BASIC ELECTRONICS
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LECTURE-13
Basic Characteristic of an Amplifier
Simple Transistor Model, Common Emitter Amplifier

Hello everybody! Today in our series of lectures on basic electronics learning by doing, we will go further. Before we do that let us quickly recollect what we did during the last lecture. You might remember we discussed about the characteristics of a transistor specifically in common emitter configuration and we also discussed some of the biasing schemes like the emitter biasing, voltage divider biasing, etc and we tries to do some simple numerical examples, problems based on the biasing concepts. Today let us move on to using the transistors in amplifiers which is one of the major applications of these devices. Before we do that let us try to find out some characteristics of an amplifier in general. Instead of looking at any specific device let us look at the important characteristics of an amplifier in general.

What is an amplifier? An amplifier as you can see on the screen is a device which has got an input and an output.

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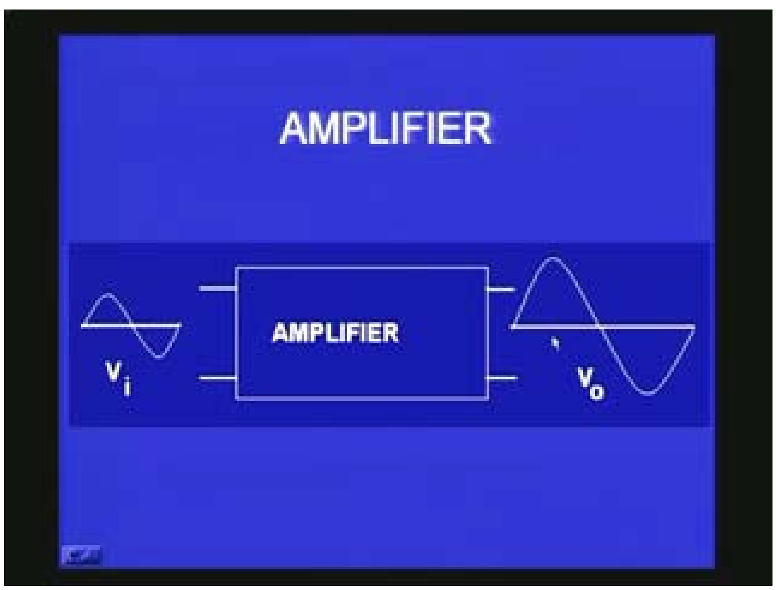

If I give a small sinusoidal signal as shown in the figure with an amplitude V_i at the input, you get a magnified version of the same sine wave at the output, V_o. An amplifier is basically a device which magnifies or amplifies AC signals, alternating signals given at the input and you get a magnified version of the same signal at the output. We expect the output should be exact reproduction, faithful reproduction of that we have given at the input. So what are the characteristics? I have shown here an amplifier with two terminals on the left side which are called the input terminals and two other terminals on the other side, on the right side which corresponds to the output terminals and we have also designated the various voltages and currents.

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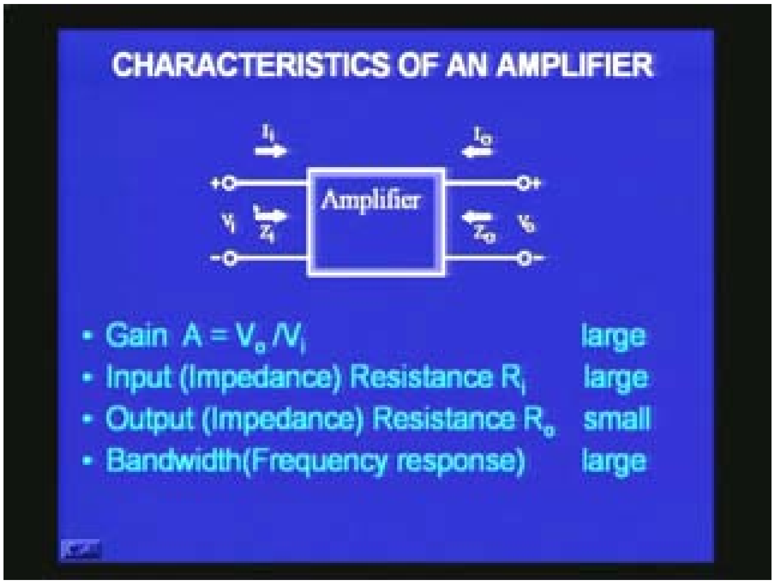

The input voltage is called Vi and the current corresponding to that is called Ii flowing through the input terminal and there is a resistance or impedance associated with the input stage of an amplifier. That is if I stand here and look inside the amplifier what will be the impedance offered by the device irrespective of the circuits that we have here. It is equivalent to looking at the Thevenin's equivalent resistance of this amplifier across this terminal. That is what we call input resistance or input impedance in general. Similarly at the output you have Vo which is the output voltage and there is an Io which is designated with a positive corresponding to current flowing into the amplifier from the output terminal and there is also an associated impedance which is called the output impedance similar to the input impedance on the input side. The Zo is output impedance and you can also consider Ro the output resistance if you are not looking at the general situation of impedance.

This is a general block diagram of an amplifier and one of the important characteristics of the amplifier is the gain, gain A which is defined as Vo divided by Vi. Vo is the voltage at the output Vi is the voltage given at the input. The ratio of the output voltage to the input voltage is what is called a gain. In any good amplifier we should have reasonably large gain. The gain in general should be large. Then the other characteristic is the input impedance or the resistance that I already mentioned to you. I have shown it in the form of Ri and this also in general should be very large for an amplifier. Why should this input resistance be large for an amplifier?

You can easily understand this because when I apply a signal here using a signal source a sinusoidal or any other from a microphone, that source will always have corresponding source impedance, the internal resistance of the source. If I want to show the source connected at the input terminal I will show a voltage source which is corresponding to the signal amplitude and a resistance in series which is corresponding to the internal impedance or resistance of the source. That comes in series with the internal resistance or the impedance of the amplifier and the voltage signal that is applied is now going to be divided between two resistors; one is the source resistance the other is the input resistance of the amplifier and whenever two resistances come in series the voltage will be divided. Even though I have a signal corresponding to Vs when it is applied to the amplifier the Vi which is the signal applied at the terminals of the amplifier will be different from Vs. It will most probably be less than Vs because you have a finite R_S the source resistance in series with the Zi. We have seen similar situations in other circuits when we discussed and if I want the entire signal Vs that I apply should be applied across the amplifier terminal then this is possible only if R_S becomes zero.

We all know that. But R_S is not in our hands. R_S is the internal resistance or impedance of a given source. It can be a microphone, it can be a function generator or it can be a signal generator and we have no control on that. What we can control is in the design of the amplifier. We can try to make Zi or Ri input resistance on the amplifier as large as possible so that any source resistance that comes along with that signal will become very, very small in comparison to the input resistance of the amplifier. That way I would reasonably make sure that most of the signal Vs will be applied across the signal and Vi will almost be equal to Vs if I ensure the input resistance of the amplifier is very, very large. That is one of the reason why you must always try to have input resistance of an amplifier especially voltage amplifier as large as possible.

What about the output resistance or the output impedance? The output resistance should in general be very small. That is again because after you amplify you have to apply the output voltage to a load. The load that I talk about here could be a simple resistance or it could be a loud speaker or it could be any other amplifier. Whatever it is you can also look at it as an equivalent resistance, here R_L the load resistance. When I connect a load resistance I must make sure that the entire voltage is applied across the load. There is nothing which will be lost due to the internal resistance of the amplifier output stage. I will try to make the internal resistance of the output stage to be very, very small so that the entire output voltage is applied across the load in a very similar argument and good amplifiers will have output resistance very, very small input resistance very, very large. Ideally it should be infinity and this should be zero.

Then there are several characteristics which are important in any amplifier. But I have listed very important considerations and the fourth one what we want to look at is what is known as the bandwidth. What is the bandwidth? It is actually the frequency response of the amplifier. Amplifiers are meant to amplify AC signal. AC signal is characterized by very specific amplitude and a specific frequency. If I take for example a simple public address system when I speak the sound produces several frequency components. Amplifier should be able to amplify all the frequency components which form part of my speech without any distortion or any change at the output and amplifier should have a reasonable band width. That means it should treat equally several ranges of frequencies at the input. That is how good an amplifier is able to amplify signals belonging to different frequency ranges is known by the factor called the bandwidth or the frequency response of the amplifier.

No amplifier can have infinite bandwidth. That means it cannot amplify all signals from very low frequency of few hertz to very high frequencies in mega hertz and giga hertz. So you will always have a finite bandwidth for a given amplifier. If for example it is an audio amplifier an amplifier which is made use of to amplify audio frequency then the audio frequencies range from about 20 HZ to about 20,000 Hz and I should make sure that my amplifier is capable of amplifying all frequencies equally well starting from some few tens of Hertz to 20,000 or more. Then you would see that this will be a very good audio amplifier. Similarly when I look for higher frequencies, then I should make sure my amplifier also has got a larger bandwidth covering may be mega hertz. One has to be very careful in designing amplifiers for any specific purpose. We must make sure that the amplifier has got the required bandwidth or the frequency response to amplify the input signal belonging to equal frequencies.

How do we measure bandwidth? For that we have to plot for a given amplifier what is known as the frequency response curve. That means the frequency versus the gain. In the next screen a figure is shown.

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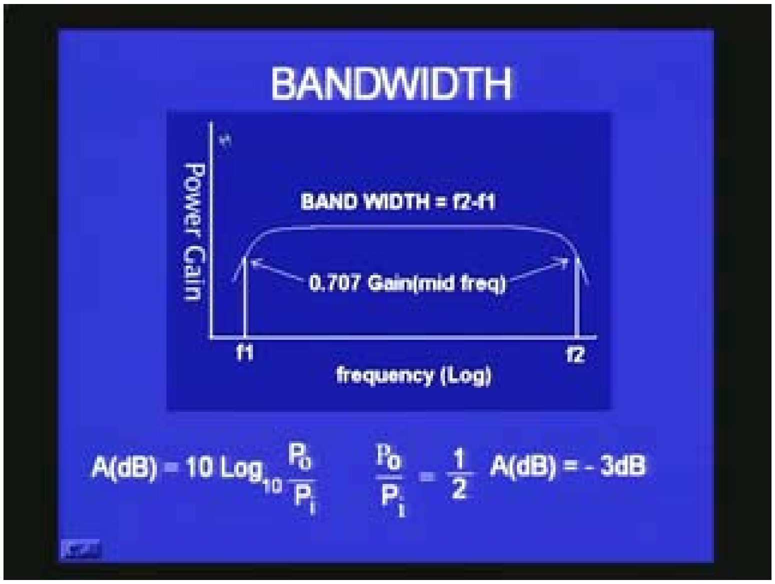

On the Y-axis I have got voltage gain and the X- axis I have the frequencies. But it is in the logarithmic scale because frequencies can go from few Hertz to several thousands of Hertz. If you want to represent all frequencies within a short distance then you have to go for a logarithmic scale which is in powers of ten and here the frequency is in the X-axis in logarithmic scale and the voltage gain is on the Y-axis and what I have drawn here in the form of a curve is actually the frequency response of a typical audio amplifier or whatever amplifier. That means at low frequencies somewhere here this is the gain. If I keep increasing the frequency the gain slowly increases and quickly comes to a constant value and remains constant over very large decades for several hundreds and thousands of frequencies and then at the extreme end, at very high frequencies again it starts falling due to several reasons and then it comes to a very low value.

If I have a graph like this then how do I fix my range corresponding to the bandwidth of the amplifier? That is shown here to be 0.707 times the gain at the mid frequency for a voltage amplifier. But let us try to understand how we come about this number. In general our ears are sensitive to logarithmic scale of amplitude or intensity and that is the reason the gain also in general will be represented in logarithmic scale as it is called a board plot, the log log plot; log of gain with log of frequency. If I have a fall in the power output of an amplifier by nearly half then perhaps I will not able to recognize it well and the point at which I would like to fix starting point of my bandwidth would be a point corresponding to which the power falls by one half of what it would be at the middle frequency where it is almost constant. With reference to this middle frequency when the gain falls by nearly half the power gain, that is what is important, that is the point where I would like to fix my starting point of my bandwidth consideration. For that the unit of the power, sound power or audio power is in terms of bell. Bell comes from the famous Alexander Graham Bell the man who invented the telephone. In honor of him the unit of power is kept and because that is a small number if you want to have a larger number that is called decibel.

The gain A in decibel unit is ten times logarithm to the base ten of power output by power input. This is the definition of 1 dB or one decibel. When the power output is one half the input power then if you find out what is ten log ten of half that would be -3 dB. When the power goes below -3dB you will know that the power has really halved; it has gone below half and that point is chosen as the reference point for the bandwidth on the left side as well as on the right side. It is called also half power point. This point, cutoff point f1 and f2 which define the bandwidth is given by f2-f1. f2 is a higher frequency f1 is a lower frequency. f2-f1 gives me the bandwidth of the amplifier. f1 point is chosen corresponding to the 3dB point or in terms of power gain or as the half power. But now we are discussing here the voltage gain. If you consider the voltage ratio or the voltage gain then the power is related to the voltage as V square by R. Power is proportional to V square by R where V is the voltage and I must now have a square or if I want to look at Vo by Vi it is going to be one by root two. Vo by Vi will be one by root two.

The voltage gain will be corresponding to one by root two and if you calculate one by root two it is 0.707. 0.707 times the mid frequency gain when I get I will mark that point as the cutoff point for the frequency for the f1 or f2 depending upon where I mark the point. The bandwidth is defined as the point at which the voltage gain drops to about 0.7 times the mid frequency gain and from that I will be able to get the bandwidth. Once you know the bandwidth let us try to find out how do we get the other characteristics of an amplifier in general? For example on the screen let us look at the input resistance. I have an amplifier, I have a source and I can introduce a resistance R_{sense} deliberately or it could be the resistance corresponding to the source resistance.

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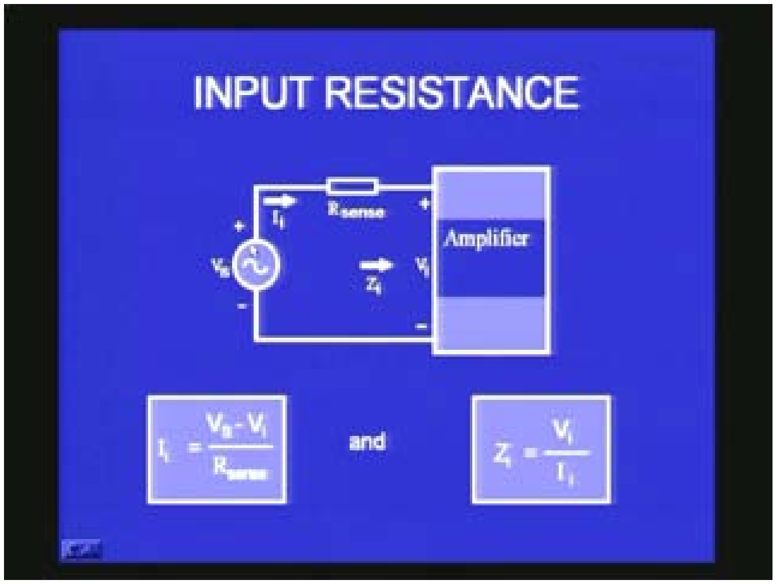

But it is always useful to introduce deliberately a resistance here if you want to measure the input resistance. We should not in general make use of a multimeter. We will not be able to measure using a ohmmeter in the ohms range for measuring the input resistance of an amplifier. So I have here a resistance introduced which is called R_{sense} in series with the signal and what is the input current? The input current is the voltage Vs which is the applied signal voltage minus Vi which is the actual voltage appearing across the amplifier. That is the voltage that is available across this resistance and the difference in the two will be responsible for the current through the resistance. Vs-Vi divided by the R_{sense} will give the current by simple ohms law. The voltage difference, the potential difference divided by the resistance gives me the current according to the ohms law. Vs-Vi by R_{sense} gives me the current. I can measure the input current by simply introducing one known resistance and finding out what is the voltage across this resistance; divide that by the resistance you will get the input current and the input impedance or the resistance is measured as the voltage at the input Vi measured using again a multimeter divided by the Ii measured as explained shortly before.

Zi is Vi by Ii; this way you will be a position to measure. In actual practice in the laboratory this R_{sense} can be kept as a variable resistance and you can vary this till you get Vi half of the Vs. When I get Vi half of Vs the voltages divide only when the resistances are equal. That means the R_{sense} should be equal to the input resistance of the amplifier. This will be one of the ways. This is called a half deflection method. You would have used in several applications like measuring the resistance of a mirror galvanometer; you would have used what is known as the half deflection technique. You have zero resistance and obtain a deflection then you start introducing resistance in the circuit till the deflection becomes half. Then you know the resistance of the meter is equal to the resistance that you have included now in the circuit and thereby you can measure the resistance. A very similar principle is used here to measure the input resistance. Usually the input resistance of any amplifier will be very large these days, several meg ohms and it will be very difficult to get resistances in the order of meg ohm, very precise value and it is not a bad idea to use any resistance and measure the voltage across them and divide by the resistance and thereby find the current, know the input voltage applied and divide the two you will get the input resistance of the amplifier. This I already mentioned to you.

What about the output resistance? When I want to measure the output resistance I will do a very similar scheme.

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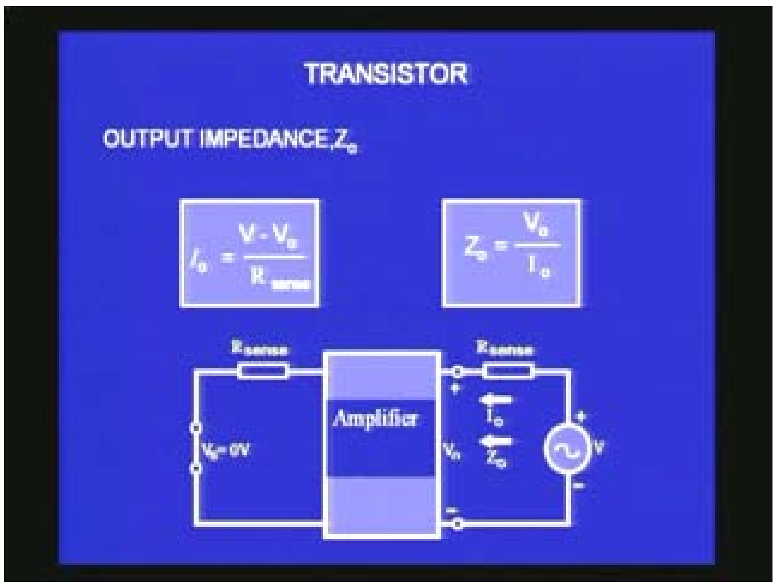

You have V-Vo. That is again I will put an output sense. I will short the input and at the output I will put the signal source and I will put a sense and apply the signal. V-Voutput is the voltage across R_{sense}. V-Vo by R_{sense} gives me the output current Io flowing. Zoutput is equal to Vo divided by Io by ohms law. I will be able to measure the output impedance or the resistance of an amplifier.

I have given here a very simple example to show the effect of input resistance on the signals. I already mentioned to you why the input resistance of an amplifier should be very large. I have here a signal source which has got a 10 millivolt amplitude signal coming and the R_{source} or the sense that I use is about 600 ohms and the input resistance is 1.2K ohms. We have to find out what is the actual voltage which will appear across the input terminal of the amplifier. The voltage source Vs is going to be divided by two resistors coming in series. One is the source resistance Rs which in general will be around 600 ohms and the input resistance of the amplifier which is given in this case to be 1.2K ohm.

The 600 ohms and 1.2Kohm will divide 10 millivolt in the ratio of their resistor values and Vi will be the one corresponding to Zi. Zi into the current which is Vs divided by Zi plus R_{source}. This will be the voltage developed across the Zi which is the actual input voltage. If you substitute the values 1.2Kohm for Zi, 10 millivolt signal strength and 1.2K ohm plus 0.6Kohm, 600 ohm is written as 0.6K ohm, and if you simplify it is around 6.67 millivolts. That means even though we apply 10 millivolts only 6.67 millivolt is applied across the amplifier because of the existence of the source resistance which is reasonably very high value in relation to the input resistance which is 1.2K ohms. It is actually half of the input resistance and even though you apply 10 millivolts only 6.67 millivolts is applied across the amplifier.

Apart from input resistance and output resistance the voltage gain we already defined A_V as the output voltage by the input voltage.

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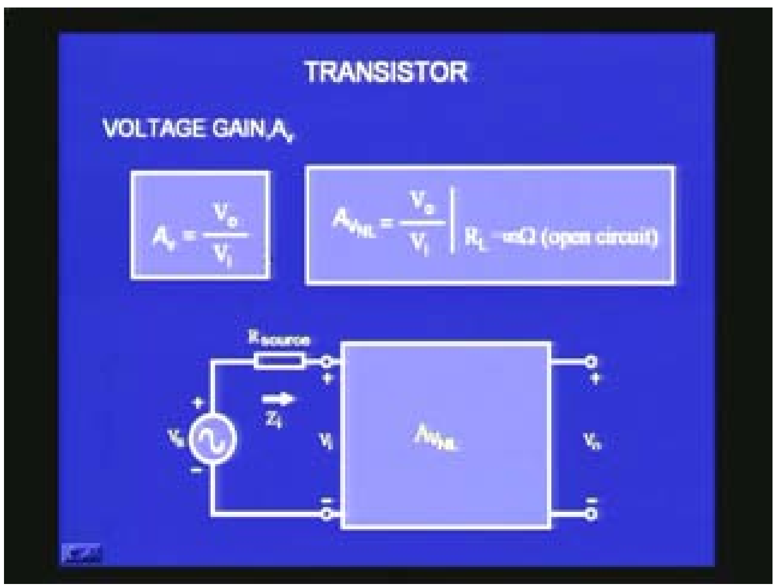

This we can do under condition of no load at the output. We have not connected any load. That is it is open circuit. Under that condition Voutput by V input with R_L equal to infinity open circuit is the gain Av_{NL}. This is the gain under no load condition. This is the general gain Av. Vi as we have already seen is Zi Vs divided by Zi plus Rs which we have seen and Vi by Vs is Zi by Zi plus Zs from this. If I bring that Vs to the left side it will become Vi by Vs is equal to Zi by Zi plus Rs and the voltage gain Av is Voutput by the V input signal Vs and that is Vi by Vs into Vo by Vi so that Vi and Vi will go. You will get Vo by Vs but Vi by Vs we already got is Zi by Zi plus Rs and Vo by Vi is the voltage under no load condition.

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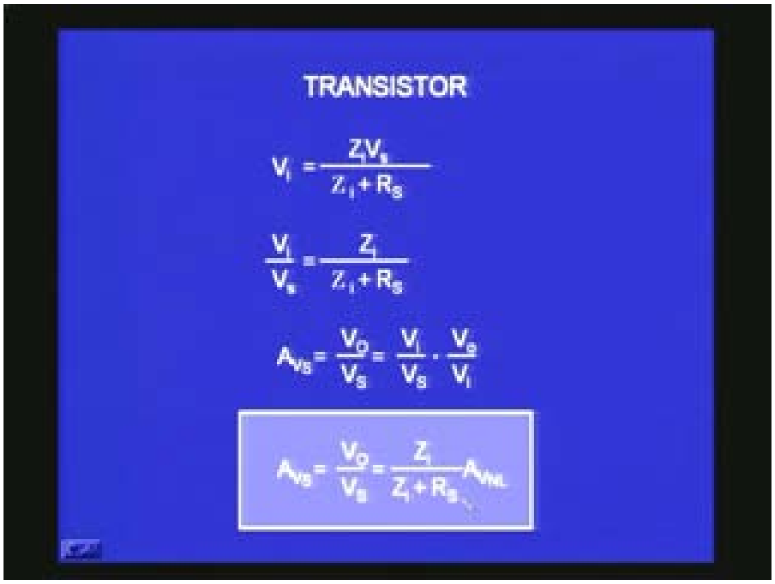

Voltage gain Av in general is given by Zi by Zi plus Rs into amplification under no load condition. You will get maximum gain corresponding to no load. But the moment you start connecting the load the gain will decrease. That is what you understand from this. Then there is what is also known as a current gain in some devices; in some amplifiers you can also get a current gain.

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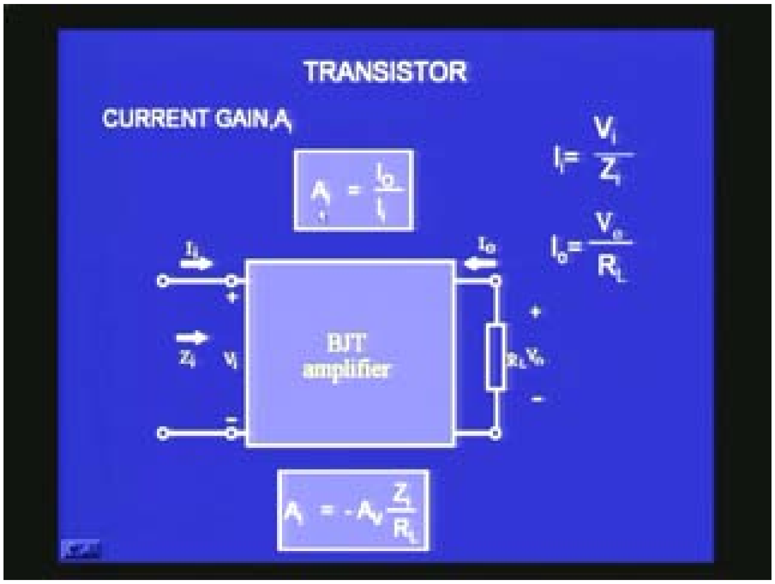

The current gain Ai is defined as the output current divided by the input current. The input current is given by the input voltage divided by the input resistance and the output current is given by the output voltage divided by the load resistance and the output current gain Ai will be given as -Av Zi/Zr. If I divide Io by Ii in this case it will be Vo by Vi which is nothing but Av the voltage gain into Zi by RL and that that is the input resistance and the load resistance. There is a negative sign. The negative sign shows that there is a change in the phase. There is a current coming out instead of going in. Io is positive when it is goes into the terminals of the output and there is a negative sign corresponding to this.

Having learnt some basic characteristics of the amplifier let us move on to look at one simple configurations of a common emitter amplifier which we have already seen in an earlier situation when we looked at the biasing circuits.

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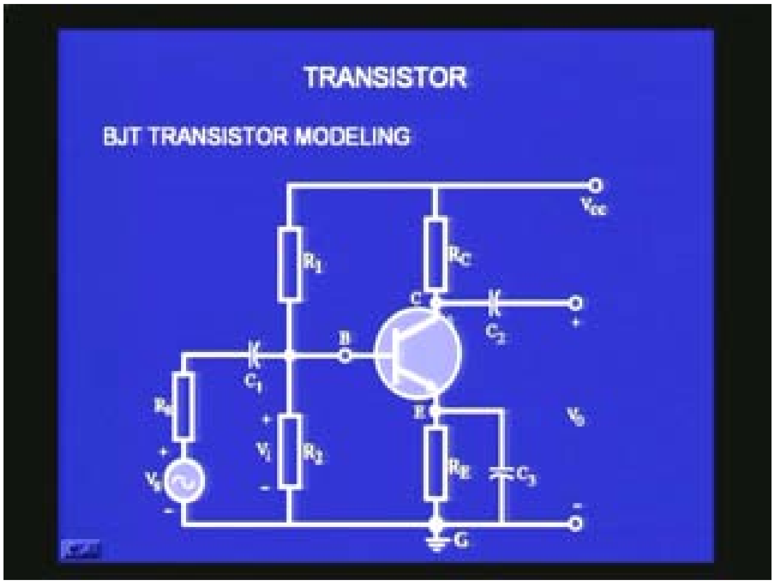

It has got the voltage divider bias with the emitter resistance R_E. You have a R_C here. You have the coupling capacitor C_1 and C_2 which will block the DC coming from the other stages and you have a C_3 which is called the bypass so that as far as the AC is concerned the emitter is at the ground potential. That is the function of the C_3. There is a signal source applied Vs along with the series source resistance R_S. I want to analyze this and try to obtain the different parameters or characteristics of this amplifier like its input resistance looking from the input side. This is input side; from here what is the input resistance? From here what is the output resistance and what is the current gain and what is the voltage gain etc.

How do we go about analyzing this simple circuit? The first thing that we should remember is now we are trying to look at the performance of the circuit under AC situation. We are going to apply an alternating voltage. So what happens to that? That is what is of great importance to us and I must look at the AC equivalent circuit of this circuit that I have drawn. If I want to look at the AC equivalent circuit what we have to do? The DC source is not going to be there. That means I must short the DC source. The $+V_{CC}$ and minus ground here will be together; it will be folded and connected to the ground as far as the AC is concerned which is equivalent to saying the two resistors R_1 and R_C are now grounded as far as the AC is concerned. Because this was previously the

V_{CC} now because we are looking at the AC equivalent this is grounded. Anyway R_2 is already in the ground potential, emitter is in the ground potential because you have put a capacitor there that capacitor will become a low resistance path for AC and this is a short here. This becomes the equivalent circuit. You can bring them all down so it is more convenient to look at them. What I have got is the equivalent circuit of the full amplifier that we saw. R_1 R_2 are now in parallel and this R_B, the base resistance is actually the parallel value of R_1 and R_2 and you have R_C coming here which was the collector resistance because of the AC equivalents it has come to the ground.

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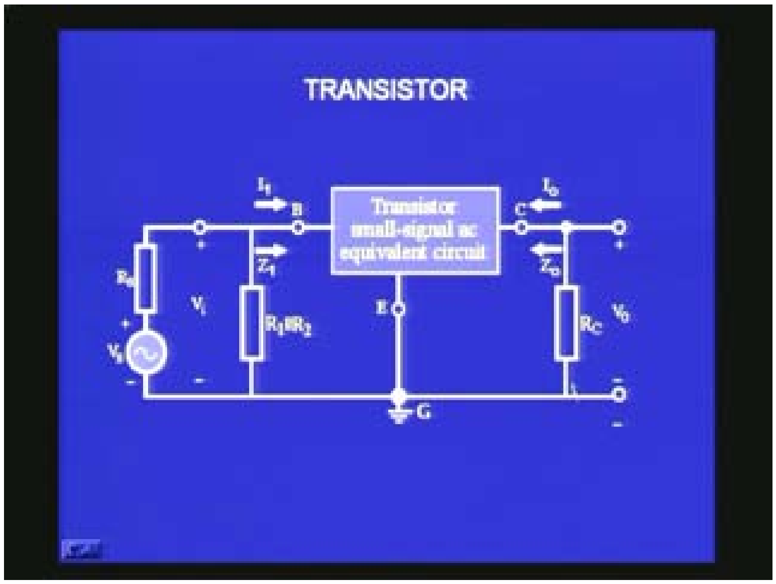

This is a transistor. I must try to have some equivalent circuit corresponding to the transistor here and the capacitors are all missing. The coupling capacitor C_1 and C_2 are also missing because they will become short for the AC signals, for the operating signals. For the frequencies of interest they will become almost short and I have removed them from the circuit by a short. This is the AC equivalent circuit. I do still have the source Vs and Rs in series. But if I want to analyze and obtain complete information about the performance of the amplifier then I must replace this transistor also by some equivalent resistors, capacitors, voltage source, current source, etc. Then this whole problem becomes simplified into a simple network. That we have already discussed in our earlier lectures. You can find the output voltage and what is the input because it is a series of number of resistors, voltage sources, current sources, etc. We will be in a position to apply the known theorems like Thevenin's theorem and Norton's theorem. We will be able to apply the concept that we already learnt and understand the various voltages appearing across the different terminals. From that we will be able to obtain information regarding voltage gain, input resistance, output resistance, etc.

The problem now is how to get an equivalent circuit for a transistor? Let us for simplicity take initially a common base transistor. The common base transistor in the figure is shown like this.

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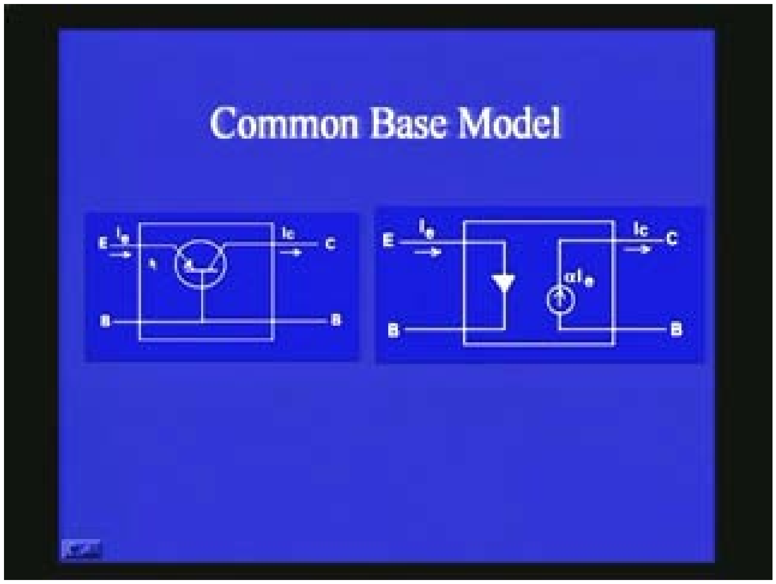

This is the emitter and this is the collector and the base is common to both the input and the output. This is a very simple common base transistor shown in all its complete picture. If I want to draw the equivalent circuit of this then as far as the emitter base terminals are concerned there is going to be the forward junction; emitter base junction. I can replace the emitter base junction by a simple junction diode. This is a diode which comes in the emitter base junction and with reference to the collector whatever is the Ie I get an Ic which is alpha times Ie where alpha is the current gain for a common base transistor and Ic is almost equal to Ie except for a small base current here and alpha is going to be very close to 1 or 0.9.

I introduce a current source in the collector circuit which is given by a value alpha Ie where alpha is the current gain Ie is the input emitter current. This, because alpha is very close to one it is almost equal to Ie. That is the one which will be flowing out as Ic in this direction. This is a very simple idea of an equivalent circuit for a common base transistor. It is still not convenient because we still have a diode. We should try to replace the diode by the equivalent resistance. For that we can look at the general diode equation. The diode equation for any p-n junction diode I_D is equal to I_S exponential qV by e KT minus one where I_S is the reverse saturation current, the V is the voltage across the diode and q is the charge; K is the Boltzman constant and T is the temperature. This equation if I differentiate and then obtain dV_D by dI_D then it becomes the resistance. That resistance is a equivalent dynamic resistance of the diode r_e and when I substitute the values for the charge q 1.6 into ten to the power of 19 coulomb and K the Boltzman constant, T the room temperature for example around 300 Kelvin and I_S is going to be very small which I will approximate to I_D. Then this will become almost equal to 26 millivolt divided by I_D. That will be the resistance of a diode corresponding to a given current I_D.

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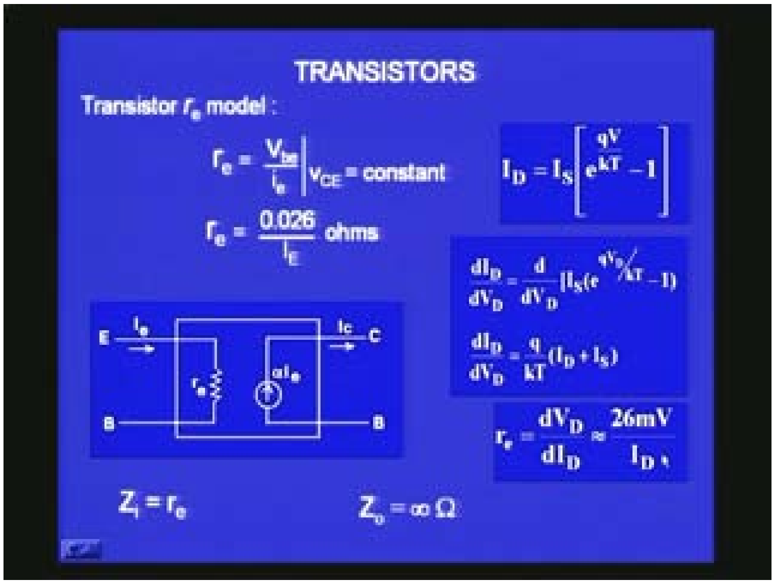

Once we know that now I can replace the diode that I have shown in the previous model with a resistance whose value is called r_e and r_e is nothing but V_{BE}, the voltage between the base emitter divided by Ie when the V_{CE} is maintained constant and in this case it is going to be 26 millivolts by Ie. The 26 millivolts here is written as 0.026 volts by current in ohms. r_e is 0.026 by Ie ohms. That is the resistance here and this current source is alpha Ie. There is a resistance here which is the output resistance which can be easily obtained graphically. If you remember the output characteristics of a common base transistor will have almost flat response. If you look at the resistance, the resistance will be very, very large corresponding to the slope of the curve that we get and we can almost take it as infinity and that is not shown here. In principle there will be a r_o here; that r_o is very, very large; that is ignored in this example. When I look from here I can get the output resistance. When I look from the emitter base junction into the transistor I will get the input resistance. When I look from this side the resistance that I will be looking at will be r_e. The Zi is r_e in the case of common base amplifier or transistor. Similarly the Zoutput I will be looking into a constant current source. The internal resistance of a constant current source is infinity; very large and the Zoutput is infinite ohms.

The whole idea becomes very simple now for the common base transistor. Voutput is nothing but Ioutput into R_L. The voltage developed across the R_L is due to the current flowing out of the terminal. There is a negative sign to show that current is coming out instead of going into the output terminal. So this is -Ic the collector current into R_L and Ic is alpha times Ie. That we also know. The output voltage is given by alpha IeR_L. The input voltage is the emitter current multiplied by input resistance that is emitter current multiplied by Ri. In this case Ri is nothing but small r_e which is the diode resistance. Ie into r_e which is 26 millivolts by Ie. That is the current here.

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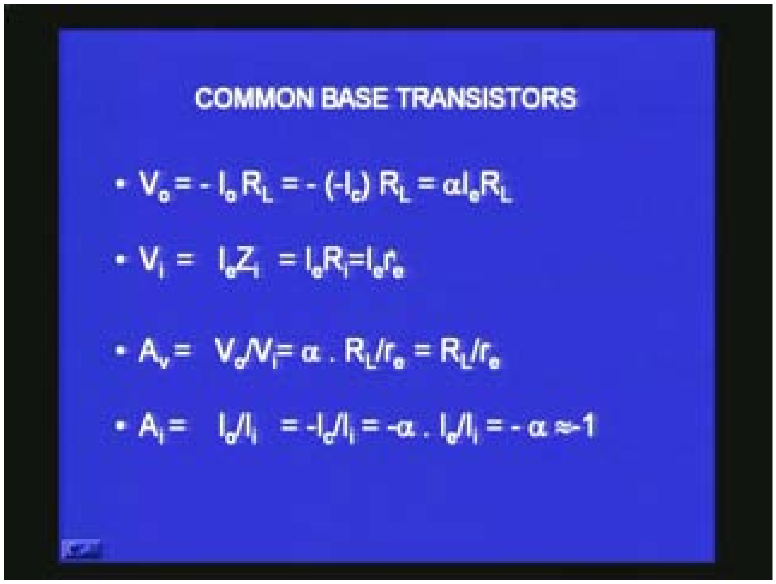

Now what is Av? The voltage gain is Voutput by Vinput. Voutput is alpha IeR_L divided by $I_e r_e$. The Ie and Ie will cancel. You will get alpha times R_L divided by small r_e. Because alpha is almost equal to one this will be almost equal to R_L by r_e. The voltage gain of a common base amplifier transistor is R_L by r_e where r_e is the base resistance due to the diode. What about current gain? Current gain Ai is output current divided by input current. The output current is –Ic, the collector current which is flowing out divided by Ie and it is minus alpha. Because Ii is actually the emitter current the ratio of the collector current to the emitter current is what is called alpha. Therefore it is minus alpha and because alpha is nearly equal to one it is going to be minus one. So the current gain is minus one. This is about common base transistor.

But we are interested more in common emitter amplifier because in common emitter amplifier you get much larger gain. Let us try to look at the equivalent circuit of a common emitter transistor. In the picture a common emitter transistor is shown with the base I_b as the input current as against the common base where Ie was the input current. I_b the base terminal is the input terminal, emitter terminal is a common terminal between the input and the output and you have the collector terminal here. If I have this then I can form the base emitter junction diode again here as you see in the screen and between the base and the collector I have got the current source which is now beta times I_b where beta is a very large number in the case of a common emitter amplifier. Beta times I_b where I_b is the base current. Base current usually will be in microamperes and the collector current will be in milliamperes.

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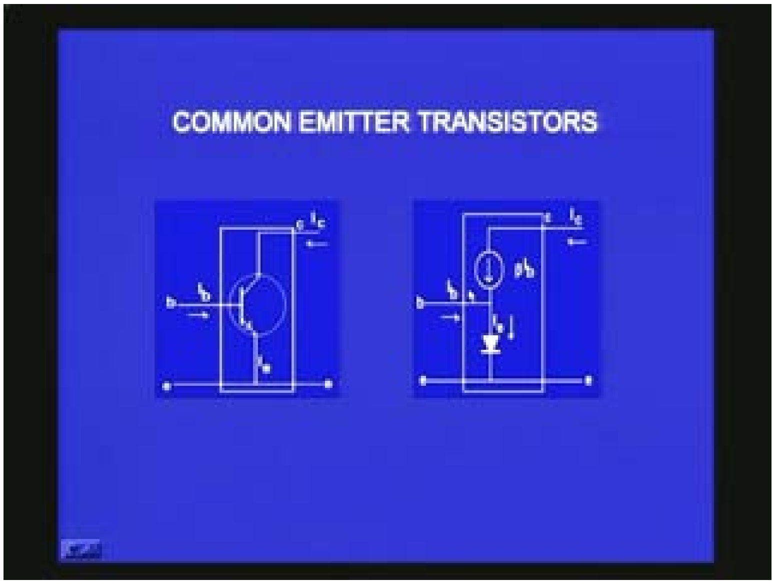

That means hundreds of times larger current will be in the Ic corresponding to the I_b and beta will be a few hundreds 150 or 200 etc. This is the equivalent circuit of a common emitter transistor.

I now replace the diode by the equivalent resistance r_e and beta I_b is the current source corresponding to the base collector region and what is Ic? Ic is beta times I_b; you know that.

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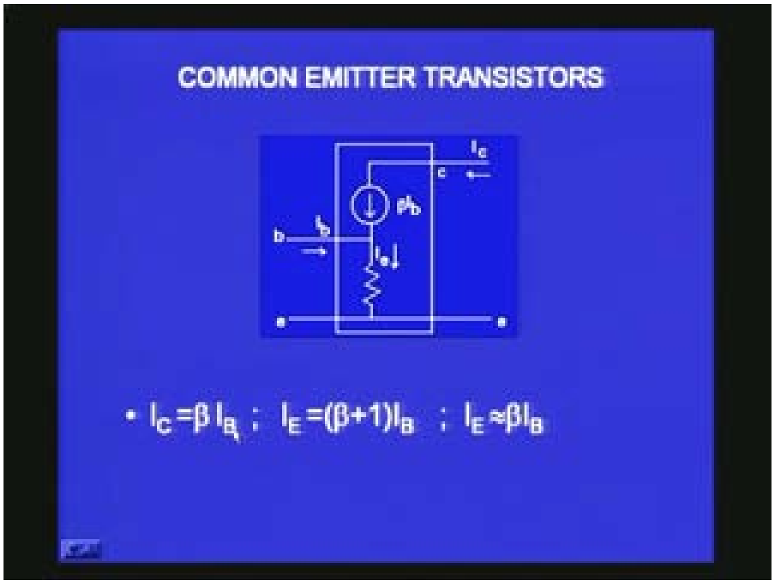

I_E is beta plus one times I_B because there is also I_B there. I_B also joins together with I_C to form I_E. Beta plus one times I_B. But we will neglect the one. So I_E is almost equal to beta times I_B. Usually I_E and I_C will be almost equal; you know that.

What about Zi, the input resistance or the input impedance? Vi voltage input divided by the current Ii which is in this case the current input Ii; this should be Ii. It is V_{be} the voltage between the base and the emitter and I_b. I_b is the input current and Vi is V_{be}. You know that. The input voltage is nothing but the input voltage applied across the base emitter junction V_{be}. That is Ie into r_e and I_b is beta times $I_b r_e$. This is beta. Beta times $I_b r_e$.

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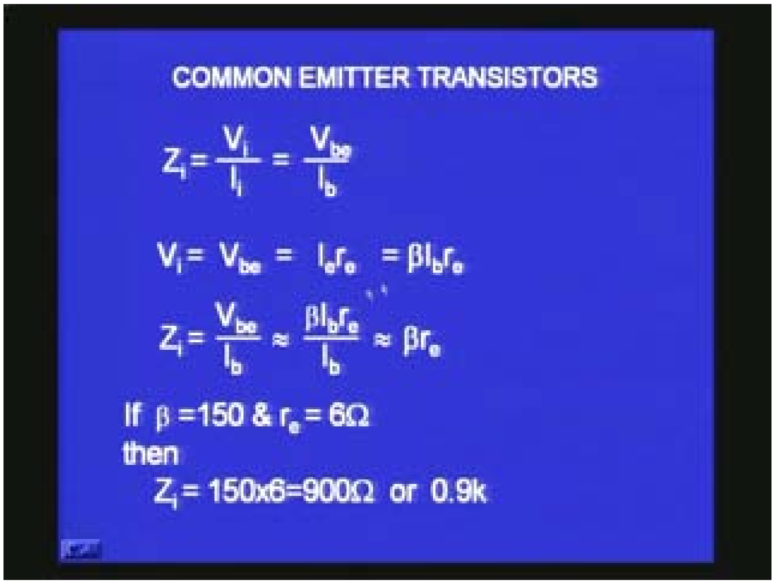

Zi input resistance or impedance is V_{be} by I_b and beta times $I_b r_e$ by I_b. That is beta times r_e. Beta is around 150 in a typical case. If I take about 150 for beta, this b is actually beta symbol r_e is around 6 ohms. Then the input resistance is a product of 150 into 6. That is 900 ohms or nearly 0.9K. In the case of a common base amplifier the input resistance was very, very low whereas in the case of a common emitter amplifier the input resistance is around 1 or 2K. It is about 1K in this case 0.9K. It's a larger value.

Let us now look at the common emitter transistor and then try to understand the gain. Voutput in that case is output current multiplied by R_L, the load resistance and here it is IC. -Ic into R_L that is beta times $I_b R_L$. That is the output voltage. The input voltage Vi is minus IiZi. That is I_b beta r_e and the gain is Voutput by Vinput. That is beta times $I_b R_L$ by I_b into beta times $r_e I_b$ and beta will cancel. So you will get R_L by r_e alone. It is very similar to what you got in the previous case R_L by r_e and the minus sign shows that the output is 180 degrees out of phase with reference to the input.

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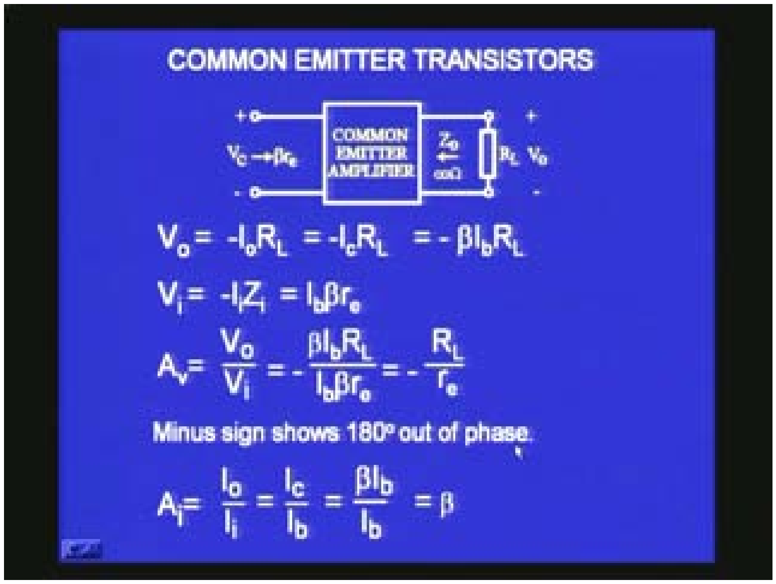

If you look at the current gain, Ai is output current divided by input current. Output current is Ic input current is I_b. It is almost equal to beta. So the current gain is beta the voltage gain is given by R_L by small r_e where small r_e is the resistance of the base.

Having understood this let us take a very simple example of a common emitter amplifier with a value of beta equal to 150 and the I_E is 3 milliamperes and the output resistance is almost infinite resistance here and now we have to determine Zi the input resistance or the impedance, Av the voltage gain for a load of 2K ohms and Ai with the same 2K ohm.

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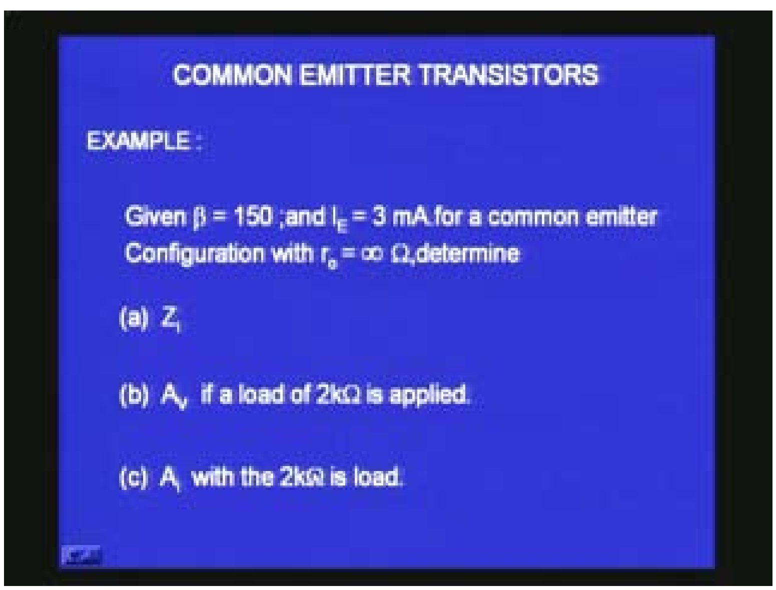

Find out Zi, the voltage gain and the current gain for the case of common emitter amplifier with the transistor having a beta of 150 and the current I_E of 3 milliamperes.

We can get r_e first. r_e is nothing but 26 millivolts divided by I_E and the I_E is given in the problem to be 3 milliamperes. So 26 millivolts divided by 3 milliamperes gives me 8.67 ohms. 8.67 ohms is the resistance of the internal diode that you come across between the base and the emitter junctions. The Zi will be beta times r_e and beta is given as 150. Then 150 times 8.67 ohms and that will be around 1.3K ohm. The input resistance of a common emitter amplifier with the specification given is 1.3K ohm which is reasonable large but not very large and what is the voltage gain? The voltage gain is given by R_L by small r_e where R_L is the load resistance and r_e is the base emitter junction resistance and that is 2K ohm is the R_L, 8.67 ohms is the input r_e resistance and the ratio comes to be around 231. The minus sign shows that there is an inversion.

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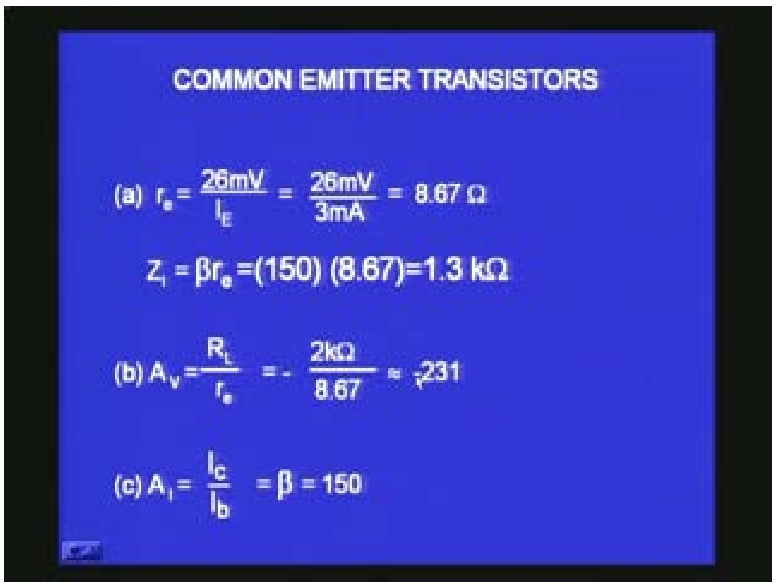

We did not get the minus sign in the case of common base amplifier because there the output is in phase with the input whereas here the output is 180 degree out of phase with the input. That is why we get a minus sign. What about current gain? Current gain is Ioutput by Ic and that is nothing but beta and the current gain is around 150. What we have now done is we have taken the simple scheme of assuming the transistor to be equated to a diode at the input side and a current source at the output side and when you look at the common emitter configuration it will be something like this and just by knowing r_e and the current source we will be in a position to find the simple relationship corresponding to the voltage gain, current gain, input resistance and output resistance.

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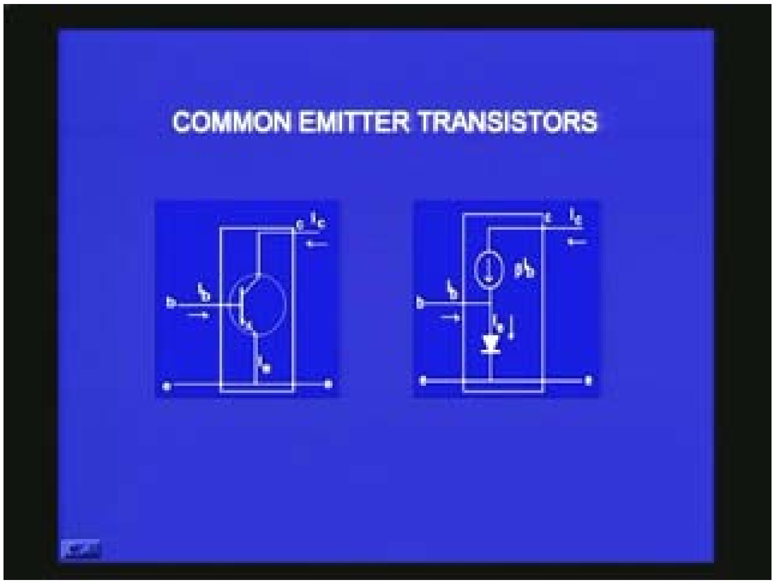

Still we have not discussed anything about the bandwidth. Because when I want to look at the bandwidth then we have to take into account the frequency dependent resistances in the circuit. We have for the present, for the sake of simplicity ignored all the capacitors. We have ignored the presence of C_1 C_2. Quickly I will show you the circuit and tell you what I mean by that. In this circuit for example I did not consider the effect of C_1, the effect of C_2, the effect of C_3. I have assumed that this is the short for the frequency range in which we are looking at the circuit this will be a short; this will be a short; this will be a short and in my equivalent circuit I never considered the presence of r_e.

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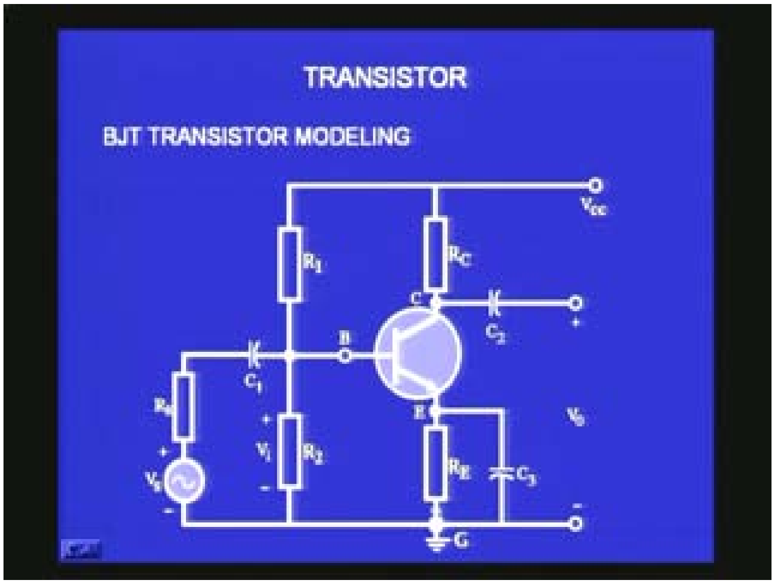

I considered only the emitter connected to the ground. Here also this will be just a short here and a short here. But if you want to really look at the frequency response of a common emitter amplifier then we have to take into account the frequency dependent impedances like the reactances of the capacitors. Later on we will have a detailed discussion about considering the frequency response of any amplifier. There they will correspond to the low frequency response of the amplifier. The low frequency cutoff will be decided by the combination of these capacitors and the high frequency will be decided by the bypass capacitors. This is called the bypass capacitor because AC will be bypassed from flowing through r_e. This is called a bypass capacitor. The bypass capacitors will decide on the high frequency side and the coupling capacitors will decide on the low frequency side, the bandwidth. This is a very simple scheme of analyzing a common base or a common emitter amplifier.

In the next lecture we would like to consider a more popular method of analyzing transistor amplifier that is by making use of what is known as hybrid model; hybrid parameter 'h' parameter scheme of drawing the equivalent circuit of a transistor. Because in the data sheet of many transistors from the manufacturers they will always list out some of the parameters like h_{11}, h_{12}, or h_{ie}, h_{fe}, h_{re}, etc. We must be able to also make use of those parameters if I want to analyze a transistor amplifier and in principle the transistor can be looked at in different ways. In terms of purely resistive networks then it is called R or Z parameters or you can write a equivalent model for the transistor using only conductances or admittances then it is called as a Y parameter or you can have hybrid parameter. Hybrid means you will have some which are voltages, some with ratio, some with current ratio, some is a input resistance and another is a conductance. The parameters will be having different dimensions. Some will be ratios, some will be ohm, some will be conductance and siemens. If I look at that way, that model is called a hybrid model. We can analyze a given transistor using hybrid model also.

We will perhaps take up in the next lecture how to go about considering the transistor as a hybrid equivalent circuit; the various parameters which will come into the modeling and then we will try to analyze the same circuit using hybrid parameter, 'h' parameter the input resistance, output resistance, etc and then we will correlate whatever results we get from the hybrid parameter discussion with a corresponding considerations with reference to the r_e that we considered today. What we considered today with r_e and beta times Ic and I_b, etc are the simplest way to consider. If you are given an amplifier to analyze if you want to very quickly obtain some reasonable numbers close to the values of the gain, the input resistance and the output resistance, etc the r_e model is very, very useful because it is very simple. All that we have to know is the current through the I_e and then 26 millivolts by Ie gives me the resistance r_e and in the common emitter amplifier the input resistance is beta times r_e. Beta also equivalently in the hybrid parameter corresponds to h_{fe}. We will see that and the correlation between the hybrid parameter and the r_e parameters also will be highlighted and the simplest way of doing is what we have so for discussed today and in the next lecture we will take up a more rigorous discussion about the 'h' parameters and then we will also apply wherever necessary simplification or approximation and try to look at the simplest way of analyzing a given circuit in terms of 'h' parameters and then obtain the corresponding quantities like the input resistance, output resistance, the voltage gain, a current gain etc. That is the idea and if possible we will also try to construct an amplifier and then measure its input resistance and output resistance and try to see whether we are able to get the value which we obtained from our calculations, by actual experimentation. Thank you!