Basic Electronics

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

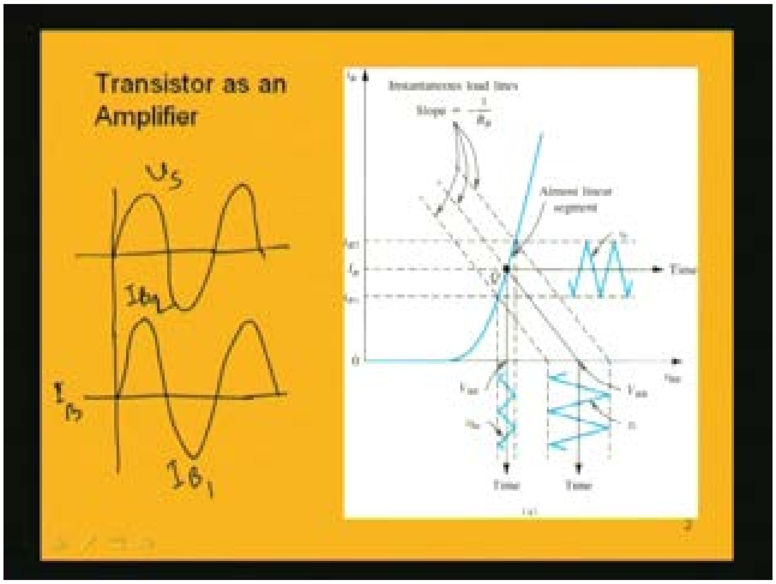
Module: 2 Bipolar Junction Transistors
Lecture-5

BJT Small Signal Analysis

In the last classes we have seen how biasing of the transistor is done and we were considering different biasing schemes. All these biasing schemes are basically for using the transistor as an amplifier for faithful amplification of an input signal. Today we will discuss about the transistor being used as an amplifier and to understand the operation of the transistor as an amplifier we have to first understand the analysis of the BJT when a small signal is applied. So small signal analysis of a BJT will be discussed today. The small signal means the magnitude of the AC signal which is applied should be small enough to keep the transistor still in the active region of operation because we want the transistor to operate in the active region. Only then the transistor will be able to faithfully amplify an AC input signal. If that signal amplitude is very high then it is seen that the transistor will be driven into either saturation or cut off region because when you have very large signal at the input then the base current signal will be having a high magnitude. Peak to peak value of the base current will be high.

You look back into the input and output characteristics of the transistor which we have discussed earlier. Let us recall the transistor characteristics. The input biasing current is large enough because of the application of a signal at the input which is having a high peak to peak value. Suppose this is the signal which is applied at the input of the transistor amplifier. Then what will happen is that due to the application of this large signal the biasing current in the transistor will also be high. The biasing current signal, starting from the DC bias current will be going up and down. These values of the peak positive and peak negative of the small signal will be large enough. When we apply a large signal then the biasing current IB will also be high and if we start from say DC biasing current then it will also be large. The maximum and minimum values of the biasing current in the transistor will also be high. Suppose this is IB2, this is IB1.

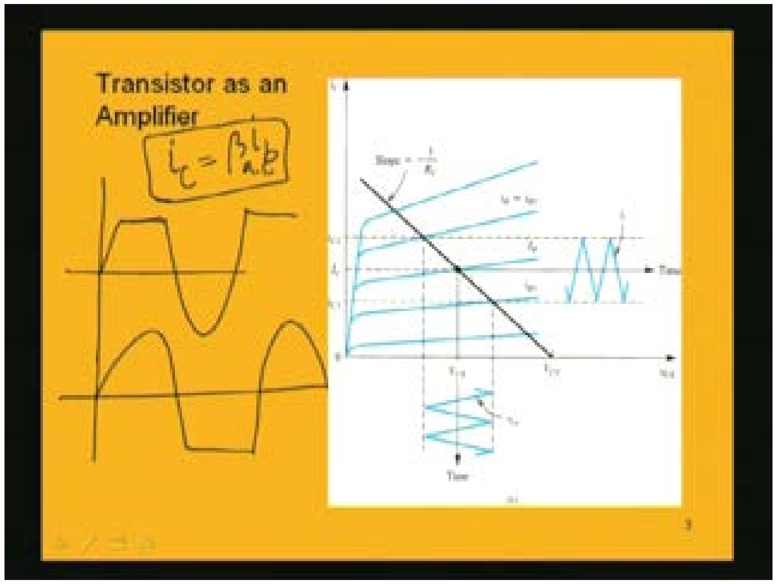
(Refer Slide Time: 4:48)



This large signal at the input of the transistor will again cause a large IC because IC is equal to beta times of IB.

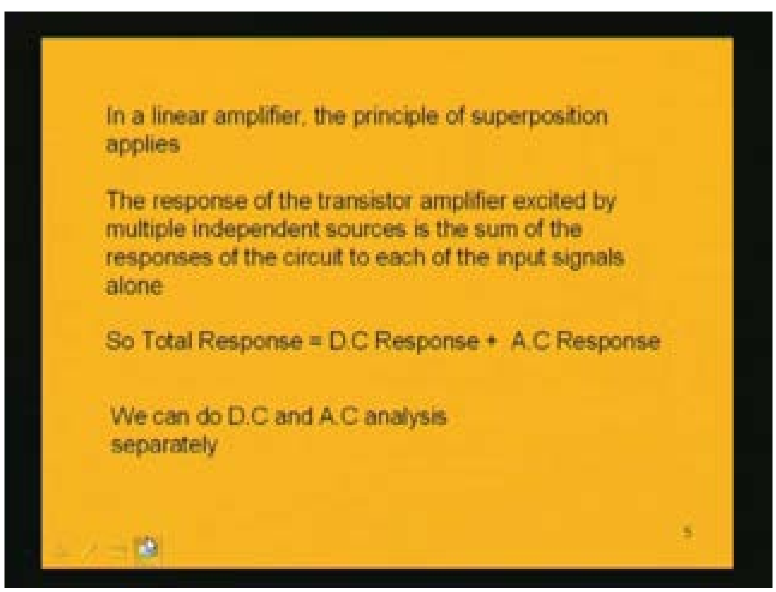
If we now see the output characteristic then this IC signal starting from the DC value of the collector current which is because of the Q point, this current IC will also be large. If IC is so large that it enters into saturation or IC is so large in the other half that it enters into the cut off then what will happen is that we will not be getting a reliable amplification because if the transistor is over driven that is, it is either entering into the saturation or the cut off region then one portion of the output signal which is VCE that will be cutoff. If it enters into saturation in this negative half, one portion will be clipped off. If it enters into cut off then the portion in the positive half will be cutoff or it will be clipped. We will not be getting a faithful amplification; rather we will be getting a distorted signal. If we get a signal like this or we get a signal like this, this will not be desired. We do not want any distortion in the output signal than what we are giving in the input signal. This is happening because the signal which we are applying is large enough to over drive the transistor. The transistor is then driven either into saturation region or into the cut off region.

In order that this does not happen we must be careful enough to apply the signal at the input which should be small enough. If this small signal is applied at the input then we can ensure that the transistor is in the active region of operation. That is what it should be for amplification. When it is in the active region the transistor is operating as a linear amplifier because we know that in the active region the collector current relation with the base current. Beta times of ib is the collector current; ic is equal to beta times ib and when we consider only the signal that is the AC quantities, this will be AC beta. But AC beta and DC beta does not have magnitude wise much difference. For all reasons which are valid we can assume that the AC value and the DC value of beta are almost equal.
(Refer Slide Time: 7:55)



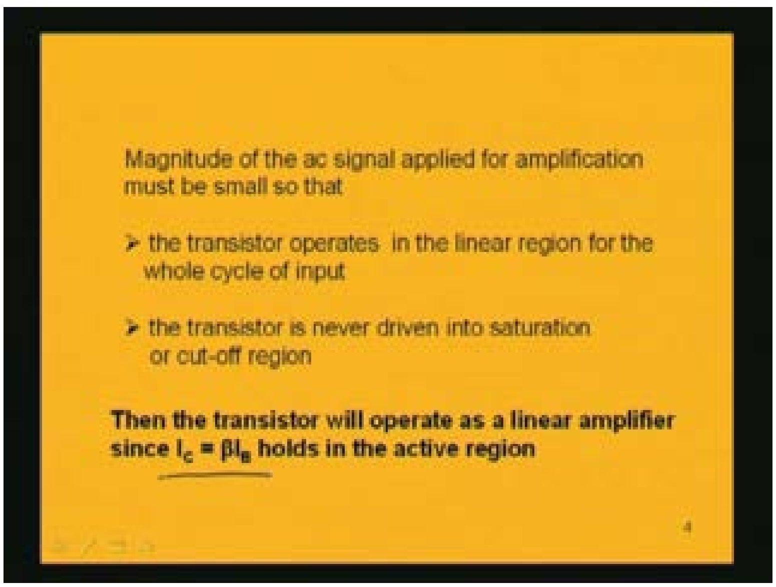
If beta times ib is equal to ic that means it is a linear relationship and when the transistor is linear, one advantage of analyzing the transistor in the linear region is that we can separate out the DC analysis and AC analysis. When a system is linear and if we apply multiple signals to the system which is linear then the total response of the system will be the superposition of the individual responses. That means the superposition theorem holds when a system is linear and that has advantages for analysis of the transistor. The superposition of the transistor means that principal of superposition is held. The response of the transistor amplifier excited by multiple independent sources is the sum of the responses of the circuit to each of the input signals alone.

(Refer Slide Time: 9:05)



If we have a DC voltage for biasing if we recall earlier we were discussing the DC analysis. That was because we were concerned about the DC equivalent circuit since we are concerned about the biasing schemes and the operating point. That is why DC equivalent circuit when we considered we were only discussing the DC condition. When we are applying an AC signal for amplification then we will be concerned about the signal analysis; that is the response of the BJT for an AC signal and because this transistor is operating in the linear region which is due to the fact that we are applying a signal which is small enough which will ensure that the transistor operates in the linear region or active region. We can now see that the total response of the transistor amplifier will be the summation of the responses due to DC plus and the AC. DC response plus AC response can be now summed up to give the total response and we can do the DC analysis and AC analysis separately giving the corresponding voltages like DC voltage when we apply we will have the DC equivalent circuit and we can analyze the transistor under DC condition and when we apply the AC signal we will consider the transistor in the AC condition. That is the advantage of this active transistor; that active transistor being operated in the active region or linear region. That's what we are going to do. This condition is prevailing because the signal being applied is small and we are having the linear relationship given by I_C is equal to beta times I_B.

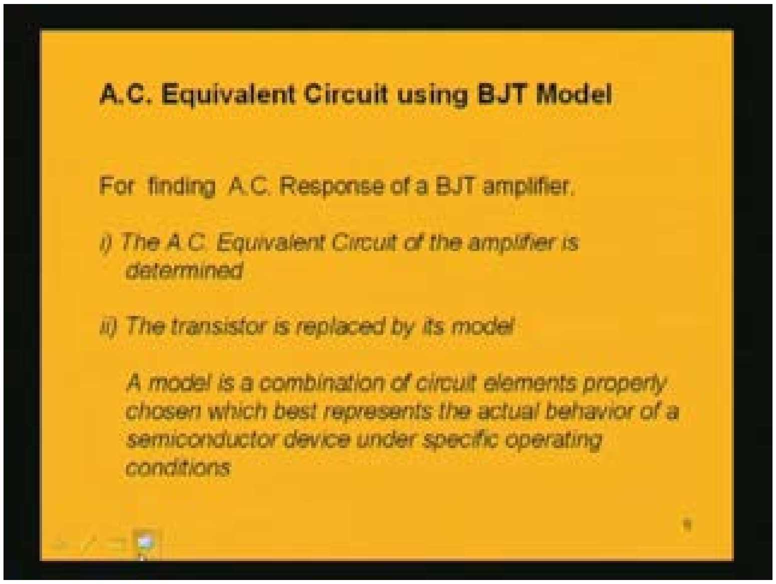
(Refer Slide Time: 11:23)



In earlier discussions we were discussing about the DC conditions and biasing. That was the DC analysis. Let us do the AC analysis of the BJT. When we are applying an AC signal at the input, what will be the output and other relevant parameters we will find out considering the AC analysis. In a transistor amplifier because of the presence of the DC and AC both we are separating them out; we are separating the DC and AC analysis and we are now concentrating on AC analysis. First of all we must know how to draw the AC equivalent circuit for a transistor amplifier. That we will discuss today.

AC analysis can be done if we first draw the AC equivalent circuit for the BJT amplifier and for finding out the AC response of a BJT amplifier first we must determine and draw the AC equivalent circuit. When I say AC equivalent circuit I forget for the time being, the DC part of the amplifier and after drawing the AC equivalent circuit for the transistor amplifier the transistor, which is a device and that, is the semiconductor device, we must represent its electrical equivalent model. As it is a semiconductor device physically we know what a transistor is. But then in order to fit it into the circuit analyses we must draw the equivalent model of the transistor. The transistor used to be replaced by its equivalent model

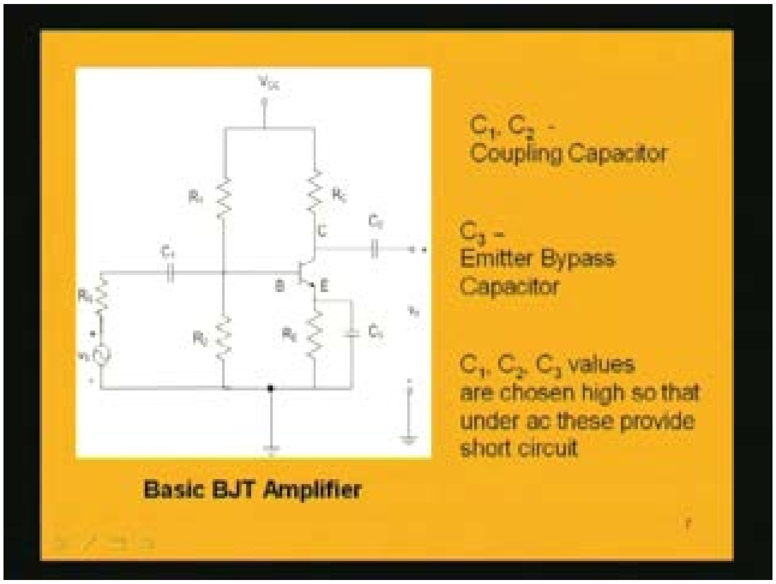
(Refer Slide Time: 13:30)



What is a model? Basically a model is the combination of circuit elements properly chosen such that it best represents the actual behavior of a semiconductor device under specific operating conditions. Suppose we are considering a common base or a common emitter transistor. Then from the input and output characteristics which we know we must model the transistor equivalently which can be done by choosing the right parameters for expressing the behavior of the transistor under operating conditions. From the actual physical transistor we must derive its model by properly combining the circuit elements so that the behavior of the transistor, behavior means the input as well as output characteristic which we have studied, that can be reflected by the model.

We have to first build the model for the transistor. If it is a common base transistor equivalent model for that common base transistor has to be first derived. Then we must fit that model for the transistor into the AC equivalent circuit. If we consider a transistor amplifier practically for example we are considering a BJT common emitter transistor amplifier circuit and it is an NPN transistor. The whole circuit for the amplifier is shown here.

(Refer Slide Time: 15:24)

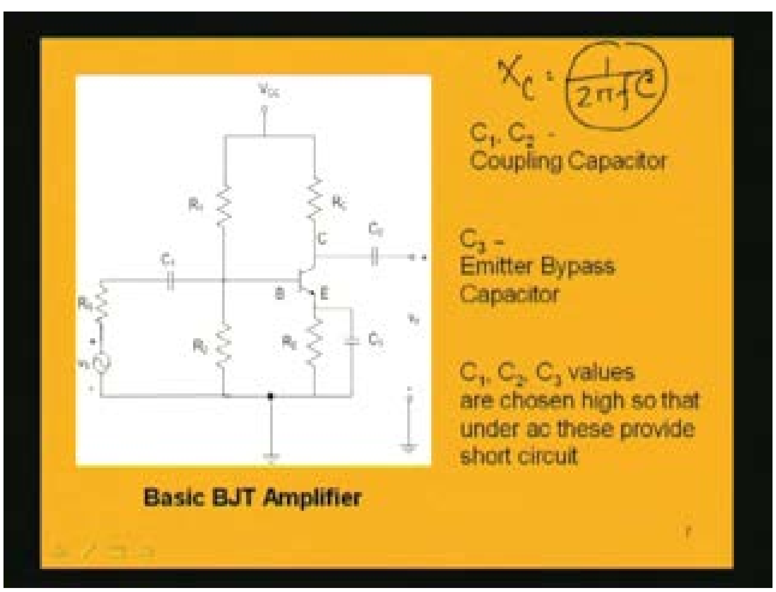


As per our earlier knowledge we know that these resistances R_1, R_2, R_C and R_E are in the biasing scheme and we are applying signal V_S that is the applied source, which has to be amplified. We must get at the output an amplified distortionless signal and this resistance R_S basically it is a series resistance which is present in a source in series with it and it should be very small. Ideally it should be zero. But it is not true that it will be zero because practically there is a small resistance in series with all the sources that is denoted by this R_S. We are now having three capacitances C_1, C_2 and C_3 in the practical circuit. The purpose of incorporating these capacitances is that C_1 and C_2 are coupling capacitors. These capacitors are present to couple the signal and this capacitance C_3 is emitter bypass capacitor. The reason for applying C_1 and C_2 which are coupling capacitors are that these coupling capacitors are used to pass the AC signal only and block the DC component. That is basically a transistor amplifier may have a number of stages in cascade. That is in series we may have a number of amplifiers so that the final amplified signal should be large enough. Instead of having only one BJT amplifier we may have a number of BJT amplifiers in series. If that happens, suppose we have number of stages coupled with this single stage then we can very well see that the output at this stage, that means the amplified signal which we are having here which is amplified version of this signal, this will be again fed back as input to the next stage.

When we apply this input signal we expect that only the signal should be amplified. The DC voltage which is present in this circuit should not affect the input signal at the next stage and that is ensured by the presence of this coupling capacitor because this capacitor offers open circuit for DC. The DC voltages which are present in this first stage of the amplifier will not be affecting the next stage and the signal at the input will be only AC because this capacitor will prevent the DC voltage from interfering into the second stage input. That is why this capacitance is called coupling capacitor because it is coupling the output from the first stage to the input to the next stage. This coupling capacitor which is present here is serving another purpose. We can see that this DC voltage which is used for biasing should not reach the source V_S. We are interested in only amplifying this AC signal. This voltage which is present for biasing only should not affect this source. Meaning is that we need to amplify only this signal which is small signal or AC signal, V_S and in no way it should be corrupted by this DC voltage and that is ensured by this coupling capacitor because this coupling capacitor is blocking the DC to reach the source. That is why we are applying a coupling capacitor here also. This C_3 is called an emitter bypass capacitor. This emitter bypass capacitor is the capacitor which bypasses the signal present here to pass through this capacitor and it is bypassing this resistance. We will later observe this fact that because of the presence of this resistance R_E which is part of the biasing scheme voltage gain of the amplifier is actually reduced.

If the AC signal is present in this resistance R_E, then the voltage gain will be reduced because of this drop and that can be avoided if we connect a capacitor in parallel to this resistance R_E and if this capacitor is chosen properly having a high value of capacitance, then the reactance offered by this capacitance will be very, very small as if it is short circuiting for the AC signal and that is why the AC signal will be passed through this capacitance. It will not be going through this R_E. That is it is to avoid this R_E. For actually getting rid of that problem of reduction of the voltage gain this capacitance, which is emitter bypass capacitor is used. While choosing the capacitance value C_1, C_2 and C_3 we must be careful and have to choose a higher value for all these capacitances. There is a particular reason because if the C_1, C_2 and C_3 capacitors are high, the capacitive reactance offered by this capacitance will be very small under AC condition. The reactance offered by capacitance is 1 by 2 pi FC. This is the reactance offered by capacitance. If this capacitance is high, under the frequency of operation where we are operating, this signal V_S has frequency under that frequency of operation the denominator value should be high enough so that the overall quantity becomes very small as if it is like short circuit, almost like zero.

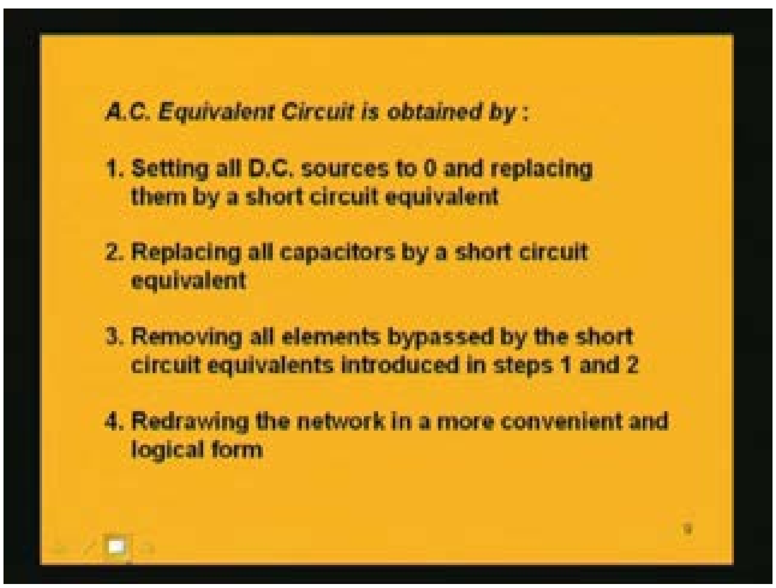
(Refer Slide Time: 22:19)



If this quantity is very high in the denominator, the overall quantity will be very small almost equal to zero. That means C_1, C_2 and C_3 if they are very high then the parts of these C_1, C_2, C_3 capacitors will be like short circuit for AC. Under the AC operation it will be like short circuit and that is ensured by choosing a very high value and under DC condition it is open circuit. This has to be remembered. Only then we will be having the faithful amplification and this overall circuit is having DC voltage as well as AC voltage both and applying the linear condition of super position we will be now able to consider the whole circuit in DC and AC separately.

DC analysis we have earlier done in biasing schemes. That we discussed earlier. We will focus on the AC operation and then the first and foremost thing is to draw the equivalent circuit for AC. We have to draw AC equivalent circuit for this. In order to draw the AC equivalent circuit for this amplifier first thing is we must make all the DC sources zero. That is we have to short circuit the DC sources because we are not interested in the DC voltages and this is only for biasing and we are now concerned about amplification of the AC signal. So we have to make the DC voltage zero. V_{CC} which is the only DC voltage available here is to be made zero or it is short circuit to ground. The AC equivalent circuit is drawn. First step is setting all the DC sources to zero and replacing them by a short circuit equivalent.

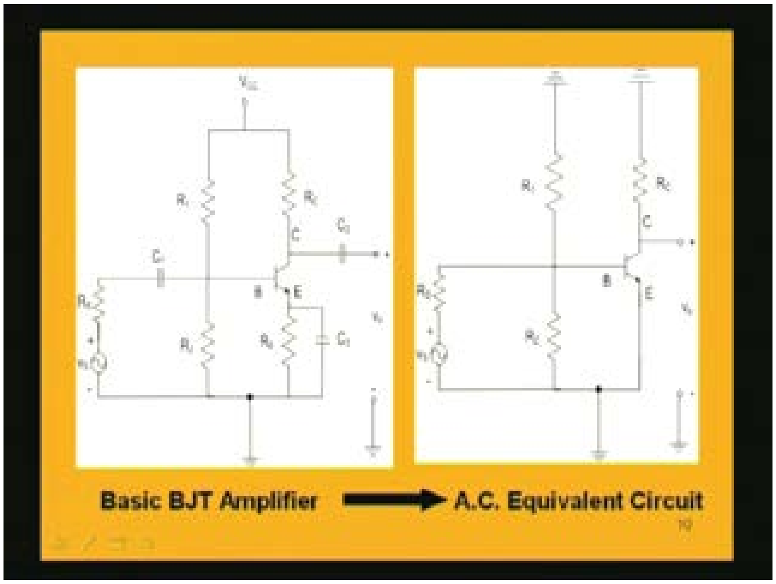
(Refer Slide Time: 24:39)



Then next step is you replace all the capacitors by a short circuit equivalent because we have chosen all the capacitance values quite high so that for that frequency of operation of the AC signal it is like short circuit because the 1 by 2 pi FC times will be very, very small, almost like zero since the C value is very high. Then number 3 step is to remove all the elements bypassed by the short circuit equivalents which I introduced in steps 1 and 2. While we did steps 1 and 2 then we got some short circuited paths. All the elements which are bypassed by the short circuited paths those elements can be very conveniently now ignored or removed. That has to be done and after doing these 3 steps redraw the network in a more convenient, logical form so that the analysis can be conveniently done. We can now redraw the whole network after doing all this 1, 2 and 3 steps.

Let us now see how to draw the equivalent AC circuit for this BJT amplifier; it is a common emitter amplifier employing the DC biasing potential divider by a scheme. Following the steps the first step is to make the DC sources zero. That is done by making V_{CC} zero or it is like short circuiting, means it is grounded. The ground potential is zero; that is done. If we just look into this point it is having 2 resistances R_1 and R_C, both connected to V_{CC}.

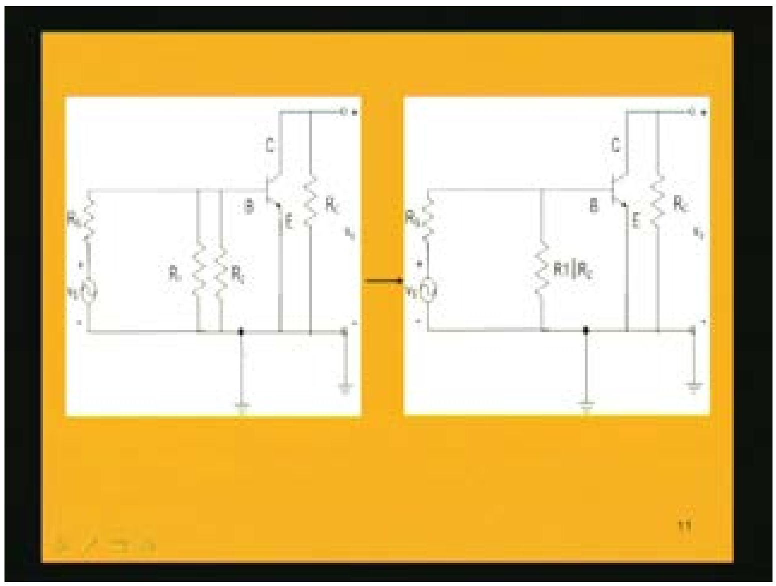
(Refer Slide Time: 26:36)



When we are making this V_{CC} grounded then these two resistances are also grounded. We are conveniently showing them by showing them separately. The R_1 is also grounded, R_C also is grounded now. Then after this we have to see the capacitances which are offering short circuit paths under AC. That is because we have chosen C_1, C_2 and C_3 to be large enough and that has to be kept in mind. For designing this amplifier the values of C_1, C_2 and C_3 should be conveniently large enough so that equivalently we can draw it like a short circuit. That is being done here. Instead of the C_1, C_2 and C_3 we see that these are short circuited paths. C_1 is short circuited path, C_3 is short circuited and this path, coupling capacitor is also having a short circuited path. After doing these steps we can also notice here that because of this short circuiting by this C_3, R_E is just removed totally because the current will be short circuited. It will go by this path; short circuited path. Emitter current will go by this path. It will not take this path or this resistance because when it is offered a very easy path like having no resistance at all short circuited, then this resistance will be bypassed. That is why there is no purpose for this resistance to exist here because this short circuiting path is there. That is why this R_E is removed according to the step 3.

This is the equivalent circuit under AC. We can do a step further and draw it more conveniently because one point we are noting here is that this base is having R_1 resistance to ground as well as R_2 resistance to ground. It is like two resistances R_1, R_2 which are parallel from base to ground. We can combine this R_1 and R_2 resistance and instead of drawing separately we can find out equivalent of R_1 and R_2 which is a parallel combination of R_1 and R_2. Then we can combine into a single resistance whose equivalent is R_1 parallel R_2. That is R_1 into R_2 by R_1 plus R_2. That is done next. Here we notice R_1 and R_2 both are parallel from base to ground.

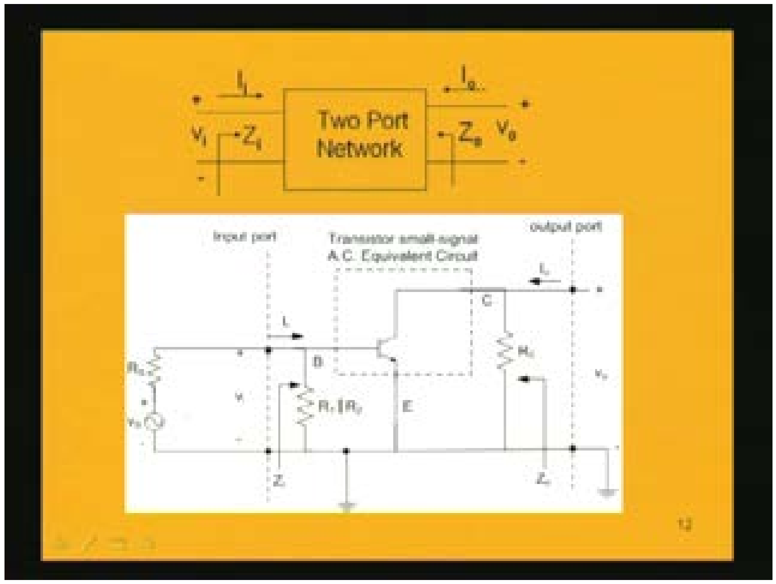
(Refer Slide Time: 29:25)



We are combining R_1 and R_2 into an equivalent resistance R_1 parallel R_2 and also this R_C, if we look back here, R_C is grounded from this collector but conveniently or most commonly it is not drawn upwards. This ground is shown as downwards and that is why conventionally we are drawing again by connecting this collector through resistance R_C to ground. This point is ground. This is the conventional circuit which we have derived from the transistor amplifier and applicable under AC. AC equivalent circuit is this one. After drawing this AC equivalent circuit we can go on to find out the required parameters like voltage gain, current gain, etc for this particular amplifier. But then one obstacle is existing here itself because of this presence of this physical transistor.

This physical semiconductor device as it is shown is a transistor. Here it is common emitter but this transistor if it is kept like this it will not be possible to analyze the circuit in terms of actual electrical engineering. That is why we have to replace this transistor also by its equivalent model. Equivalent model of this transistor can be found out or can be drawn if we recall the input and output characteristics of a transistor. From the basic analysis of the behavior of this transistor or input and output characteristic of this transistor we will try to find out the equivalent model for this transistor. That has to be done. Only then we can fit in the transistor and its equivalent model into this circuit and then proceed for finding the voltage gain, current gain and other related parameters of this transistor. Basically at this point the whole amplifier after drawing the AC equivalent circuit will look like this. Basically this source and resistance are there.

(Refer Slide Time: 32:05)

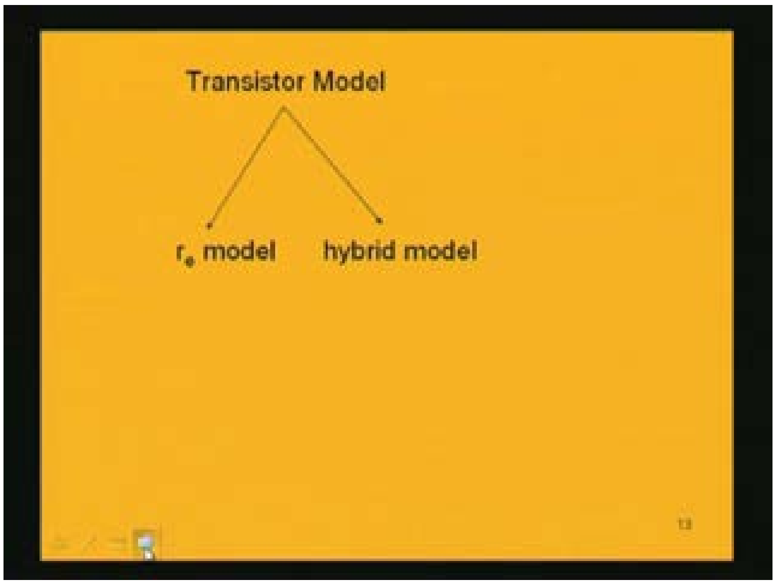


This point is base, this point is emitter. We are talking of common emitter transistor. This is collector and this is emitter. This type of circuits like a transistor are best expressed by two port system or two port network; means those systems are having a pair of input circuit and pair of output circuit terminals like shown here. Suppose we are having this 1, 1 dash as the input terminals and 2, 2 dash as the output terminals. This is like two ports; input port and output port. There is a circuit in the input side, there is a circuit in the output side and this network is called basically two port network. For example transistors as well as transformers are best expressed by this two port network and in the transistor analysis also we will follow this. That is why I am introducing this two-port network at this point. If we look into the whole circuit between these two points, this is the input port and this is output port. Source and load will be external to this whole two-port system. So the input port is having all these parts along with transistor. The circuit R_1 parallel R_2 and R_C will be there; only the source and the load are external to this two-port network and we can analyze the whole circuit in the light of this two-port network which we are going to do next.

In this two port system there are quantities; input voltage, input current, output voltage, output current and conventionally the polarities and directions are shown like this. Upper point is positive with respective to the lower point of these voltages and the currents are towards the system. I_1 and I_2 are conventionally shown towards the two-port system. V_1I_1, V_iI_i are the quantities of the voltage and current at the input port and V_OI_O are the voltage and current at the output port and from this knowledge of V_iI_i, V_OI_O we can find out the input impedance. Input impedance means V_i by I_i that is equal to Z_i. It is input impedance that can be found out from this ratio. Similarly at the output we can find out Z_OV_O by I_O is Z_O output impedance. We can find out voltage gain V_O by V_i. We can find out voltage gain, we can find out current gain. All these quantities are very important for an amplifier and these can be found out by considering the whole transistor amplifier as a two port system; we will use that. Still we are left with finding the model for this transistor.

In order to find out the transistor model basically there are two approaches. One is the r_e model, another is the hybrid model. These two models are used for equivalent models of a transistor.

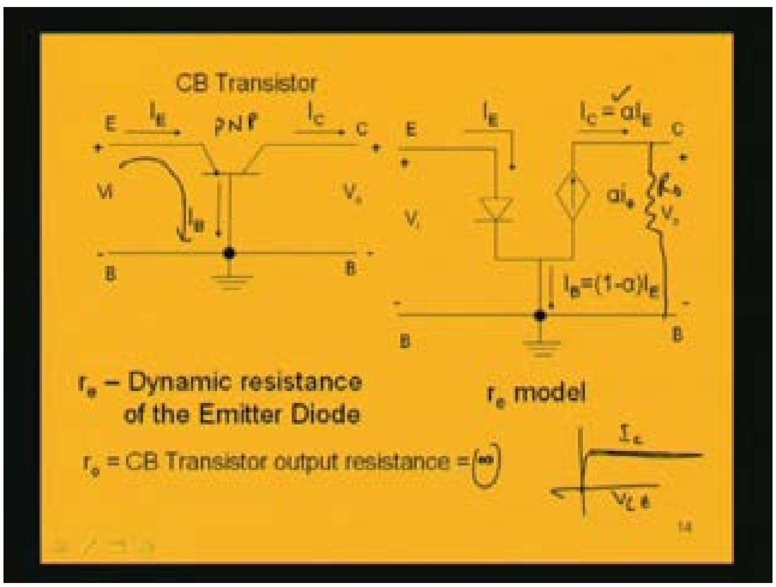
(Refer Slide Time: 35:48)



Now we will discuss r_e model. r_e actually means dynamic emitter resistance model and this model has to be first derived; for the different configurations of transistor we will see. First let us take for example a common base transistor. Common base transistor we take and we are considering say for example PNP transistor. This is the PNP transistor. In the light of this two-port network which we have just now seen, this is input port, emitter and base. This is the collector and base port is the output port. The transistor is having input current I_E and collector current I_C is the output current and this is the base current. This is a common base transistor. In order to find out this common base transistor's equivalent model we have to consider the emitter to base part of the transistor as a forward biased diode. It is nothing but a forward biased diode. Emitter base junction is forward biased in a transistor and collector base junction is reverse biased in a transistor. If we consider emitter to base, this part, then this part which is a forward biased diode can be replaced or represented by a diode which is forward biased.

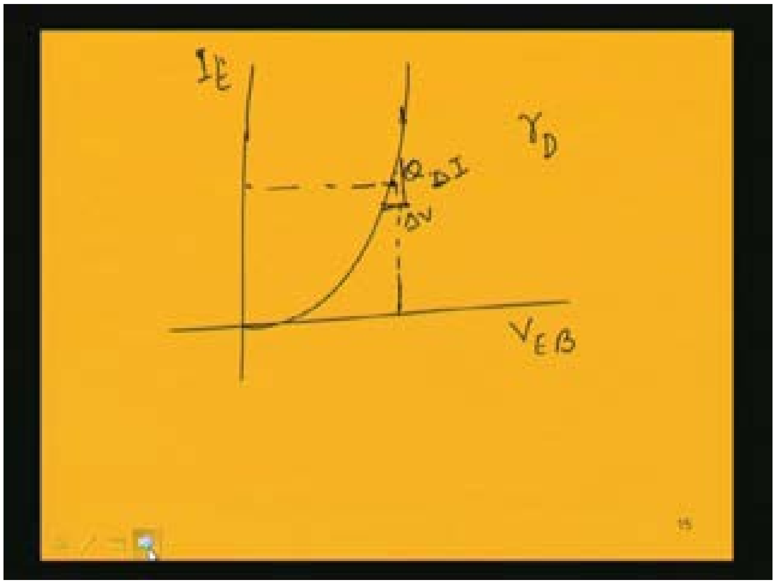
This is a PNP transistor. Forward biasing means this P will be connected and N will be connected in this fashion. This is P, this is N. It is forward biased by this voltage. Emitter to base voltage is the input voltage and the output side if we consider the collector current it is nothing but alpha times of I_E. This is like a current source. I_C is equal to alpha times I_E is a current source we are having at the output. It can be best represented by a dependent current source. This is the symbol for dependent current source. This dependent current source is nothing but alpha times I_E which is equal to I_C and base the current is there which is I_E-I_C or I_C can be written as alpha times of I_E. It is nothing 1 minus alpha times I_E. This is the output voltage and one more thing which is not shown here should be a resistance at the collector. This resistance is R_O. If we recall the output resistance of common base transistor it is almost infinity. Because of this horizontal curves in the output characteristic even if you go on increasing the collector to base voltage the current I_C does not change. It is almost having horizontal shift. It is like this type of I_C we were getting across V_{CE}. Basically this is the active region. This is almost horizontal means the resistance in the output circuit is so high it is almost like infinity so that even if you change this collector to emitter voltage the current is not going to change and that fact is the reason why we have not shown R_O or it is almost like infinity. This R_O value is infinity.

(Refer Slide Time: 39:48)



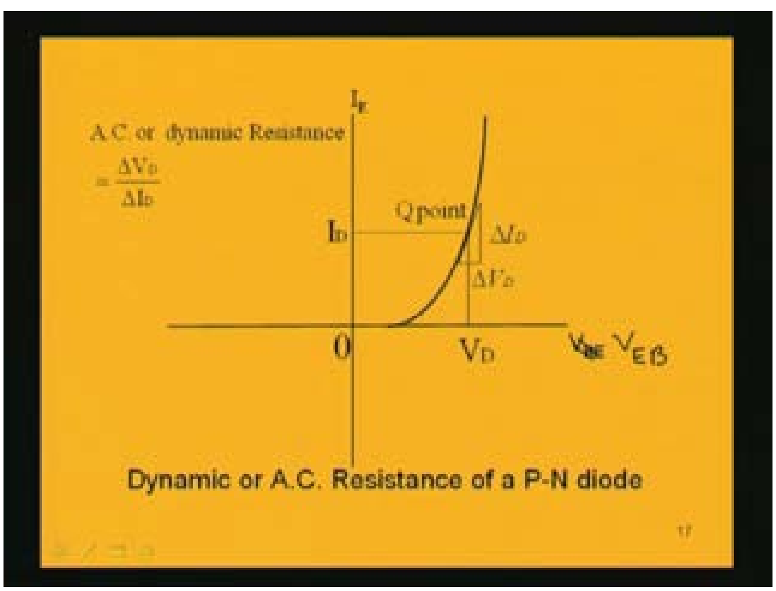
It is well equivalent to not showing because if there is path having infinite reason there will not be any current flowing in that resistance. It is like open circuit. That is why very conveniently we can remove this R_O but exactly the whole circuit will be having this R_O also. If we look into this forward biased diode it's not right to keep it like this because we have to find its equivalent and replace it by the relevant parameters. If we look into this forward biased diode and remember the input characteristic then we can replace this forward bias diode by a resistance which is the dynamic resistance of the diode. If we consider the input characteristic of the diode, the input characteristic is a characteristic like this. Input current is I_E here versus the emitter to base voltage; that's what we are having in the input characteristic V_{EB} and I_E. This characteristic is forward biased diode characteristic. Consider a particular point of operation, say, Q point of operation. This is the DC biasing current. Around this point, a small portion if we consider then del V, this is del I; the del V by del I that will be the dynamic resistance of this diode. This dynamic resistance can represent the forward biased diode and that's what we are going to do.

(Refer Slide Time: 41:52)



We are considering a common base. So it is V_{EB}. This should be V_{EB}. Emitter to base; base is common. Input current is I_E. This is the diode characteristic between emitter and base junction. If we now consider the dynamic resistance it can be found out around this operating point that is the DC biasing point actually. The current which is flowing, the DC current is I_E and we are finding out this dynamic resistance by finding out the slope del V_D by del I_D. V_D and I_D are the diode voltages and currents.

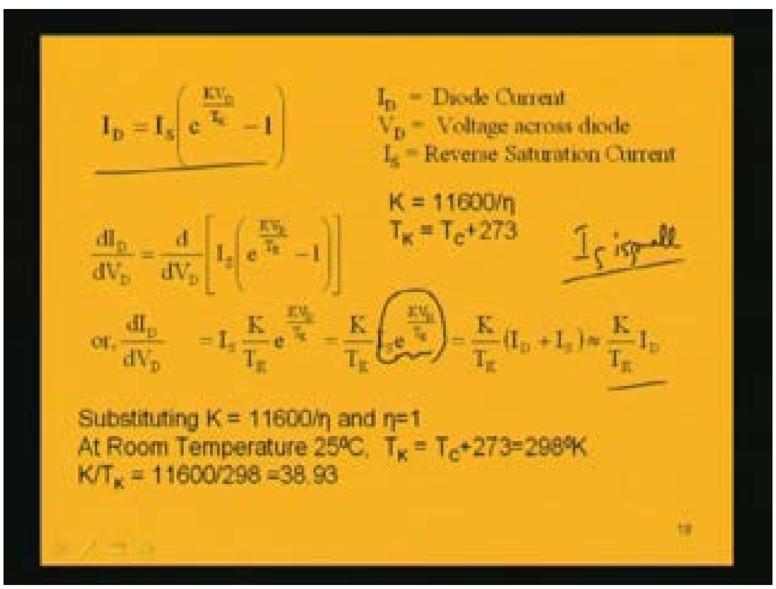
(Refer Slide Time: 42:45)



In order to find out the dynamic or AC resistance of this diode we will start with basic equation of the diode; I_D is equal to I_S into e to the power KV_D by T_K minus 1. The symbols I_D is diode current, V_D is voltage across the diode, I_E is the reverse saturation current and K is 11600 by eta, eta being the value 1 or 2 and if we consider the higher region or active region, eta both for silicon and germanium will be only 1; value 1 for both germanium and silicon and for the higher portion or active portion of this linear region of the diode, eta value is 1. Eta value will be considered as 1. T_k is the kelvin temperature; centigrade plus 273. We now find out the derivative of this current with respect to voltage V_D that is differential with respect to V_D of this quantity. This I_S is constant, reverse saturation current is constant. That is the leakage current. This is not going to change it, V_D. That is constant for this VD.

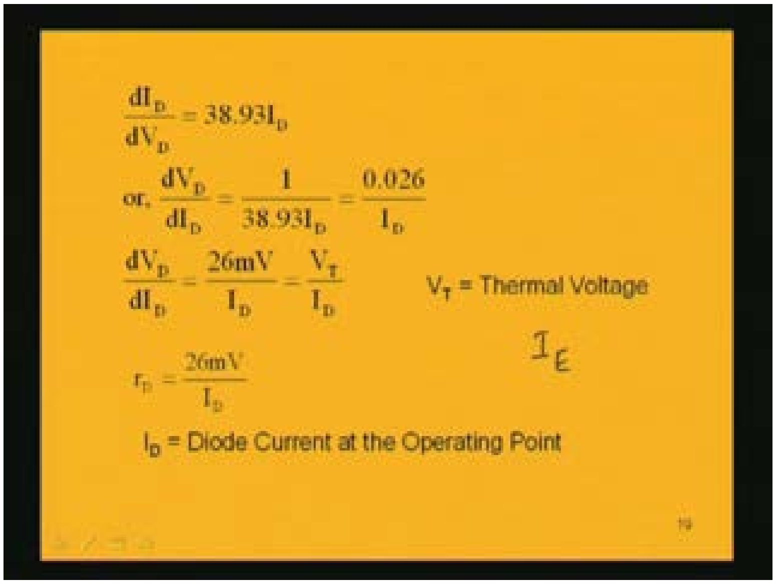
This IS will be coming out. This derivative if I find out K by T_K will come here and e to the power K by T_K into V_D will be left; K by T_K into I_S into this part. If we consider this equation we get that this e to the power KV_D by T_K is nothing but I_D plus I_S. If we transfer this I_S to the left I_D plus I_S will be I_S into e to the power KV_D by T_K. This whole term I_S into KV_D by T_K can be represented by I_D plus I_S and that is almost equal to we can write K by T_K into I_D since I_S is very small. As I_S very small we can approximately write this equation. At room temperature, considering 25 degree centigrade room temperature which is typically done in all these calculations, 25+273 will be 298.

(Refer Slide Time: 45:26)



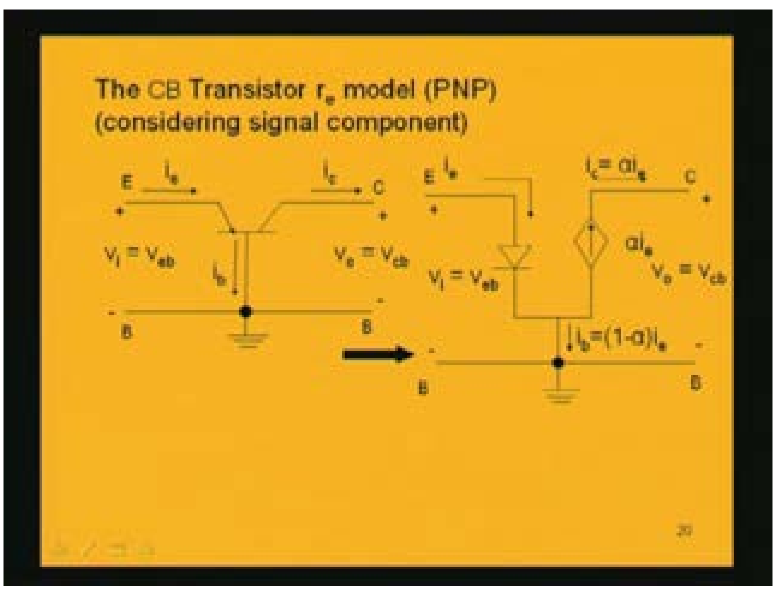
The value of K by T_K then becomes 11600 because eta value is 1, K is 11600 by 298 which gives 38.93. Replacing this in the original equation here dI_D by dV_D is equal to 38.93 into I_D that we are getting. But we want dV_D by dI_D which is the dynamic resistance. Dynamic resistance is actually dV_D by dI_D. dV_D by dI_D is equal to 1 by this whole term and after calculation 1 by 38.93 becomes 0.026. It is in volts. We can write it 26 millivolt by I_D and this 26 millivolt is called the thermal voltage V_T. Basically we can write it V_T by I_D. This dynamic resistance of this forward bias diode is now 26 millivolt by I_D. If we consider the emitter base junction for our particular transistor, common base transistor, this I_D will be nothing but capital I, capital E, I_E. That is the emitter current which is basically the diode current in the forward bias junction.

(Refer Slide Time: 46:45)



This was the circuit and this was the diode.

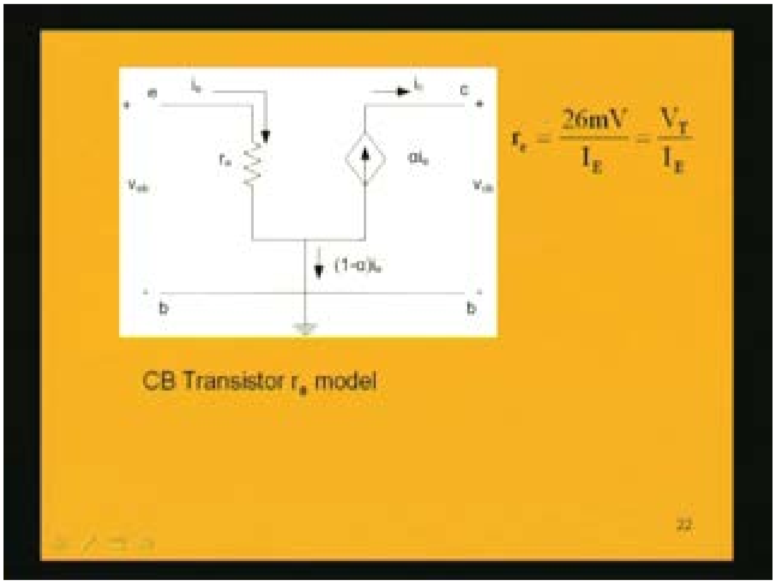
(Refer Slide Time: 46:58)



If we replace it by the dynamic resistance of the emitter we are having the circuit like this. That is this resistance r_e which is 26 millivolt by capital I capital E, I_E, because the current which is the DC current that current is capital I capital E, I_E. 26 millivolt by I_E

becomes the dynamic resistance of the forward bias junction for the common base transistor.

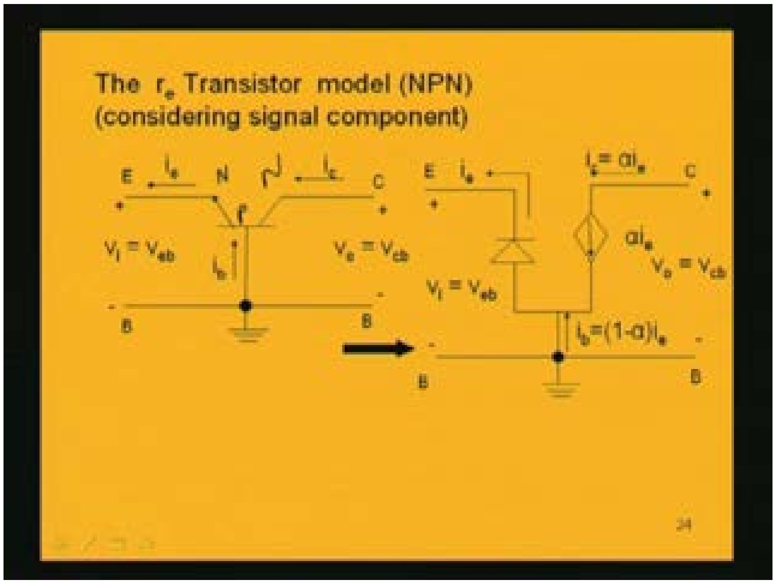
(Refer Slide Time: 47:28)



If we again redraw the circuit in place of this forward bias diode we will be replacing it by this r_e and other part being the same. This is the r_e model for the common base transistor. Here the value of r_e, dynamic resistance we can calculate for a particular biasing point. What will be the DC current in the emitter I_E? If we substitute in this term I_E then we get the value of r_e; that we will have to fit in. We are having the equivalent model for the common base transistor. In the AC equivalent circuit we can incorporate this model for the physical transistor and we can proceed to find out the parameters like voltage gain, current gain, input resistance, output resistance, etc for a common base transistor amplifier.

This example was for common base PNP transistor. If we consider common base NPN model it will be similar. Only difference will be the direction of this forward biased diode. Since it is NPN, this is N, this is P and this is N. The diode will be forward biased from P to N. So the direction will be like this and the current directions will also be different because now emitter current will be going out and base current and collector current will be coming into the transistor and this current source direction will be this way. That is towards the transistor.

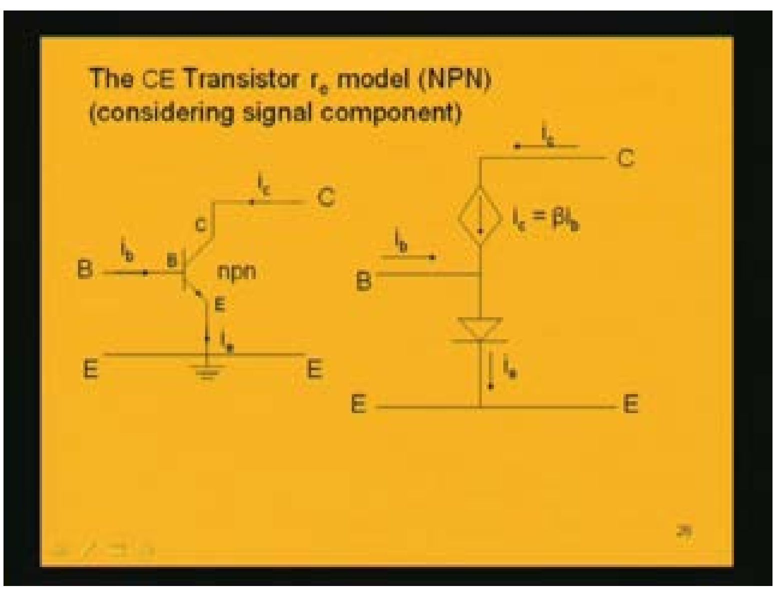
(Refer Slide Time: 49:08)



This is the difference between the NPN and PNP but it is the same model. This is for common base transistor.

Let's now see for common emitter transistor what will be the equivalent model? In a common emitter transistor if we want to draw r_e model, let us start with an NPN transistor and the small signals are represented by the small letters. The signal component is shown, not the DC component. That is why small letters are being used to denote that this is the AC.

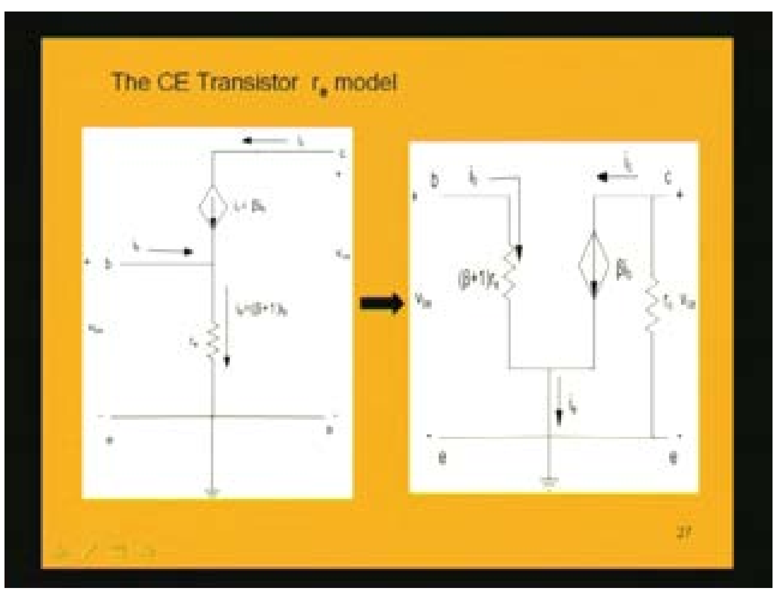
(Refer Slide Time: 49:52)



If we consider the common emitter, the emitter is common and grounded between the input and output circuits. So base and emitter is the input circuit, collector and the emitter is the output circuit and the currents which are flowing for this NPN transistor, emitter current is i_e which is coming out of the transistor base current and collector current will be towards the transistor. If we want to draw the model for this transistor, equivalent model we can draw by considering the emitter base junction which is forward biased and we are taking an NPN. This point is N, this is P and this is N. The diode which is in the forward bias condition will be from P to N. So B to E will have a forward biased diode and the output circuit if we now focus that is the collector to emitter basically we are having a current source in the collector which is nothing but beta times of i_b. i_c current can be expressed by beta times of i_b and in the collector to emitter output circuit there will be presence of a dependent current source beta times of i_b. But one thing to be noted here is the point of joining between the input and output circuits.

In the earlier case for common base transistor if we notice this point, which was common between input and output was grounded. But then here this point is connected. The current which is flowing through this diode is emitter current i_e. This current is i_b input current, this current is collector current both are joining at this point. Total current i_b+i_c is the emitter current. If we replace this forward bias junction by its equivalent resistance just like we have done in common base basically that is same. We can represent this forward bias diode by its equivalent dynamic resistance r_e for this part that is the emitter base junction part. We will do that and this part that is the current source which will be the collector current is current source because it is dependent on the base current by the factor beta. So beta times of i_b is equal to i_c. Equivalently we can draw this circuit. This circuit will have this resistance r_e and the current through this resistance is not i_e. You have to mind that this current is beta plus 1 i_b. That is the emitter current and the input current is i_b. Output current is collector current which is represented by this current source. Output side is having a current source.

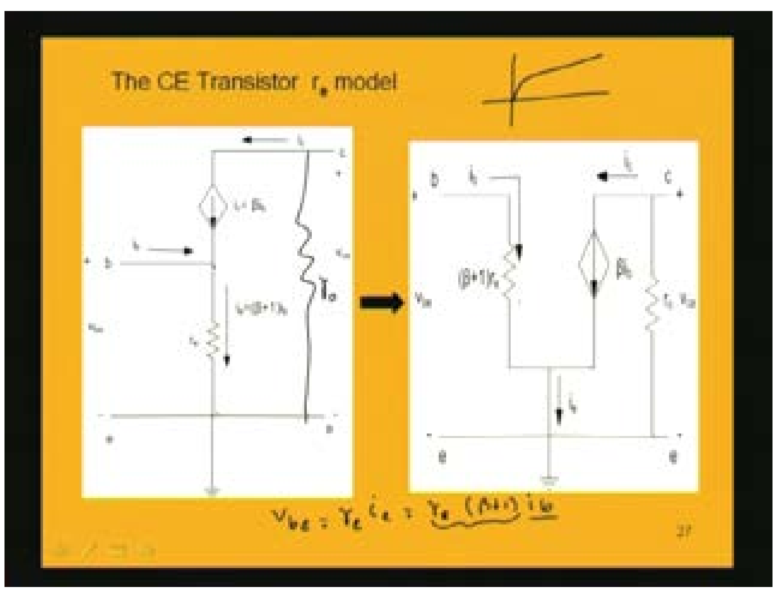
(Refer Slide Time: 53:02)



Apart from this again we have to note one fact that the resistance between collector and emitter has to be incorporated because this common emitter transistor does not have infinite output resistance. It is smaller than common base transistor because of the presence of a slope in the common emitter output characteristics. If we remember the common emitter output characteristic was having a slope to the right and because of the presence of this slope, there is a resistance which is not infinite which is less than infinite. That has to be incorporated to exactly represent this transistor in its equivalent model. r_o will be there. In fact that value of r_o is in the order of mega ohm but still to have exact representation of the common emitter transistor we must have its presence here. It is not ignored since it is not infinite. But in common base we conveniently ignored it or just removed it because it was almost infinite. Since the presence of horizontal curves but it is not horizontal. That is why the slope has to be represented by this output resistance. This value is high. In this circuit we are having a resistance r_o here also. If I look into this resistance, the current flowing through this resistance is beta plus 1 i_b.

In order to conveniently separate out the input and output circuits for further convenient analysis one trick we can do here is that we can represent this resistance by another, in another way because if we consider the voltage drop between these two points B and E, this voltage drop v_{be} is equal to r_e into i_e. That is r_e into beta plus 1 i_b. If we keep i_b and keep this together what I get? r_e into beta plus 1; but the current can be expressed by the same current i_b flowing through this resistance but the resistance value will be different now. It will be beta plus 1 into r_e.

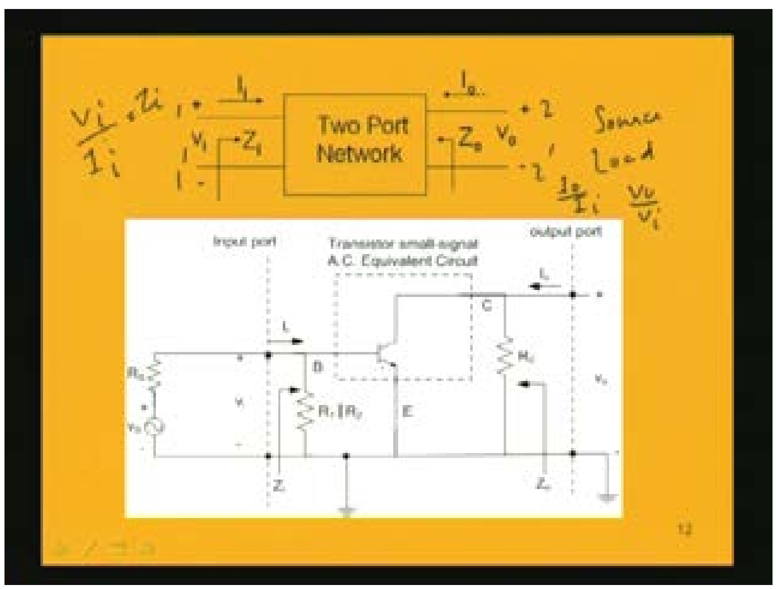
(Refer Slide Time: 55:19)



This circuit and this circuit are not different. These are the same circuits. There is no ambiguity or any confusion between these two circuits. Only conveniently it is drawn like this just for easy analysis and actually the resistance r_e is now reflected as beta plus 1 r_e. But this is the base current which is same current flowing in the resistance as well as the starting or the input current. This current i_b is flowing through this resistance meeting here with the current which is from the collector. This is beta times i_b. i_c plus this i_b is now i_e which is flowing in this part. At this point both i_b plus ic are meeting. So i_b plus i_c is here and this is far better circuit than this because our main problem was at this point these two were joining and this current is not i_b. It is i_e. It would lead to some difficulties in analysis. We have conveniently removed the difficulty by drawing the circuit in this fashion and it will be easy because you can now notice that input and output circuits we are conveniently separating out.

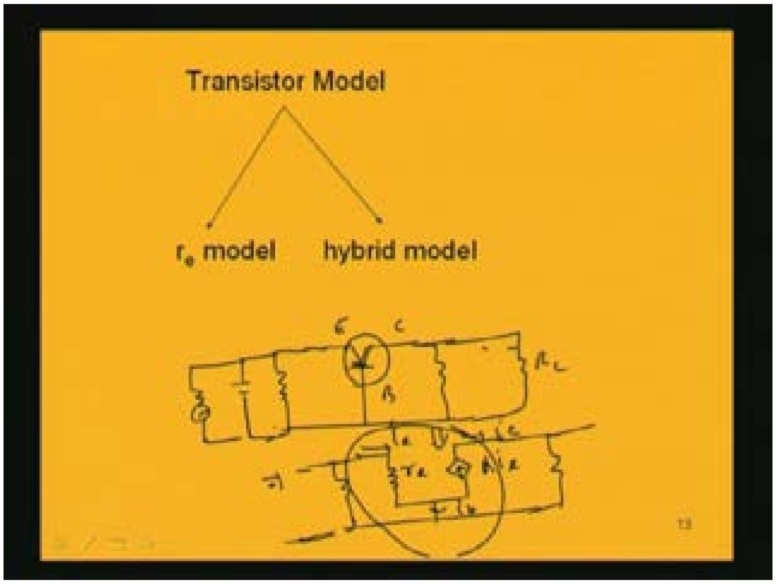
This is done by writing the equivalent or reflected resistance for this r_e which is nothing but beta plus 1 r_e. This circuit is the common emitter transistor equivalent circuit which will be used in the AC equivalent circuit and further analysis will be now done for finding out the relevant parameters like input impendence, output impendence, voltage gain and current gain. All this will be found out. This AC equivalent circuit whatever we discussed in the beginning, this AC equivalent circuit will be having this transistor incorporated into it by this equivalent model. We will have instead of this transistor physical model or symbol we will be incorporating that model which you have just now derived into the transistor replacing this transistor by this equivalent model.

(Refer Slide Time: 57:53)



If we consider the whole circuit again we can draw it by replacing this transistor. We have this transistor; we are taking this common base transistor. Apart from this we are having the other things which will be there. For example there will be biasing voltage, this is base, this is emitter and this is collector. There will be biasing voltage; there will be biasing resistances, etc. All this will be there; load resistance will be there, source will be there and all this will be there. But this transistor can be equivalently represented by its model. It will be like this. It will be alpha times of i_e. Apart from this, this is your emitter current. This is the collector current, this is the base current and other things will be AC equivalent circuit will be there. From this circuit we have now conveniently represented this transistor which is replaced by this model. Actually this part we have derived today.

(Refer Slide Time: 59:43)



We will now incorporate this in the whole circuit, find out the parameters of the overall amplifier; that we are going to do next.

In today's discussion we have basically done the AC analysis, starting from AC equivalent circuit then finding out or deriving the model for the transistor and our next job is to fit in the equivalent model for the transistor into the AC equivalent circuit and analyze the whole circuit in order to find out the relevant parameters for an amplifier and these parameters are voltage gain, current gain, input impedance, output impedance, etc which will basically represent a BJT amplifier and that we will do next.