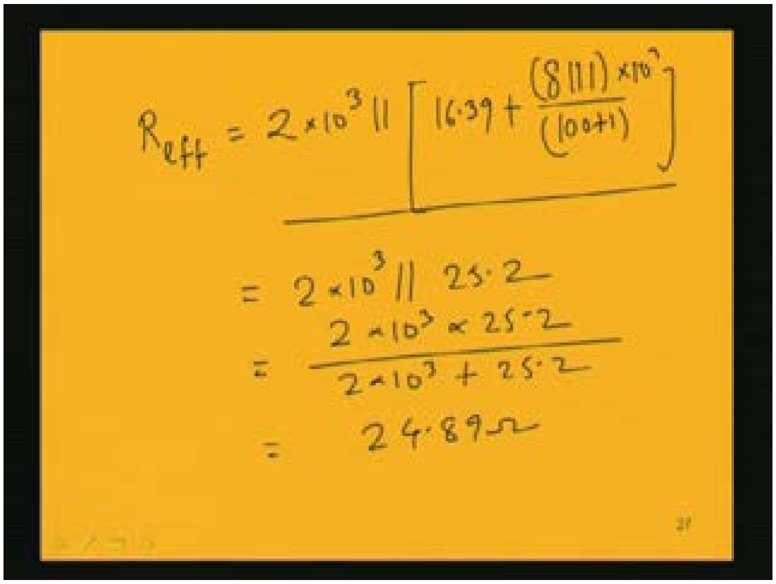

If this is the value of the effective resistance now you can find out the lower cut-off frequency f_{LCE}. 1 by 2 pi, R effective we have found out to be 24.89 and the value of C_E is 20 micro Farad. You can look into the amplifier circuit and verify. It is 20 micro Farad. Putting these values 20 micro Farad you place here. Since it is micro Farad, 10 to the power of -6 is the factor by which we have to multiply. So this value comes to 319.72 Hertz. Now we have three lower cut-off frequencies f_{LCS}, f_{LCC} and f_{LCE}. The lower cut-off frequencies is due to the coupling capacitors C_S, C_C and emitter bypass capacitor C_E. These values we have found to be equal to 6.71 Hertz, the value due to C_C is 25.67 Hsertz and the value due to C_E is 319.72 Hertz and this is the highest value. Out of all the three, the value due to C_E which is 319.72 Hertz is the greatest value or largest value of the lower cut-off frequency.

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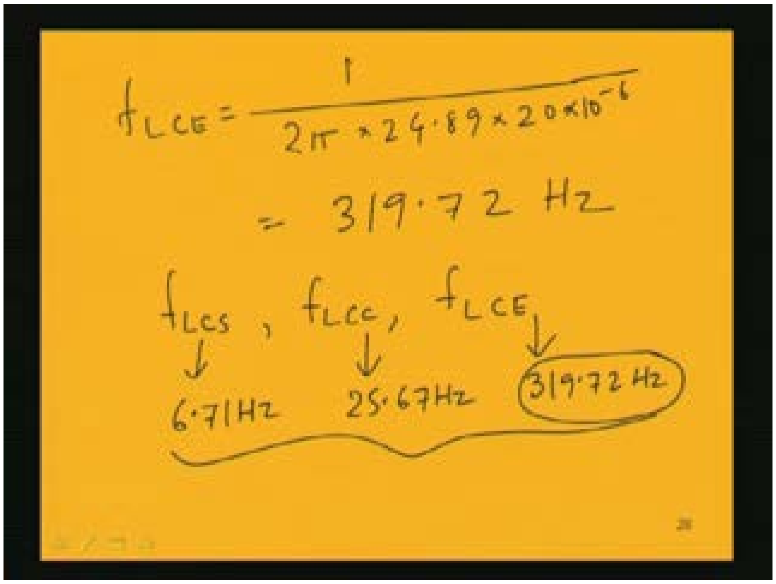

We have to choose the largest among all the three lower cut-off frequencies and that will be finally the value of the lower cut-off frequency for this amplifier circuit because in the lower frequency region you have to take the largest value among all the lower cut-off frequencies. So what will be the final value or the overall lower cut-off frequency? f_L, I am naming it as f_L which is the overall lower cut-off frequency for the amplifier circuit and that is equal to the value which is due to the emitter bypass capacitors C_E because that is the largest value among all the three and that is equal to 319.72 Hertz. Finally this is the lower cut-off frequency in this amplifier. Mid band frequency region gives a voltage gain constant but lower and higher frequencies offer a voltage gain which are reduced and here in this particular example we have seen that the value where the 3 dB cut-off frequency exists is the value 319.72. This type of voltage gain actually we get in the amplifier because of all those capacitances. This is the value of the lower cut-off frequency f_L because here at this point the voltage gain drops to 1 by root 2 times A_V if this is A_V. Out of all these three we have selected this value.

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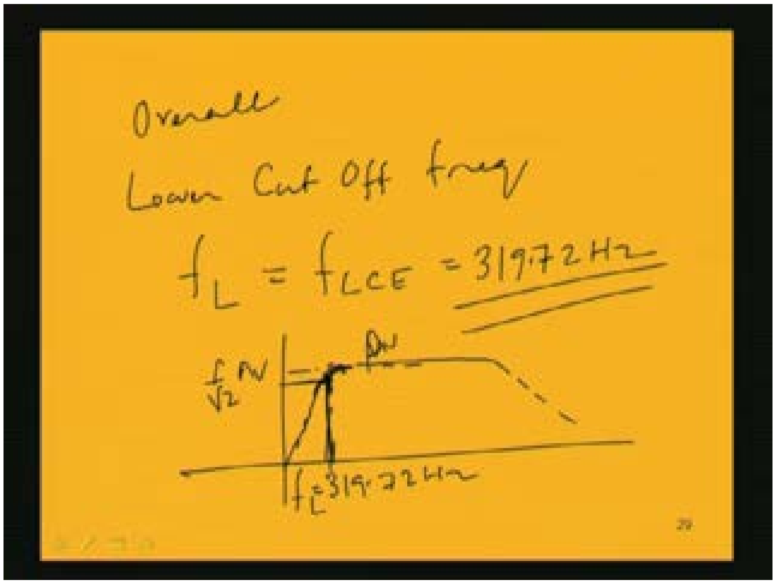

Similarly we can also find out in the high frequency region the upper cut-off frequency for the amplifier. Then we will have to know the junction capacitances in the model of the transistor. This example just shows the way of calculating the lower cut-off frequency. Similarly we can calculate the upper cut-off frequency for an amplifier in the high frequency region and if we have a modern one cut-off frequencies that will be the case if you consider the junction capacitance C_{BE} and C_{BC}, base to emitter and base to collector junction capacitances then we will take the lower among the two. In the high frequency region when we find out the upper cut-off frequencies we have to take the lower among the two. But here in this lower cut-off frequency we take highest among the three.

In this analysis whatever we have done till now involving BJT amplifier we have seen how amplification takes place how to find out all those parameters involved in amplification like voltage gain, current gain, etc and also we have seen the effect of capacitances which are present in amplifier. How the voltage gain is affected because of the capacitances but all the analysis was done considering a small signal and this analysis is complete as far as BJT amplifier is concerned.