Basic Electronics
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Lecture – 25
BJT amplifier

Welcome back to Basic Electronics. One of the major applications of BJT or even other transistors is amplification. In this lecture we will look at the basic idea behind amplifying a signal with the help of a BJT. We will then look at simple BJT circuit which can be used as an amplifier, by suitably selecting the resistance values. Let us begin.

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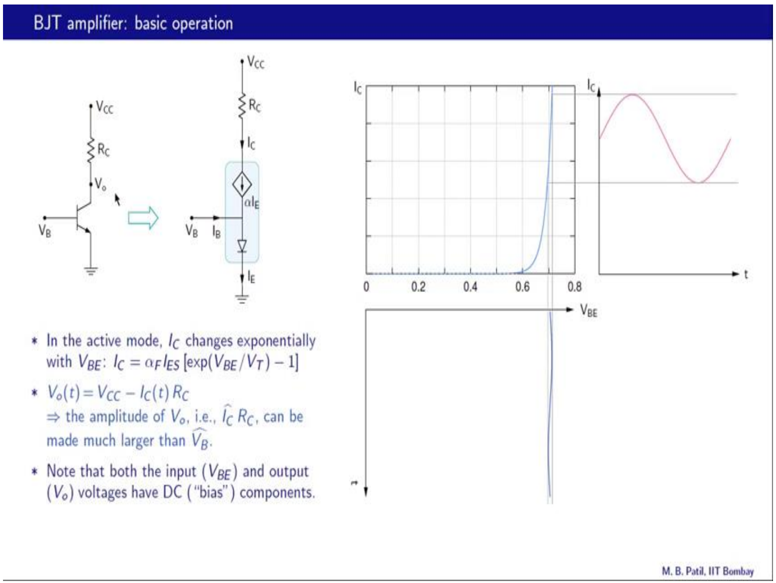

We are now going to discuss a BJT amplifier circuits. And let us begin with basic idea behind BJT amplifier shown here. Here is an NPN transistor, voltage source is connected here, voltage supplier V CC. And there is the resistor R C. When we replace this NPN transistor with it is equivalent circuit we get this circuit here. Assuming of course, that the transistor is operating in it is active mode or the linear region. And therefore, we have a diode and a current controlled current source. Let us look at the plot of I C versus V BE. Now V BE is the same voltage as the voltage across the diode here, and therefore I E versus V BE is going to look like a diode I V curve. What about I C? I C is simply proportional to I E, equal to alpha times I E. In fact, I C is approximately I E because alpha is generally closed to one. And therefore, I C versus V BE is also going to look like a diode I V curve and that is exactly what we see over here. Up to about 0.6 the current is very small and then it takes off and becomes appreciably large.

Let us see what happens if we apply a time dependent voltage at the base, which is the same as V BE. So, that is V BE as a function of time. So, we have a sinusoidal varying V BE here, it is not sinusoidal with 0 average value it has got some DC value around which it varies. And as V BE varies the collector current also varies. For example, this maximum V BE corresponds to this maximum I C here and the minimum V BE corresponds to this minimum I C here. And of course, there is variation from the maximum to minimum in between. So, let us summarize in the active mode I C changes exponentially with V BE as we just saw. I C given by alpha f times I E and I E in the active mode is I E s times exponential V BE over V T. This one of course, is too small. So, that is how I C varies.

Now, the output voltage which we take at this node at the collector right there is V CC minus this I C R C drop. And since I C is varying with time V o also going to vary with time. And the amplitude of V o can be made large that is I C cap times R C where I C cap is the amplitude of the I C waveform. So, that is from there to there. And we can arrange the resistance value and V CC supplier value etcetera. So, that the amplitude of V o that is I C cap times R C can be made much larger than V B cap. What is V B cap that is the amplitude of this sinusoidal here? So, our input voltage has an amplitude of V B cap and the output amplitude can be much larger and that is how we have an amplifier. So, that is the basic principle of BJT amplifier.

One very important point to note here is that both the input that V BE and the output voltage V o have a DC component. For example, V BE is not varying around 0 here it is varying around some DC value. Similarly, I C is not varying around 0 here it is varying around some DC value. And V o also will do the same. So, this is very important point and let us make a note of that.

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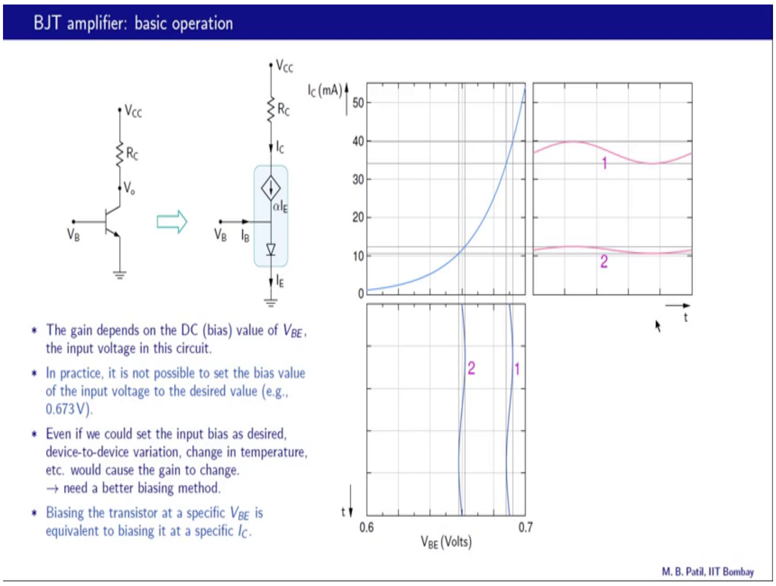

We now want to look at the effect of the DC component of the input voltage V BE on the amplitude of the output voltage. So, here is V BE and that is I C. Similar to what we had in the last slide except, we now have V BE going from 0.6 to 0.7 volts and that is our I C, I C versus V BE. We are going to apply 2 voltages. 2 input voltages both sinusoidal one and 2. And their amplitudes are identical. The only difference is that their DC components are different. So, this voltage one, input voltage one is centered around this DC value whereas, input voltage 2 is centered around this DC value here.

We can map these input waveforms one and 2 to the collector current versus time plane and that is what we have done here. And we notice that there is a substantial difference between the amplitudes for the second waveform and the first waveform. And this change in amplitude between these 2 cases is not because these amplitudes are different. In fact, these are the same. It is entirely because these 2 wave forms differ in their DC values. And if I C of t has a different amplitude in these 2 cases Vo of t will also have different amplitudes, that is because the amplitude of V o is simply, the amplitude of I C times R C, or V o cap is I C cap times R C as we saw in the last slide.

So, let us note down these important points. The gain that is the amplitude of V o versus the amplitude of V BE depends on the DC or the biased value of V BE. The DC value around which these input waveforms are centered that is called the DC or biased value of V BE. Now in practice we might say that this looks better than the second waveform and therefore, let us choose the DC value to be this one rather than this one, but it is not really possible to set the bias value of the input voltage, to the exact desired value that we would like for example, 0.673 volts. We simply do not have that kind of a voltage supplier. And even if we could set the input bias as desired for example, by some means we manage to set it to that value there is still a problem, because there is a device to device variation. There is a change in temperature etcetera. And all of these things would cause the gain to change.

So therefore, we are building the circuit with the certain gain in mind and after we build it we will find that the gain is something else and we would not really know what exactly went wrong. Clearly we need a better biasing method, this kind of extreme filter and so on. The exact DC value is not really helping us. Finally, let us note also that biasing the transistor at a specific V BE is equivalent to biasing at specific I C. And that is simply because there is a mapping between the DC value of this input curve and the DC value of the I C versus t curve.

So, that is an important observation and In fact, we are going to use that when we study amplifiers. Before leaving this slide let us look at this point in more detail. What exactly do we mean by device to device variation. What we mean is this curve which is I C versus V BE, would change from device to device, and as because there are variations in the doping densities or geometry etcetera of devices. So, instead of this curve suppose we had a different curve let us say something like, this that would change the mapping between the input and the output and we will get an entirely different collector current versus time for a while.

Similarly, if there is a change in temperature for example, you are expecting the circuit to operate at 25 degrees and it is actually operating at 40 degrees. Then what happens, then this curve is going to shift, it turns out that at higher temperature this shift will be in that direction. And once again because of that the same input voltage will now result in some other I C of t, and that is why even if we could set this input bias exactly as we want it there is still a problem and calling for a better biasing method.

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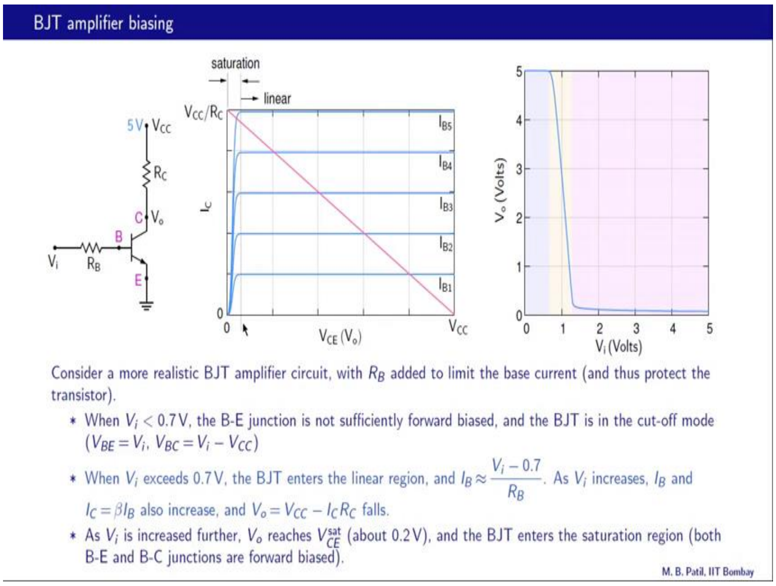

Let us consider a more realistic BJT amplifier circuit this one, in which we have added this base resistance R B and that helps to limit the diode current here. If the diode current increases then this voltage drop also increases and therefore, even if V i is large like 5 volts, the base emitter voltage is still limited to something like 0.7. And thus the transistor is protected. If the current became very large like amperes, then the heat generated in this device would destroy the transistor.

So, these are much more realistic amplifier circuit as compared to the last one and let us see how this one works. We are plotted the I C versus V CE for this transistor. What is V CE? V CE is a same as V o that is what we have mentioned here. And here is the load line that is imposed by this resistance R C here. And we have seen this earlier. Just to revise when the collector current is 0, V CE is equal to V CC, and that should be obvious also from this figure. If there is no current here, then V o or V CE is the same as V CC because there is no voltage drop there.

On the other hand, if V CE is 0 if this was 0 volts then this current would be V CC minus 0 by R C that is V CC, by R C that is what is shown over here. And for the transistor we have this family of curves one corresponding to IB1, 1 corresponding to IB2 and so on. And IB2 of course, is greater than IB1. IB3 is greater than IB2 etcetera. When V i is less than 0. 7 volts the base emitter junction is not sufficiently forward biased and therefore, this diode current is negligibly small. No voltage drops here across R B and V B is then the same as V i. If the diode is off the transistor is in the cut off region as mentioned here and therefore, there was no collector current, V o gets pulled up to V CC.

So, V BE is then the same as V i which is not yet 0.7 volts and V BC is V i minus V CC, and that definitely is a reverse bias. Where are v in this figure the base current is 0 so; that means, we there is one I C curve coinciding with the x axis, here and that is where we are. The operating point then is the intersection of this I C V CE curve and the load line that is right here. So, our V CE is the same as V CC. Where are we in this figure we have not yet reached 0.7 volts all the turn on voltage for the transistor and V o is then V CC which is 5 volts here. This is V i and that is Vo.

When V i exceeds 0.7 volts then the BJT turns on, and it enters the linear region. What do we have for IB then, IB this current is V i minus this voltage drop, which we will say is about 0.7 divided by R B. So, that is V i minus 0.7 by R B and as V i increases IB also increases and therefore, I C also increases, now if I C increases this current increases what happens to V o this voltage drops increases and therefore, V o which is V CC minus that voltage drop will decrease. So, that is what it says here, V o which is equal to V CC minus I C times R C starts falling.

So, let us see where we are in this figure now, now we have finite IB non-zero IB and the IB value is increasing as V i is increasing. So, we are now moving from this curve to that curve to that curve and so on. And as a result the intersection of the load line and the I C V CC curve also goes on changing. So, this was our output voltage earlier, when the base current is IB1 the output voltage is here, when the base current is IB2 the output current is here, sorry the output voltage and so on.

So, the output voltage starts falling for sure. And that is also apparent in this figure. V i is increasing here IB is increasing, I C is increasing, and therefore, V o is falling. And that fall can be seen right here. As we keep increasing V i, the output voltage V o will reach V CE at some point. What is V CE sat it is the value of V CE in the saturation region. So, it is between 0 and 0.2 and we often take it approximately as 0.2. And when that happens the BJT enters the saturation region that is both the base emitter and base collector junctions are now forward biased. What is happening in this figure our V i is increasing. So, our base current is also increasing, and the intersection of the I C, V CE curve and the load line is also therefore, shifting.

Now, here we are still in the linear region, but for IB equal to IB5, we now enter the saturation region. So, that is how the transistor has entered the saturation region and what happens if we increase the base current further, let us say we are on I C V CE curve here that curve would go like that and then in the saturation region it will come down, and again the intersection would be somewhere there. And what we just discussed also reflects in the V o versus V i curve. This was cut off then as we kept increasing V i the transistor entered the linear region, and finally it reached the saturation region and then it stays in the saturation region.

To summarize, we have look at how a BJT can be used for amplification. We have also seen a simple BJT circuit that can work as an amplifier in the next class, we will continue with this simple circuit, and then identify important issues which must be considered in building practical amplifier. That is all for now see you later.