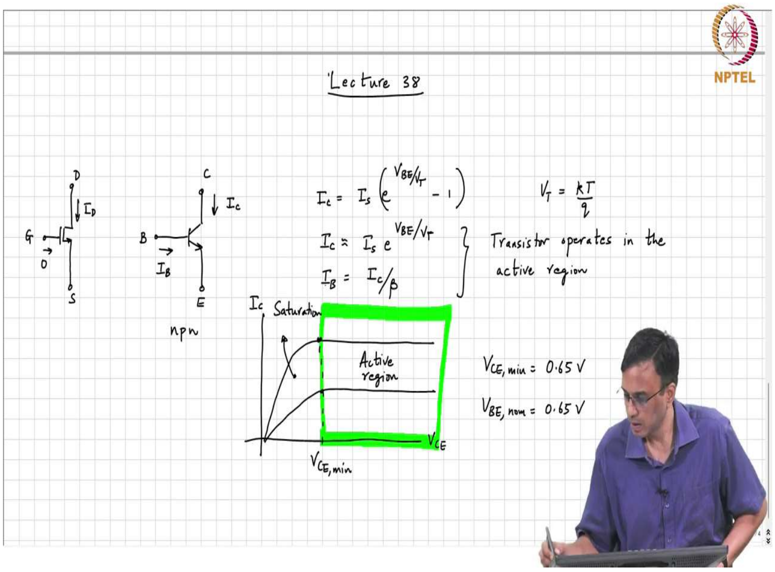
Analog Electronic Circuits
Prof. Shanthi Pavan
Department of Electrical Engineering
Indian Institute of Technology, Madras

Lecture - 80
Bipolar Junction Transistor Circuits-Device Equations and Small Signal Model

(Refer Slide Time: 00:19)



So, for the course of the last 37 lectures, we have basically seen you know how to work with MOS transistors. And as you can very well imagine there are other possible devices which also are capable of amplification. And like we discussed in the early part of this course, those devices also exhibit basically very similar characteristics.

So, here is an example of another device that exhibits similar kind of characteristics and you know I would like to draw your attention to the similarity with respect to the MOSFET. So, in the MOSFET this is the gate, this is the drain, and this is the source and this is the drain current I_D. The gate current I_G was 0 and therefore, the drain current and the source current are equal.

Now, in the bipolar transistor this terminal is called the base, this is called the emitter, and this is called the collector. And the collector current is obviously I_C. And the collector current is related to the base emitter voltage as,

$$I_C = I_s\left(e^{\frac{V_{BE}}{V_T}} - 1\right)$$

And where V_T in the bipolar case is the thermal voltage kT/q. It is not to be confused with the threshold voltage of the MOSFET. And so, for sufficiently large V_{BE} I mean, so V_{BE} in excess of a few V_T, we see that this is approximately $I_s\left(e^{\frac{V_{BE}}{V_T}}\right)$, ok.

Now, how this equation comes about is you know again left to the device physics guys. So, they basically you know look into the device and then do all sorts of fun stuff and finally, come up with these equations. And these are all that these equations are all that we are concerned about, correct.

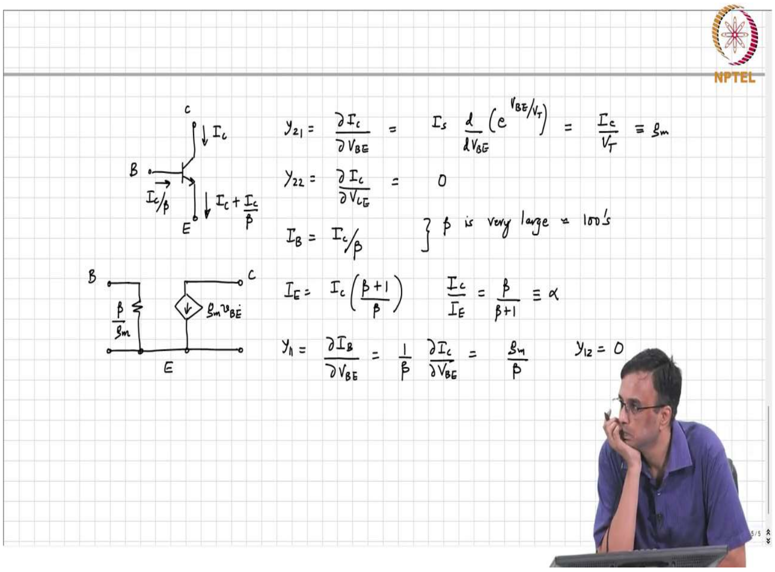
And so, unfortunately it turns out that the base current which is analogous to the gate current in the MOS transistor is not 0, it just turns out that $I_B = I_C/\beta$, alright. And so, if you now think that all this is provided, the transistor operates in the active region, and again, we need to go back to device physics to figure out you know the limits of the active region.

But we know that the characteristics, that is if you plot I_C versus V_{CE}, the output characteristics in the case of the bipolar transistor, this is called the npn transistor, analogous to the NMOS transistor and the output characteristics are I_C versus V_{CE}, right, alright. And so, you can plot them for different values of V_{BE}. And it just so turns out, just turns out that the minimum V_{CE} = 0.65 volts.

And the base emitter voltage is just like a diode, if you have a transistor operating in the active region, the nominal base emitter voltage is also about 0.65 volts, ok. Just like a forward biased diode. And so, as a lot of this is the, this region here is the active region and rather unfortunately this region is called, this region is called saturation, ok because in this case it has to do some connotation with what happens in the device. So, but I mean this can be a bit confusing, right.

In a MOS transistor, you want to operate in the saturation region which corresponds to the active region of operation for the MOSFET. But you know that is basically not where you want to operate, saturation is not the region you want to operate when you are working with a bipolar transistor, ok.

(Refer Slide Time: 06:35)



So, now that we have done this, the next thing to do is basically figure out what these device equations are. The next thing to do is figure out what the small signal models for the transistor are. And again, once you ensure that the transistor is operating in the active region, then as usual we will go and figure out what the incremental y matrix is.

What is the incremental y matrix? y_{21} which is the change in the collector current due to a change in the base emitter voltage. Now, earlier it was I_D though, change in I_D versus due to a change in the V_{GS}. Now, you know it is just changing terminal names. So, basically, change in the collector current due to change in the base emitter voltage. And that basically as you can see is I_{Sd}/V_{BE} of I_C which is $e^{\frac{V_{BE}}{V_T}}$ and that is simply I_C/V_T, ok. So, you know the nice thing about this is that regardless of the saturation current I_S, the trans conductance of the device is simply I_C/V_T, where V_T is the thermal voltage.

There are no square roots, μ and C, all that complicated stuff is not there anymore, that way calculation of the trans conductance is very simple.

What about y_{22}? The change in I_C due to a change in V_{CE}, right. And in the active region the current does not depend on the collector emitter voltage. So, this basically is 0, alright. Now, the base current, so is the collector current by β. Typically, β is very large, meaning you know you know 100 or a few 100s, ok. And therefore, this I mean admittedly this base current you know is small. Ideally, it is supposed to be a very very tiny fraction of the collector current.

So, if this is I_C, this is I_C/β, what is the emitter current? I mean simply that if you draw a node around a surface around these three terminals, the net current coming in must be equal to the net current going out. So, this must be $I_C + I_C/\beta$. So, the ratio that the emitter current therefore, it is nothing but $I_C (\beta + 1)/\beta$.

And so, often rather than code β which is a large number manufacturer's code I_C/I_E which is $\beta/(\beta + 1)$ and this is defined to be alpha. So, this α is a number close to 1. And it is telling you how much of the collector current is, I mean how much of the emitter current is lost in the base.

Now, with this, what is y_{11}? It is $\partial I_B/\partial V_{BE}$, and which is $1/\beta \; \partial I_C/\partial V_{BE}$ which is g_m. So, by the way as usual this is called the trans conductance of the transistor g_m. So, this is nothing but g_m/β. Does it make sense, ok.

So, and y_{12}, again the base current does not depend on the collector emitter voltage, right and therefore, y_{12} is 0. So, the small signal equivalent of the mass of the bipolar transistor therefore, you can see is y_{11} which is basically now a resistor of value $\beta = g_m$, and there is, this is $g_m \, V_{BE}$.