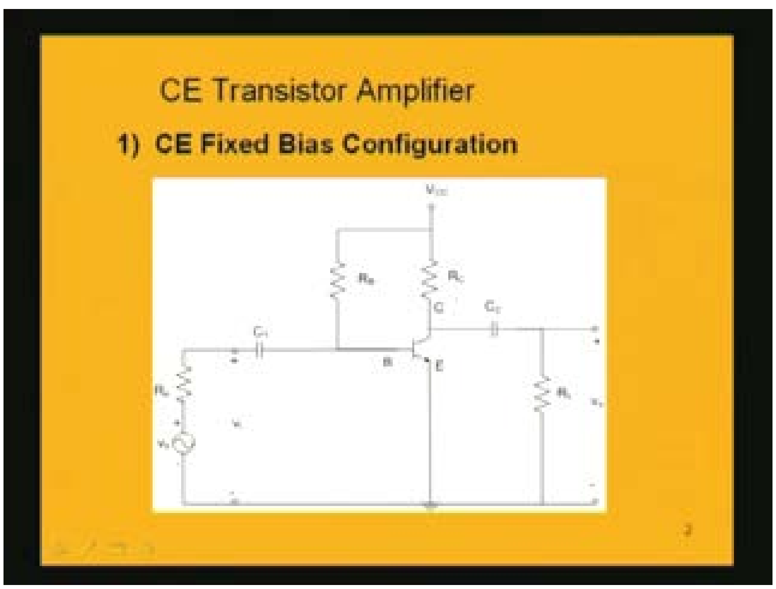
**Basic Electronics**
**Prof. Dr. Chitralekha Mahanta**
**Department of Electronics and Communication Engineering**
**Indian Institute of Technology, Guwahati**

**Module: 2 Bipolar Junction Transistors**
**Lecture-6**
**BJT Amplifier – Part 1**

In the last class we discussed about the different biasing schemes used for amplifiers and we studied about the significance of proper biasing scheme so that a week signal given as input can be faithfully amplified without any distortion occurring at any portion of the signal. Today we will discuss about the amplifier which is used for such amplification of week signal with different biasing schemes and today we will start discussing a BJT amplifier in the common emitter configuration. The common emitter BJT amplifier with fixed biasing scheme will be discussed first. The fixed biasing scheme as you have studied earlier is having a biasing resistance given here by this $R_b$. This resistance is connected to base terminal and its shares the same $V_{CC}$ with the collector which is used for reverse biasing. We are taking for example an NPN transistor which is common emitter configuration. Here apart from these biasing resistances there are capacitances, which are used for coupling the signals.

(Refer Slide Time: 2:36)



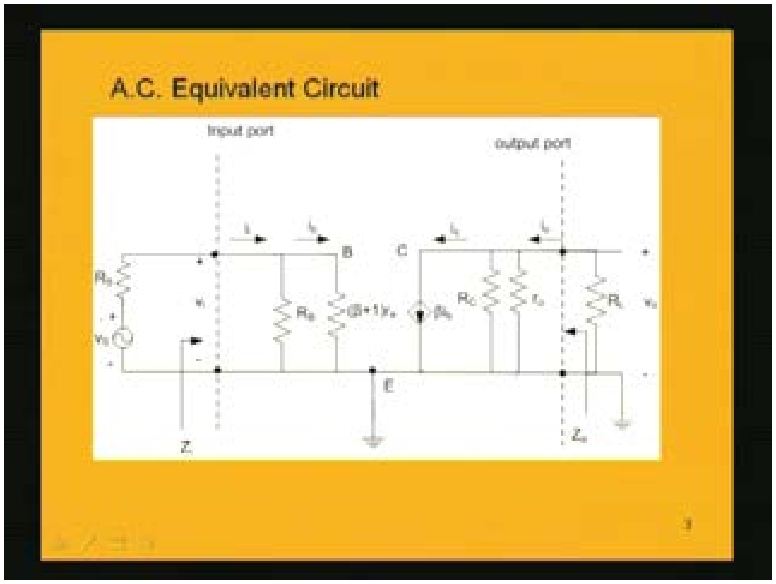

The $C_1$ is the input coupling capacitor which is coupling the signal $V_S$ and the output which is obtained at the output terminals this output is $V_O$ and this output is obtained by coupling the collector with a capacitor $C_2$ and this $V_S$ which is the input signal this is having a series (00:03:00) resistance $R_S$ and we are getting the output voltage $V_O$ across this load resistance $R_L$. This amplifier has the source resistance $R_S$ in series with the source $V_S$ and it has a load resistance $R_L$ and we are getting the output voltage across this load resistance and $R_B$ is the resistance which is connected in the base for biasing and $R_C$ is the resistance at the collector. This scheme is a simple biasing scheme which is known as fixed bias scheme.

In order to know how this amplification is taking place by considering the AC equivalent circuit we can proceed now to find out the different parameters which are involved in this amplifier. We can find out the voltage gain that is the ratio by which the output voltage is increased with respect to the input voltage $V_I$ or with respect to the source $V_S$. As well we can find out the current gain, the ratio between the output and input currents. Also we can find out the input impedance, output impedance, etc. But before that we must draw the AC equivalent circuit for these amplifiers including the transistor model which we discussed earlier. $r_e$ model will discuss here. That is we will take the $r_e$ model for replacing the transistor.

First we will draw this AC equivalent circuit. Following the procedure which we discussed earlier we can draw the A C equivalent circuit by first making the DC sources zero that is short circuiting the DC source. Then we will assume short circuit part for the AC input as far as the capacitors are concerned because the capacitor are chosen high values so that under the signal which is being applied the capacitors offer almost zero impedance or capacitive reactance such that it is like short circuit. Following this procedure if we try to draw the AC equivalent circuit for this fixed bias transistor amplifier we will make the $V_{CC}$ zero. Here it is only having the DC source $V_{CC}$ shared by this $R_B$ and $R_C$. This source will have to be made zero first. That is we will be grounding this $V_{CC}$ and after grounding this $V_{CC}$ we are left with the $R_B$ and $R_C$ resistances being grounded. As far as this figure here $R_B$ and $R_C$, these two resistances are connected to ground and then we will consider the capacitances $C_1$ and $C_2$ and make them short circuit because we are drawing the AC equivalent circuit and as these capacitors are having large values it is almost equivalent to being short circuited as far as AC is concerned. This pat involving $C_1$ and $C_2$ will be short circuit as far as the signal is concerned. Short circuiting means we will simply remove these capacitors by short circuit part.

As far as this base terminal is concerned, it will have an $R_B$ which is grounded as well as it will be connected to $V_S$ the signal at the input through this resistance $R_S$ and this coupling capacitor will also be now removed and it will be a short circuit part from collector through this load resistance to ground and another part will be there from the collector which is through this resistance $R_C$ to ground because $V_{CC}$ is now grounded and emitter is already grounded. The whole circuit as far as AC equivalent is concerned, will have this base, collector, emitter terminals as coming from the transistor. From the base terminal this $R_B$ is connected to ground and another part will be to this $V_S$ through this $R_S$.

(Refer Slide Time: 7:07)



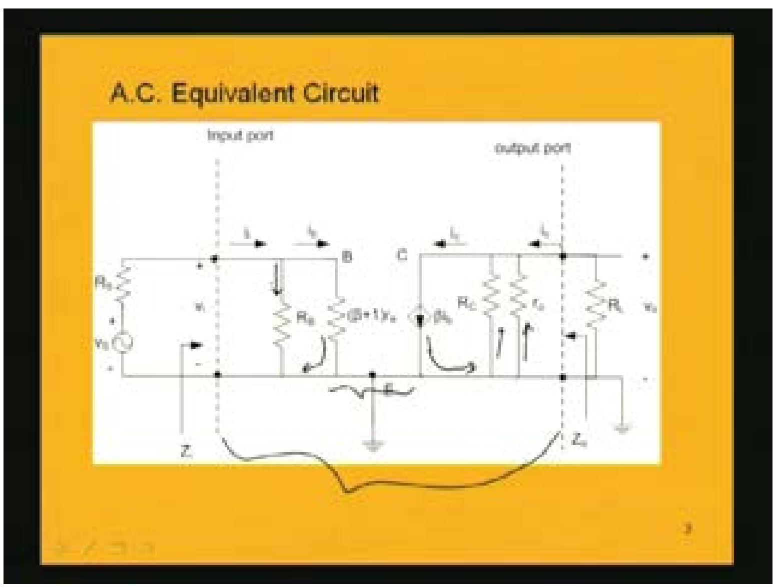

Collector will also have this $R_C$ to ground and $R_L$ is the load resistance connected at the collector to ground; it will be there as far as this transistor is considered and we have already discussed how to draw this equivalent $r_e$ model that is emitter resistance model for this transistor. We will replace simply the equivalent transistor model for the common emitter transistor. This base, collector, emitter this is the transistor basically. Here the emitter is having the resistance beta plus one $R_E$ and collector is having a dependent current source beta times $I_B$ which is equal to $I_C$. This part is replaced by this transistor model and incorporating this transistor model into the whole circuit we are getting this AC equivalent circuit for the amplifier.

Now we want to find out the voltage gain. For example if we try to find the voltage gain we will find out the ratio between the output voltage and the input voltage. We have to see which are the input terminals and output terminals? Always we will see from the source to find out the input terminals and we will look from this load to consider the output terminals. That means the whole amplifier will be having the source and load externally. As if we are sitting at the source and looking into the amplifier, in that way we have to find out the parameters. Similarly as far as output is concerned we will be looking from the load as if we are sitting on the load and looking into the amplifier. This point is important because we will have to exclude the source and load while finding out the parameters in the whole amplifier. In between these two dash lines is the whole amplifier and a source and the load are external to it.

Now we want to find out the voltage gain that is gain means the amplification between the output voltage and input voltage. The output voltage is between these two points. That is the voltage across this load resistance and input voltage is between these two points. $V_I$ is the input voltage and $V_O$ is the output voltage and conventionally this input and output currents if we consider they are into the amplifier. Customarily the direction is shown as into the amplifier. So $I_I$ that is the input current which is coming from the source, it will be flowing into the amplifier at this input terminal, so this is the input current and output current at this output terminal into the amplifier. The $I_O$ current is flowing through this resistance $R_L$ into the amplifier and input current is coming from source into the amplifier.

If we look into this input current we notice that the input current is having two parts. One part is through this resistance $R_B$ and other part of the current is through this resistance beta plus one $R_E$. This input current basically has two parts: one is through this, one is through this and if we consider the current source of the output, $I_C$ is the current source which is equal to beta times of $I_B$ and the current which will be flowing, will be flowing in this direction. It will be going to the output side; input current, base current will be coming and it will be flowing like this. Here the beta times of $I_B$ current which is the collector current has actually three parts: one is through this $R_C$, one is through this $R_O$. $R_O$ is the output resistance of the transistor. We generally ignore this because it is having a very high value in the order of mega ohm but to be exact this should be there and after words we can ignore. If we are told that it is very, very large you can ignore it. But for time being while drawing the exact equivalent circuit we will be having this $R_O$ at the output side. This $R_O$ is the output resistance of the common emitter transistor and that is generally having very high value.

(Refer Slide Time: 11:07)

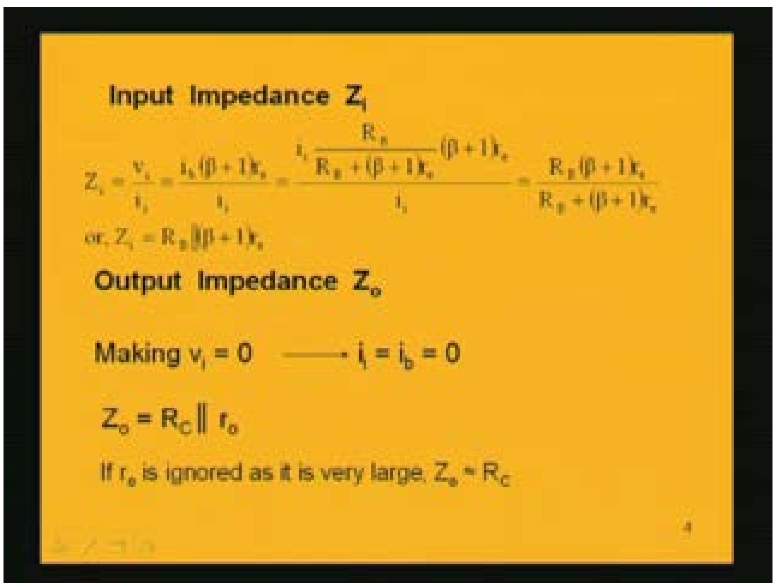



This collector current beta times of $i_b$ has three parts one is through $R_C$ and one is through this $R_O$ and other is through this $R_L$ which is nothing but the conventional output current $i_o$ as it is shown here. We want to find input impedance; $Z_i$ is denoting the input impedance. We have to take the input terminals; the voltage at this input terminal is $v_i$ divided by the current $i_i$. Input voltage by input current will be the input impedance and output impedance we will look into the output terminals from the load and we will find out what is the output impedance by taking the ratio between $v_o$ and $i_o$ that is $v_o$ by $i_o$ making the input source zero. That is $v_s$ you make zero that will make $v_i$ zero means $i_b$

will be zero, so $i_c$ will be zero. We will be left with this two resistances being in parallel at the output side so that will constitute the output resistance. These parameters we are going to find out. But one thing to notice is that while finding these parameters we will exclude this source and load from this amplifier. That means we will look from the source to the input side or we will look from the load to the output side while finding of these parameters. We will find out these parameters one by one from this equivalent circuit.

We want to find out what is the input impedance $Z_i$? The input impedance means the ratio between $v_i$ and $i_i$. $Z_i$ is equal to $v_i$ by $i_i$. We can find out what is $v_i$? If we look into this figure between these two terminals or two points, the voltage across this resistance beta plus 1 $r_e$ or the voltage across $R_B$ that is the input voltage. We can find out in two ways. That is the current which is flowing through $R_B$, multiply it by $R_B$. That is the $v_i$ or current $i_b$ multiplied by this resistance beta plus 1 $r_e$ that is the input voltage. We will follow the latter. That is we will follow the input voltage expression that is $i_b$ into beta plus 1 into $r_e$ and denominator is $i_i$. Our purpose is to eliminate those active components. We will eliminate or cancel out the currents and we will be left with only the passive elements.

(Refer Slide Time: 13:32)

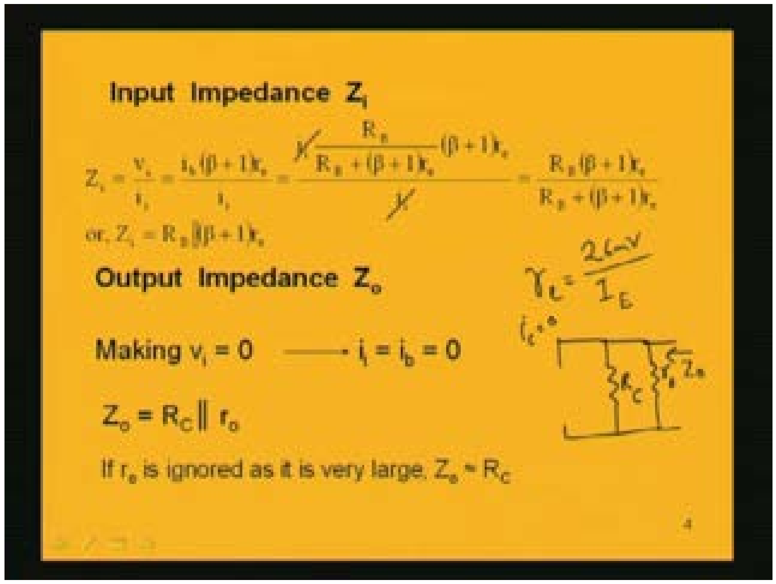



That is why this $i_b$ if we want to express again in terms of $i_i$ in order to cancel them out, we look back into the circuit and find out the base current. Base current is that part of the current which is flowing through this resistance coming from $i_i$. Input current is $i_i$. One part goes through this resistance $R_B$ and other part is through this resistance beta plus 1 $r_e$. We are interested in finding out $i_b$. What is $i_b$? These two parallel parts are there, so current division is taking place. So $i_i$ into $R_B$ divided by $R_B$ plus beta plus 1 $r_e$ that gives us the value of $i_b$. Expressing $i_b$ in that way $i_b$ is equal to $i_i$ into $R_B$ by $R_B$ plus beta plus 1 into $r_e$, the remaining terms are there; beta plus 1 into $r_e$ divided by $i_i$. We can very well cancel $i_i$ and $i_i$. We are left with $R_B$ into beta plus 1 $r_e$ divided by $R_B$ plus beta plus 1 $r_e$. This is the exact expression for the input impedance for this amplifier in the fixed bias mode and here we find that all these parameters are passive parameters; means they are either resistance or they are either current gain beta and in fact we will have to find out the small r, small e that is the resistance coming from the transistor model and we can find it out.

In this particular example we can find out $r_e$ because $r_e$ is nothing but 26 millivolt divided by emitter current capital I, capital E, $I_E$. Once we know $I_E$ from the DC equivalent circuit we can plug in the value here and find out the small r, small e. That exercise has to be done in order to proceed further. In order to find out all these parameters we have to consider both the DC equivalent circuit and AC equivalent circuit. DC equivalent circuit we have to consider because we want to find out what is small $r_e$. After we find out small $r_e$ we can plug in here and we can find out the other parameters. Input impedance we have found out and here $Z_i$ can be expressed as a parallel combination between the two resistances $R_B$ and beta plus 1 $r_e$. That is exactly what is happening because if we look into this expression $R_B$ into beta plus 1 $r_e$ by $R_B$ plus beta plus 1 $r_e$, this is nothing but the parallel combination of these two resistances $R_B$ and beta plus 1 $r_e$ and in fact this is very, very obvious. If we look into the circuit from the input terminals then there are two resistances at the input one is $R_B$ and one is beta plus 1 $r_e$, both are in parallel. Intuitively also we can see that this is the equivalent parallel resistance between these two resistances which are in parallel. That is what exactly we are finding out here, the parallel impedance between these two resistances that is $R_B$ parallel beta plus 1 $r_e$. 1636 This is the input impedance.

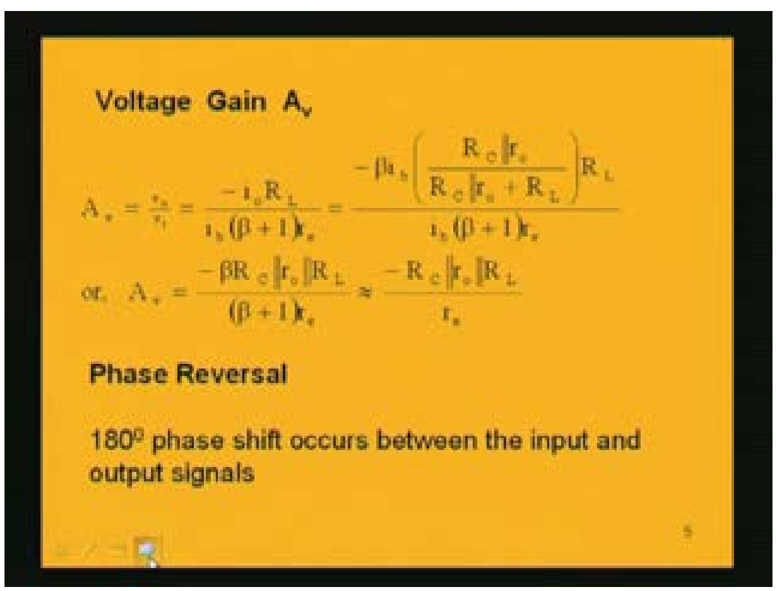
We look into the output circuit and find out what is the output impedance? Here we have to find out looking from this load. Output impedance can be found out if we make this input voltage zero because we are interested only in the quantities in the output side. Input side components or input side currents or voltages must not interfere with this output side. If we make this $V_i$ zero then $i_b$ will be zero, so $i_c$ will be zero. This is like open circuit. This part will not be there. We will be left only with two parallel resistances $R_C$ and $R_O$ because our circuit will be like this. This part will be $i_b$ is zero, so $i_c$ is equal to zero and there are these two resistances; one is $R_C$ and one is $r_o$, small $r_o$ that will be there at the output side and we are finding of this output impedance. This output impedance is the parallel impedance $R_C$ and $r_o$. Output impedance is $R_C$ parallel $r_o$ making the input $v_i$ is equal to zero. That is the procedure to be followed in order of find out what is output impedance?

(Refer Slide Time: 17:45)




At this point I want to mention that if $r_o$ is considered to be very, very large which is actually the case, it is in the order of meg ohm; 10 to the power 6. As compared to $R_C$ it is higher. So we can neglect this resistance or we can ignore this resistance because it is very high, it is almost like infinity. If it is very high or infinite what will happen is that there will be practically no current in this part. Because it is offering infinite impedance current will not flow in this part. That means it is like open circuit, $r_o$ will be simply ignored. Then we are left with only $R_C$. Then we can say that $R_C$ is the output resistance. This is the case when you ignore $r_o$. $r_o$ means the output resistance of the transistor. These two parameters $Z_i$ and $Z_o$ we have found out. What about the voltage again?

(Refer Slide Time: 18:37)



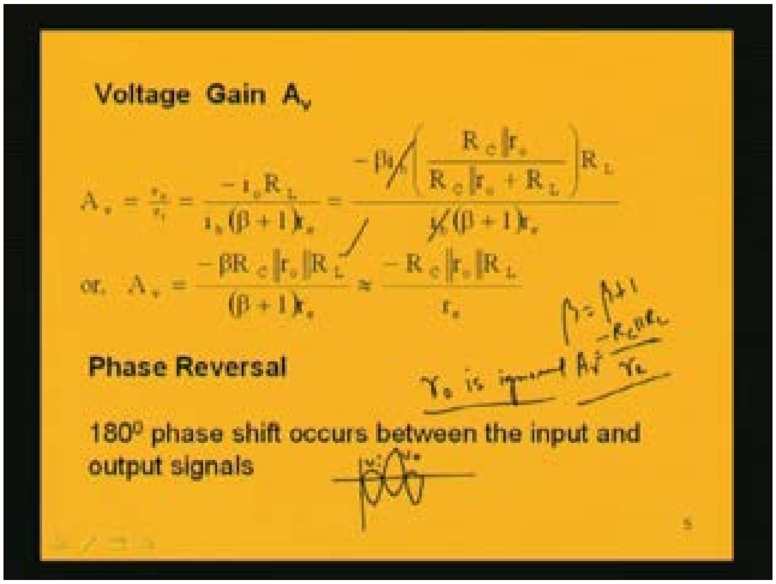
Voltage again is the ratio between the output voltage and input voltage. That means it is a ratio between $v_o$ and $v_i$. If we look back what is $v_o$ here? This $v_o$ is nothing but $i_o$ into $R_L$ but with a minus sign because we have denoted $v_o$ upper point is positive with respective to the ground but this $i_o$ is following in this direction. This is $i_o$. $i_o$ is this current. It is flowing from higher potential to lower potential as far as this sign is concerned. The voltage drop if we consider it as $v_o$ it will be $i_o$ into $R_L$ with a minus sign. Minus $i_oR_L$ will be equal to $v_o$ because as far as direction of current this is positive point, this is negative point. But voltage we have denoted as $v_o$ as upper point is positive. $v_o$ is equal to minus $i_o$ into $R_L$ and input voltage we know. We have already found the input voltage is $i_b$ into beta plus 1 $r_e$. Replacing these values here $v_o$ is equal to minus $i_o$ into $R_L$ and $v_i$ is equal to $i_b$ into beta plus 1 $r_e$.

Again we replace the $i_o$. If we look back into the circuit, what is $i_o$? $i_o$ is that part of current of $i_c$ which is flowing through this resistance of $R_L$ because if we look into this output side the current source is beta times $i_b$ which is equal to $i_c$. This current is flowing in this output side and this current has three parts. As I have just now mentioned one part of current beta times $i_b$ is flowing through $R_C$, other part is through $r_o$ and other part is through $R_L$ and we are interested in finding out that part $i_o$. If we combine these two $R_C$ and $r_o$ together as $R_C$ parallel $r_o$ that is one resistance; other is $R_L$. According to current division beta times of $i_b$ is divided into this parallel resistance and this resistance. We are interested in finding out this current through this resistance $R_L$. That will be equal to beta times $i_b$ into this equivalent parallel combination $R_C$ parallel $R_L$ divided by $R_C$ parallel $r_o$ plus $R_L$. That is written here. Beta times of $i_b$; minus sign is there because minus $i_oR_L$ is the voltage at the output. Here we are replacing this $i_o$ by beta times $i_b$ into $R_C$ parallel $r_o$ by $R_C$ parallel $r_o$ plus $R_L$ into $R_L$. $R_L$ is already there in the original expression and $v_i$ input voltage is given by $i_b$ into beta plus 1 into $r_e$.

We can further simplify this expression by writing minus beta into $i_b$, $i_b$ cancel. Upper term or the numerator term if we again consider it is nothing but parallel combination between these three resistances $R_C$, small $r_o$ and capital R capital L, $R_L$. Because this is $R_C$ parallel $r_o$ into $R_L$ divided by $R_C$ parallel $r_o$ plus $R_L$. This is the parallel combination between this and this. Finally we have a parallel combination between all the three in the numerator divided by beta plus 1 into $r_e$. Beta and beta plus 1 are almost equal because beta is a high value; suppose 100 and 101 there is not much difference it is almost equal. We can conveniently cancel them out. Then it gives a further simplified expression and that is equal to minus $R_C$ parallel $r_o$ parallel $R_L$ by $r_e$ and here again if we now consider that $r_o$ is very high then we can further ignore $r_o$ and if $r_o$ is ignored then we will get another further simplified expression of $A_v$ which is equal to minus $R_C$ parallel $R_L$ divided by $r_e$, small $r_e$. This is a very, very simple expression to remember because now we have ignored $r_o$ because it is very high. But this is the exact expression and further simplification can be done conveniently looking into the practical aspects.

One thing to be noted here is the minus sign. Actually this minus sign has significance or it has a meaning because minus sign means the phase reversal of 180 degree or the output voltage is out of phase by 180 degree with the input. That is actually denoted by this minus sign. 180 degree phase shift occurs between the input and output signals. That is why $v_o$ by $v_i$ is having a minus. If I have input voltage like this, I will be getting an output voltage which will be amplified no doubt but it is out of phase by 180 degree like this. So we will get 180 degree phase difference between the input and output and that is denoted by this minus sign.

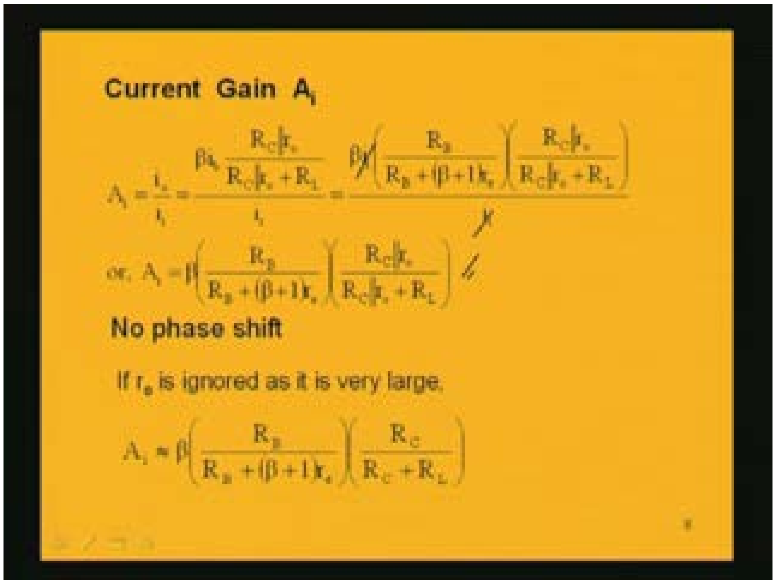
(Refer Slide Time: 23:40)




If you want to find out another term which is current gain, the current gain is the ratio between output current $i_o$ and input current $i_i$. Output current, as we have just now done, can be expressed as beta times of $i_b$ into $R_C$ parallel $R_L$ by $R_C$ parallel $R_L$ plus $R_L$ divided by $i_i$. It is better to look into the equivalent circuit to find out what is the $i_b$? $i_i$ into $R_B$ by $R_B$ plus beta plus 1 into $r_e$; that also we have done earlier. Writing in that way that is what is done here; $i_i$ into $R_B$ by $R_B$ plus beta plus 1 into $r_e$. That is the value of $i_b$ and the rest of the part is as it is divided by $i_i$. We can cancel out this $i_i$ and $i_i$. We are left with $i_i$ is equal to beta times of $R_B$ by $R_B$ plus beta plus 1 $r_e$ into $R_C$ parallel $r_o$ by $R_C$ parallel $r_o$ plus $R_L$. Mind it here we cannot make a parallel combination because the numerator does not have this $R_L$ term. So as it is we have to write. Further simplification can be done only if we consider that here in this term, we can look into the beta plus 1 $r_e$, $r_e$ is small. If we write down the $R_B$ plus beta plus 1 $r_e$ equivalently or approximately then only we can do further simplification. But let us not do and keep it exactly in this same way.

One thing we can do is, $r_o$ is ignored. If $r_o$ is ignored then we will be left with beta into $R_B$ by $R_B$ plus beta plus 1 $r_e$ into $R_C$ by $R_C$ plus $R_L$. That much simplification we can do and here one thing to be noticed is that there is no phase shift between the output and input currents.

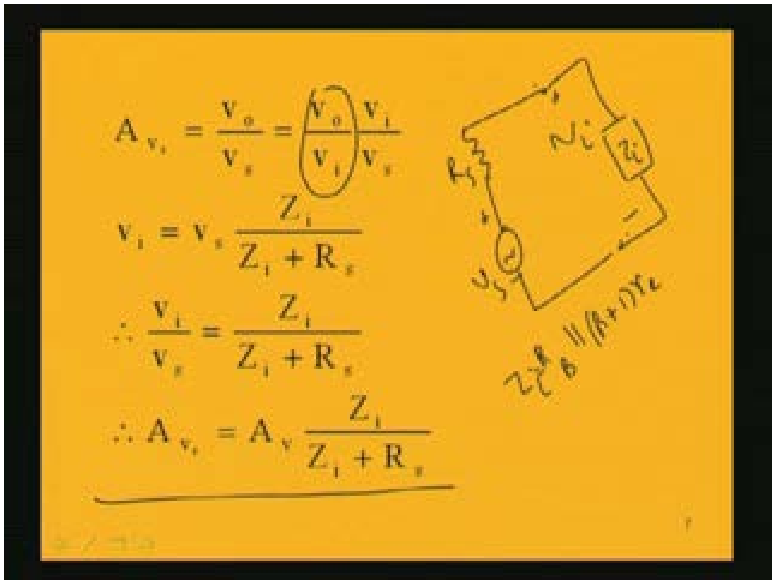
(Refer Slide Time: 25:34)




If output current is towards the transistor, input current will also be towards the transistor. There is no sign change, so there is no phase reversal. The current gain does not have any phase shift, only the voltage has. But one more thing I would like to find out here is the voltage gain with respect to the source. If we look into the voltage gain, what we have just now found out, it is $v_o$ by $v_i$. That means with respect to the input voltage we are finding out the ratio by which the output voltage is increased. The input voltage means this voltage. But again if we look into what is $v_i$ with respect to $V_S$ because one part of this input signal which you are giving as input, that part is lost in the resistance $R_S$ because there is a drop in the resistance $R_S$ and the rest is what is available as $v_i$.

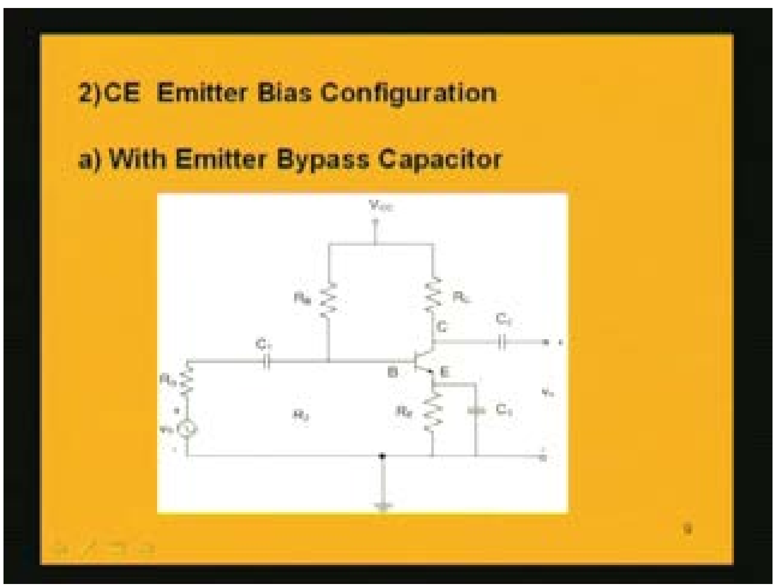
If we want to find out the voltage gain with respect to the source and term it as $Av_s$ denoting the voltage gain with respect to the source then we have to write it as $v_o$ by $v_s$ and that can be further expressed by chain which is $v_o$ by $v_i$ into $v_i$ by $v_s$. Because $v_o$ by $v_i$ we have already found out we can write it as Av but what about $v_i$ by $v_s$? We have seen that the signal $v_s$ which you are applying at the input, there is a resistance at which there is drop; rest part is available as $v_i$. This voltage we want to express in terms of $v_s$. What will be that voltage? This input side is having input impedance $Z_i$, which we have already found out. We can find out voltage division because voltage division is taking place here. What is $v_i$? $v_s$ into $Z_i$ by $Z_i$ plus $R_S$. This is the voltage available at input and that is what is written here. $v_s$ into $Z_i$ by $Z_i$ plus $R_S$ and $Z_i$ we have found out. That is equal to the $R_B$ parallel beta plus 1 $r_e$. That is $Z_i$. That we have just now found out; $R_B$ parallel beta plus 1 $r_e$. Putting the value of $Z_i$ we can find out now the expression for $v_i$ by $v_s$ that is equal to $Z_i$ by $Z_i$ plus $R_S$. What is $Av_s$? $Av_s$ is equal to $A_v$; this part is $A_v$ into $v_i$ by $v_s$ is nothing but $Z_i$ by $Z_i$ plus $R_S$. So this is the voltage gain with respect to the source. We are finding out two things. One is with respect to the input voltage; one is with respect to the source.

(Refer Slide Time: 28:07)



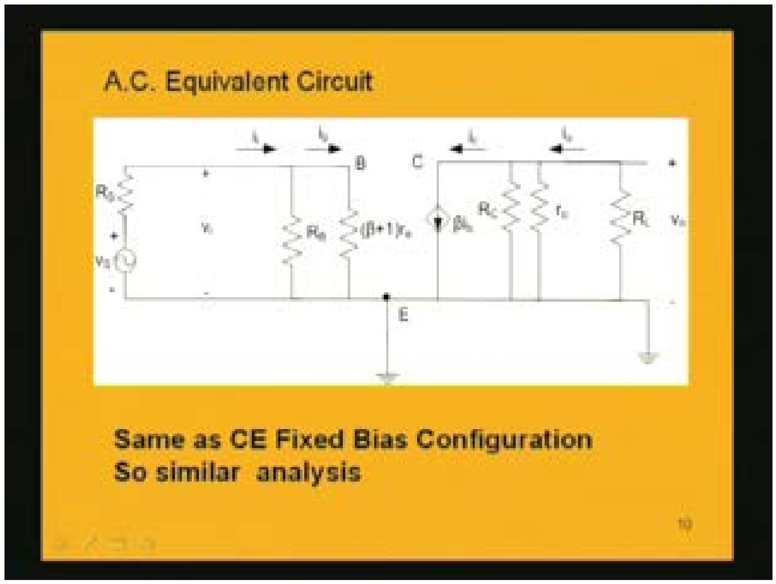

This was about the fixed bias configuration. Let us go to another configuration which is having resistance at the emitter. That is self bias is there but with a by pass capacitor.

(Refer Slide Time: 28:22)



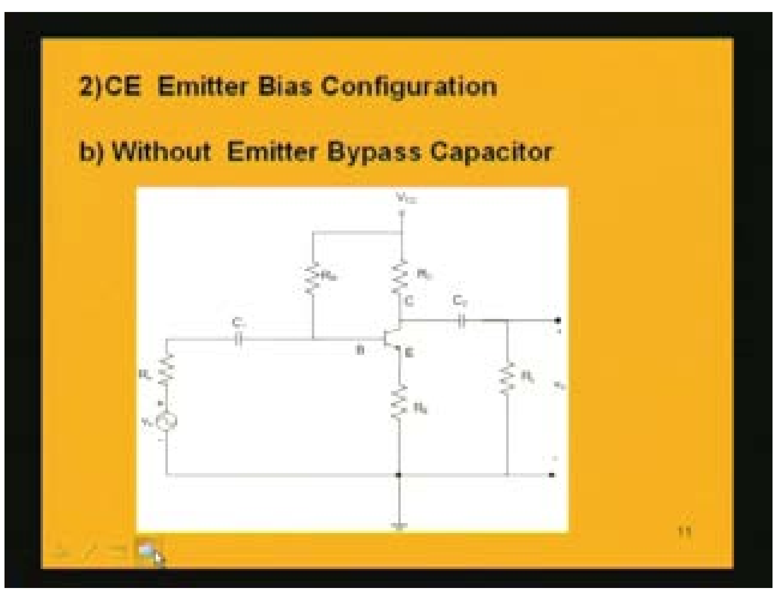

If we consider this figure, this is a self bias in the emitter. That is the difference between the fix bias and this bias which is called the emitter bias configuration. But there is a bypass capacitor. If we look into the circuit and compare with the earlier one there is no difference as far as the AC equivalent is concerned because as there is a bypass capacitor and it is like short circuit in AC. The emitter resistance $r_e$ will be bypassed. But the emitter current is nothing but the same circuit which we just now analyzed because the equivalent will be like this only. Because the emitter is bypassed it will be directed to the ground not through this resistance in the emitter $r_e$ but it will be having a short circuit path and others are exactly the same. This circuit and the earlier fixed bias circuit do not have any difference as far as AC equivalent is concerned. So we need not analyze it again and similar analyses as the earlier, still holds for this circuit. That is this amplifier with self bias in the emitter with a bypass capacitor.

(Refer Slide Time: 29:36)




But if the by pass capacitor is not present in the emitter then the circuit will be different. That is what we are going to do.

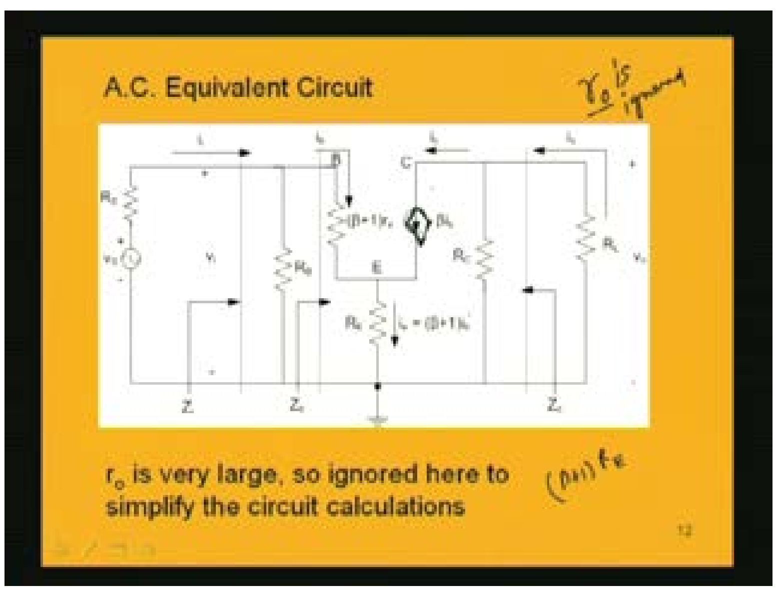
(Refer Slide Time: 29:44)



We consider common emitter bias configuration without the emitter bypass capacitor, bypass capacitor is not there mind it and that is why there is the existence of this $r_e$ that is the emitter resistance in the emitter part. If we want to draw the equivalent circuit for this amplifier following the usual procedures that we have followed earlier we will get a circuit like this. This is the transistor side; equivalent model for the transistor or the common emitter and the input is having this $R_B$ as well the source and resistance $R_S$ which is the series resistance with the source and output is $R_L$, the load resistance, $R_C$, $r_e$ is there. But here one thing is missing. $r_o$ we are ignoring and $r_o$ is conveniently ignored here because inclusion of this $r_o$ will further complicate the whole analysis. So very, very conveniently we can ignore $r_o$. That is what is done here, $r_o$ is ignored. Otherwise it will be very complex circuit to analyze and in order to avoid all those complication we can very well ignore $r_o$ as it is practically also true. Excluding the $r_o$ we are having the circuit and at the output side only $R_C$ will be there. $R_L$ is there which is the load resistance and $r_e$ is there is in the emitter. The current following through this emitter resistance $r_e$ if we look, it is the ammeter current. That is equal to beta plus 1 into $r_e$. This resistance $r_e$ can be very well written as the reflected resistance beta plus $1r_e$.

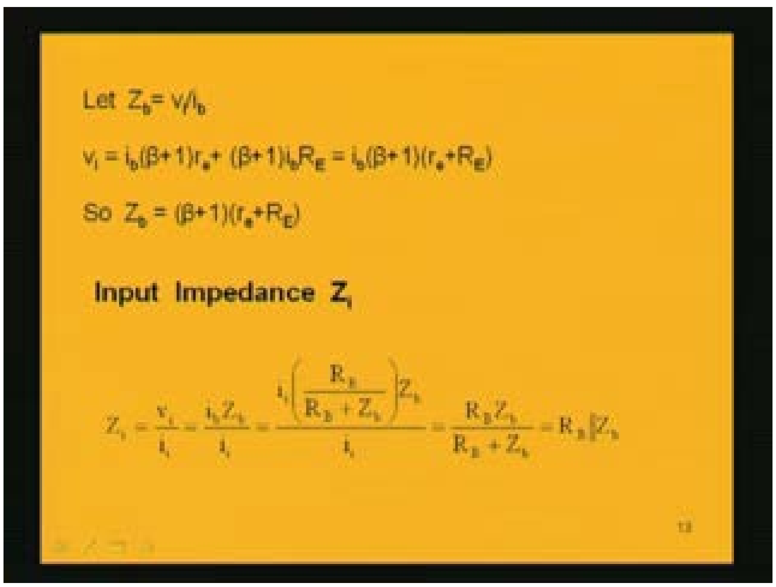
Instead of $r_e$ we can write beta plus 1 $r_e$ in the emitter resistance and we can keep this $i_b$ same. That is same current $i_b$ is flowing having a resistance here beta plus $1r_e$. That is conveniently done because then our analysis will also be easier and we are not doing anything wrong because if we consider the voltage drop, the voltage drop is $i_b$ into beta plus $1r_e$ plus i into $r_e$. But i is again nothing but beta plus 1 $i_b$. The voltage drop is same. Only thing is we are writing it differently. That is instead of $r_e$ we can write beta plus 1 $r_e$ and the current $i_b$ is same. Other current is beta times $i_b$. This should have a symbol of a diamond because this is the symbol for a dependent current source.

(Refer Slide Time: 32:17)



It is not the circle; circle is independent current source. This is wrong. In order to write it correctly we should have diamond signal which is the symbol for a dependent current source; because it is a dependent current source, dependent on $i_c$, dependent on $i_b$. In this circuit all the parameters which we found for the other circuit are to be found out. For that we start with input impedance. If I consider input impedance, $v_i$ by $i_i$ is the input impedance; looking from this source into the input that is the input impedance. Input impedance is basically parallel impedance between $R_B$ and this whole resistance. This whole resistance is this resistance plus this resistance. Let us name it as $Z_b$. For clear understanding I am denoting it separately; $Z_b$ is equal $v_i$ by $i_b$. That is this voltage by the current $i_b$. As we have expressed it as beta plus 1 into $r_e$ keeping the $i_b$ same, what is this resistance? This resistance is nothing but the series resistance between beta plus 1 $r_e$ and beta plus 1 capital $R_E$. We are writing here $v_i$ is equal to the input voltage is $i_b$ into beta plus 1 into $r_e$ plus beta plus 1 $i_b$ into $R_E$.

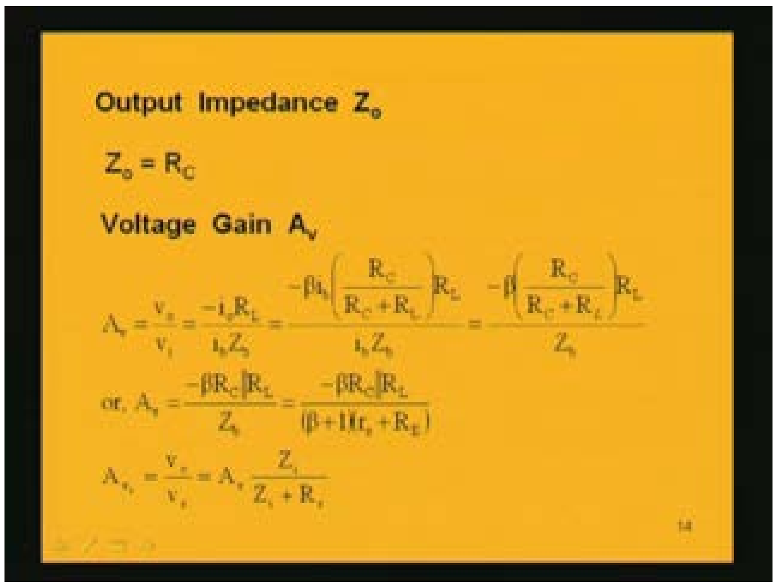
(Refer Slide Time: 33:34)




We are writing it in a different fashion. We are keeping $i_b$ same and writing it as beta plus 1 into $r_e$ plus $R_E$ where now we can denote $Z_b$ is equal to beta plus 1 $r_e$ plus $R_E$. The whole resistance from this point to this point, beta plus 1 into small $r_e$ plus capital $R_E$, is denoted by $Z_b$. Now we can find out the input impedance easily. What is this input impedance? This resistance $R_B$ parallel to $Z_b$. $Z_i$ is equal to $R_B$ parallel $Z_b$. That is input impedance $v_i$ by $i_i$. If we write down the whole expression of $v_i$ $i_b$ into $Z_b$ is this $v_i$ divided by $i_i$. Again if I proceed in that way which we used earlier $i_b$ is equal to $i_i$ into $R_B$ by $R_B$ plus $Z_b$. This current following through this resistance is $i_b$. Find out that current. That current is equal to $i_i$ into $R_B$ by $R_B$ plus this whole resistance; that is current division. That is what is written here; $i_i$ into $R_B$ by $R_B$ plus $Z_b$ into $Z_b$ by $i_i$. Canceling out these two, I am left with $R_B$ into $Z_b$ by $R_B$ plus $Z_b$ which is $R_B$ parallel $Z_b$. I look into the circuit from this terminal and find out $Z_i$. Intuitively I can say RB parallel this whole resistance and that's what I have also found out proceeding from this initial expression for $Z_i$; that is giving the same result.

This is input impedance, what is output impedance? We look into the output circuit. I look into the amplifier from the output side, from the load. We have to look from the load. That is output impedance; skipping this $v_i$ zero, making $v_i$ zero means this $i_b$ is also zero. It is like this part is open. This part is open means I am having only 1 resistance $R_C$ at the output. Output impedance $Z_O$ is $R_C$. We want to find out voltage gain $A_v$, following the expression $v_o$ by $v_i$ and doing all the replacements like $v_o$. What is $v_o$? $v_o$ is minus $i_o$ into $R_L$. Like previous example this is the direction from bottom to top of this current. Minus $i_o$ into $R_L$ is equal to $v_o$ divided by $v_i$. $v_i$ is again $i_b$ into this whole resistance $Z_b$. That is followed here, minus $i_o$ $R_L$ by $i_b$ into $Z_b$.

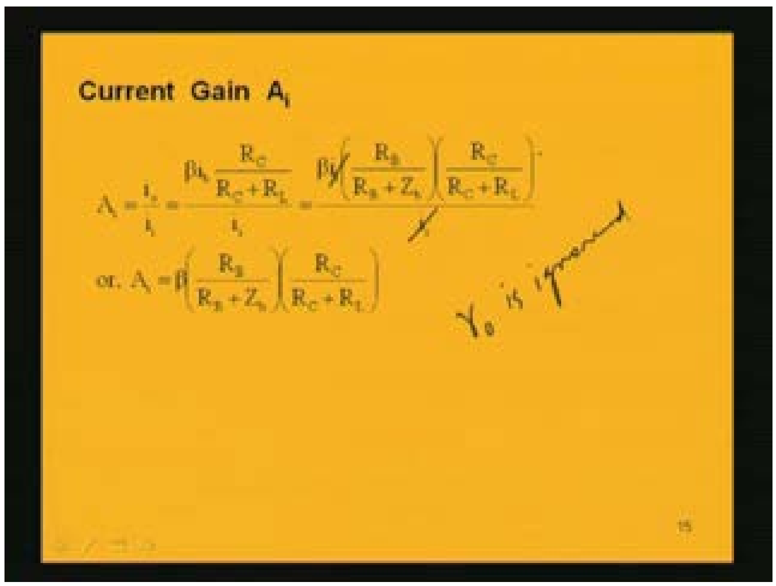
(Refer Slide Time: 36:12)




Again what is $i_o$? That part of the current which flows through $R_L$. The current which flows through $R_L$ is $i_o$. The dependent current source beta $i_b$ is what is flowing in this output circuit. You see the current part. One is $i_b$, base current; one is the collector current. Both are combined here to give the emitter current. The current which is starting from a source it should end up at that same source. So after this point again $i_b$ will be flowing this way and $i_c$ will be flowing this way. $i_c$ has again 2 components. One is through $R_C$ and another through $R_L$. I am interested in finding out the current through $R_L$. That is what is $i_o$; beta times of $i_b$ into $R_C$ by $R_C$ plus $R_L$ is $i_0$. That is what is done here. It is beta times of $i_b$ into $R_C$ by $R_C$ plus $R_L$ into $R_L$. Since $R_O$ is not there, 3 parts are not there. There are only 2 parts. That is the difference which is made here otherwise it will be more complex, divided by $i_b$ into $Z_b$ equal to minus of beta into $i_b$, $i_b$ cancel; $R_C$ $R_L$ by $R_C$ plus $R_L$. Again this is nothing but the parallel combination between the $R_C$ and $R_L$, in the denominator $Z_b$ is there. What is the voltage gain $A_v$? That is equal to minus beta into $R_C$ parallel $R_L$ by $Z_b$. Again $Z_b$ we can a replace. That is equal to beta plus 1 into small $r_e$ plus capital $R_E$. This is the expression for voltage gain $v_o$ by $v_i$. We want to find out the voltage gain with respect to the source $v_o$ by $v_s$. That is $Av_s$ we want to find out. What is $v_o$ by $v_s$? As we know $v_o$ by $v_s$ is equal to $A_v$ into $Z_i$ by $Z_i$ plus $R_S$. $Z_i$ we know. We found out $Z_i$. Simply replacing by this quantity for $Z_i$ we can now get this $Av_s$. $A_v$ we have just now found out. Voltage gain we have found out.

We want to find out the current gain $i_o$ by $i_i$. $i_o$ by $i_i$ is the current gain and $i_o$ again we will write in the same way; beta times of $i_b$ into $R_C$ by $R_C$ plus $R_L$. That is the part of current which flows through $R_L$ and divided by $i_i$. Again if I replace $i_b$ by that part of the current which flows through the $Z_b$ that is the $i_b$, out of the input current $i_i$ this portion goes through this $Z_b$; $i_i$ into $R_B$ by $R_B$ plus $Z_b$ is $i_b$ and the rest is this one, same $R_C$ by $R_C$ plus $R_L$ divided by $i_i$. Then this and this will cancel. Current gain becomes beta into $R_B$ into $R_C$ by $R_B$ plus $Z_b$ into $R_C$ plus $R_L$. This is the exact expression for current gain. $r_o$ is ignored here.

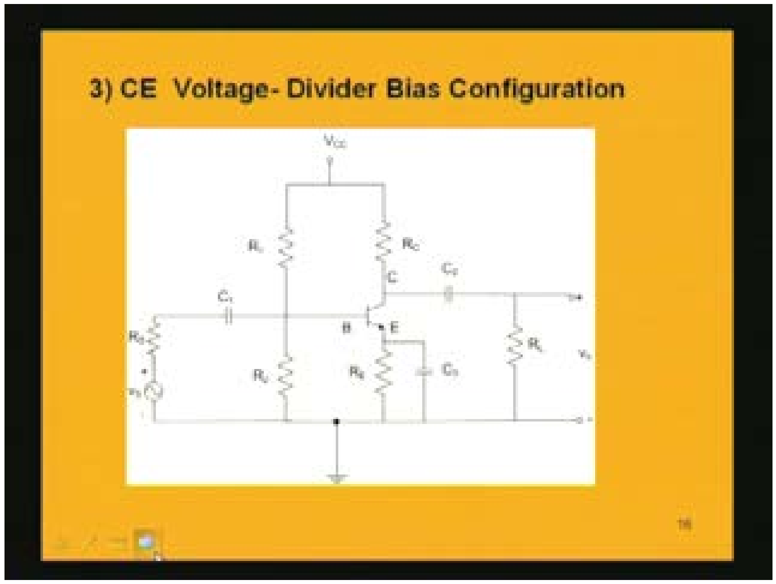
(Refer Slide Time: 39:07)




This circuit, that is the circuit having the emitter bias, emitter resistance which is un bypassed, there is no by passing capacitor there we get this expression or parameters which are involved in that amplifier.

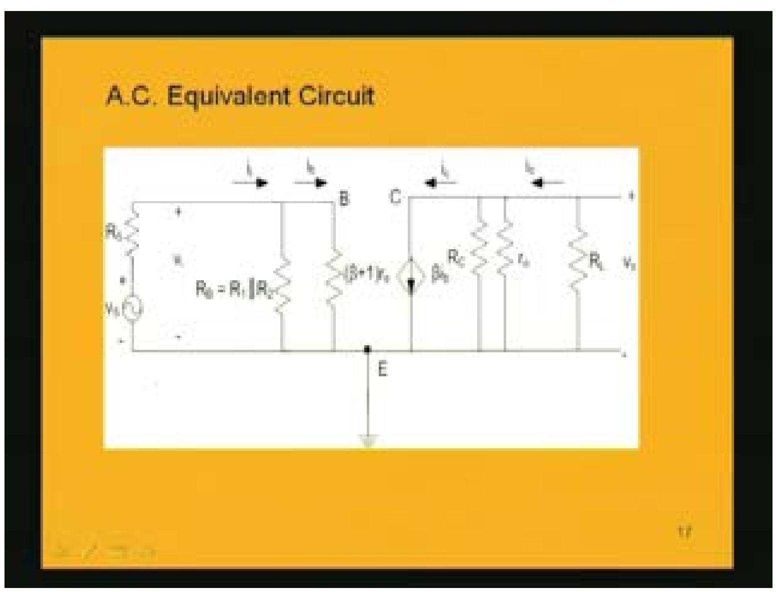
Another example which is very powerful, which we have earlier discussed and which is very, very much used in all these practical amplifiers is the voltage divider bias configurations. We now have this common emitter voltage divider bias configuration. This is the circuit having $R_1$ $R_2$ parallel at terminal B and connected to $V_{CC}$. These resistances $R_1$ and $R_2$ are 2 separate resistances, instead of one single resistance $R_B$ as was discussed in the earlier cases. Others are same. Other parameters in this circuit are same. In fact if I analyse this circuit, draw the AC equivalent circuit it will be similar. Only difference that will be there is that we have to find that the Thevenin's resistance $R_B$ which is the parallel equivalent of $R_1$ and $R_2$ and that will be the factor which will be differing than the earlier circuits.

(Refer Slide Time: 40:22)



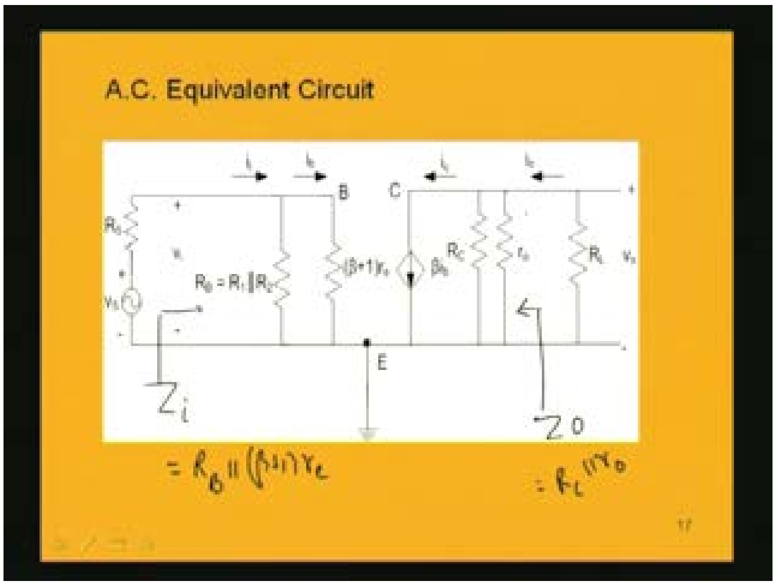

If we draw the AC equivalent circuit for this voltage divider biasing scheme following the usual procedures that AC equivalent circuit will have $R_1$ and $R_2$ parallel because it is grounded. Since $V_{CC}$ is grounded, in AC equivalent circuit these two resistances which are both connected at base and connected to ground this also will be grounded. Because this will be grounded, this is also grounded. These 2 are parallel. These parallel equivalent if i denote by capital R capital B which is $R_1$ parallel $R_2$, all others are same than the earlier discussed circuits.

(Refer Slide Time: 40:58)



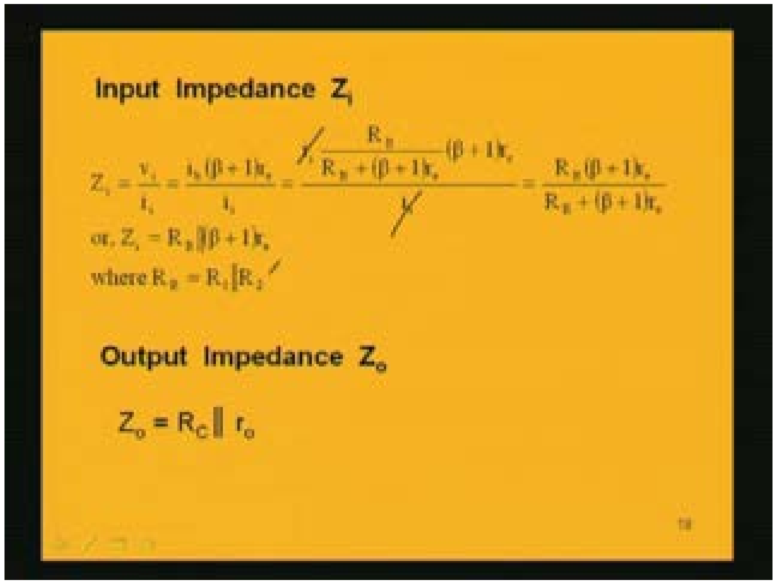
$R_C$, $r_o$ is kept, $R_L$ is there. In this circuit we can easily find out the parameters involved. We can find out what is the input impedance? If I look from this point find out what is the input impedance $Z_i$? This resistance parallel this resistance; $R_B$ parallel beta plus 1 $r_e$ and this $R_B$ is $R_1$ parallel $R_2$. That is the only thing which is differing than the fixed bias circuit and as this emitter is bypassed by this capacitor, ultimately we are having the short circuited part like this. What is $Z_i$? $Z_i$ is equal to $R_B$ parallel beta plus 1 $r_e$. Even if you follow this usual procedure of finding out $v_i$ dividing it by $i_i$ which will give you $Z_i$ that will give you finally the same result. But I can intuitively very well see that this is nothing but the parallel combination between these two resistances at the input. I can immediately right down this input impedance like this and similarly I find out the output impedance. I look from this load into the amplifier in the output circuit. Look from here, look from this load. Then it is parallel combination between $R_C$ and $r_o$; that is the output impedance.

(Refer Slide Time: 42:17)



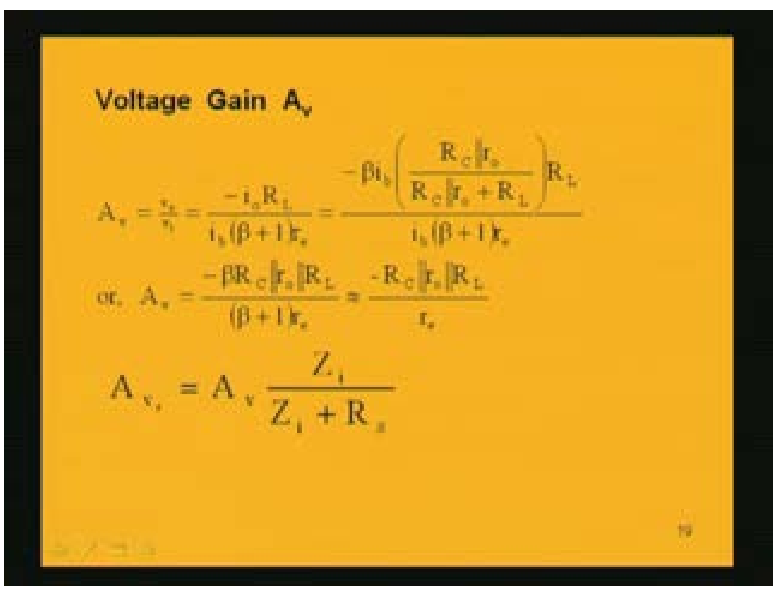

These two can be immediately found out. In the traditional way of finding of all these expressions of voltage, current, etc also you will finally get the same result. If I find out $Z_i$ is equal to $v_i$ by $i_i$ again what is $v_i$? $v_i$ is $i_b$ into beta plus 1 $r_e$ divided by $i_i$. $i_b$ again I replace in terms of $i_i$. That part of the current which flows through the resistance beta plus 1 $r_e$ that is $i_b$; $i_i$ into $R_B$ by $R_B$ plus beta plus 1 $r_e$. That is this current $i_b$ into beta plus 1 $r_e$ divided by $i_i$. These two cancel. I am left with $R_B$ into beta plus 1 $r_e$ by $R_B$ plus beta plus 1 $r_e$. This is nothing but a parallel combination between these two resistances $R_B$ and beta plus 1 $r_e$. $R_B$ we know is $R_1$ parallel $R_2$.

(Refer Slide Time: 43:13)




Expression vise if I see the earlier circuit also, there is no difference. Because earlier also in fixed bias scheme we have found out that input impedance $Z_i$ was $R_B$ parallel beta plus 1 $r_e$ and this is also $R_B$ parallel beta plus 1 $r_e$. Only difference is that now we are having $R_B$ as parallel combination between $R_1$ and $R_2$, not a single fixed resistance. That is the difference, others are same and output impedance as we have seen is $R_C$ parallel $r_o$. I need not again analyze it in detail. That is very clear and voltage gain, $A_v$ can be found out in a classical way of finding out the voltage and finding out the gain. $v_o$ is equal to minus $i_o$ into $R_L$.

(Refer Slide Time: 43:59)

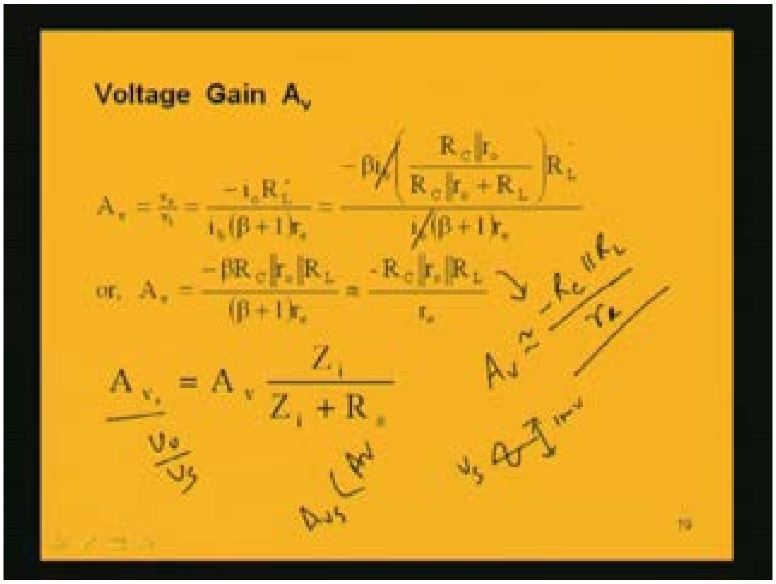


Here this is $v_o$. Current is flowing in this direction. So minus $i_o$ into $R_L$ is $v_o$. As $v_o$ has been denoted, upper point is positive with respect to the ground and again $v_i$ we know $i_b$ into beta plus 1 $r_e$. That is replaced here and find out $i_o$ from the output circuit. The current source that is beta $i_b$, this current is divided into 3 parts. I am interested in finding out this current through $R_L$ that is equal to beta $i_b$ into $R_C$ parallel $r_o$ by $R_C$ parallel $r_o$ plus $R_L$. That is the current $i_o$. This $R_L$ is already there divided by $i_b$ into beta plus 1 $r_e$ and now I can cancel out this $i_b$ and this $i_b$ and I am left with minus beta into $R_C$ parallel $r_o$ into $R_L$ by $R_C$ parallel $r_o$ plus $R_L$. This is nothing but the parallel combination of $R_C$ parallel $r_o$ and $R_L$. Finally I am getting parallel combination between these 3 resistances $R_C$, small $r_o$ and capital $R_L$. That is what is here minus beta into $R_C$ parallel $r_o$ parallel $R_L$ and in the denominator beta plus 1 into small $r_e$.

This is the exact expression that we obtained for this voltage divider biasing scheme and here we can conveniently further simplify by approximating this beta plus 1 and beta. As these are almost equal we can cancel out these two and then write down this expression is minus $R_C$ parallel $r_o$ parallel capital $R_L$ divided by $r_e$. This is a further approximation. Even further approximation I can do by conveniently ignoring $r_o$ because in all practical cases $r_o$ is very high. I can even further approximate by writing it down as minus $R_C$ parallel $R_L$ by $r_e$. This is after approximation one step further. Finally we can see that this voltage gain is actually high in common emitter amplifier because small $r_e$ is in the order of ohms. This is less as compared to the parallel combination of $R_C$ and $R_L$ because $R_C$ $R_L$ are generally in the order of kilo ohms. Finally in the numerator if I get a kilo ohm order of quantity and the denominator is in the ohm order, 10 to the power 3, it is almost like 100 times or more than that you get in enhancement of the input signal. That is actually what happens in a common emitter amplifier and I try to find out what is the overall voltage gain? With respect to the source how much voltage gain I am getting?

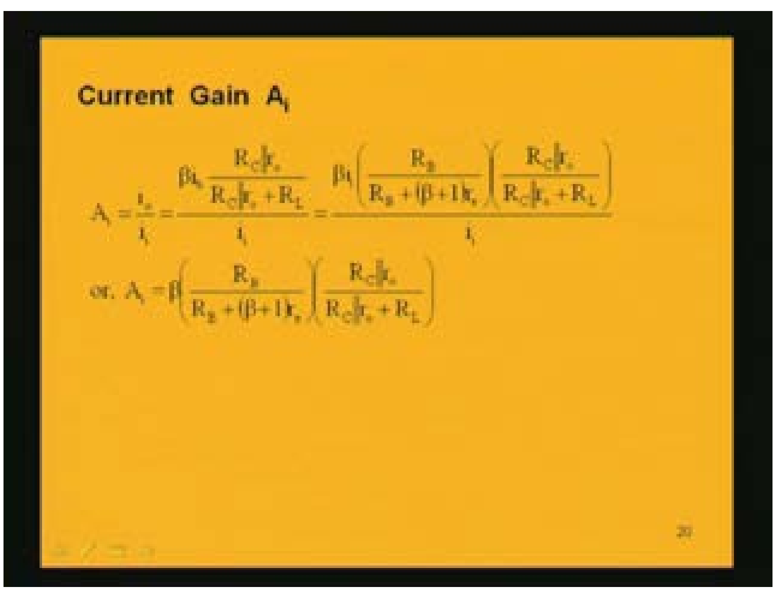
Suppose I apply source which is in the order of 1 millivolt peak to peak. I am applying a small signal $V_S$. Its peak to peak value is 1 millivolt. Then how much amplified signal at the output I get that can be found out by finding the overall voltage gain $Av_s$. Because $Av_s$ is nothing but $v_o$ by $v_s$, final output voltage by input signal at the source that is actually giving you the measure of overall voltage gain and by using the expression that we have already discussed $Av_s$ is nothing but $A_v$ the voltage gain into $Z_i$ by $Z_i$ plus $R_S$, then we can find out what is this overall voltage gain and if we do this we will find out the voltage gain. With respect to the source this overall voltage gain will be less than the voltage gain, $A_v$ because if we look into the denominator $Z_i$ plus $R_S$, $R_S$ is the series resistance. It has a small value. But still the denominator value being higher than the numerator, in this case it will be a fraction. $A_v$ multiplied by fraction means ultimately it will be a reduced value than $A_{v.}$ Overall voltage gain if we consider having the series resistance in the source it will be less. $Av_s$ is generally lesser than $A_v$.

(Refer Slide Time: 48:18)




Overall voltage gain is lesser than the voltage gain which would have been possible had there been no series resistance in the source and similarly current gain, $A_i$ we can find out. Ai current gain is $i_o$ by $i_i$ and $i_o$ is the current which flows through the load resistance $R_L$. The load resistance $R_L$ is having the current $i_o$ which is part of the current beta times $i_b$ and that current is beta times $i_b$ into $R_C$ parallel $r_o$ divided by $R_C$ parallel $r_o$ plus $R_L$. That is replaced here; $R_C$ parallel $r_o$ by $R_C$ parallel $r_o$ plus $R_L$. 4854

(Refer Slide Time: 48:54)




That is the part of this current beta times $i_b$ which flows through $R_L$ which is $i_o$ divided by $i_i$. Again we can express this $i_b$ as $i_i$ into $R_B$ by $R_B$ plus beta plus 1 $r_e$ because that is the part of the current which is flowing through this beta plus 1 $r_e$; that is the base current. Out of the input current $i_i$ a part is flowing through this beta plus 1 $r_e$ that is the base current. That is nothing but $i_i$ into $R_B$ by $R_B$ plus beta plus 1 $r_e$. That we are replacing here. Instead of $i_b$, I am writing $i_i$ into $R_B$ by $R_B$ plus beta plus 1 $r_e$; others are same. This is same as it is. Then I can now cancel out. Writing it in that order has a purpose of cancelling out those two $i_i$. We are having current gain expression as beta into $R_B$ by $R_B$ plus beta plus 1 $r_e$ into $R_C$ parallel $r_o$ by $R_C$ parallel $r_o$ plus $R_L$. This is the exact expression of current gain in voltage divider biasing scheme. There is no phase difference in the current gain. That means there is no phase shift between the input current and the output current and in the voltage gain there is a phase reversal of 180 degree.

The input signal is out of phase by 180 degree with the output signal and if we look into the current gain I can further simplify it by ignoring $r_o$. If I ignore $r_o$ that will be $R_C$ by $R_C$ plus $R_L$ and beta is generally very high in common emitter. It is 100 or even more than 100; it can be say up to 500. Even if it is say in hundreds, beta is in hundreds, the voltage gain is very much higher and basically that is the reason why common emitter amplifiers are used for voltage amplification. You get a high voltage gain and the high voltage gain actually can be seen here. Because small $r_e$ is there in the denominator that is very small as compared to the numerator, it is always greater than 1. In the order of hundreds also you get voltage gain in common emitter amplifier. For voltage amplification purposes we use common emitter amplifier. There is a phase reversal of 180 degree and that has to be remembered.

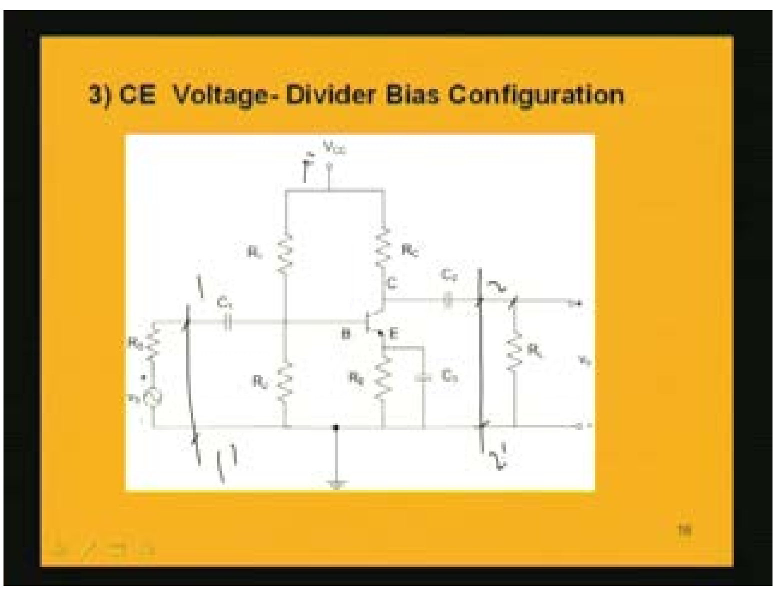
In this discussion we have today covered the different biasing schemes and if we understand the way to proceed in the AC equivalent circuit to find out all those parameters which are involved in the amplifier like voltage gain, current gain and input impedance, output impedance, these are the major parameters and a related parameter may be power gain. That you can find out. If we multiply voltage gain and current gain we will get the power gain expression also. But that is just a secondary gain I get from voltage and current gain and once I know voltage and current gain, you can find out the power gain. The major parameters we have found out. We have found out the input impedance and output impedance, we have found out voltage gain and current gain for different biasing schemes. Out of all these biasing schemes the voltage divider biasing scheme which we have just now discussed is very popular because it generally has the capacity to stabilize the operating point.

Although we have discussed today the amplifier from the perspective of the AC equivalent circuit, prior to it we have already discussed the biasing schemes. Once we have set upon a good biasing scheme stabilizing the q point or the operating point that should not shift afterwards. Even because of change of beta, because of change of the transistor or because of temperature change there should not be significant change or shifting of the operating point. After ensuring the biasing only we proceed to find out the amplification of the amplifier that we have considered. Voltage divider biasing scheme is very, very popular because it guarantees the stability of the operating point. That is why it is very much used in practice.

With the voltage divider biasing scheme along with those capacitances which are coupling capacitances and by pass capacitance we have found out all the parameters which are involved in the amplifier. We can find out for any biasing scheme if we proceed in a similar way from the starting principle. In order to find out the voltage gain we must proceed from the starting point which is nothing but the ratio between the output voltage and input voltage. What is output voltage, what is input voltage? Those expressions we have to find out keeping in mind the AC equivalent circuit or referring to the AC equivalent circuit along with the transistor model being incorporated into it. We can find out any parameter for any biasing scheme amplifier proceeding in the same manner which we discussed today and even if some of the resistances are absent; for example we have no resistances in the emitter. That is emitter is having no resistance.

In this circuit if there is no resistance in this emitter or simply it is connected to ground, then also we can find out. By proceeding from the first principle, there is no difficulty in finding out the parameters for any circuit with even some of the resistances being not there; instead of 2 there is only 1 single resistance as we discussed in the first case. Always we have to proceed with the first principle. That means if we want to find out the input impedance it will be $v_i$ by $i_i$. But one thing to be noted here is that we will be considering the source and a load outside the purview of this two terminal network. That means input terminals will have the source resistances and the source outside and the output terminal will have the load resistance outside. This point has to be remembered and the whole network will be in between these two points or two pair of terminals, input and output; 1 1 dash and 2 2 dash, if we name it.

(Refer Slide Time: 56:03)




In that way we can proceed and find out the parameters which are required or which are important for this amplifier and we can find out for any of the configurations. Basically if we are asked to find out the voltage gain of this particular amplifier, then by plugging in all the values we can find out the gain.

Next we will consider the numerical example. If I want to find out numerically the value of any of the parameters for any of the configuration we can do that. Today's discussion actually leads us to going a step further for exactly finding out the amplifier parameters. But we have to keep in mind that we are still considering the small signal analysis. Our signal is still small enough to make the transistor operate in active region only. The transistor should not be overdriven into either saturation or cutoff. These two conditions should never arise. Then only this whole discussion is valid. Whatever small signal analysis we are doing, we are applying it to the transistor amplifier and in view of this small signal being applied we are still in the active reason or the transistor is operating in the active region. That is why we can write down that $i_c$ is equal to beta times $i_b$. If it is saturation we will never be able to analyze it in the way that we are analyzing. This point has to be kept in mind that we are dealing with a small signal analysis and we are trying to find out all those parameters involved in the amplifier taking example of different biasing schemes and finding out all this.

Today we discussed about common emitter transistor amplifier, BJT common emitter configuration with different biasing schemes. Also there are common base and common collector amplifiers and these common base and common emitter amplifiers are basically used for some difficult, special applications; like a voltage buffer or current buffer, etc, it will be used. We will discuss that but then today we have discussed about the most frequently or commonly used amplifier for voltage amplification and in that case generally the common emitter amplifier is used. We have discussed extensively about common emitter amplifier in different configurations of biasing. We will also discuss about common base and common collector amplifiers next.