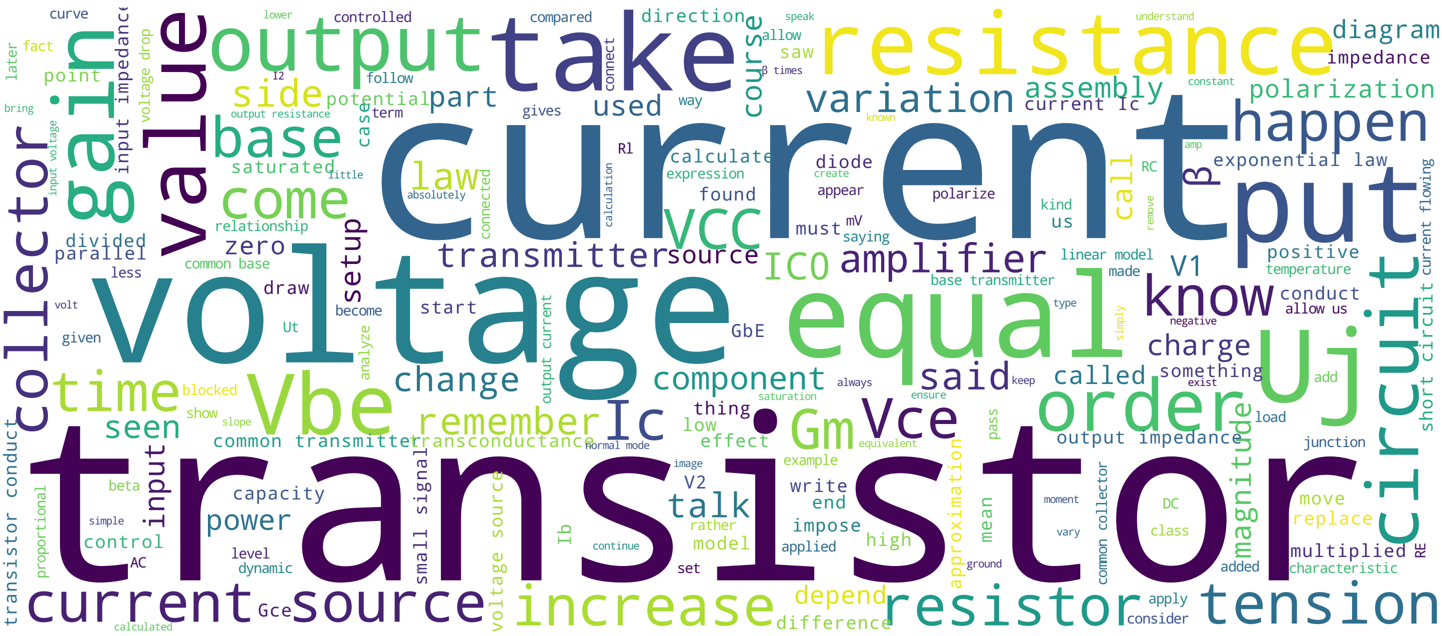
ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

1.2-Transistor Bipolaire

Modèles

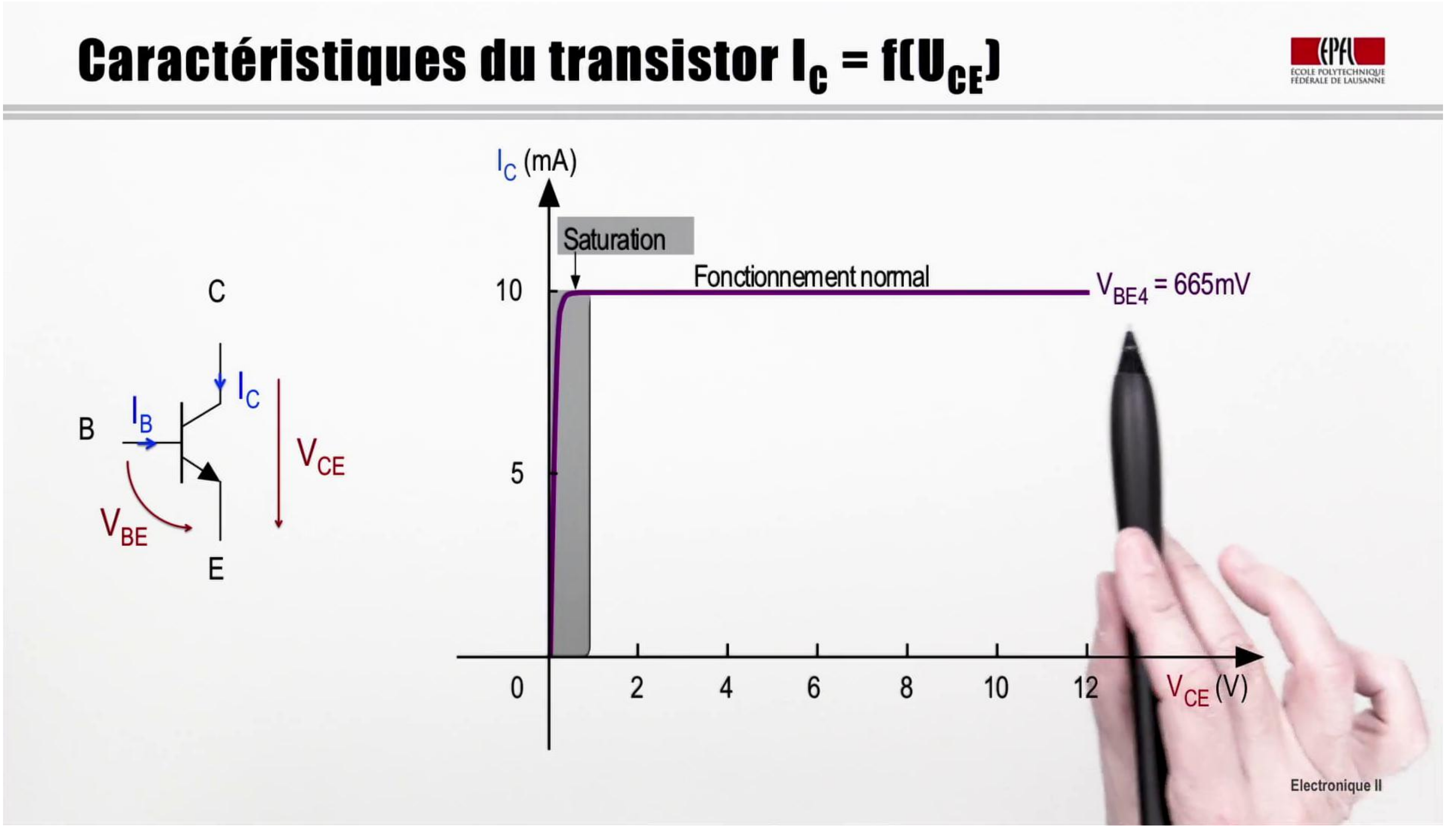
Prof. Maher Kayal

Electronics Laboratory-ELAB



Video

EPFL

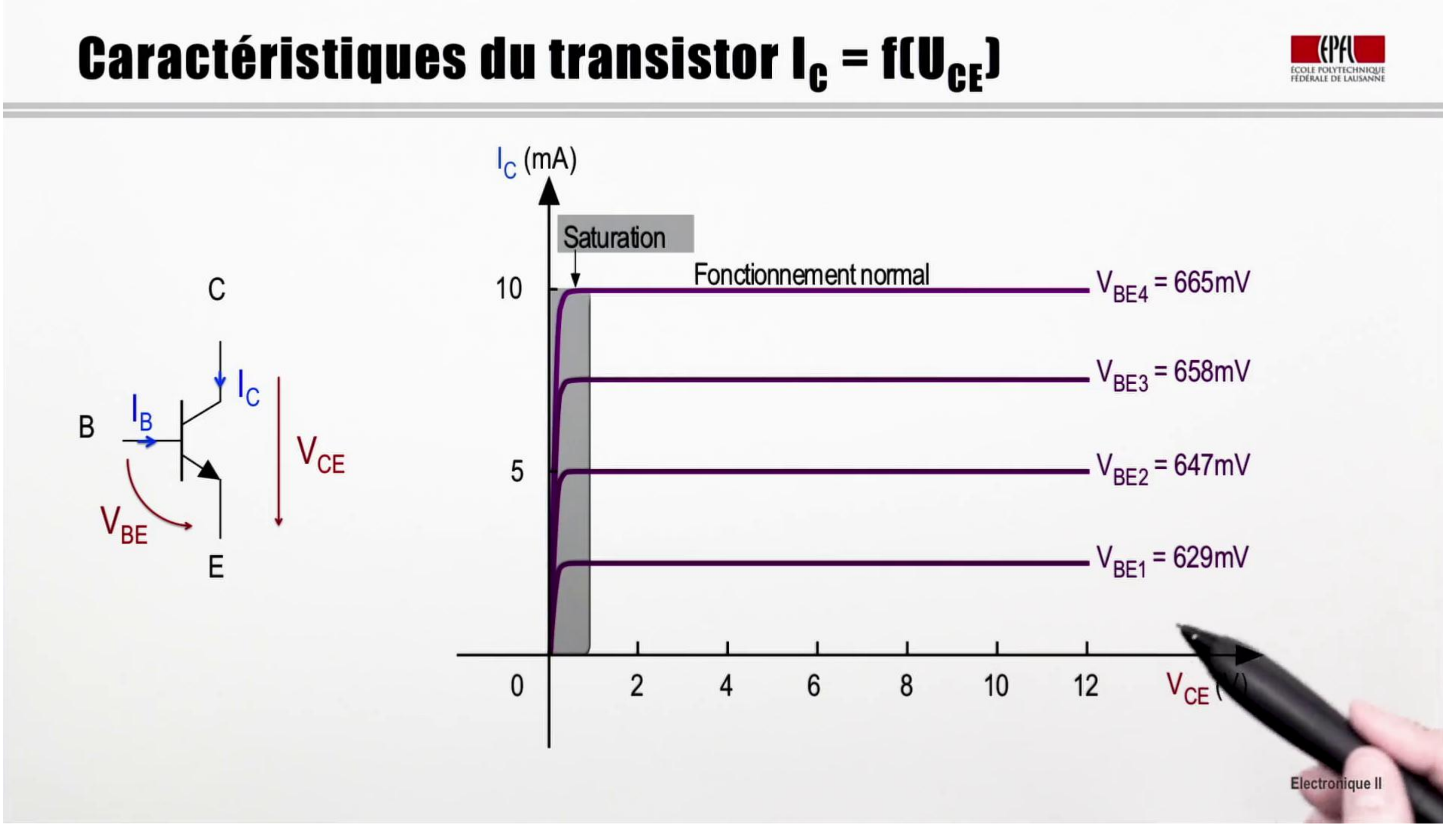


We saw the transistor in its transfer characteristics that is Vbe F(Ic), so the input voltage and the output current. We have seen the relationship between Ib and Ic which gave us the β of the transistor. Now we will study the transistor effect, that is, this current source that man wanted to create to make electronic circuits. We will pass on to the output characteristic of a bipolar transistor. If you look at this feature here and you look at what's on the axes, let's come back to this diagram. Here I have Ic and here I have Vbe and I am looking at Vce. I'd like to see what will happen with the transistor when Vce will vary. All our attention is on this Vce, since we have already demonstrated that Ic is controlled by Vbe. We've seen that this current is controlled by this. How this transistor effect is and what are the characteristics that allow us to analyze what will happen to the output? Remember, the output will often be between the collector and transmitter or transmitter or collector, it depends on which side we will connect our charge. This is the IcVce law. But look what I noticed here in the constant voltage I just put a Vbe4 voltage, I called it 4, it is equal to 665 mV.

Notes

Summary

0m 04s

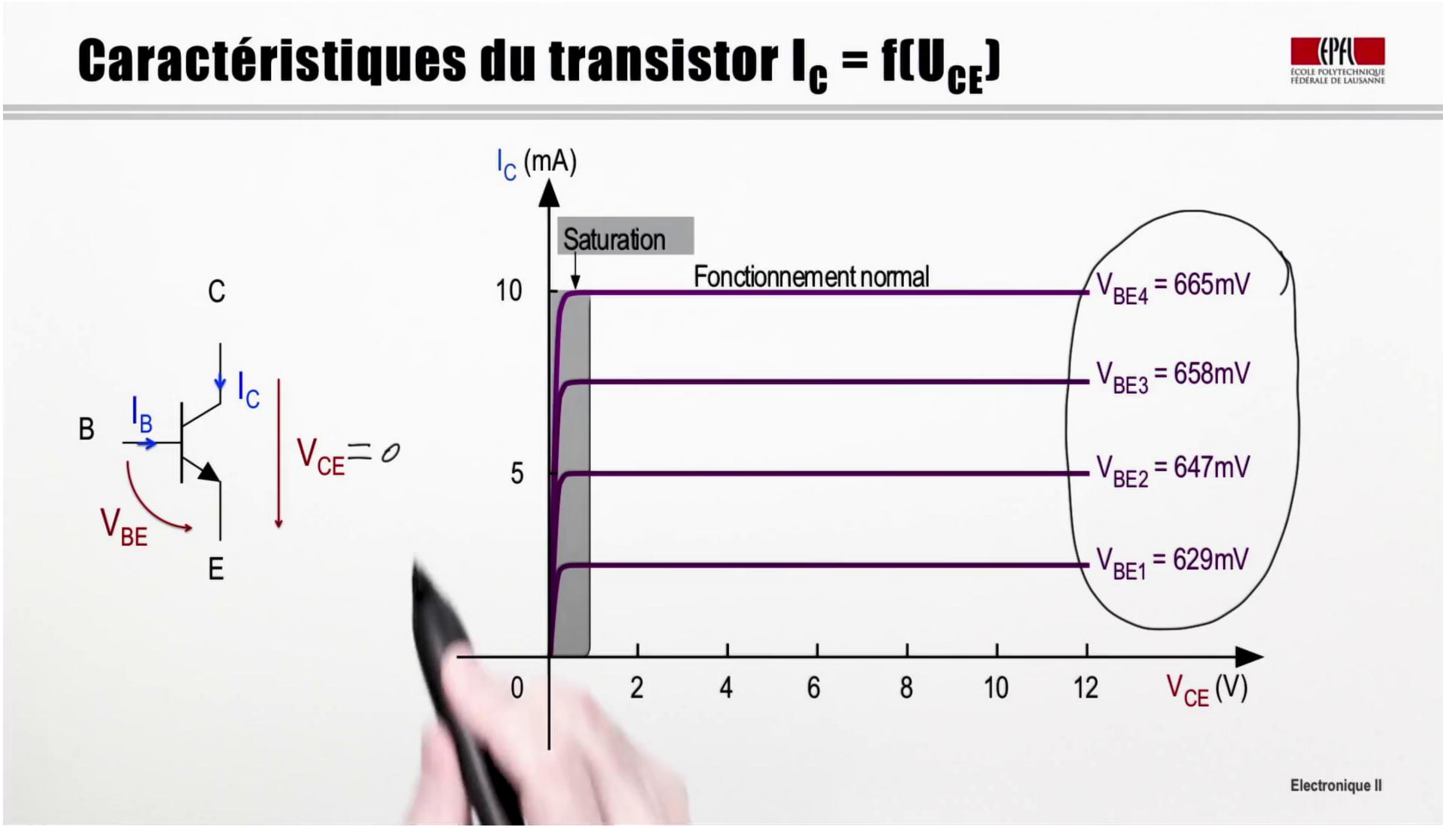


So, for a voltage here of the order of magnitude of Uj, but of course Uj we said it was the exponential and it is a value taken on the exponential law. When you look here, you see that the current has been absolutely independent of the the voltage variation Uce. You vary Uce as you desire. So you vary Uce throughout this range, you will see that Ic is not at all affected by what happens. So it is a source of current. The current is fully controlled by it because if you now vary Vbe, if suddenly you put another voltage Vbe, look what happens. I put a slightly lower voltage and I lowered the current that is controlled by it. This voltage, I lowered it, the current will follow it according to the famous exponential law we had seen. If you keep doing the same thing, you change Vbe and you again put a lower voltage. But when I say lower, look at the difference it is always around the same value. Remember that the control of IcVbe is an exponential law, so we just need a little variation on this Vbe so that the current varies exponentially in relation to this and that's what I'm doing. I'm going to lower it again, so I get to a certain value of Vbe. Whenever I move this tension here, the current changes with it.

Notes

Summary

1m 44s

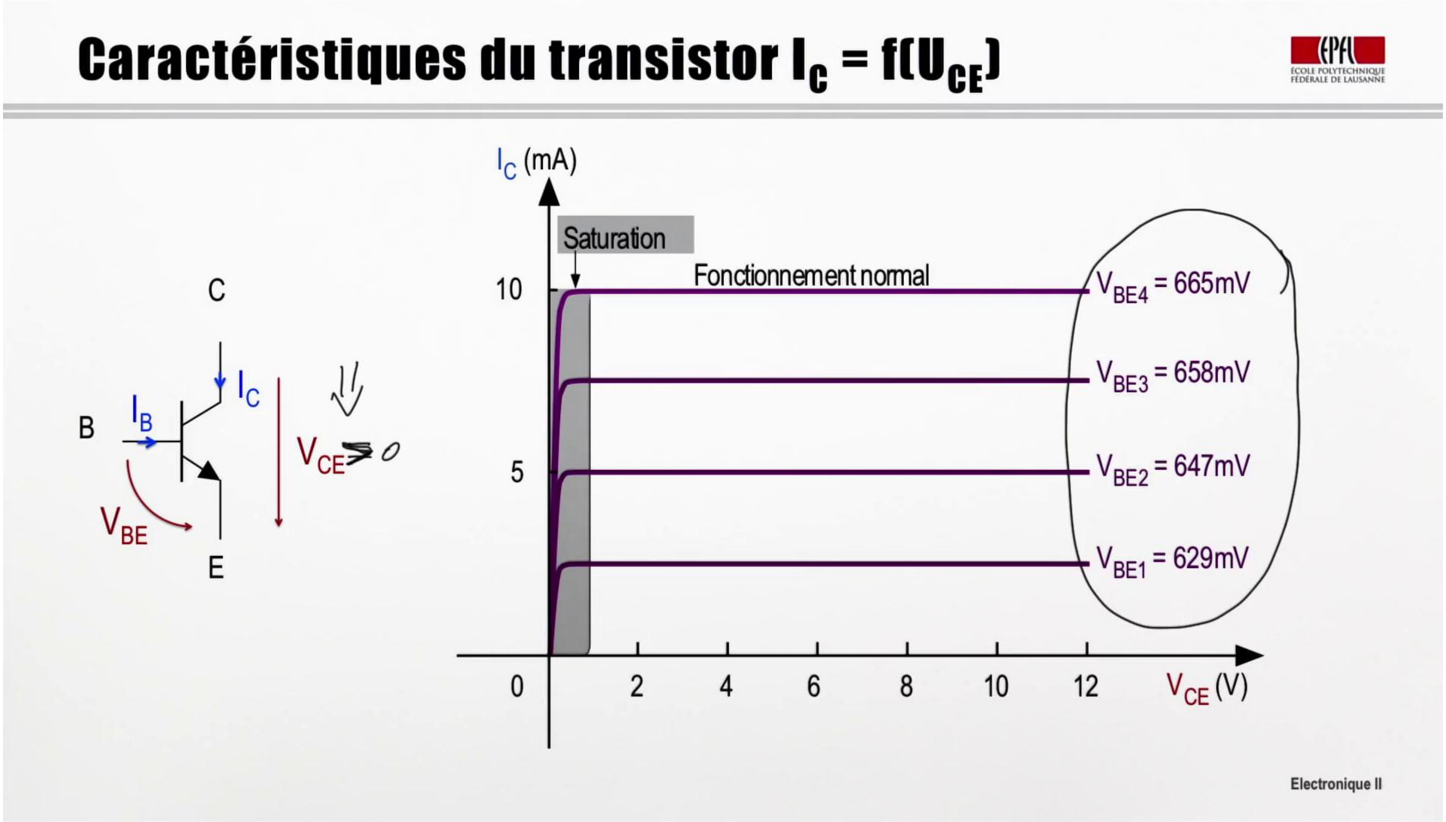


So I increase the voltage, I lower the voltage and I have current sources. It's called controlled current sources that will follow the variation in the voltage Vbe. I insist on the fact that when you look at the Vbe variation, remember that it is controlled by an exponential law, so very little variation here induces a lot of variation on the current here. This is why I have variations between 629 mV to 665 mV which varies the current of something of the order of 2.5 mA to 10 mA. It is this tension that has no effect, but look carefully, when the voltage Vce gets somewhere in this area called the saturation zone, we will explain it, and especially when Vce goes to 0 and close to 0, this superb power source and this constant value of the current Ic is not as constant than we imagine, it starts to fall. When Vce is equal to 0,in first approximation the transistor enters something we call saturation. And I'd like to emphasize this before moving on to another explanation. It was said that Vce does not affect the current Ic. I'm saying if and only if Vce is equal to 0, this affects. This is simply confined to that condition that we lose the transistor characteristic in current source.

Notes

Summary

3m 29s

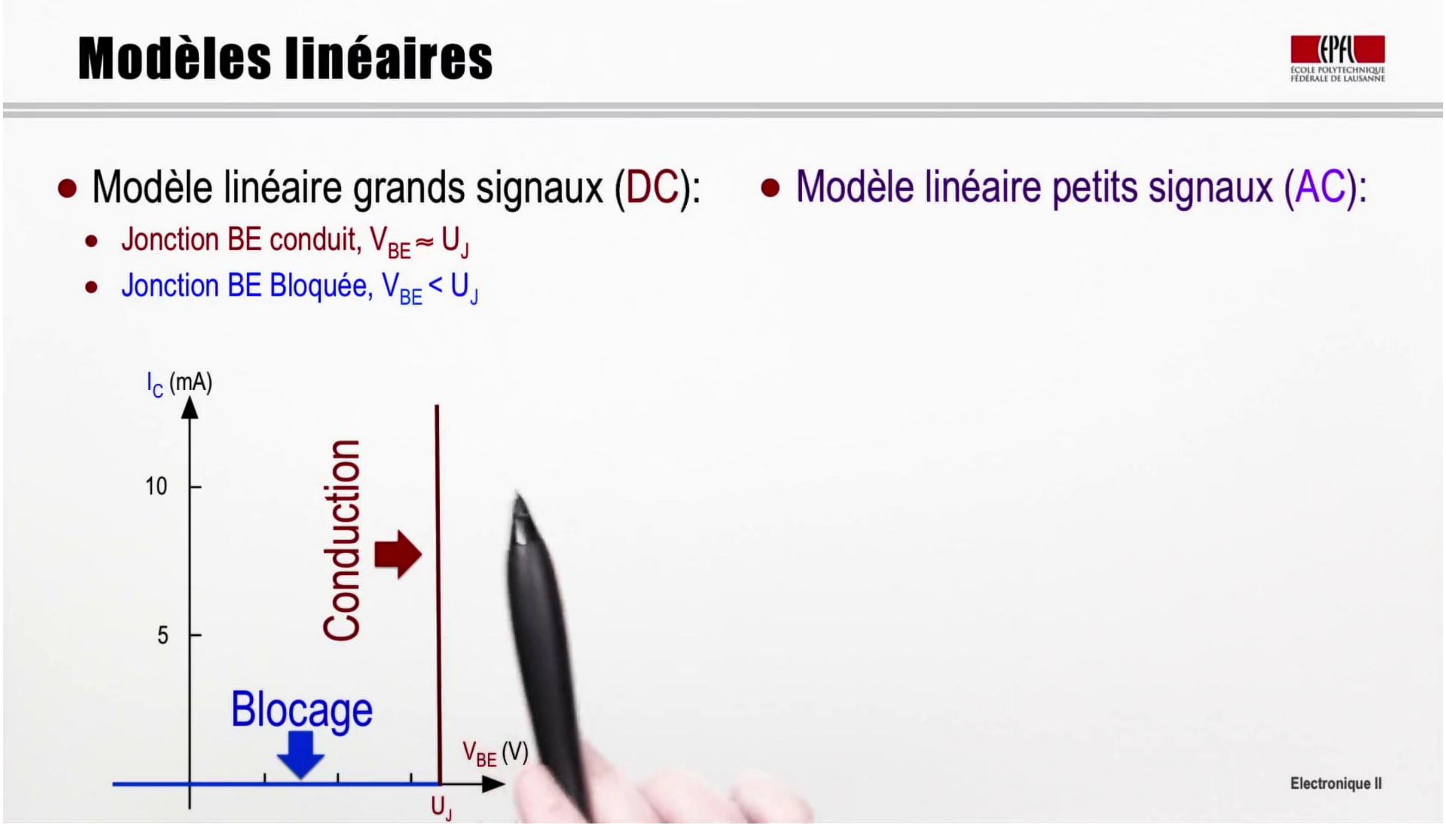


The value of current we have is controlled by the Vbe. This is the famous electrons tap that allows this transistor as Vce is not equal to 0 to stay in normal running. I just added an extra word and a second word also, I speak of a transistor that conduct, but when it conducts, it has two states. A state called normal is what will be of interest to us in analog circuits, and a state we call saturation is when the voltage Uce becomes 0. Please retain these two things and remember that ultimately Ic controlled by Vbe has no longer this law that interests us when Vce is 0. Who will decide that Vce is 0? It is you who will decide, it is your circuit. If by chance you put a resistor in which you move the current (at) Ic, the higher the current (at) Ic increases, the more voltage drop at the edge of this resistance will increase. So you risk saturating the transistor. This is not a proper transistor characteristic, it's up to you in your circuit to ensure that Vce is greater than or strictly greater than 0 to ensure that your transistor is in normal operation. It is as if you were saying "I want to use the transistor from here to certain values", that's up to you to decide. But make sure that Vce does not come here because I do not have this behavior I see here.

Notes

Summary

5m 10s

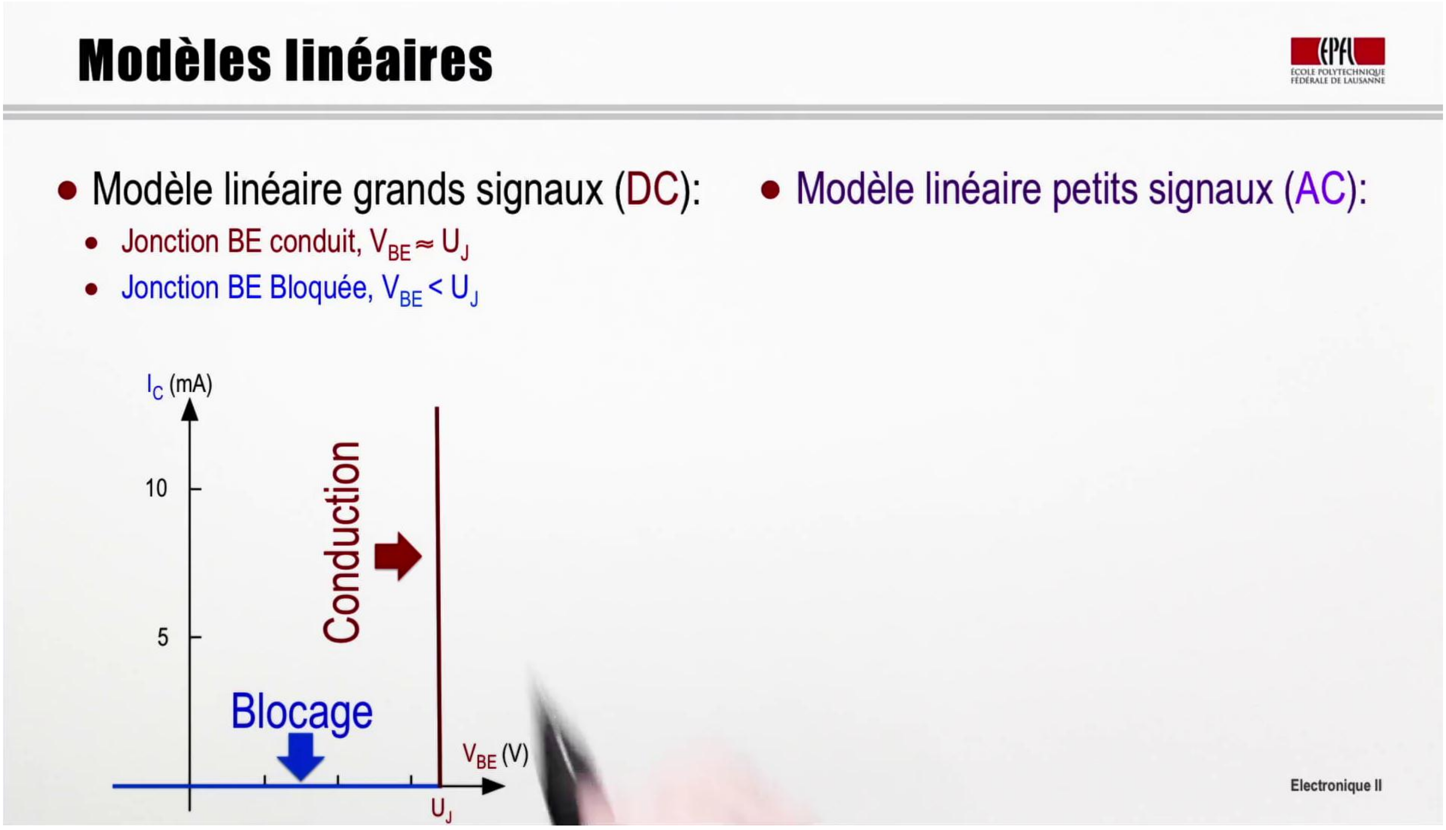


I'd like to start now to introduce the modeling of what we presented so far. I told you of linear large-signal model, we will call it large-signal. I repeat, we will talk about a DC mode, that is we are in the world of direct current and direct voltage. We will talk of this model and this model will be fully differentiated from this model called linear model small signals. We will talk about AC. The fundamental difference between one and the other, it will help us always to polarize the transistor. This will allow us to use the transistor for amplifying signals and allow linear signals using the transistor. Remember, the transistor can be blocked. And remember that the transistor can be saturated. These two words we selected earlier, blocked and saturated, are the two key words that will guarantee us if the transistor is not blocked or saturated, I can use it and here I'm talking about small signal linear model. But you have the opportunity to better understand this with examples. When I take the linear large-signal model, remember that the base-transmitter junction for the transistor conducts should be in the order of magnitude of EG. So I'll use this model.

Notes

Summary

6m 44s

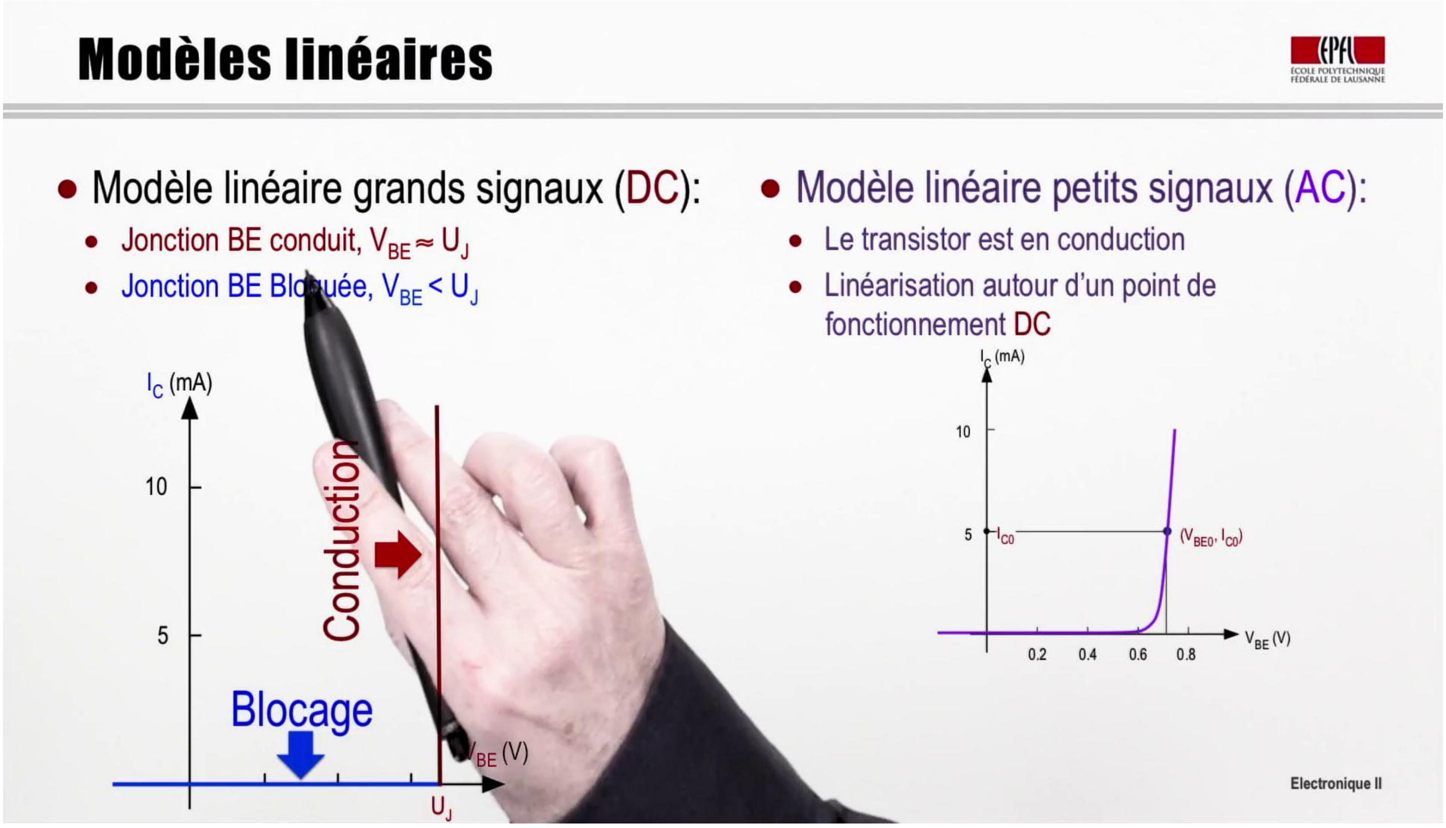


Believe me, this is the model you are going to use all the time when you put your transistor in a set-up and you put voltages and direct current before superimposing anything as variable signals we'd like to amplify. We are in a purely DC world and we will use this model, it is of tremendous simplicity. Your voltage, if you can guarantee that Vbe is of order of the magnitude of Uj, know that the transistor will conduct, so know that you will have current in the transistor. What is the value of this current? Nobody knows, you will have to put it in a circuit. But there is one thing, if there is a current in the transistor, you can immediately replace Vbe by Uj. This is an approximation and it is an approximation just because you replaced the exponential by this. I take the transistor and say "If I do not have Vbe is equal to Uj, so I'm in somehow a lower position", know that there is no current flowing in either the transmitter or in the base. It is at the limit, if you are here, and you remove the transistor from the circuit and you will not see anything. It has two operating conditions that give us immediately a voltage that can be used, saying "The transistor conducts.

Notes

Summary

8m 16s



I have observed that there is a current in the collector. So there could be current in the base since both are linearly proportional." At that time, I will say "Vbe is equal to Uj and this curve shows it to me." The law that shows us what is the largest linear model in DC slot comes down to this part of this curve and this part. No current, a non defined current but which exists, but especially when it exists, there is an AUj voltage. I would like to take the small signals linear model. Look what I drew here and look what I drew here. Here, I do not draw this, this I will use just to simplify the calculation and to say Vbe is equal to Uj is all I'll get out of this. I will now move on the real exponential law. I insist on the fact that you will see that the law itself will serve me analytically, but it's rather the derivative of this law that will serve me that the law itself. If you guarantee me that the transistor conducts, so that you are here, and this voltage is equal to this, so you're here. If anyone can verify that Vbe is equal to Uj, of order of magnitude it's 0.6; 0.65; 0.71; all this means that it is of the order of magnitude of the junction voltage.

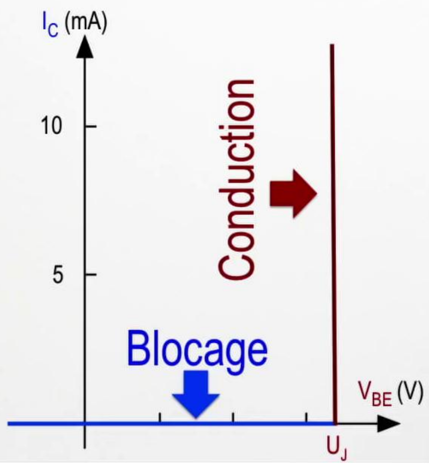
Notes

Summary

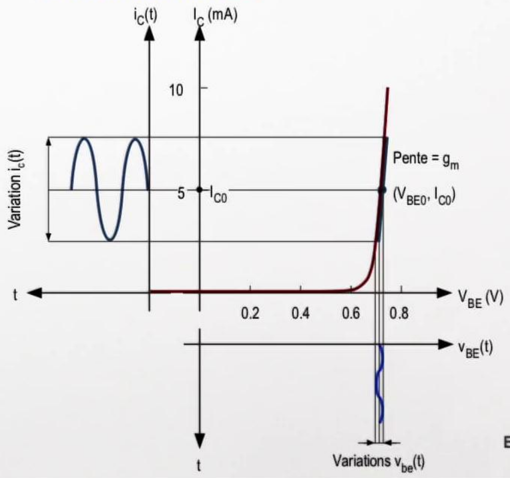
9m 35s

Modèles linéaires

- Modèle linéaire grands signaux (DC):
  - Jonction BE conduit, $V_{BE} \approx U_J$
  - Jonction BE Bloquée, $V_{BE} < U_J$



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

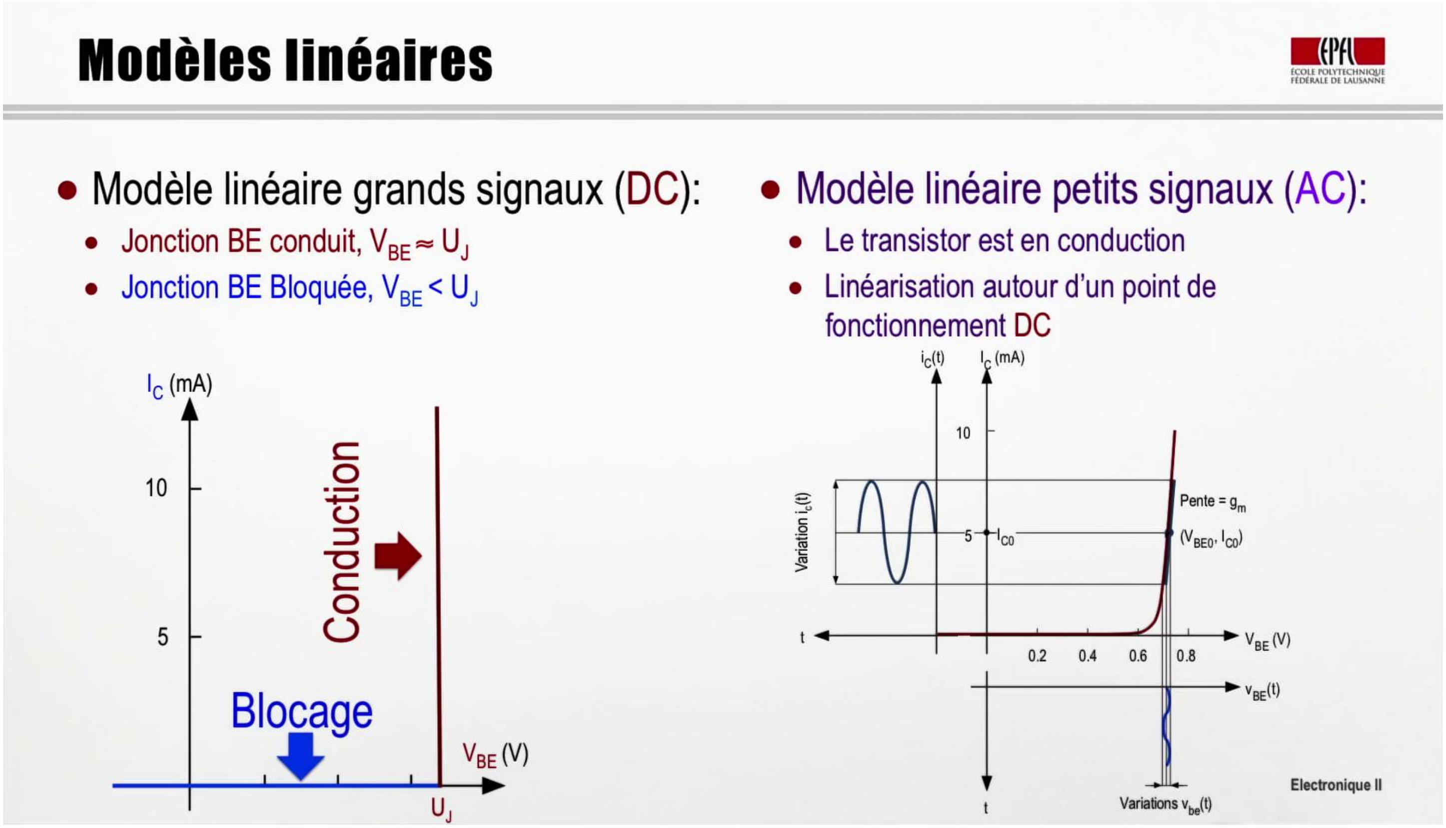


Electronique II

Know that your transistor is currently conducting. So you're somewhere here. As it was approximated by a straight line, here I take the real exponential law. There is a current flowing through your transistor and this is the Ic current for which there is of course a voltage of the order of Uj. But then if you now superimpose this voltage which is here, which is of course not the latter because it is a rough approximation, if you put that point in the exponential law, you are on an operation point, hence the name operating point. There is a continuous current and a voltage Vbe0 of a given value. Know that your transistor is on this law or on this exponential slope of the relationship Ic Vbe. What is happening here ? What will happen when you take this law and this explanation I just gave and you take the point that we just saw a moment ago with a direct current, a direct voltage. And you come here, and superimpose a small variation, we call it increase. I remind you when we looked at the output characteristic, we were talking of mV there, so if you take a few variations of Vbe few mV, you will see a change in the current following it.

Notes

Summary

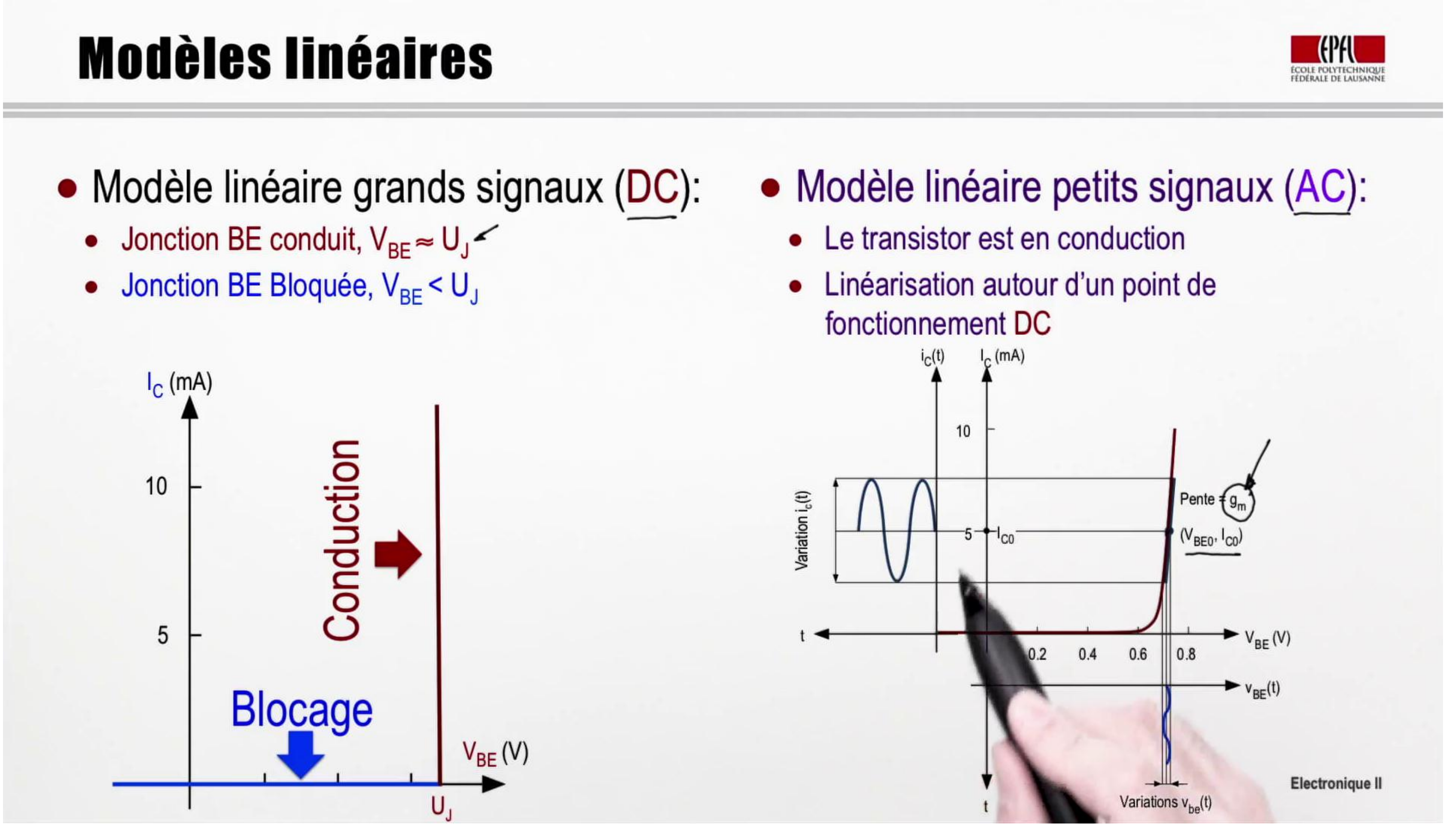


Remember that Vbe is the tap that controls the current flowing, and we fixed a point and then started moving around the fixed point in order to control a current, and that current, will give us a current in the collector which is in the image of this voltage. This is the transistor: it took Vbe, it transformed it into a current Ic. And if this law and this are linear, you have found, what we will call trans-conductance later on, that is, the approximation of the exponential law around these two points we extracted from these that we applied to this curve one. And we take another point and if you vary this voltage then between base-emitter, it will control you the current in the collector. And the one that say that I have current in the collector of a given value, you just need to put this current in a resistor, it becomes a voltage. So I converted a Vbe voltage into a current. If I put this current, which is the image of Vbe, I find a voltage which is the image of this current. And that is done through the resistor. So what I'd like you to remember of this curve here: when I speak of an AC model is that I have surely already used the DC model.

Notes

Summary

12m 27s

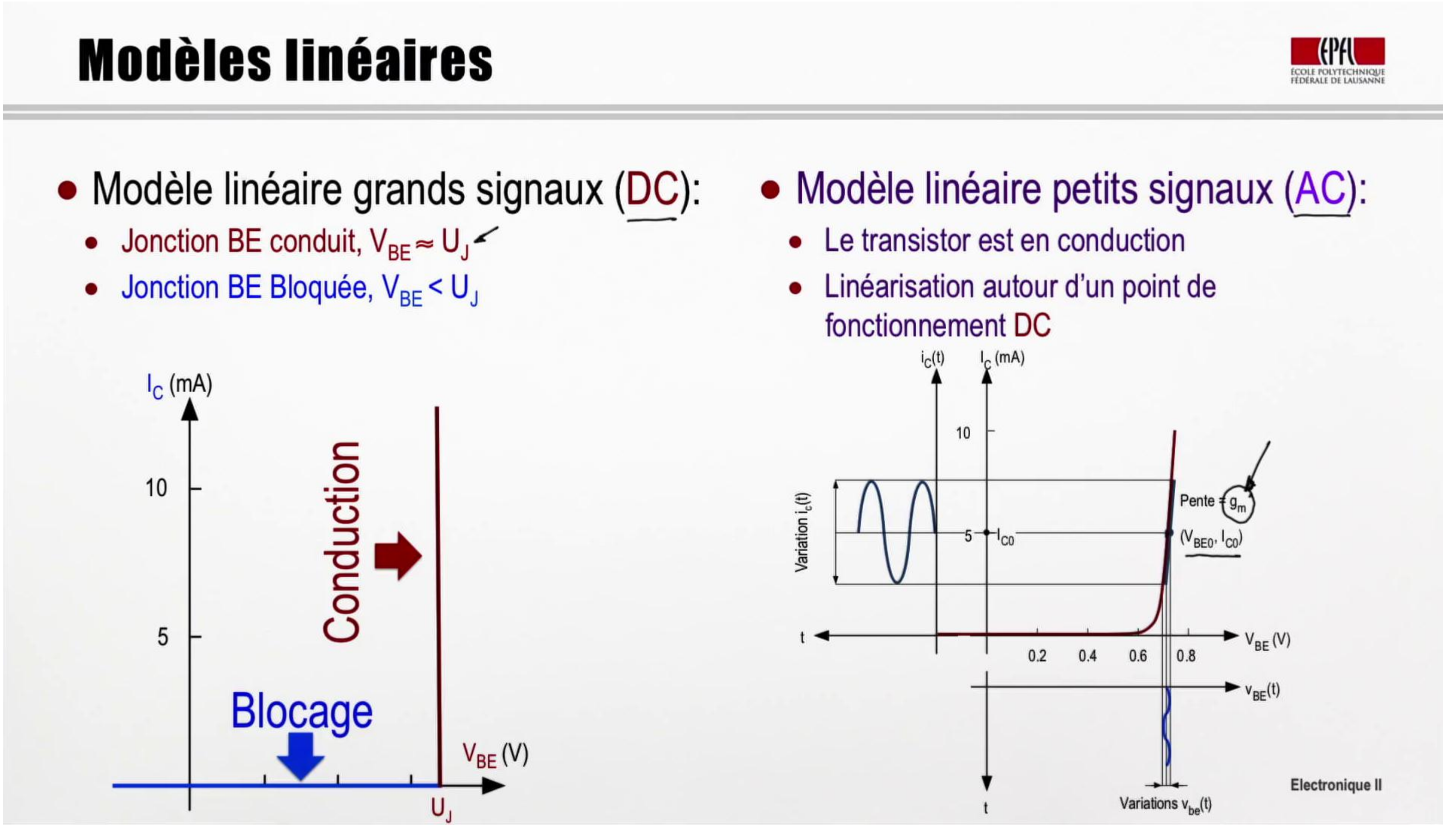


And when I used the DC model, I applied an approximation, but I do not know the exact value I applied. But when I apply this and I do a DC calculation, it will allow me to know the values that will come out here. And values from here will allow me to make the approximation that here, I'm on the exact law. But from this exact law, what should I take? Should I take this whole curve? Not at all ! I could just accept, approximating a small portion of this curve, which is tangent on this point and I do the approximation that the slope of the tangent I'll call the Gm is the conversion of Vbe into a current, we will call the transconductance, that means I'm in AC and I just have to know the value of Gm and that will be a goal in itself, on how to extract the Gm of a transistor, so what is the slope of the tangent that we see here on this feature and once we have it, you will see the door of the use of linear models is wide open, it will allow us to consider that any change in voltage is transformed into a variation of current. And that this current could change if one wishes or keep it in current, or put it in a resistor and convert it into voltage.

Notes

Summary

13m 48s

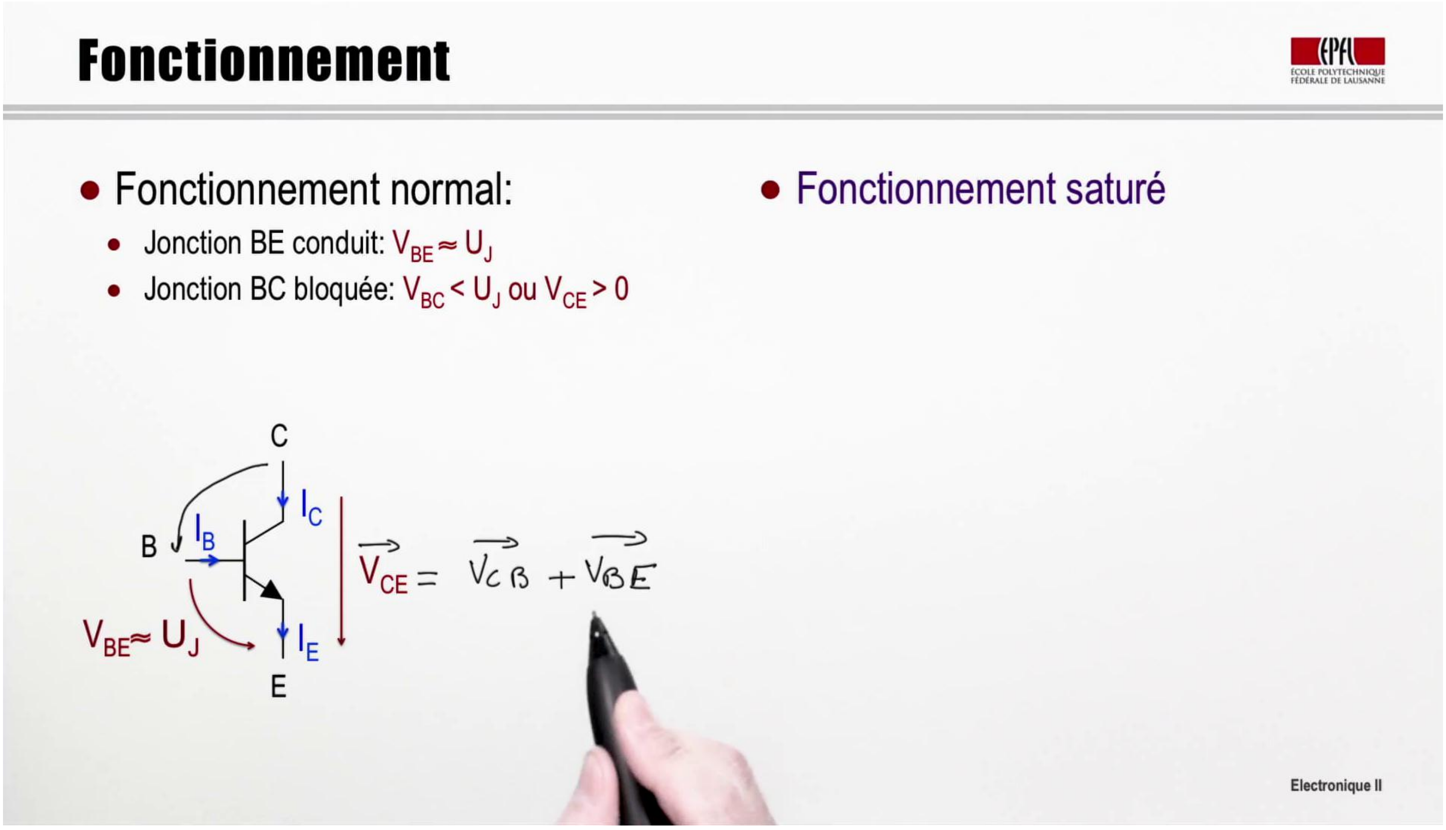


We would have made with that, a voltage amplifier: I will take a base-transmitter variation and I'll watch its image in current with the output current and I will put the output current in a resistor so I convert it into an output voltage and it will be the first amp that we will study later.

Notes

Summary

15m 14s

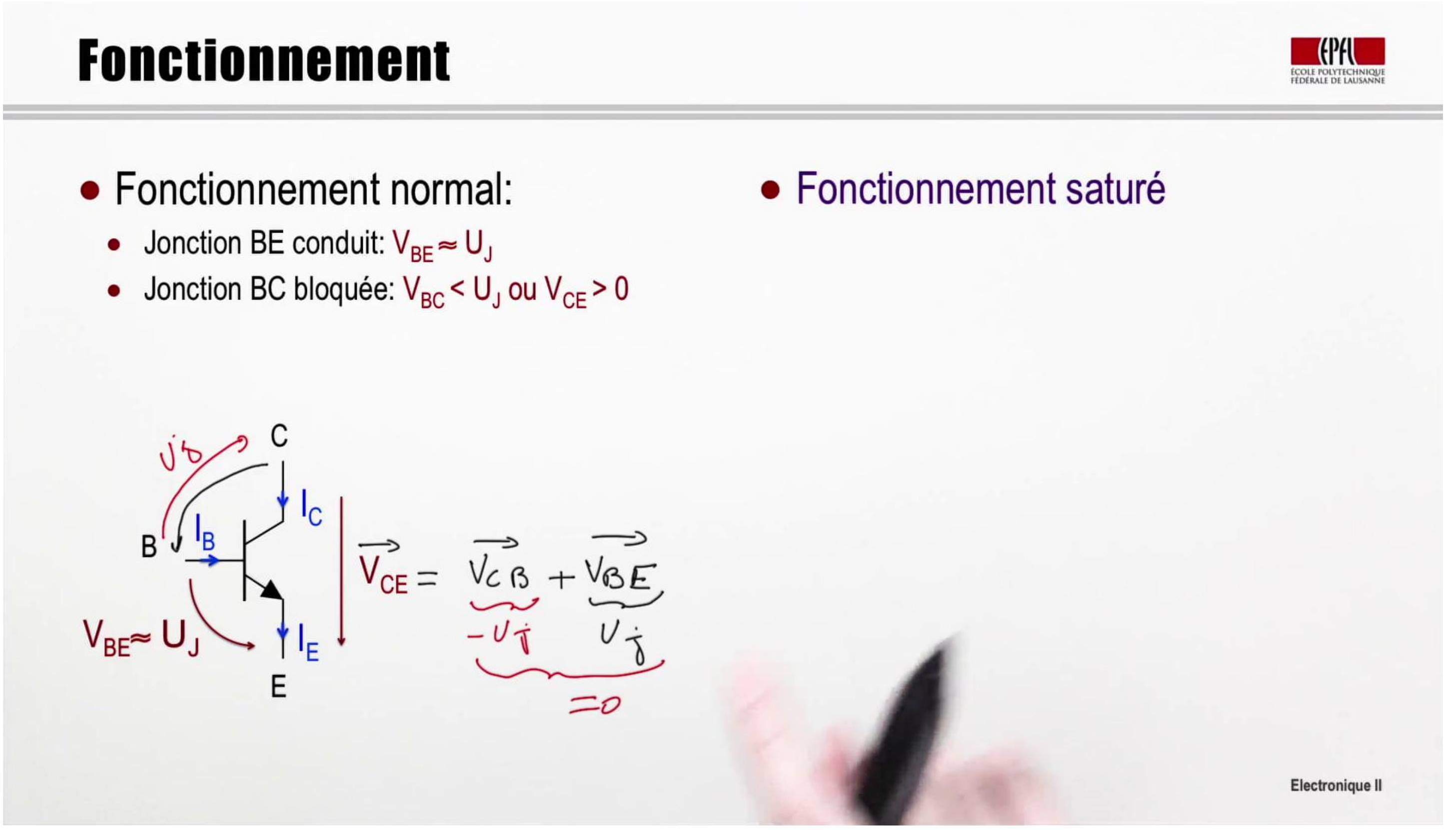


I would like to now take these different things and use the transistor in the normal world. I would also repeat that we said when a transistor conducts, there is a risk of being saturated, that is when Uc is zero. So I would like to differentiate the two: the transistor conducts as soon as I said that the transistor is conducting, I can immediately say, when a transistor conducts, the base-transmitter junction is of the order of magnitude of Uj. That, I think everyone now understands that the linear model by segment in which I made this vast abstraction, that there is no exponential, and I have two parts which describe the exponential. Here, when I am told that there is an Ic current, I will tell you, "yes the Vbe voltage is of the order of Uj. What will happen with this junction here? So, the transistor, it has: collector, base, emitter. I'll write vectorially what happens with Vce I will write: Vce = Vbe + Vcb. So these three vectors, it is a vector addition. Vce is from here to here, Vcb is from here to here. So this vector is equal to the sum of this plus this and this is what I noted here. Knowing that, I just said: "When the transistor will conduct, I have all the time, in the order of magnitude of j." So that, I'm not going to change it.

Notes

Summary

15m 36s

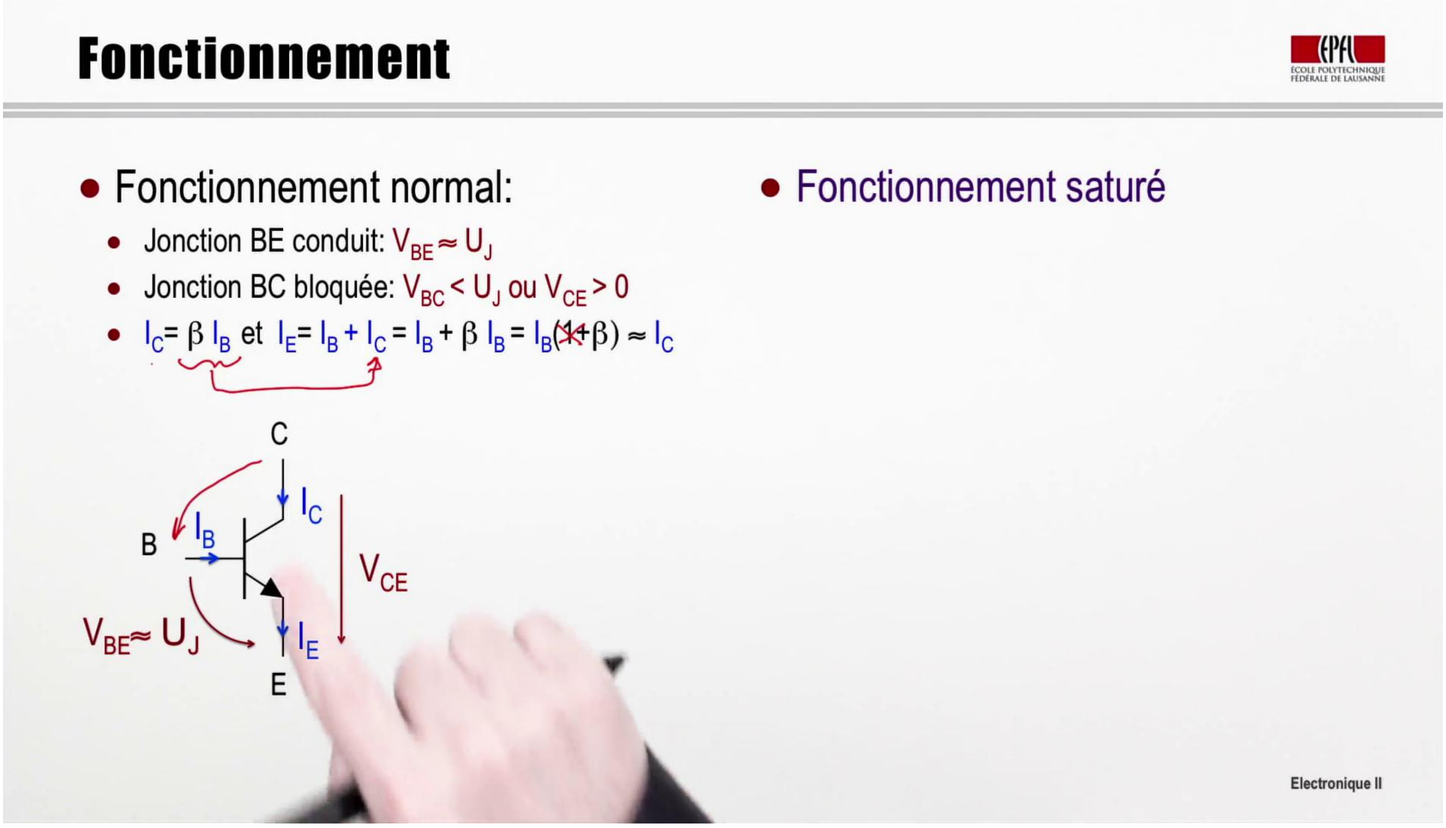


That's going to remain like that. So, what's up with Vcb? Vcb is less than Uj, why? The transistor is in normal mode when the voltage from here to here is positive in all time. So if I put my two fingers there, the potential there is above the potential here. This potential is then fixed. So the difference between this and this, it must be positive in that sense. So that's a positive Vcb junction therefore, Vbc, it must be negative and less than Uj, once the junction begins to reverse, therefore, when the junction begins to be positive in that sense, it can not go beyond a voltage Uj, why? Because I'm having a PN junction here, as a diode, a PN junction here as a diode. And a diode, it also imposes a voltage Uj and Uj. So we take in first order, if this equals this, therefore, Uce will be zero. So if this equal to -Uj, remember that this is Vcb, so Vbc is equal Uj, so Vcb equal to -Uj, both things will be zero and there, we will find ourselves in the saturated mode. So to ensure that my transistor is fully in the normal mode, I must at all costs ensure that Vbe equals to Uj and Vbc less than Uj, which induces that Vce is greater than zero, then it is a positive voltage.

Notes

Summary

17m 14s

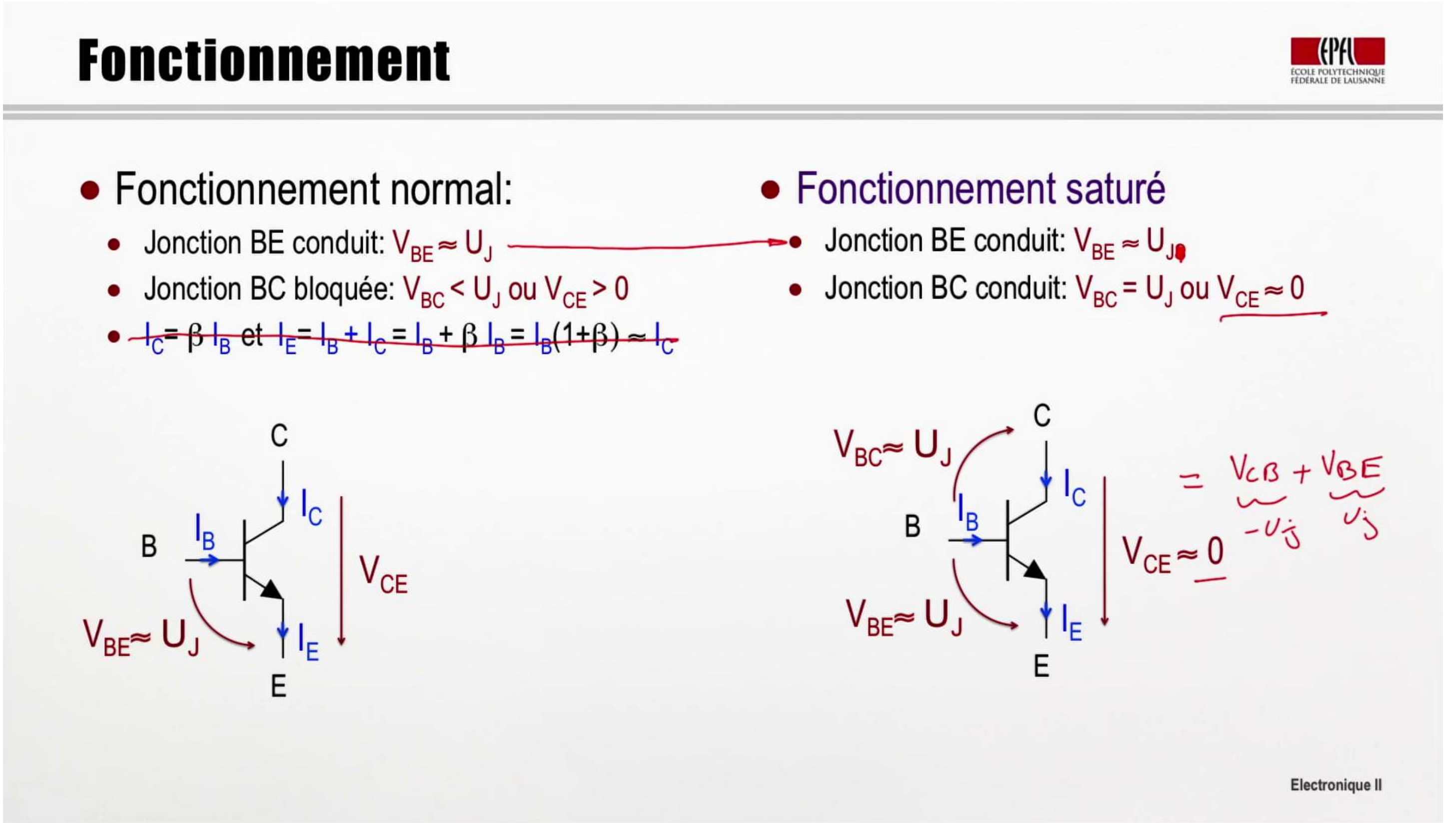


So it's sure that the collector potential can decrease below the base potential and can approach zero and at that moment, this junction becomes positive in the other direction and my transistor will be saturated. At that time and only for this mode of operation, I can say that the current Ic is linearly proportional to β. And the current Ie, it's the two currents entering my transistor, they are summed and come out by the transmitter. So Ie = Ib + Ic. So if you change the Ic, here by β times Ib, you can write it like this: you have a current Ie which is equal to Ib which multiplies 1 + β, the β, we said, is something quite large, that is of the order of 100, 200, 300 + 1. So, the 1, I can overlook it and I endup with the current Ie is almost equal to Ic. This is an approximation that makes sense, this current here, it is so small compared to this, this one, it is 200 to 300 times higher, which makes Ie approximately equal to the current Ic. And all that under normal condition because we were able to ensure that the Vcb junction is positive in this direction and that Vce remains at that time, strictly positive. So the tension from here to here is all the time positive.

Notes

Summary

19m 00s

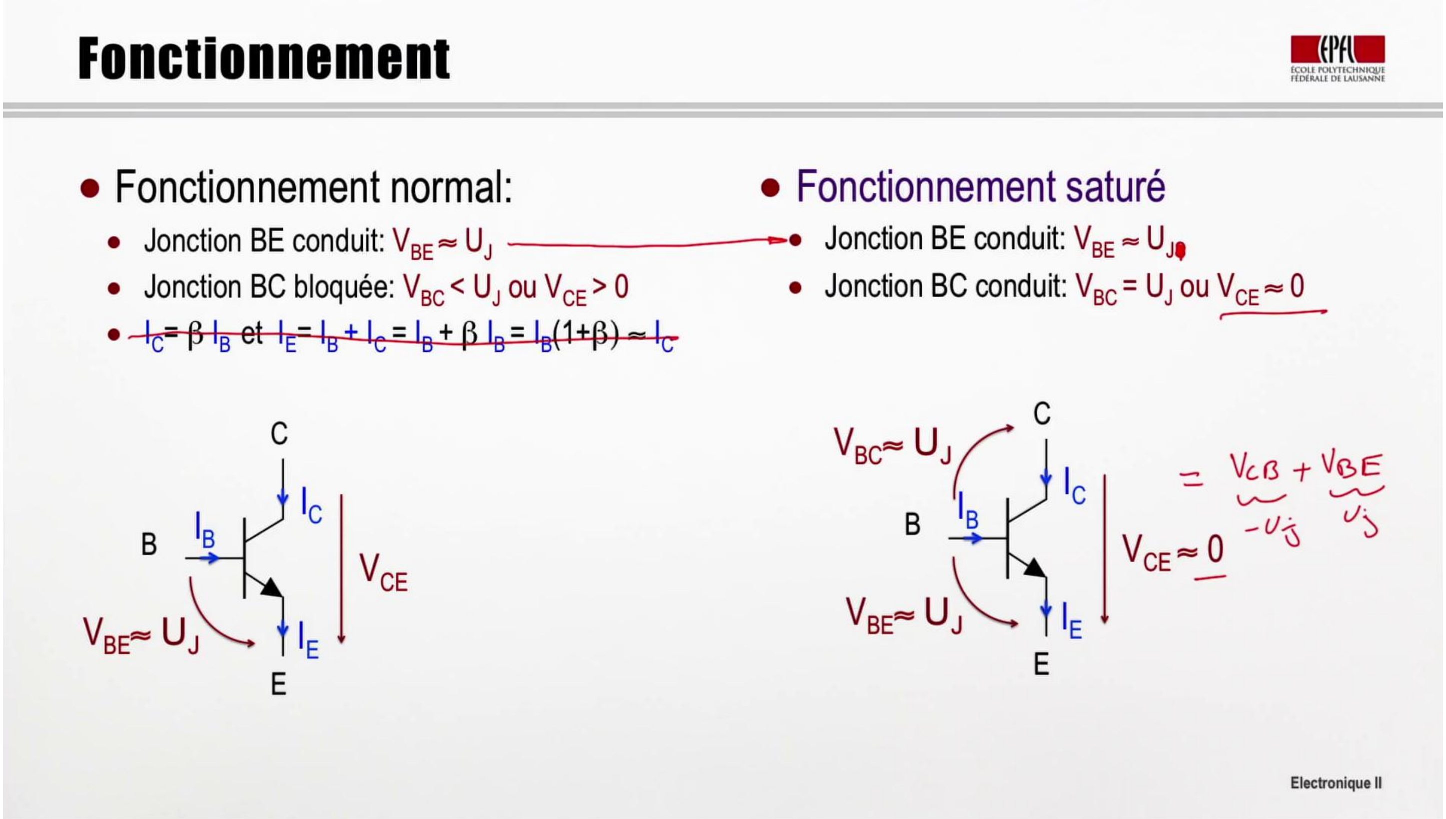


Now we will see what will happen with the transistor when it is saturated. Here is what happens with a saturated transistor, this line and this line are the same. The transistor conducts, in both cases, the transistor conducts current. So when it conducts current, we saw that Vbe is automatically equal to Uj. And then there is a mistake, "S" has no place here. So here you have the UBE is equal to Uj. But we have seen that, if you take Vce which is equal to Vcb + Vbe and you put here Uj and you put here -Uj, this voltage is then equal to zero. If this is zero, that is to say, from here to there, I have a voltage where my transistor starts to conduct, finally rather, this junction has a positive voltage in this direction and this junction has a positive voltage in this direction, Vce is zero and there is the condition for which your transistor is saturated. So, what happens with a saturated transistor? A saturated transistor, you've violated this law. This law is no longer correct. You can't talk no more about the relationship between base current and collector current, on one side and in the output characteristic, you can no longer talk of a current source.

Notes

Summary

20m 40s



So this transistor, here, the base-transmitter voltage controls the collector. Here, the base-transmitter voltage won't control no more the collector current when Vce equals zero and we can't talk of a transistor which could be used in the analog circuit. You will see it is a transistor that could be used in a digital circuit. So I would like us to make the difference between the two and later we will see that saturating a transistor is connected to the circuits, it has no effect on the transistor itself, this is not related to its characteristics, that is linked to the circuit in which we have placed it at a given time where the current is increased in a way that the voltage Vce will become zero and at that moment, we can not talk of this no more. We must, at that moment say that Ic is different from β times Ib and here we talk of a saturation current and we say the saturation current in the base will be, of course, greater to this law we found here β times Ib or Ic equal β times Ib, this current can be increased and there is nothing that will prevent it if you do not brake it with strokes of resistor.

Notes

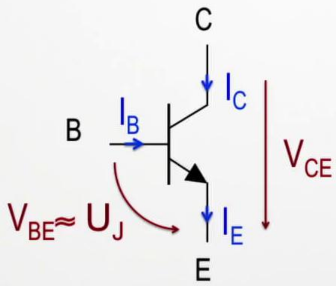
Summary

22m 15s

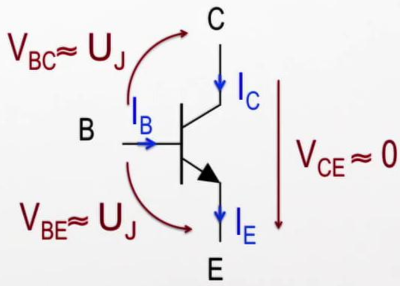
Fonctionnement

EPFL ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

- **Fonctionnement normal:**
  - Jonction BE conduit: $V_{BE} \approx U_J$
  - Jonction BC bloquée: $V_{BC} < U_J$ ou $V_{CE} > 0$
  - $I_C = \beta I_B$ et $I_E = I_B + I_C = I_B + \beta I_B = I_B(1+\beta) \approx I_C$



- **Fonctionnement saturé**
  - Jonction BE conduit: $V_{BE} = U_J$
  - Jonction BC conduit: $V_{BC} = U_J$ ou $V_{CE} \approx 0$
  - $I_C \neq \beta I_B$ avec $I_{Bsat} > I_{csat}/\beta$



Electronique II

So, I think we analyzed what's happening with the transistor when it conducts and when it is in the normal mode and in the saturated mode, and on the left we can use the transistor in a linear set-up it behaves as a current source. On the right, it will depend on what we put as limitations, but it is a transistor that is no longer used in an analog circuit.

Notes

Summary

23m 28s