ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

2.1-Transistor Bipolaire Modélisation

Modèle linéaire petits signaux

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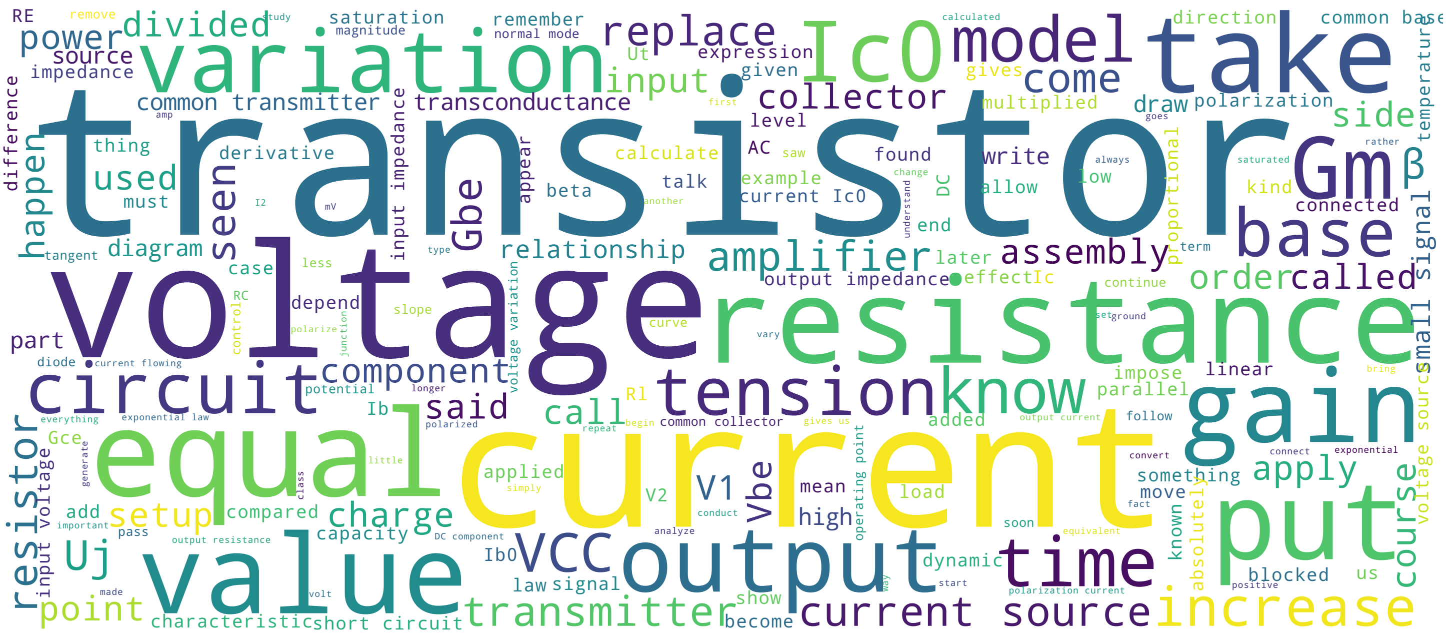
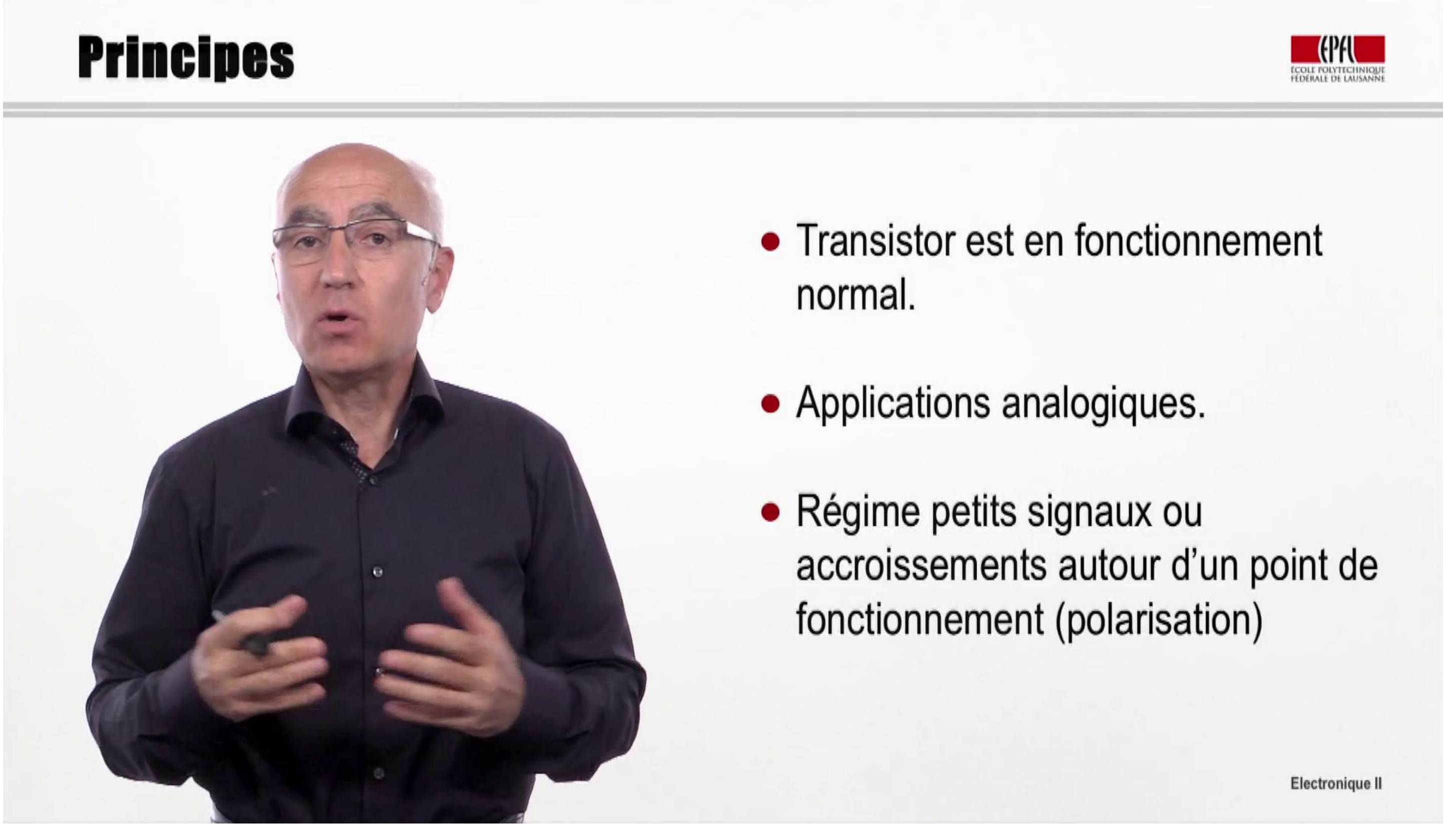


Video

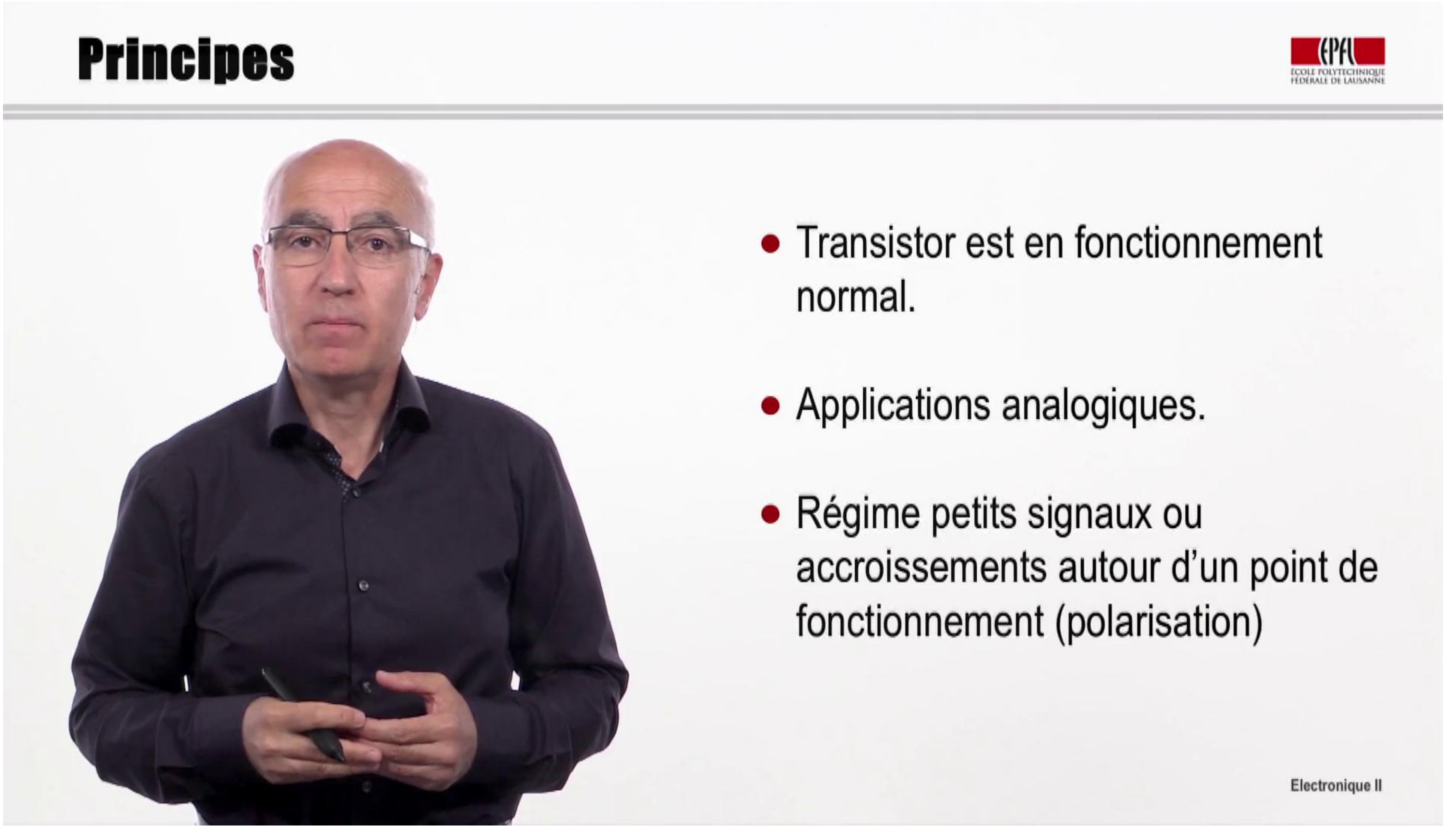


Good morning everyone. Today we'll tackle small signals models. Small signal models it's really the essential of transistor use in the analogic circuits. As you know, the world around us is more analog in nature than digital. And we want to make linear functions and the transistor in its normal operation, should allow us to use it in functionalities mainly analog. So we'll spend some time to model it so that it is quite linear between the input voltage and the output current which is of interest to us. So understand this transistor capability to play its transconductance role. To study the different principles, how we make a transistor useable as a linear analog component, we will study it first by looking at the unique feature that allows us namely the normal mode. Therefore a transistor which is used as component in its linear region, should not be neither saturated nor blocked. And if you remember this, you begin to understand that all along this part your transistor is in normal mode. And you will always check that it is never saturated or blocked when we apply to it a voltage that can push it towards saturation or blocking. So, it was very clear that saturation or blocking is due to your circuit and not the transistor itself.

Notes

Summary

0m 04s

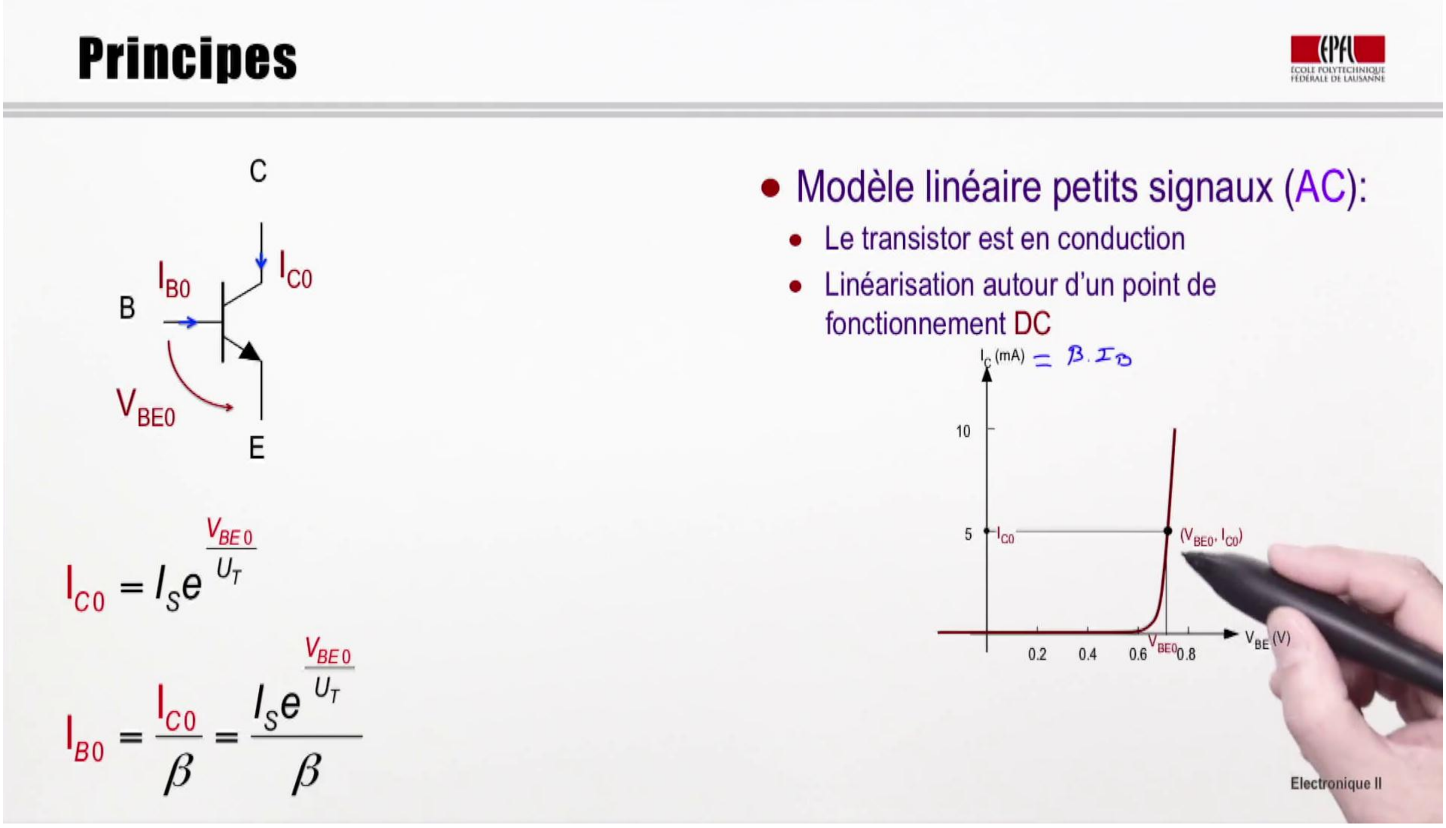


If your circuit blocks the transistor by a supply voltage or prevents current from flowing in for a certain dynamic, well know that your transistor is no longer in normal mode. So the transistor should be in normal mode. It is mostly used for analog circuits. And we will introduce the concept of the increment. Increments, it means tiny variations. And we call this, the small signals. Which gave the name to this model that we will study called the small signals transistor model or model for increase.

Notes

Summary

1m 41s

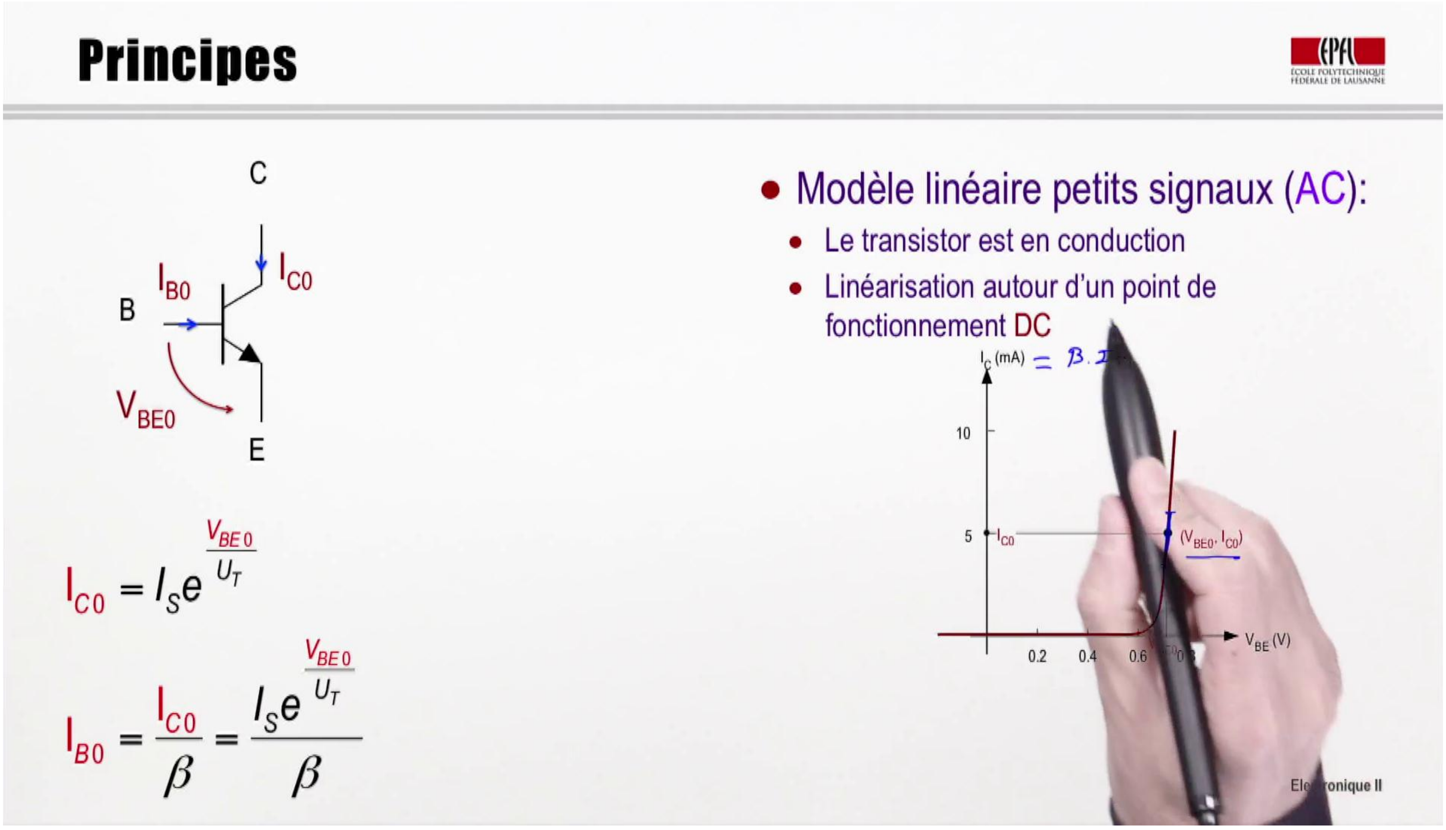


I would like to come back to the transistor seen with the symbol and remind you very quickly it is nonlinear. Look at the current controlled by the voltage, it gives us an exponential law so it is not linear. If you look here, you'll see the same for the base current in the transistor since the relationship is linear with Ic0, first approximation, we have to divide it by the β of the transistor and we get the current Ib0. So Ic0 and Ib0 give us two laws that are exponential and not linear. And we will see this law that is here. Here we drew Ic. I can easily write it = β.Ib. And this allows us to see that Ib is nothing other than this exponential curve also divided by β. Therefore the transistor when it will be used, it should be conducting. So we said here, it is blocked. Here it will conduct and the saturation, is due to something related to your circuit. So what is certain is that you have to apply to your transistor, a current called polarization current. Why do we do this ? It's that we want linearize the transitor function that is nonlinear. Look at it very well. It is a nonlinear function. It's all that. But we will focus on an operating point and it is called operating point.

Notes

Summary

2m 16s

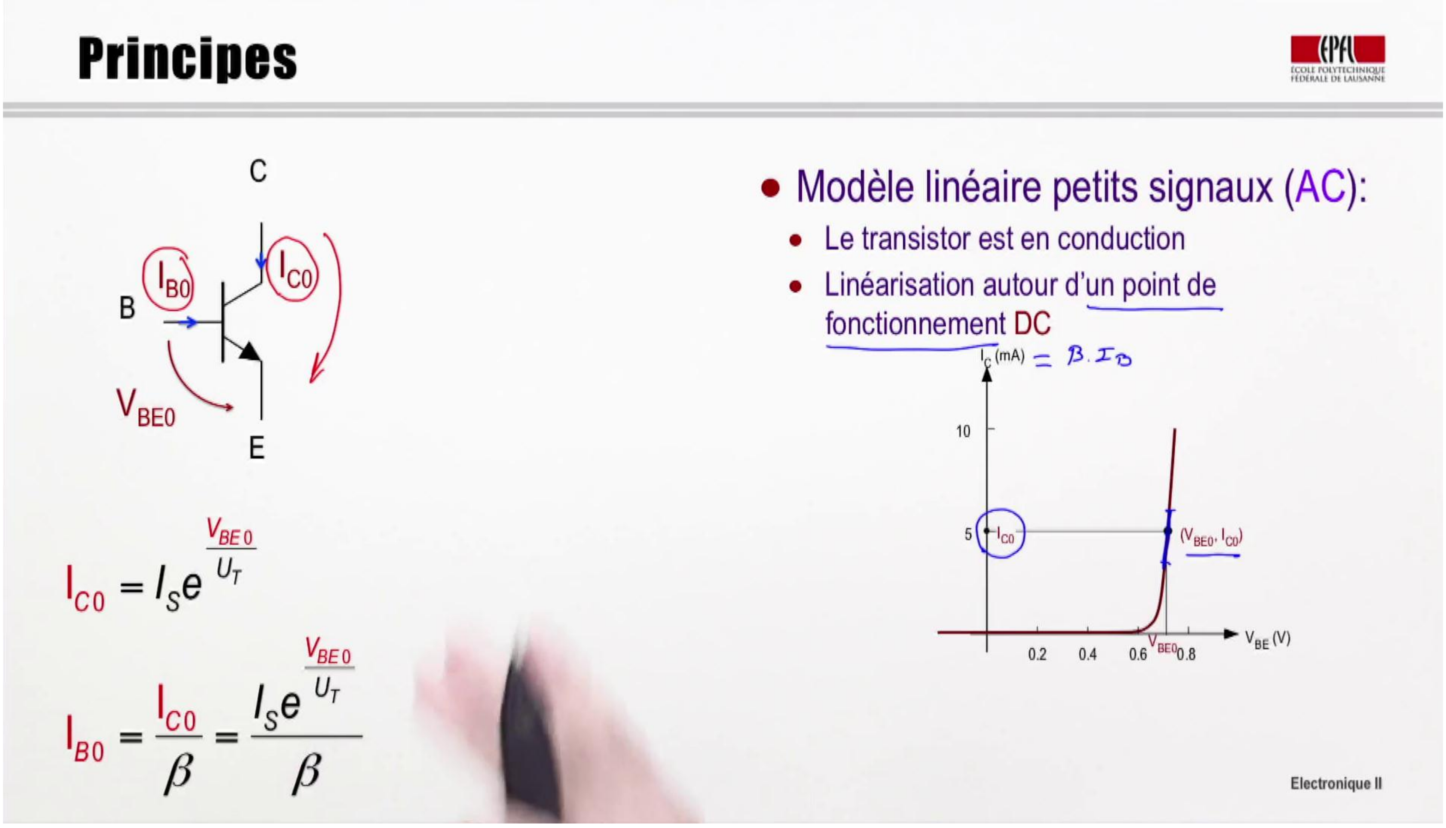


We will go to that point. We apply a direct current in the transistor that will generate a given Vbe0 voltage. And once there is this current that flows in the transistor and this Vbe0 voltage, we will focus on a small portion of this exponential law to say, and if ever we limit the dynamics of the signal we impose between the base and the transmitter, this variation about a few mV, very very few dynamics between the base-transmitter junction, which controls the current, it is sure and certain that this change, this range will generate an almost linear current regarding it. And if we say almost linear, it is as if it had been a small line that was completely confounded with the characteristic itself of the transistor. And we call it, the tangent at an operating point. Someone who understood the operation, has understood that first, we need to apply it. That's the first thing. So we can not use a transistor in an AC mode without applying a DC component. So we will all the time superimpose the AC and DC in order to use the transistor. You must bring it to a selected operating point because it is you who will choose the the most important parameter and you will see that it is the most important thing, it is the polarization current.

Notes

Summary

3m 45s

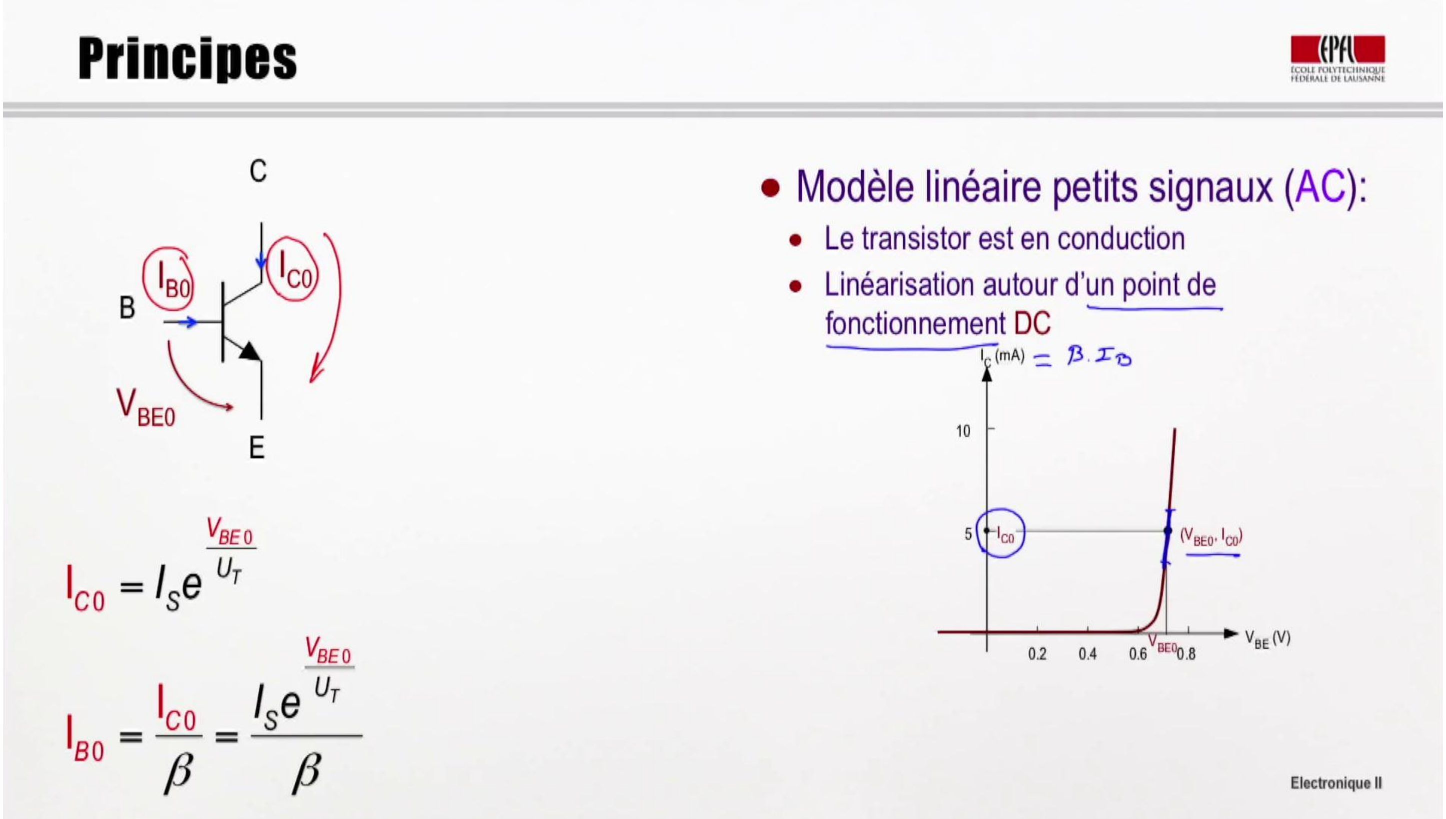


Nobody looks at what is Vbe0. This would give something only if you replace it, Ic0 and you look for the corresponding Ib0 provided that you know the Is, I remind you that the thermodynamic voltage is 26 mV. You have a Vbe0 voltage, but no one will see what it is,because we're polarizing the current. Once we do that, we will say what is the slope of the tangent here. And then we will move to a variable component around Vbe0 which will be superimposed around this value which we do not know, the Vbe0. And we will see that a variation will be seen, that goes around Ic0, that had been applied in the transistor, to vary the current here. And that's it, we have a line between the variation of the input voltage versus the variation of the output current. And that's the famous transconductance of the transistor that we seek to define and model. So I repeat, we will no longer look at the transistor as such because it will contain two things. It will contain what is in red, namely everything that concerns direct current, DC voltage. So this voltage, will be continuous. So there will be a variety of continuous components.

Notes

Summary

5m 16s



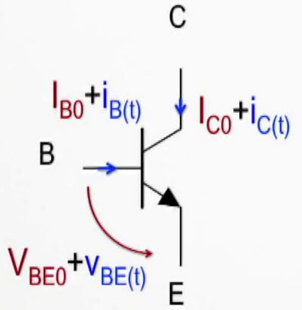
But that is independent of the use of transistors because after we move to a model so it is not the reality it is a model we will confound in a non linear law that will come out of this analytical law here, a transconductance which is linear because it will bind a variation of the input voltage to the variation of the voltage, the output current. That is what we will do.

Notes

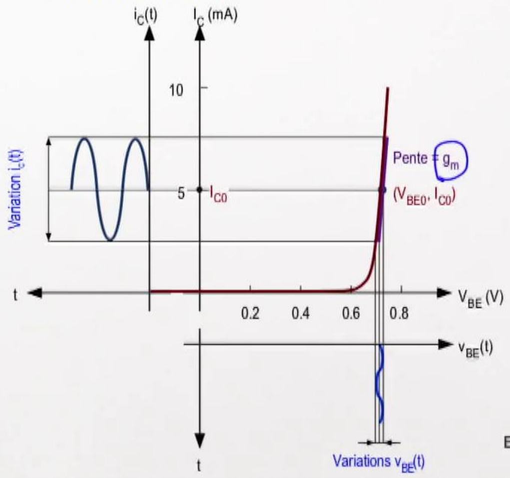
Summary

6m 40s

Principes



- Modèle linéaire petits signaux (AC):
  - Le transistor est en conduction
  - Linéarisation autour d'un point de fonctionnement DC



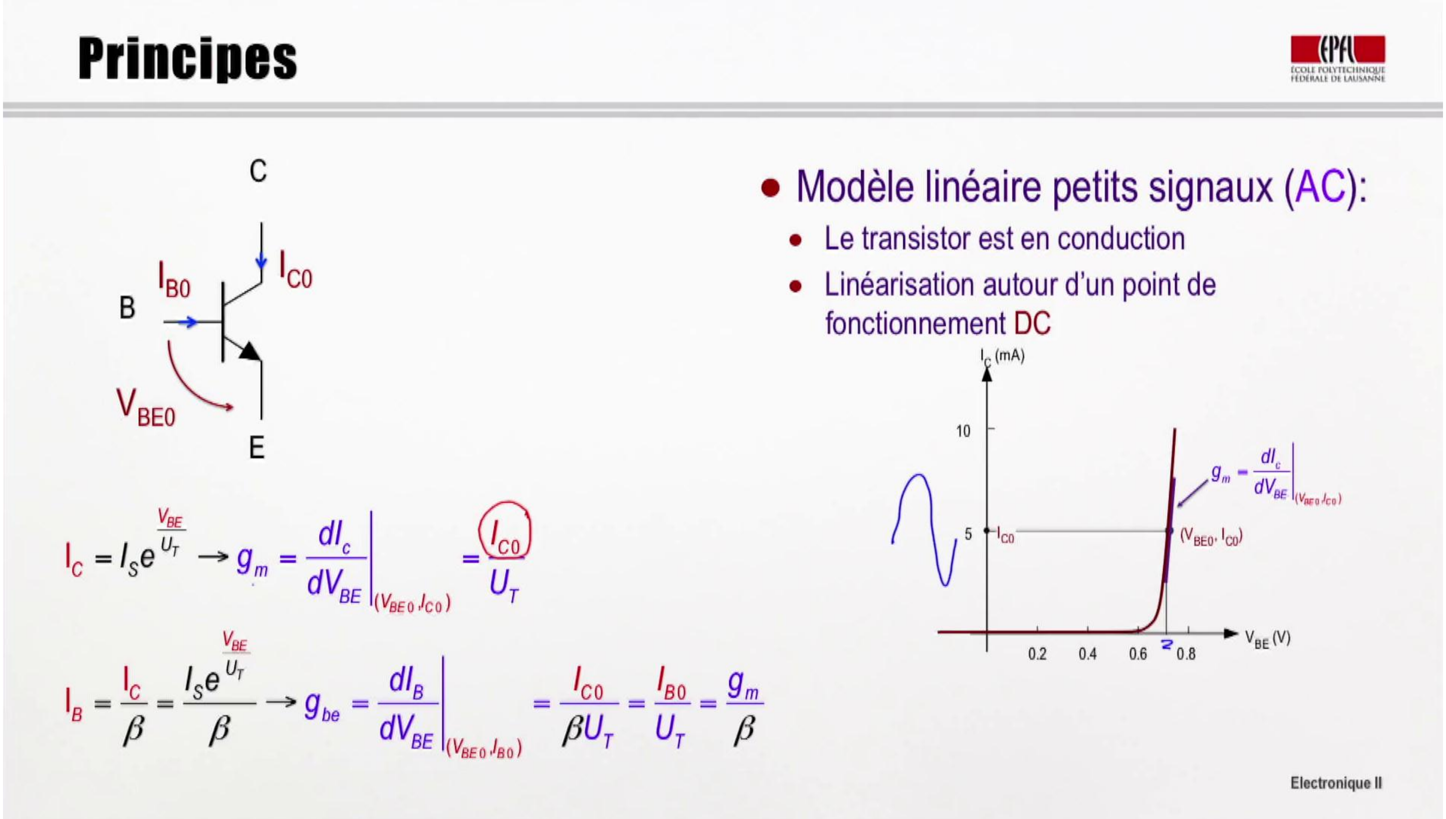
Electronique II

Continue the reasoning around this basis, that we started with a DC component on which we will add a variable component. And here is the variable component. We said the ΔVbe. Notice I wrote a lowercase, what is in red I wrote in capital letters and it is constant and what varies with time, and there I drew a sinusoidal voltage whose amplitude is a few mV, very small, hence the name increase. And this variation will control over this curve here, on the exponential law, the current that goes through your transistor. And that's it, if you admit that the Gm of the transistor is a component that will link the voltage variation to a current change,that's it you're about to give a linear model because you have confounded a straight line end on a part of the exponential and you have found a law that will convert U to I and it is called the transconductance, the famous law of the transistor.

Notes

Summary

7m 03s

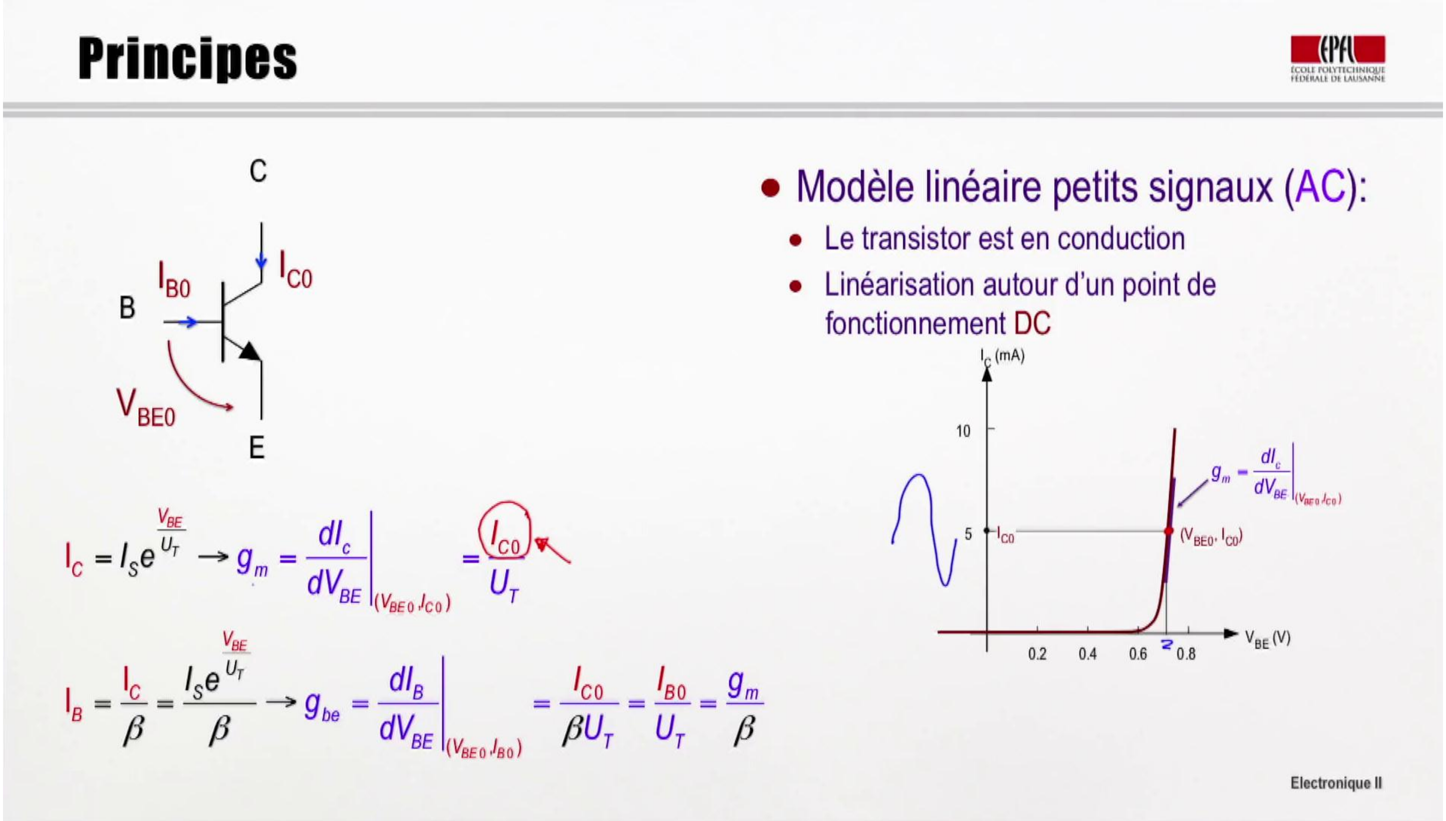


And now this is what I would like to extract on the Gm. So if Gm is a straight line on one point of an analytical expression it is of course the derivative at this point. This everyone knows that the tangent at a point on an analytical law corresponds to the derivative in which we made a point which is the famous operating point the Vbe0 Ic0. So we will apply it. So the transistor itself has this relationship. And if I want to derive this relationship, so to extract the tangent of the slope at a point, I derive this current over this tension and then I replace in the derivative the point in where I am seeing this curve and in this case it concerns current Ic0 and Vbe0. And I get this relationship that gives me the slope of the tangent which now allows me to convert any variation here in a variation that will appear here in current with ΔI which is equal to ΔV.Gm with a Gm equal to Ic0/Ut. It deserves nevertheless to be looked at. When I insisted earlier to tell you that the polarization current Ic0 is very important, here. So that's your choice, it is you who will apply a polarization current with a given amount. We will learn later how to define this Ic0 current.

Notes

Summary

8m 15s

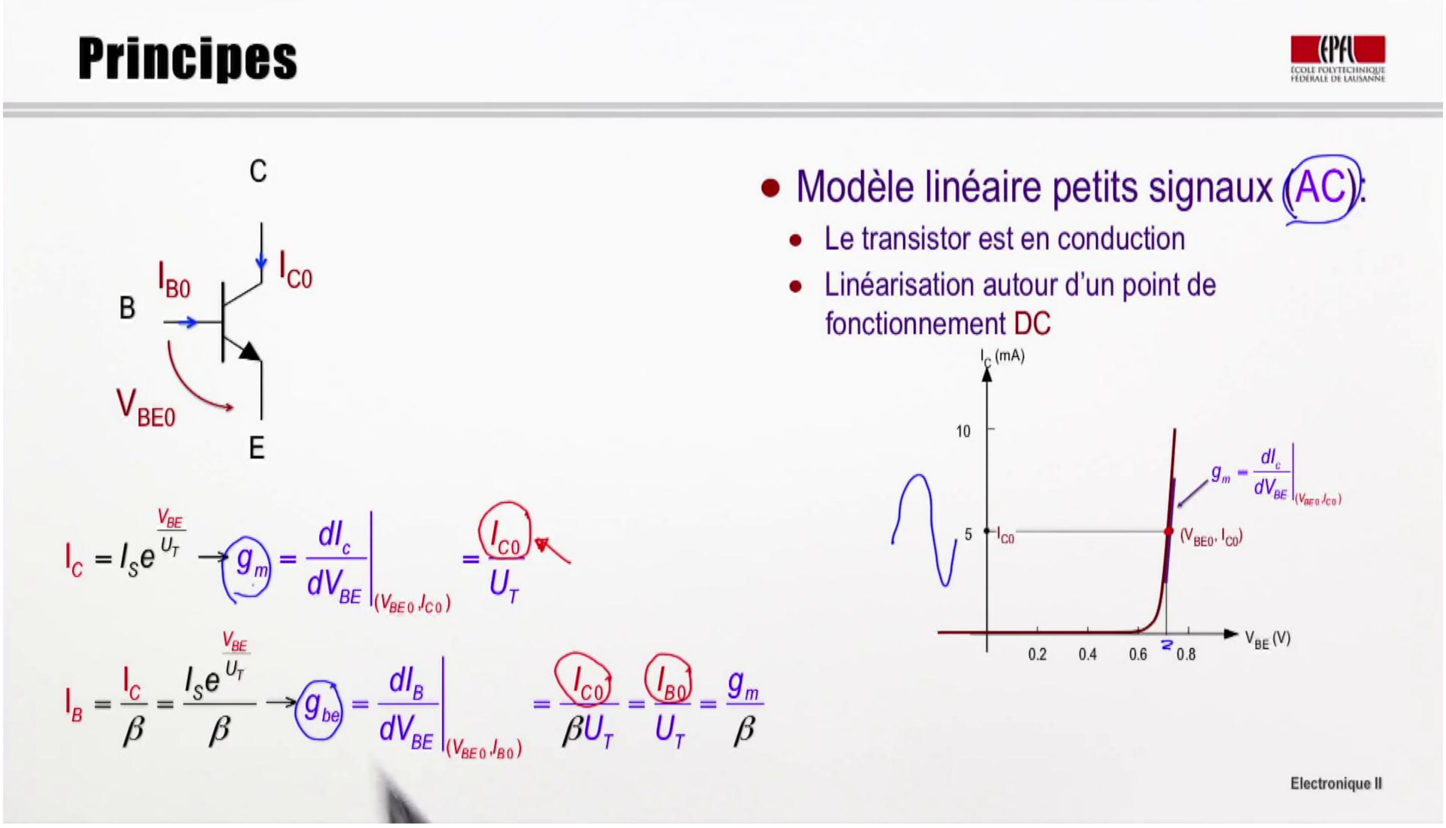


So as soon as you set current Ic0 by your polarization layout, which will allow you to determine on which point of your curve you will be, this is it, your Gm will have a value, it is directly proportional to Ic0. Remember that Ut, it's known, it is a value equal to 26mV at room temperature. So as soon as you set Ic0 it's like you set Ib0. Ib0 is the famous Ic0/β so you'll find Ib0 = Ic0/β. So similarly, if you look at the transistor and you look at what happens between the base and transmitter, you will say, if Ic0 gave us the Gm what will happen upon something that would later be connected here? I have two fingers that are placed on a termination, it's as if I look at a resistance at the edge of which I have a Vbe voltage and current Ib, of course I speak of values that vary over time, it is like a resistance and we call it 1/Gbe whose Gbe conductance is again the derivative of dIb/dVbe. So this law you see here at an operation point which is Ib0 Vbe0 and Ib0 is proportional to Ic/β, and you will find this. And once you recognize here the famous Ic0.

Notes

Summary

9m 51s

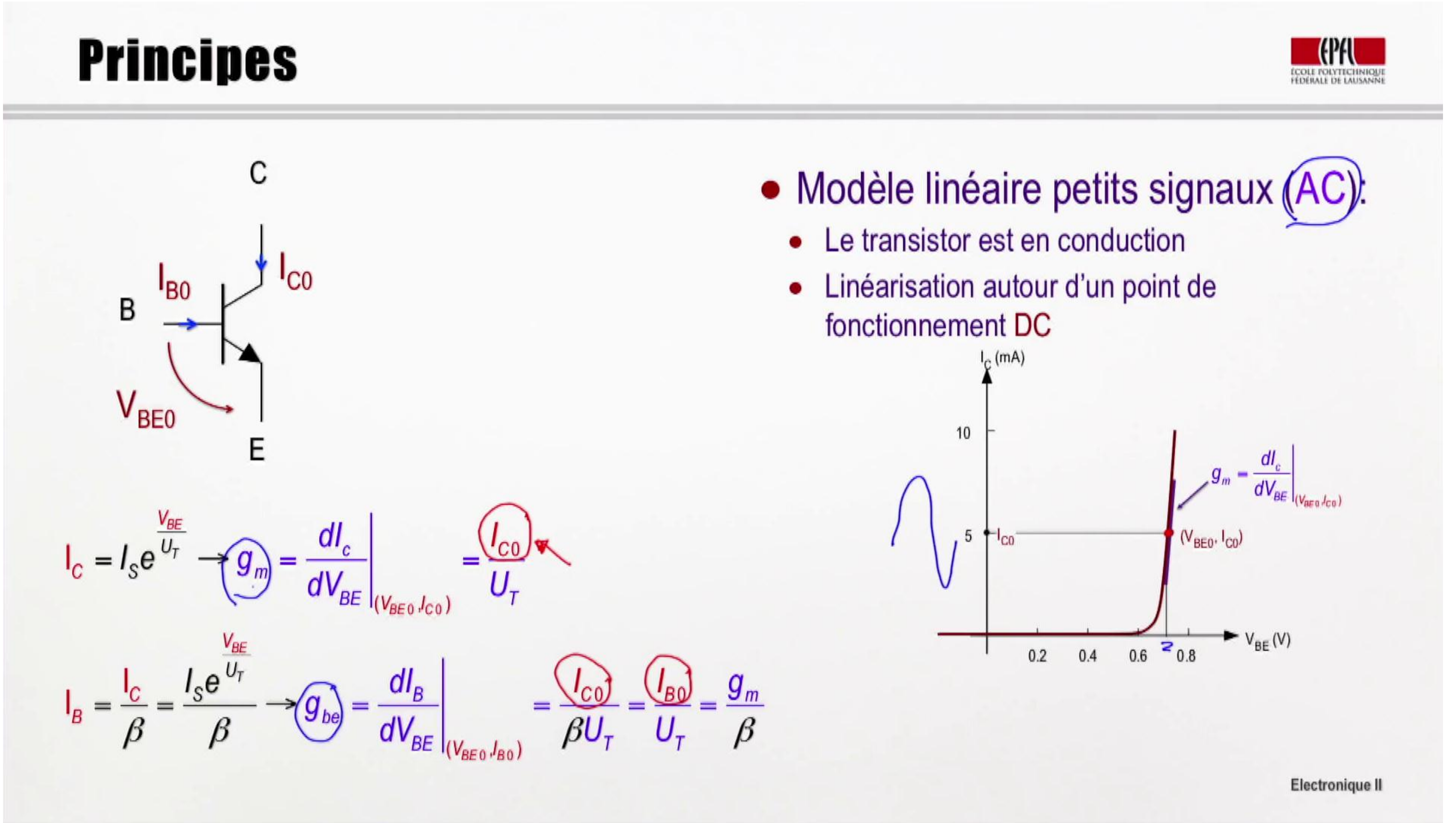


Which says Ic0 for a transistor and given beta says Ib0 is also known So we end up with, between base and transmitter, a kind of resistance that will draw some current when there is a voltage variation and that resistance, linearized, give us something proportional to the famous Gm we just calculated. So the analysis sequences lead us each time to apply a polarized current, which gives us immediately a value of transconductance. So as soon as you have applied the Ic0 you know you will achieve a Gm. And once you have applied this Ic0 you will immediately find your Gbe and this Gbe is proportional to this, it is the same Ic0, the β and in the transistor, it belongs to the value you get with your transistor and the Ut is given. And that's it, the transistor is now linear. For all that is AC, it behaves between these two points and this point like a transconductance linking the variation and converts it to current. So at this Ic0, when it encounters a ΔVbe, so when it encounters a small Vbe of T, it will add here Ic0+ (Ic of t). And the same, when it encounters a Vbe change here, it will draw current in the base that is proportional to this current ΔIb and which is linked to it.

Notes

Summary

11m 23s

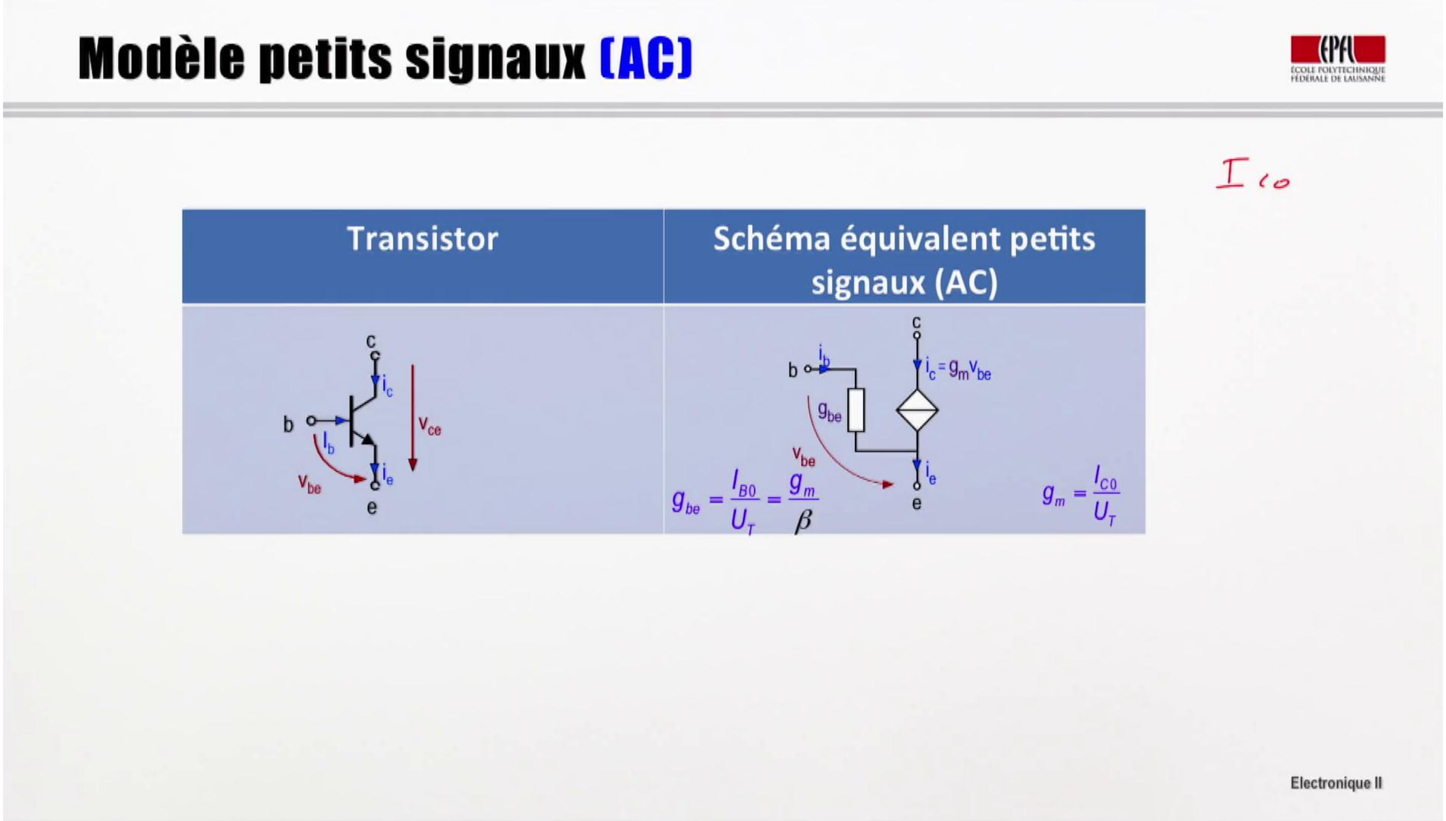


So everything is in the Ic0. Once we set Ic0, we've finally replaced the transistor with a resistance from here to there, a current source from here to here and this is achieved by the Gm, and this will be like a resistor that draws current. And that's it, we have seen our transistor with the model called the linear small signal model it is indeed linear, you just have to see it with this linearization merely obtained by derivative. Now I want to emphasize that. What did we do to linearize? We derived. We watched a change in current, divided by a voltage variation. So in other words if you do not have a voltage change somewhere, if you have a component somewhere that has no voltage variation, this gives us a value of 0. So this is what will allow us to use this model in a context in which there is a circuit and where there are fixed voltage sources.

Notes

Summary

13m 01s

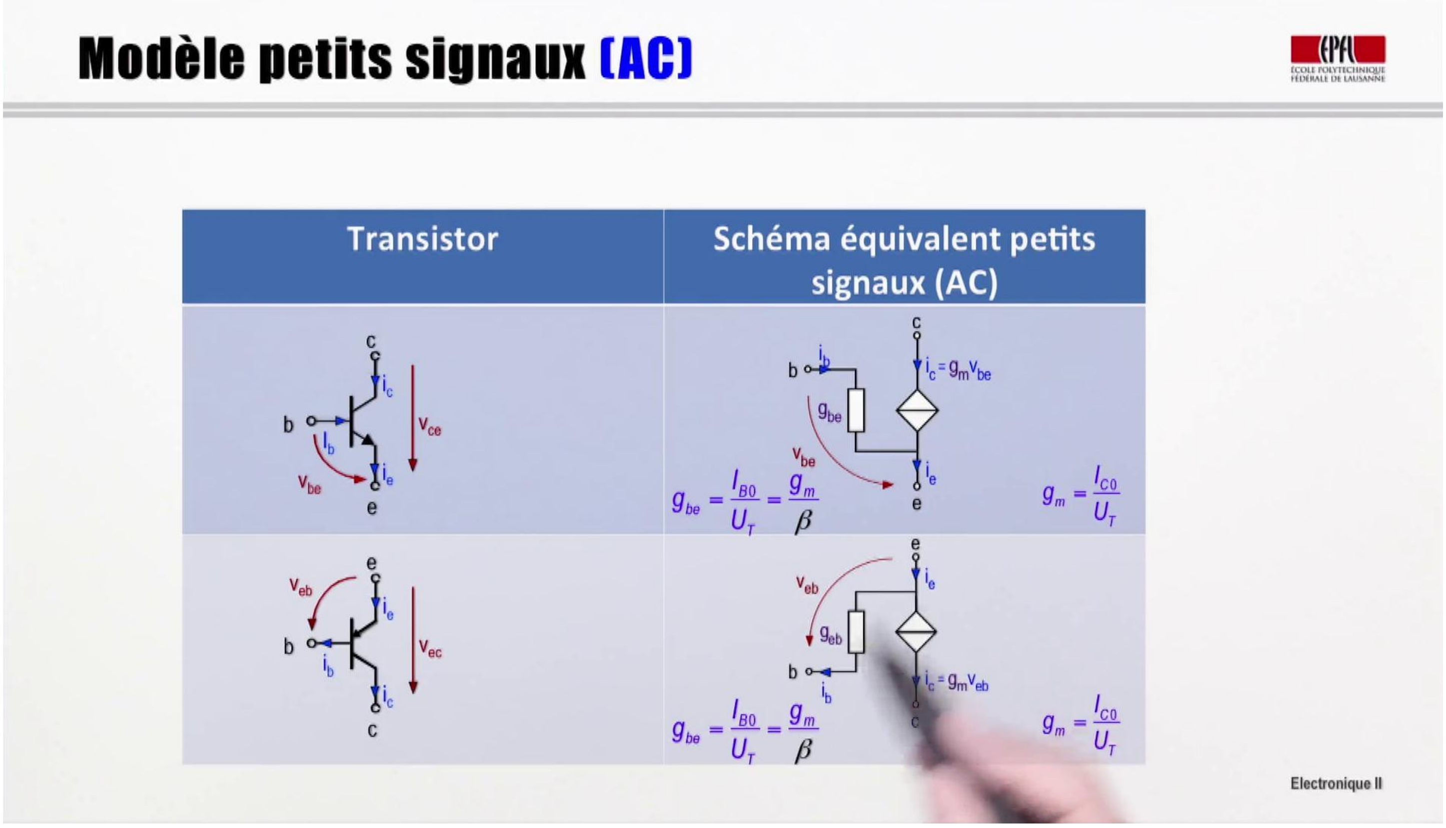


The model of my transistor is now this. If I ask you to replace the transistor by its AC model, what does that mean? That means you have polarized your transistor because you put it in an already polarized circuit. So you already know the famous Ic0. And as we said, no one will look at something else. We will seek to apply Ic0 that will give us the Ib0 because there is the β of the transistor. And once we get the Ib0, that's it we have all this we could immediately draw. I can remove my transistor as a layout, replace it with a vision model, that is to say something that looks like this and I repeat, to be able to do this, i have to verify that my circuit or my transistor is not saturated or blocked. This sentence is extremely important, that is to say you must check that later when you are going to vary Vbe and you will vary Ic, and this is found in a circuit context, you must check for linearity to exist and the transistor behaves like that, you must be absolutely sure that your transistor never comes into saturation, never will your transistor be blocked. We will have the opportunity to talk of it and this brings us to talk about something called dynamics which is one of the most important parameters as to designing a circuit.

Notes

Summary

14m 03s

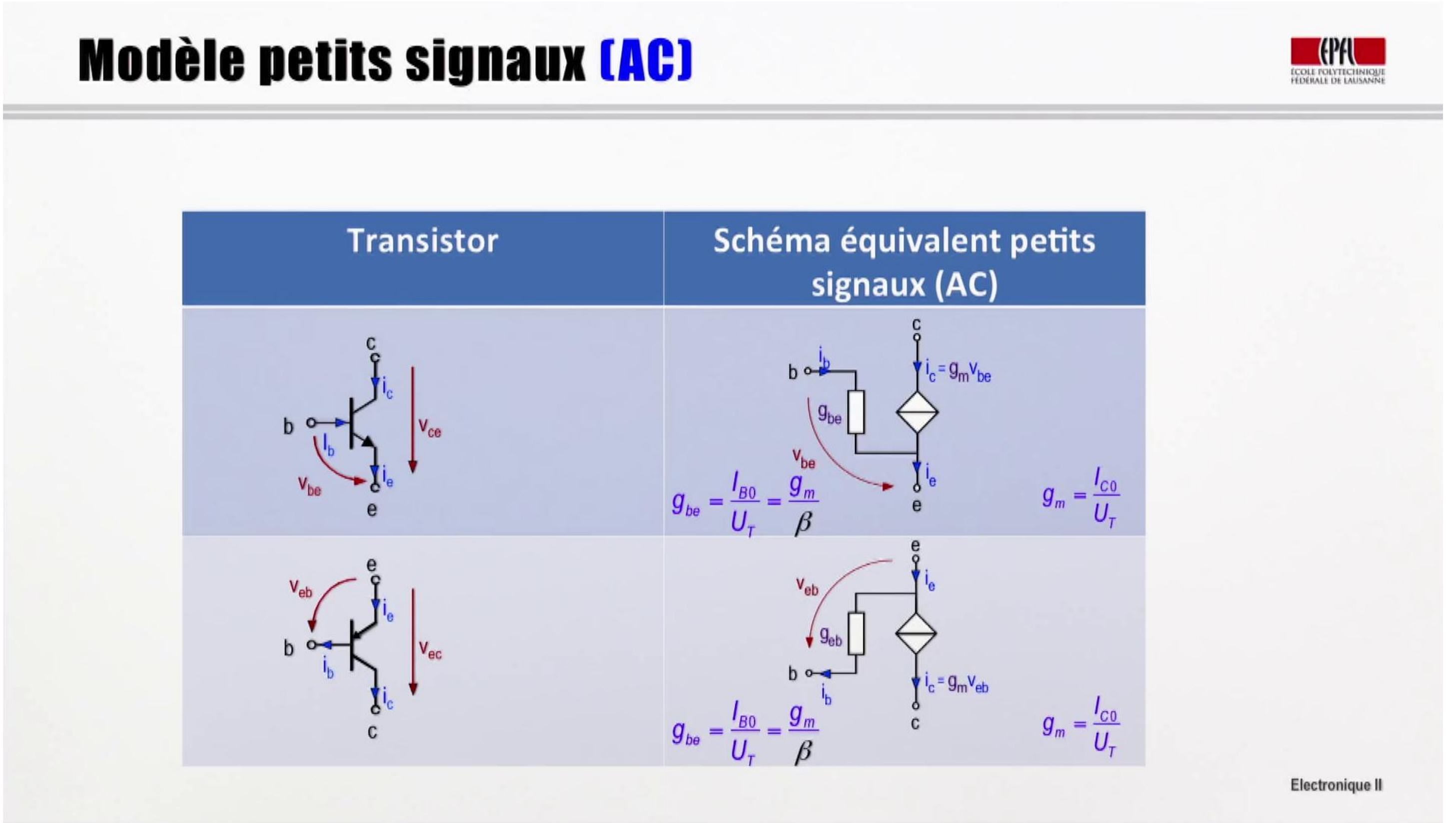


When I applied this current Ic0, I can take my transistor (Ot) and replace it by something like that. So we go into a linear circuit analysis. I have a resistance which is equal to 1/Gbe. I can write here Gbe or 1/Gbe, it's the same. It's up to me to know if I write a Gbe conductance, I must consider the relationship between voltage and current and if I speak of 1/Gbe it is U = RI therefore U = (1 / Gbe).Ib. But what is important here is to watch these two relationships. We have the famous Gm and the Gbe that will be immediately calculated as soon as you applied your Ic0 current. This is an example with an NPN transistor, it would give us the same thing with a PNP transistor, there is absolutely no difference, it would give you the same model and the same values for both. And there you have the complete diagram of two supplemantary transistors where you remove this and replace the linear model instead when it concerns a circuit especially where we look at the changes, small signals or increase. Same for the PNP, you replace it with this, the expressions are exactly the same, nothing changes. Given that we have a variation here Vbe and Veb remain the same so it would give us the same thing.

Notes

Summary

15m 35s



There is no difference problem between the two transistors, we apply the same laws. We now have seen what to do with a transistor when it is used in a circuit context replacing it with this model. I would absolutely like to repeat this sentence. I just derive the current change divided by a voltage change in a circuit. I'll keep this state and with this state I could replace my transistor with a linear model where the transistor is seen as a resistor between the base and transmitter which is equal to 1/Gbe. It is seen as a controlled current source between the collector and the transmitter, at the output, and which is controlled by the input voltage Vbe. To overcome this we must see this in a context of an example with a full circuit because we are, all the time, made to cohabit the direct current with variable voltage in a circuit because the transistor would never have found its linear AC model if it had not been polarized by a constant current that will cause constant tension all around this transistor in the complete circuit as we shall see. So we'll soon move to the second video which will follow a model or rather a circuit that shows us how we use this model.

Notes

Summary

17m 03s