ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

7.2- Alimentations stabilisées

Références de tension

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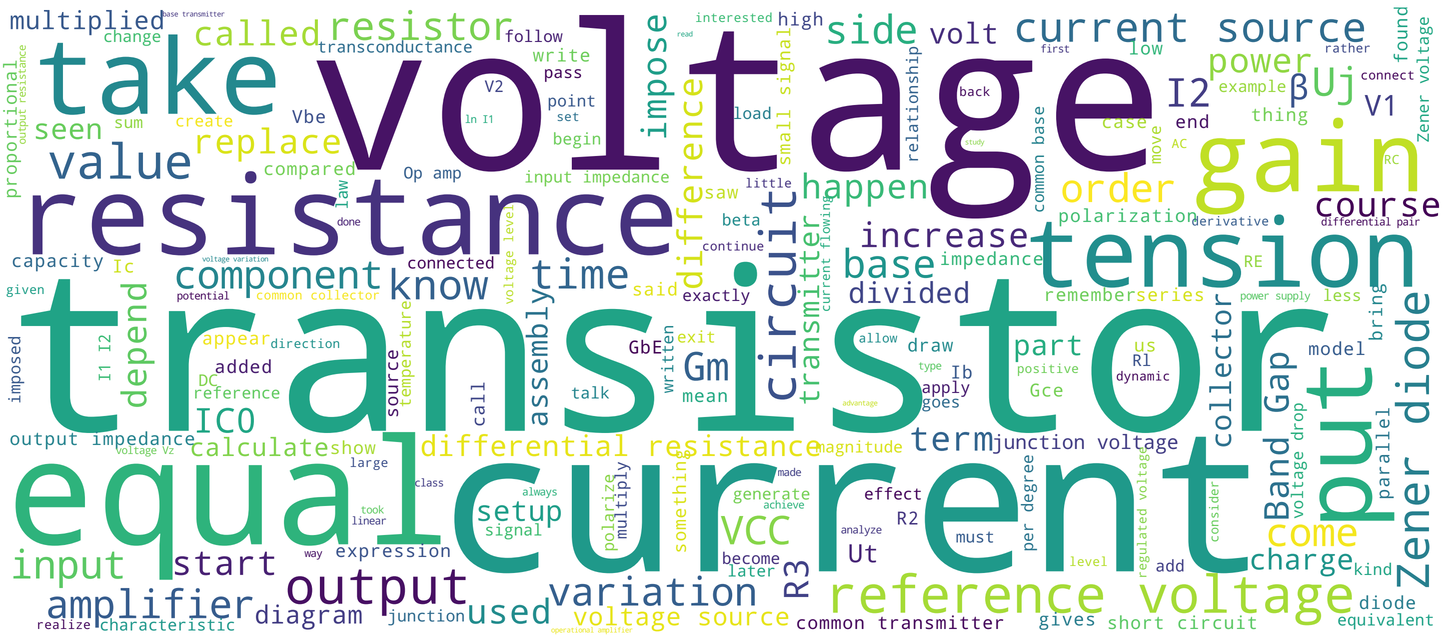
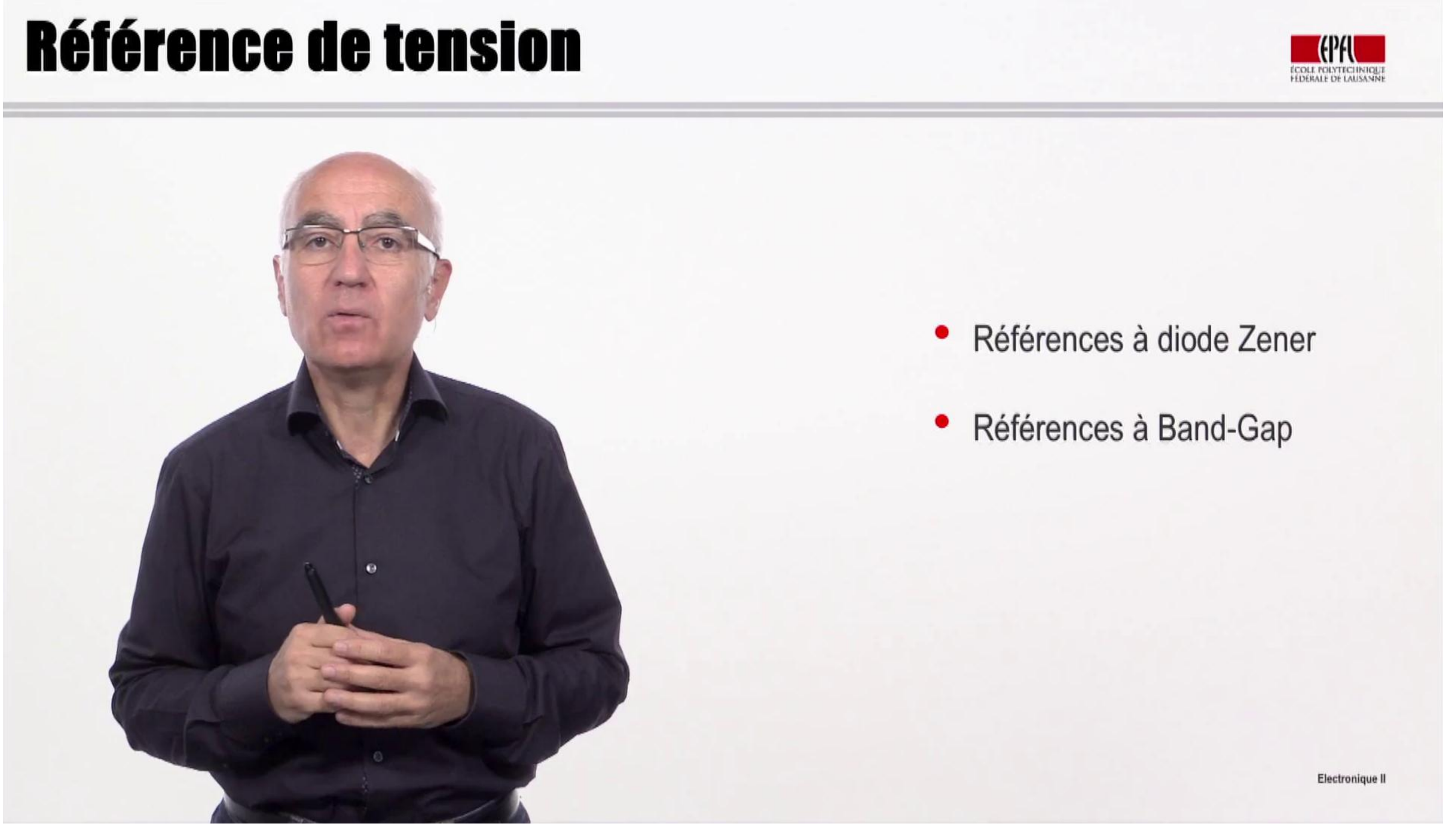


Video

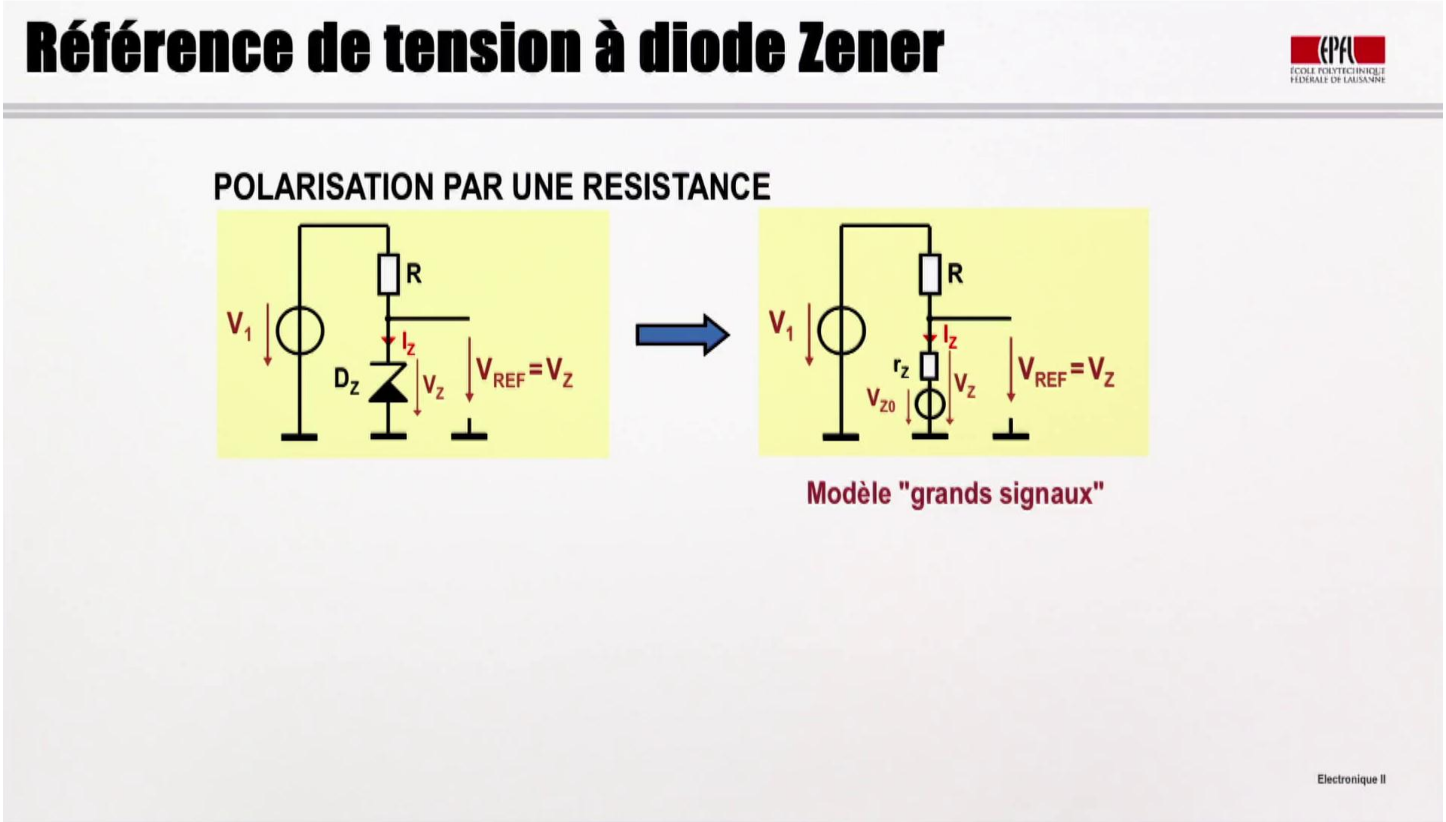


In this video, we'll study voltage references. So with stabilized power supplies, we saw that there is a need for a steady voltage and that steady voltage should be independent of all sorts of variations, namely the entire fluctuation of the unregulated voltage that we also used to supply this reference voltage, in any case to start should in no way influence the voltage level of this reference and especially the thermal drifts and many other considerations that we'll see throughout this video.

Notes

Summary

0m 04s

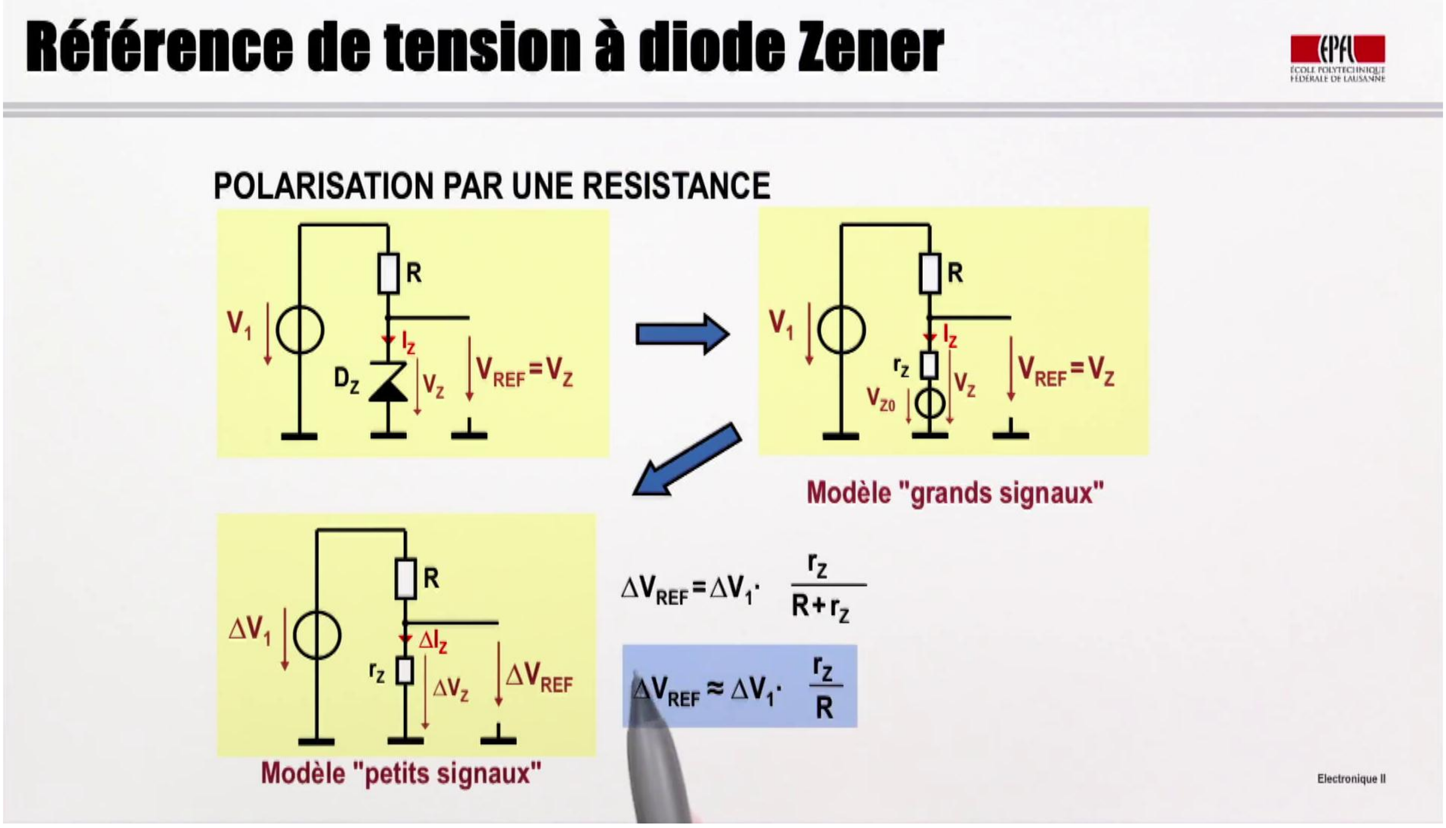


We'll start with the reference voltage at Zener diode. So that the component who is a zener diode, This is a component which is very well known in discrete and integrated electronics. We can impose in this diode, which is connected in the reverse direction of a normal diode, a current and this current will generate a stable voltage which is the Zener voltage which is due to the avalanche phenomenon in the Zener diode. So the best way or the simplest say to generate a Zener voltage, is to polarize with two voltage levels. We have a tension here which is may be not be controlled if it and another Zener voltage that will be a reference. So between the two we put a resistance of a and this resistance will impose the Iz current flowing in there. We will look at the stability of the Vz voltage versus of the instability of the voltage V1. So a Zener diode, if you want to replace it with a "large-signal" model, that model is summed to the following thing: the model of the diode becomes a fixed voltage wich will be the Zener voltage vacuum plus a resistance called the differential resistance of the Zener diode Rz. That's a simple model that pays enough...

Notes

Summary

0m 38s

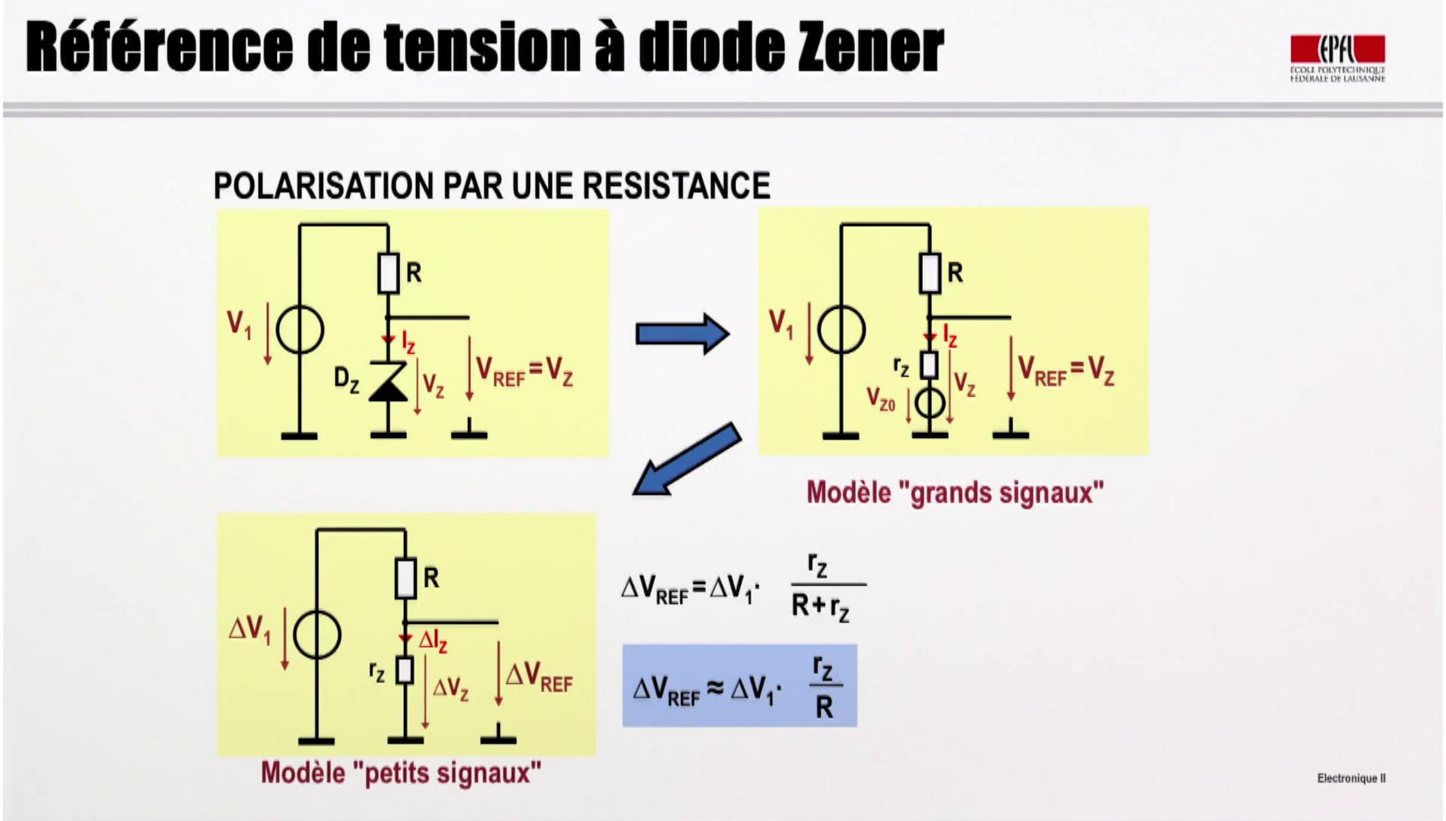


with my sore precision the reference voltage and we will consider the effect of the differential resistance of the diode which is added in series with the voltage source. So any voltage variation will be reported here on this variation that. So we will interest to the derivative. We have to watch the ΔVref and see ΔVref effect compared these two resistances, R and rz. So if we look for ΔVref derived, we find the model "small signals" because it replaces V1 by the voltage variation and we will iterest at the variation in voltage here by replacing the voltage source here by a short circuit we shown here because it is a model "small signals". So in the model "small signals" for a Zener diode, this is equivalent to the differential resistance of the zener diode. And there we has a resistive divider. The resistance that we added to polarize is the differential resistance <of the zener diode and we can write immediately ΔVref as a function of ΔV1 And that's what we're interested in. This ΔVref voltage depends on ΔV1 multiplied by the resistance ratio So rz, the resistance to the terminal which we look ΔV1 the effect divided by the sum of these two.

Notes

Summary

2m 00s

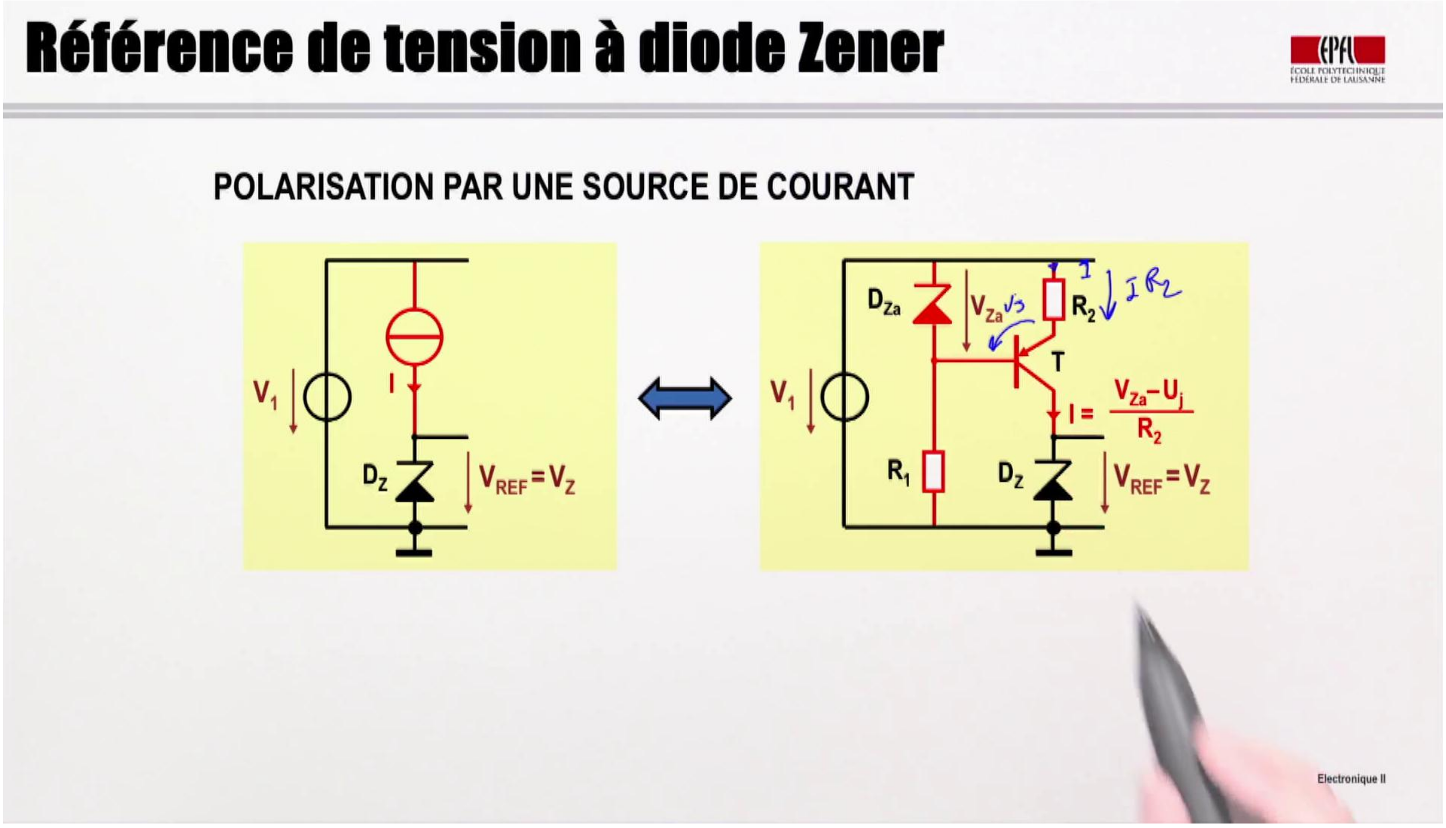


And we can approximate it for the simple reason that the differential resistance of a Zener diode is very very very low compared to the polarization resistance that we have added to impose the current in the Zener diode. So we find ourselves with a reference voltage that fluctuates according to the fluctuation of the unregulated function ΔV1 multiplied by the ratio of the differential resistance and divided by the resistance R. So we see indeed that the bigger, the better the behavior of this ΔVref tension. It goes to 0 when R tends to infinity. And we know that resistance to the infinite, is a current source. So an improvement of such concept would be replaced by a polarization resistance with a true current source that we will see right away.

Notes

Summary

3m 22s

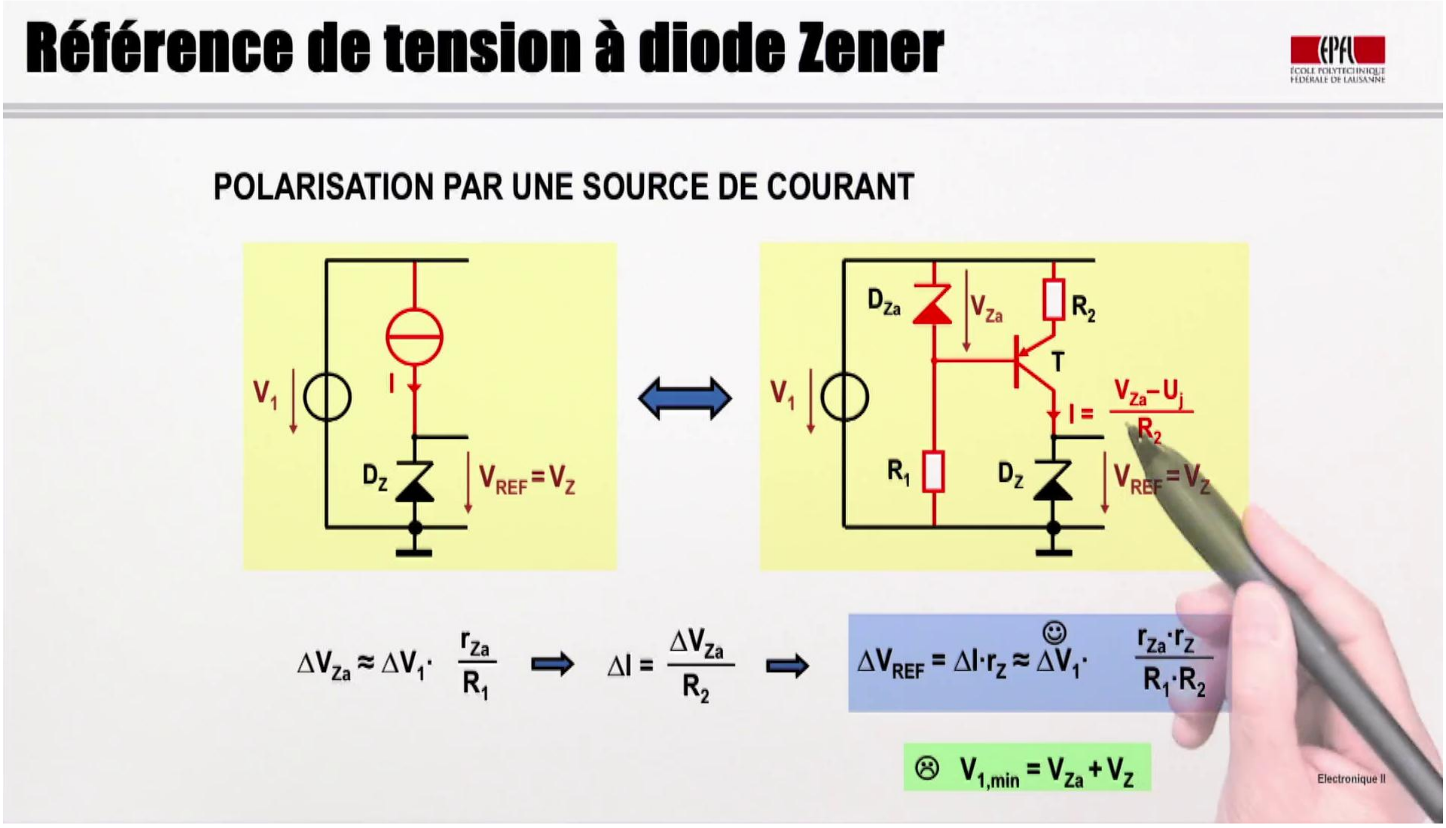


Here is a diagram of the zener diode when it imposes a current source I in this Zener diode and is supposed now give us a reference voltage and will show that the reference voltage, and she quite decoupled of the unregulated supply thank's to this current source that absorbs the variations of the voltage. So it will be necessary to realize a current source you all know how to do it. we could be done by putting the following scheme: this scheme and the following diagram. I take a PNP transistor. I polarizes a fixed voltage on its base. The example I give here also uses a Zener diode. It is obvious that if I take a resistor and a Zener diode, I get a voltage Vz based on a transistor that I will use to apply, Once I removed the junction voltage Ui of my transistor here, it will stay me the current through this resistance I, So the current I multiplied by the resistor R2 gives me the voltage drop here, what I have written here. The voltage less this one is equal to this one and that's what is written there. So Vz - Ui = I x R2. In other words, I can express the current I which is proportional to the voltage of the Zener diode, thereof, minus the voltage drop due to the junction of a transistor divided by the resistor R2.

Notes

Summary

4m 13s

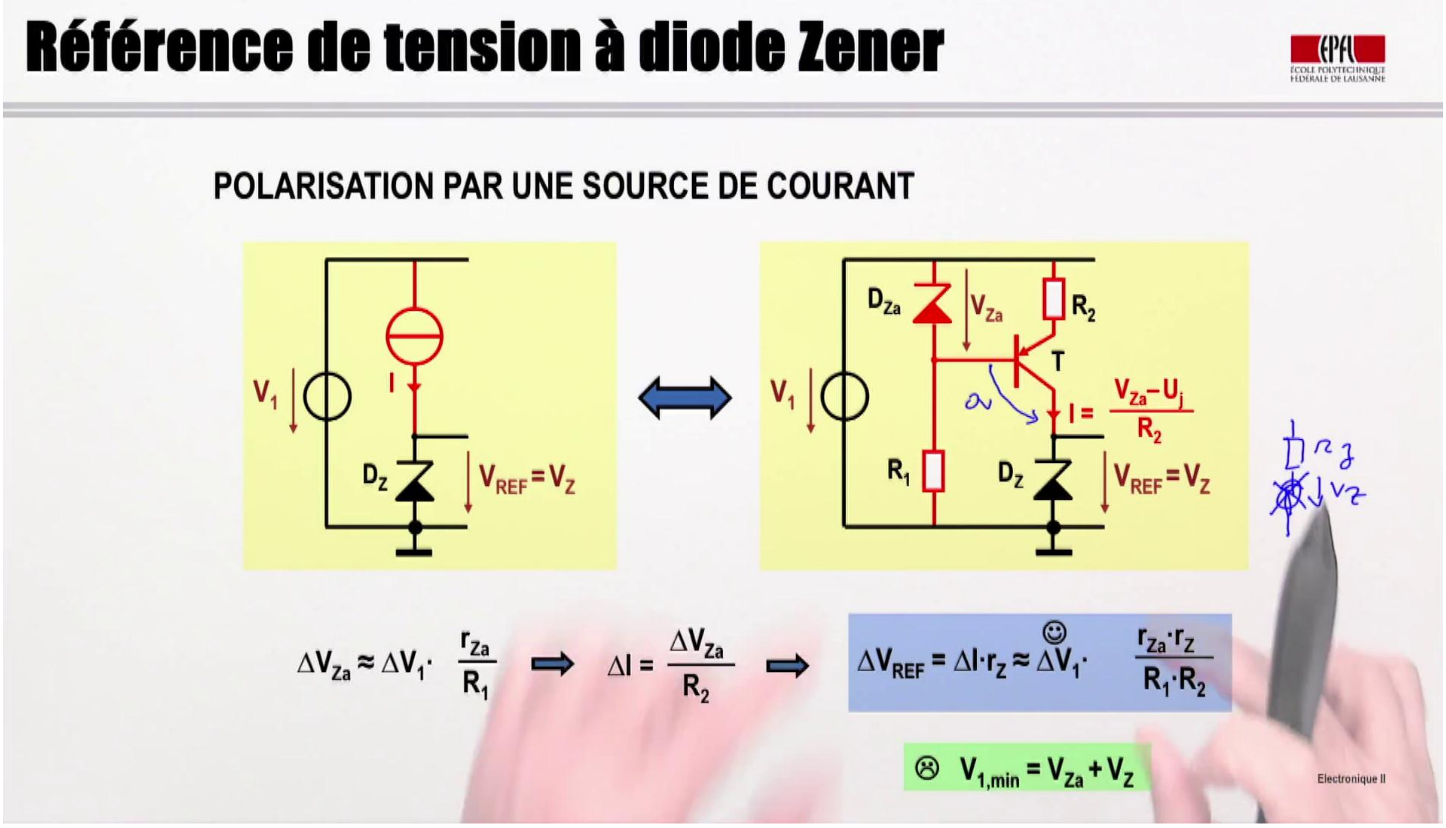


Now this current, it is the current that I will impose my diode, the one that I will use to extract the reference voltage. So we know this circuit because we just do it. So resistance we used, a Zener diode just before to show that this voltage Vz really depends or ΔVz fluctuation depends on the differential resistance of the diode divided by R1 and I'll rewrite this relationship to extract the ΔVza over ΔV1 as follows: If this describes what happens when the variation of tensions here, this voltage variation then, when I report to the exit, I'm interested in the variation ΔVref which also depends of course on what this ΔI will be in the differential resistance. This time, I mean of the Zener diode, which also has a differential resistance I call rz on this side and I would call rza the differential resistance of this diode here. that I see ΔVza there which is equal to ΔV1 rza multiplied by the ratio divided by R1. That's what we had seen before. Now I want to bring this to the other side. I bring it over ΔI. So ΔI, it is dependent on ΔVza that I substituted by ΔVza / R2 and then a this point the ΔI I inject it in the differential resistance of the diode Once I replaced by equivalent.

Notes

Summary

5m 55s

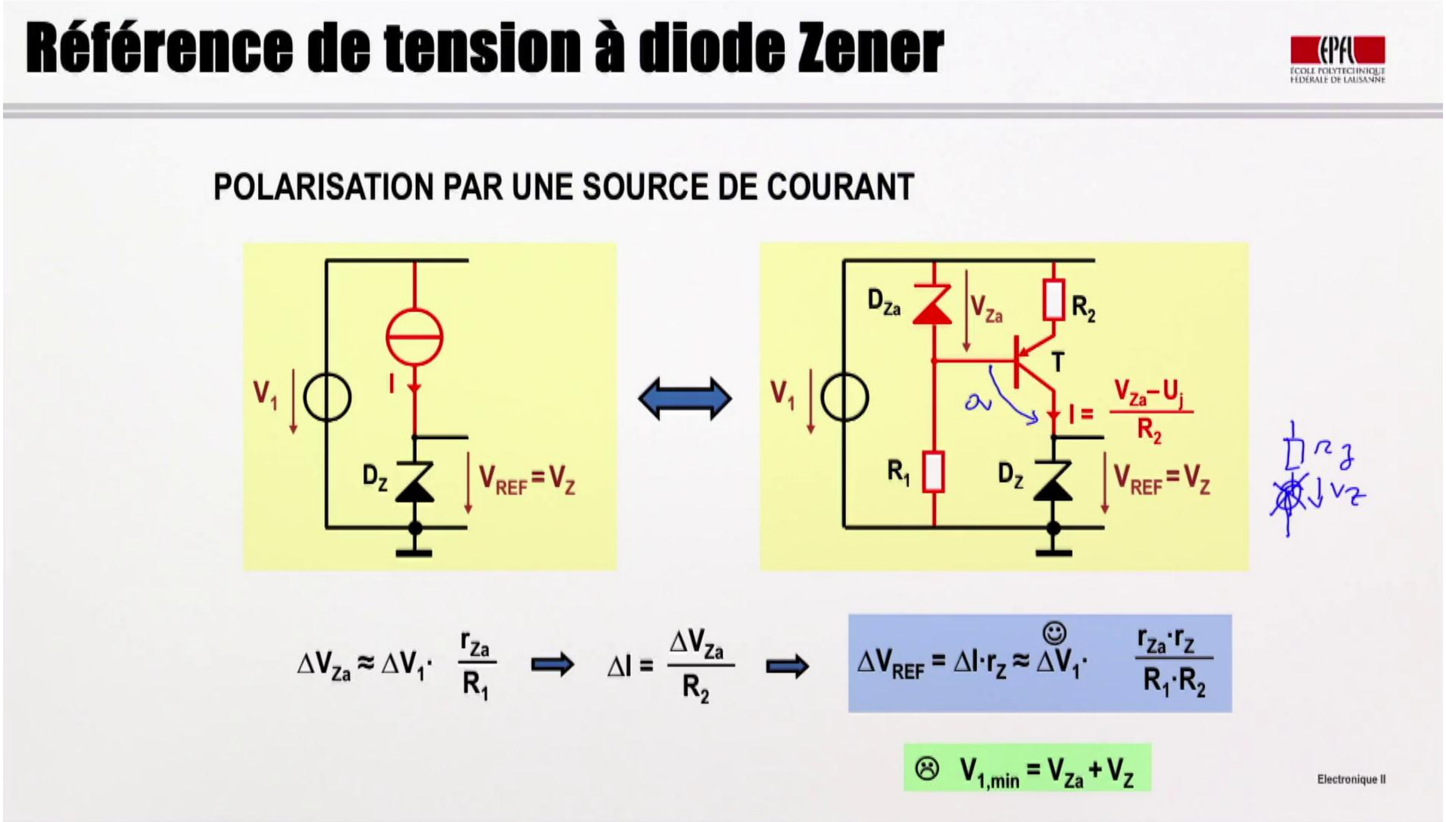


So this diode becomes for me a differential resistance rz in series with a voltage source corresponding to the voltage Vz. This voltage source, I take it off in from a pattern "small signals". It will remain for me rz and I look.DELTA.I in rz which gives me immediately ΔIrz equal to that. And we note that the reference voltage that we see there, compared to what we had seen before, which was this one, is divided by R1 x R2. So what is the product of two differential resistances D2 divided by the product of the two resistors. It is enough that the two resistances are very very large and here we come to reduce this greatly. So we are very happy with that. Unfortunately what happens with this kind of circuit, we needed a voltage VZA. So this tension then compared to a power rail equals VZA. Suppose your transistor is biased at the saturation point. That is to say, here you put a voltage of about 0 volts to keep 0.7 volt from here to there and be sure your transistor acts as a current source. So I have Uj from here to there and from there to there Uj so I have 0 volts there. The difference of these two voltages is equal to the time it more thereof.

Notes

Summary

7m 33s

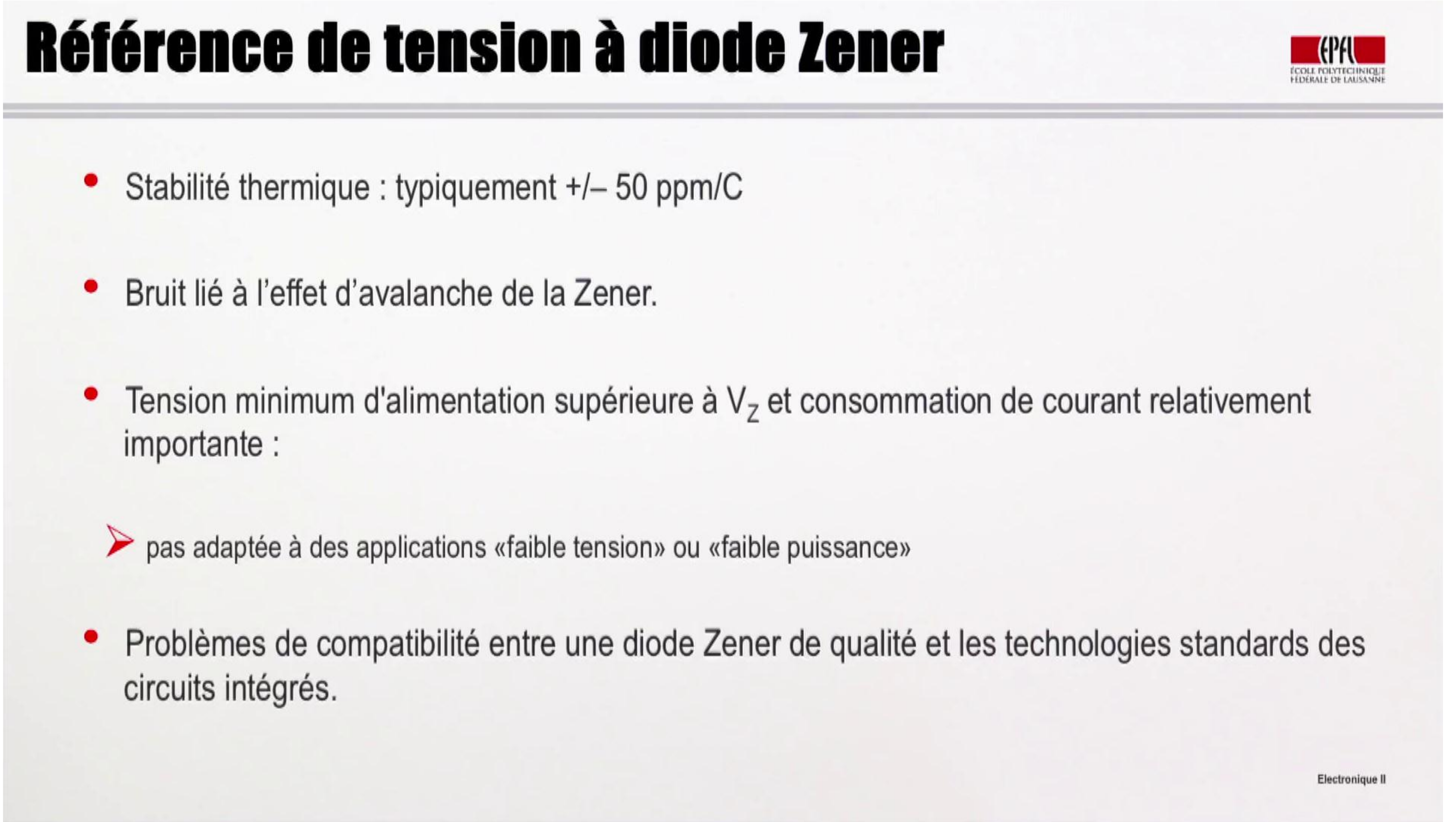


So I cannot give my supply voltages to get out a reference voltage based on this concept then beyond VZA + Vref. So this is what will give me the relationship of the minimum usable voltage. And this is a handicap. When you want to use very very low power and have a reference which is independent of the fluctuation of the voltage To obtain a characteristic also good but unfortunately I have to use two zener voltages series to get this, which gives me a minimum voltage limited by the Zener voltage that I own in the technology that I'm in to realize my circuit.

Notes

Summary

8m 53s

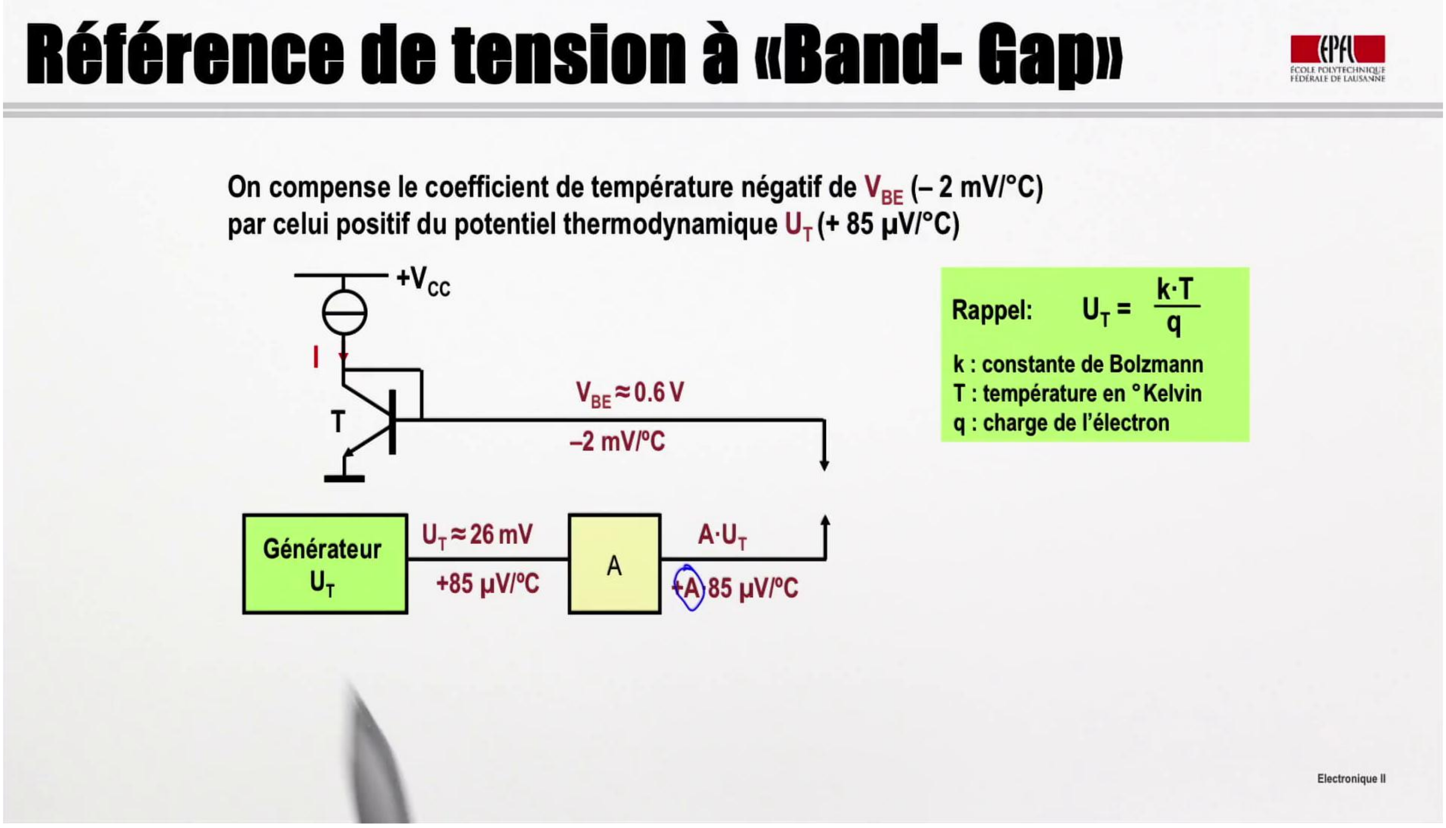


So when I'm talking about the Zener diode reference,, Unfortunately, I will suffer of this thermal stability of the Zener diode. It will also be necessary to make circuits to compensate them. I have not spoken in this circuit. There is the noise associated with the Zener diode is known due to the avalanche who will also give me a source of noise at the output and I'll find myself with what I have just explained associated with this minimum voltage of the Zener voltage. If I have to put two is much more disabling but if I have even put one Zener voltage levels proposed in the technologies are relatively high so when there is a voltage "low voltage", , I am annoyed by the voltage levels that I have. And finally, not all technologies of the integrated circuit give available zener diodes. So it's a voltage reference that is not badly used in discrete circuits or certain integrated circuits typically bipolar. In the MOS transistors, we do not easily Zener diodes available. So we will learn to make a reference voltage which is called the reference voltage of Band-Gap.

Notes

Summary

9m 36s

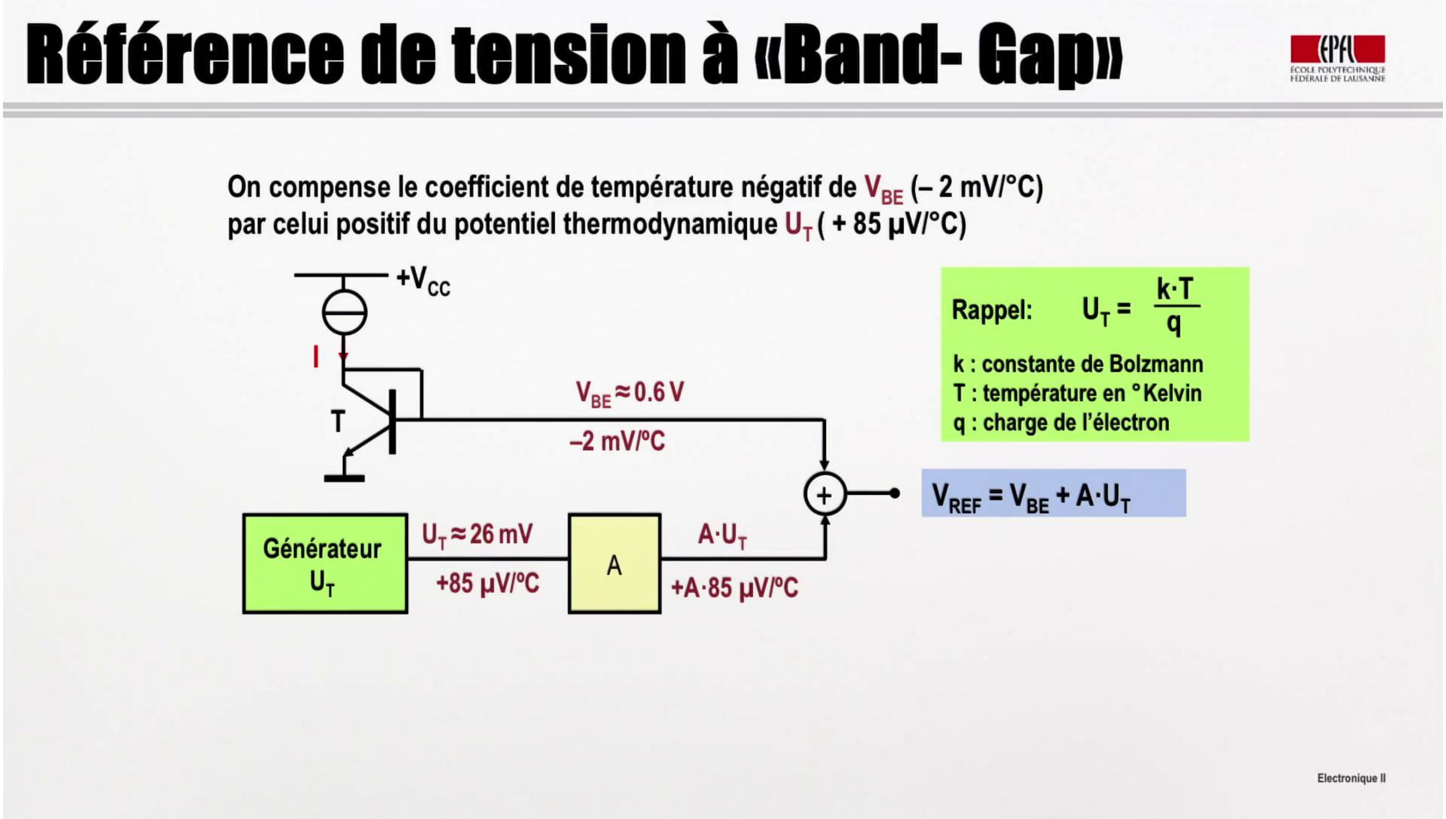


A reference voltage Band-Gap, that is the combined use two physical phenomena. The first phenomenon is a voltage across a junction Pn or is the voltage across a diode because we know that Vbe voltage of a transistor used as a diode drift -2 millivolts per degree. And if we take another phenomenon, another phenomenon such as the thermodynamic potential we know is Ut, which is proportional to the Boltzmann constant multiplied by the temperature divided by the electron charge, has a drift over 80 microvolts per degree. So if we can combine the two so that one compensates the other if both are made with electronic circuits so the addition of both means that the same temperature applied to the two leads us to a temperature drift which is equal to 0. And we will do as follows: So first, I'll take a Pn junction. I take a transistor, I connect it in diode. I imposes a current to him. The Vbe voltage is a voltage between 0.6 and 0.7 volts. So I have a fixed tension here in the junction voltage which will drift -2 millivolts to each variation of one degree. Now I'll get another circuit which is that. This is a circuit we will learn to achieve that is called the thermodynamic voltage generator Ut.

Notes

Summary

10m 52s

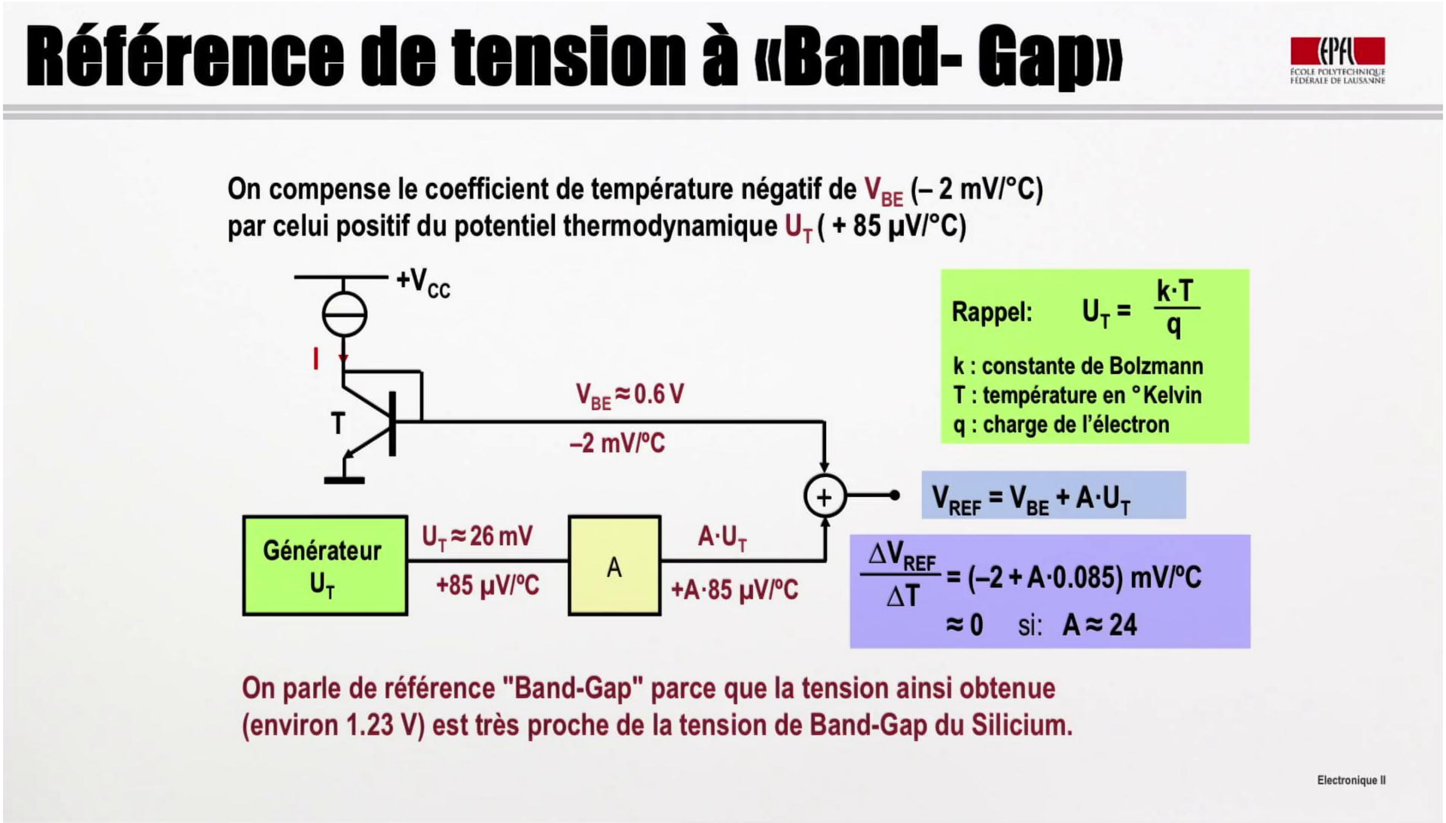


We will find the 26 millivolts that derives on 80 microvolts per degree and I'll try to multiply it by a gain. This gain I see here is a gain that I have to calculate. I have to make sure that the gain A multiplied by the voltage Ut compensate the thermal drift of -2 millivolts. So what I'll do, I'll calculate the gain by looking at the sum of these two tensions and deriving the sum of these two voltages for the thermal drift to be equal to 0. So I'll do that right now. That's the tension that I will see at the exit. So I'll find a voltage Vref. It is worth what tension Vref? It is worth this 0.6 volt, finally 0.61 or 0.62, it depends on the tension that I find here, the more the gain that I will calculate that multiplies 26 millivolts. Now, I am interested in this voltage as an absolute value which is the sum of the two, so it will tend towards the magnitude of 1.2 volts. Vbe is 0.6. That you'll see that I need 24. So 24 x 26 millivolts will give me this factor also in the order of 0.6. So we will find the order of 1.2 volt at the output and i'll have to find the derivative of both to be 0.

Notes

Summary

12m 30s

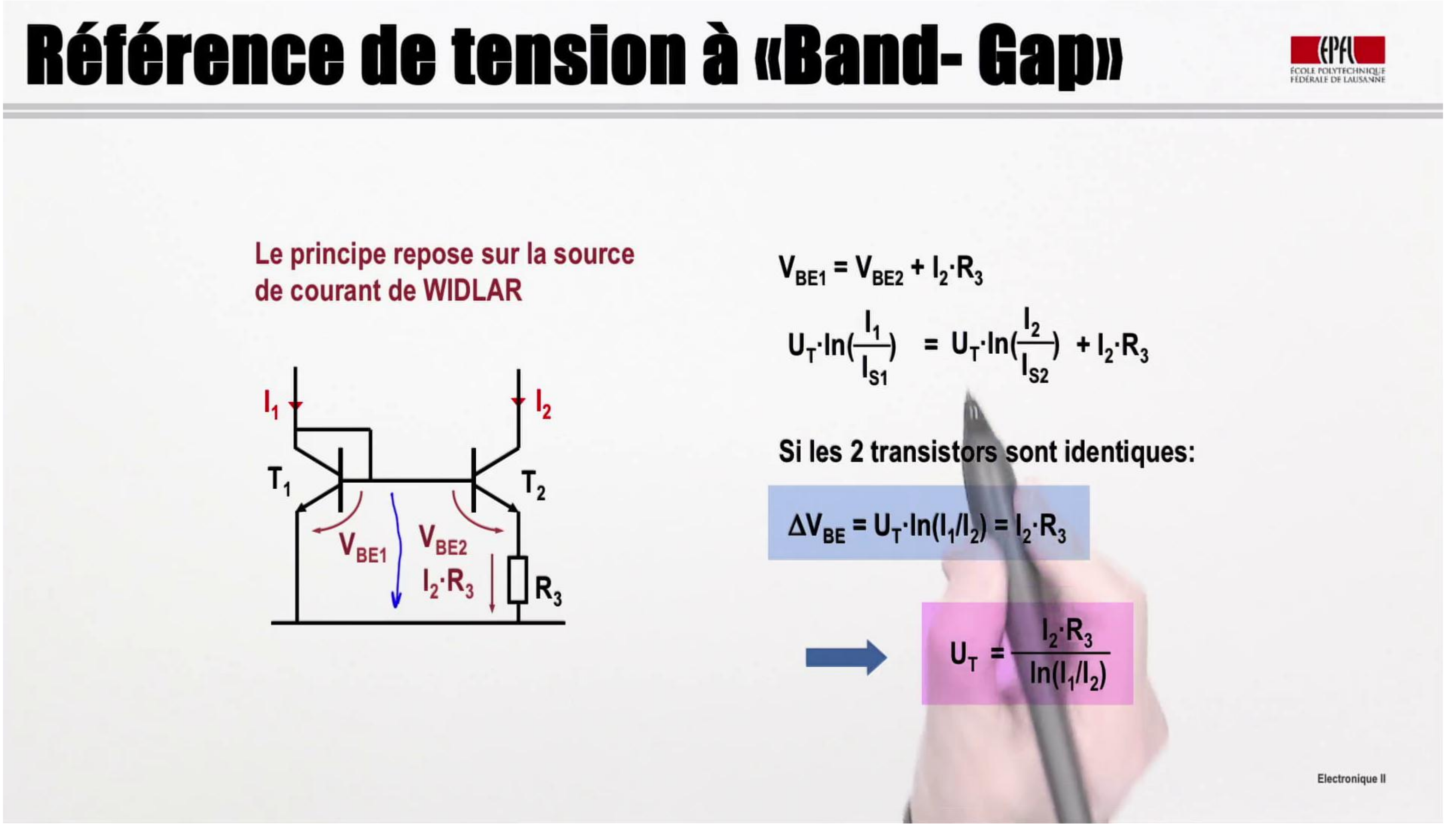


This is indeed the case because if I multiply the 24 times 85 since it's going to be 24 and I add whit the 2 mV, both will give me a derivative compared at the temperature equal to 0, and here it is. The derivative, the ΔVref / DT, its ΔVbe / DT which is 2 millivolts per degree and the derivative of A x 85 which is A that I do not know what time millivolt 0085. Well I'll find for this term to cancel A = 24. If we can make a gain equal to 24 that multiplies a thermodynamic tension extractor from a circuit, we get a reference voltage equal to 0.6 volts plus 24 x 26 which would give a voltage of the order of 1.2 volts which is very close to the voltage of Band-Gap Silicon. That is the goal of this part and we will learn to achieve this extract and this multiplier voltage and then, after making a reference voltage of this style.

Notes

Summary

13m 54s

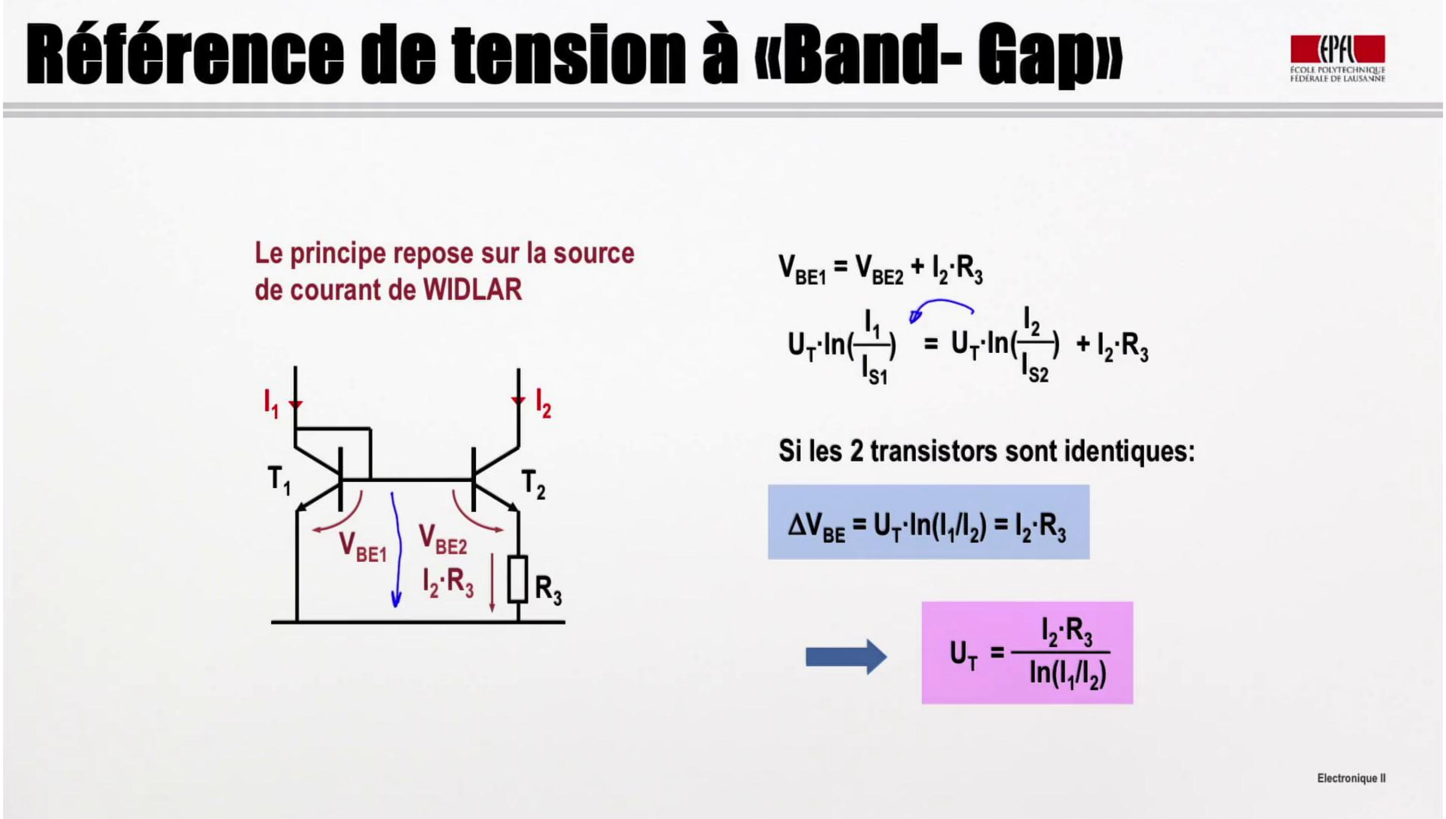


The technique for performing multiplication or extraction of the bed is to make a loop in which I have 2 junctions base transmitter and base transmitter of 2 transistors. I relate the difference between these two voltages to Ohm's law. So I have to see here a current times resistance which is proportional to the difference of the two. And we will have to prove it now. If you take the power from there to there, the one here, you can say = Vbe1 Vbe2 + (I2 x R3) what is written here. = Vbe1 Vbe2 + (I2 x R3). And I replace the junction voltages values, I know the exponential law which links the current tensions and I write it. So the current, the voltage Vbe1, it's Ut ln (I1 / Is 1). I1 is the current through the transistor. Same for the second. In the second part of that side, I must add I 2 x R3. So as I said earlier, if I can bring here the difference between the two junctions, I win because it will be proportional to Ut. If you move it to this side of the equality, so I have a difference between two voltages, and express yourself and you have similar transistors that is to say Is1 = Is2, you fall back on a variation Or rather a difference between two junction voltages that are reported on a resistor.

Notes

Summary

15m 05s

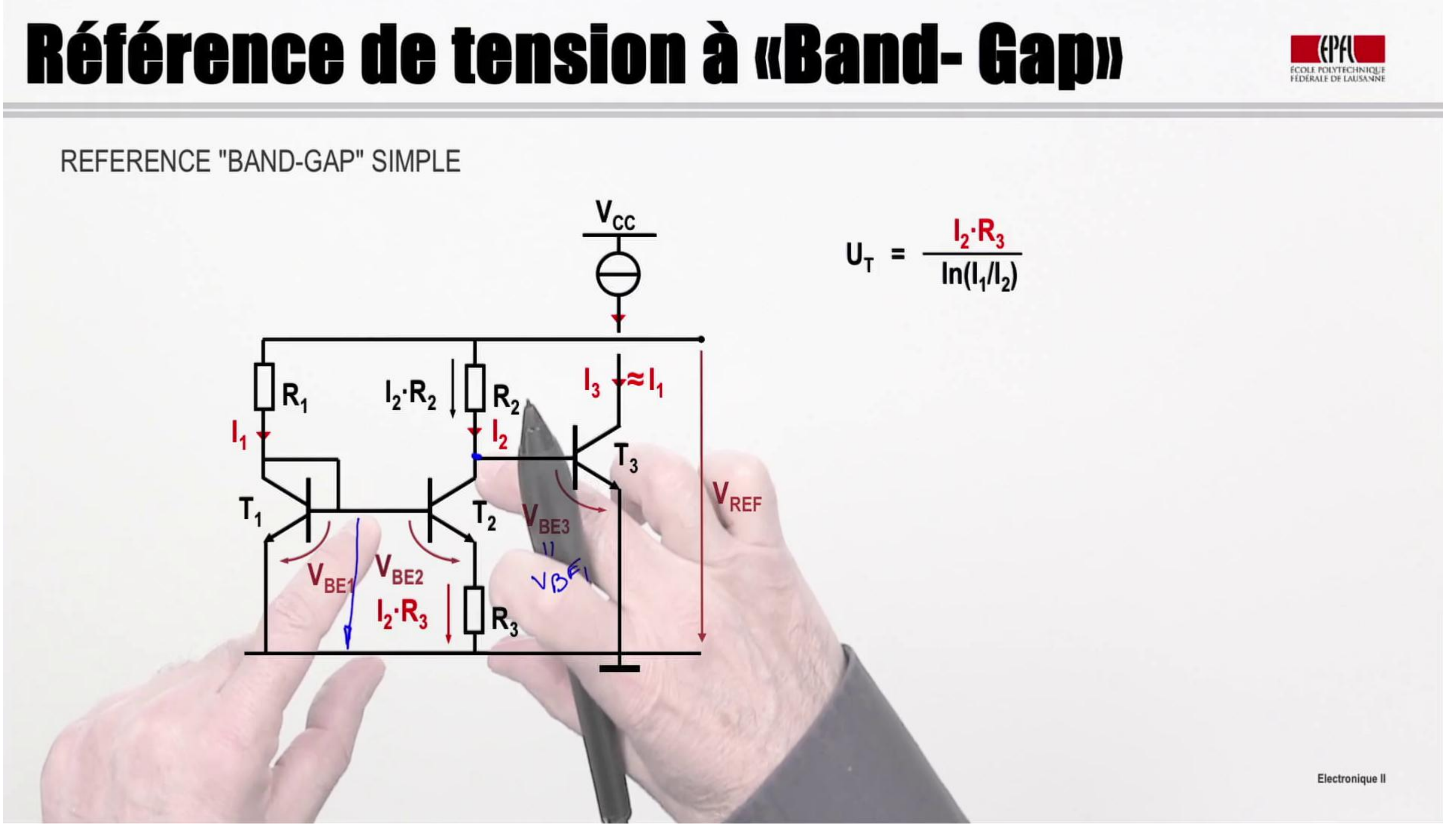


So the difference between these two junction voltages brings me back to a ratio of ln (I1 / I1) because here Is1 and Is2 are the same. Once I brought it, the log has the right to transform me the difference in division and that will give me the report logarithm current I1 to I2 which is equal to I2 × R3. And see the extraction of the Ut. I see it here. So I pass this logarithm below and it gives me I2 x R3. So I just have to think now in terms of current I1 and I2 and replace it by the components that I can resize myself in the circuit. So the basic construction of the extraction of Ut, of a simple way, can pass through a current mirror that we call Widlar current mirror.

Notes

Summary

16m 43s

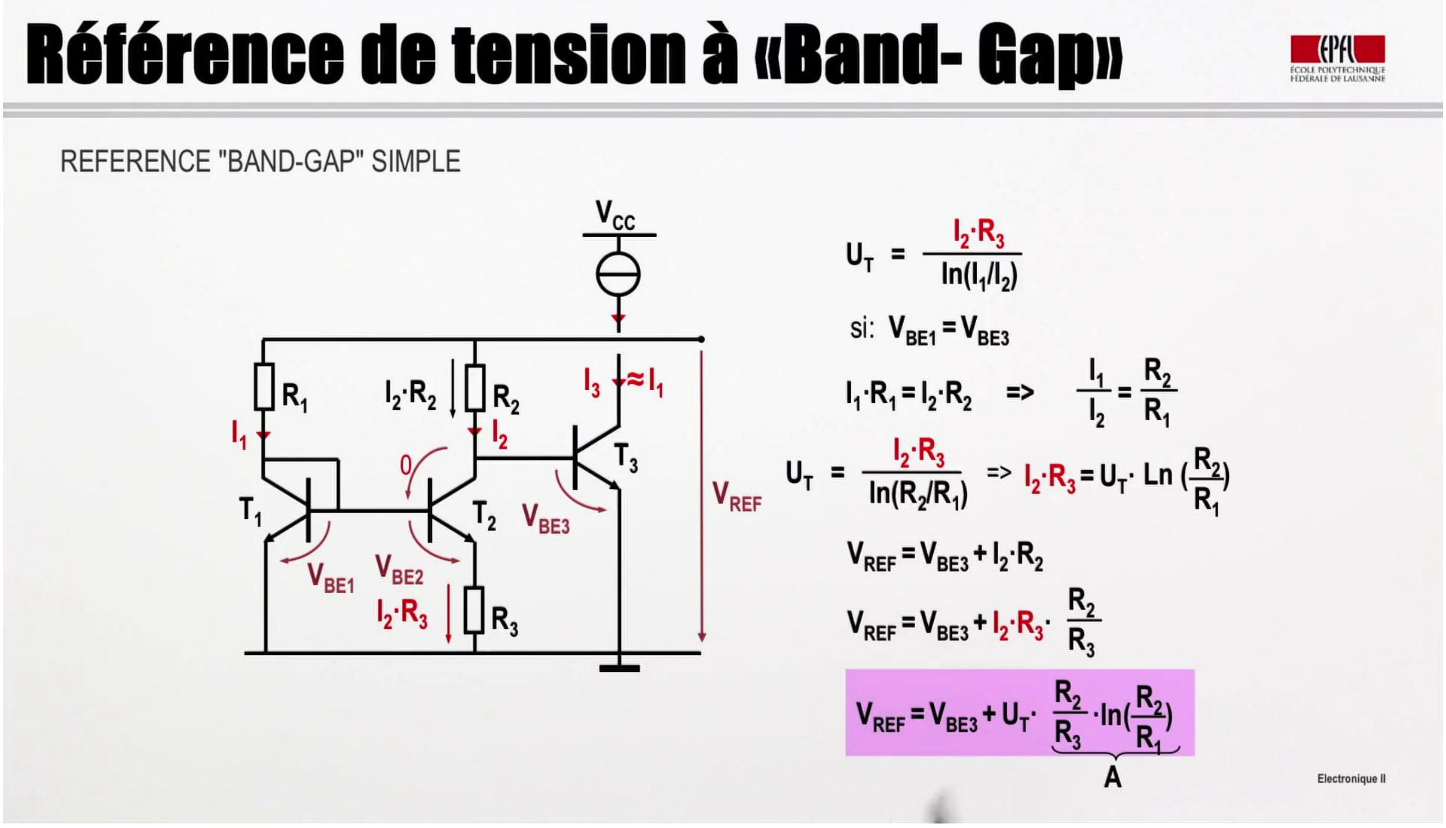


The first part of building my Band-Gap Is to take the 2 currents that interest me that are in the denominator, whose report is in the denominator and injecting them into two resistors R1 and R2. So I think Ut is equal, what I have demonstrated just now, (I2 x R3) / ln (I1 / I2). I'd like to replace it I1 / I2 by another term which will be dependent of resistance that I have dimension in a circuit that would lead me after to calculate the values of my resistances and move towards the famous ratio of 24 or 24 gains to get my reference voltage. So to do that, I will impose a tension here. And I will impose the following manner: I take a transistor similar to this. So I take the same transistor I used there and I put it here. I imposed the same current as the transistor, that it will generate a tension that is the same thereof. So I can write Vb1 = Vbe3. But look what will happen with this transistor. This transistor is the transistor T2, it is at its base with a Vbe1 tension. It is found here with Vbe3 = Vbe1. So this same voltage is here and there on each other, on its collector and its base. So like I'm saying that this voltage is the voltage therefore the voltage difference here is equal to 0.

Notes

Summary

17m 36s

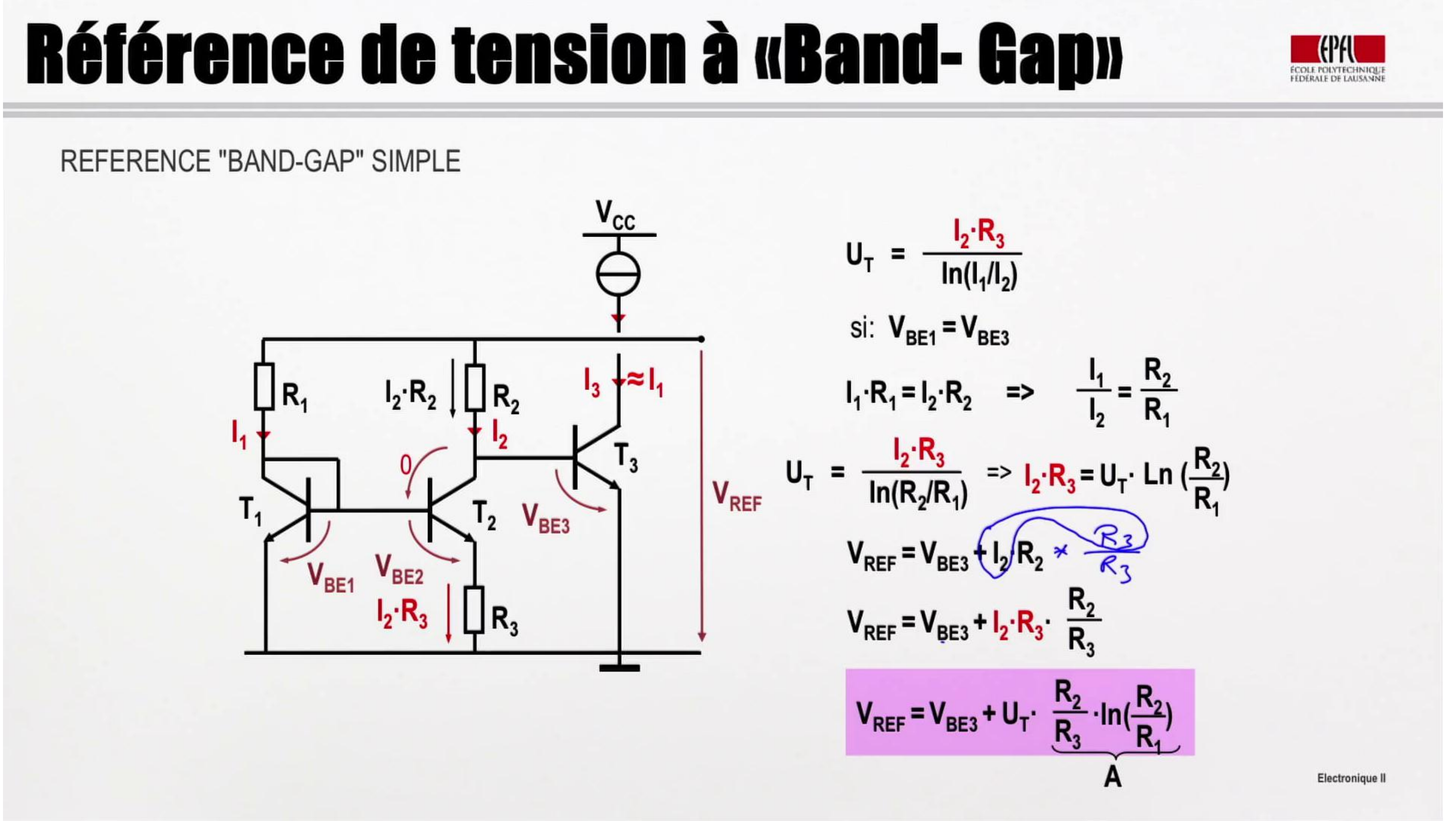


So, I did a short circuit for the same effect. there I do not need to make a short circuit because I copied tension there and I imposed here in an external way with this. This is what I have done and I express it and show it with an arrow that says the voltage difference from here to here =is equal to 0. I will continue my reasoning. Let's see what will happen in this cell here. This voltage is equal to the tension. This voltage is equal to the tension. So obviously, this voltage is equal to the tension. So I can say I1 x R1= I2 x R2, I'll note right away. I1x R1 = I2 x R2 So I found a report I1 / I2 I1 / I2 proportional to R2 / R1 resistance. So in that expression, I brought the ratio of two currents I do not know at a ratio of two resistors that I have to choose. So this report then it is for me to size him according to R2 and R1 which I will use. It will stay that expression I2 x R3 that I must also bring it to something that I can design with my circuit. So let's analyze what we just saw here. I copy this. I place it here. So this is the expression, the same thing that I saw here. So I can write I2 x R3, the one that interests me, as the Ut x ln (R2 / R1).

Notes

Summary

19m 13s

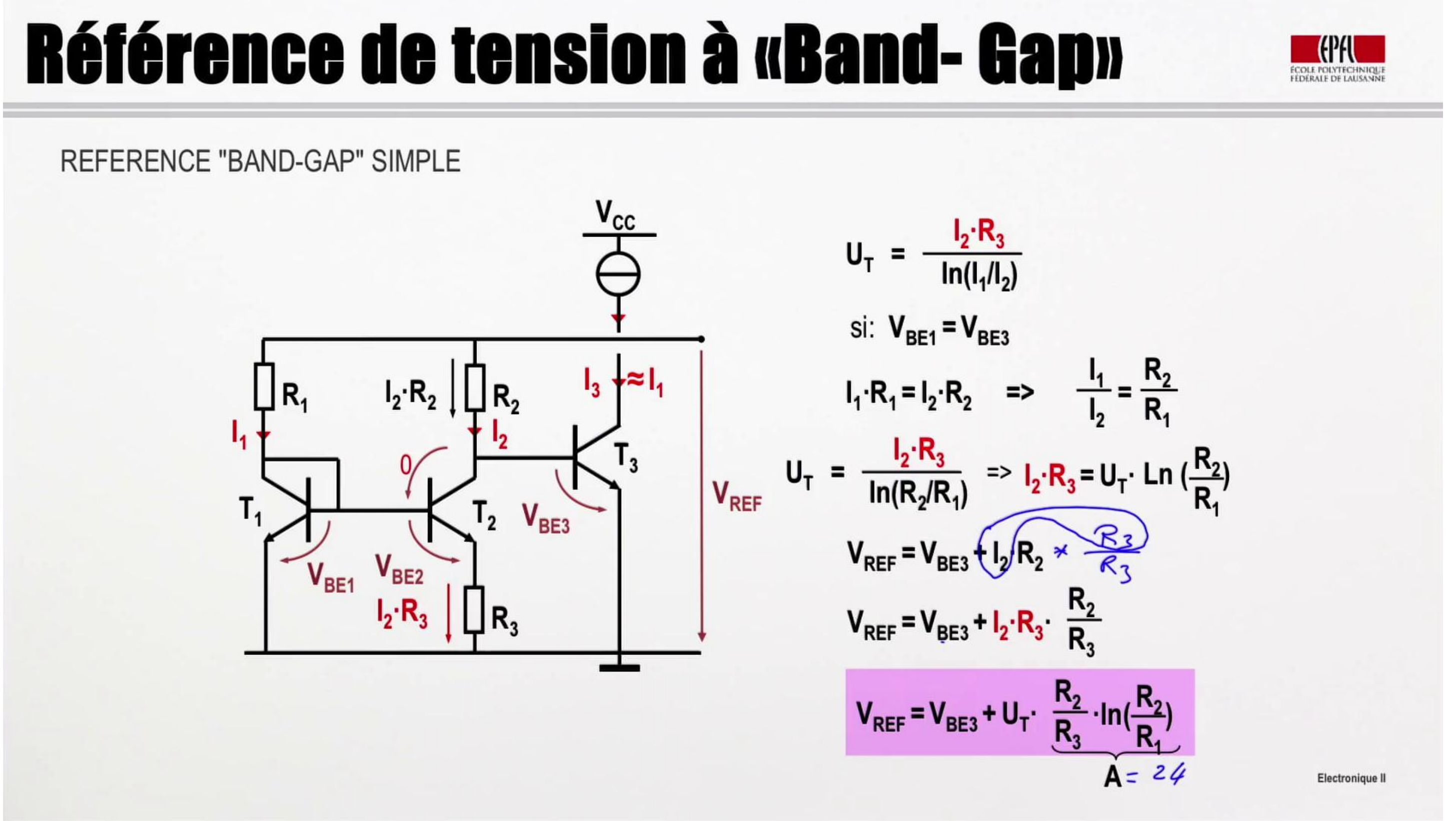


Now, when I look at the reference voltage, that I want to read from here to there, it is what this reference voltage? It is worth this tension thereof. So I the sum of these two voltages that I noticed here. The reference voltage is Vbe3 + (I2 x R2). That's it. I2 x R2, I'm interested in I2R3. Easy! I just have to multiply it by an R3 and I divide by R3 and this is my I2 x R3 as I try to get and replace here. In writing this, I 2 x R3 x (R2 / R3), and I2 x R3 is the term that we calculated earlier that depends on Ut multiplied by a certain ratio. So I replace this term by its value here and I find myself with a reference voltage, exactly what I was seeking, a junction voltage Vbe3 plus what I copied from here, So Ut x ln (R2 / R1) that multiplies the R2 / R3. And that's it, I have a multiplier of thermodynamics Ut voltage by a factor A that should be equal to 24.

Notes

Summary

20m 38s

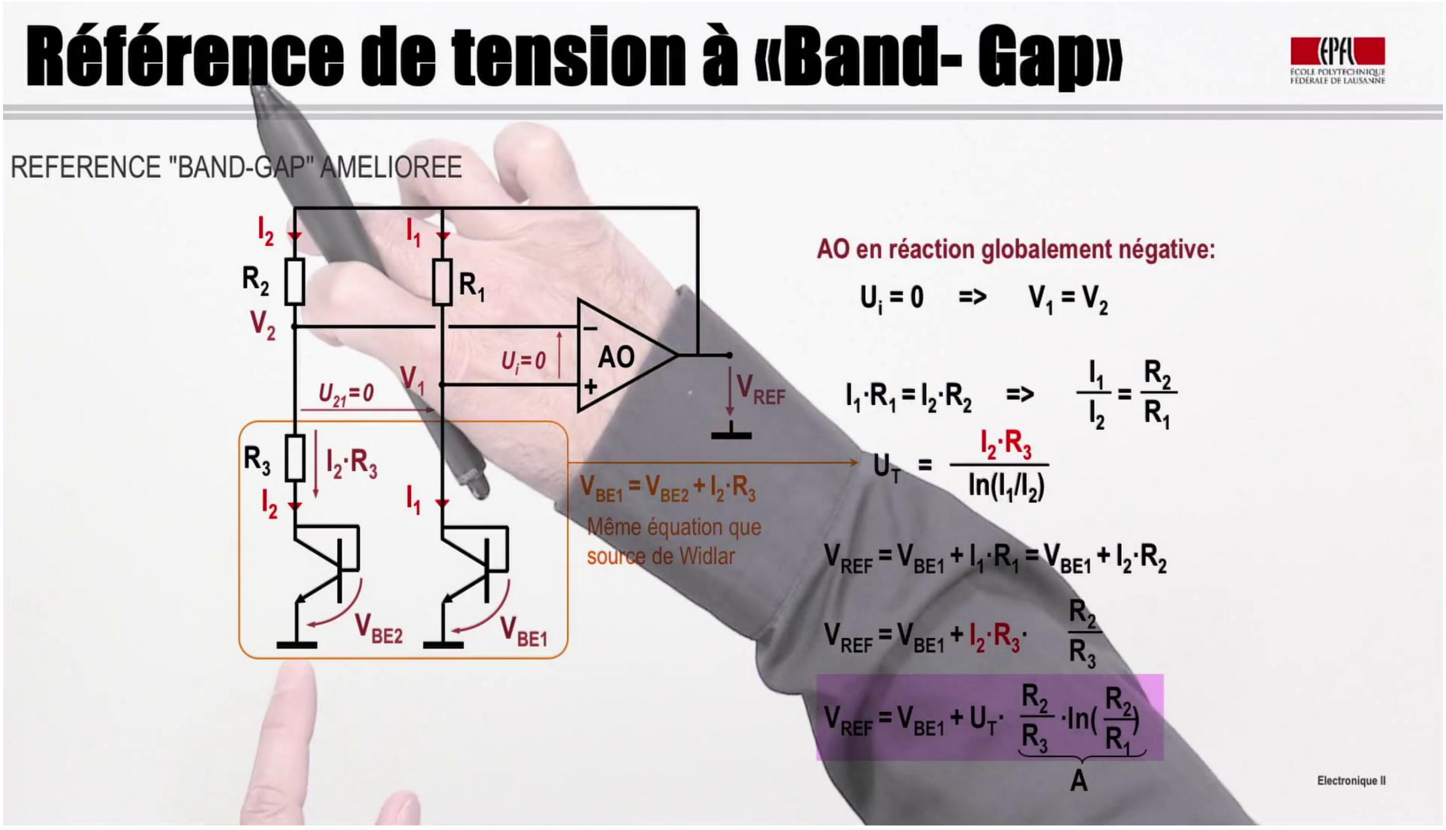


And the Vbe3 voltage, which is a transistor that I imposed a stream in, so it is a junction voltage of a transistor that will derive from -2 millivolts per degree and this, it will divide by + 26 millivolts per degree multiplied by 24 and I find myself with the reference voltage whose absolute value is in the order of magnitude that I said earlier, so 1.2 and the derivative compared to the temperature approaches 0 If I correctly dimensioned all these parameters and if I have a technology where all my transistors, I control in terms of technology that is available to me. Can you make this a little more elegantly circuit? Yes, we can. This is usually done with a against reaction that way one.

Notes

Summary

22m 04s

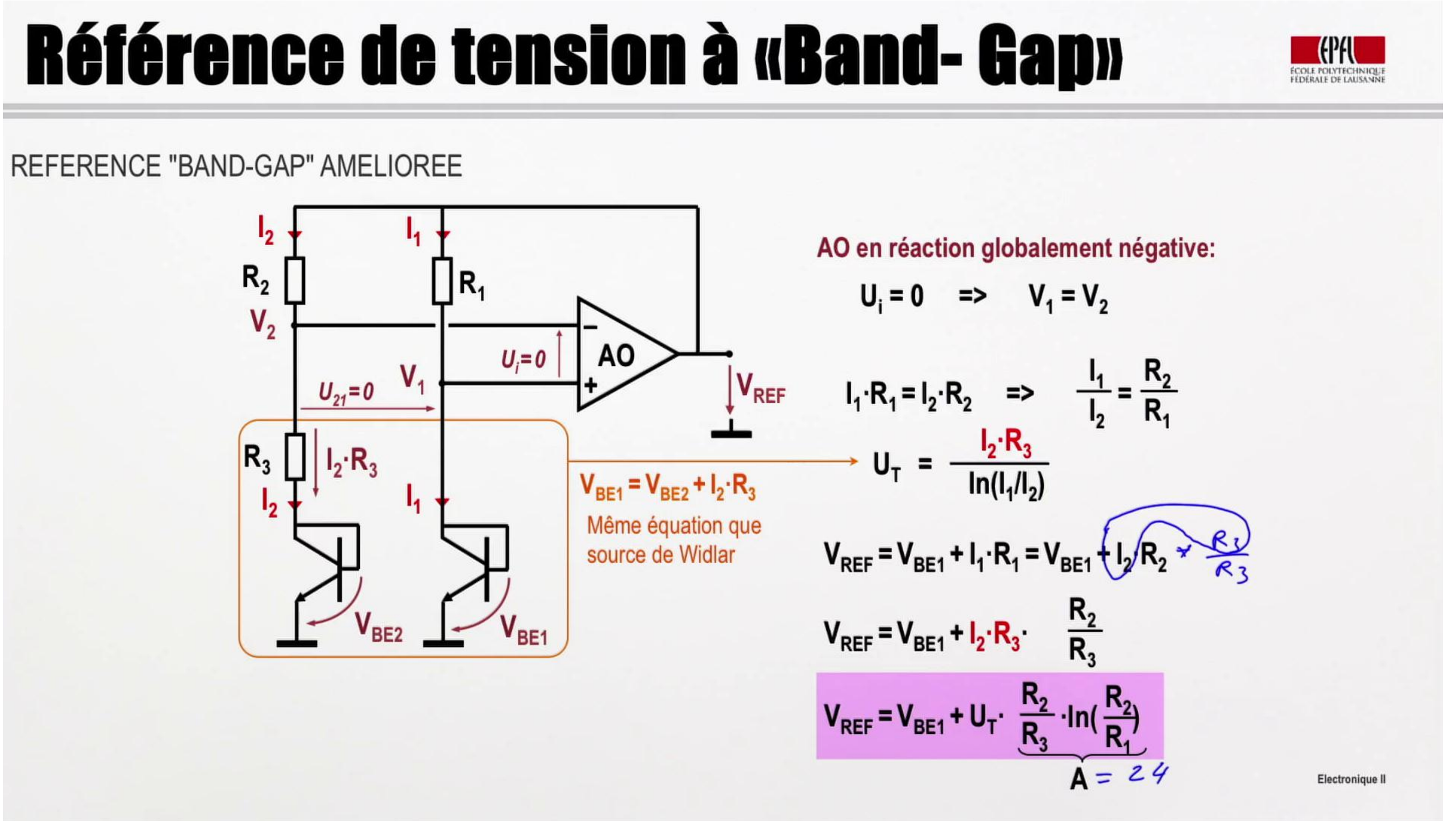


In order to create the same phenomenon, that is to say have the difference of two junctions attached to the terminals of a resistance so that the voltage of this pn junction less this Pn junction is equal to the one I see here I create a feedback against an Op amp. So if you remember what a Op amp fact, it creates a voltage difference here is equal to 0. When it is in the linear region, these two voltages are the same. So I am with V1 = V2 and if I say V1 = V2, the voltage U of 1 equal to 0. So the tension I see in this cell here, is (I2 x R3) + = Vbe2 Vbe1, what I have written here. This voltage then equal to this more thereof. This is the same as a Widlar current source. This is exactly the same thing that brings me back to retrieve the same story. The thermodynamic potential, it is proportional to the current, rather this tension I2 x R3 / ln (I1 / I2). My reference voltage, it is found at the exit an Op amp. This is an advantage, that. So, I can draw some power on it, on the Op amp, without disrupting the reference voltage. Which is a good thing. If I look Vref, it is this tension there. So it is from here to here and from here to here. And I can read it by different paths.

Notes

Summary

22m 53s

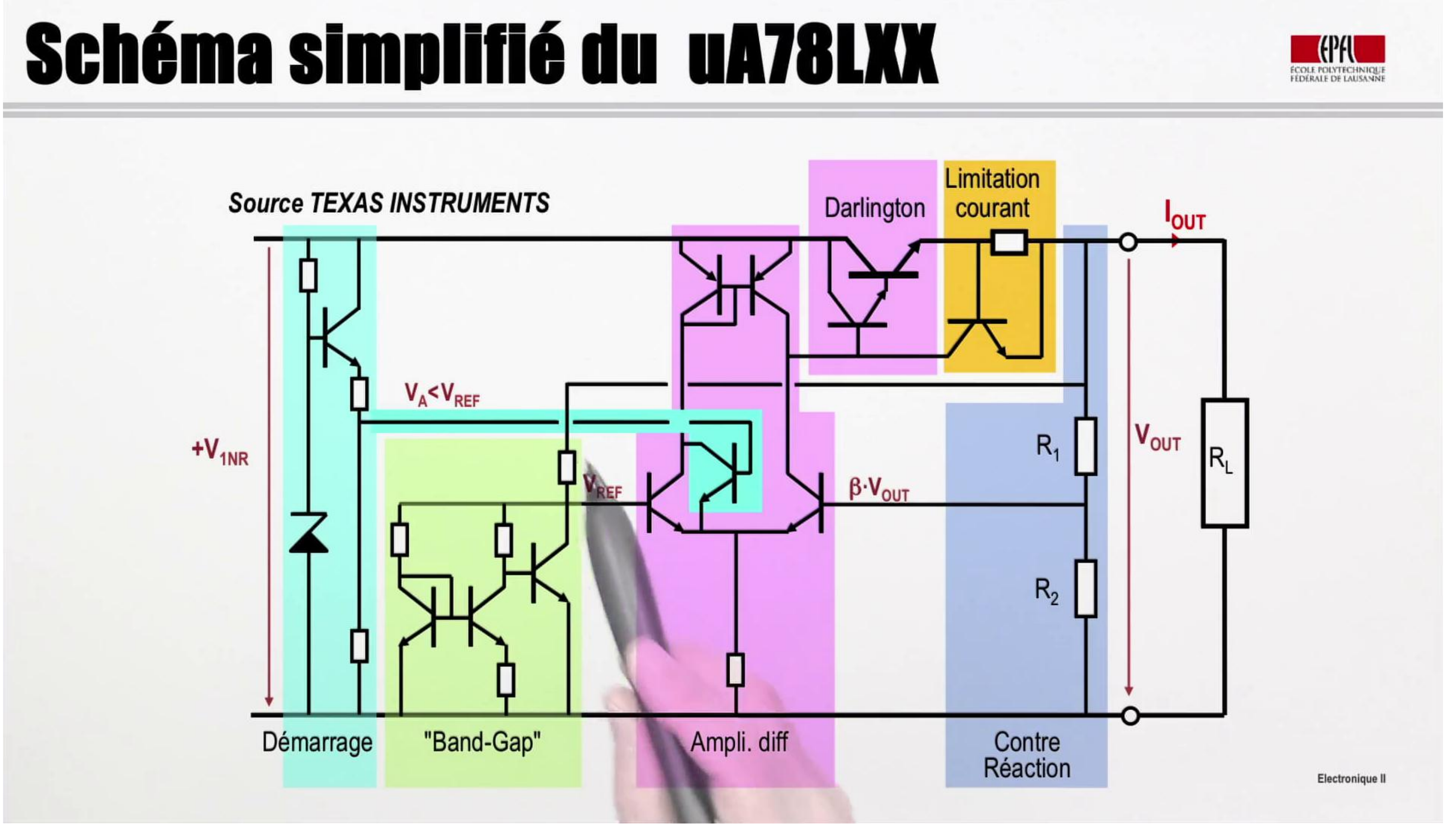


So what is this tension from here to here and it is 0 per Op amp, by reaction against. There I Vbe1 + I1 x R1. Again, I Vbe1 / I2 x R2 more I2 x R2, and I can read it from that side as I2 + I2 x R2 R3 + X Vbe2. And I will write my reference voltage I have to say is the Vbe1 from here to here more I1 x R1 and I also rewrote Vbe1 more this tension there, I2 x R2. And as I take it, I multiply by R3 and I divide by R3 and I end my term as earlier I2 x R3 which is here, I'm seeing as there and I substituted Ut x ln (I1 / I2). And as I have I1 / I2 which is the resistance ratio R2 / R1 which is also written here. I replace this report by the resistance ratio and I develop. I have exactly the same expression as earlier. So I have a reference voltage that depends a junction voltage, thereof, plus a multiplier of voltage Ut which is equal to A. And A = 24. So we are left in the same condition still with an amplifier that achieves counter reaction and that allows me to draw a current here without disrupting what happens to that side through the power of this operational amplifier.

Notes

Summary

24m 26s

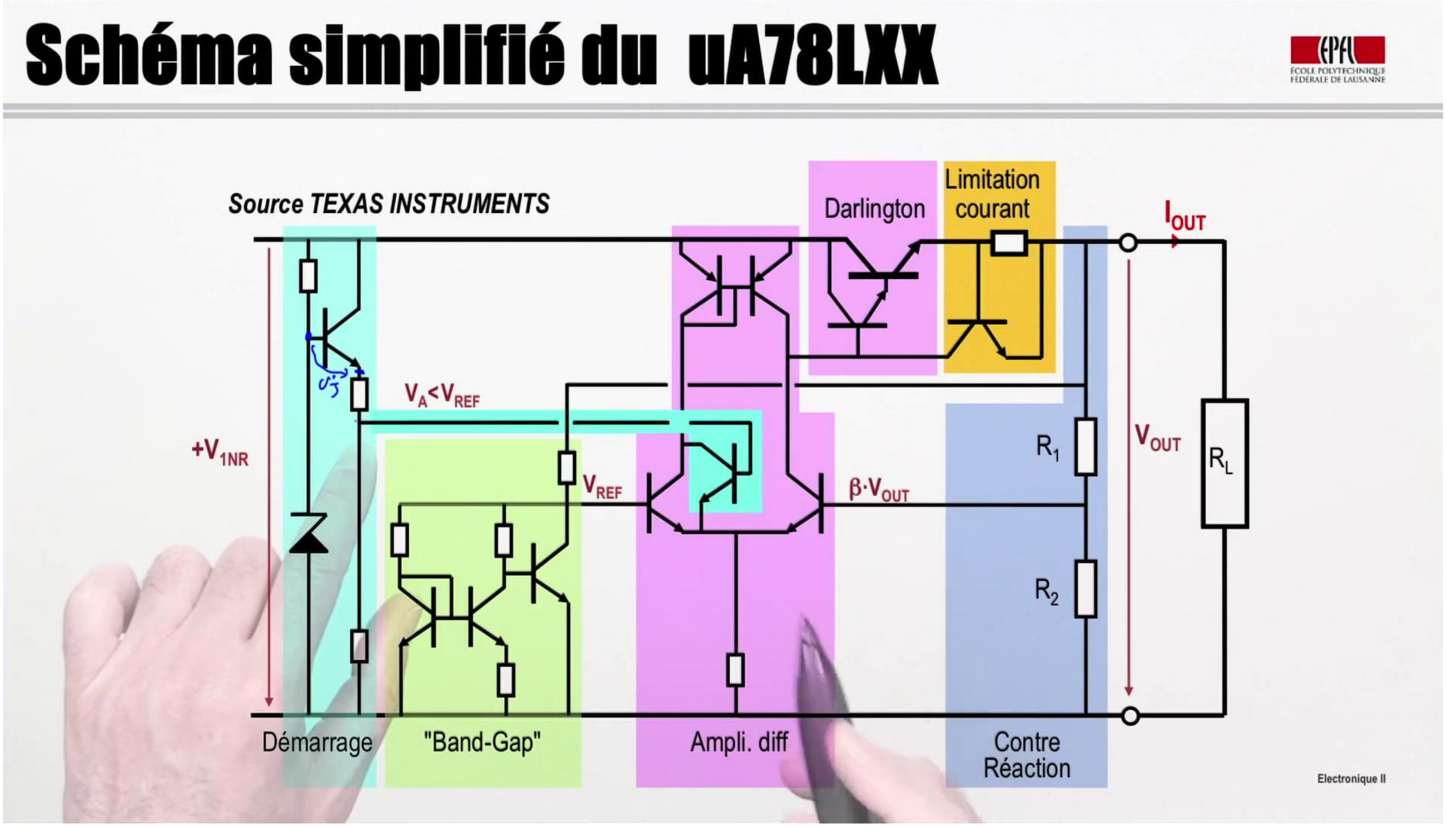


Let's see a complete scheme now that everyone knows how we make a power. I took a simplified diagram of a circuit known family manufactured by Texas Instruments and I looked at the internal patterns. So you remember, we analyzed the power is based on a transistor which is located between an unregulated voltage and a regulated voltage. Here this transistor. It is carried out by a Darlington. The advantage of Darlington, is I'm going to find with a β is very large. So this is a big advantage over the current I draw here and compared to the output impedance I see there. There is a current limitation circuit we've seen in the previous video which drive the transistor to start deriving the current command the bypass transistor and the series transistor. When starting to overcome excessive current, it was a reaction against to an Op Amp. This op amp is achieved by a single OTA, So perdif with an active load, and there I will add what is in this circuit in terms of voltage reference and here. The reference voltage that is generated at the entrance of this amp Op, So all that part corresponds to the amp Op, against his feedback and the follower stage and this part here is the Band Gap voltage In this circuit family, they used a Band-Gap.

Notes

Summary

26m 04s

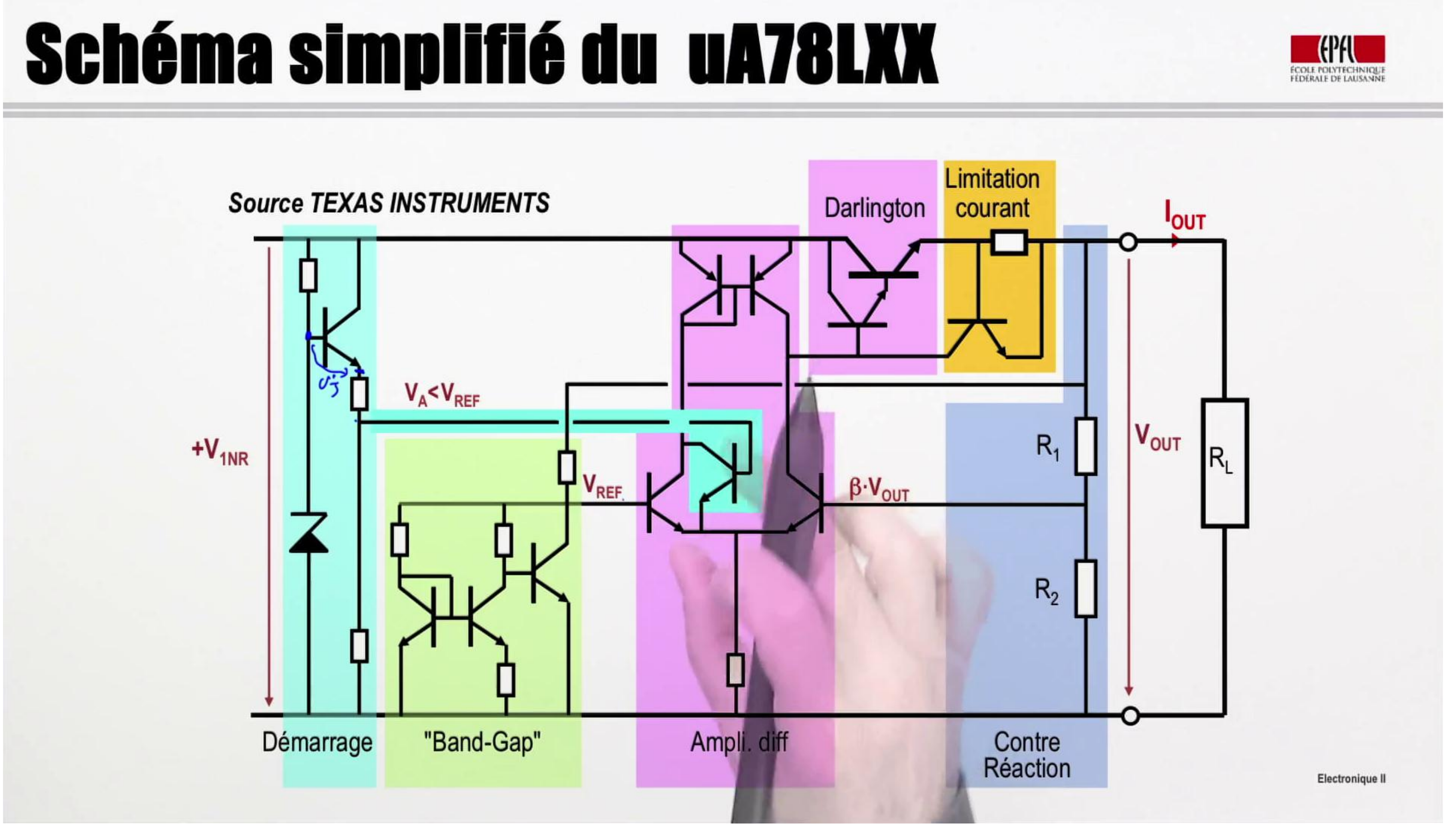


It acknowledges. This is the Band-Gap we just study here. You should know one thing: if we want to achieve this Band-Gap, we have to start the Band-Gap because it will take still there is a current that goes in there for the reference voltage is established at the entrance to the circuit. This manufacturer has proposed the following solution: he used part he calls the start. The boot is a Zener diode, It has a Zener diode in its bipolar technology where he realized this IC, which ignites it. When you take an unregulated voltage here, there is a voltage Vz will appear here. As soon as this voltage Vz appear here, in the fall of 0.7 volts, So, I have a voltage drop Ui, and it will appear on the resistive divisor. So here I have a Vz voltage fraction is and he arranged the manufacturer to make the differential pair of our Ta and take one of the transistors and replaced by a transistor which starts at the beginning and then after, it will disappear. Why? Because if I choose a starting voltage of the transistor So this transistor then does not work there is another instead that binds a reference voltage which is one.

Notes

Summary

27m 39s



Not that we do with the Band-Gap, that's another reference voltage equal to some Vz - Go but he arranged for this voltage level is always less than the reference voltage, that he wants to get in the end. The advantage of doing like that, is that my differential pair I see here, before it is controlled by an input that comes from Vref, it will start. So suddenly, the differential pair begins to establish a current that passes. The tension here, she comes from a reference voltage and the output of my regulated voltage begins to regulate themselves. So I begin to have a V out. This V out there, it is regulated. It is a tension of its own not like this one. I start on this tension not clean, the one that fluctuates. After I take this clean output voltage and I use to bias my Band-Gap. So my Band-Gap is feeding with a clean output voltage that the fluctuation is low and I start with a circuit as soon as the reference voltage appears here, This voltage then, is less than the reference voltage So I do it by building less than Vref so that this transistor one will disappear. There will be blocked immediately and come back with the transistors of the perdif.

Notes

Summary

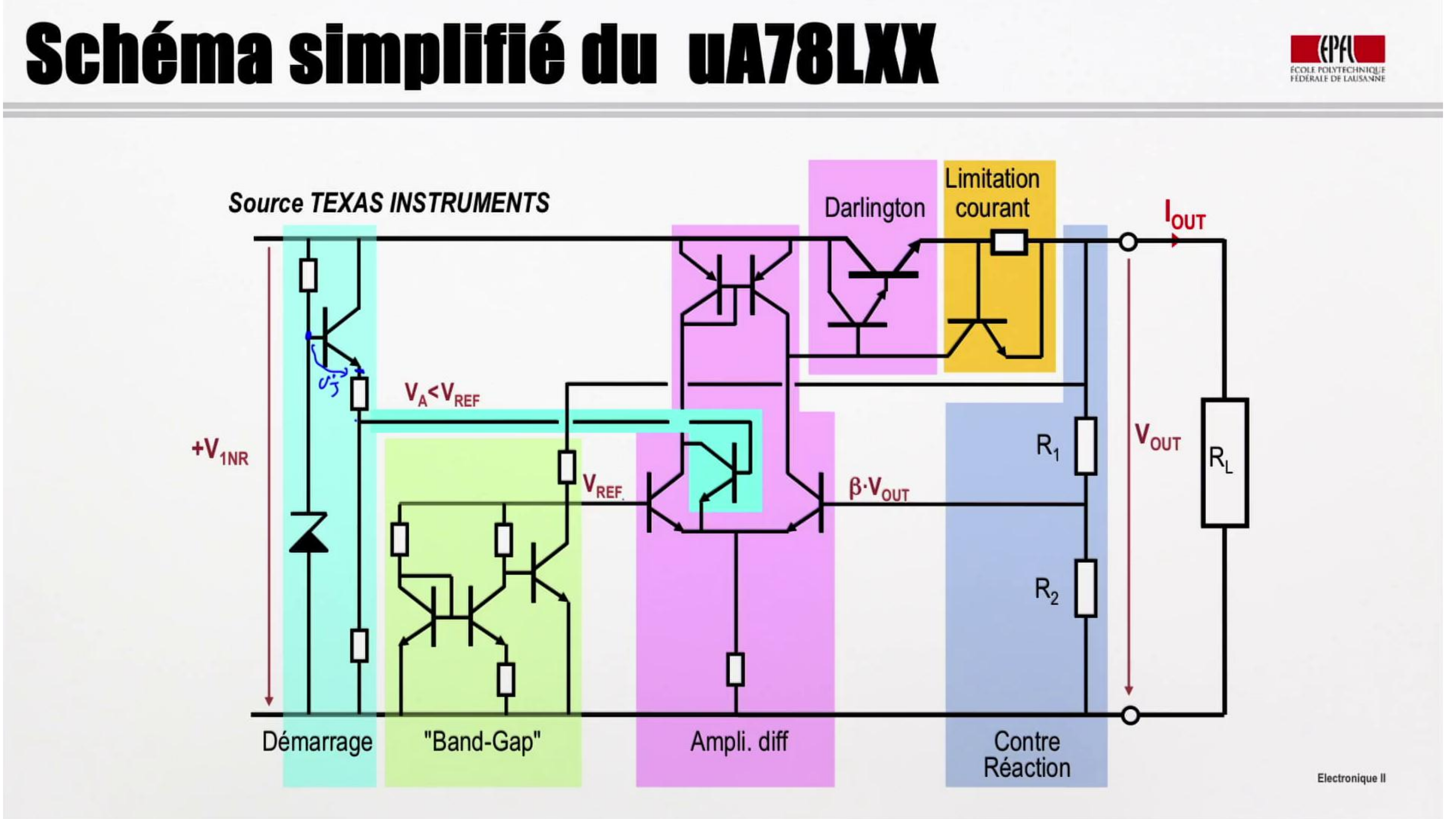
29m 00s

So all this part and light blue or cyan, all that part is simply used to start my circuit and switches off electronic use and my circuit is reduced to that. I have a regulated voltage I use to feed my Band-Gap. I have a reference voltage generated which is independent of the temperature variation then after, classic story who realize my regulated power supply series. And it is about a diagram that you find in the market, in a circuit with three legs which receives an unregulated power supply with a mass you and generates a regulated voltage at the output which has a certain value depending on these reports R1 / R2 which are added by the manufacturer within its circuitry. To close this series on cleaning supplies, we have the set of components that allow us to build a series regulator. This is an excellent example on regulation and this is a great example that shows all you can do with a transistor or with functional blocks based on bipolar transistors or other, of course, and that allows us to One of apthe plications which is the series voltage regulator. So it's an advantage to see regulators because it is a test voltage, roughly, to the exit.

Notes

Summary

30m 22s



Of course, if we push the studies a little far, we have to make very intensive analyzes in terms of bandwidth usage, which is not the objective of this course. Because when you start putting charges whose current variation is very demanding in terms of frequency, it means I have a current that varies at very high frequencies as a micro controller that works at megahertz, well, at this point we're led to look at the problem differently and begin to complicate the analysis of this circuit. I just settled on showing you the construction of a stabilized power supply to use it as a classic example of using functions, based on transistors.

Notes

Summary

31m 46s