Basic electronics
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Lecture- 14

Hybrid Equivalent Circuit, H- Parameters

Hello everybody! In our series of our lectures on basic electronics learning by doing we will move on to the next lecture. Before we do that let us just recapitulate what we discussed in our previous lecture. In our previous lecture we discussed about the basic characteristics of an amplifier like the gain, the input impedance, the output impedance, the bandwidth, etc.

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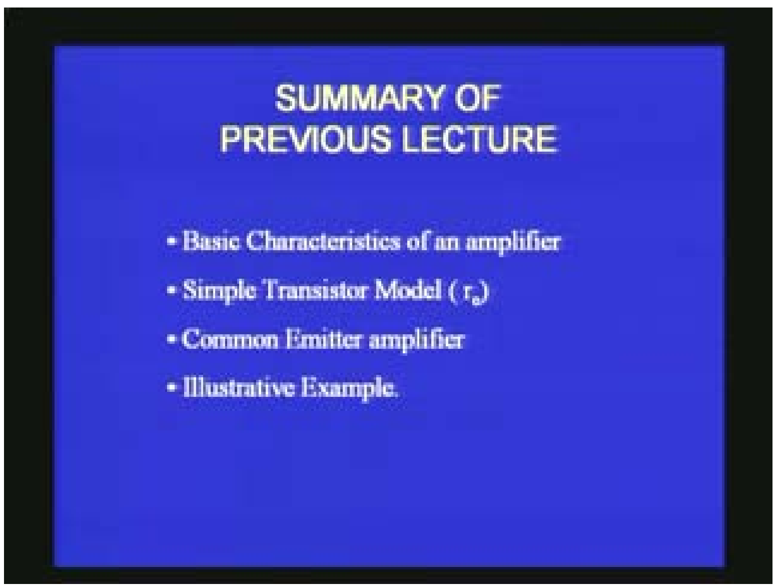

We also saw a very simple model of the transistor namely the re model of the transistor and we applied that model for a simple common emitter amplifier and discussed the various parameters like the gain, the input impedance, the output impedance, etc. We did an analysis. We also took illustrative example of an actual circuit with the various resistors in place and we also looked at how to evaluate the different parameters of the given amplifier, common emitter amplifier corresponding to the gain, the input output impedance and current gain, voltage gain; all those things. Now let us move on to another model which is more popular that is the hybrid model.

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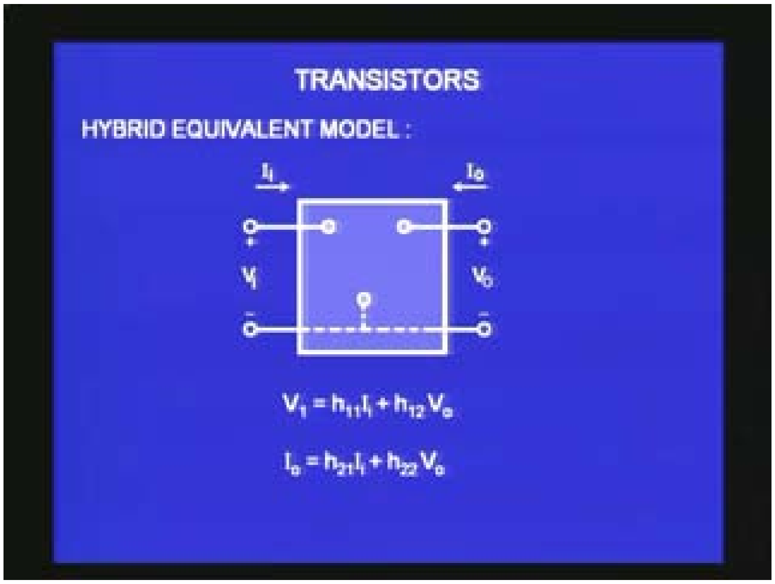

In general any circuit can be looked at as a two port network. As you can see on the screen you have something like a black box. We call this as a black box because we are not interested in the details of the circuit inside but we know that this has got several components may be transistors and resistors and we have an input port and an output port. You have two terminals here corresponding to the input port and you have other two terminals at the output port. This is a simple two port network and now we can apply a voltage here and measure the current and we can measure here the output current, output voltage, etc. By performing some measurements on this two port network we can get a lot of information about the type of circuit that we have inside this black box. The box is called black because we are ignorant of what is inside. We are not aware right now of what is inside. In a general situation it can have any kind of a circuit. If it is an amplifier for example, there is a very specific relationship between the input parameters and the output parameters. In this case the voltages and the currents at the input and the voltages and the current at the output.

Therefore now out of these four variables that we have V_i I_i corresponds to the input, I_o and V_o corresponds to the output. We can always choose two of them as independent variables and two other as the dependent variables. So we can have enough combination of these things. For example I can make the two voltages as dependent variables and I can write them in terms of the independent variables I_i and I_o. Then you know V_i can be some constant factor of I_i plus some other constant of I_o where these constants will have dimensions of resistance because V_i is nothing but resistance into the current. We are using the current as the independent variable and therefore we must have the two constants having magnitude of resistance.

This is now looked at as a network of resistors and therefore this way of handling the circuit or the model is called r parameter model. You can also relate the other way. That is I and I_o can be written in terms of V_i and V_o. Then it will become admittance, the one by resistance which will be the magnitude of the constant that we make use of. So we can analyze it in that way also. But the most popular way of looking at these for several reasons is the one that I have written at the bottom. As you can see the V_i, in this case it is actually V_i, we can call it as V_1 and V_2. The V_i is equal to h_{11} I_i plus h_{12} V_{out} where h_{11} and h_{12} are constants of suitable dimensions. In this case you can see the dimensions of h_{11} and h_{12} are different. How do you know the dimensions of h_{11} and h_{12}. It is a very simple matter to understand that this is voltage here that is equal to something multiplied by current. That means you know what it has to be. From Ohm's law this has to be a resistive element. The constant should be having the dimensions of the resistance and therefore h_{11} is a resistance. If you look at h_{12} it relates a voltage V on to your voltage V_o. Therefore the dimensions of the h_{12} should be a constant. It is dimensionless, unit less. So V_1 is some constant multiplied by V_o. Therefore you find in the same equation, you have a constant which is having dimensions of resistance another constant which is unit less.

Similarly if you look at the other dependent value I output, that again can be written in terms of I_i and V_o but I call that $h_{21}I_i$ plus $h_{22}V_o$ where h_{21} will have dimension of ….. This is relating to current to current therefore this should also be a constant. h_{21} should be a dimensionless constant whereas h_{22} relates current to voltage and therefore this should be a conductance or one by resistance. So you can see of the four constants that I have used in these two equations to relate the two dependent variables with the two independent variables of this four port network h_{11} has got dimensions of resistance, h_{22} has got dimensions of admittance or conductance. h_{12} and h_{21} are dimensionless quantities. Therefore you have combined different constants in these and therefore it is a hybrid equivalent model of any two port network. Our interest is on the model of an amplifier making use of transistors. So let us go further and see how do we look at this equation? How do we get h_{11}? How do we evaluate h_{11}? When I make Voutput zero this quantity will be lost from the equation. This will no more be there and at that condition if I divide V_i by I_i whatever I get is actually corresponding to h_{11}. So that is what written in the next page.

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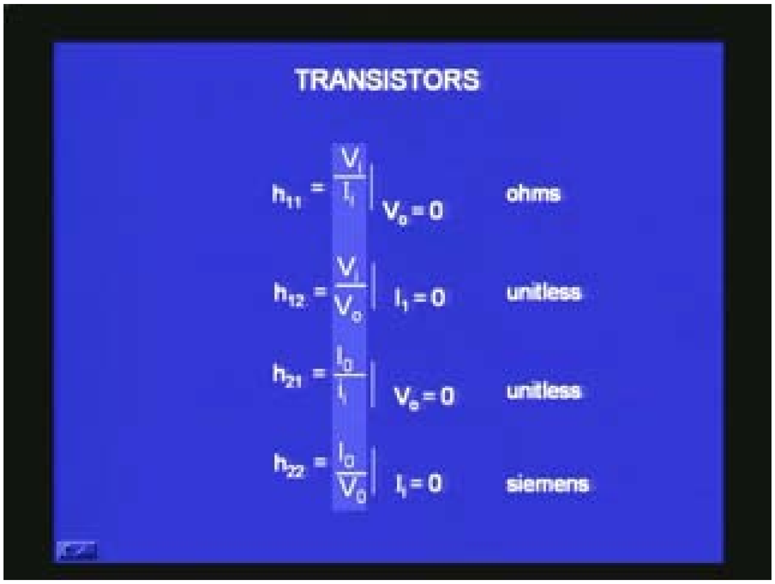

h_{11} is nothing but V_i divided by I_i at V_o equal to zero, when the output is zero. What do you mean by output zero? The output should be short then only the voltage will become zero. The voltage across a zero resistance is zero. Therefore when I short the resistance, when I short the output terminals with a good conducting wire the output voltage is zero. At that time if I measure what is my V_i, the voltage which I impressed, the corresponding current if I measure using the current meter the ratio of that will give me the first constant h_{11}. h_{11} is V_i by I_i when V_o is zero and because it is a relationship between voltage and current you know it is resistance in ohms. h_{11} will be in ohms.

Similarly h_{12} that is the second constant I want to evaluate. So how do I do that? You can see when I_i is zero this term will vanish and h_{12} will become V_i by V_o. That is what is shown in the second equation. h_{12} is equal to V_i, the voltage impressed at the input divided by the voltage at the output at I_i equal to zero. What do you mean by I_i equal to zero? I_i will become zero only when the input resistance is infinity. That means you are open circuiting the inputs. When you open circuit the input the current becomes zero. There is no current there and h_{12} will be equal to Vi by Vout. Because it relates two voltages it won't have any dimensions or unit less. Similarly from the second equation we can obtain h_{22}. h_{22} is given by Io by Vo, I output by V output when I_i is zero in the same way. Similarly if you want h_{21}, h_{21} will be obtained as a ratio of I output by I input when V output is zero or the output is shorted. That is what is written in the other two equations here. h_{21} is I_o by I_i when Voutput is equal to zero. That means the output is shorted at that time the ratio of the current. In effect it is nothing but a current gain, a current gain corresponding to the output and the input. This is actually a voltage gain V_i by V_o corresponding to the network and the h_{22} is I_o by V_o when I_i is zero. That means when you open circuit the input, the ratio of the output current to the input voltage is what is called h_{22}. So it has got dimensions of one by resistance or conductance. That is why it is written in siemens. Conductance is measured in siemens and therefore you can also see that it is nothing but one by V_1 by I_2. That means one by resistance is conductance. In this case this relates to the output and therefore this will be one by output resistance.

Now we can try to model our given transistor using these hybrid parameters.

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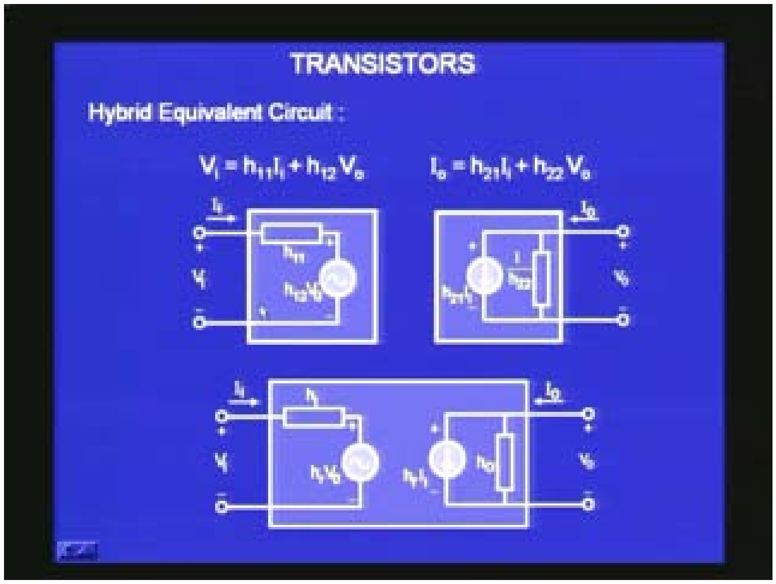

Our transistor has got three terminals and therefore we want for a four port network, four terminals. We have only three terminals. Therefore we have already discussed that we can have one of the terminals as a common terminal between the input and the output. Correspondingly you get three different configurations common base or common emitter or common collector. So you can have transistors configured in three different ways as I mentioned. For example in general if I take the transistor, this box corresponds to the input side. You can see in the input side V_i and I_i are there and this box will contain a resistance which I now designate as h_{11} corresponding to the equation that I wrote for the hybrid parameters and h_{12}Vo which is actually a current gain. It is actually current gain but it is in the reverse ratio.

Usually current gain is given by output voltage by input voltage. In this case you find h_{12} is obtained by V_i by V_o when I_i is zero. Therefore you get a reverse gain factor or it is a reverse ratio between the input and the output. h_{12}. If I multiply that ratio by the output voltage I will get the voltage which is available at the input due to the presence of the output alone and that is why this voltage source comes here $h_{12}V_o$. This input side corresponds to this equation and you have one more on the other side which corresponds to the output side of the transistor. In this case you have 1 by h_{22} is the resistive component but it is actually a conductance. That is why it is written as 1 by h_{22}. h_{22} is conductance. 1 by h_{22} is resistance and h_{21} is a current gain factor. So if I multiply by the input current you get h_{21} into I_i as a current source here which I have here and therefore this actually links the input to the output whereas the h_{12}Vo component links the output to the input sign. Because it is a solid state device whatever that happens at the input can have an effect on the output. Whatever happens at the output can have an effect on the input. That is why these two things are coming in the model. This is how the transistor input side and the output side can be modeled. This is a general equation. We have not taken anything as common here. We just assume this as the input side and this as the output side and therefore we have written the equivalent circuits for the two sides independently.

This is actually the combination of the two and this has got slightly extra meaning here. For example the h_{11} is now replaced in the model of the transistor as h_i which corresponds to the input resistance and h_r which corresponds to the reverse voltage ratio. $h_r h_{12}$ we know is a reverse voltage ratio that is normally designated in the transistor equivalent circuit as $h_r V_o$ and similarly h_f corresponding to the forward ratio of the current h_r. $h_f I_i$ is the source at the output due to the input current I_i and 1 by h_o this is actually 1 by h_o; h_o is the conductance at the output, 1 by h_o is the output resistance when I look from the output side. This is the normal way to designate a transistor model except that you will add an additional subscript here along with i or f and o depending upon the configuration that we use.

For example if you are using a common emitter transistor model then the emitter is common to the input and the output and therefore you have an I_B here which is your I_i in this case.

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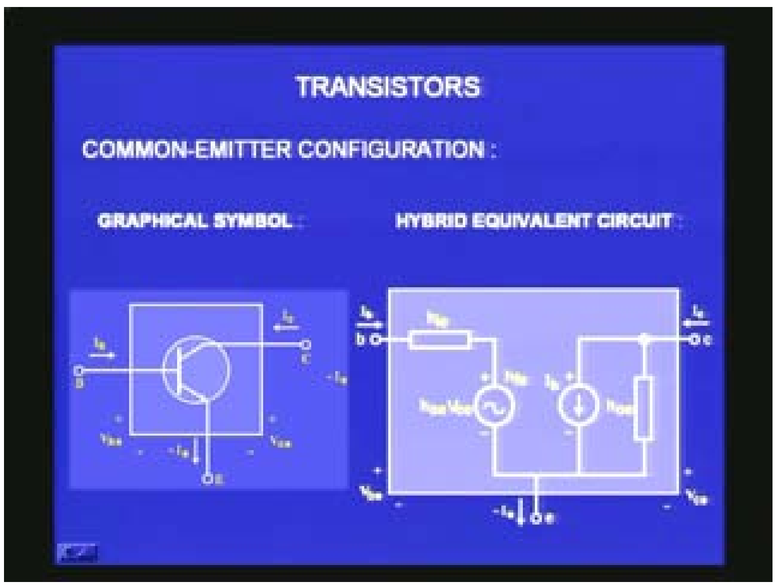

Your I_c is actually the I_o that we talked about and you have V_{be} the voltage between the base emitter which is the input voltage here and V_{ce} at the output which is the output voltage and the corresponding equivalent model is shown on the right side. The input resistance, h_{11} is now called h_{ie}. h_i corresponds to the input resistance of the h parameter and the e comes because it is a common emitter configuration. So for all common emitter configurations, all the h parameters will come with an additional subscript e which shows that it corresponds to the common emitter configuration. This is the base terminal; this is the collector terminal; this is the emitter terminal. This h_{ie} is the input resistance corresponding to the hybrid model and this should be h_{re}; $h_{re}\,V_{ce}$ is the reverse ratio of the voltage that is the source that is coming here and this is $h_{fe}\,I_b$ which is the current gain times the I_b that is the output current source that comes because of the I_b at the input. 1 by h_{oe} as I already mentioned is the resistive component at the output.

Now what will be the magnitude of all these parameters in a very typical situation corresponding to a given transistor? If I take a normal transistor like dc 107, the general purpose transistor, you would find the h_{11} parameter especially the h_{ie} parameter for a common emitter configuration will be 3.5 kilo ohm approximately few kilo ohm; 1or 2 kilo ohm.

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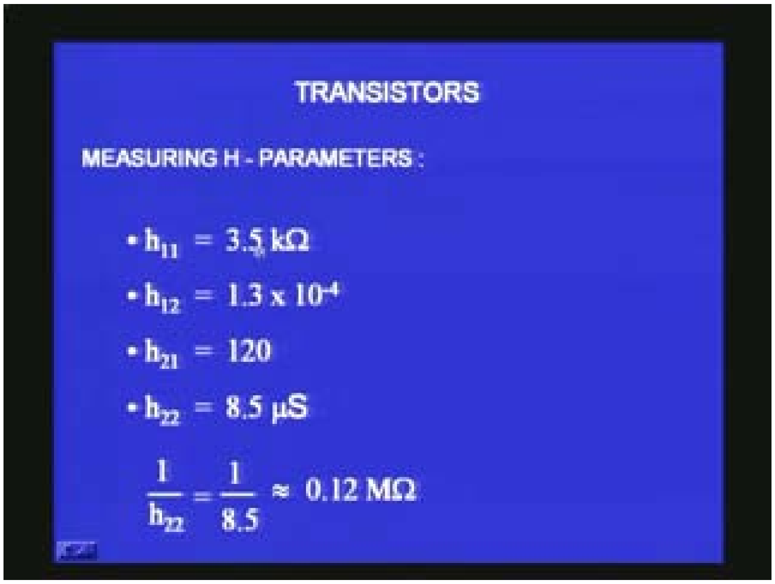

The h_{12} which is the reverse ratio of the voltage is 1.3 into 10 to the power of - 4 typically. That means it's a very, very small number. So this small number multiplied by the output voltage will be the additional voltage coming at the input due to the output voltage alone therefore you can see this is going to be a very, very small component, small contribution in the circuit. h_{21} two one is actually h_{fe} in the case of the common emitter amplifier and therefore h_{fe} the forward ratio of the current or the current gain and this is typically around 120 or so up to 200 or so for a normal transistor and the last one which is 1 by h_{oe} is the resistance, output resistance or h_{oe} is the conductance and that will be approximately 8.5 micro siemens. This is micro siemens and if I calculate the 1 by h_{oe} around 120 kilo ohms or 0.1 meg ohm approximately. So this will be a very large number several hundreds of kilo ohms at the output. It is a very large value at the output resistance. It is very small value of the voltage reflected at the input. Therefore you would find in most of the simple discussions we can if you are not we can just interested in getting the reasonable number close to the actual value you can comfortably neglect the role played by these two when you want to do a very quick calculation of the various parameters of an amplifier. What is more important is the h_{ie} which is a few kilo ohms at the input side and the h_{fe} the 120 ohms.

You can also relate the hybrid parameters with reference to the 'r_e' model that we discussed in the previous lecture and you would find that h_{ie} that I refer to here will be related to the r_e. It is actually the beta r_e that we have seen in the earlier discussion. That is what is shown here. I have shown the two models side by side for comparison. In the simplest model of the r_e parameter you would find the input resistance will be related as beta r_e where beta is the current gain of the common emitter configuration. In this case it is h_{fe}.

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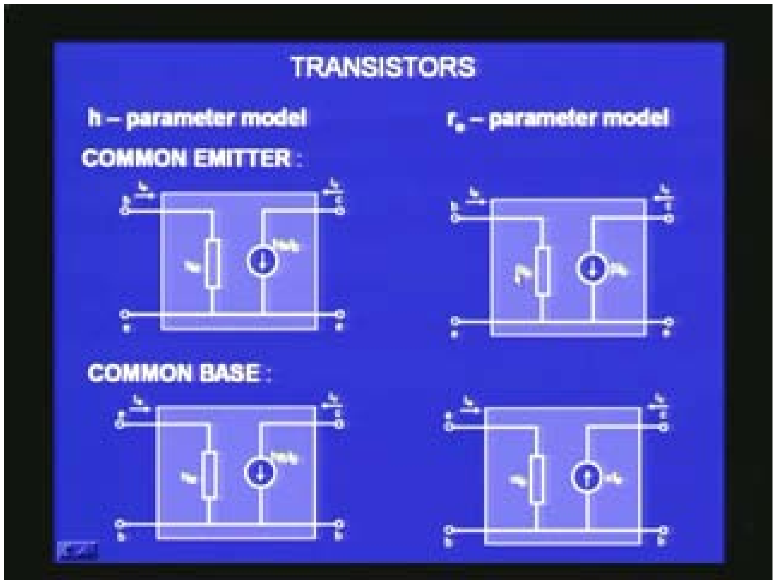

So this is the resistance and that is shown as h_{ie} here. So these two are the same. Similarly h_{fe} into I_b, the current gain into I_b is what I will get in the hybrid parameter here. In simplified …… we have neglected the very small quantities corresponding to the h_{re} parameter and the h_{oe} and therefore you find here the beta I_b is the only current component that is coming here due to the current gain h_{fe} or in this case the beta. The beta is equal to h_{fe} you can see that.

In the same way if you go to the common base configuration which is also used sometimes for some specific reasons, for specific applications h_{ib} there will be equal to alpha r_e and h_{fb} I_b that we get, the current source will be corresponding to alpha times I_e. This is actually the e; so alpha times I_e. This is for the common base configuration. In comparison, this is for the common emitter configuration; a comparison between the hybrid parameter in the simplified model and the corresponding r_e model that we already discussed. If you become familiar with this, in any transistor amplifier we can replace the transistor with this type of a model circuit. So you find it becomes very simple. Whatever on the input side we have to take it to account the presence of h_{ie} and for the output side we have to take note of the current source that is available at the output. With this we can relate the rest of the resistors, capacitors connected here as well as here and we can try to obtain the various parameters corresponding to the transistor amplifier in different configurations.

This again is to just bring home the idea that h_{ie} in the case of common emitter amplifier is nothing but beta r_e that we have already discussed and h_{fe} is the beta ac, the current gain factor.

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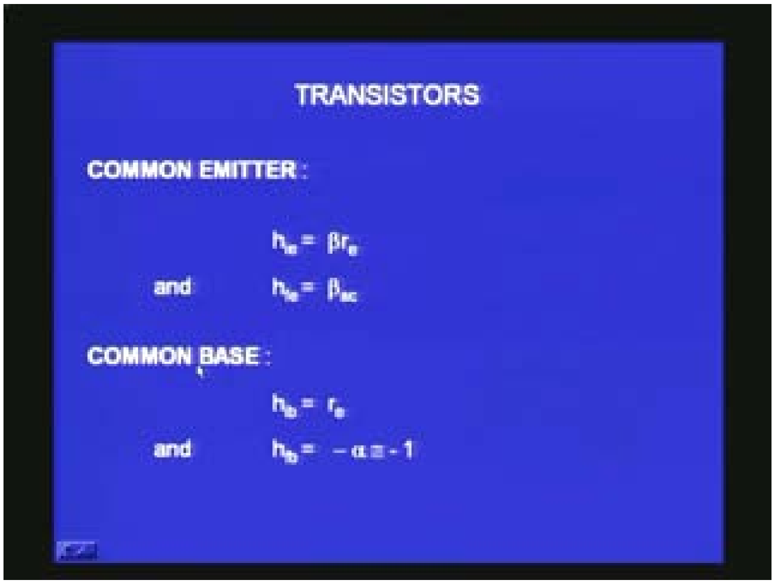

Similarly for a common base h_{ib} is r_e. hib is approximately minus alpha and the alpha is very close; I_c the current in the collector is almost equal to the I_e the current in the emitter and therefore this is close to one. That is what is stressed here.

We can also evaluate the various h parameters graphically. One advantage of h parameter is that all of them are measurable. You can see h_{ie} is nothing but the input resistance of a transistor. h_{re} is the reverse voltage ratio which can be obtained from the simple gain that you get from the transistor and h_{fe} is the current gain which also can be measured and h_{oe} is nothing but one by output resistance which also can be measured. So all the four parameters that we normally come across can be very easily evaluated in this case and that is one of the advantages of using h parameters. We try to look at the same thing here whether we can get it from the characteristic that we discussed the transistor characteristics. So what is h_{ie}? h_{ie} is nothing but the change in the base emitter voltage divided by the change in the I_b corresponding to the ac. Whenever I use small case letters it corresponds to the ac parameter, when I use capital letters here that corresponds to the dc parameter.

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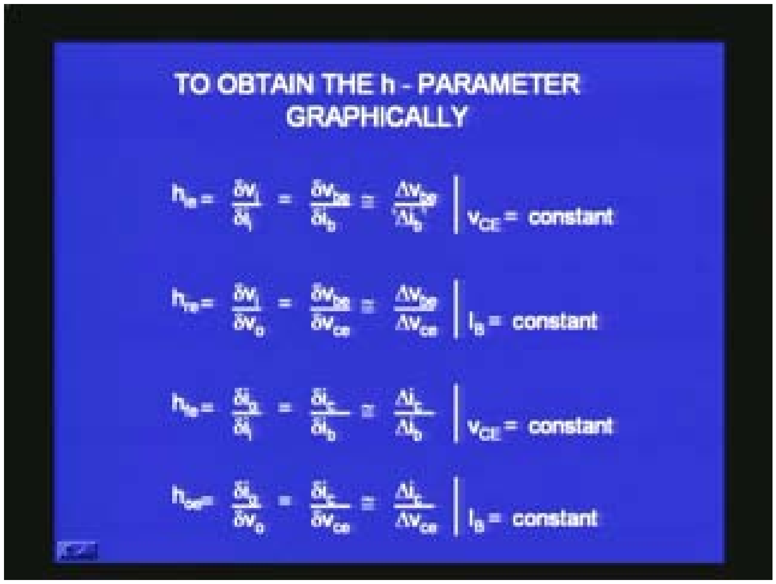

Because it is an ac parameter you can relate it to the change in the base emitter voltage corresponding to the change in the base current when the V_{CE} is maintained constant. We discussed about it in the dc case that this should be equal to zero. Here we say it can be a constant. Maintaining constant find out what is delta V_{be} by delta i_b? That will give me the h_{ie}. Similarly h_{re} is delta V_{be} by delta V_{ce}. It is the ratio of the voltages from the input side to the output side and therefore this is called a reverse ratio. That is why that r comes. It is a reverse ratio of the voltage when I_B is equal to constant and h_{fe} is delta i_c by delta i_b the current gain when V_{CE} is equal to constant. The h_{oe} is the reverse resistance and that means reciprocal resistance, the change in current by change in voltage when I_B is equal to constant. So this is very useful for us in evaluating the values of h parameter from the characteristics. One important concept is that the h parameter will have to be different at different places. The slopes are different at different points in the characteristics and therefore the values of the h parameter can be different. Usually if you look at the data manual of a transistor from the manufacturer side you would find he will always say under what voltage or operating conditions the h parameters are given. So he will give a set of h parameters but he will also specify the voltage and the current at the condition and therefore one has to be careful not to take the h parameters at face value. But we should always look at, at what biasing condition or at what point on the q point or the operating point around which these h parameters are obtained and only if you use the same operating point these h parameters can be used in your calculations. Otherwise one has to evaluate corresponding to the operating point you would choose around the operating point all these h parameters.

How do you evaluate that is what I am now trying to show with the graph that we have in front of us which is basically an output characteristic the V_{CE} on the x-axis and the I_c the current along the collector along the y-axis and you can see these are the family of graphs that we get for the different base currents I_b is equal to 60 micro amperes, 50 micro amperes, etc and you can see the he bottom one is long and the top one is short. You know why? It is because here there is another graph which is actually an hyperbola coming which corresponds to the power rating of the transistors and therefore there is no point in extending these lines beyond because after sometime there will a break down and therefore this is the typical output characteristics of a transistor and I have shown a Q point operating point at which the transistor may be biased and therefore I would like to evaluate the different h parameters around this operating point. For that what do I do?

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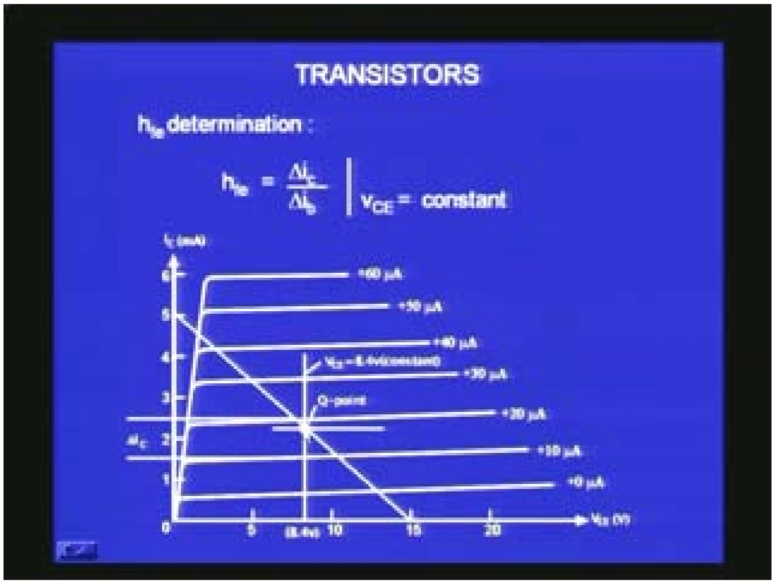

I just take one example here h_{fe}. So h_{fe} is nothing but change in the collector current divided by the change in the base current when the collector emitter voltage is maintained constant. This corresponds to the V_{CE}, the voltage between the collector and the emitter. If I choose a constant point for example here the operating point is at 8.4 volts; it is shown in the bracket here. So I choose the Q point at which the V_{CE} is 8.4. I keep this constant and I start moving along the constant voltage graph which is the vertical line we ordinate here. If I go from one graph corresponding to one base current to another graph corresponding to another base current you would find the change in i_C, the collector current is given on the y vertical axis. The difference is delta i_C between this point and this point and what is the change delta i_b. I have already calculated delta $i_{C.}$ That is this difference in the graph and delta i_b is the difference in the two graphs. This is for 20 micro amperes this is for 10 micro amperes and the difference in the collector base current, delta i_b is 10 micro amperes.

The denominator is 10 micro ampere and numerator is approximately about 1 milli ampere. This is about 1.5 to 2.5. This should be 1 milli ampere. So 1 milli ampere divided by 10 micro ampere that will be the h_{ie} value. The milli and micro it will go. It is 1by 10 into 10 power 3. It will be around 1000 ohms approximately. Is that right? This is 10 micro amperes. This will be 1 milli ampere. So 1 by 10 kilo it is about 100 ohms, it looks like. So in this case it is about 100. It depends on the point you choose. If you calculate here it may be different. If you calculate some other point it may be different. One has to be careful about the point to choose. It is always good to measure the various parameters around the Q point. That is what I want to stress.

Now let us move on to the next value which is h_{oe}. The two parameters can be calculated from the d_{ce} i_c graph. The second parameter is h_{oe} which is nothing but the change in the collector current corresponding to a change in the collector emitter voltage with constant I_B. The change in collector current, how do you get that? For example I can go with reference to 8.4. I can go somewhere close to the operating point. Two points here for example 5 and 10. From here I find out what is the collector current and with reference to this I can calculate what is the collector current here. This change is what I call delta i_e here and this difference here is the delta V_{ce}. Actually it is nothing but the slope of this line that I have here but we want to do it at the Q point and therefore we have to choose two voltages here and the two corresponding current and thereby we can calculate what is delta i_c by delta V_{ce} and we have to go along the same I_B that is most important. This is the I_B. I will explain once more may not be clear.

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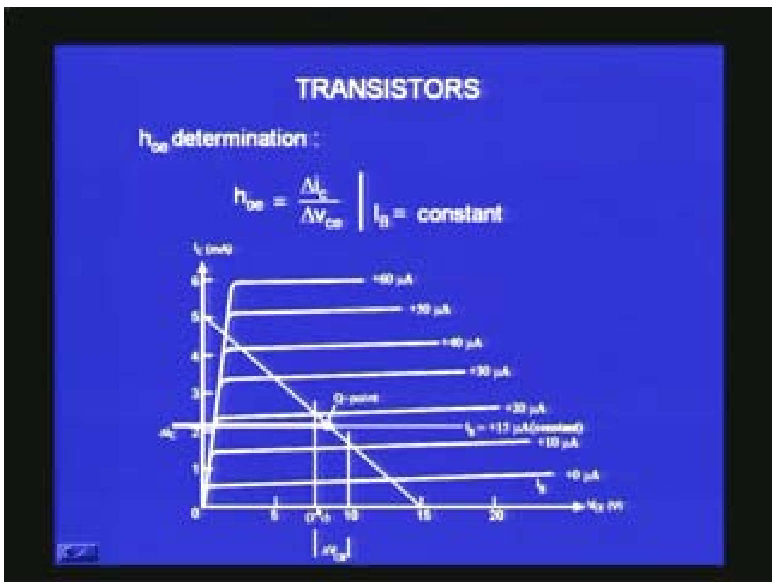

I choose a I_B here. This I_B is in between 10 and 20. So it is written as +15 micro amperes and it is a constant. So this is a constant I_B line and I want to find out the change in i_c. So I take two points above and below; whatever is the two point. This is one point here this is another point. This change is the delta i_c and the corresponding change here is the delta V_{ce}. So if I now put delta i_c by delta V_{ce} with I_B constant at 15 micro amperes this gives me the h_{oe} and $1/h_{oe}$ is the output resistance. From the graph we can always take two neighboring points and find out what is the corresponding value here.

Let us move on to the next value which is h_{ie}, the input resistance and h_{ie} is change in base emitter voltage to the collector base current and that can be obtained from the other graph which is corresponding to the input characteristics. You have a V_{be} here. You have i_b here for the common emitter configuration. Around 0.7 also it starts increasing; the current starts increasing. What we want is the change in the base emitter voltage corresponding to a change in base current.

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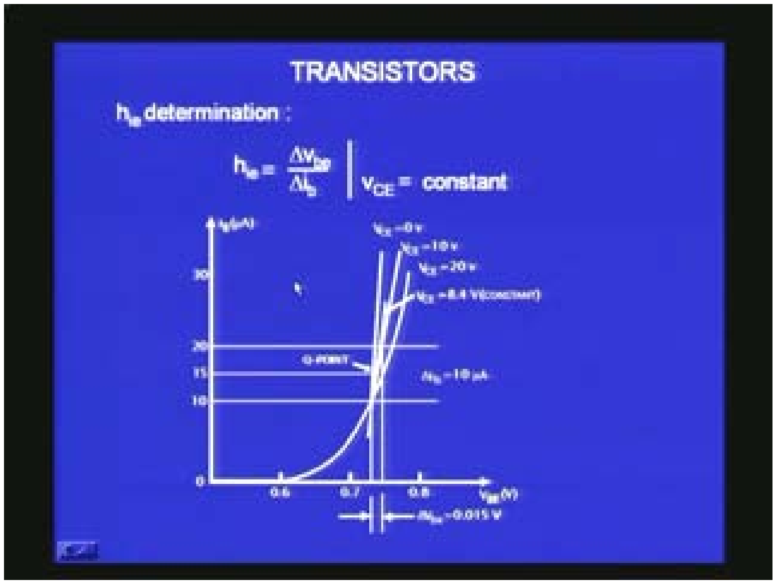

I choose two small points and draw ordinates here and here where it cuts and from that I will draw the lines on the base i_b graph. This corresponds to 10 and 20. So the difference is about 10 and the corresponding difference is about 0.015. I divide the delta V_{be} by the delta i_b that I get here at constant V_{CE}. This one graph is for the constant V_{CE}. There is another graph; this graph is for constant V_{CE} 20 volts. This current is constant with V_{CE} is equal to 0 volts. You have different graphs and you should go only along the graph which has got constant $V_{CE.}$ For example this is the graph we have used and these two ordinates meet at this point and this point. That is why these two lines are drawn. So the difference here is 10 milli amperes; it is in micro amperes 10 micro amperes and this voltage is about 0.015 volt and if you divide one by the other you will get the h_{ie} value from the graph .

For the h_{re} parameter delta V_{be} by delta V_{ce} is at constant I_B. Therefore you draw a horizontal line corresponding to the constant I_B which is 15 micro amps. In the previous case you maintained the same 15 amperes. At constant I_B you go from one graph to another. There are three different graphs here corresponding to the three different values of V_{ce} and you find out corresponding V_{be} here and here; find the difference and the difference is 0.008.

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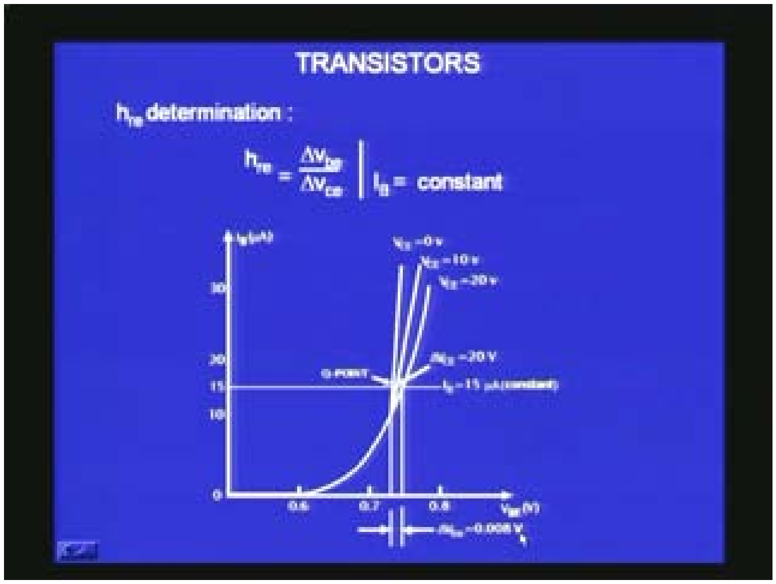

0.008 is the numerator value, delta V_{ce} is the difference between the 0 and the 20 volts, 20 volts. So 0.008 by 20 volts is the value corresponding to I_B equal to 15 micro amperes which is constant and this gives me the h_{re} parameter. By using the two input characteristics and the output characteristics we can obtain all the four h parameters; h_{ie}, h_{re}, h_{fe}, h_{oe} easily. They can also be measured as I already mentioned to you by an actual experiment. I have not discussed that part. But let us quickly make use of this h parameters in a very typical case of an amplifier and see how we can evaluate the various important values of the current gain, voltage gain, input resistance, output resistance which are of importance to us immediately.

I have given you here a simple amplifier; single stage, one transistor, common emitter amplifier which is very familiar to you by now. We have discussed several times earlier also. You have a coupling capacitor here. You have a voltage source, the signal source here which is characterized by a voltage source in series with Rs, the series resistance corresponding to the generator and internal resistance of the generator and this the coupling capacitors C_1 which blocks the dc and R_1 R_2 is the voltage divider bias that you have for the transistor amplifier. R_c is the load resistor here and you put a coupling capacitor and connect it to an external load here R_L if you want and here is emitter bias resistor R_E which is only for biasing and you have a capacitor which takes care during ac that this resistance will have no role to play because the capacitor for the normal operating frequencies will be a short across the resistor and therefore I can almost take this equivalent to this point for ac equivalent circuit. We also know in this case of a common emitter amplifier there is a 180 degree phase shift between the input and the output.

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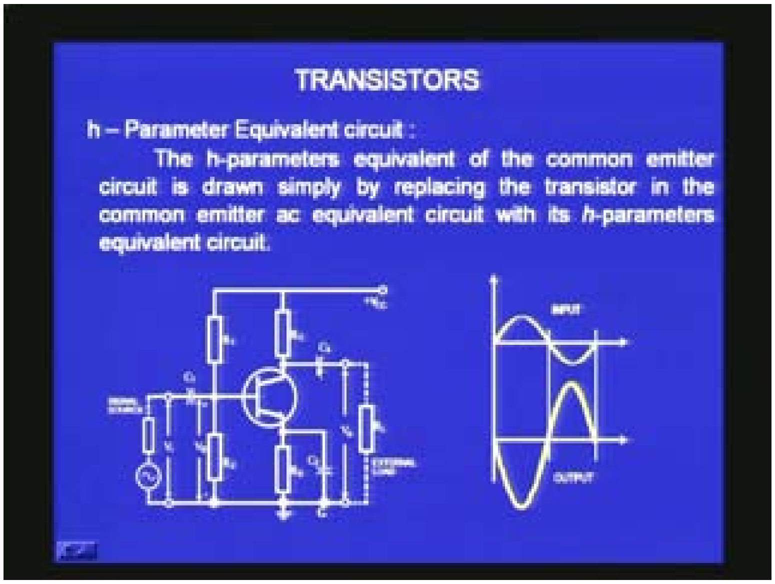

We have discussed number of times earlier also and therefore if the signal is sinusoidal at the input with small amplitude the output will be large amplitude because there is amplification and you can also see the phase is just opposite of the input. That means it is 180 degree. When it is increasing here the output is decreasing and when it is decreasing it is actually increasing and then decreasing. So we can see there is a 180 degree phase difference between the input and the output in the case of common emitter amplifier. All these things are already known to you. Let us try to see how to write the ac equivalent circuit of this. You know the rules of the game. The rule of the game is that the dc supply should be short. That means you have to take a wire and connect to it to …… to get the ac equivalent which is equivalent to saying that this point is same as this point as far as ac signals are concerned and therefore this R_1 can come over here this R_c can come in parallel here and that is what we have done in the next slide.

You still have the input signal generator with V_s and the R_s. You have this Z_i which is actually the R_1 and R_2 resistors coming in parallel at the input side and then you have this transistor within the dotted line box, the box with a dotted line. This is the h_{ie} of the transistor. This is the h_{re}, V output and this is the h_{fe}; i_b corresponding to the input is 1/ h_{oe} the output resistance and therefore this E, E, B, C corresponds to the emitter, base, collector terminals of the transistor.

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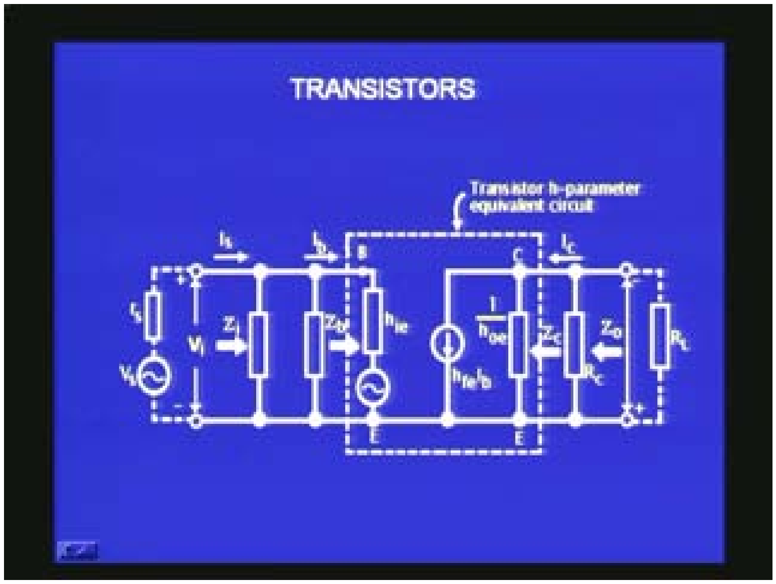

The box which is in dotted lines shown here corresponds to the transistor. That is why I have replaced the transistor by the equivalent circuit using the hybrid parameters here and these are the R_1 and R_2 resistors that we have used for biasing the voltage divider bias and the output you have the R_c coming again in parallel to this because of the ac equivalent and this R_L is the external load resistor that we have connected. So this is the ac equivalent circuit of the full amplifier showing including the signal generator input and the external load connected at the output. Therefore this becomes very simple. You can see it is nothing but a network of sources and resistors on the input side and again a network of resistors and sources at the output and we can easily evaluate various things using this.

In my common emitter amplifier if I don't have this capacitor that means for the ac equivalent circuit also this resistor will come into the circuit. That is what is shown here. An unbypassed emitter resistor is included in the circuit. That means we have removed the capacitor here and therefore this R_e will have to come into the circuit and that is shown here. This will be the equivalent circuit of an unbypassed common emitter amplifier and the corresponding equivalent circuit here is the equivalent circuit of the transistor. There is no change. It is exactly similar to what we have already seen and these are the R_1 R_2. This is R_C, collector resistance and this is the external load R_L.

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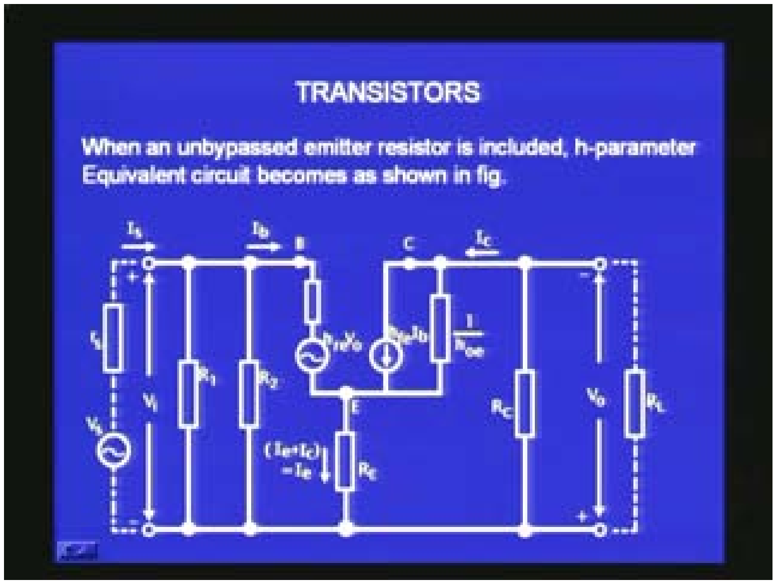

So this will be the circuit I should use when I have an unbypassed emitter resistor. So the relationship and the input gain, input resistance, output resistance, gain, etc., will also include contributions due to this additional resistor R_E. That is what we should remember. Let us now go ahead and start looking at how to analyse for example input impedance? How to obtain the input impedance? Because we have already said that h_r variable for a hybrid parameter is very, very small quantity therefore we can almost neglect the contribution due to this and that becomes rather simple. The circuit becomes simpler to analyse.

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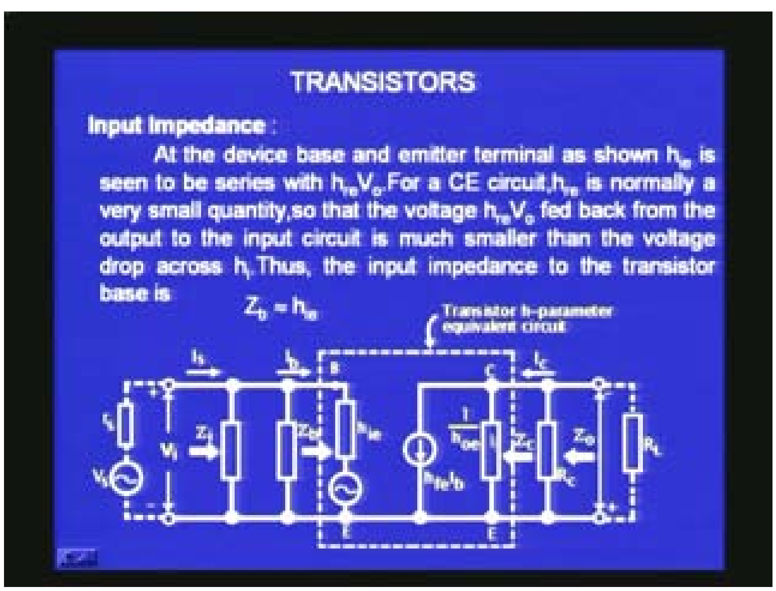

Similarly the 1 by h_{oe} is a large value compared to any of these resistors R_c or R_L. These will be 2 kilo ohms; this will be hundreds of kilo ohms and therefore when I bring the parallel values of different resistors, the large resistor will have very little contribution. The contribution will mostly be due to the smaller resistance and therefore we can afford to neglect the contribution from $1/h_{oe}$ most of the time and therefore later on you could see that I can neglect the h_{re} contribution here and the $1/h_{oe}$ contribution here. Then it becomes much simpler to analyze and what I want to ultimately obtain is the input impedance. So what is the input impedance at the transistor? is at b It is nothing but h_{ie} because this also I have now neglected. Therefore there is only one resistor which is coming at the input side between the base and the emitter and therefore the Z_b at the base of the transistor is just h_{ie}. So this h_{ie} now is going to come in parallel with the other two resistors and therefore if I take the input resistance of the amplifier then the Z_i will be equal to R_1 parallel R_2 where R_1 R_2 are the voltage divider bias resistors in parallel with Z_b here and this Z_b now is h_{ie}. So it is very simple. It is nothing but the input resistance Zi is R_1 parallel R_2 parallel h_{ie}. If you know the h_{ie}, if you know R_1 and R_2 you can find the parallel value of all these three and that will give you the input impedance. You can evaluate the input impedance. If you use an unbypassed emitter resistance R_e then the calculation becomes slightly more complicated. But it is rather simple.

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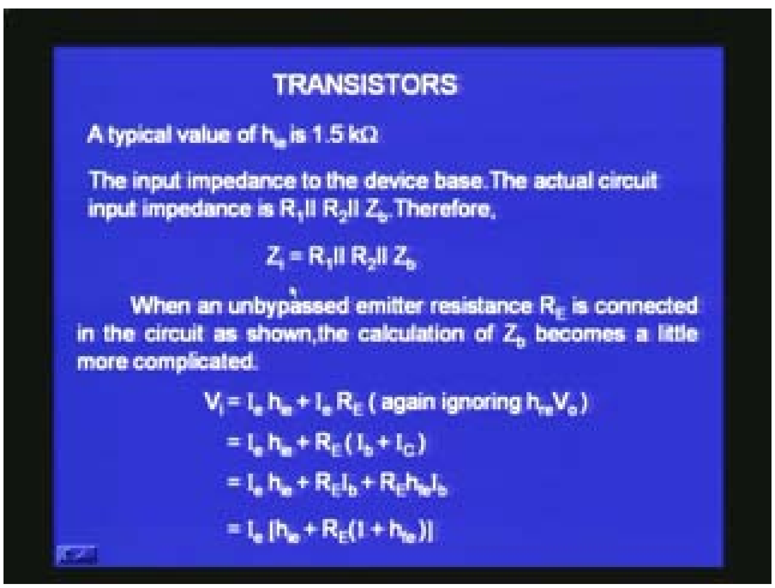

V_i is I_e into h_{ie} plus I_e into R_E because now h_{ie} and R_E both are coming in the circuit in series as you can see quickly.

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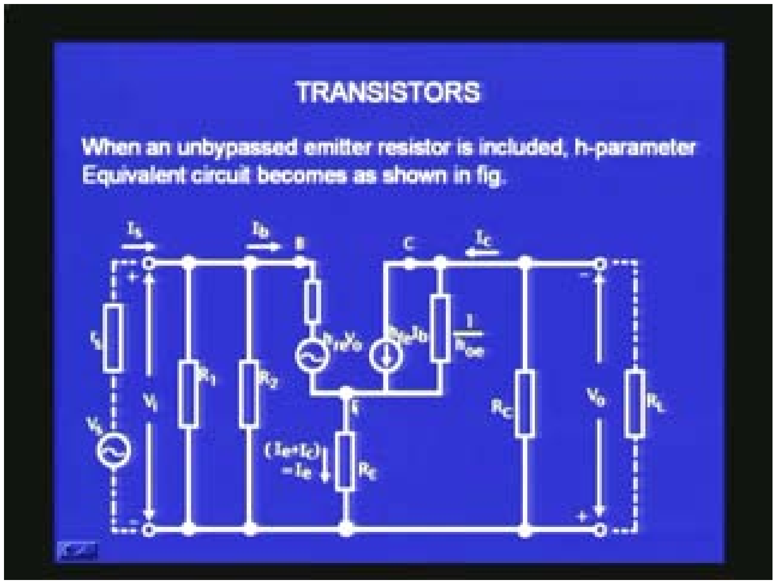

This is neglected. This is h_{ie}. It comes in series with R_E. Therefore the I_b will be flowing through both and therefore the I_e into h_{ie} I_e into RE ignoring h_{re} V_o and what is I_e? It is nothing but I_b plus I_c. You know that and therefore I_e h_{ie} plus R_E into I_b plus I_c. Now you rearrange. You can see it is I_e into h_{ie} plus R_E into one plus h_{fe} because I_c is nothing but h_{fe} into I_b current gain hfe and therefore if you now divide V_i by i_b or in this case you will find it will be h_{ie} into R_E into one plus h_{re}. In the previous case when the emitter resistance was bypassed, the input resistance was just h_{ie} of the transistor.

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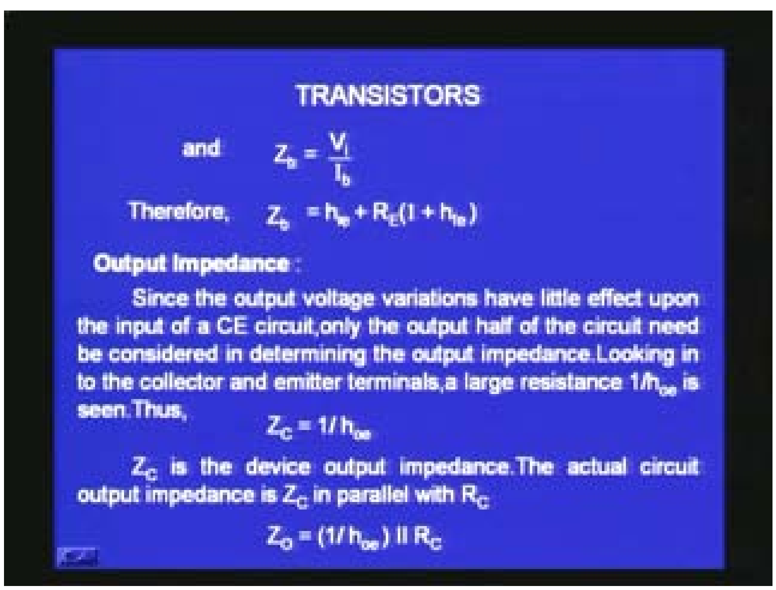

Now because we have R_E also you would find it will have an additional term which is R_E into one plus h_{fe}. It is not a small value because you see h_{fe} is large value. It is about 100 or so for a given typical transistor and therefore if it is about 1 k or 2 k it will be multiplied by 100 or so and therefore this value will become very large compared to h_{ie} which is usually of the order of 1 or 2 kilo ohms and therefore this will have more important role to play than h_{ie}. If R_E is bypassed this entire term will vanish and therefore you will be only worried about the h_{ie} which comes at the input stage. Similarly if I want to measure the output resistance the output voltage you have again Z output is equal to $1/h_{oe}$. Because this is a large value we neglect that. Otherwise what we should do? The output resistance is $1/h_{oe}$ parallel R_c. Because R_c is very small few kilo ohms, $1/h_{oe}$ is very large hundred of kilo ohms therefore the effective resistance will almost be equivalent to R_c.

The voltage gain is given by the equation A_V voltage gain of the amplifier is V output divided by V input. What is V output? V output is the collector current which passes through that parallel value of R_C and R_L. This is the output voltage; Ic R_C parallel R_L multiplied by I_C and what is the input resistance?

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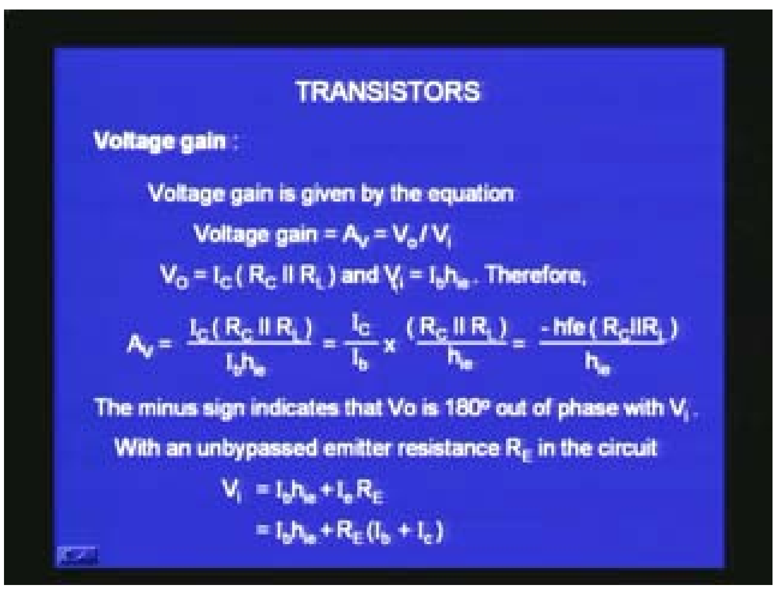

I_b multiplied by h_{ie}. Here I have now taken a bypassed R_E case and therefore it is only the h_{ie} that I have to worry and this is the value and what is A_V? V_o by V_i. V_o is this I_c multiplied by R_C parallel R_L and V_i which is I_b into h_{ie}. If you calculate this you find this is nothing but -h_{fe} into R_C parallel R_L by h_{ie}. So if R_L is not connected only up to the C_2, the coupling capacitor if you take h_{fe} into R_C by h_{ie}. This hie I already told you is nothing but beta re, small re and the beta is nothing but h_{fe}. So hfe into small re this h_{fe}, h_{fe} will go. So A_V the voltage gain in normal transistor is nothing but R_C by small re. That is what we also got in the previous discussion if you recollect. But in general the expression is -h_{fe} R_C parallel R_L when you also include the external resistor and divided by h_{ie} which is the input resistance parameter. There is minus here. Why do we get a minus sign? The minus sign is here because we know the input output are related by 180 degrees phase difference and that is taken care of by this negative sign.

If you consider the case of the unbypassed emitter resistance then it will be slightly different. You will have the I_b h_{ie} plus R_E that one plus h_{fe} into R_E will also come in and therefore you will have the output I_C into R_C parallel RL. There is no change in that but with reference to input I_b into h_{ie} plus R_E into one plus h_{fe}.

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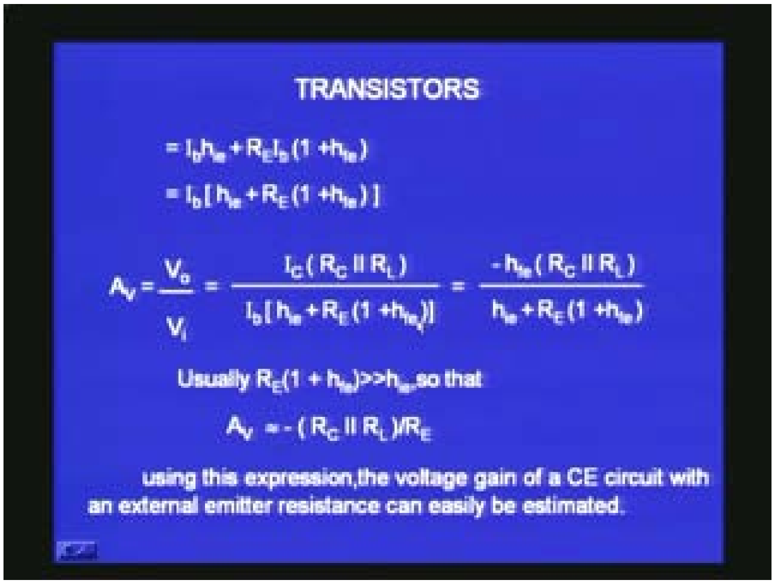

So this is an additional term comes which you have already seen and therefore A_V, the voltage gain will be $-h_{fe}$ R_c parallel R_L divided by h_{ie} plus one plus h_{fe} times R_E. This is slightly modified by the additional term that you have in the denominator. That comes because of the R_E which is unbypassed. With reference to this R_E into one plus h_{fe} which is large value h_{ie} can be neglected. In that case you would find it will almost be $-R_C$ parallel R_L divided by R_E. This h_{fe} and h_{fe} can go because compared to one, hfe is very large. So these two will go. We will be left with R_C parallel R_L divided by R_E. This also is a small value and therefore $-R_C$ parallel R_L divided by R_E will be the quick estimate of the voltage gain in a unbypassed R_E resistor included in the circuit. So we can get the voltage gain.

Let us move on to get the current gain. What is the current gain? h_{fe} is I_c by I_b and you should remember this I_b is actually related to I_s which is the source current coming from the generator and the relationship because there is a divider, the two parallel resistors are coming the R_s and the R_B. R_B is nothing but parallel value of R_1 and R_2.

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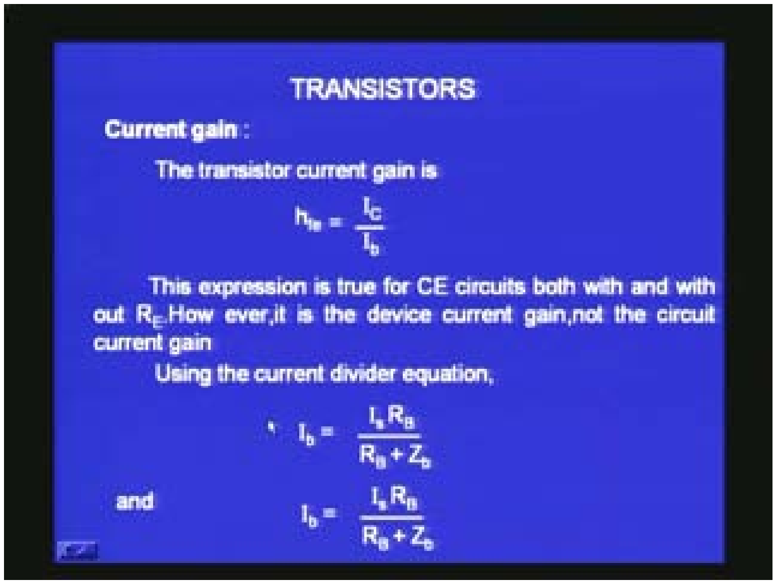

So the I_b will also be given by I_s R_B divided by R_B plus Z_b. This is coming from the current divider equation and therefore we can consider with that the current gain I_c by I_s will be a h_{fe} R_B by R_B plus Z_b.

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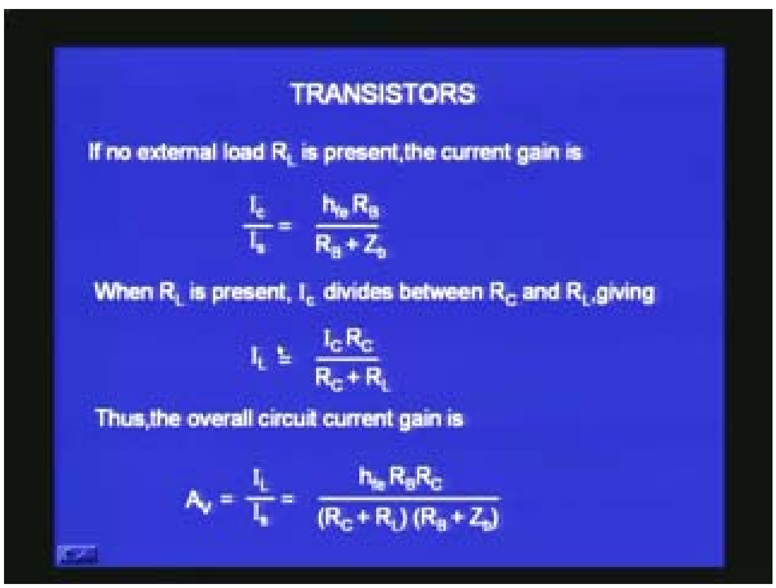

Similarly at the output I_L the load current will be divided by R_C and R_L. So it will be I_c R_C divided by R_C plus R_L using the current divider equation and therefore the overall current gain is I_L the load current divided by I_s the source driving current Is and that will be given by the big expression here which is combination of these two; h_{fe} into R_B into R_C divided by R_C plus R_L due to the input side and R_B plus Z_b due to the output side.

We can also go further and obtain the power gain.

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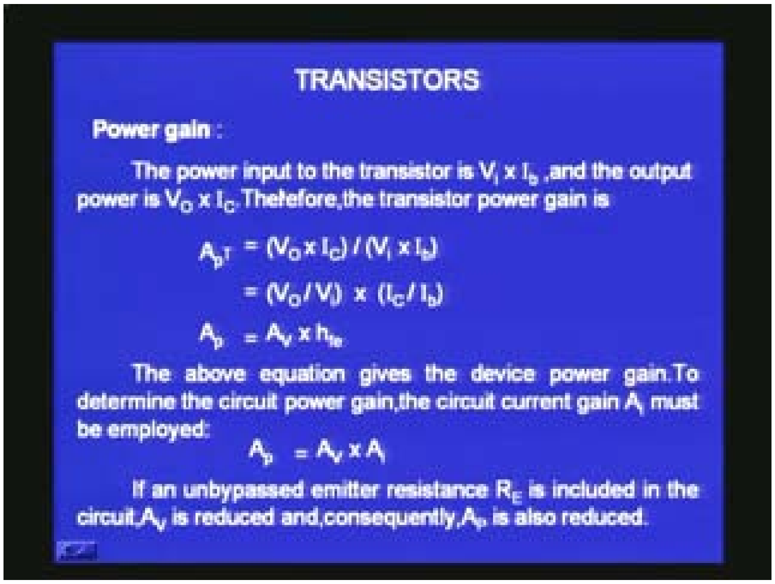

What is the power gain of the transistor? The power gain of the transistor is given by the output power divided by the input power. The output power is output voltage multiplied by the output current divided by the input voltage and the input current. In this case the input current is I_b the output current is I_c. Therefore V_o multiplied by I_c divided by V_i multiplied by I_b. I can now group them as V_o by V_i multiplied by I_c by I_b and what is V_o by V_i. It is nothing but voltage gain. What is I_c by I_b? It is nothing but the current gain of the transistor h_{fe} and therefore the power gain is voltage gain multiplied by h_{fe}, the current gain of the transistor. So this above equation corresponds to the transistor power. If you want the overall power gain of the amplifier then in place of the h_{fe} you should use the current gain of the amplifier. Instead of I_c I_b you will have I_L divided by I_s which is nothing but A_i the current gain. So power gain is nothing but the voltage gain multiplied by the current gain. If you have an unbypassed R_E into the circuit the voltage A_v will be reduced. The voltage A_v will be reduced when we use R_E and therefore correspondingly the power gain will also be reduced.

What is it that we have done so far? We considered about the h parameter. How the transistor can be modeled using an h parameter? We found that there are four different parameters that come into the circuit corresponding to h_{ie}, h_{re}, h_{fe} and h_{oe} when we consider the common emitter amplifier. So we obtained the equivalent circuit of a transistor in terms of these four parameters and then by looking at the numbers the h_{re} and the h_{oe} contribute very little to the circuit because h_{re} is very small value, h_{oe} is large value and $1/h_{oe}$ is very large value of resistance and therefore they can be neglected effectively in the circuit. So we simplified the model. We obtained the ac equivalent circuit of the common emitter amplifier and we obtained the voltage gain, the current gain, the input resistance, the output resistance and finally the power gain. We also looked at two different distinct cases where the emitter resistance R_E is bypassed with the capacitor which becomes the smaller resistance at the operating frequency, normal audio frequencies and therefore R_E will be neglected from the circuit. In the other case we did not use the bypass capacitor. Therefore R_E makes a significant contribution in the circuit. At that time the voltage gain becomes less compared to the other case and therefore correspondingly the power gain also becomes less.

What we are going to see next? We would perhaps in the next lecture like to take an example with definite values of the different resistors, take a typical amplifier circuit with numbers and then evaluate the various things as we have discussed now; the voltage gain, current gain, the input resistance, the output resistance and all these things. Then we would like to go on to a next model which is a common collector amplifier which is also called an emitter follower. The common collector amplifier or the emitter follower has got a voltage gain of almost equal to one. It is almost less than one; very close to one. Still it is very useful circuit when you come across impedance matching situations when you want to match the input impedances for maximum power transfer we will make use of common emitter amplifier which is – delete? common collector amplifier which is nothing but the emitter follower. So in the next lecture we will take an example, numerical example of an actual common emitter amplifier and we will perform the various calculations and obtain all the parameters of the amplifier and then we will go on to look at a common collector amplifier or emitter follower and obtain the input output resistance and gain and you would see at that time that the input resistance is very large for the common collector amplifier or the emitter follower and the output resistance is very small and therefore this becomes very useful circuit in impedance matching applications. So with this let me wind up the present lecture. So you will discuss the rest of the thing in next lecture. Thank you.