Basic electronics
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Lecture- 15

Circuit Analysis using H-parameters

Hello everybody! In our series of lectures on basic electronics learning by actually doing the experiments we will move on to the next lecture. Before we do that let us look at what we did in the previous lecture.

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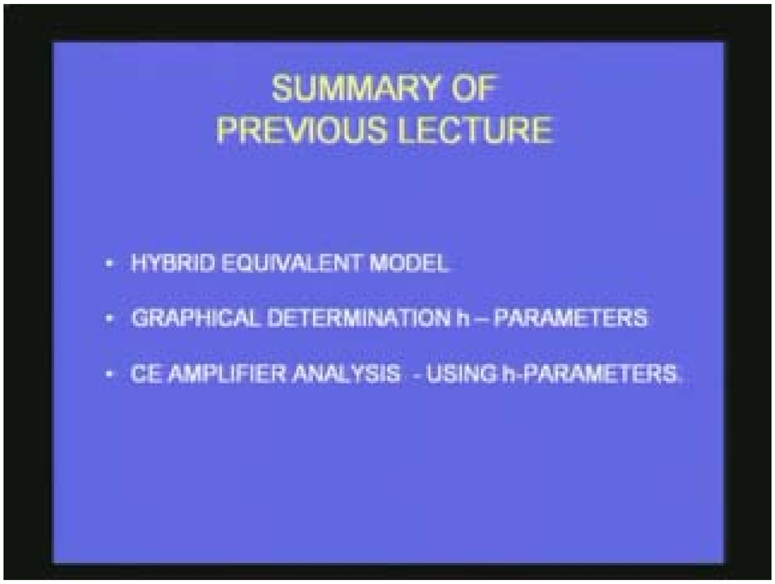

SUMMARY OF
PREVIOUS LECTURE

- HYBRID EQUIVALENT MODEL
- GRAPHICAL DETERMINATION h – PARAMETERS
- CE AMPLIFIER ANALYSIS - USING h-PARAMETERS.

You might recall we discussed about the hybrid equivalent model of a transistor and then we also defined all the h parameter as they are called. We also found how they can be determined or evaluated from the graphical outputs that we have. Usually the output characteristics and the input characteristics can be used to obtain the hybrid parameters of the transistor. You saw how it could be done in the previous lecture. We also took up a common emitter amplifier which is the most popular amplifier, voltage amplifier and then we saw how the hybrid equivalent model can be used to obtain the different parameters like the input impedance, the output impedance, the voltage gain, the current gain, etc.

Now let us move on to the next one. Before we do that let me just recapitulate the various expressions that we got for the common emitter amplifier circuit performance. If you see on the screen you can see without the R_E in the circuit that means when the R_E resistor in the emitter is bypassed with the capacitor what will be the various expressions?

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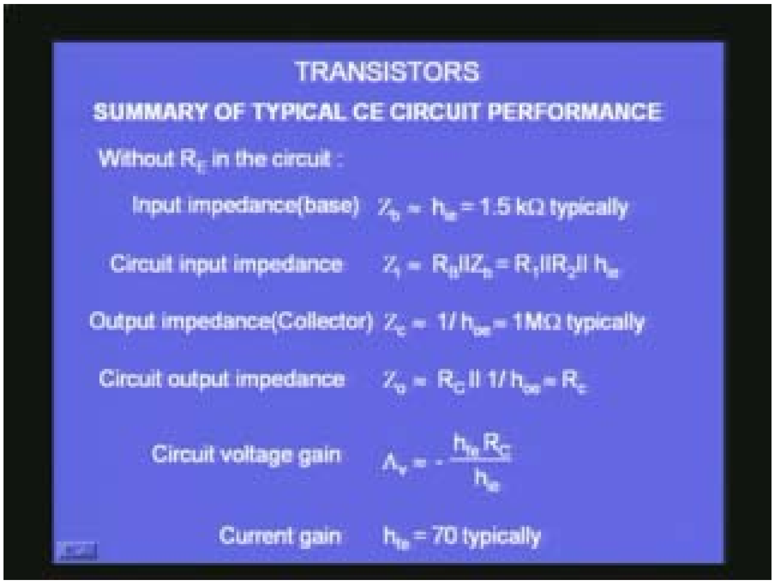

TRANSISTORS

SUMMARY OF TYPICAL CE CIRCUIT PERFORMANCE

Without R_E in the circuit :

Input impedance(base) $Z_b = h_{ie} = 1.5\ k\Omega$ typically

Circuit input impedance $Z_i = R_B || Z_b = R_1 || R_2 || h_{ie}$

Output impedance(Collector) $Z_c = 1/h_{oe} = 1M\Omega$ typically

Circuit output impedance $Z_o = R_C || 1/h_{oe} = R_c$

Circuit voltage gain $A_v = -\frac{h_{fe} R_C}{h_{ie}}$

Current gain $h_{fe} = 70$ typically

You might recall the input impedance at the base of the transistor which I call Z_b is almost equal to the h_{ie}, h parameter, which typically you know is around 1.5 kilo ohms for a normal general purpose transistor that we normally use. The circuit input impedance which is including the various other resistors that we have connected in the common emitter amplifier the Z_i which is very important for us in the amplifier is R_B parallel Z_b. R_B is actually the base effective resistance which is actually the parallel values of R_1 and R_2 in the voltage divider bias circuit. So R_B is actually R_1 parallel R_2. Z_b is h_{ie}. Therefore the input impedance Z_i is R_1 parallel R_2 parallel h_{ie}. Similarly the output impedance at the collector is basically given by the h_{oe} parameter or, or of the h parameter that is $1/h_{oe}$. Because h_{oe} is a conductance and $1/h_{oe}$ is the impedance which is the effective impedance at the collector of the transistor and this normally will have approximately about 1 meg ohm and therefore the circuit output impedance including the other various resistors R_C, etc, that we have connected in the circuit if you take into account the output impedance of the amplifier will be R_C, the collector resistor that we have used, parallel the $1/h_{oe}$ which is due to the output impedance of the collector. Because $1/h_{oe}$ will be a very large number for example about 1 meg ohm whereas R_C will be few kilo ohms. When you make a parallel combination of these two the effective resistance will almost be close to the smaller value. The smaller value is R_C and therefore the output impedance will almost be equal to R_C in the case of the common emitter amplifier.

What about the voltage gain? The circuit voltage gain you may recall A_v that I show here is h_{fe} times R_C by h_{ie} where h_{ie} is the input impedance. This is also represented by small re, beta times small re, where re is the 26 milli volts by I_e that we have discussed in our earlier lecture. Therefore this R_c and the small re are the two parameters which actually determine the voltage gain in the case of a common emitter amplifier. Current gain approximately will be around 70 or about 100 in the case of a common emitter configuration and therefore the current gain A_i is again given by a big expression h_{fe} R_B, R_B is R_1 parallel R_2 divided by a circuit, R_c the collector resistor R_B +Z_b which is h_{ie} in this case, $R_c + R_L$ where R_L is the external load resistor if you have connected one. This is the general expression and if you simplify then you would find it will almost be dependent on R_B and $R_B + h_{ie}$.

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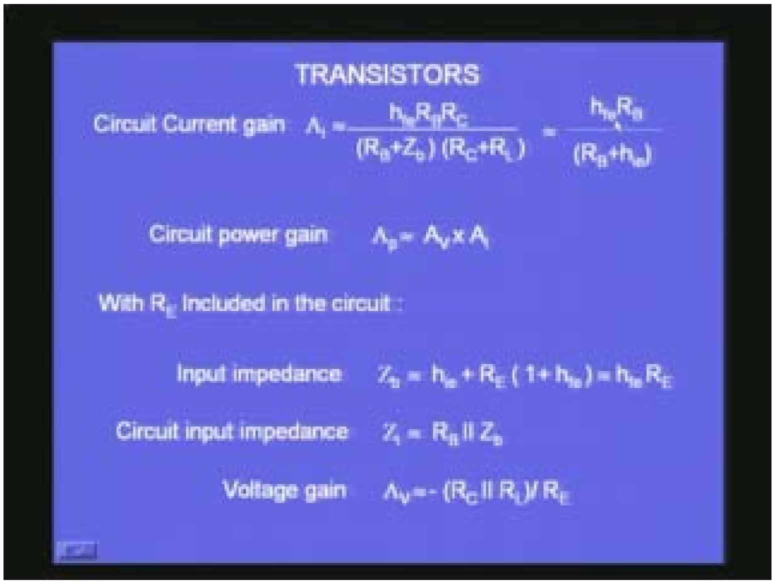

TRANSISTORS

Circuit Current gain $A_i = \frac{h_{fe} R_B R_C}{(R_B+Z_b)(R_C+R_L)} = \frac{h_{fe} R_B}{(R_B+h_{ie})}$

Circuit power gain $A_p = A_v \times A_i$

With R_E Included in the circuit :

Input impedance $Z_b = h_{ie} + R_E(1+h_{fe}) = h_{fe} R_E$

Circuit input impedance $Z_i = R_B \parallel Z_b$

Voltage gain $A_V = -(R_C \parallel R_L)/R_E$

So this h_{fe} into R_B by $R_B + h_{ie}$ it will give current gain of the common emitter transistor amplifier. The power gain as you all know is nothing but product of voltage gain and the current gain. A_v into A_i gives you A_p the power gain. So once you evaluate the A_v and A_i using the expressions that we have already discussed the power gain can be obtained by the product of these two numbers.

What happens when I do not have the bypass capacitor at the emitter? Then what will happen? The R_E will also come into the circuit. With the R_E included in the circuit what happens to the various parameters I have written here. You can see the input impedance which will be the combination of the small re and the capital R_E because small re is very, very small value, few ohms the input impedance at the transistor will almost be decided by the capital R_E and you can see there is a product term coming here which is h_{fe} which is actually the beta that we always know off and that will be very large number about 100 and therefore you find the input impedance is obtained by multiplying the R_E the emitter resistor by h_{fe} parameter of the transistor. Therefore this input impedance is going to be very, very large. The R_E which is on the emitter side is transformed into a very large resistance given by h_{fe} into R_E at the input impedance. Therefore the major contribution to the input impedance comes from the h_{fe} into R_e and therefore this is the one which will decide what will be the input impedance. If you look at the circuit impedance then it is R_B which is R_1 parallel R_2 in parallel with this h_{fe} R_E which will be the effective resistance and usually if R_1 R_2 are not so big h_{fe} into R_E can be very large then it is almost decided by the h_{fe} R_E. If you look at the voltage gain, voltage gain is $-R_c$ parallel R_L by R_E if you include R_L. If you don't include R_L it will be $-R_c$ by R_E where R_E is the emitter resistance,

R_c is the collector resistance. This will be the voltage gain when you include R_E in the circuit without the bypass capacitor.

Having seen that let us quickly go for a simulation. Here you see a bread board and you have a voltage source which is given for the V_{CC} supply and this is a ac source with the various voltages I can give from here, it is an oscillator and in the bread board you have a transistor you have the various resistor for example this is R_1 which is 30 kilo ohm and this R_2 is about 6.8 kilo ohm, the R_c is 3.8 kilo ohm the R_E is 1 kilo ohm and the R_E is bypassed by this capacitor and these two other capacitors are the coupling capacitors there at the input and the output side.

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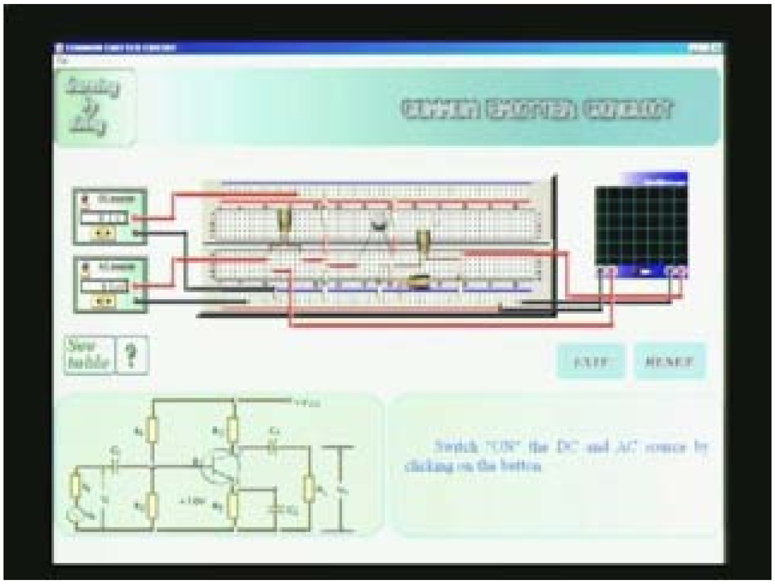

Switch "ON" the DC and AC source by clicking on the button

This is exactly a simple common emitter amplifier wired on the bread board and the various connections for example this is given to the V_{CC}; this is the V_{CC} line and this is the ground line at the bottom and you also connect the ac source at the input and the other end of ac source is connected to the ground. On the other side you have an oscilloscope and you can see it is a two channel oscilloscope here and one of the channels is connected to the input; the other channel, the red line here, is connected to the output. So this oscilloscope will simultaneously monitor the input sine wave and the output wave, the amplified wave.

I have shown you the exact circuit at the bottom here. You can see this is a voltage source with a internal resistance R_s of the signal source and you have the coupling capacitor R_1, R_2, R_c, R_e, rest of the things. You can also identify the same circuit is wired here with a finite value of the various resistors. Now let me switch on the DC supply and let me switch on the AC source and the frequency is around 1 kilo hertz. Then you can immediately see the input wave is the small sine wave. It will keep on moving and the output wave is an amplified wave which is much larger than the input wave.

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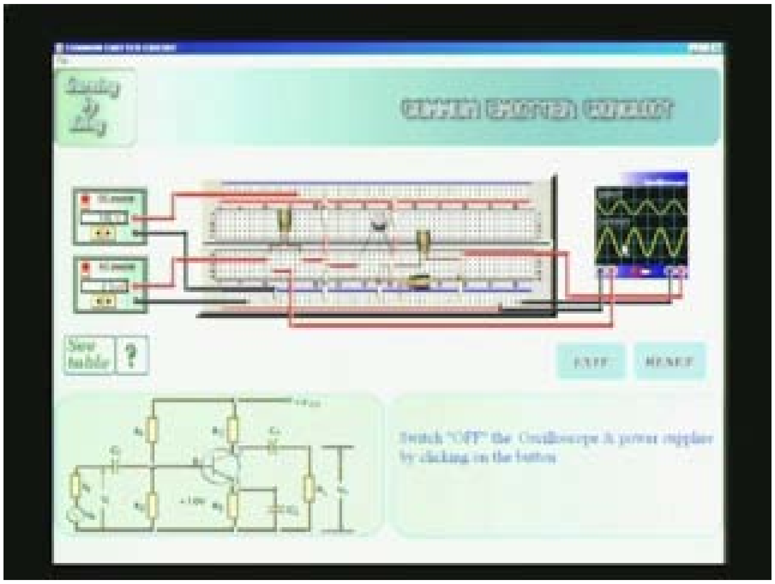

Switch "OFF" the Oscilloscope & power supplies by clicking on the button

As a mater of fact this can be very large; sometimes of the order of 100 times the input waves. Even though here it is qualitatively shown that there is amplification in reality this amplification can run to several hundreds. This is a very simple example of an actual circuit having being wired on the bread board. If you do it in the lab you would be able to get this in a very easy way. Let me move on to the table and show you an actual circuit working. Here you see a bread board.

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The transistor and the circuit is wired. You have the R_1 and R_2 the biasing resistors. This is the coupling capacitor. There is one other coupling capacitor on this side and you have this R_E here and you have the capacitor which is bypassing this and this is the R_c resistor. So this is again the same common emitter amplifier with voltage divider bias and an R_E with the bypassed capacitor. I am having here a signal generator which can produce sine waves and now I have set it for 1 kilo hertz frequency with very small amplitude and this output I have now connected to the input between the coupling capacitor and the ground and at the output I am monitoring using a cathode ray oscilloscope, CRO. This CRO as you saw in the simulation has got two channels and in the two channels I have given the input and the output. You can see the input is very small value and the output is an amplified voltage and you can see the beautiful sine wave there.

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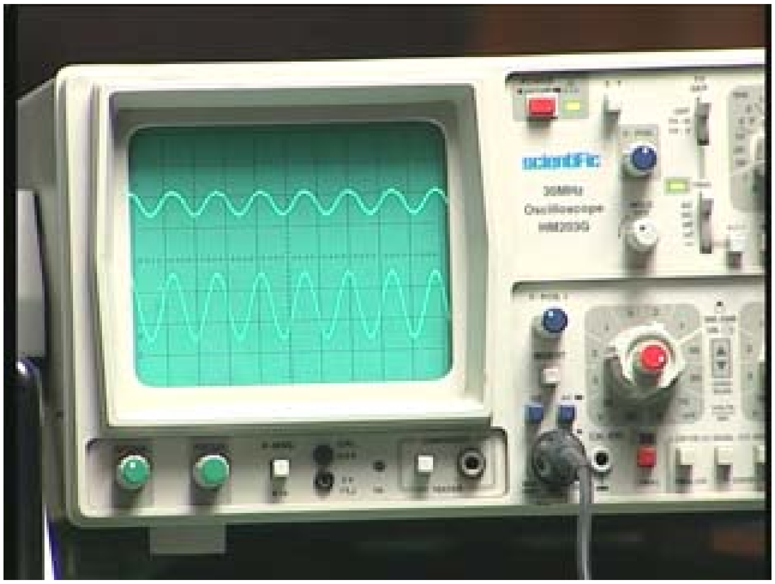

Now how do I know that this is the output? Let me change the frequency at the function generator and correspondingly see what happens at the oscilloscope? You can see the oscilloscope signal is changing corresponding to this.

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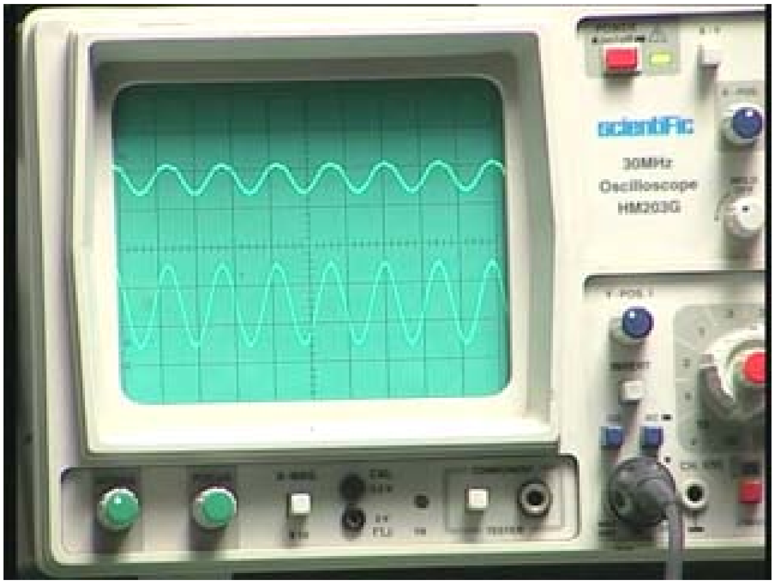

Similarly if I now change the input voltage you can see the output is also changing. That means the amplifier is working very well and you see if you actually come closer and look at the amplification this is the output and this is the input and the input is almost in the order of milli volts and the output is in the scale corresponding to 2 volts per division. This is 2 volts per division. Approximately it comes to about two divisions. That means 4 volts peak to peak is what you are getting. Here it will be around 20 or so milli volts. Therefore there is a gain of nearly about 100 and odd; 125 or so if you actually calculate. This is a very simple common emitter amplifier and the voltage gain is obtained by the oscilloscope by measuring what is the actual peak to peak voltage here and the peak to peak voltage here if you divide one by the other, the output divided by the input you will get the gain factor. But apart from that we also evaluated the input impedance and the output impedance of this amplifier. How do we do that?

If I want to measure the input impedance and the output impedance how do I measure? Let me tell you how it will be measured? I will perhaps show it to you on the screen and then I will come back here and show you how to measure the input impedance and the output impedance. I have shown on the screen the same common emitter amplifier connected to a signal source and the output is measured using a digital voltmeter, the V output. So this is the same. The square box encloses the amplifier circuit. Now what I do is I have deliberately introduced a resistor R, the variable resistor R here in series with the signal source and initially I keep the resistance zero.

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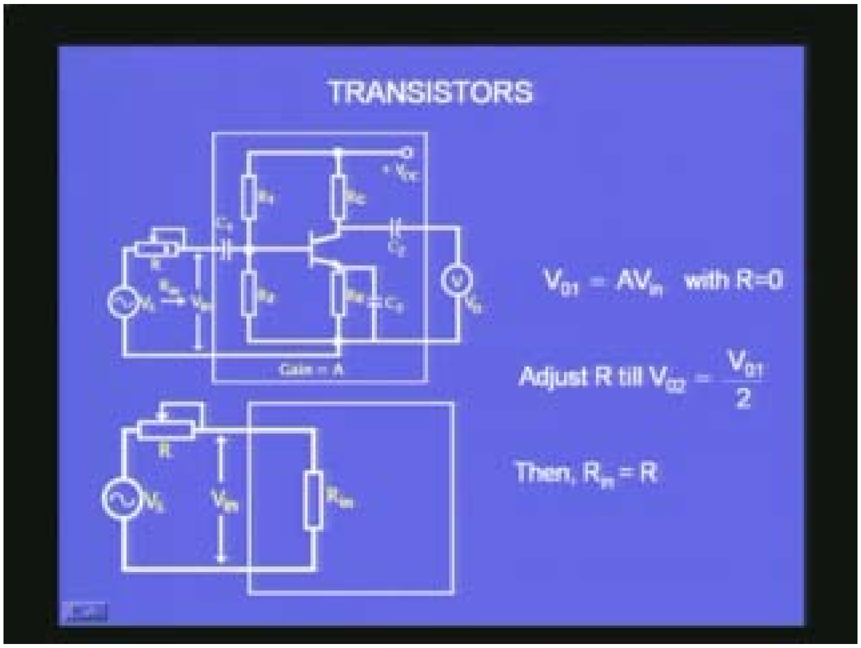

TRANSISTORS

$V_{01} = AV_{in}$ with R=0

Adjust R till $V_{02} = \frac{V_{01}}{2}$

Then, $R_{in} = R$

So what will be the output voltage? I call that V_{01}. V_{01} is equal to A times, where A is the gain, the V_{in} the V input which is actually in this case V_s because this resistance is zero the voltage of the signal source is applied at the input and therefore V output one, V_{01} is equal to A times V_{in} when R is equal to zero where this R is the external potentiometer that I have connected, variable resistor that I have connected in series with the signal source. I hope you understand this.

Now what I do? I measure this V_{01} without the resistor that means having the resistor value zero now I slowly increase the resistance and keep observing what happens? When the V_{02} the measurement that I do now I call it V_{02} and the V_{02} when it becomes $V_{01/2}$ that means when it becomes half of the value that I measured previously I stop the variation of the resistor. I keep the resistance at this stage and then if I now remove the resistor from the circuit and measure its value I can say the value of the resistor is equal to the input resistance of the amplifier. The principle is very simple. I have already explained it in one of my earlier lectures.

If I have a voltage source and this input impedance what I have from the amplifier is the Thevenin's equivalent resistance for the amplifier and this is the external resistance I have connected. Therefore these two resistors come in series with the voltage source. So if the output voltage is halved, divided by two, that means the input voltage also has been divided by two because amplifier is a linear device and the output is related to input by a simple constant factor A and therefore when the output is divided by two the input which is connected exactly at the input terminals of the amplifier should also be divided by two. That can happen in a potential divider only when the two resistors that I have connected are equal in magnitude. So when the two resistors are equal in magnitude this voltage will be divided equally between these two resistors and therefore I have now indirectly measured the input impedance of the amplifier by connecting in series the resistor and then varying this till I get a voltage half of what I got previously with the resistance zero. So this is a very simple technique of measurement of input resistance of an amplifier.

How about output resistance? Can we measure the output resistance of the amplifier? How do we do that? The principle here is also very similar. But then what we do here is we connect the resistor, variable resistor at the output but in parallel to the voltmeter that I have connected. It is in the shunt form. So with this shunt resistance infinity that is without connecting this R, I measure the output voltage. That I call again V_{01} in the circuit and that will be A times V_{in} because here the entire voltage is connected. I get an output voltage which will be multiplied by the gain factor A. So V_{01} is A times V_{in} with R is equal to infinity. That means this resistor is not being connected to the circuit.

When I connect the circuit and vary this resistor till I get a value which is half of the previous value that is when V_{02} becomes $V_{01/2}$, now by the same argument that I gave you before the resistance now measured by the variable resistor is equal to the output impedance. How do we understand that? You can see the output side of the amplifier can be equivalently represented by a voltage source which is A times V_{in} where A is the gain plus an output resistance in series added to that and therefore when I connect R, external resistor, this R_0 and R come in series and when the V_o is divided by two that means half the value has been dropped across the internal resistance R_o and the rest of the voltage is dropped across the external resistance R that I have connected and they are equal and therefore they also equally divide the voltage and that is why the output voltage becomes half. This shows you that if I now disconnect this resistor from the circuit we should not measure the resistance while the resistance is in the circuit. Because the circuit is a complicated combination network of resistors and when I measure I may have some other parallel resistors coming in along with this resistor and therefore when I measure in circuit I will not get the exact resistor that I want to measure. Therefore whenever you want to measure resistor you should switch off the amplifier remove the resistor and then measure outside using a good multimeter. When you measure the out using the multimeter outside then whatever resistance it shows will be the resistance of the output or the output impedance of the amplifier. So these are the two methods by which the input impedance and the output impedance of an amplifier can be measured.

I will quickly show you the amplifier that we already saw. I can connect one of the series resistors and vary it till the amplitude becomes off and then we will measure the output impedance using a multimeter. Here we have come back again with the same circuit. You can see I have connected a variable resistor, it is a potentiometer. One end is not connected in the circuit; the other two ends, the center one and one another corner are connected in series with the input which is the input from the function generator here, sine wave oscillator.

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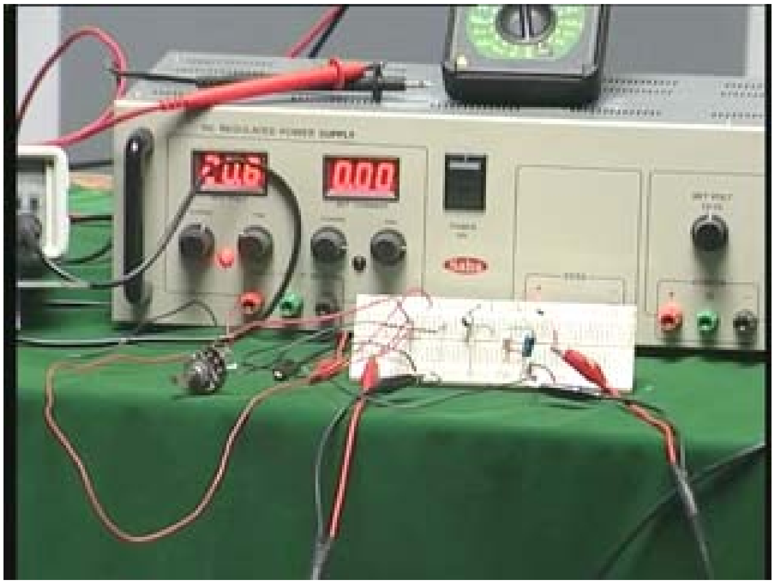

I have connected in series as I have shown you in the picture before and now I have kept this in the minimum position, the resistance in the minimum position and now you can see what you observe on the oscilloscope.

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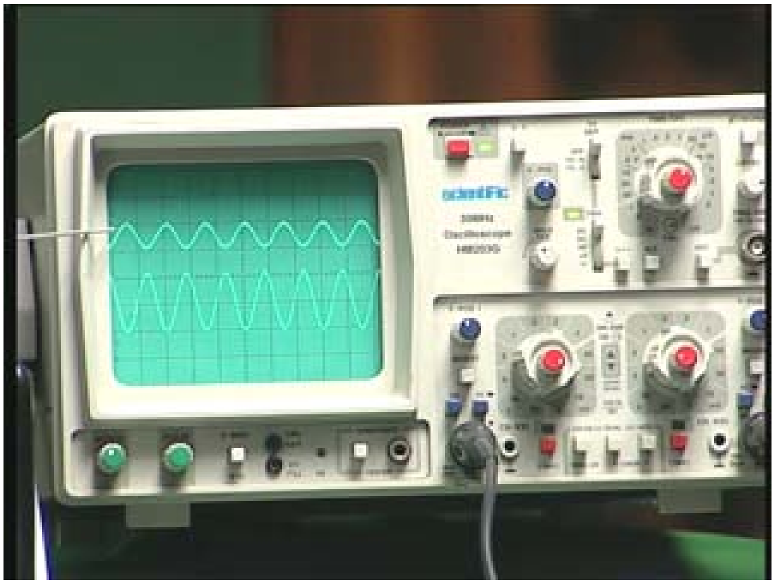

You see the input signal and you have the amplified signal. Now what I am going to do is I am going to vary this potentiometer slightly till I get the signal reduced to half the previous value. You should concentrate on the bottom sine wave which is the actual output wave form. When it becomes half I will stop and then I will disconnect the resistor and I will measure the value of the resistor using the multimeter. Now I am going to vary the potentiometer. You must observe the sine wave that you get in the oscilloscope at the bottom which is actually the output. Right now I have got zero resistance in the potentiometer. Now I slowly increase the resistor and you see what happens. You can see the amplitude is decreasing. It is around 1.5 divisions half of the previous value.

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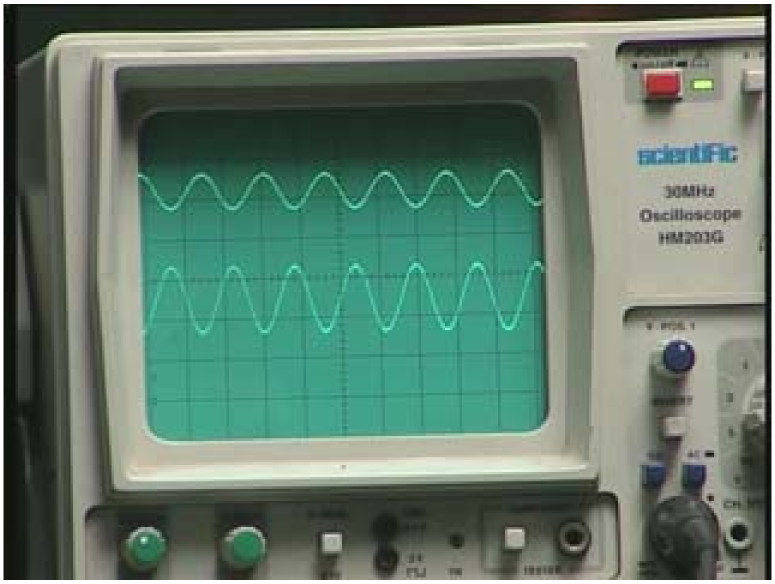

Having done that I will switch this off and disconnect the resistor from the circuit. I will use the multimeter to measure the resistance between the two terminals and you see it is around 25 kilo ohms. I hope you are able to see the reading on the multimeter. This 25 kilo ohm is the input resistance of this amplifier.

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This gives you a method by which you can measure the input impedance of an amplifier. In a similar fashion I can connect this at the output in parallel and I can try to do the simple half duplex method. That is when the output voltage becomes half whatever is the resistance I should disconnect and measure. It is very similar therefore I am not showing. But you can measure the output impedance also in a very similar way. Having seen the live demonstration of the common emitter amplifier, the gain and also how the input and the output impedances can be measured now let us take an example in the form of a small problem and try to analyze it using the h parameter and the various expressions that we obtain for the gain, the input impedance, the output impedance, etc.

On the screen you can see there is a common emitter amplifier with the signal source connected and the load resistor R_L connected. The important point I don't know whether you observed on the oscilloscope the input signal and the output signal were 180 degrees out of phase.

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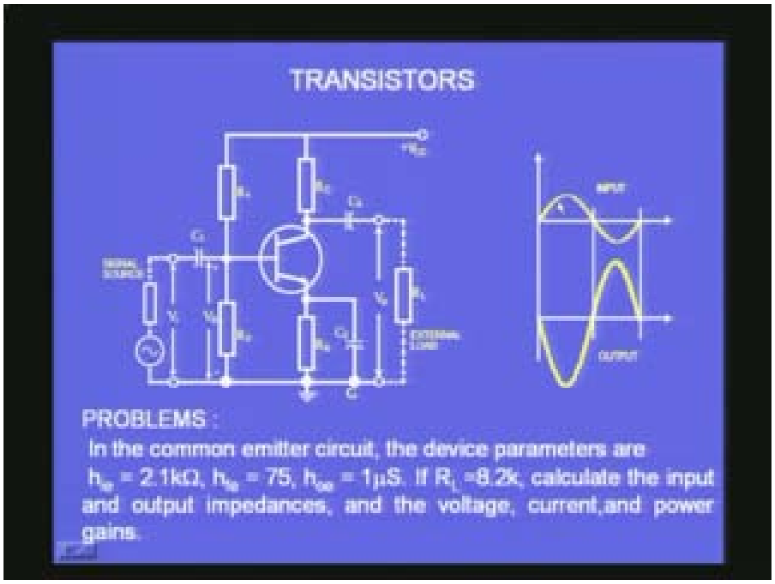

TRANSISTORS

PROBLEMS :

In the common emitter circuit, the device parameters are h_{ie} = 2.1kΩ, h_{fe} = 75, h_{oe} = 1μS. If R_L =8.2k, calculate the input and output impedances, and the voltage, current,and power gains.

So when the input signal is increasing the output signal was decreasing and when the input signal is decreasing the output signal was increasing which shows that there is a 180 phase difference between the input and the output in the case of a common emitter amplifier. I am sure some of you would have observed in the oscilloscope when I showed it actually on the demonstration. Now the problem here that I have is in the common emitter circuit the device parameters are given. h_{ie} is 2.1 kilo ohms, h_{fe} is 75, h_{oe} is 1 micro siemens. If R_L is equal to 8.2 kilo ohms calculate the input and the output impedances and the voltage current and power gain. Exactly the same way as we did in a general case, given the numerical values for the various parameters we should calculate the various things.

What is Z_b? Z_b is the impedance at the base of the transistor and that you know is almost equal to h_{ie} and therefore the value of h_{ie} is given as 2.1 kilo ohms in the problem. Therefore the Z_b is 2.1 kilo ohm. Then what is the circuit impedance? The circuit impedance is Z_i which is equal to the parallel combination of the input impedance due to the transistor plus the parallel value of R_1 and R_2 which are the two resistors used in the voltage divider bias. The Z_i therefore is equal to 2.1 kilo ohm parallel R_1 is 68 kilo ohm, R_2 is 56 kilo ohm given in the problem. Compared to 68 and 56, 2.1 kilo ohm is a very small value and therefore it comes very close to the smallest value in the three resistors and it is 1.97 kilo ohm if you actually calculate the value. So what about the output impedance at the collector? The collector of the transistor it is given by $1/h_{oe}$ where hoe is the output conductance. $1/h_{oe}$ is about 1 meg ohm corresponding to the value given in the problem and therefore the circuit output impedance is nothing but Z_o; Z_c in parallel with R_c. Z_c is about 1 meg ohm in parallel with 3.9 kilo ohm and therefore 3.9 kilo ohm is very small compared to 1 meg ohm. So the effective resistance will almost be very close to the smaller value 3.9 kilo ohm. So the input impedance is about 2 kilo ohm, 1.97. The output impedance is around 3.9 or 4 kilo ohm approximately.

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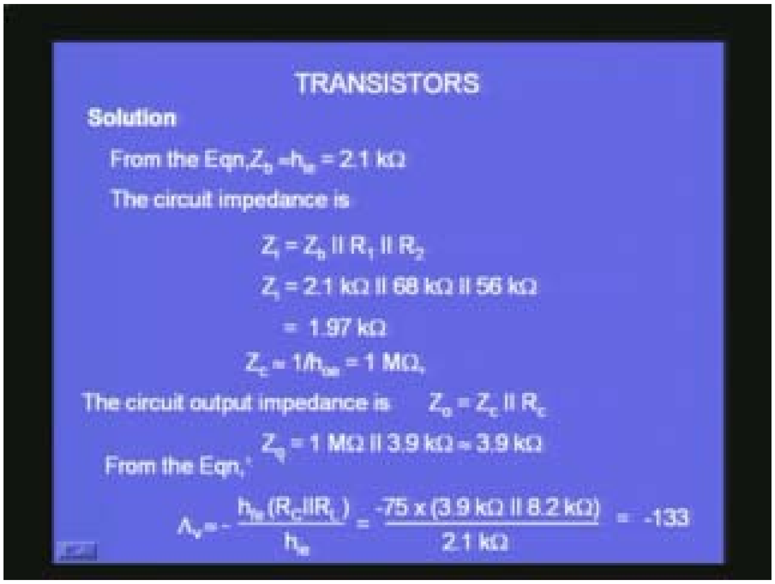

TRANSISTORS

Solution

From the Eqn, $Z_b = h_{ie} = 2.1\ k\Omega$

The circuit impedance is

$$Z_i = Z_b \parallel R_1 \parallel R_2$$

$$Z_i = 2.1\ k\Omega \parallel 68\ k\Omega \parallel 56\ k\Omega$$

$$= 1.97\ k\Omega$$

$$Z_c = 1/h_{oe} = 1\ M\Omega,$$

The circuit output impedance is $Z_o = Z_c \parallel R_c$

$$Z_o = 1\ M\Omega \parallel 3.9\ k\Omega \approx 3.9\ k\Omega$$

From the Eqn,

$$A_v = -\frac{h_{fe}(R_C \parallel R_L)}{h_{ie}} = \frac{-75 \times (3.9\ k\Omega \parallel 8.2\ k\Omega)}{2.1\ k\Omega} = -133$$

What about the voltage gain? Voltage gain A_v is minus. What is this minus corresponding to? This minus shows the phase difference between the input and output is 180 degree. That is why you get the minus here. So it is h_{fe} R_c parallel R_L divided by h_{ie} and if you now substitute the values h_{fe} is 75; R_c is 3.9 kilo ohm, R_L is 8.2 kilo ohm given in the problem and divided by h_{ie} is 2.1 kilo ohm. If you calculate this value it comes to around 133. The voltage gain of the amplifier is around 133. We also saw in the actual demonstration the gain was close to 125 or 130. The R_B which is actually the effective resistance or the Thevenin's resistance of the base is the parallel value of 68 kilo ohm and 56 kilo ohm which is about 30.7 kilo ohm.

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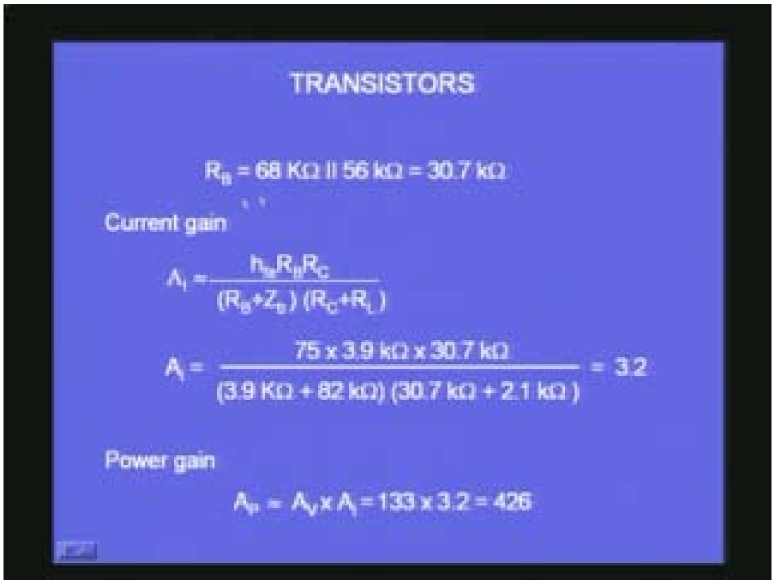

TRANSISTORS

$$R_B = 68\ K\Omega \parallel 56\ k\Omega = 30.7\ k\Omega$$

Current gain

$$A_i = \frac{h_{fe} R_B R_C}{(R_B + Z_b)(R_C + R_L)}$$

$$A_i = \frac{75 \times 3.9\ k\Omega \times 30.7\ k\Omega}{(3.9\ K\Omega + 82\ k\Omega)(30.7\ k\Omega + 2.1\ k\Omega)} = 3.2$$

Power gain

$$A_p = A_v \times A_i = 133 \times 3.2 = 426$$

Let us obtain the current gain. The current gain if you remember the expression h_{fe} R_B R_C divided by R_B plus Z_b into R_c plus R_L. This is a complete expression where you also have R_L and you have R_B.

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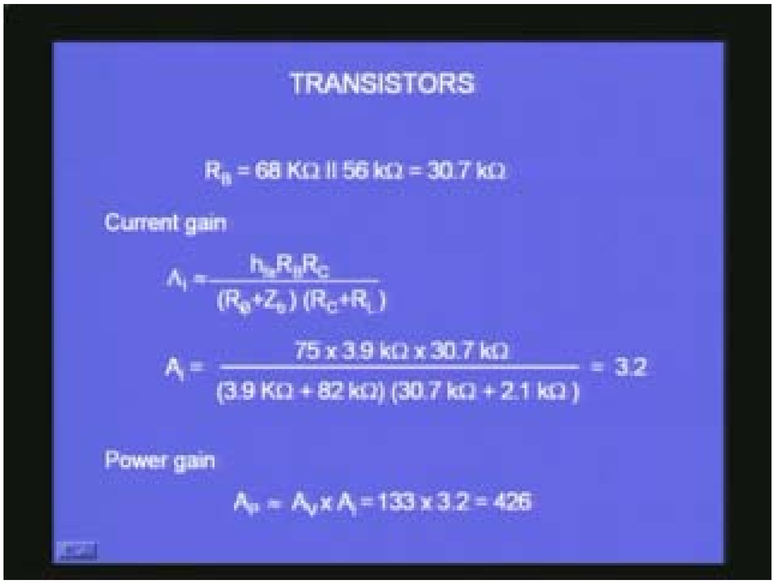

TRANSISTORS

$R_B = 68\ K\Omega \parallel 56\ k\Omega = 30.7\ k\Omega$

Current gain

$$A_i = \frac{h_{fe} R_B R_C}{(R_B + Z_b)\ (R_C + R_L)}$$

$$A_i = \frac{75 \times 3.9\ k\Omega \times 30.7\ k\Omega}{(3.9\ K\Omega + 82\ k\Omega)\ (30.7\ k\Omega + 2.1\ k\Omega)} = 3.2$$

Power gain

$$A_p = A_v \times A_i = 133 \times 3.2 = 426$$

The current division is happening between the R_B and the Z_b at the input side, the current is divided at the output due to the presence of R_c and R_L and therefore these expressions becomes somewhat complicated. But if you substitute the various values h_{fe} is 75, R_B is 3.9 kilo ohm, R_B is 30.7 kilo ohm, R_c is 3.9 kilo ohm divided by the corresponding values R_B and Z_b and R_c, R_L, etc. The value comes out to be 3.2. The current gain of the common emitter amplifier is around 3. It is a small value compared to the voltage gain and the power gain which is the product of the voltage gain and the current gain is 133 into 3.2 which comes around 4.26. We can analyze the complete circuit and obtain all the important parameters of the amplifier and so this was illustrative example of the common emitter amplifier, how it can be analyzed using h parameter.

Having done that now let us move on to the next configuration, most important configuration which is called common collector amplifier. I have already mentioned to you what a common collector amplifier is. It is also called by a different name namely emitter follower circuit. You have here the common collector amplifier and you can see there is no R_c here. The R_c is removed and the output voltage is actually taken across R_E, the emitter resistance. Instead of taking from the collector the output is now taken from the emitter with a coupling capacitor and the R_L is added in parallel to R_E. This is a very important variation from the common emitter amplifier. You still have R_1 R_2. That means it is a voltage divider bias that you have here and the most important point here is what is V_E? V_E, the voltage at the emitter terminal V_E is nothing but V_B the voltage at the base terminal minus V_{BE} the voltage drop across the base emitter junction. Other important point with reference to the common collector amplifier is that V_E is less than V_B.

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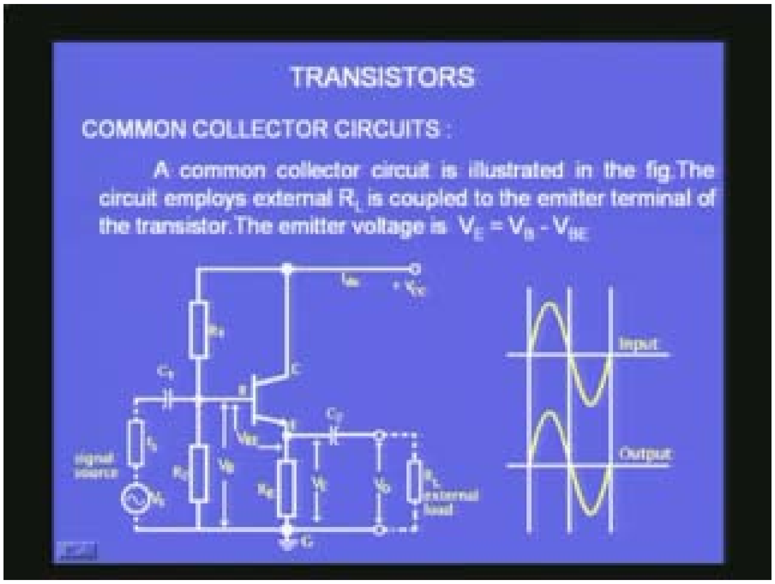

TRANSISTORS

COMMON COLLECTOR CIRCUITS :

A common collector circuit is illustrated in the fig.The circuit employs external R_L is coupled to the emitter terminal of the transistor.The emitter voltage is $V_E = V_B - V_{BE}$

V_B is basically the input voltage. V_E is the output voltage and V_E is V_B - V_{BE} as I already mentioned to you and therefore the output voltage is always going to be somewhat less than the input voltage because of the drop across the base emitter junction. Therefore you are not going to get an amplifier. An amplifier is a device which will amplify which will magnify whereas here you find the output voltage is slightly less than the input voltage and therefore the gain is less than 1, almost very close to 1. But it is not an amplifier. Then why are we discussing this amplifier? That is a very important question that we should answer. Before we do that you can also see when the V_B increases, when the voltage at the base increases, the voltage at the emitter will also increase because of the relationship that we see here. Therefore the two voltages the input voltage and the output voltage, they both will be in phase unlike the case of common emitter amplifier where they were out of phase. We saw that. When the input is increasing as shown on the right side, the output also is increasing and there is not much difference in the amplitude because here only difference is the V_{BE} drop across the base emitter junction and therefore there is no gain. The gain is almost equal to one and they are in phase. These two are very important aspects of common collector circuit or emitter follower. But I also mentioned to you some time back why it is called common collector amplifier. It looks very similar to a common emitter amplifier as you can see here but still it is called common collector amplifier. Why do we do that?

For that answer you have to go to the ac equivalent model of the common collector amplifier. For the ac equivalent model the V_{CC} supply will have to be connected to the ground. That means the V_{CE} is short. Once you short then you find the collector point becomes the ground point and the emitter point is the output point here. The collector point is the ground point and the base is the input point, the emitter is the output point. Therefore the collector is common, as far as the ac signals are concerned, common to both the input and the output. Therefore it is called a common collector amplifier and it is not an amplifier that we have seen. The gain is almost equal to one. But it has got a very important application and that is with reference to impedance matching.

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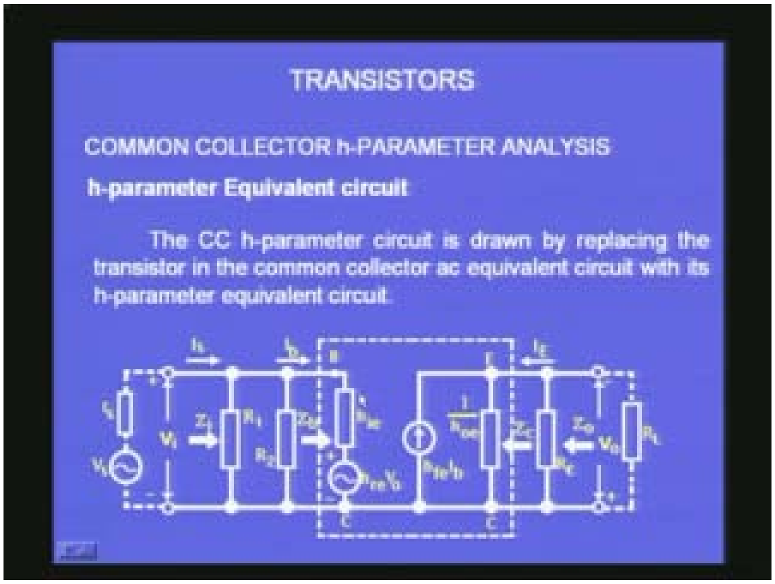

TRANSISTORS

COMMON COLLECTOR h-PARAMETER ANALYSIS

h-parameter Equivalent circuit

The CC h-parameter circuit is drawn by replacing the transistor in the common collector ac equivalent circuit with its h-parameter equivalent circuit.

When we discussed maximum power transfer theorem we saw the maximum power will be transferred only when the load impedance is equal to the internal impedance of the source. Only when these two impedances match there will be maximum power transfer and therefore you would normally find in the case of for example common emitter amplifier the output impedance was the large value may be few kilo ohms and when I want to connect it to a load like a loud speaker, a loud speaker is a very small load. It has got only a few ohms. It is a simple copper wire solenoid inside a magnet. You know the principle of the loud speaker. The impedance of a loud speaker is a very small value few ohms and the output impedance of an amplifier like a common emitter amplifier is very large few thousands of ohms and how do I transfer maximum power from the amplifier to the loud speaker?

If I connect the loud speaker as such in place of the load you would find nothing will come out because the impedance of the loud speaker is too small compared to the impedance of the amplifier. I must have one another circuit which will be introduced between the output of the common emitter amplifier and the loud speaker. That …… of that circuit is to match the two impedances. So that circuit will have high impedance on the input side so that it matches with output impedance of the common emitter amplifier and at the output side this circuit will have a low impedance and therefore it will match with the low impedance of the loud speaker. So by introducing another circuit in between which matches the two impedances which are to be connected I am able to solve the problem of energy transfer from the amplifier to the loud speaker and this is the principle of impedance matching here and for this purpose the circuit that I want to introduce here need not have a gain. The importance here is not the gain.

The importance of that circuit is it should be able to match the two impedances on the two sides. On one side it should have high input impedance so that the energy can be transferred to that circuit and at the other side it should have low impedance so that it can drive the loud speaker on the other side. So the circuit now I am describing is exactly the circuit that we would like to use and that is the emitter follower or the common collector amplifier. That is why in common collector amplifier even though the gain is very close to 1 we still study about it. We still want to understand the working because it is used for impedance matching purposes. Now let us look at the figure that I have drawn here which is actually the equivalent circuit of the common collector amplifier.

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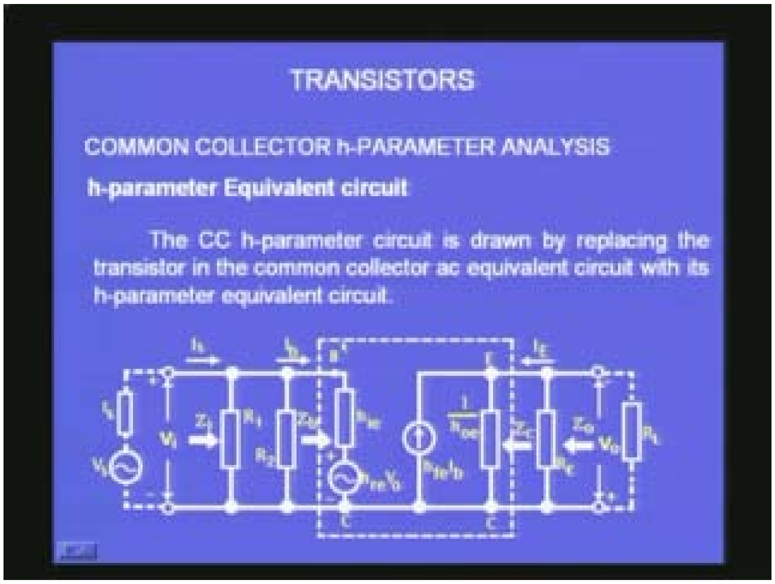

TRANSISTORS

COMMON COLLECTOR h-PARAMETER ANALYSIS

h-parameter Equivalent circuit

The CC h-parameter circuit is drawn by replacing the transistor in the common collector ac equivalent circuit with its h-parameter equivalent circuit.

You can see the R_1 R_2 are coming parallel along with the voltage source and you have the h_{ie} here and you have the h_{re} V_o. I have shown all the h parameters completely in this equivalent circuit of the transistor here and you can see the h_{fe} I_b the current gain factor and $1/h_{oe}$ the output resistance factor here. This box that I have shown here, perforated box corresponds to the transistor equivalent model in terms of h parameters and these are the external resistors R_1 R_2 divider bias and on this side you have the R_E and you can also have an additional R_L connected at the output which in the simplest case could be a loud speaker. So this is the equivalent circuit.

Now let us try to analyze it using h parameter. We must remember certain important points with reference to the circuit. It is different from the common emitter amplifier that we discussed. Why? Here h_{re} is equal to 1. Why is that? Because the entire voltage output is fed back at the input and h_{re} becomes 1 in this case. V_i the voltage at the input is equal to I_b the base current into h_{ie} the resistance. That h_{re} we neglect because the voltage is very small. So V_i is equal to I_b into h_{ic} plus V_o and what is V output? V output is nothing but the emitter current passing through the effective resistance and therefore it is I_e multiplied by R_E parallel R_L. This is the effective resistance at the output side and therefore total expression is I_b h_{ic} plus I_e can be written as h_{fe} times I_b the current gain. So h_{fe} times I_b into R_E parallel R_L and because I_b is common I take the I_b out.

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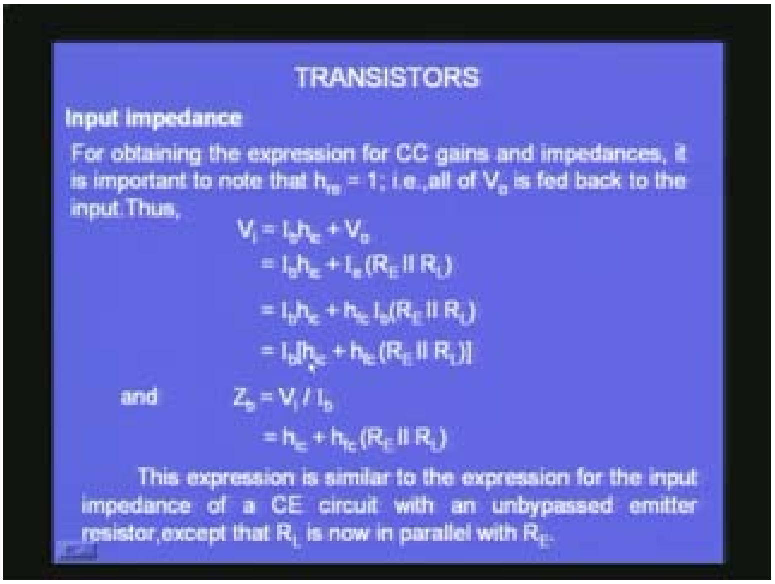

TRANSISTORS

Input impedance

For obtaining the expression for CC gains and impedances, it is important to note that $h_{re} = 1$; i.e.,all of V_o is fed back to the input. Thus,

$$\begin{aligned} V_i &= I_b h_{ic} + V_o \\ &= I_b h_{ic} + I_e (R_E \parallel R_L) \\ &= I_b h_{ic} + h_{fc} I_b (R_E \parallel R_L) \\ &= I_b [h_{ic} + h_{fc} (R_E \parallel R_L)] \end{aligned}$$

and

$$\begin{aligned} Z_b &= V_i / I_b \\ &= h_{ic} + h_{fc} (R_E \parallel R_L) \end{aligned}$$

This expression is similar to the expression for the input impedance of a CE circuit with an unbypassed emitter resistor,except that R_L is now in parallel with R_E.

V_i is equal to I_b within brackets h_{ic} plus h_{fc} R_E parallel R_L and therefore what is Z_b, the input impedance at the base side of the transistor? Input voltage divided by the current I_b and if you divide V_i by I_b this expression in the bracket is the answer. That is h_{ic} plus h_{fc} into R_E parallel R_L. h_{ic} you know is actually related to re small re which is the base resistance of the transistor and this is going to be very small compared to h_{fc} into R_E parallel R_L. The effective resistance at the base will be mostly decided by the R_E value that I have connected here.

Let me move on to the total input resistance. How to obtain the total input resistance of the circuit, the common collector circuit and that is nothing but Z_i which is R_1 parallel with R_2 parallel with Z_b the resistance at the base. We have already evaluated R_b h_{ic} plus h_{fe} into R_E parallel R_L. That I should introduce here and then find out what is the total resistance here, parallel combination that will give me the input impedance of the common collector amplifier and this will be very large because there is a factor coming h_{fc} into R_E that will almost decide what the input impedance is. That will be very large value compared to all these things. What about the output impedance?

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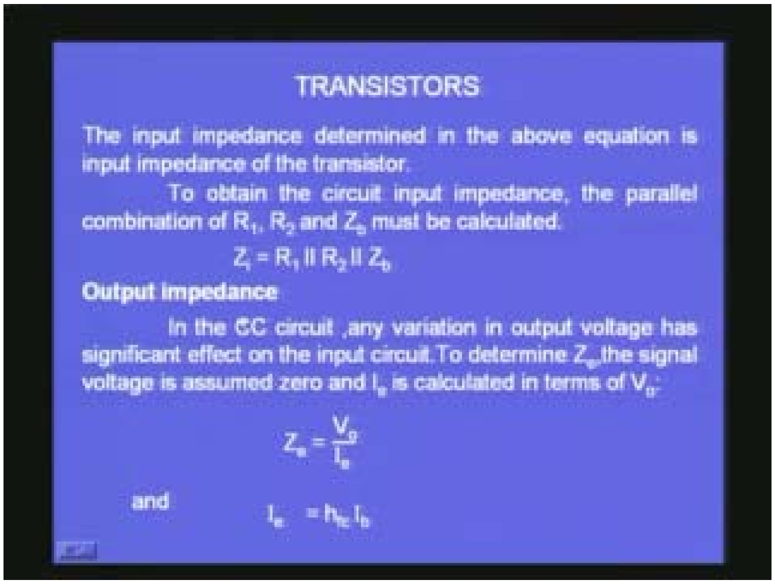

TRANSISTORS

The input impedance determined in the above equation is input impedance of the transistor.

To obtain the circuit input impedance, the parallel combination of R_1, R_2 and Z_b must be calculated.

$$Z_i = R_1 \parallel R_2 \parallel Z_b$$

Output impedance

In the CC circuit ,any variation in output voltage has significant effect on the input circuit.To determine Z_e,the signal voltage is assumed zero and I_e is calculated in terms of V_o:

$$Z_e = \frac{V_o}{I_e}$$

and $$I_e = h_{fc} I_b$$

The output impedance is actually corresponding to the output voltage divided by the current I_e because it is in the emitter V_o by I_e. I_e is again related to I_b by h_{fc} into I_b the current gain. When I have $V_s = 0$ that is if I do not connect any signal I short the signal input then I_b is produced by the V output and therefore I_b is V output divided by h_{ic} plus R_1 parallel R_2 parallel r_s and the I_e is h_{fe} times I_b. I multiply this expression by h_{fc}. h_{fc} times V_o divided by the whole expression and therefore Z_e the resistance at the emitter is V_o by I_e and that is given by this expression h_{ic} plus R_1 parallel R_2 parallel r_s divided by h_{fc} where r_s is the resistance of the signal source.

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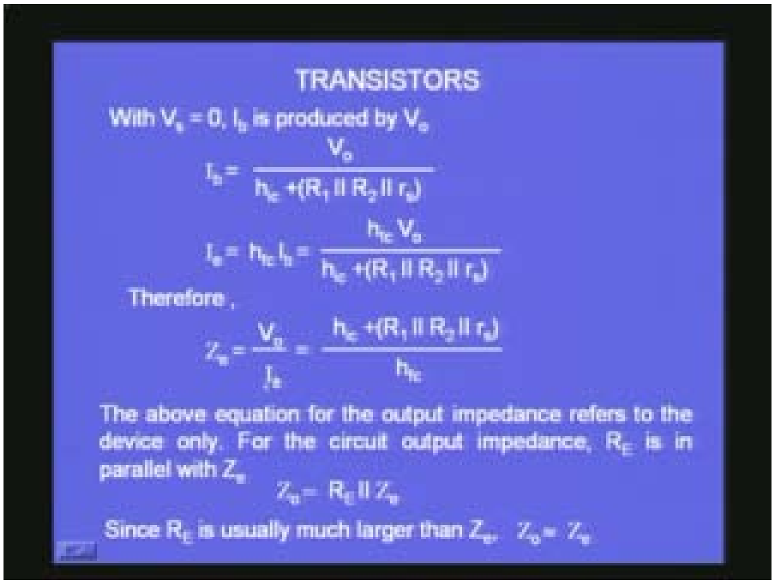

TRANSISTORS

With $V_s = 0$, I_b is produced by V_o

$$I_b = \frac{V_o}{h_{ic} + (R_1 \parallel R_2 \parallel r_s)}$$

$$I_e = h_{fc} I_b = \frac{h_{fc} V_o}{h_{ic} + (R_1 \parallel R_2 \parallel r_s)}$$

Therefore ,

$$Z_e = \frac{V_o}{I_e} = \frac{h_{ic} + (R_1 \parallel R_2 \parallel r_s)}{h_{fc}}$$

The above equation for the output impedance refers to the device only. For the circuit output impedance, R_E is in parallel with Z_e

$$Z_o = R_E \parallel Z_e$$

Since R_E is usually much larger than Z_e, $Z_o = Z_e$

The above equation for the output impedance refers to only the device emitter of the transistor. If I want the total output resistance of the common collector amplifier then the Z out is equal to R_E parallel Z_e. R_E is the resistance in the emitter that I have connected in parallel with Z_e and usually the Z_e factor will be very small compared to R_E the bigger part. This Z_e will be the one which will be finally deciding what the output resistance is. What about the voltage gain?

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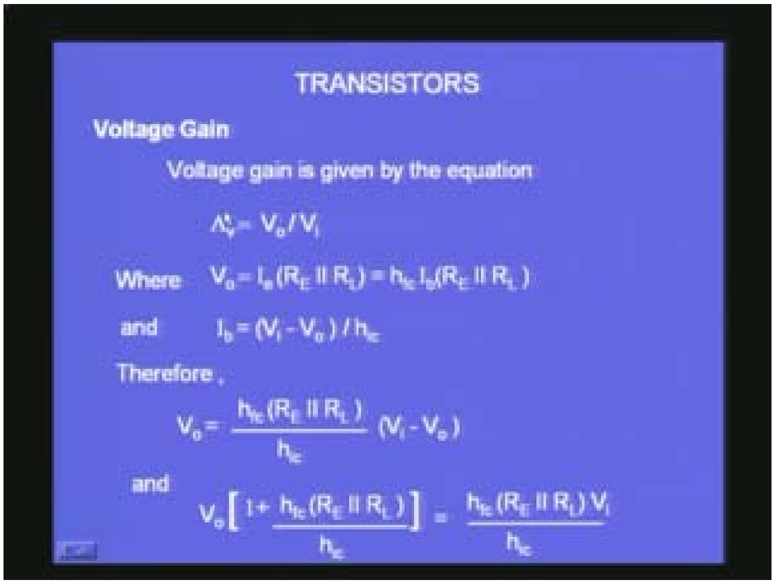

TRANSISTORS

Voltage Gain

Voltage gain is given by the equation

$$A_v = V_o / V_i$$

Where $V_o = I_e (R_E \parallel R_L) = h_{fc} I_b (R_E \parallel R_L)$

and $I_b = (V_i - V_o) / h_{ic}$

Therefore,

$$V_o = \frac{h_{fc}(R_E \parallel R_L)}{h_{ic}} (V_i - V_o)$$

and

$$V_o \left[1 + \frac{h_{fc}(R_E \parallel R_L)}{h_{ic}} \right] = \frac{h_{fc}(R_E \parallel R_L) V_i}{h_{ic}}$$

Voltage gain is the output voltage by input voltage. Output voltage is given by I_e multiplied by the parallel combination of R_E and R_L and that is h_{fc} into I_b into R_E parallel R_L and I_b is V_i minus V_o by h_{ic} and therefore the V output is h_{fc} R_E parallel R_L divided by h_{ic} V_i minus V_o from these two expressions and therefore you would find if I simplify this the voltage gain A_v is equal to V output by V input and that is given by the large expression that I get here. These two are almost equal. The numerator and one plus whatever term that I have in the denominator these two terms are identical and therefore if these two terms are very large compared to 1 then you know what is going to happen? The gain is almost going to be 1 and that is what happens in the common collector amplifier. The voltage gain of the common collector amplifier is almost equal to 1. It's actually less than 1, slightly less than 1. It can never be equal to 1 because V_E is V_b minus V_{be} that I have already mentioned.

What about the current gain? The current gain is given by I_e by I_b for the transistor and for the CC current, the common collector circuit it is h_{fc} R_B R_E divided by R_B parallel Z_b R_E parallel R_L.

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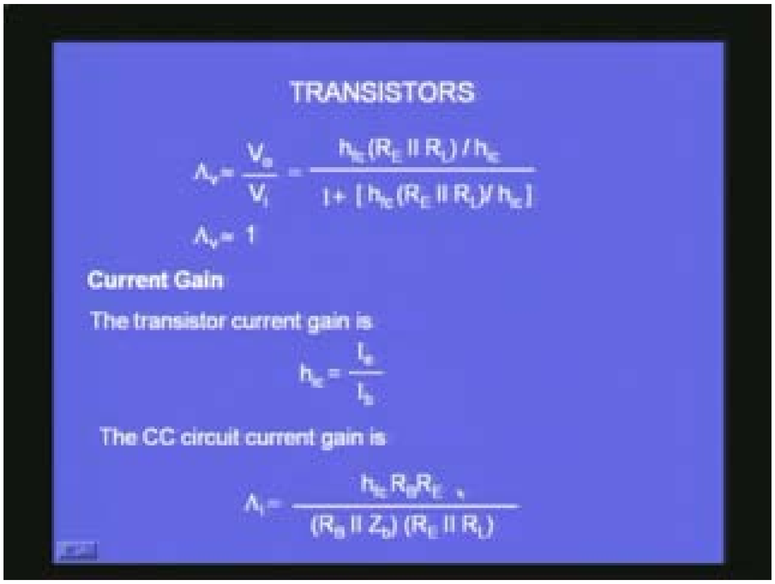

TRANSISTORS

$$A_v = \frac{V_o}{V_i} = \frac{h_{fc}(R_E \parallel R_L)/h_{ie}}{1+[h_{fc}(R_E \parallel R_L)/h_{ie}]}$$

$$A_v \approx 1$$

Current Gain

The transistor current gain is

$$h_{fc} = \frac{I_e}{I_b}$$

The CC circuit current gain is

$$A_i = \frac{h_{fc} R_B R_E}{(R_B \parallel Z_b)(R_E \parallel R_L)}$$

This is obtained because of the current division at the input due to R_B and Z_b and at the output due to R_E and R_L. So this is clear; got similar expression in the case of the common emitter amplifier and if you substitute the values you will get ….. and the power gain of the common collector circuit is very similar to the common emitter circuit. It is nothing but voltage gain multiplied by the current gain. The current will almost be equal to h_{fc} and A_v the voltage gain is almost equal to 1 and therefore power gain is almost equivalent to h_{fc}. The power gain is almost equal to h_{fc}, the current gain of the common collector transistor.

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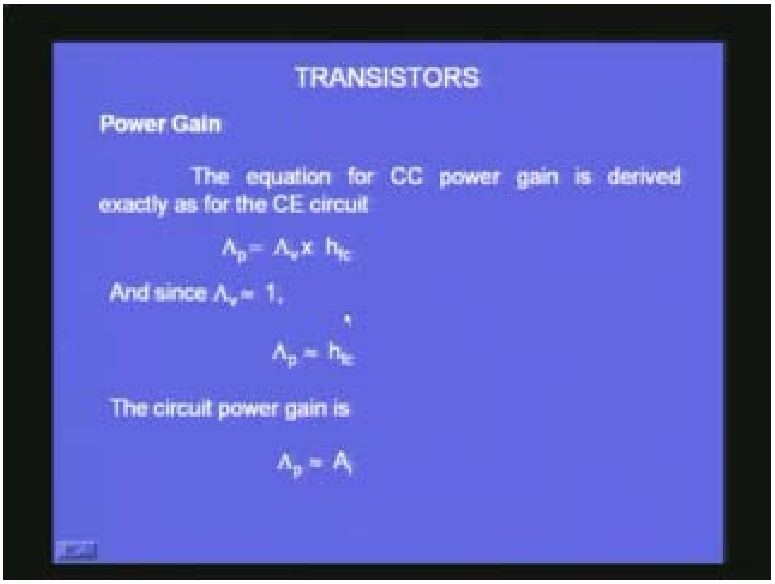

TRANSISTORS

Power Gain

The equation for CC power gain is derived exactly as for the CE circuit

$$A_p = A_v \times h_{fc}$$

And since $A_v \approx 1$,

$$A_p \approx h_{fc}$$

The circuit power gain is

$$A_p \approx A_i$$

The circuit power gain will almost be equal to A_i the circuit current gain because the voltage gain is 1. Having seen that let us just summarize the various numbers that we got. The Z_b which is input impedance at the transistor is given by h_{ic} plus h_{fc} into R_E parallel R_L.

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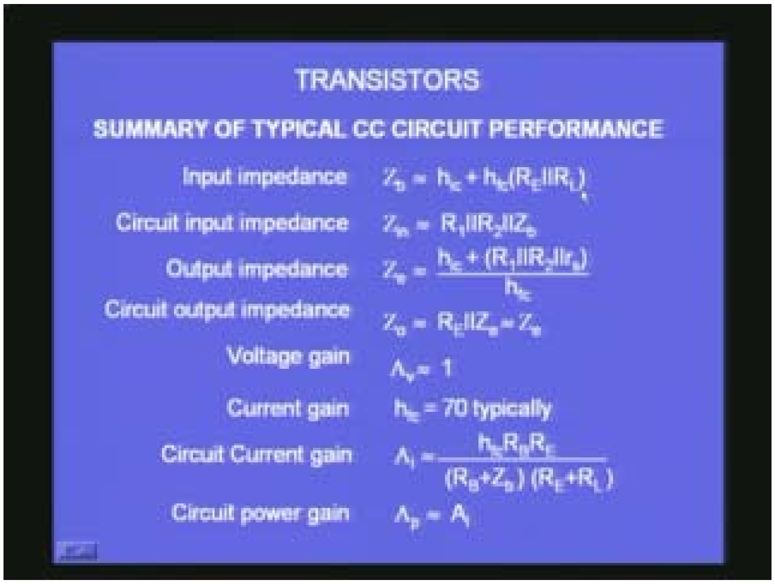

TRANSISTORS

SUMMARY OF TYPICAL CC CIRCUIT PERFORMANCE

Input impedance	$Z_b = h_{ic} + h_{fc}(R_E \| R_L)$
Circuit input impedance	$Z_{in} = R_1 \| R_2 \| Z_b$
Output impedance	$Z_e = \frac{h_{ic} + (R_1 \| R_2 \| r_s)}{h_{fc}}$
Circuit output impedance	$Z_o = R_E \| Z_e \approx Z_e$
Voltage gain	$A_v \approx 1$
Current gain	h_{fc} = 70 typically
Circuit Current gain	$A_i = \frac{h_{fc} R_B R_E}{(R_B + Z_b)(R_E + R_L)}$
Circuit power gain	$A_p = A_i$

Circuit input impedance is Z input which is parallel value of R_1 R_2 and Z_b. The output impedance at the transistor is Z_e which is given by h_{ic} plus R_1 parallel R_2 parallel r_s divided by h_{fc} the current gain and the circuit output impedance is given by R_E parallel Z_e and it will almost be decided by Z_e and this value will be very, very small. Z_e is almost decided by the h_{ic} divided by the h_{fc}, this value. It will be a very small value and that means the output impedance of the common collector amplifier is a very small value. Similarly the input impedance is going to be Z_b is almost equal to h_{fc} times R_E. This will decide what the input impedance is and this will be a very large value. The output impedance is a very small value and precisely for this reason this common collector or the emitter follower circuit is used in different applications, for impedance matching applications. Voltage gain is almost equal to 1, always less than 1 and the current gain is about 70 typically which is actually the h_{fc} and circuit current gain is very close to that value if you calculate and the power gain is equal to the current gain because the voltage gain is 1. The power gain is actually voltage gain multiplied by current gain because the voltage gain is 1 the power gain is almost equal to the current gain.

Let me just show you a very simple simulation of the same circuit common collector amplifier. This is the common collector amplifier on the screen. There is a R_1 R_2 voltage divider bias; you have a R_E, you do not have any resistor in the collector R_c. There is no R_c and the output load is R_L. Same is wired on this bread board. You have the transistor with a emitter base collector and you can see this is the emitter connected to the 1 kilo ohm resistor R_E and R_1 is around 30 kilo ohm and R_2 is around 6.8 kilo ohm and you have a coupling capacitor connecting it to the input signal source and there is an output coupling capacitor which is connecting it to a oscilloscope, one channel of the oscilloscope the output channel and similarly the input voltage is also connected to another channel of the oscilloscope.

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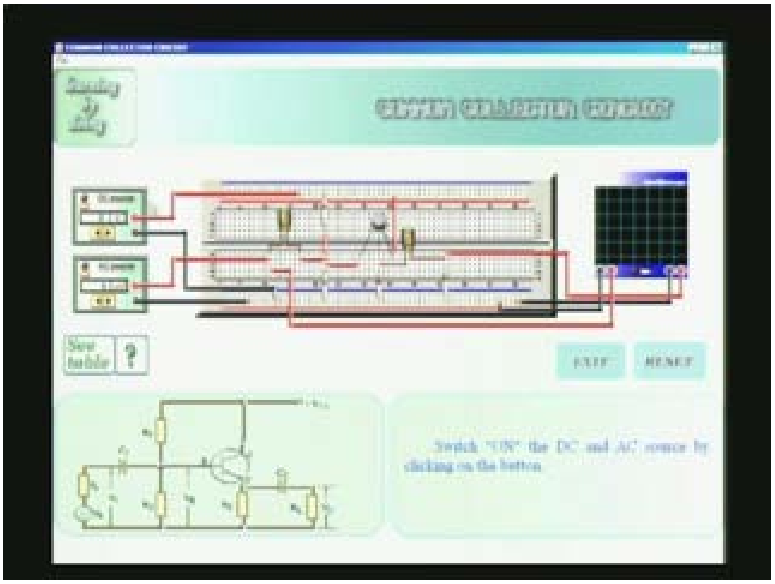

Switch "ON" the DC and AC source by clicking on the button.

You have the V_c power supply which is given for the V_{CC} and the ac voltage source can be varied using the bias here. Let me now switch on the power supplies and the oscilloscope. If I give about 2 milli volts at the input you find the output also is almost equal slightly less input and the output are almost equal.

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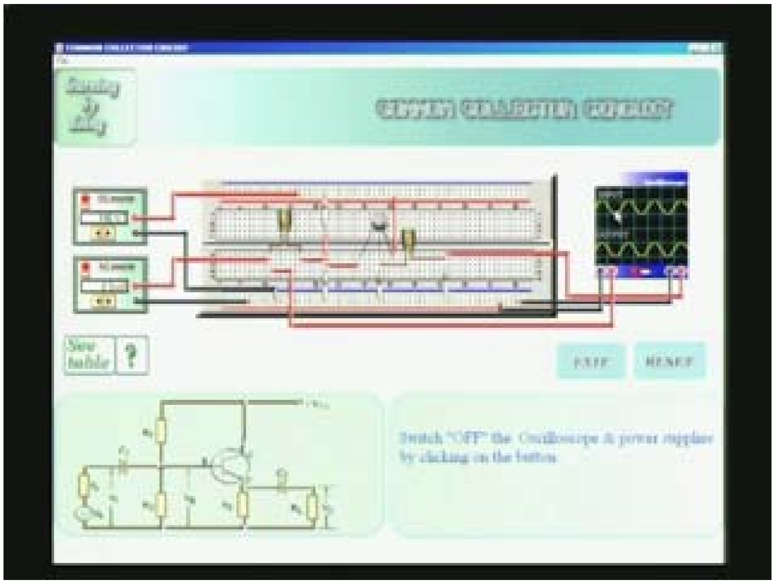

Switch "OFF" the Oscilloscope & power supplies by clicking on the button.

That means the gain is 1. We know that the gain is very close to 1 and the input impedance will be very large. You can measure input impedance in a similar manner that I mentioned with reference to the common emitter amplifier and the output impedance can also be measured and it will be very, very small and this amplifier has got not much gain but in terms of an application it is a very, very useful circuit because it is used for matching the impedances of the input and the output. Let me quickly close this and move on to the example. Let us try to look at a simple problem.

We will take a problem, the common collector circuit. The transistor parameters are h_{ie} 2.1 kilo ohm similar to the example that I took for a common emitter amplifier. h_{fe} is 75 and h_{oe} is 1 micro siemens. If R_E is equal to 5K calculate the input and output impedances and the voltage gain. Assume R_L is very, very large compared to R_E. So these are very useful for us and h_{ic} is actually h_{ie}. Both are equal and it is equal to 2.1kilo ohm. h_{fc} is $1+h_{fe}$ and it is around 76. h_{fe} is given as 75 therefore h_{fc} is 76.

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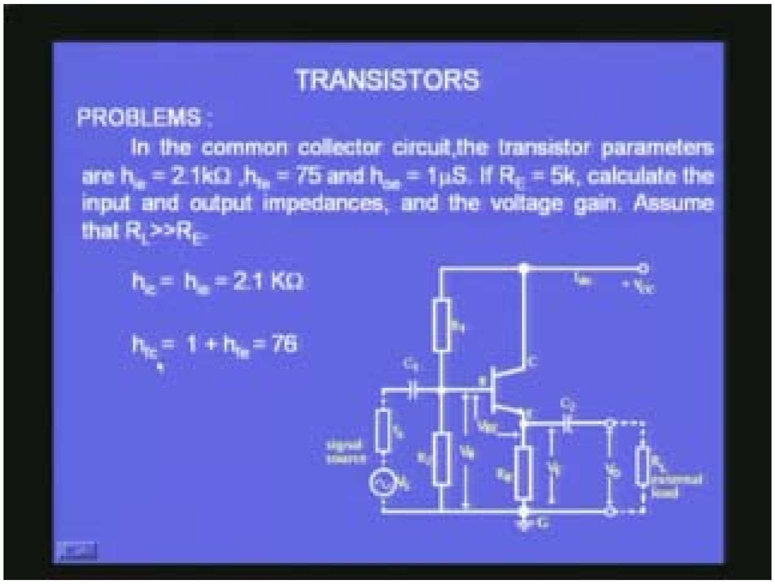

TRANSISTORS

PROBLEMS :

In the common collector circuit,the transistor parameters are $h_{ie} = 2.1k\Omega$,$h_{fe} = 75$ and $h_{oe} = 1\mu S$. If $R_E = 5k$, calculate the input and output impedances, and the voltage gain. Assume that $R_L >> R_E$.

$h_{ic} = h_{ie} = 2.1\ K\Omega$

$h_{fc} = 1 + h_{fe} = 76$

This is the circuit that we have and we have got the different expressions already. The input impedance at the base Z_b is equal to h_{ic} plus h_{ic} into R_E. That is 2.1 kilo ohm plus 76 times 5 kilo ohms and it is 382.1 kilo ohm. The product 76.5 is 380 and this 2.1 is very small compared to this product and therefore this is almost decided by h_{fe} times R_E factor. The input impedance of the transistor in the common collector mode is very high. What about the circuit impedance? Circuit impedance I have to include the other resistors R_1 parallel R_2 along with the Z_b and when I do that it is again the 10 kilo ohm and 10 kilo ohm that I have used. R_1 R_2 are very small compared to 382 and therefore the resistance will be decided only by the smaller value of the resistors R_1 and R_2 and that is about 4.94 kilo ohms.

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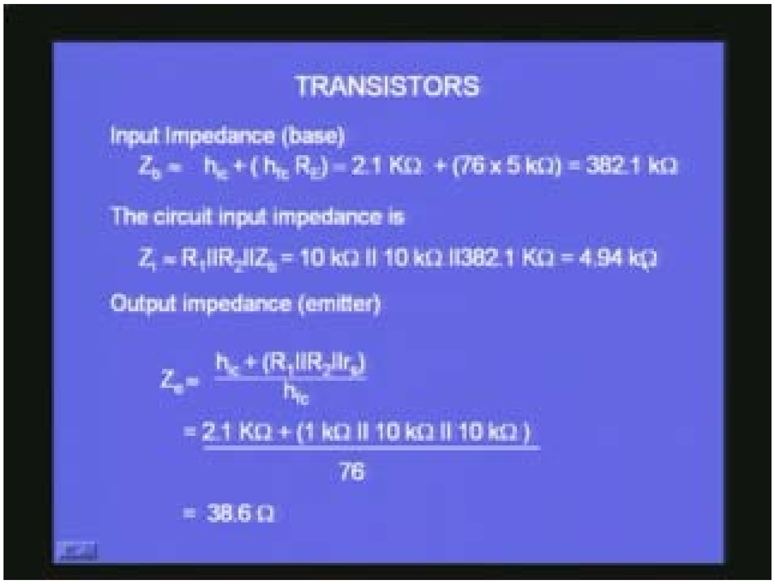

TRANSISTORS

Input Impedance (base)

$Z_b \approx h_{ic} + (h_{fc} R_E) = 2.1\ K\Omega + (76 \times 5\ k\Omega) = 382.1\ k\Omega$

The circuit input impedance is

$Z_i \approx R_1 || R_2 || Z_b = 10\ k\Omega\ ||\ 10\ k\Omega\ || 382.1\ K\Omega = 4.94\ k\Omega$

Output impedance (emitter)

$$Z_e \approx \frac{h_{ic} + (R_1 || R_2 || r_s)}{h_{fc}}$$

$$= \frac{2.1\ K\Omega + (1\ k\Omega\ ||\ 10\ k\Omega\ ||\ 10\ k\Omega)}{76}$$

$$= 38.6\ \Omega$$

What about the output impedance? At the emitter output impedance is given by h_{ic} plus R_1 parallel R_2 parallel r_s divided by h_{ic} and if I now do that 2.1kilo ohm, 1 kilo ohm is r_s value and 10 kilo ohm parallel 10 kilo ohm divided by 76 that is coming to about 36.6 ohms. So you can see the output impedance of the transistor is very small in the common collector mode. What about the circuit output impedance? Z_o circuit output impedance is R_E parallel Z_e because Z_e is very small, few ohms R_E is large 5 kilo ohms. The effective resistance will almost be decided by Z_e. The output impedance is around few ohms only; 38.3 ohms not kilo ohms just ohms.

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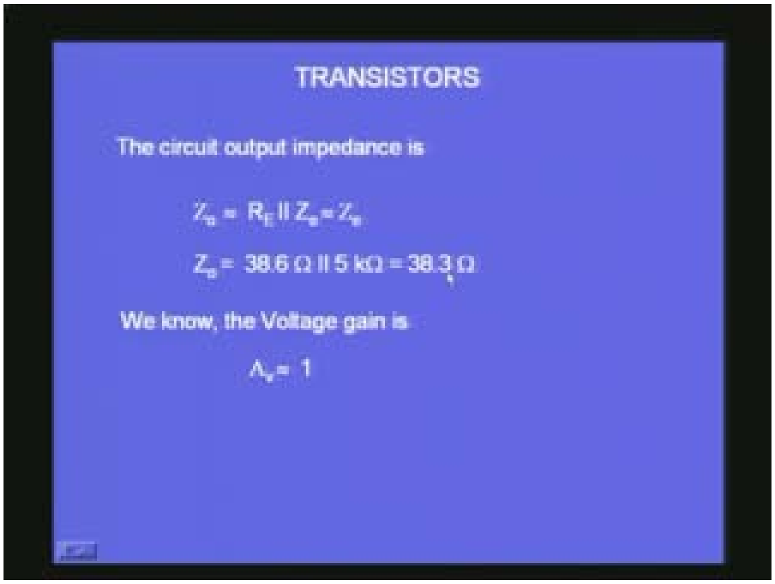

TRANSISTORS

The circuit output impedance is

$Z_o \approx R_E || Z_e \approx Z_e$

$Z_o = 38.6\ \Omega\ ||\ 5\ k\Omega = 38.3\ \Omega$

We know, the Voltage gain is

$A_v \approx 1$

So output impedance is very small, the input impedance is few kilo ohms and the voltage gain is 1. So we can see very quickly we can get all the information about the common collector amplifier.

Today what we have seen is the simple common emitter amplifier. We have discussed the h parameter in the previous lecture. So we took an example and worked out the various parameters like input impedance, output impedance and the current gain or voltage gain and then we also saw an actual demonstration of the common emitter amplifier and we saw there was a considerable gain and there was also inversion at the output between the input and the output 180 degree phase difference and then we also tried to measure the output impedance and the input impedance. Actually I did demonstration of the input impedance. How it can be measured by introducing another variable resistor in series with the signal source initially keeping it zero so that output voltage is obtained and then introducing this resistor till the output voltage becomes half of the previous value. When that happens the input resistance should be equal to the series resistance that I have included in the circuit and the input impedance can be measured by this scheme. Then we also took up a new configuration corresponding to common collector amplifier and the gain of the common collector amplifier was found to be almost equal to 1 or slightly less than 1. Even though the gain is 1 or less than 1 the circuit is of great importance to us because it has got very high input impedance and very low output impedance. This can be used in conjunction with a good amplifier like a common emitter amplifier which has got a very high gain so that the load can be connected directly with maximum power transfer. This is used as an impedance matching circuit. The common collector amplifier or the emitter follower is used as a circuit for matching the impedances at the input and the output of any load. The emitter follower, the name itself suggests that emitter voltage follows the input voltage. That is why it is called emitter follower and that is also the reason the phase difference between the input signal and the output signal is zero. It is almost in phase and therefore it is called emitter follower. The output is almost following the input variations. We also discussed the various parameters h parameters, analysis of the common collector amplifier or the emitter follower and then we took a very simple example numerical example and worked out the various parameters like the input impedance, output impedance at the transistor and then for a divider voltage bias circuit and then we saw also that the output impedance is only about few ohms whereas the input impedance is few kilo ohms and therefore the characteristics of the common collector amplifier or the emitter follower namely the output impedance is very small, input impedance is very large is brought about in this example. That is what I have shown.

Next perhaps we will move on to the frequency response of the amplifiers. We have always considered 1 kilo hertz as the operating frequency which is called the mid band frequency. That is the normal audio frequency that we worry about and we should also see the frequency response of the amplifier at the extremes. When I go to very high frequencies and when I come to very low frequencies how the amplifier will behave is also of importance. We will try to take up the frequency response of amplifier in the next lecture. Thank you!