ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

4.2-Polarisation et sources de courant

Implémentation et dimensionnement pratique

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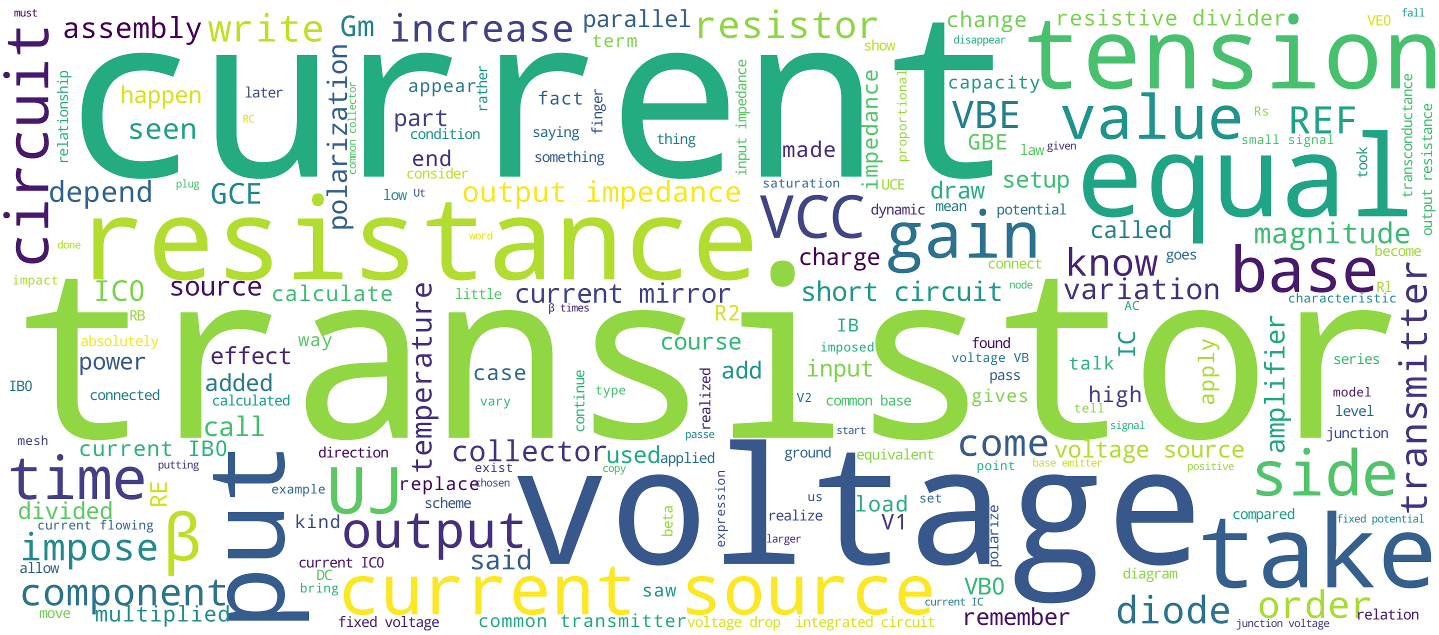
Electronics Laboratory-ELAB



Video

EPFL

As soon as we learned how to polarize a transistor and we have seen that it will be necessary to apply a fixed voltage to its base, to impose a current in its transmitter, in this part, we will learn how to realize this circuit. That is to say, we are going to approach the realization of a fixed voltage to impose on the base of a transistor. You will see, it is extremely simple. Once we have finished with this part, we will go immediately to the use of the polarized transistor. And you'll see, it's the same thing that we will call suddenly "power source". Because it is enough to look at it from its collector and we will see that there is a fixed current that comes out or which is absorbed by the collector, and we will use it as a current source. Once we have finished with the demonstration that a transistor seen from the collector and wich is polarized with the resistance, we will see immediately, brings us to a current source, we will immediately address the integration of the same circuit, which has been realized by passive components with discrete components, and we want to pass on an integrated circuit. So we would like to implement on a silicon chip, what we call an integrated circuit, and demonstrate that it would become much simpler.

Notes

Summary

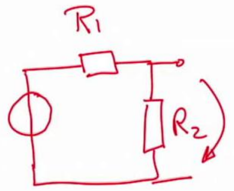
0m 05s

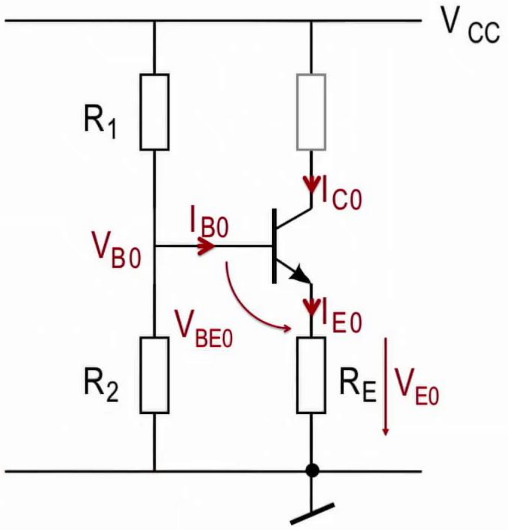
Schéma pratique de polarisation

- Considérations pratiques:
  - V_{E0} entre 10% à 30% de V_{CC}
  - Choisir le courant dans R_1 et R_2 environ 10 fois I_{B0}.

$$V_{B0} \approx V_{CC} \cdot \frac{R_2}{R_1 + R_2}$$

$$I_{C0} \approx I_{E0} = \frac{V_{B0} - U_J}{R_E}$$





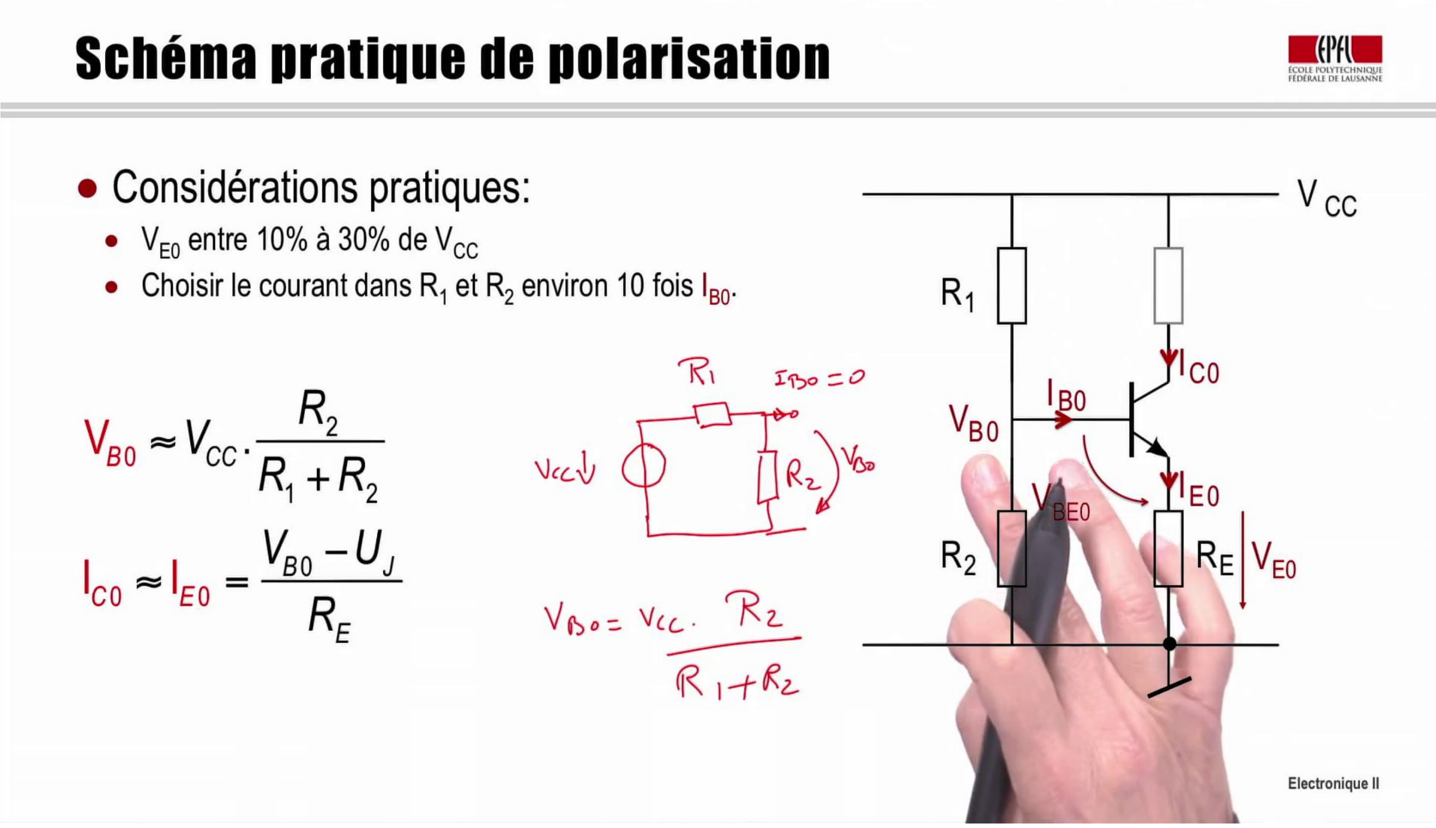
Electronique II

And we remove many of these passive components, and we'll count on the transistor itself and realize cells we'll see at the end of this video, to make current sources. Let us consider the pattern that we saw earlier, so this famous transistor: to polarize and impose a IC0 current, we had said that we will impose a VB0 voltage. Imposing a voltage VB0 on a node of a transistor by having a stabilized power supply available. So it always gives us what are called power rails and we will put a resistive divider which is made by the resistors R1 and R2 to lower this voltage and bring it to a potential VB0 of our choice. Because that's how we had seen that the objective is to impose VB0; we used the transistor which will cause this voltage to fall of the order of magnitude of a junction voltage, and the VE0 voltage that remains to us allows us to impose IE0. I would like to take the source of VCC voltage which is there, so that is here, I draw my VCC source, and I'll put a resistive divider which will be realized by the resistor R1 and resistor R2 and remind that this kind of circuit will, empty, give me a voltage there. And that tension, it's proportional if I talk about voltage V...

Notes

Summary

1m 20s

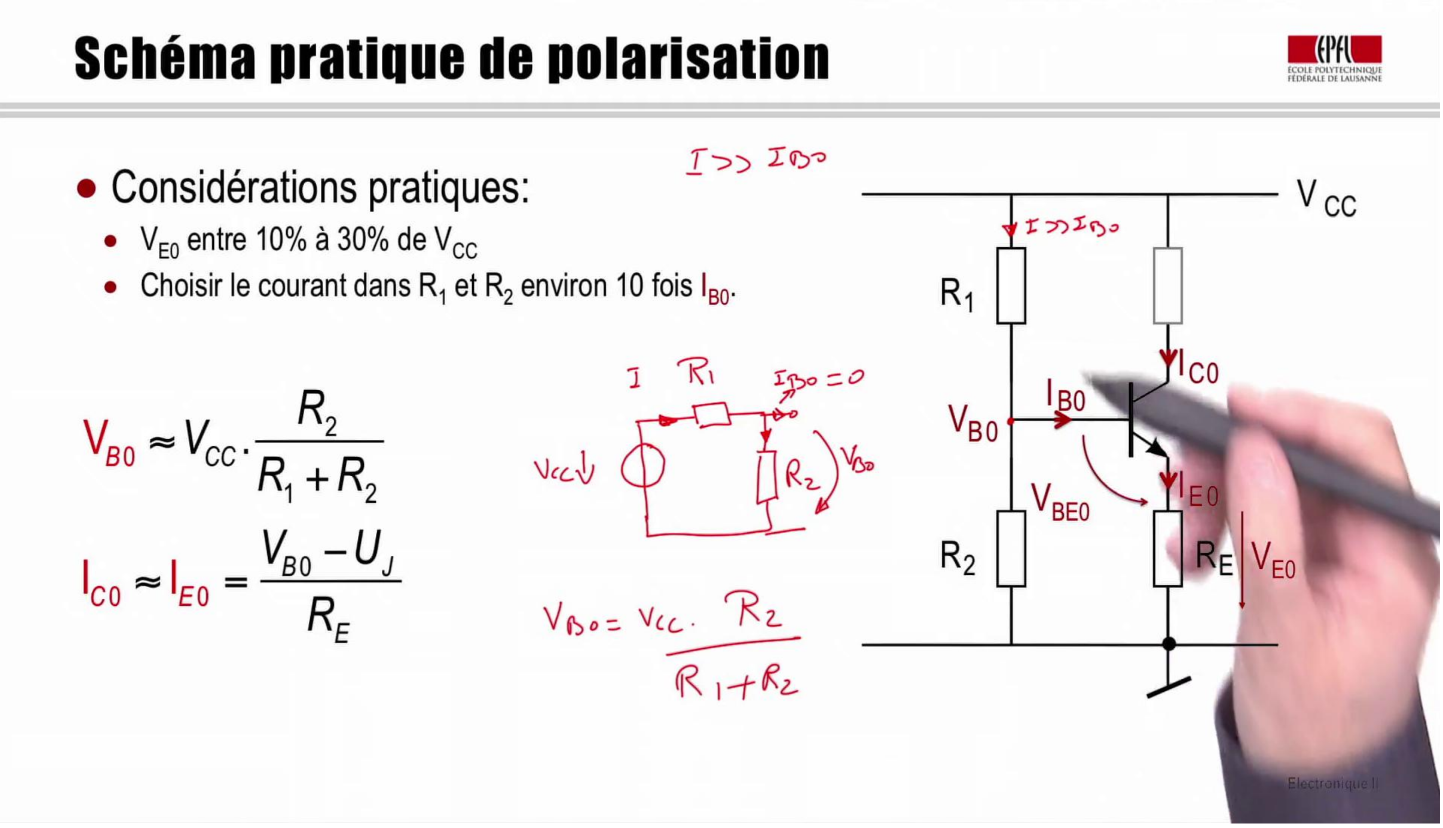


and I'll call it VB0, you see, because it will be the same as this, so I'll write VB0 in this circuit equal to... this, that's VCC equal to VCC which multiplies R2 and which is divided by the sum of the 2, R1 + R2. And here, I have a voltage which is always lower than VCC and depends on the resistance report that I've chosen, it's something you propably know very, very well. But this is valid only when the current I pull from there, that current I that I will write B0 of course because it will be this current one; This current IB0 must absolutely be equal to 0. I can write this and put the equality and all this is correct. But is it, really, when I realize a resistive divider here, I take it and I connect in this node one, this IB0 current is equal to 0? Absolutely not, because here there is a current IB0. So this circuit there, if I use it as it is without thinking, it will not allow me to impose a fixed voltage. So we learned that to be able to impose a current in a resistive divider, you know that the current that would pass there, this current, if the current IB0 is equal to 0 it continues its way, it comes down here.

Notes

Summary

2m 50s



Now, if by chance you pull a certain amount of current IB0, you will see, you will drop the voltage across your resistor R2 simply because a part of this current is gone. You can very, very well make this circuit and say: What happen if the current I impose there, this current I'll call I, is much larger that the current IB0? If you put that condition and you say: I have much more current here than this the very small portion of current that goes into IB0 will never drop that voltage or disrupt it, or if it disrupts it, it will disrupt it weakly. So in other words if you put that condition, so if you impose here a current called I, which is much larger than the current IB0, you manage to impose here a potential that is nearly constant. And that's what will be applied to achieve polarization with a resistive divider. So we agree that this is not an ideal voltage source. This is a source of voltage which depends on this current IB0. Here, I give you conditions: if you arrange to put here a current which is an order of magnitude 10 times greater than this, or more than 10 times, well you disrupt a little the potential VB0. And then you will tell me: so why not put all the time a current 100 times or 1000 times greater than B0?

Notes

Summary

4m 13s

Schéma pratique de polarisation

- Considérations pratiques:
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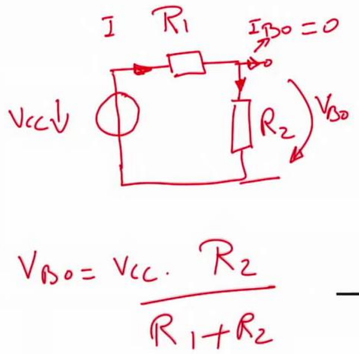
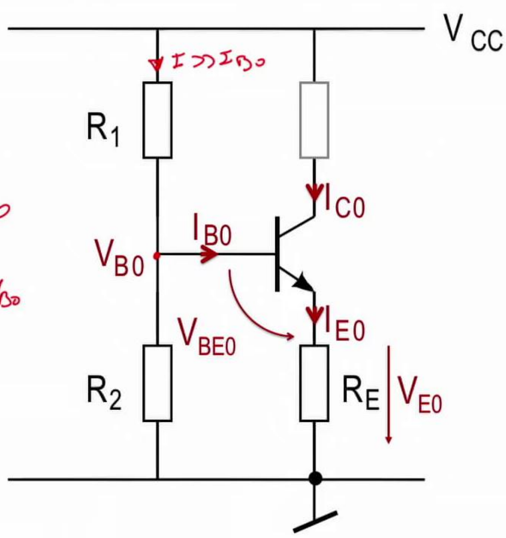
$$V_{B0} \approx V_{CC} \cdot \frac{R_2}{R_1 + R_2}$$

$$I_{C0} \approx I_{E0} = \frac{V_{B0} - U_J}{R_E}$$





Electronique II

Be very careful: the current which passes in these two resistances, it's a lost current, it's a current of polarization. This current one is effective, it is the current that allows us to calculate the small signal parameters, and this, it has absolutely no impact on this, it is simply to avoid that this potential VB0 does not match to that which would have been calculated by that relation. If you write this relationship, you get VB0 but you've considered the fact that IB0 does not exist. And if this IB0 exists, it means that you have set a higher current. But in reality, the current, is a current that is lost, and that is why we are content to move from the order of magnitude of a ratio 10 between this and this. In the worst case, if you take this current equal to this current, it means that it is the β of your transistor that connects the two, so it is as if you were saying I have β times more current than there thus β is equal to 100, 200, 300, depending on the type of transistor you have chosen. And at that time, your potential VB0 is not impacted by this.

Notes

Summary

5m 49s

Schéma pratique de polarisation

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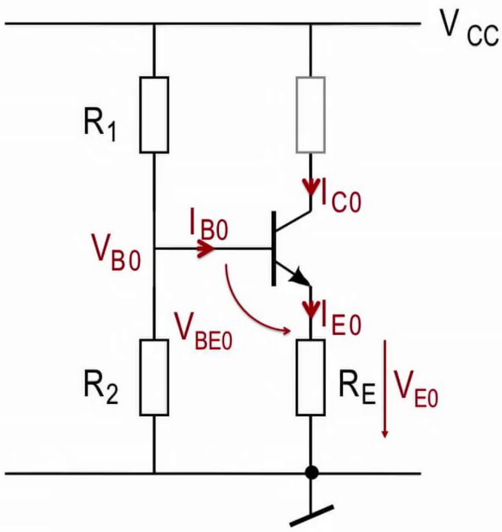


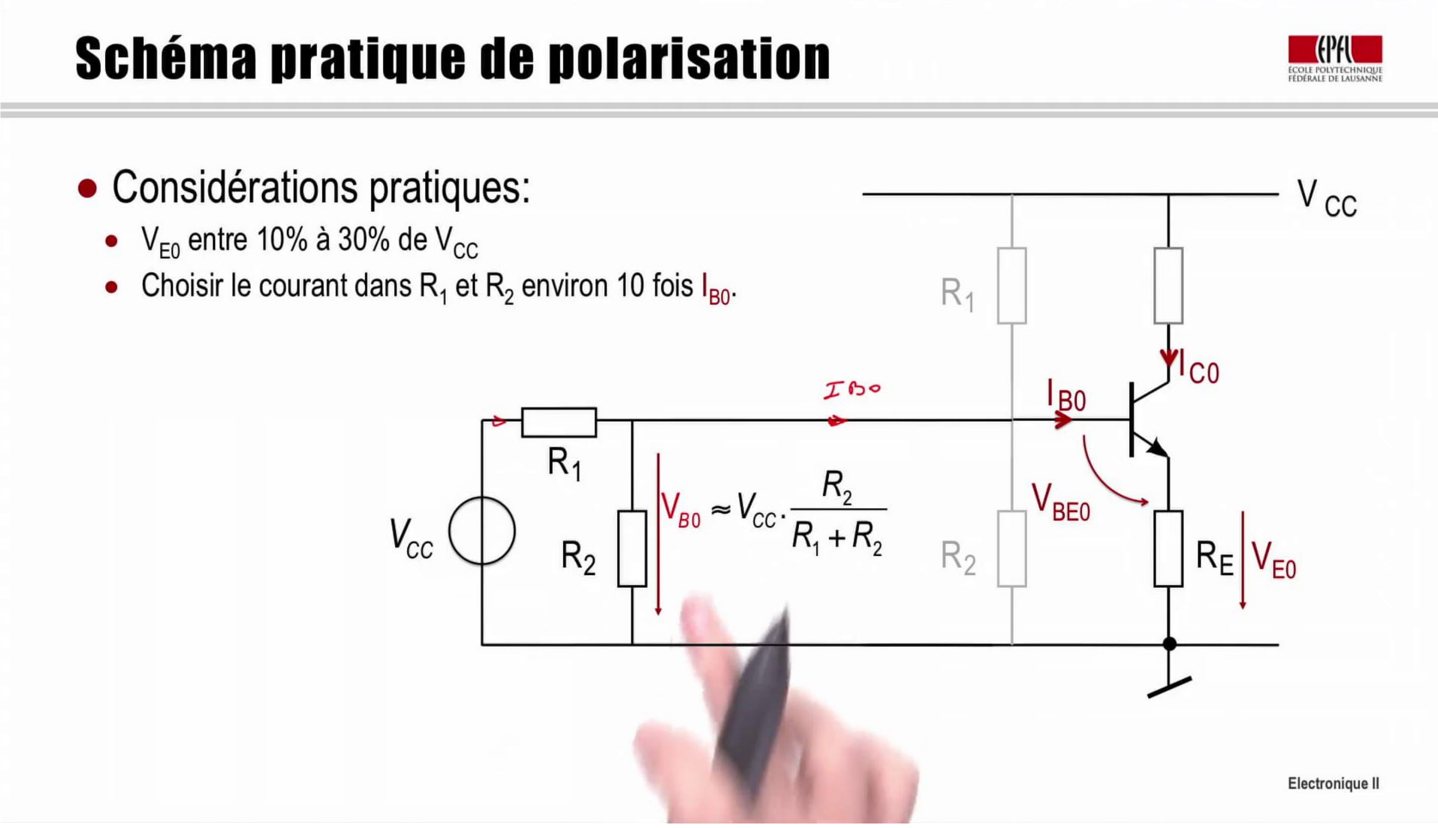
Electronique II

I intend to take this same scheme and I now intend to go to comment a little more what will happen with my resistive divider by replacing it with a voltage source such as I presented here, before clearing.

Notes

Summary

7m 01s



And here it is. So I just extract my 2 resistors, I brought my voltage source VCC and I put my 2 resistors as we saw earlier just prior to this slide, and you will see that the tension there, this is the one I have just written. And I left a little bit of 2 resistors to see that they are the same that I moved here. Now it has been said that this current which will pass here is indeed the current that will be our current IB0 and that we will calculate taking into account that the voltage source we just realized, and in reality that VB0, these are the dividers with resistors that you've chosen yourselves, with the values for R1 and R2, by applying that VB0 is equal to the tension that would have been calculated. But the factor 10 that I just mentioned, it's here. So it is arranged that at least we have 10 times more of current which passing in that branch compared to this current IB0. But if you take this tension we see, VB0 with that source, you know very, very well that if you look at the resistance from there, the source's resistor, with a voltage source realized with two resistors as a resistive divider, it is as if you did an ideal voltage source whose value is this, the VB0.

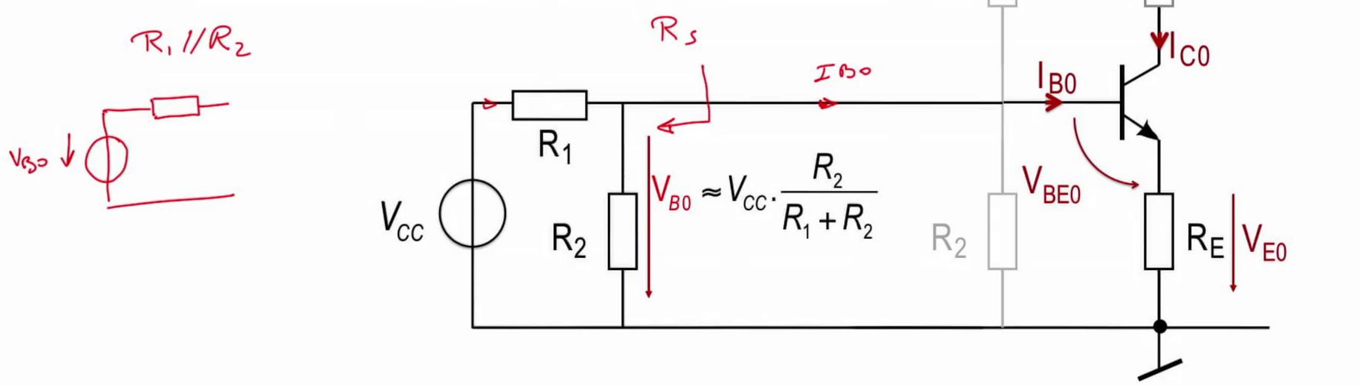
Notes

Summary

7m 17s

Schéma pratique de polarisation

- Considérations pratiques:
  - V_{E0} entre 10% à 30% de V_{CC}
  - Choisir le courant dans R_1 et R_2 environ 10 fois I_{B0}.



$$V_{B0} \approx V_{CC} \cdot \frac{R_2}{R_1 + R_2}$$

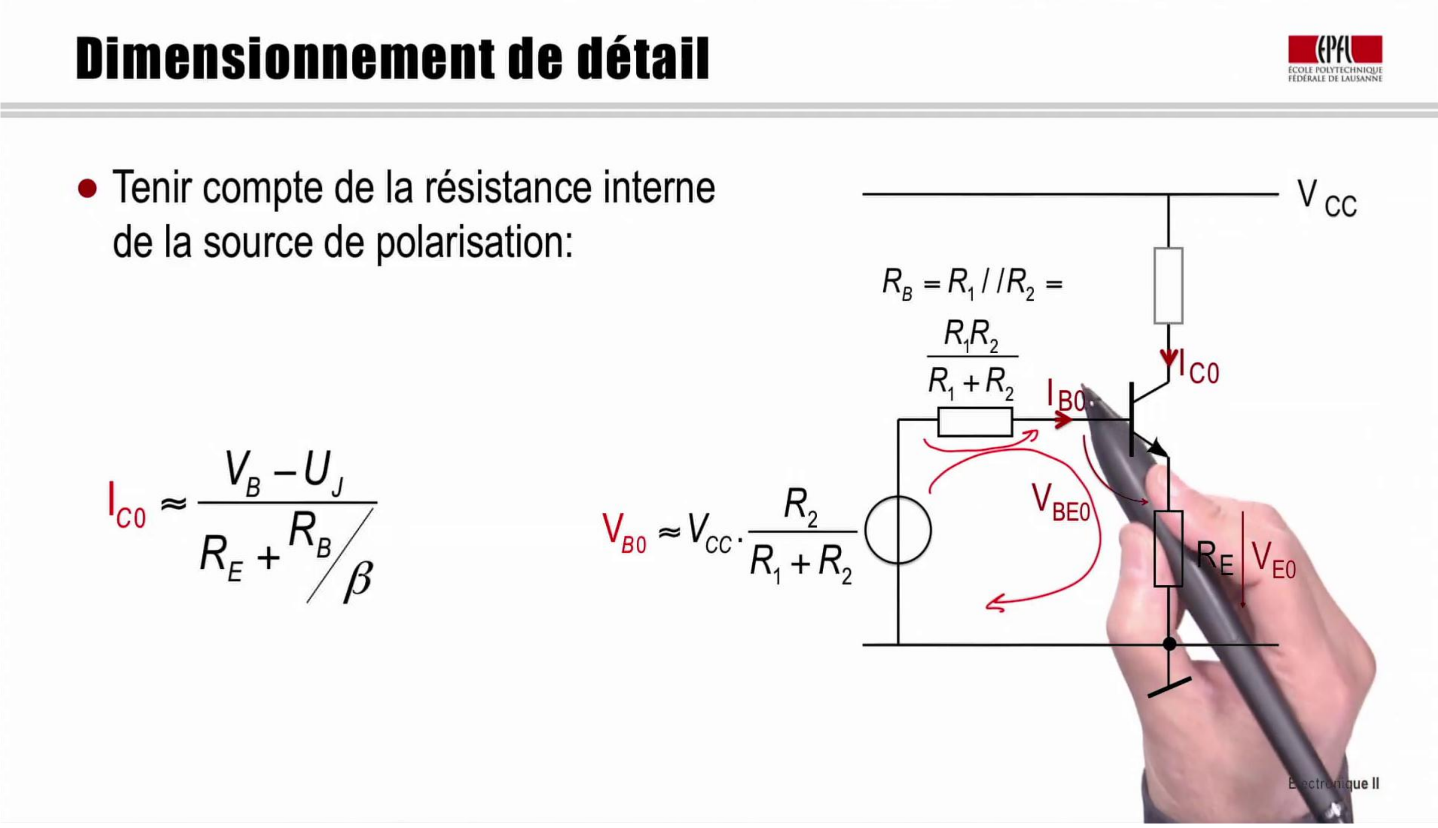
Electronique II

So empty, if I do not plug that, I have seen this tension. And the internal resistance of your source will be the implementation in parallel connection of R1 parallel with R2. Therefore R1 parallel with R2 will give us the equivalent resistance, view from here from an ideal source whose value is VB0 and whose output resistance, or the source resistance, will be R1 parallel with R2. So if I want to take this scheme there and put it here by removing the two resistors R1 and R2, I'll get this.

Notes

Summary

8m 47s



this is my schema now with my empty voltage source And the paralleling of the two resistors, and this circuit which is there matches actually something quite correct. Now, considering my current IB0, by putting it in the ideal source, putting it in this ideal values of resistances that I have chosen to impose the current passing through the resistive divider, and I shall have put an equivalent resistance which is equal to R1 parallel with R2, I can calculate exactly, the current, or rather voltage that I will see on the basis of this transistor. Or, in other words, in this mesh which is here, so the one which is there, I have to consider a voltage drop here which is equal to IB0 multiplied by RB and this IB0 x RB will give me the drop voltage here, that I have to subtract from the empty voltage to be able to really calculate the tension VE0. And as I know that the current, the link between IC0 and IB0 passes through the relation IC0 β = x IB0, well I'll find easily the exact expression of IC0 which takes account of the resistances that I added myself to realize this voltage division.

Notes

Summary

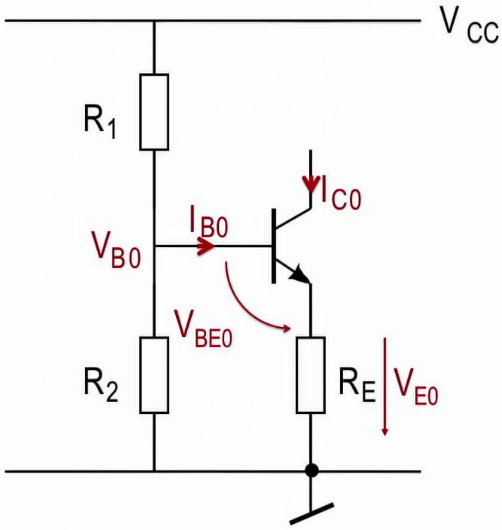
9m 26s

Résumé de polarisation

$$I_{C0} \approx \frac{V_B - U_J}{R_E + {R_B}/{\beta}} \quad et \quad V_{B0} \approx V_{CC} \cdot \frac{R_2}{R_1 + R_2}$$

$$\frac{\Delta I_{C0} / I_{C0}}{\Delta T} = \frac{2mv/^{o}C}{R_E I_{C0}} = \frac{2mv/^{o}C}{V_{B0} - U_j}$$

- Indépendance de la température $V_{B0} >> U_J$
- Indépendance de β: $R_B << \beta R_E$



Electronique II

And you will see that compared to what we had seen before, if I hide this part, you find the original expression that brings the current IC0 without the effect of this resistor RB because we have calculated, we considered qu'IB0 is 0, it is as if we had said β = ∞. If you put β = ∞, this term will disappear, and you will find the IC0 that we had calculated before. If β is finite, and if the resistor RB you have added is a finite value resistance, if you write this equation that we have extracted from the mesh, you fall on the exact expression of your current IC0 in fonction of β and RB. so, in practice, if I can impose a current here rather high compared to IB0, I can erase it; it's like I was saying the RB is much larger than β x RE. So if that's the case... sorry, excuse me, I said wrong. It's like I was saying: the RB / β is much smaller than RE, RB is so much smaller than β x RE. And we fall down on the approximation before. The exact expression and the expression taking account of the simplification depend on your choice of resistors R1 and R2, and the β of your transistor. I would like to summarize here, on what we see there, the history of polarization.

Notes

Summary

10m 54s

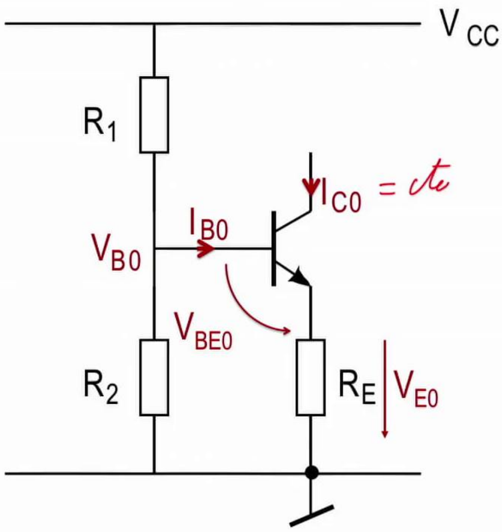
Résumé de polarisation

$$I_{C0} \approx \frac{V_B - U_J}{R_E + {R_B}/{\beta}} \quad et \quad V_{B0} \approx V_{CC} \cdot \frac{R_2}{R_1 + R_2}$$

$$\frac{\Delta I_{C0} / I_{C0}}{\Delta T} = \frac{2mv/^\circ C}{R_E I_{C0}} = \frac{2mv/^\circ C}{V_{B0} - U_j}$$

V_{E0}

- Indépendance de la température $V_{B0} >> U_J$
- Indépendance de β: $R_B << \beta R_E$



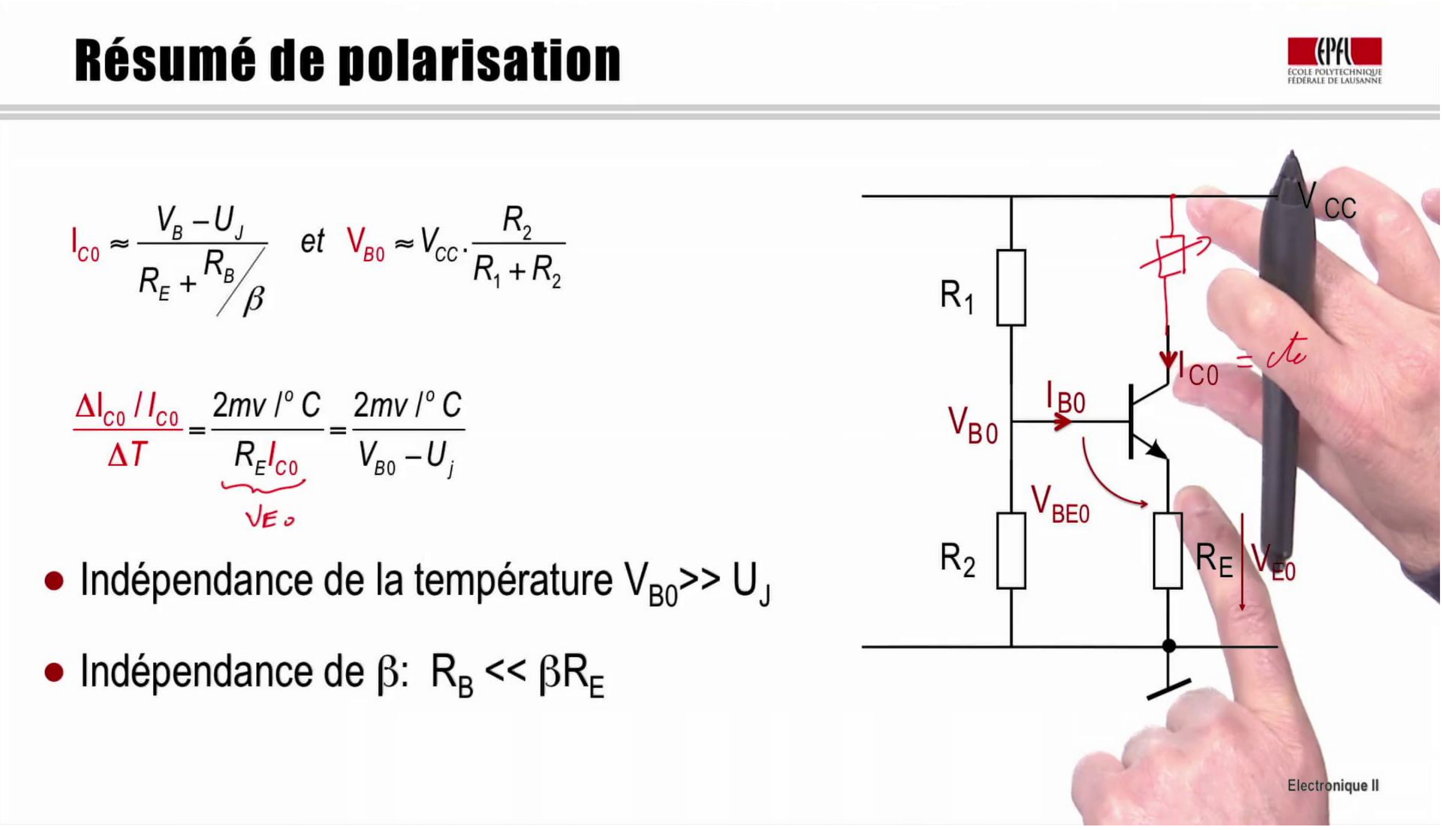
Electronique II

We used a resistive divider, we've calculate the current IC0 taking account of a resistance which is the paralleling of the 2 if we want to be exact, and it has been found that the VB0, if actually the current here is very large, is equal to this expression. And this brings us to the idea that we're trying to apply: how to make a current source where this current IC0 is equal to a constant independently of the variation of the temperature which is due to our component, the bipolar transistor. We had seen that this current will be affected the temperature drift, or the shift in temperature, or the variation in temperature of this ΔIC0 fonction of the voltage UBE0 which is 2 mV/°C, and this depends of the voltage drop you put on RE x IC0, so this is the VE0. And there, we saw that more we increase this tension, this voltage increases, that law of 2 mV which is specific to silicon will be divided by what we have chosen, so this is our conception that will make steady the variation of this current depending on the temperature. So we are in the considerations of circuit design. And it is up to the designer to take those kinds of decisions. And now, I summarized this.

Notes

Summary

12m 36s

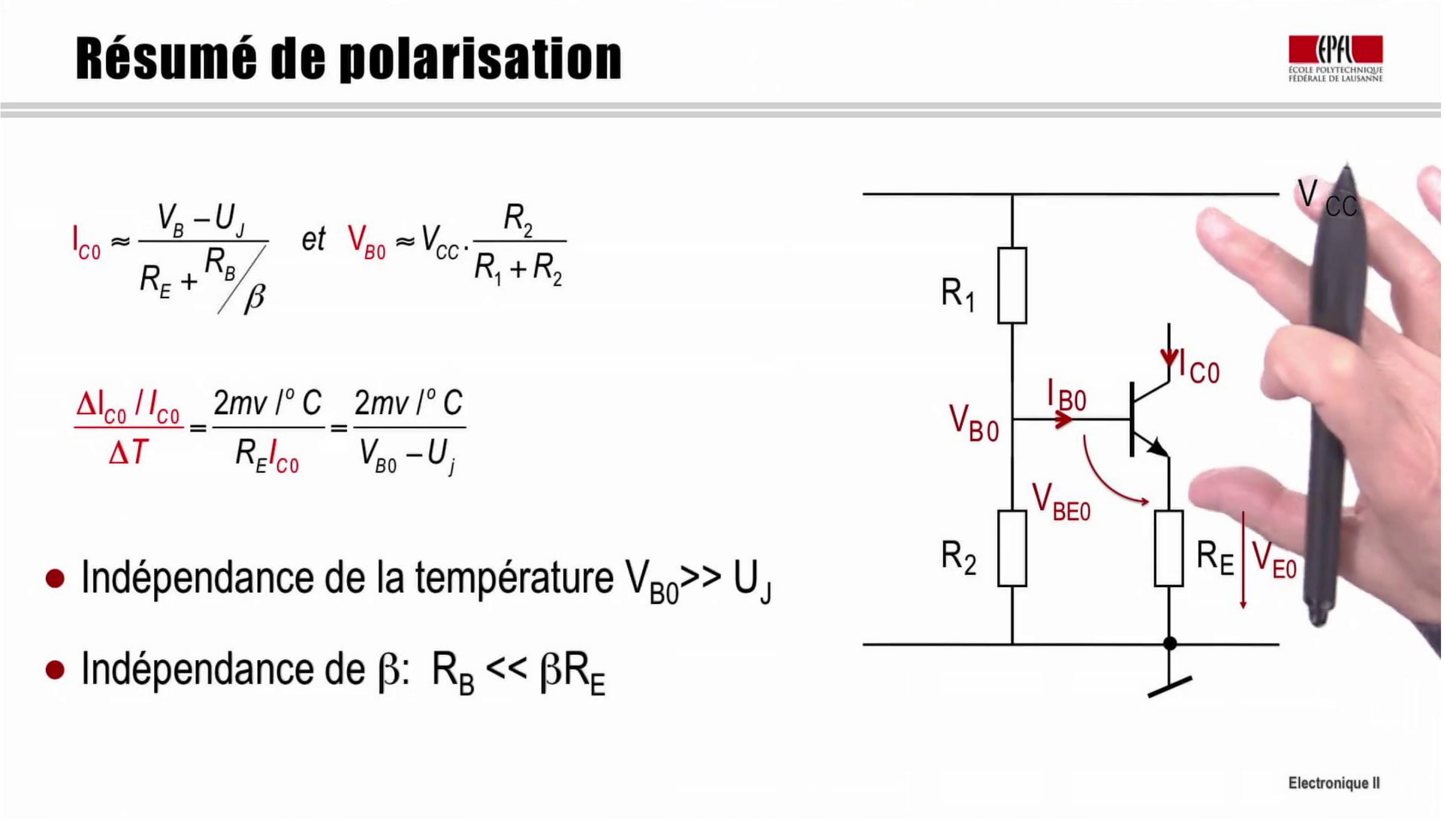


So, looking at that, I finally did what with it? I applied a current IC0= 1mA. So this current does not vary even if I vary this voltage. You remember that he was saying: UCE, when it varies, there is the Early effect and it impacts on my current IC0 who, when the CPU voltage increases, we will see that IC will increase with a slope that is linked to this Early voltage. In practice, when we use our transistor, we connect a load here. So we will have a resistance who would come there. If your resistance is variable, it means that that resistance changes in time, or it changes depending of a variation of something; so that voltage rises up or goes down; even when we are in DC so we have a DC voltage, the variation of this voltage, look at this voltage, we did everything to make it constant. And we did it in the mesh, therefore in this mesh this voltage minus this voltage give me this one constant. The one where I move my fingers, she will hit the VE0 tension. So when I increase that resistance I see rather... [stammering] I increase my current IC0 which is there, it will increase the voltage across that resistance. look at my 2 fingers or rather my finger, from here, it will go down and it goes down until it touches the other.

Notes

Summary

14m 07s



And when he touches the other, it's like I was saying: UCE = 0. When this voltage then is equal to that tension, my transistor is no longer a source of current. So I can not longer talk about polarization and an imposition of a constant current. So I cant use this assembly. What I would like say around this, I will erase what I have just added; I would like to come back to this idea: I would like to realize a current source. So here a constant current which supports any voltage variation here until the saturation of course, while having lost this range of 0 to VCC a part for VE0. So remember that at the beginning, if you put the transmitter to ground the VE0 did not exist. And this voltage VE0, we just add for this to obtain ths relation. So we have a stable current source but we still lost somewhere this VE0. And I would like to have a circuit which behaves as a current source having lost this, and see what I can do with when I vary my tension that comes here, and say that I have done a current source that will help me later to polarize by running a lot of things and that will allow me from the lesson of next week to understand that there the IC0 current it goes, or that kind of assembly will allow me to use a fixed current source that will give me infinite resistance and then I will call "active load" but we'll see next week.

Notes

Summary

15m 35s

Résumé de polarisation

$$I_{C0} \approx \frac{V_B - U_J}{R_E + R_B/\beta} \quad et \quad V_{B0} \approx V_{CC} \cdot \frac{R_2}{R_1 + R_2}$$

$$\frac{\Delta I_{C0} / I_{C0}}{\Delta T} = \frac{2mv/^{o}C}{R_E I_{C0}} = \frac{2mv/^{o}C}{V_{B0} - U_j}$$

- Indépendance de la température $V_{B0} >> U_J$
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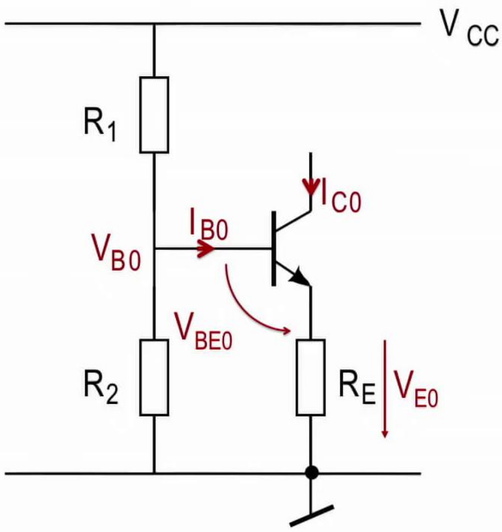


Electronique II

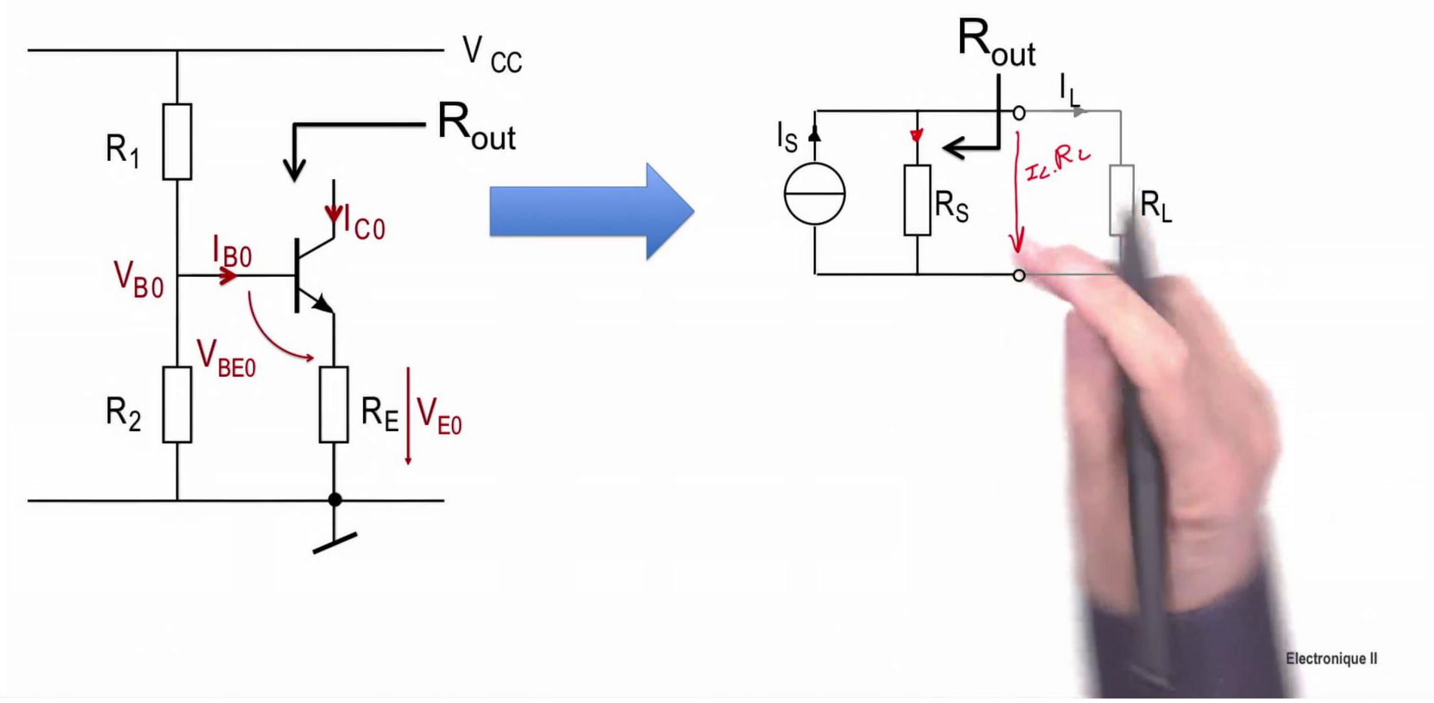
So we just saw the polarization. Now I will take this bias and see it little differently.

Notes

Summary

17m 18s

Source de courant et résistance de sortie



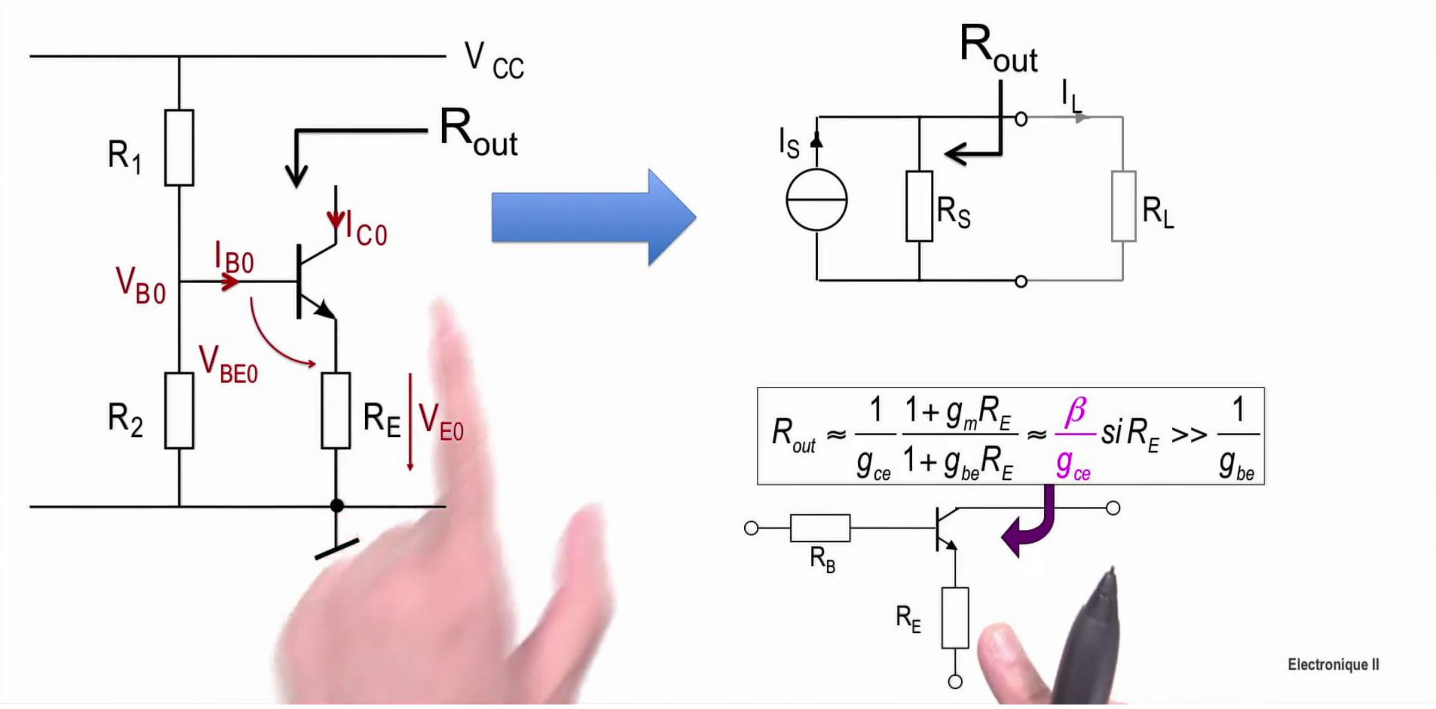
If the current is fixed and stable relative to the temperature, Look, this is a symbol of a current source. A current source, What we would like to have in parallel with it? We know that it has a fault which is due to resistance wich comes to parallel, that if this resistance does not exist and I can create a short-circuit at the output, my short-circuit current is equal, so if the UCE is équals to 0. And if I take it and I said: that's the equivalent of a UCE, if it had been a transistor, I can bypass my transistor. If there had not been this resistance, I would have all the current going through my source here and it would be amazing. we just dispel the idea that we can not short-circuited a transistor between collector and emitter because of saturation. Independently of that, if there is a resistor in parallel with a current source, the current IL which starts here will suffer a current which, when the output voltage changes, so that tension is IL x RL, when that IL x RL changes, the tension here will change. Therefore the current flowing through this resistance also. Therefore in fonction of this voltage, I run the risk of losing a proportion that passes within my current IS, that I would have liked IS = IL.

Notes

Summary

17m 24s

Source de courant et résistance de sortie

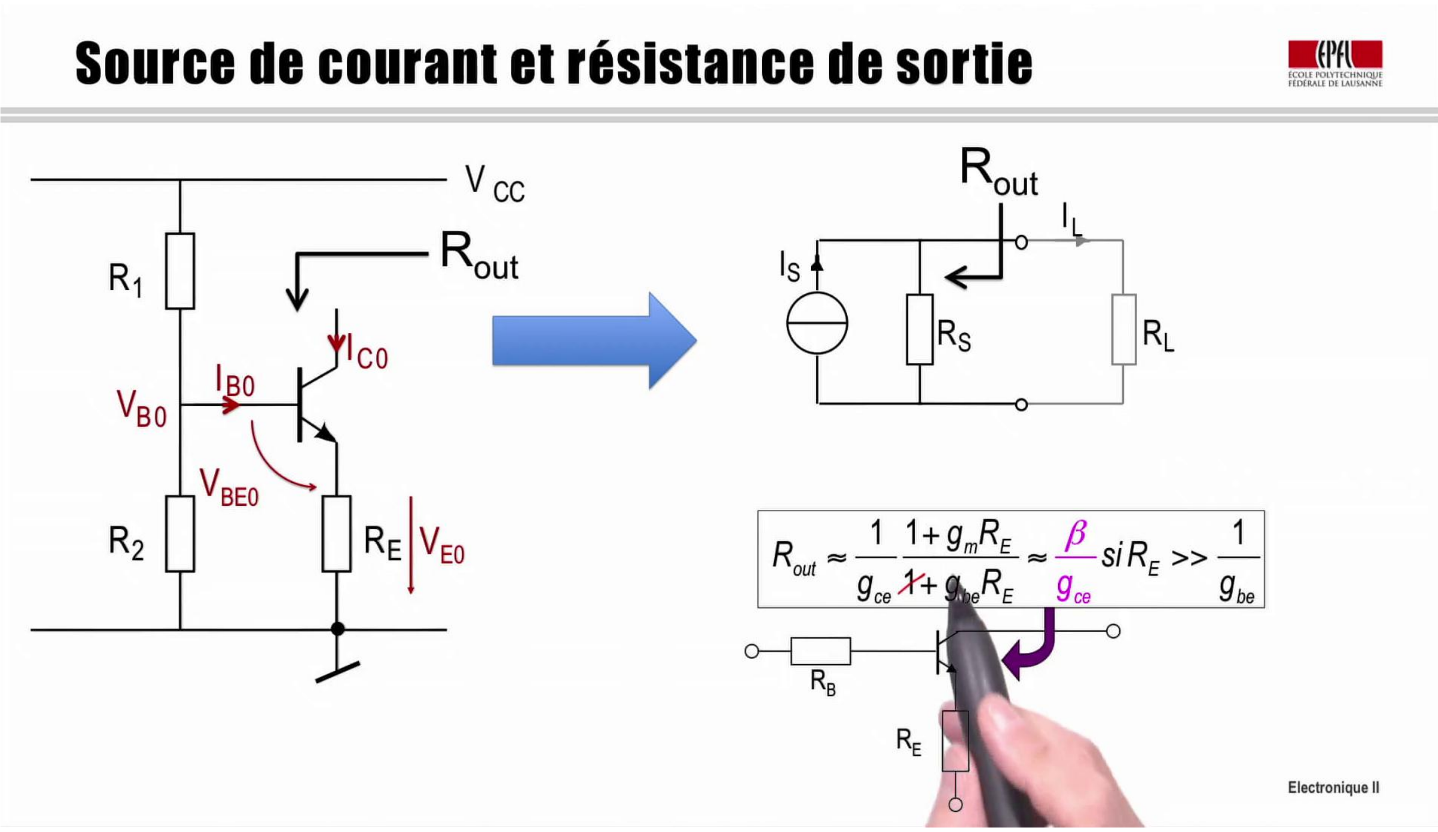


So this resistance should be infinite, it does not exist, it disappears, or the highest possible. So when I look at this current source and I ask myself: if I want to use this analogy, that is equivalent to that, which is true, What is the value of RS? So here I have a fixed current, that, it will be the IS, but then, it suffers from an output resistor. What is its value? If it were not for RE, I know very well, it's 1 / GCE. But now we added RE. Is this resistance has deteriorated or improved? The answer: R OUT resistance was perfectly improved. on the contrary. the fact of using this circuit like this putting RE will allow me to get a resistance R OUT which will be high. And it will be the circuit that we will use to make current sources. Here is my montage and here is what I want to do, this is what we had studied before to calculate what the output resistance. So I take this scheme there, I replace it with the equivalent saying these two resistors R1 parallel with R2 created me a resistance RB in the base. I added a RE resistance myself. So what is the impedance Ithat I look from the collector of a transistor having a resistance RB in the base and RE in the transmitter?

Notes

Summary

18m 50s

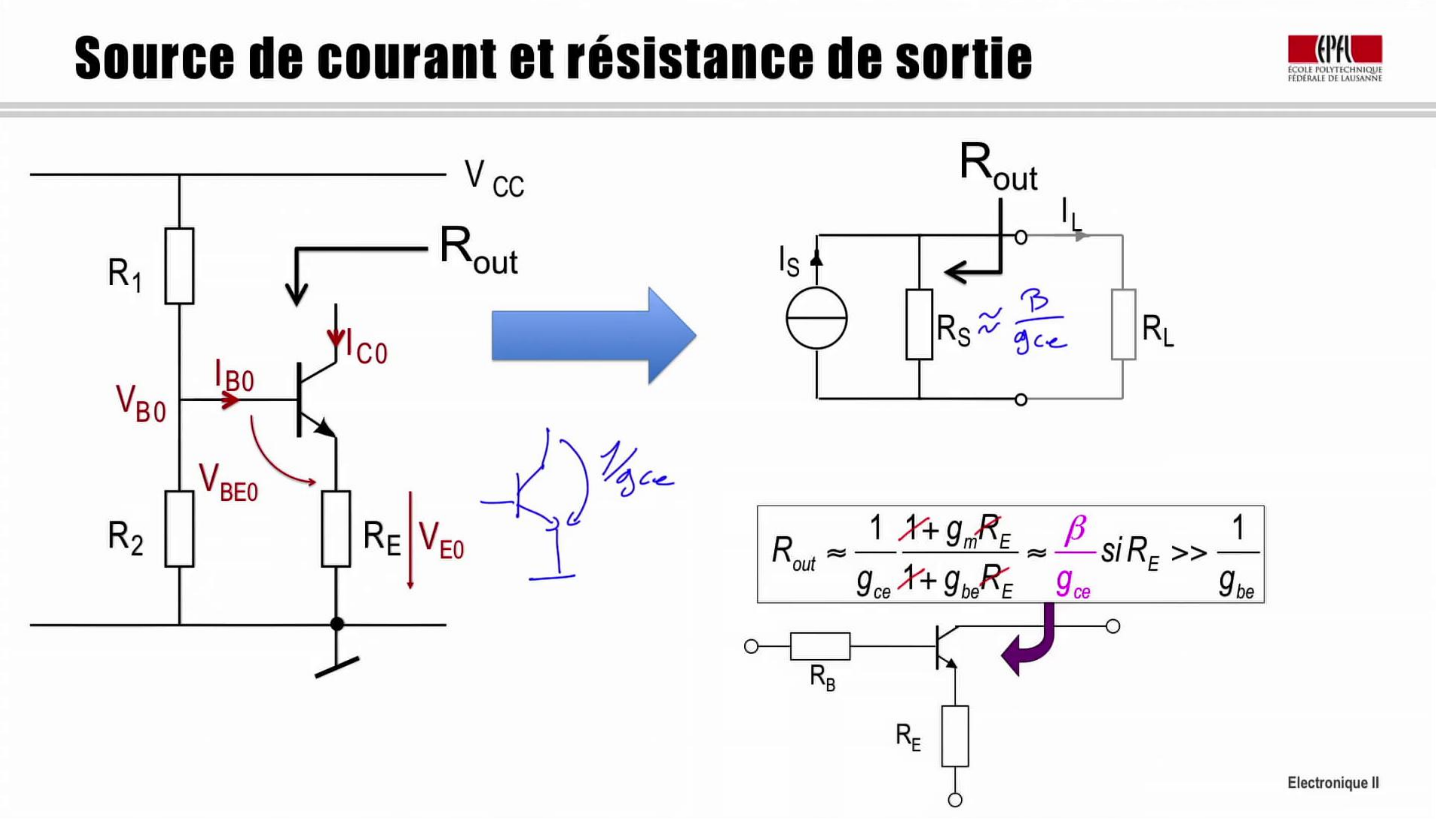


I send you the chapter where we studied it. But if I take into account an additional consideration and I say: this resistance RB compared to β x RE so I can no longer speak, I can consider that RB is almost 0, that is to say the current IB0 is very, very low, and resistors R1 and R2 who are here and are placed in parallel with the source do not affect me much in the voltage VB0, it is as if this potential was not moving So this resistance R1 parallèle with R2 becomes equal to 0. Well, I came across this approximation that we calculated in length and breadth there are some lessons before, and we was found the following things: R OUT = 1 / GCE, and the numerator is 1 + x RE GM, and the denominator is 1 + x GBE RE. If I consider GBE x RE >> 1; In other words, GBE depends on IC0 as GM, so, depends on IC0; but I put a sufficiently large ER resistance in there, that the product of the resistance I added myself multiplied by the GBE that I got by the polarization is much greater than 1. So if that is the case, I can say: the 1, it is almost negligible compared with that GBE x RE. So in this case, there it is sure that it is negligible, since I am allowed to neglect here I must surely neglect here because GM is β x GBE.

Notes

Summary

20m 16s



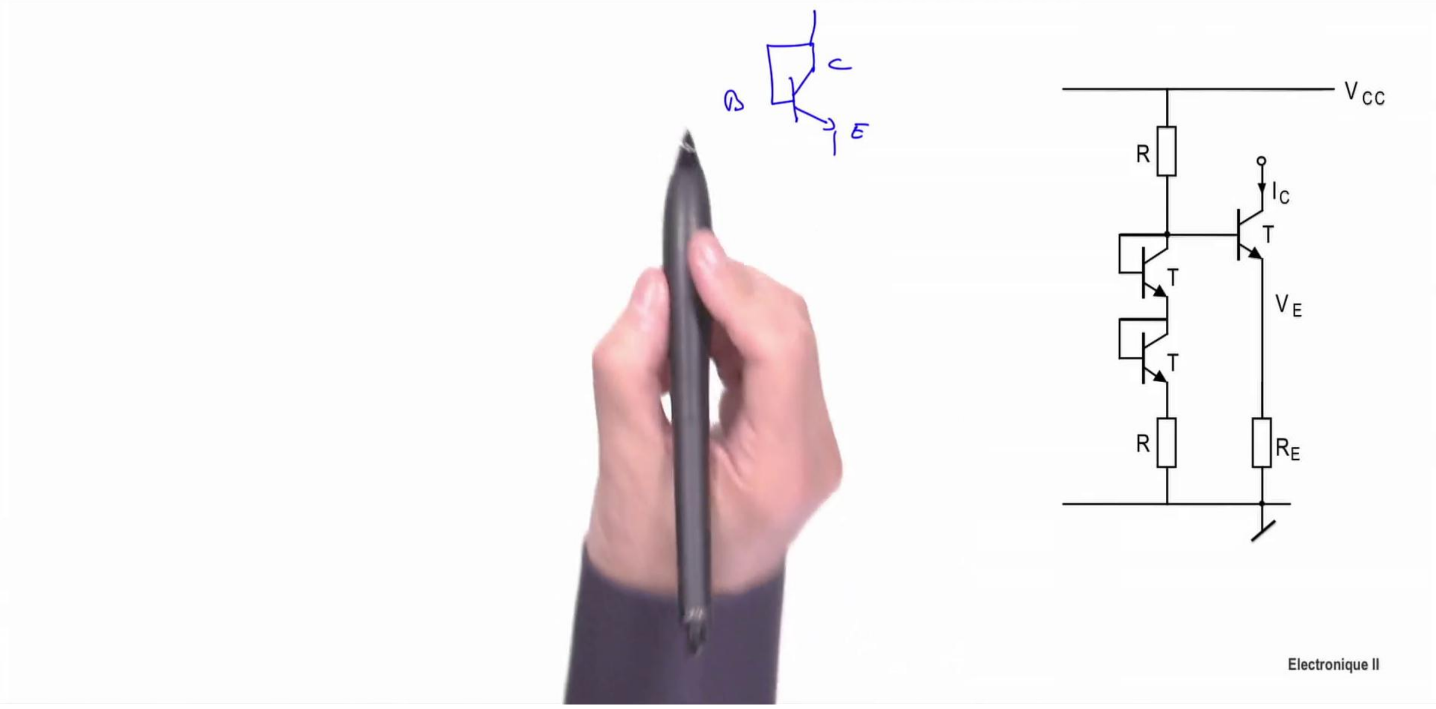
So that's much larger so I can also overlook this. And I'll find myself with (GM x RE) / (GBExRE) so I simplifie RE and RE, I find GM / GBE which is nothing other than β. So GM / GBE β = and I had the 1 / GCE: I find that the output resistance is β x 1 / GCE. I remind you that a simple transistor, if you plug your transistor and the transmitter, you will put it to ground in AC, that's 1 / GCE to Having added a resistance in the transmitter, you will find yourself to β / GCE to having imposed a fixed voltage on the base. So we are β times greater than what would have been obtained with a single transistor. Extremely interesting to do that. So here I find myself, compared to a simple polarized transistor: RS would have been 1 / GCE, and in the calculations that we've made It shows us according to the tension of Early and the current that was put in there that we tend towards something of about ten kΩ And here I found: it's β times, so you'll boost and increase your output impedance or output resistance by a β factor of your transistor thanks to that resistance. So it's very interesting and we have just completed an equivalence With an RS of the order of magnitude of β / GCE of a transistor having a polarization IC0 and a given Early voltage.

Notes

Summary

22m 00s

Amélioration de la stabilité thermique



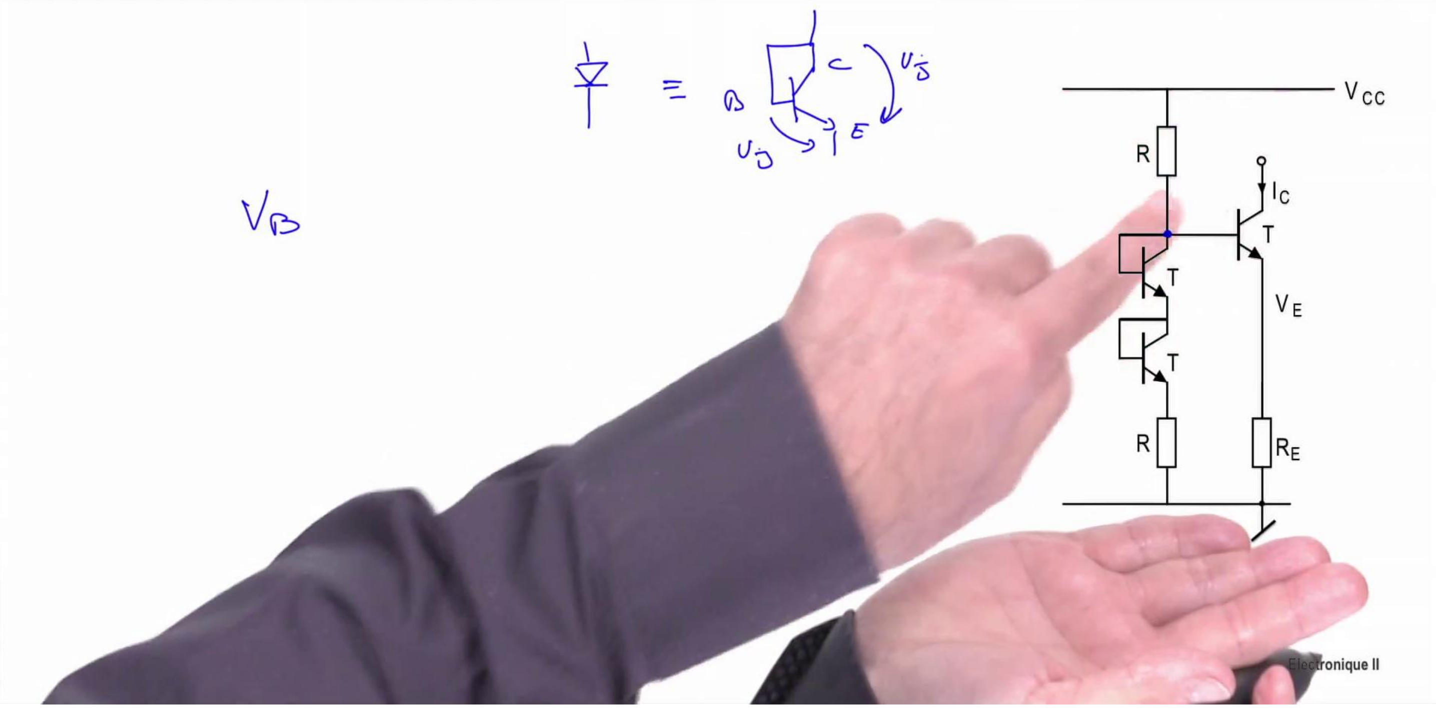
Some few words about an improved thermal stability. This resistance was added and I just made you a proposal with this scheme. And this scheme, I took a transistor and I said, I will use the same as this. So I have 1 transistor, 2, 3, which are exactly the same. Know that this, we find them when we integrate the 3 sets on the same chip of silicon, and then on the same chip, we choose the same component repeated 3 times, and we has rules that are called rules of matching, or pairing in French that is to say, it is ensured that the 3 components are similar during the production, manufactured by the same manufacturing process at the same time, So many similarities between the 3 components. And if you take a component like this, a transistor, and you short the base-collector junction, And you short-circuit the junction of Base-collector, you are canceling The transistor effect.......... you are canceling the transistor effect.......... The transistor has disappeared. You just keep a base-emitter junction. And why was that? It becomes like a diode, it's really the same with that.

Notes

Summary

23m 39s

Amélioration de la stabilité thermique

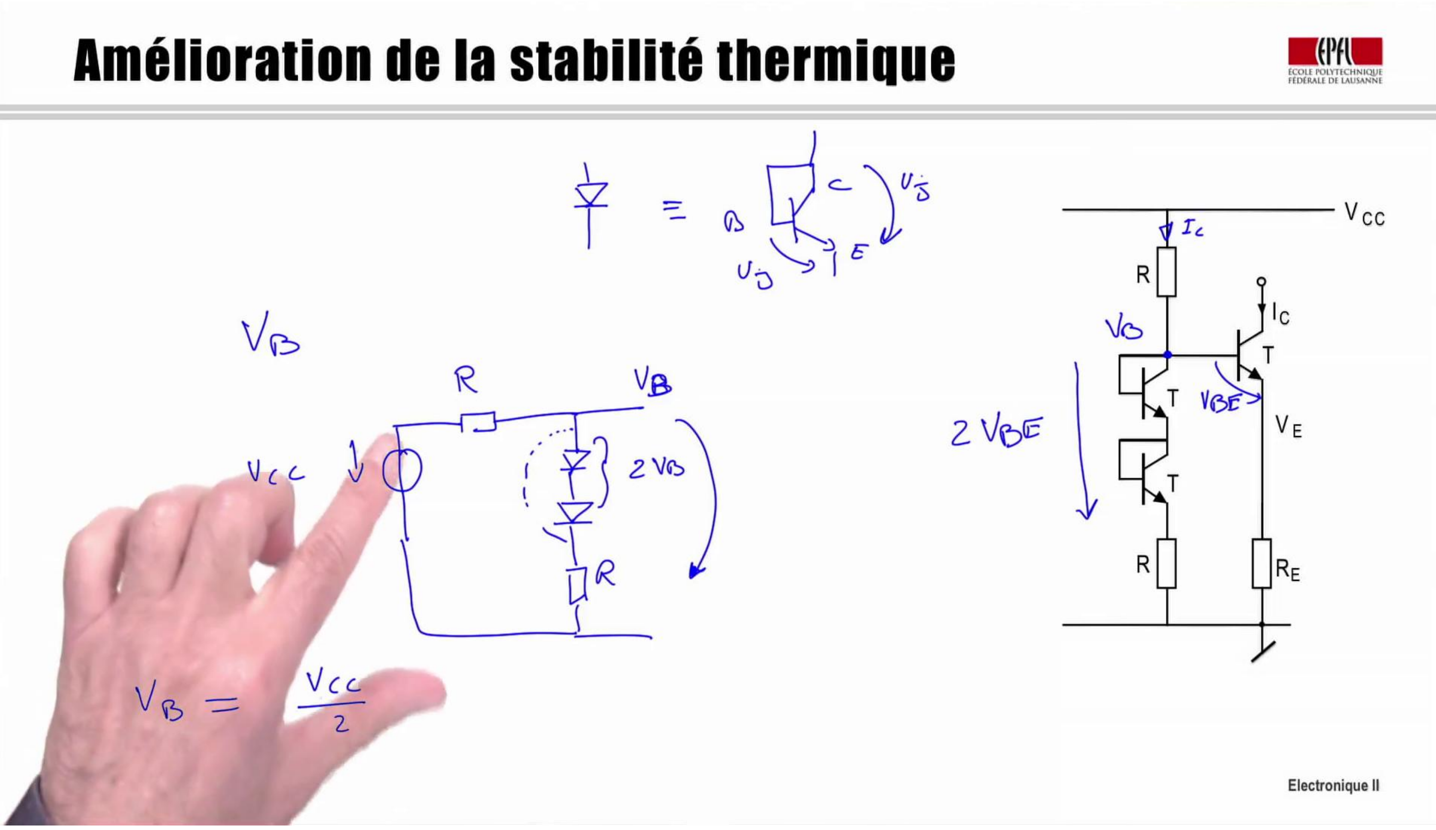


That is to say, if you take the component and you repeat 3 times, the rules of similarity between the three will be respected taking a transistor and modifying, by transforming into a diode, and it is called a "diode-connected transistor" where the base-collector junction has been completely eliminated by a short circuit. And we will remain a base-emitter junction. So this transistor, the voltage UCE is equal to UBE all the time and it is a junction voltage. So it is a voltage of the order of magnitude of UJ. And it's the same because there is a short circuit between the two. There is no more transistor, there is now a diode. I'll take this kind of scheme, I will remember you this because we will use it very, very soon, and I'll take it and do a little calculation around. I'll be interested in the tension I see here and I'll call the voltage VB. And I will write it in consideration of this resistive divider that we maintained. So I took a same resistance to both sides and I put here two diodes in series, so I'll draw this part and I'll call this voltage VB and I will write that the voltage source I see there, it will have a resistance R, a diode, in series with a second diode, in series with a third resistance or a second resistance having the same value with this one, and I'll call this tension then VB or VB0, it's like you want.

Notes

Summary

24m 55s



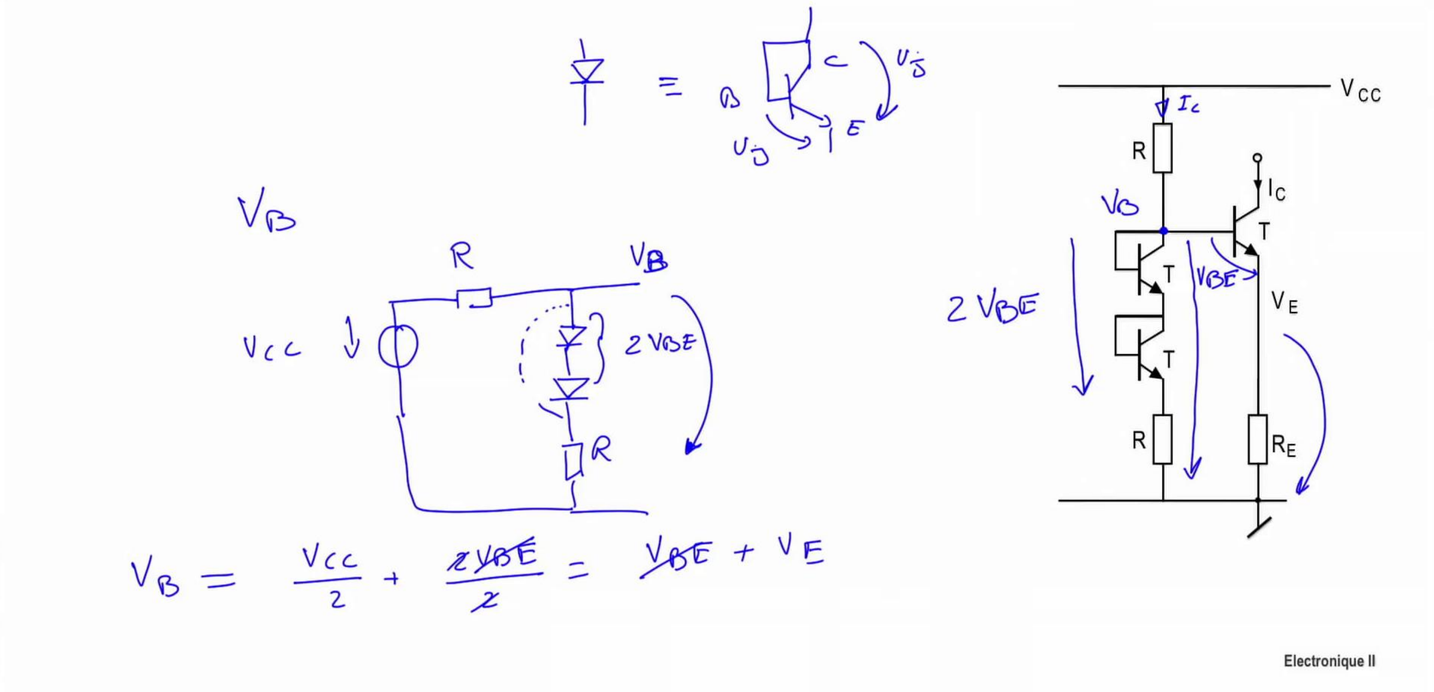
And these 2 diodes will find themselves traveled by a current therefore they will display a voltage from here to there 2 x VBE and this tension there, it is of the order of magnitude of VBE. If you consider that this current is then the same order of magnitude as this, so this VBE, this VBE and VBE are really certified copies, you have a transistor traveled by a current which is the same that you imposed here, and there, you'll have 2 x VBE. If you take it, and you look at what is the voltage VB that appears, you can apply the principle of superposition for example, like, you say: I have VCC you say: I canceled VCC and look at the effect of 2 VBE on the tension that I see here, wich is will be the voltage VB, it gives me a superposition with the fact that I cancel these 2 voltages and I look on the same voltage VCC and I add the 2, and I will find what is the potential VB. I'll write it. So if you want to write VB which is the effect of cancellation of this source, this is when I short-circuit these 2 diodes, and I look at the power I see here and it is as if I had strength and resistance and a voltage VCC, it will give me: VCC / 2. Now I cancels the voltage VCC and I look 2 VB...

Notes

Summary

26m 30s

Amélioration de la stabilité thermique



Sorry, I forgot the E here 2 VBE here this tension that I see here which in this case VB, and I find that this is equal to 2 VBE multiplied by the resistive divider realized by the two resistors, and as it is the same value, this gives me 1/2 and it will give me + VBE. So this voltage VB, I look at it according to that and I write it here. This same tension, I look to that side as calling it VE. I say: This same tension is equal to VBE + VE Indeed, this voltage is equal to VBE + VE, and VE it is from here to there. This voltage VE. So I have VCC/2 + VBE which is equal on that side, on the other side, equal to VBE + VE. So I have VBE and VBE that will disappear and I have the voltage VE who's only equal to VCC/2. It's amazing! That is to say: the fact of having added 2 junctions made by diode-connected transistors or by simple diodes, I eliminated the effect of VBE and this modification of temperature which impacts on the current, I've completely canceled by that phenomenon and I realized a current source practically independent of the temperature in having no effect of VBE, provided that I do this in an integrated technology. So a little cleaner than what I just wrote, I'll just comment very quickly on this.

Notes

Summary

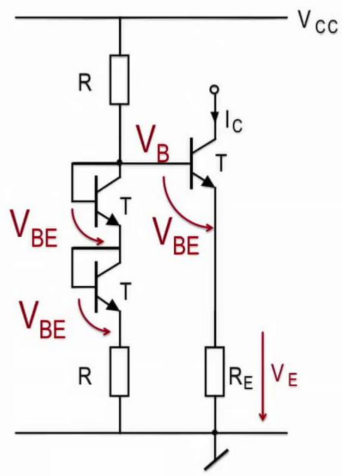
28m 12s

Amélioration de la stabilité thermique

$$V_E = V_B - V_{BE}$$

$$V_E = (V_{CC} - 2V_{BE})\frac{R}{R+R} = \frac{V_{CC}}{2} - V_{BE}$$

$$V_B \approx \frac{V_{CC}}{2}$$



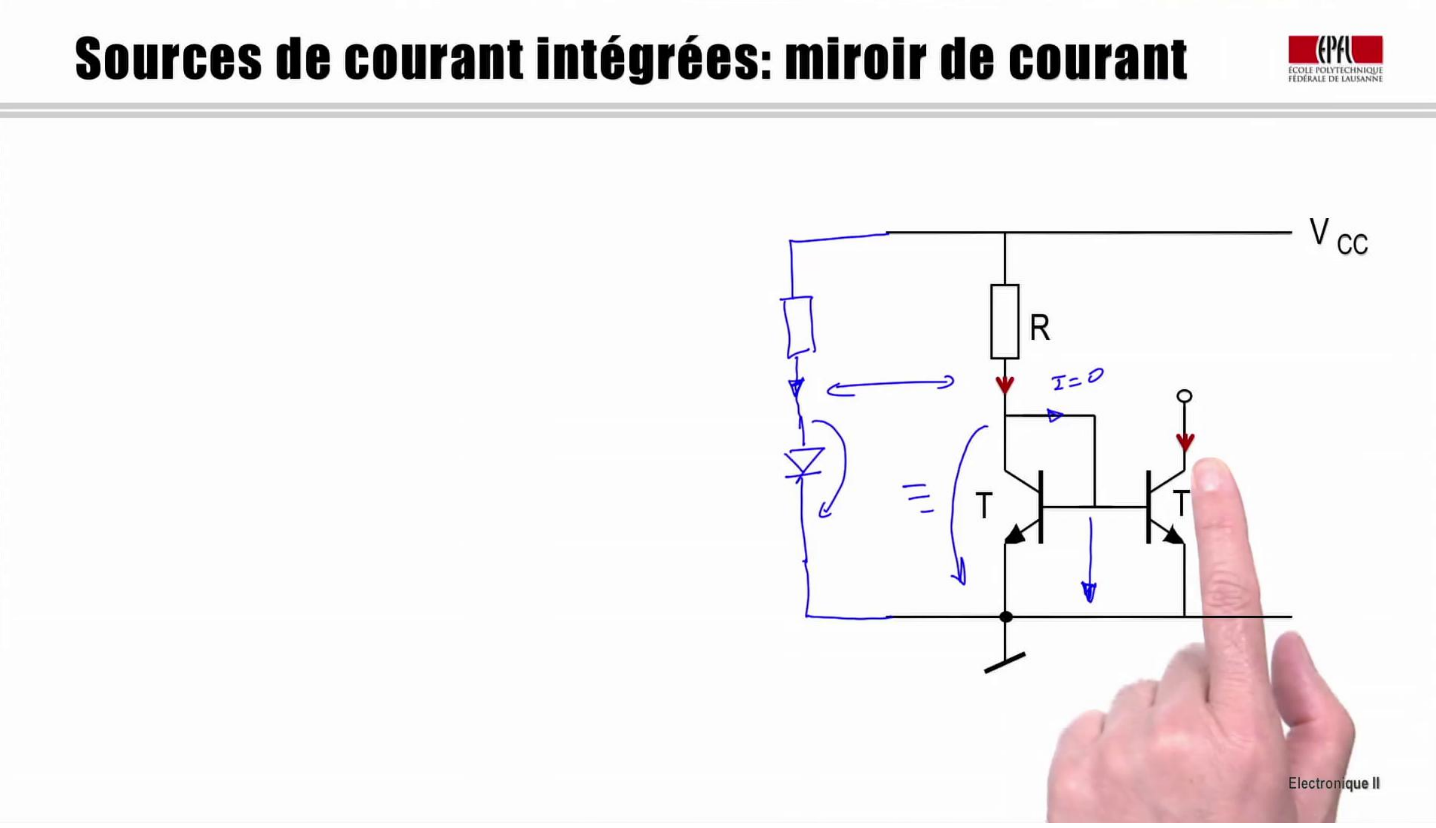
Electronique II

This is strictly drawn, and that is the same relationships I wrote on VE depending on that side, and VE depending on that side, that gives me that relation. So I equalize VE and VE and I actually fall on a voltage VB which will be equal to VCC / 2 and which depends only on the division by 2 of a supply voltage, and I hope that when you use this type of installation, your supply voltages are stable in temperature. So you managed to achieve a current which depends on a VB voltage where this tension then really does... the effect of the relation between IC and the voltage which has applied to the base has no effect of the temperature.

Notes

Summary

30m 03s



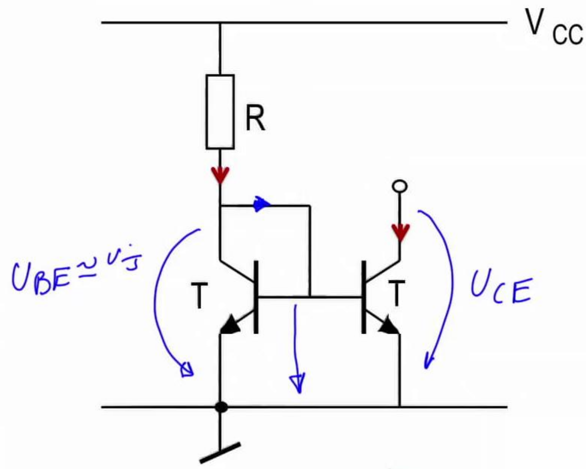
We have seen how to make a current source with discrete components. And if I present it to you, and I tell you: that, it'll be also a current source which would be integrated. Why integrated? I take the same speech of just now: I made a transistor connected in diode. So this is like if I had a simple diode. The equivalent of a transistor I've short-circuited the base to the collector, it's like a diode. And I plugged it a resistance here to bring it a current and I put it against the base. So it's going to see a current running through it. It is this current one. That's going to generate a tension That tension, I don't even want to know how much it is worth I have a current which pass through a diode. If I tell you: impose this current in this component, and take the same component, put it at other side, and read the voltage, the one who is there, that you copy here on an absolutely similar component, what is will happen to you? If you neglect the current which passes here, you say: this current is null. I take a current, I converted to voltage and in the same component. I converted the same voltage into a current. And you'll tell me: without knowing anything, I can say that this current is equal to this current.

Notes

Summary

30m 58s

Sources de courant intégrées: miroir de courant



Electronique II

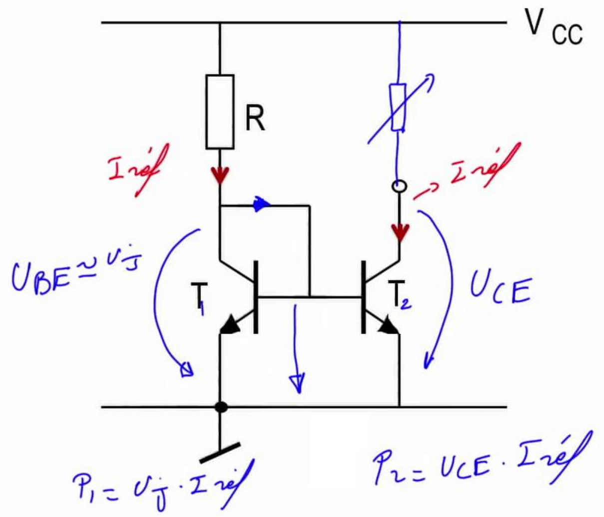
I made a current mirror. I took a current converted in voltage and I converted back to current through a similar component. It as a law, no matter it's in this case there is the exponential, current, voltage, voltage, current, then I ind myself with a perfect equality between this current there and this current one. What are the assumptions that I just do? While the assumptions are: we assume first that this current is equal to 0. So I canceled this current, whereas this current that will go into the basics is almost negligible or nonexistent. So, the second hypothesis, is that this voltage is then applie on the 2 transistor junctions, base-emitter and base-emitter which are the same in reality. But then if you look at this voltage, this is indeed it. So this tension that we see here and here is the UBE voltage of a transistor which is of the order of magnitude of a voltage UJ junction. And then when I look at the other side, I'll see that I have a transistor voltage UCE. So if there is this tension-UBE and this voltage is then UCE, and I have 2 transistors that are similar with two currents which are the same, so I'll write the dissipated power in each of these components.

Notes

Summary

32m 34s

Sources de courant intégrées: miroir de courant



Electronique II

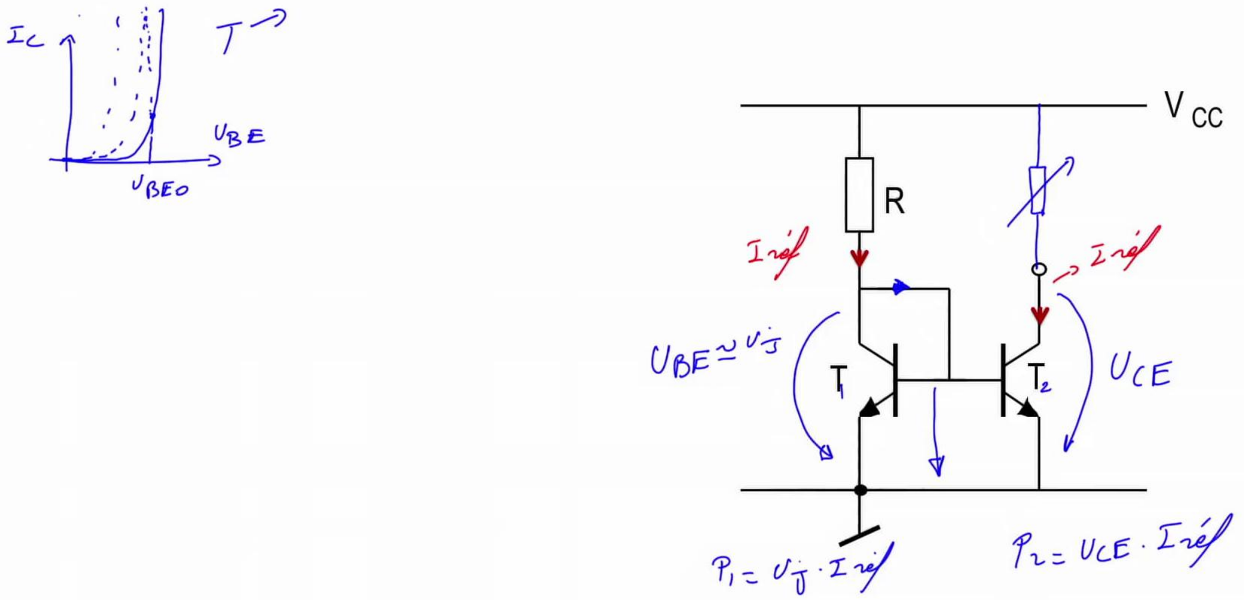
I take it this component I'll call T1 and this one I'll call him T2. And I will write the power P1 which will be current here I'll call I REF, So this current I REF, and this is the same on the other side, well I'll write the power in the transistor T1 and T2. it will give me P1 is equal to the magnitude of UJ multiplied by I REF. Contrariwise the other side, it will be the power P2 that will be of course the famous I REF but multiplied by ECU. It's UCE x I REF. Now when you look at this and you say, it will depend, there I REF I, I REF, but then it will depend on ECU. That's an almost constant voltage, it moves but very, very little. So this ECU voltage depends on what? This is what we have plugged in here. If I plug here a variable resistor, and this resistance, she will vary the voltage Since VCC to voltage saturation. So this UCE varies in a dynamic which is of the order of magnitude of VCC. If we look at this variation, So this UCE is much higher, it could be much upper than UJ which will give me a power P2 dissipated in the transistor which is much higher than transistor T1. In the transistor T1 is almost constant. So what is it going to give?

Notes

Summary

33m 57s

Sources de courant intégrées: miroir de courant



Electronique II

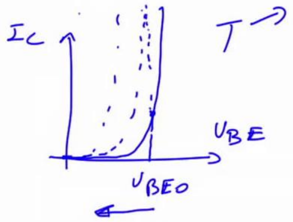
We had studied it is banned to take a transistor, to apply on him a fixed voltage and to imagine that by putting this voltage fixed, when the transistor will heat because of this power that I have mentioned here, there will be a thermal drift. Why ? Because the temperature increases. so let trace the IC characteristic according to a junction voltage UBE and we was told that this feature there, we have no right to come and apply a voltage UBE0 who come from some source of tension. And here is what we are doing. we took this tension there, we have applied to the transistor here. And early, when we spoke about that effect and we said: When the temperature increases, that feature moves in that direction. So your UBE0 will generate a higher current. So IC x UCE will give me power increases, so thus heating of your device, your transistor, which will increase, therefore your characteristic continues to move until this current here applied an extreme current in your component, which brings back to thermal bolting, and the transistor is destroyed by heat. So how come that we admit that it is feasible, Yet it was forbidden to do it before because of this phenomenon?

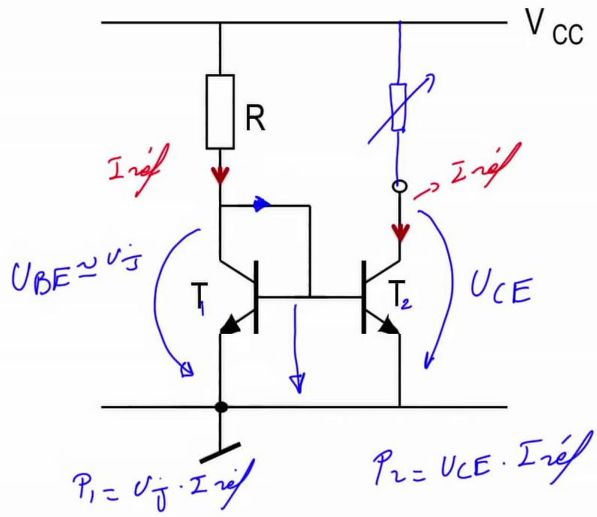
Notes

Summary

35m 25s

Sources de courant intégrées: miroir de courant





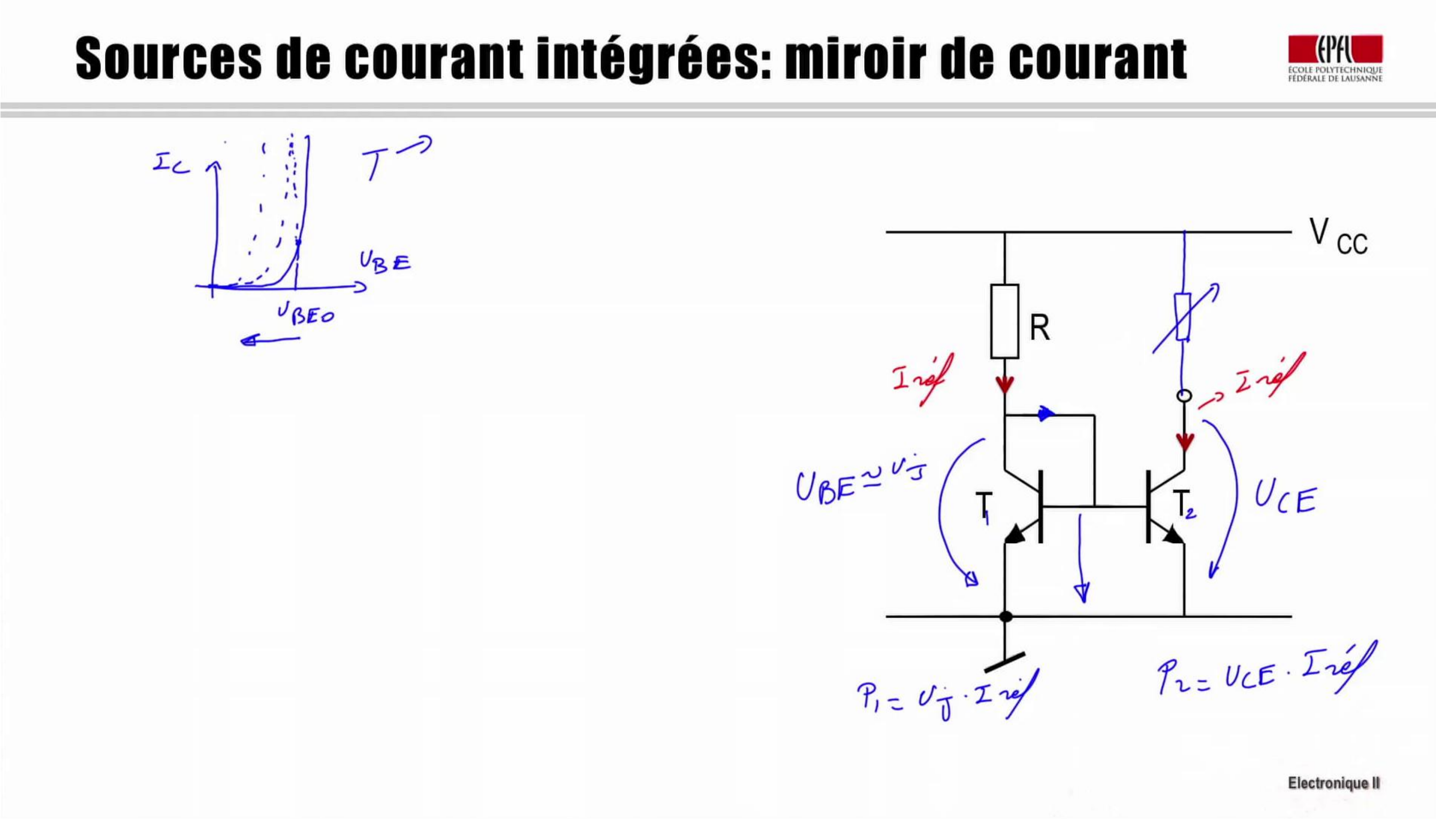
Electronique II

Well, what happens, is that when you take these two transistors, the condition of making a current mirror is to put the two side by side inside a silicon substrate. And usually when you make a layout of an integrated circuit, therefore the current mirror can only be implemented or realized in an integrated circuit, the two are really glued to one another, or even blended together in their layout, in their way of building at the level of silicon. When this transistor starts to heat it heats at the same time his neighbor. So this junction which imposes tension, it will also see its UBE0 move simultaneously. So if this tension UBE0 is the same as the other, and this transistor is warming therefore also the other is warming up, if the two transistors are similar, the 2 characteristics of the 2 transistors move in the same direction and at the same time. So this voltage continues to be changed according to the temperature of this if we ignore the thermal inertia between the one and the other, so it's an adaptation of the UBE voltage to the exponential law and to the adrift, the thermal drift of the transistor.

Notes

Summary

36m 58s

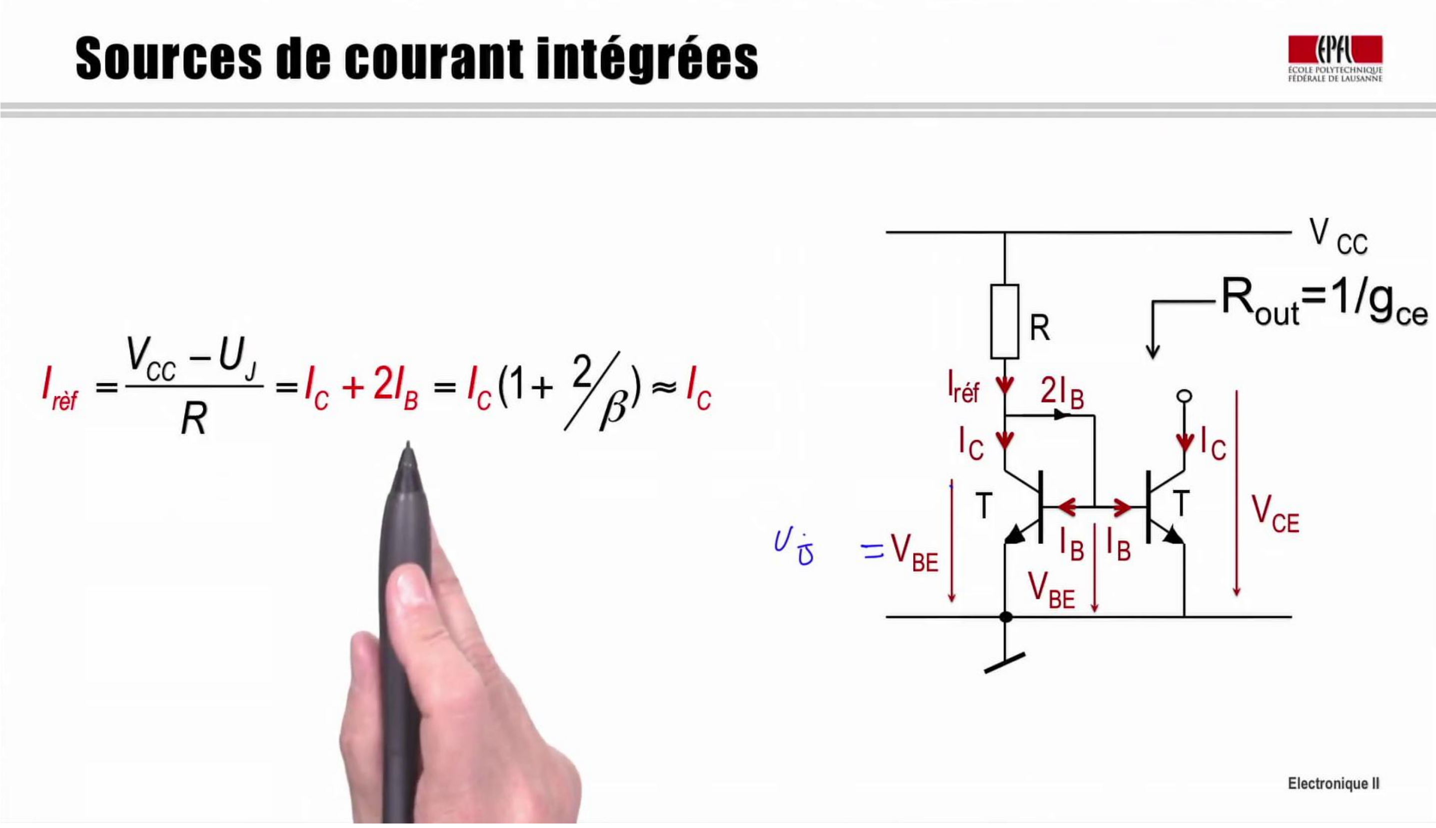


So we can make 2 transistors like this in something called " mirror of current" provided that the 2 are integrated together under conditions that you will probably learn in a course of integrated circuits where you are told: we apply the rules of matching, or matching in English, so that the two components are absolutely the same and that the temperatures are the same applied to 2. Otherwise, I would point out: you need to add one resistance here and one resistance there, which allow or enabling to prevent thermal runaway of your transistor by inserting an Ohm's law there. Now we saw the mirror of current with the condition that is here, be very careful. Do not take 2 discrete components and do not connect a component away from the other. Because if you do this and this transistor starts to increase, you can try it in the laboratory I strongly you advise against: put two transistors connected to a diode transistor and put your finger on it, as I do here. You'll see. you're going to burn your finger. Your finger will burn because he is racing so fast because you have 37 of your body temperature, by the time the temperature reaches to the junction, this transistor racing and your transistor will perhaps destroy because of the temperature, but you'll quickly feel it on your finger which corresponds to a real burning, especially if the case is metallic.

Notes

Summary

38m 14s



I drew now my current mirror with all the balance of the current flowing. I said, this current one, it will provide a current IC but it will still lose 2 IB. Why 2 ? Because there are two bases connected together, one draws a current IB, the other would draw the same current IB so I have 2 times IB. As against this base-emitter voltage is absolutely the same for the two. This transistor is still living with a VBE voltage, UCE is equal to UBE; this transistor will live with the UCE that you make it undergo as a function of the load and the voltage here which is equal to the same voltage as the other. contrariwise, the current is copy. So if you write the relation between the current I REF which will provide 2 IB, you have to write like that. I must give IC + 2 IB as noted herein. If you consider that this tension, this is the magnitude of UJ because it is connected as a diode, you will find that I REF = (VCC - UJ) / R. Now I take stock and hope that the two transistors have the same β and I calculate by saying that this IC is equal to IC: I find that the relation between I REF and the current IC, is 1 + 2 / β, the β of this transistor.

Notes

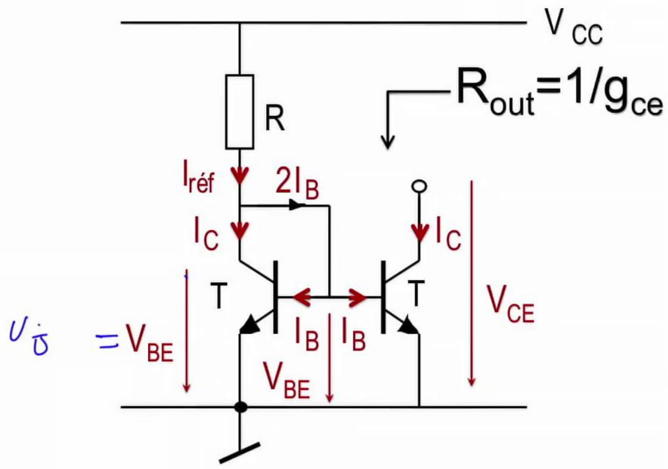
Summary

39m 42s

Sources de courant intégrées

$$I_{réf} = \frac{V_{CC} - U_J}{R} = I_C + 2I_B = I_C\left(1 + \frac{2}{\beta}\right) \approx I_C$$

≈ 0



Electronique II

So finally, the β of the transistors, if β is high, this term is very weak so you can cancel it and we can say that the 2 currents are the same. There is a ways to do better. So it happens in some assambly where we really try not to load the current I REF by 2 x IB. We can do the next thing.

Notes

Summary

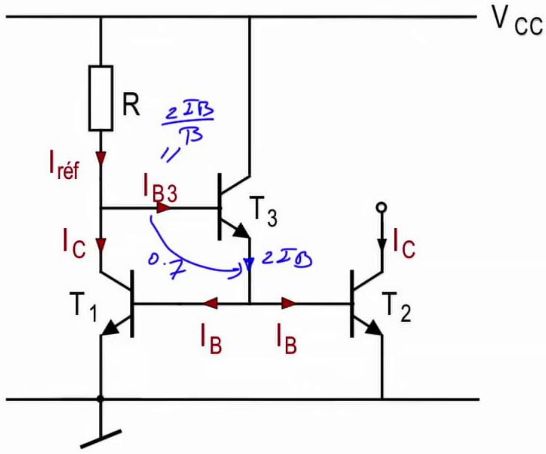
41m 04s

Compensation des courants de base

$$I_{B3} = \frac{2I_B}{\beta+1} \approx \frac{2I_B}{\beta}$$

$$I_C = I_{réf} - \frac{2I_B}{\beta} \approx I_{réf} - \frac{2I_C}{\beta^2}$$

$$I_{réf} = I_C\left(1+\frac{2}{\beta^2}\right)$$



Electronique II

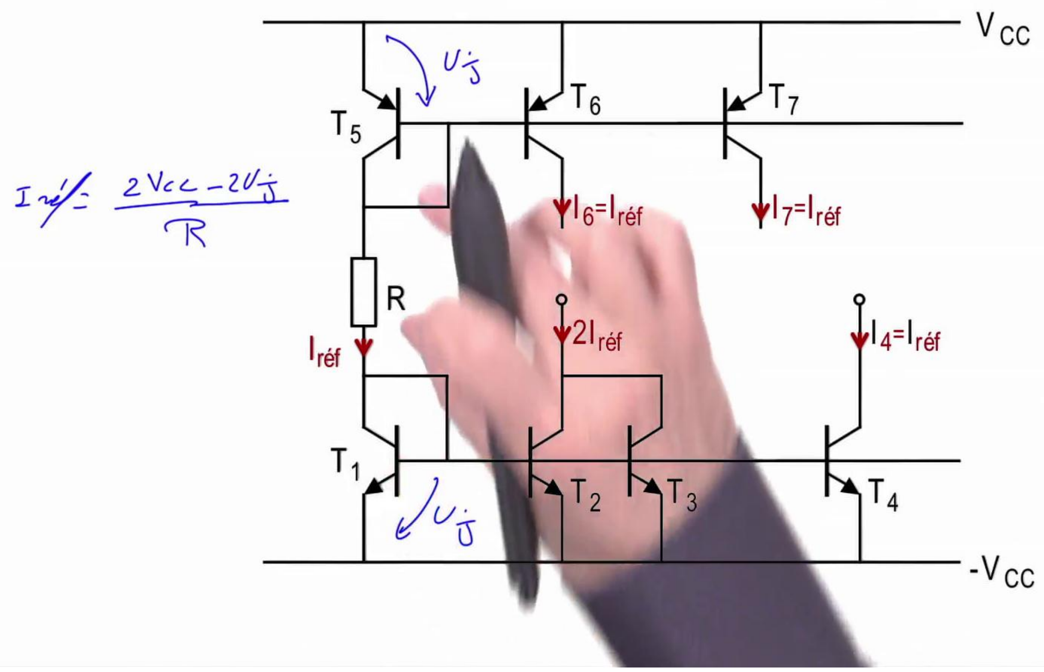
We can do that, add an additional transistor. The additional transistor would come here, and instead of putting a short circuit, we add a transistor which will impose a voltage from here to there which will be of the order of magnitude of 0.7 V. So this transistor, it is absolutely certain in normal mode, because he has between base or rather between collector and base, a voltage of 0.7 V. But that is not what interests us. What interests us is that the current I REF, before, provided a current IC and he lost 2 x IB. And here we have seen the following: the 2 x IB are still there. 2 IB are there. This current IB3 is the 2 IB divided by the β of the transistor. So we just extracted from I REF a proportion 2 IB, but divided by the β of a transistor that would have been added, and that β-there, it is 100 to 200 times so we just shot 100 to 200 times less current which disrupts I REF. So the relation between I REF and IC, it's like just now, the 1 + 2 step divided by β, it became β^2. So if you have a β equal to 100, you're going to have a factor of 10,000 that divides the famous 2 that we saw earlier, so it is a solution that reduces the impact of current in the base of the transistor.

Notes

Summary

41m 27s

Miroir à sorties multiples



Electronique II

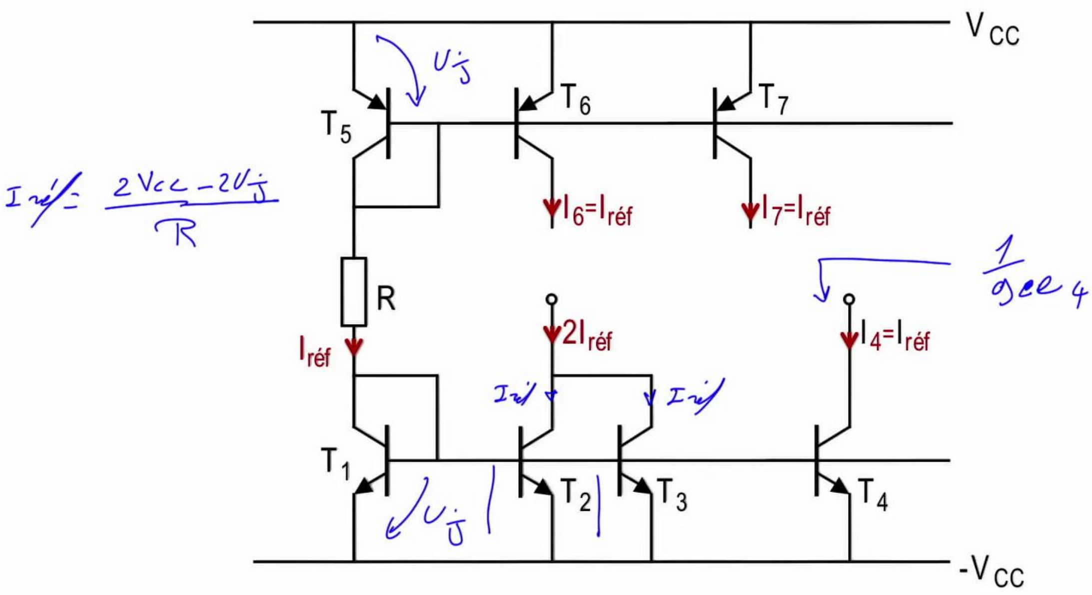
The solution that is adopted in integrated circuits, it is based on a discussion like this one. If you are going to watch a circuit implemented in bipolar technology or integrated technology, You'll see. that the manufacturer uses the power rails. Here in this case, I took + VCC and -VCC. And they add 2 batteries of current mirrors because we can copy a current mirror several times. So look at that, it corresponds to a PNP current mirror. That is an NPN current mirror. So if you take from VDC + VCC, -VCC, and you put a transistor connected in diode of type PNP, a transistor connected in diode of type NPN and you choose a strength of your choice: You can very well say: The current I REF I neglect the base current and I will write I REF which will be VCC - (-VCC) so it is 2 VDC, divided by the... Sorry. less the voltage drop I here I will approximates to UJ and the one I have where I'm going to approximate to UJ, it gives me 2 UJ that I will divide the resistance R. So it gives me: (2 VCC - 2 UJ) / R so I'll get the current I REF which I will have calculated according to my resistance R. And now I take this current and I will make the current mirrors that copy it to provide currents, current sources, which inject a current in that direction.

Notes

Summary

42m 57s

Miroir à sorties multiples



Electronique II

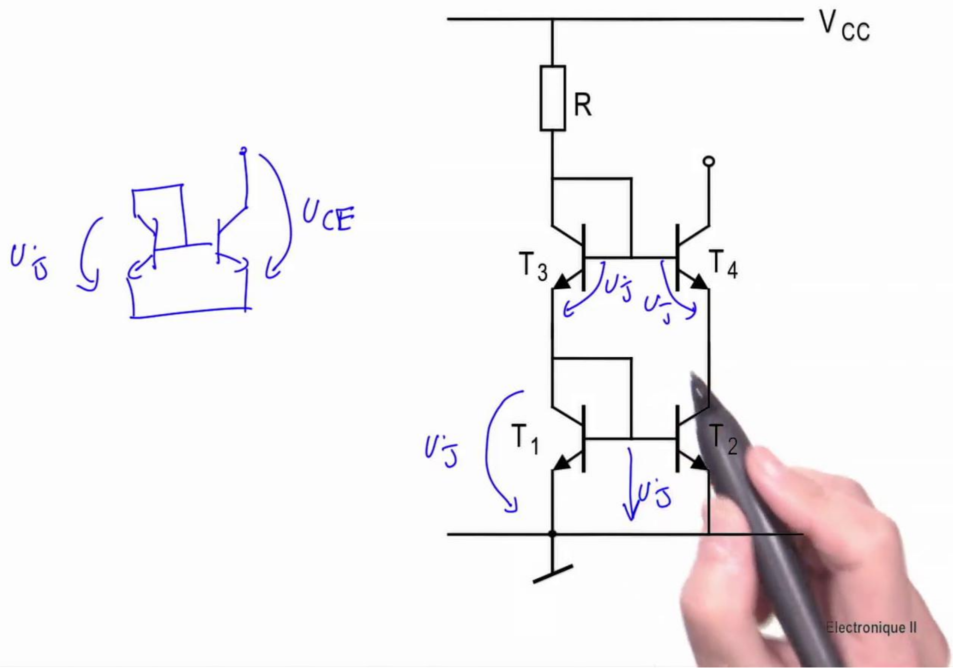
And I can copy it as many times as I want. I can make current sources that draws currents and I can also inject as many times as I want. And here, I have just made a subtlety: that is, know that if you want to multiply by a factor 2 this same current, just plug 2 parallel transistors. Take the same transistor and you put it 2 times in parallel. the current that passes here, it will be I REF and that is I REF. Why? Because they all have the same voltage, so the I REF will appear here and the I REF will appear here and there you will end up with 2 I REF. So later, when we begin to look at circuits realized with integrated circuits, you will easily see that the first thing you do in a circuit is to generate reference currents which are made in this way and we will use it anywhere. Then, the output impedance that I see everywhere, I have a transistor that I watch since collector and emitter, this output impedance, is 1 / GCE of this transistor. So what is the transistor 4, it's going to be 1 / GCE4, there it's the same thing but GCE7, and caetera, and caetera. We will see how to do better to boost this output impedance. This output impedance, she's great but can we make it bigger? Yes, we can do more. And how do we do it? This is done in this way.

Notes

Summary

44m 41s

Montage Cascode



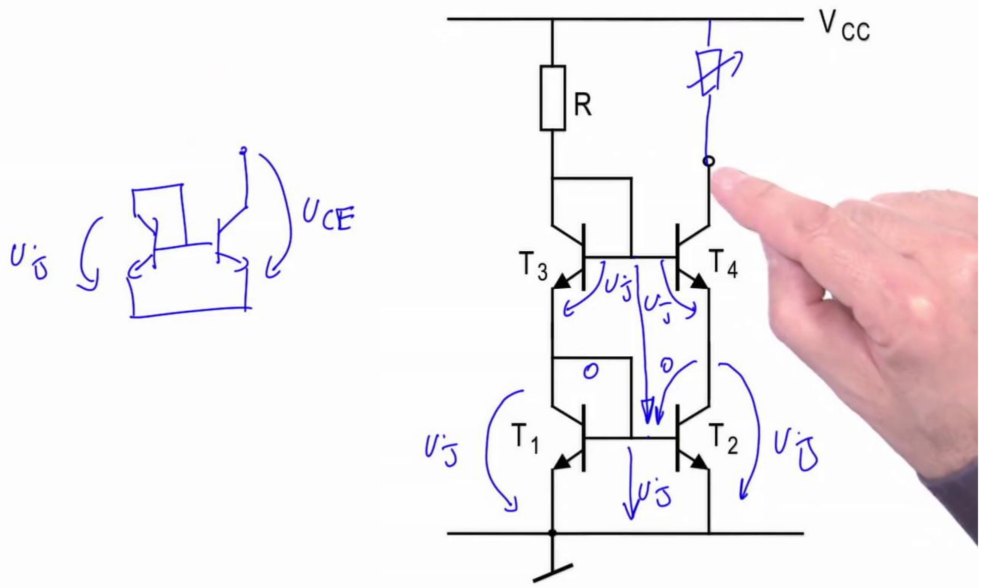
We do it like that. That's my original current mirror. And I just put on another mirror of similar current. So I do 2 floors. Before going into the details of the output impedance I have spoken to you and that will be improved, I would just like to show you this kind of installation, it is already extremely well done for drift in temperature and in order to impose a fixed voltage on this transistor T2. You remember, just now when I took the normal current mirror and I connected a diode transistor and I made a whole speech about the fact that this transistor there, it will undergo a voltage UCE and this transistor, it will undergo a voltage UJ. So that, it was a problem that the heat dissipation in this transistor will be greater. And how we improve that? By pairing, the fact that one and the other, it is on the same chip. Is this is the case Compared to T1 and T2 when I put a floor above him? Let us analyze it. I look at this transistor: what he sees here? I'll talk about UJ to simplify my life. He will see a UJ voltage What is the tension there? This is UJ. What is the tension here? It's UJ. The tension here is UJ. Then I will look at the tension which is thence to there: the tension that I see from here to there, this voltage is equal to what?

Notes

Summary

46m 06s

Montage Cascode



Electronique II

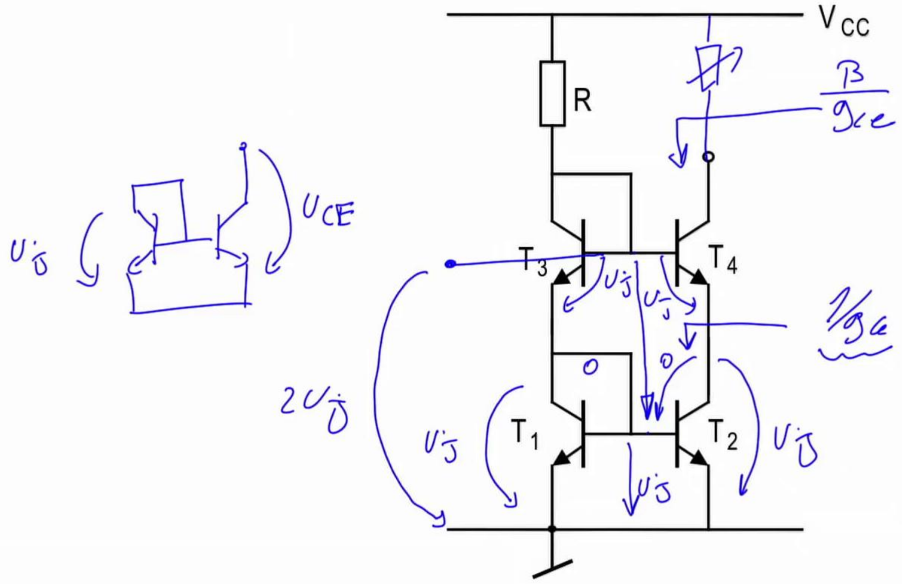
There, in that side if I hide this part it's UJ + 0, it is 0, it is a short circuit. On this side, from there to there this voltage is shared, it is the same. If on this side I have UJ and there I have 0 necessarily on the other side I have UJ and there I have a voltage drop equal to 0. So this tension there, although I do not have a real short circuit, I find myself with a potential difference that will tell me that the base and collector are at the same potential. So this transistor T2 is placed at the saturation threshold. And if he sees by construction that he has a voltage 0, that is to say that tension from here to there it is also equal to UJ. That's great ! The two voltages are the same. This transistor and this transistor will live all the time with the same voltage. So it's like I was saying: the Early effect will not appear, there will be no voltage variation. If you connect a load here and you vary this load with a variable resistance, so you'll have this tension which will drop this transistor, it sees all the time its transmitter to a fixed voltage which is equal to UJ and not moving. When the UCE voltage is equal to 0 and it saturates, this transistor has not saturated.

Notes

Summary

47m 46s

Montage Cascode



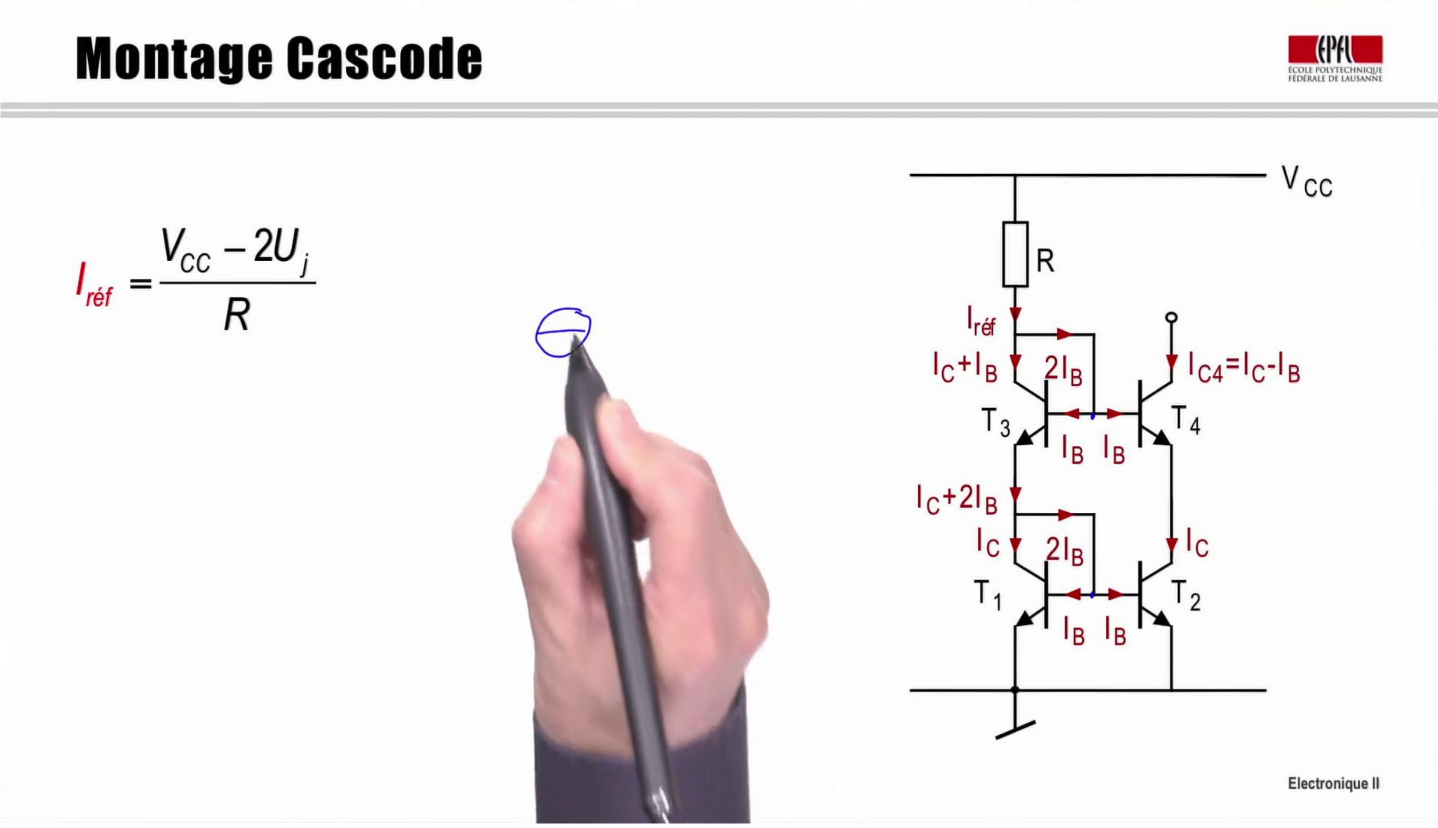
Electronique II

It is beyond saturation what will bring us to have this structure which is much more stable in terms of temperature, that's on one side, and on the other side this transistor finds itself charged with an impedance there. It had been established earlier, how much it is? It is 1/GCE. So there I have 1/GCE as impedance I put in the transmitter of a transistor. So this is a transistor where it is that the base has a fixed potential. And the base of this transistor from here to there UJ UJ + is: it's 2 UJ. Therefore the base is connected to a fixed potential, that's like a common base, I look at its impedance from this collector and its transmitter, I've put it resistance equal to something 1 / GCE which is necessarily much larger his 1 / GBE. And if you remember, when we say 1/GCE or rather the resistance that I added in the transmitter or that I called RE, is much greater than 1/GBE well I'll find myself with an output impedance which will tend towards β divided by GCE. It's great ! So I get an output impedance extremely high while having a structure in which the tension here is not moving and the top transistor will undergo a change. So this is an excellent current source. We will look at it again cleaner with all that I added as writing on this.

Notes

Summary

49m 12s



Look the same assembly now analyzed with all current balances I won't going into details, because it makes no sense to show that there is a current flowing. If we want to improve it, one only has to add the transistor that would come here to pull a component of the current, we can do the same here. But that are the solutions of second order That is rarely done in certain circuits, where when one is looking for perfection, we try to put a transistor here and a transistor there. But we come across a diagram, called the mountage Cascade that we have already studied. Because two transistors have been cascaded and we've imposed on the base of a transistor a fixed potential and at the base of a transistor, the second, a fixed potential, and impedance that I will see from here, it'll be the β x 1 / GCE. And this is repeating the same current mirror and copying the second time. And I realize that with an excellent power source. So that's the equivalent of that with an output impedance whose value is then β / GCE, compared to the simple current mirror, if I had not added another over I would have gotten that equals from here to there at just 1 / GCE.

Notes

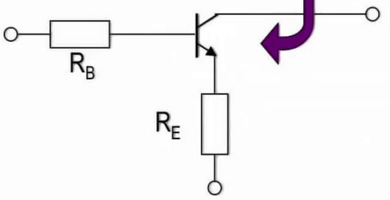
Summary

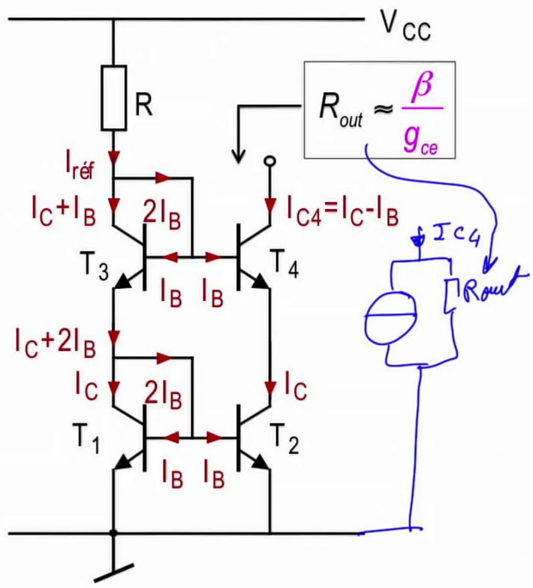
50m 55s

Montage Cascode

$$I_{réf} = \frac{V_{CC} - 2U_j}{R}$$

$$R_{out} \approx \frac{1}{g_{ce}} \frac{1 + g_m R_E}{1 + g_{be} R_E} \approx \frac{\beta}{g_{ce}} \; si \; R_E >> \frac{1}{g_{be}}$$





Electronique II

So in terms of output impedance, I just improved β times relative to a normal current mirror. And of course, all this would come with the thermal stability of this mounting. And to sum up, I do not think there is need and comment on it a second time we just saw it, and I reported this drawing, and this earns you a summary of the output impedance which greatly interests me and the reference current that I just imposed. So on that side there, I have a current I impose myself, so of diode, on the other side, I see a power source. Be very careful as to that side there is no current source: I impose a current in 2 diodes in series. And then I find myself with really a current source that is like this and this current one, it is the current IC4. And here it is required to ground and the R OUT resistance is there, it is this resistance as high as β/GCE. And know that if you repeat this and you still add a floor, you can continue to heaven, and every time you add a β times that comes here. So I'll have, bystill adding a current mirror above, I would find β²/GCE. So current sources that have an extraordinary stability and can be used to achieve current sources and current references which are extremely stable, having removed all that is related to the Early effect a simple transistor.

Notes

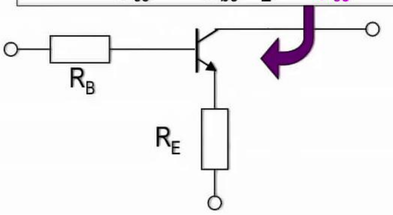
Summary

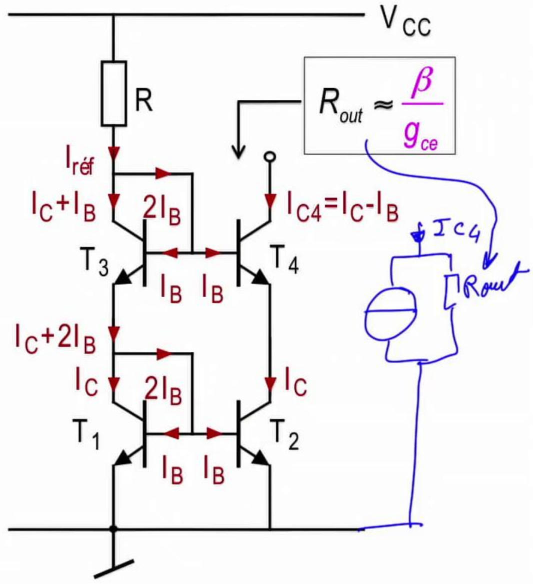
52m 17s

Montage Cascode

$$I_{réf} = \frac{V_{CC} - 2U_j}{R}$$

$$R_{out} \approx \frac{1}{g_{ce}} \frac{1 + g_m R_E}{1 + g_{be} R_E} \approx \frac{\beta}{g_{ce}} \; si\, R_E >> \frac{1}{g_{be}}$$





Electronique II

So in summary, we have seen all circuitries that is used for polarize a transistor. Know that the polarization is something absolutely... the most important in a circuit. We will see later that it impacts on the dynamics, it impacts the performance of the circuit. And we ended up towards the end with some specific polarization circuitries which have called the current sources and we will see that these current sources will be to at the orignin of the embodiment of infinite resistance, that which will used in integrated circuits and in particular in operational amplifiers. Because, if you remember that the gain of an op amp is infinite, the gain in tension, it is because we realized an infinite resistance. And these current sources will allow us to impose a fixed current or to make active loads which will be the subject of our next chapter.

Notes

Summary

53m 59s