ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

5.1-Amplificateurs élémentaires à transistors

Principes

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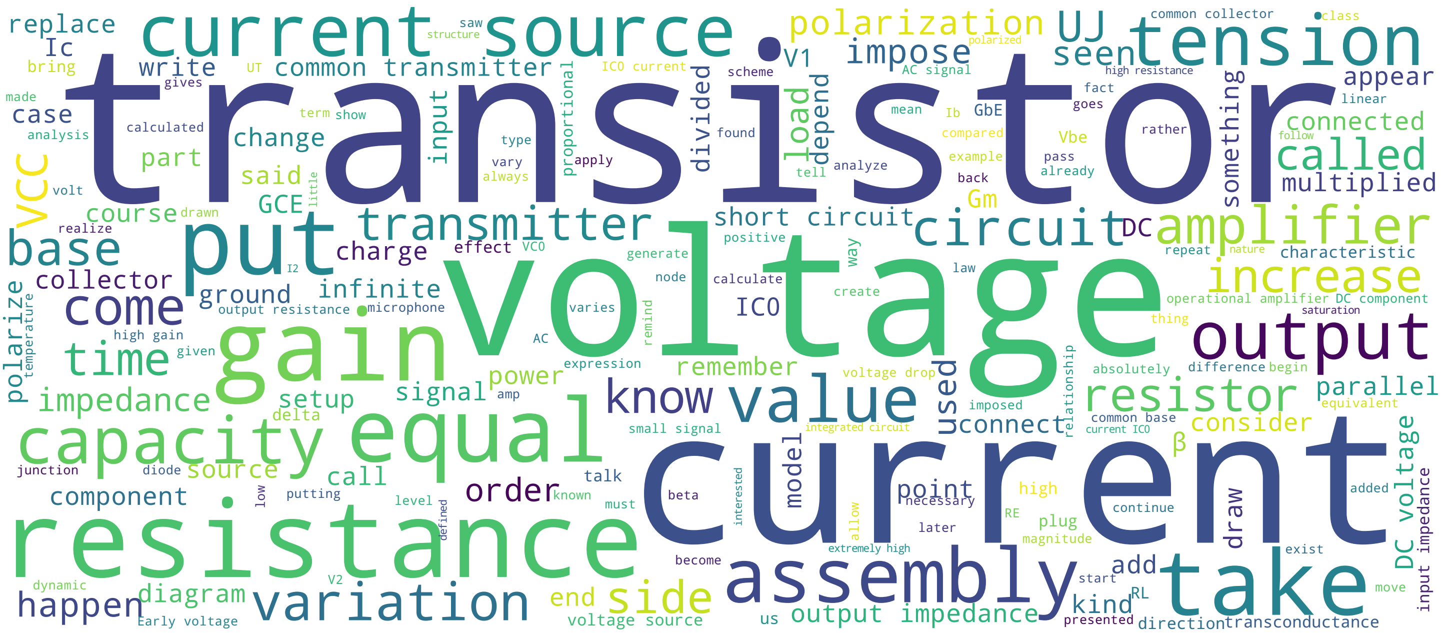
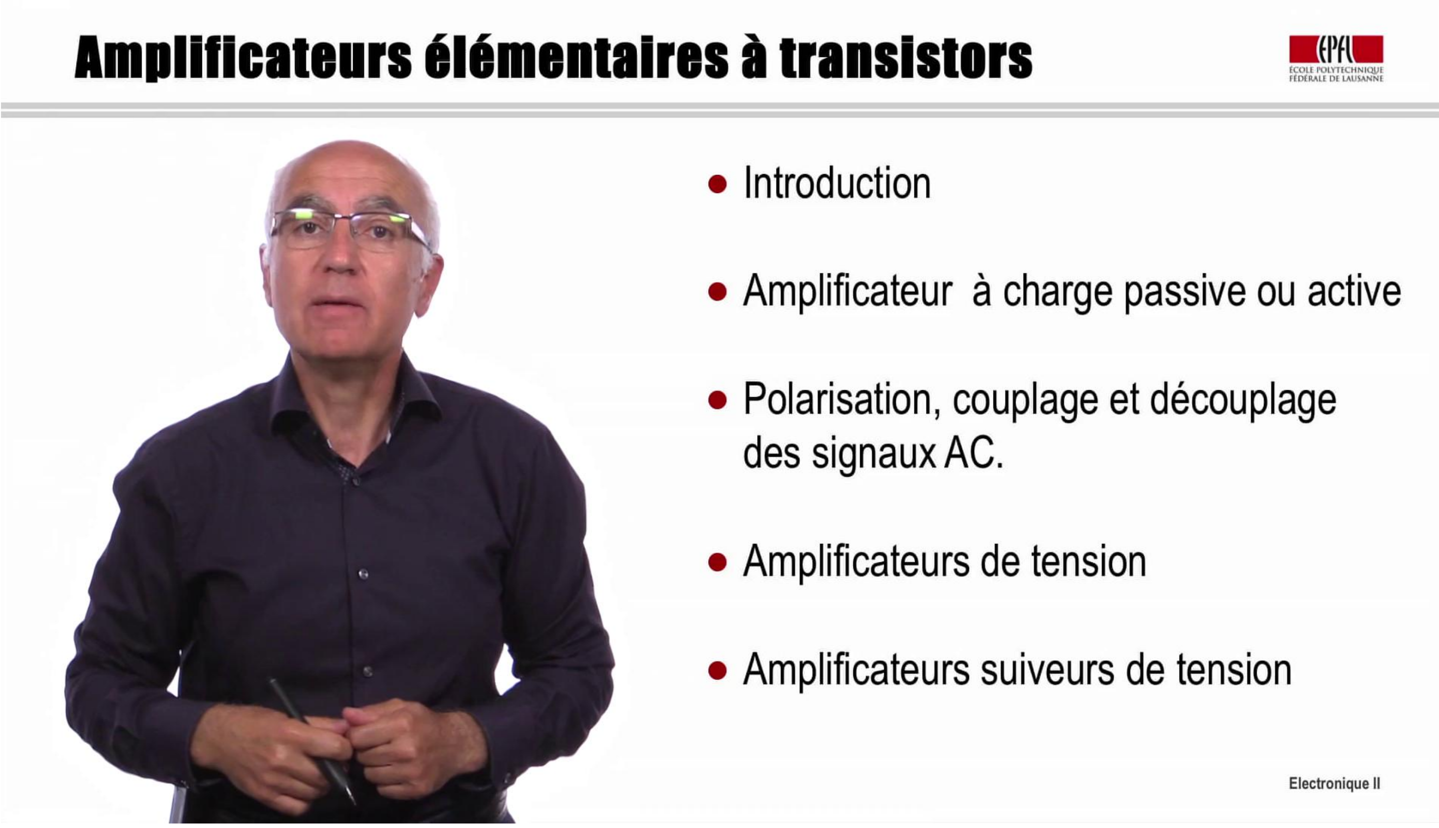


Video



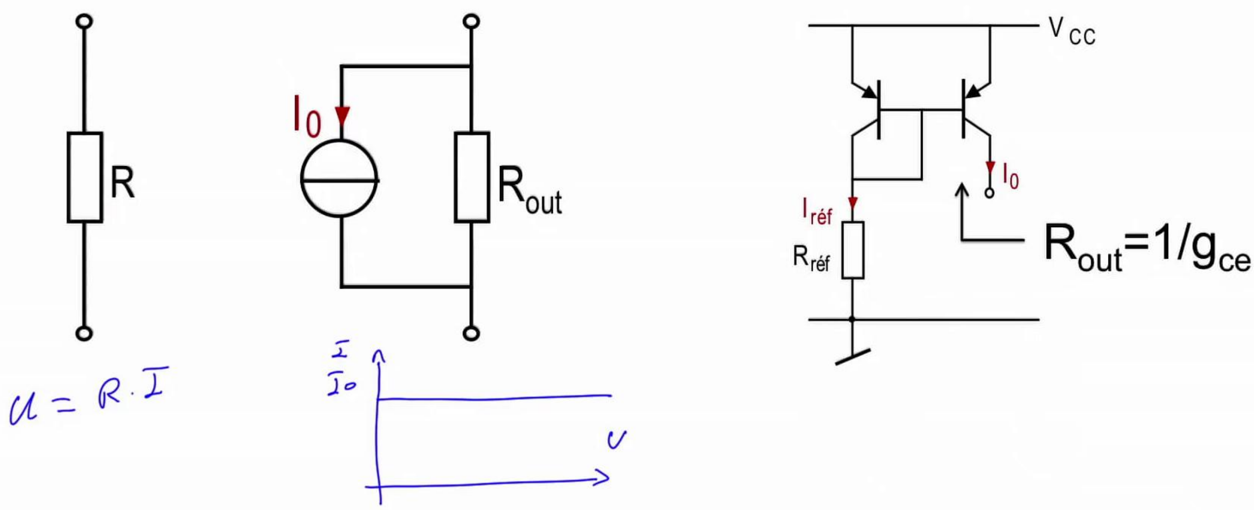
Good morning everyone. Today we will start a chapter which will open the door on the synthesis of amplifiers. So to begin that study of amplifiers, first we will pass on something called the passive and active charge. So we'll just make the difference between a passive charge that you know very well, a resistance and an active charge that will be the transistor. Once you understand that difference, we can move up in the structure of the amplifier we just quickly revisit the polarization to fix the ideas, we have a look at the diagrams, the models we have already done in previous chapters quickly like that to see the structure and the differents steps for realise an amplifier before addressing the voltage amplifiers. And there, we take the time to analyze the voltage amplifiers with passive charge and with active charge and after we pass to push the characteristics of these amplifiers to get the best bandwidth or increase the gain before analyzing the so-called voltage plus followers more later we will see the differential amplifiers. And all that I tell you now will lead us to achieve the famous operational amplifier and we will see that by putting cascaded stages we get the operational amplifier.

Notes

Summary

0m 07s

Charge passive et charge active



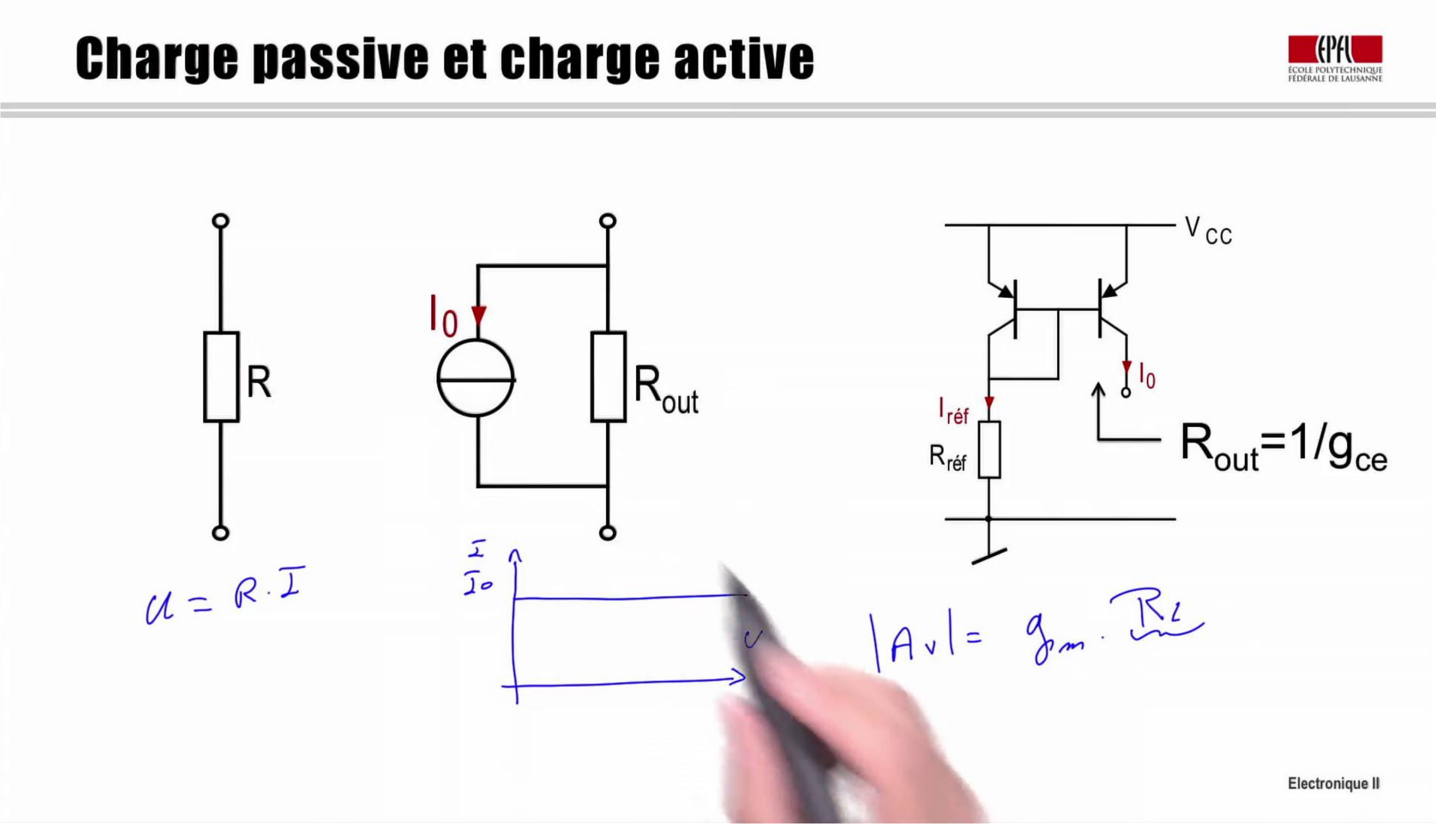
Electronique II

Just to remind you what a charge is. We know that a passive charge is something, it is something in this style this is a law U which is equal to the resistance multiplied by the current. And that is a current source. If we disregard the resistance, we do not see this resistance and we look at what a current source is we known that as a current source, it has a characteristic: I according to U which is something like that. Thus there is a fixed current I zero which is absolutely independent of U. Does that actually exist? Probably with complex tri-electronics circuits, one can achieve something of this. But generally, it has already been learned that a transistor can be taken and a current source can be made with, because the output of a transistor has a very high output impedance. This output impedance R out is the one that I symbolize here and that we will find it every time we make a current source, it's the parasitic impedance which is due to the fact that the transistor still has a sufficiently high resistance that can even increased and boosted. We will see how or we have already seen that by putting an assembly break elbow we can improve the output impedance.

Notes

Summary

1m 35s

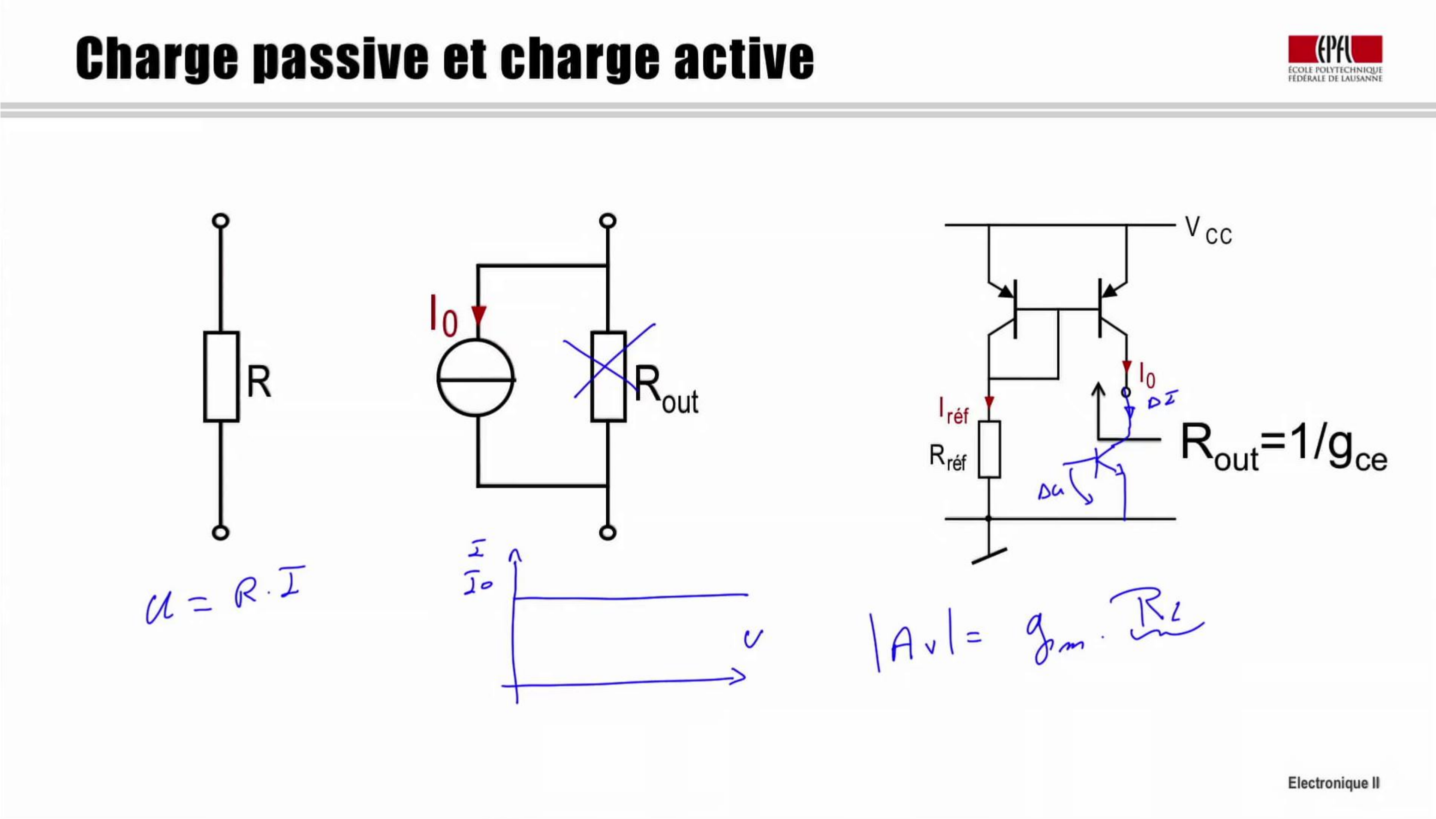


Nevertheless, this output resistance can be extremely high, which leads us to the implementation of a current source. Why do I come back to these bases of so-called passive or active elements? It's because I'm interested in apply the relationship that we had seen before: that whenever we wish to make a transistor assembly and create an AU voltage gain, we found that in absolute value this gain, it is proportional to the transistor transconductance multiplied by a load resistor. And if by chance, we can use this load resistance that we call RL as "load" to increase the gain, more this resistance is high, more high is the gain. Therefore the transconductance of a transistor depends on its polarization in contrast the resistance load that will be put to this transistor could be very high, even infinity. So if we do not possess this resistance here and we put a current source like here to a transistor that we will connect just now and you'll quickly see here and we link that to that, Well this transistor there, it will do the conversion delta U voltage into a I delta current and which will go to a very high resistance and this very high resistance will ensure that the gain increases.

Notes

Summary

2m 53s

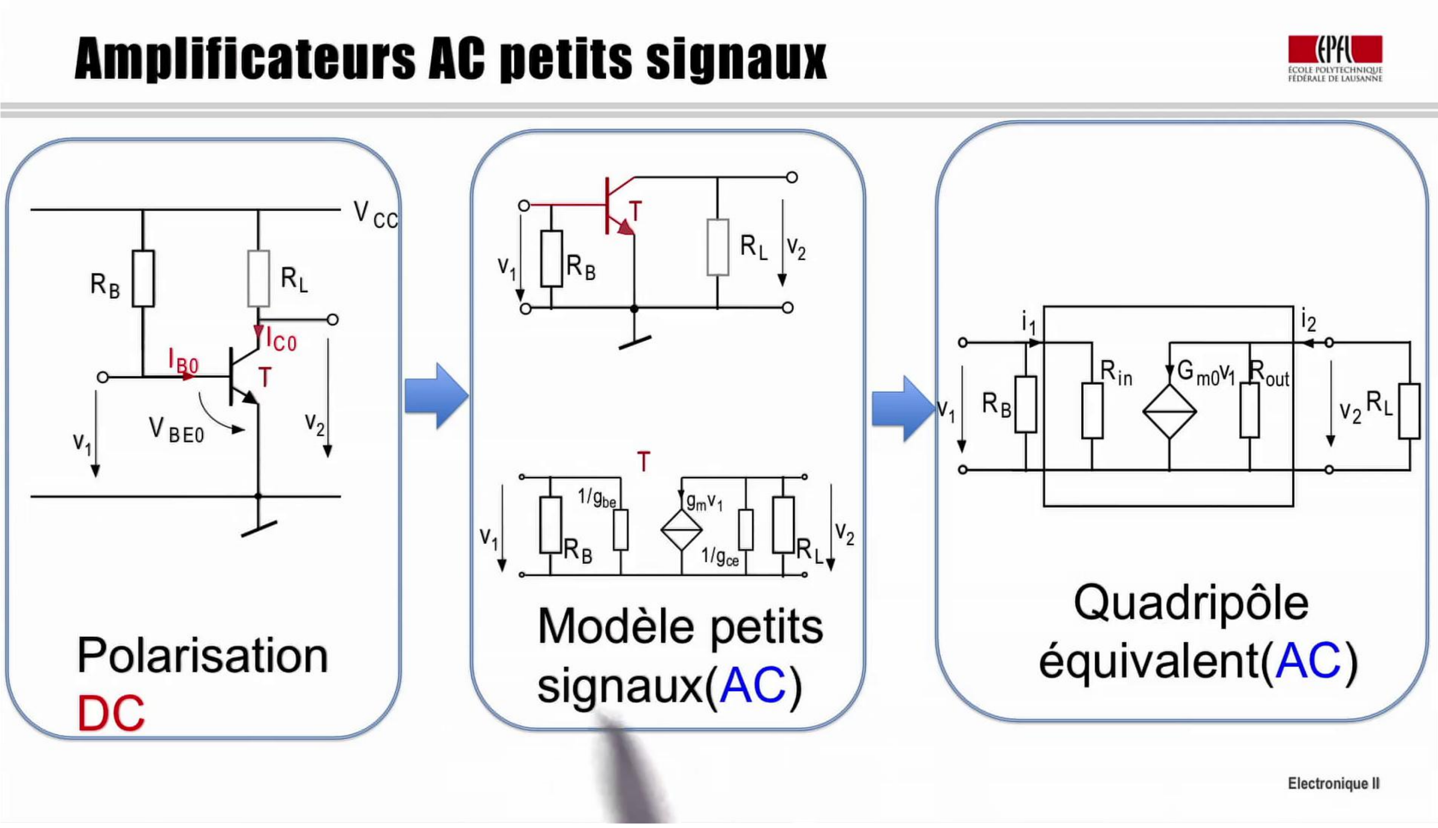


And this kind of assembly we will call it an "common emitter of active load" assembly. And that will make all the difference in relation to... to rather connect a resistor to the collector. And you will see that this kind of installation, it's typically what we will use in integrated circuits later and allowing to get infinite gains as an operational amplifier.

Notes

Summary

4m 23s

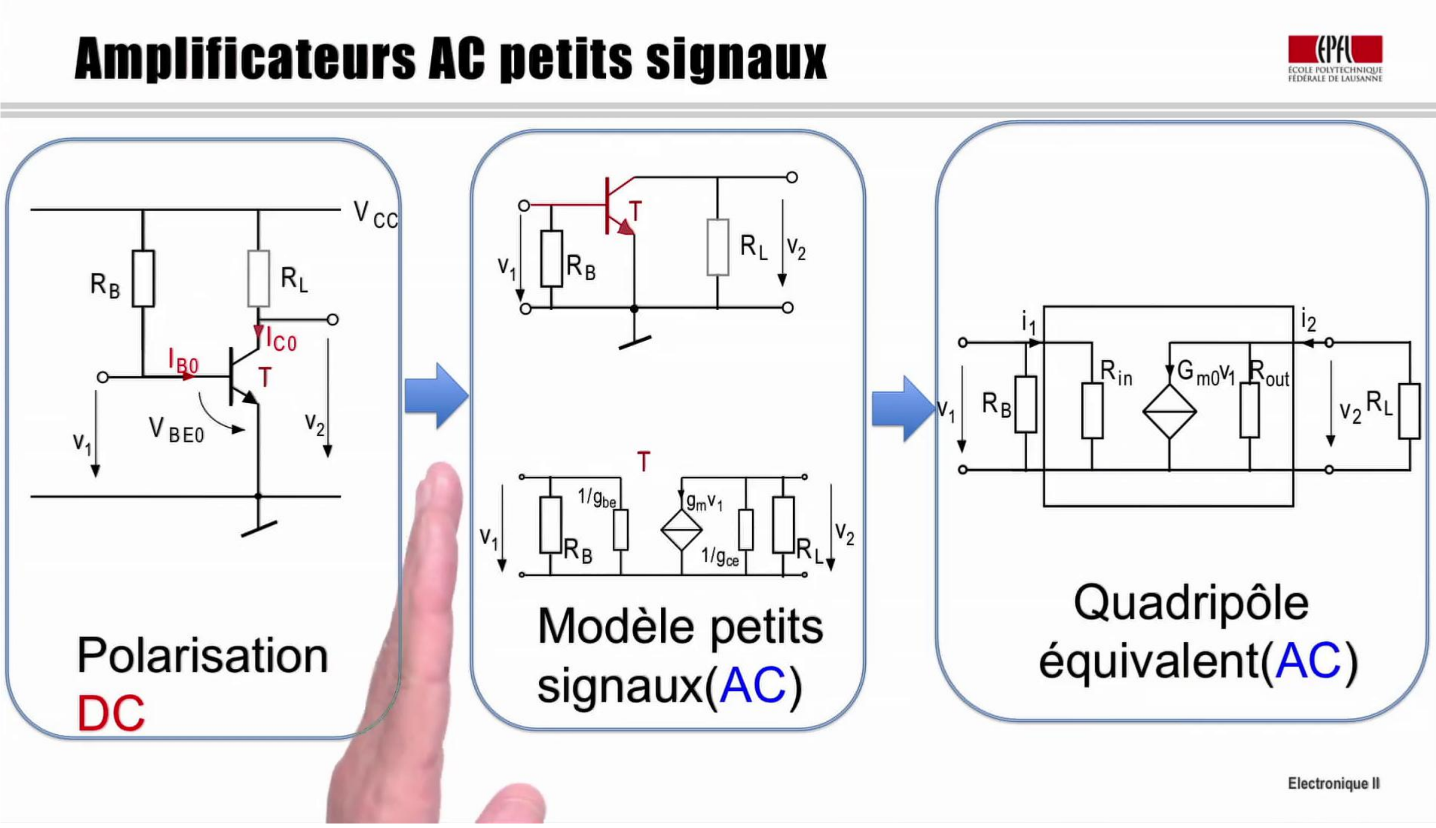


I repeat what I have called an amplifier and I will remember the sequences of achievement and I've added an AC amplifier. So this is an amplifier which can only amplify the signals of variable nature of the small signals increments. Why? Because if you connect your amplifier and you look at the 3 presentations representations of your amp, the actual pattern of the amp, I chose one of the amp possible polarizations and I choose the one by which I polarize the current in the base by a resistance which brings back the current from here and injecte it into the base. And this current multiplied by the transistor beta becomes a current of polarization IC0. It's a way to do, that is didactic very easy which just requires a resistor to be performed and it polarizes the transistor. Beside, I showed what I call the small signals model that we studied. So if you remember when you plug the transistor in that way and it is polarized, we can ignore this scheme and go to a scheme that we draw on a piece of paper to only see the transistor when we apply to him an increase or variation or small variable signals.

Notes

Summary

4m 48s

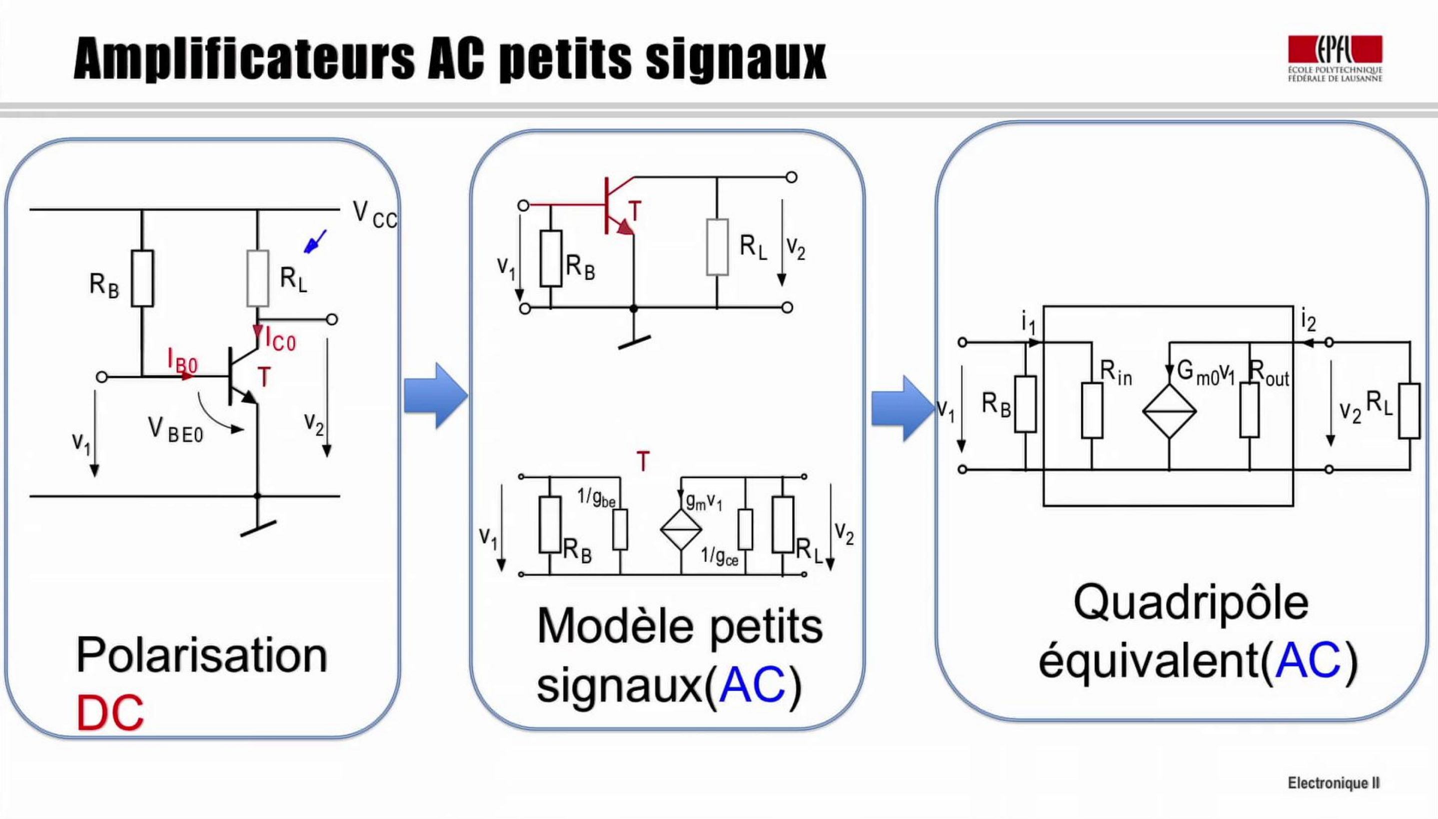


So we will connect it signals that vary in time and as we are only interested in the amplification of these variations, and well continued tensions, we make them disappear because we will be interested in all that is variable so whose derivative delta V on delta I and the delta V on delta I of a voltage source is a ground. So we convert it into a model that gets all fixed voltage sources and brings them back to the ground. And we replace the transistor by those derived therefore the different impedances of sight between base-emitter collector-emitter and the fact that there is a controlled current source and we replace the transistor by this. So we've already seen all this and made an analysis that from that, we can represent thanks to the circuit theory that any block having a voltage at the input which will be converted into a voltage at the output. It can be presented or represented by the input impedance an output impedance, a controlled current source and it's called the equivalent quadrupole. So from here to there and the reality from here to there, this is the model and the simplification for us to be able to solve and analyze transistor scheme.

Notes

Summary

6m 09s

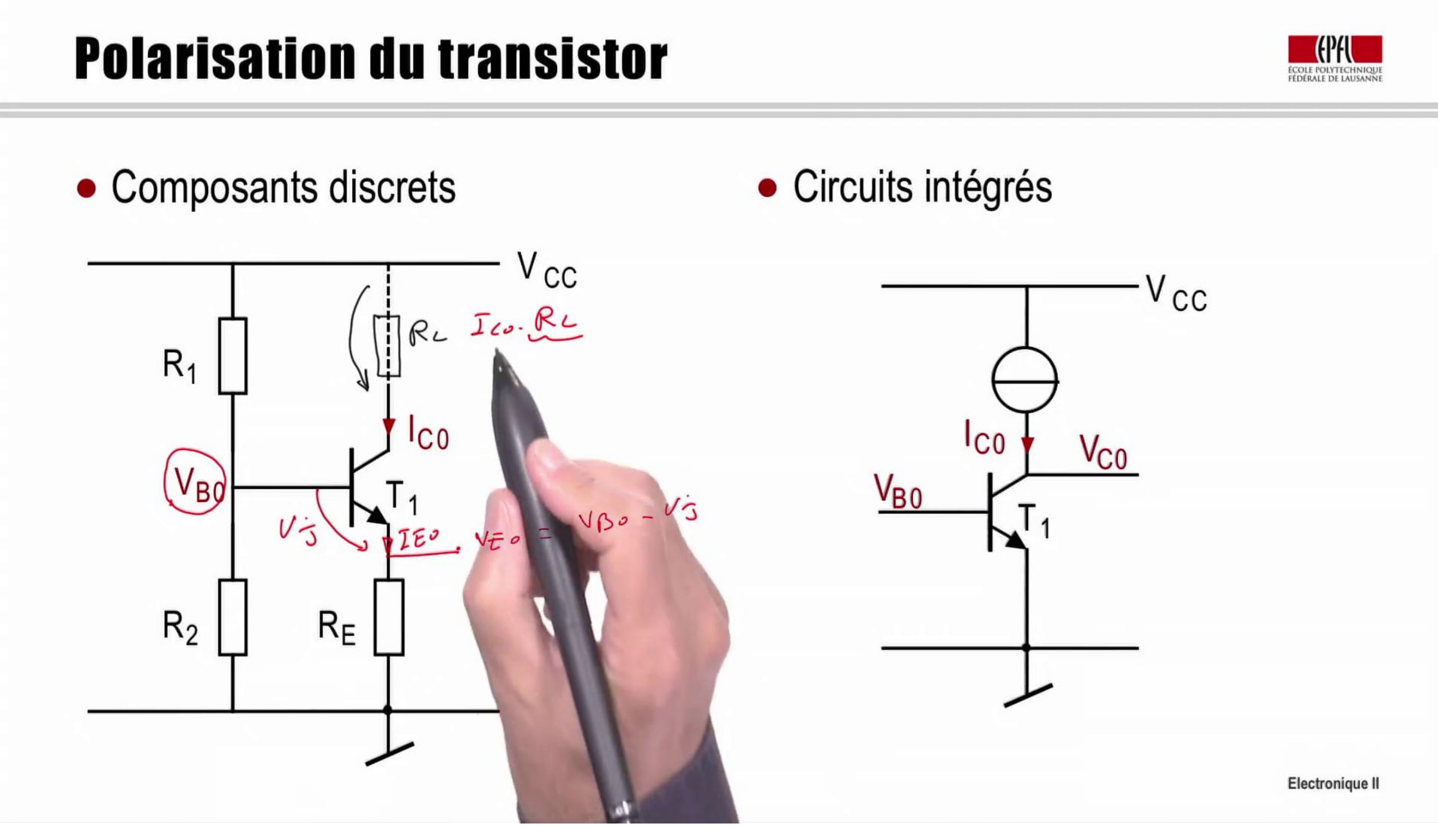


Here is a simple vision of what we'll see, but I want to draw your attention that when you put your finger here or this pen there, we will realize that here I have a voltage difference from here to there of DC nature And I will continue this explanation taking the polarization of transistor, the one we were told that this is the most appropriate polarization when you have a passive load. So the load is this one. So we connected a load in the transistor collector which is RL.

Notes

Summary

7m 24s

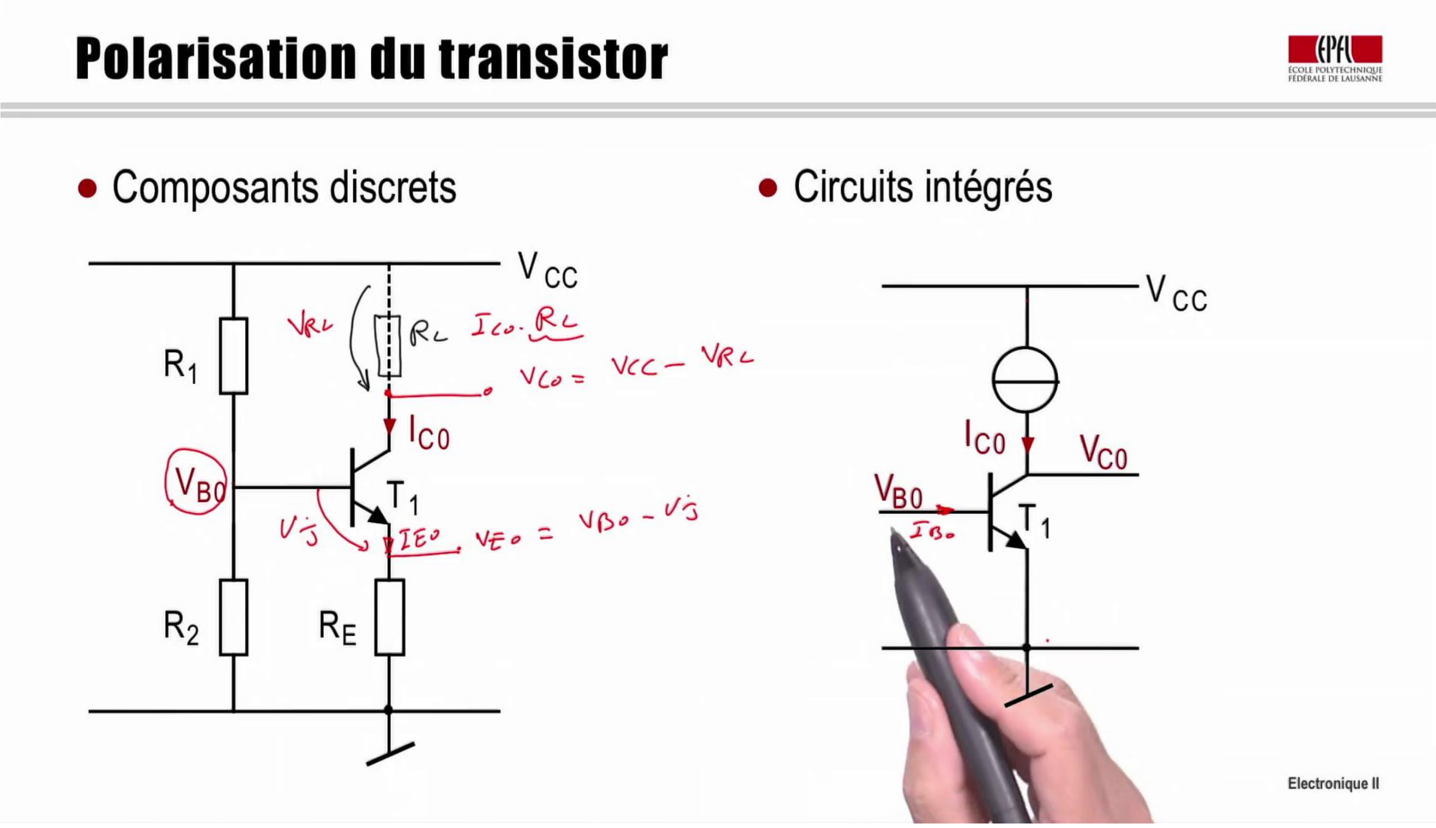


I repeat the polarization of transistor, the one we presented as really being the polarization to use, which imposes a fixed potential on the base. And to generate a constant current IC0, we impose a transistor and a current IE0 in its transmitter. Well, these two currents are approximately the same seeing the beta of the transistor that exists between the two. So in other words, we impose the current IC0 via IE0 so it's a current that we have imposed, but to get it it was necessary to impose a fixed voltage on the base. I will repeat this phrase: on the base, I have a VB0 voltage, it is a BC voltage. On the transmitter, here I have a voltage VE0 and this tension there, she's VB0 minus the voltage UJ drop. So I have again a tension which appears here, which is of DC nature. What happens here with the tension at the collector? Do I know it ? No. It will depend on the load. There, I have not drawn a load But imagine that someone accidentally adds a load here, a resistance. If you put a resistance there, this resistance, it will have a voltage drop here and that voltage drop, it will be equal to IC0 times RL. So RL, your passive load exists. The current of polarization you need it, you just create it.

Notes

Summary

8m 03s

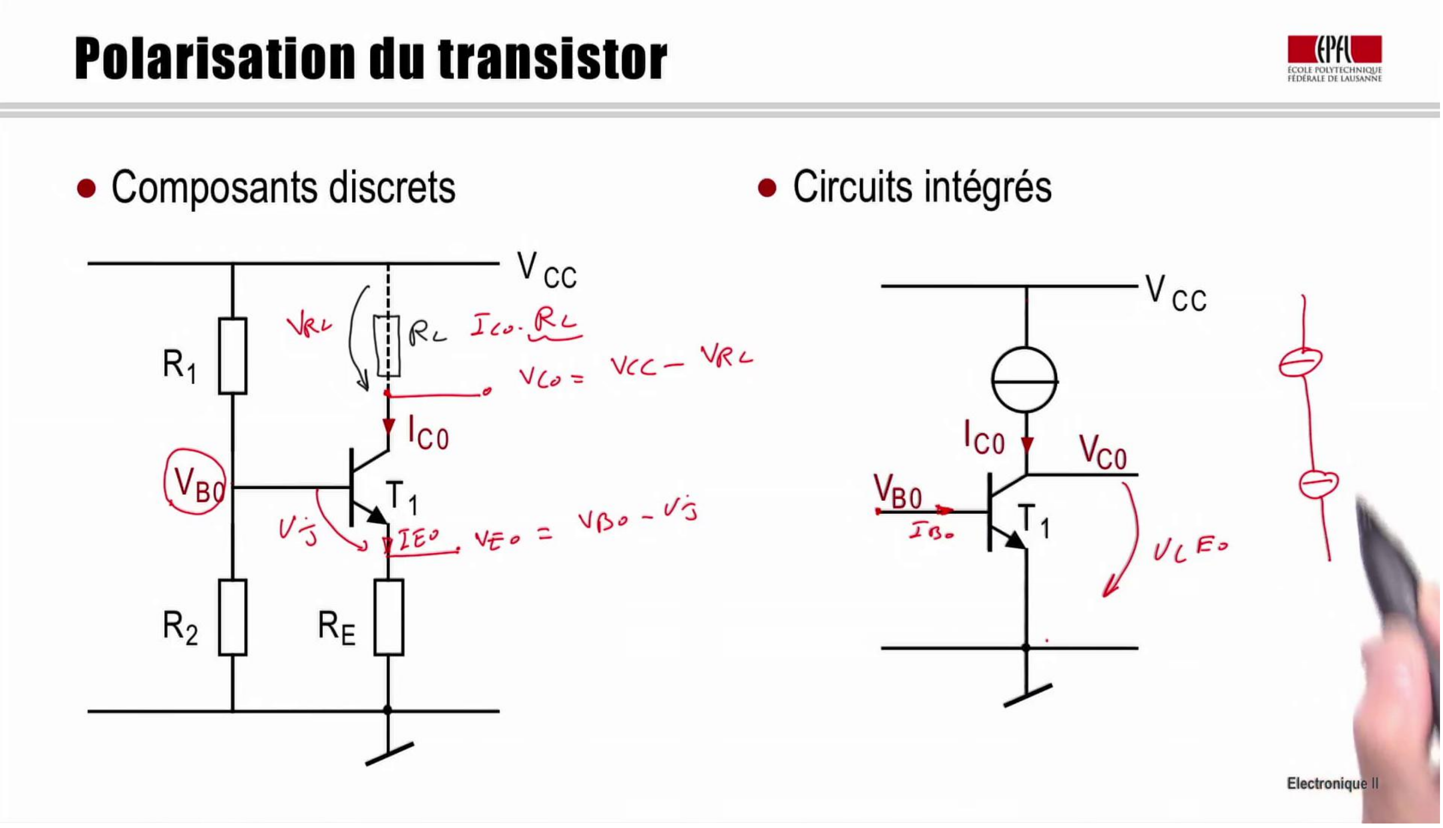


The voltage drop here, it will make you a tension VC0 which is equal to VCC minus the voltage we will call here VRL, minus VRL and that's it ! This VC0 voltage, it is defined, it is known, it hadn't been brought to a signal to be amplified, but we already see that we have a DC voltage here. So I have a DC voltage there, I have a DC voltage there and I have a DC voltage there, and you just created it yourself depending on the required polarization when you have a passive load and we can know values such as I just write here. I would like to compare it to this assembly. I take my transistor, and I put it here, instead of putting a resistance in the transmitter which was essential for creating IE0 in this case IC0, I directly connect to the ground and I come and put it a current source, so this ideal current source that I just plug here will impose a IC0 current that will pass in my transistor. This current there, it will immediately generate a IB0 current that will come from? Well, it's coming from the assembly which is here. this assembly that I have not drawn. What is the value of VB0, do I know it? Yes ! VB0, it is actually proportional to this VBE voltage which is of the order of magnitude of UJ.

Notes

Summary

9m 43s

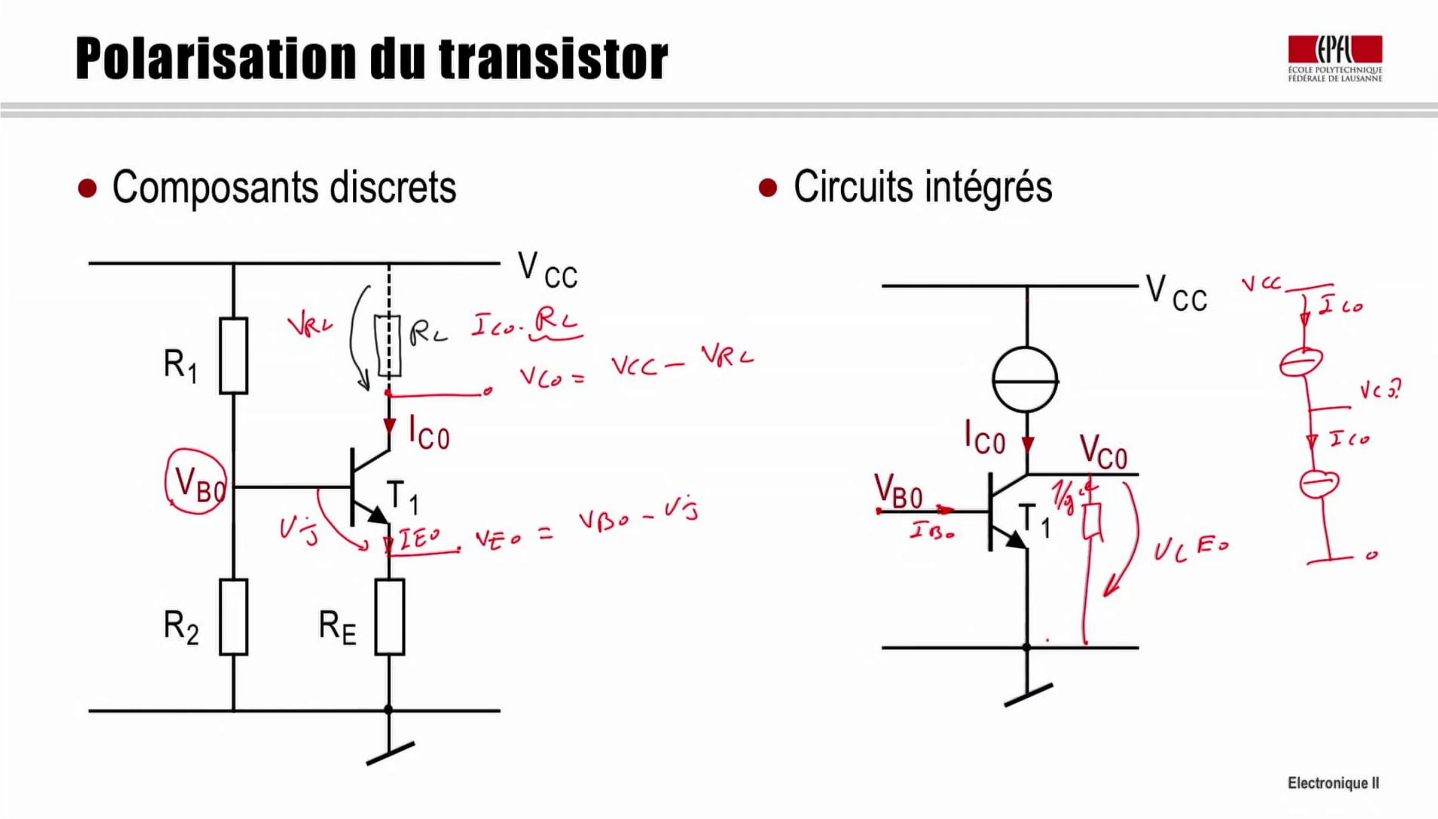


While this tension there, it will be fixed. So this almost constant tension depends on the stage just before we plug. So if you plug something here, this thing that would come before the stage that would come before, should accept the fact that a voltage VB0 is imposed on it. What happens with this VC0 tension? Do I know it? Absolutely not ! See why I can not know it as it is presented here. Do I know UC0 ? To know a voltage, IC0 must be multiplied by a resistance that I see here, between this and that, imposing a voltage UC0 to say VCC minus UC0 is equal to the voltage drop here. But what happens is that this transistor there behaves as a current source. Suppose it has no output conductance, that the effect "Early" the Early voltage of this transistor is equal to infinity. So it's like I tell you, the output resistance is infinite here. And suppose that you have a current source as drawn here and below, you will also have a power source. And this current source absorbs, everything is perfect inside: the IC0 current flows through your transistor, it is able to absorb the same IC0 current and someone asks you, when you'll assemble this between VCC and 0, what is the voltage that appears here?

Notes

Summary

11m 16s

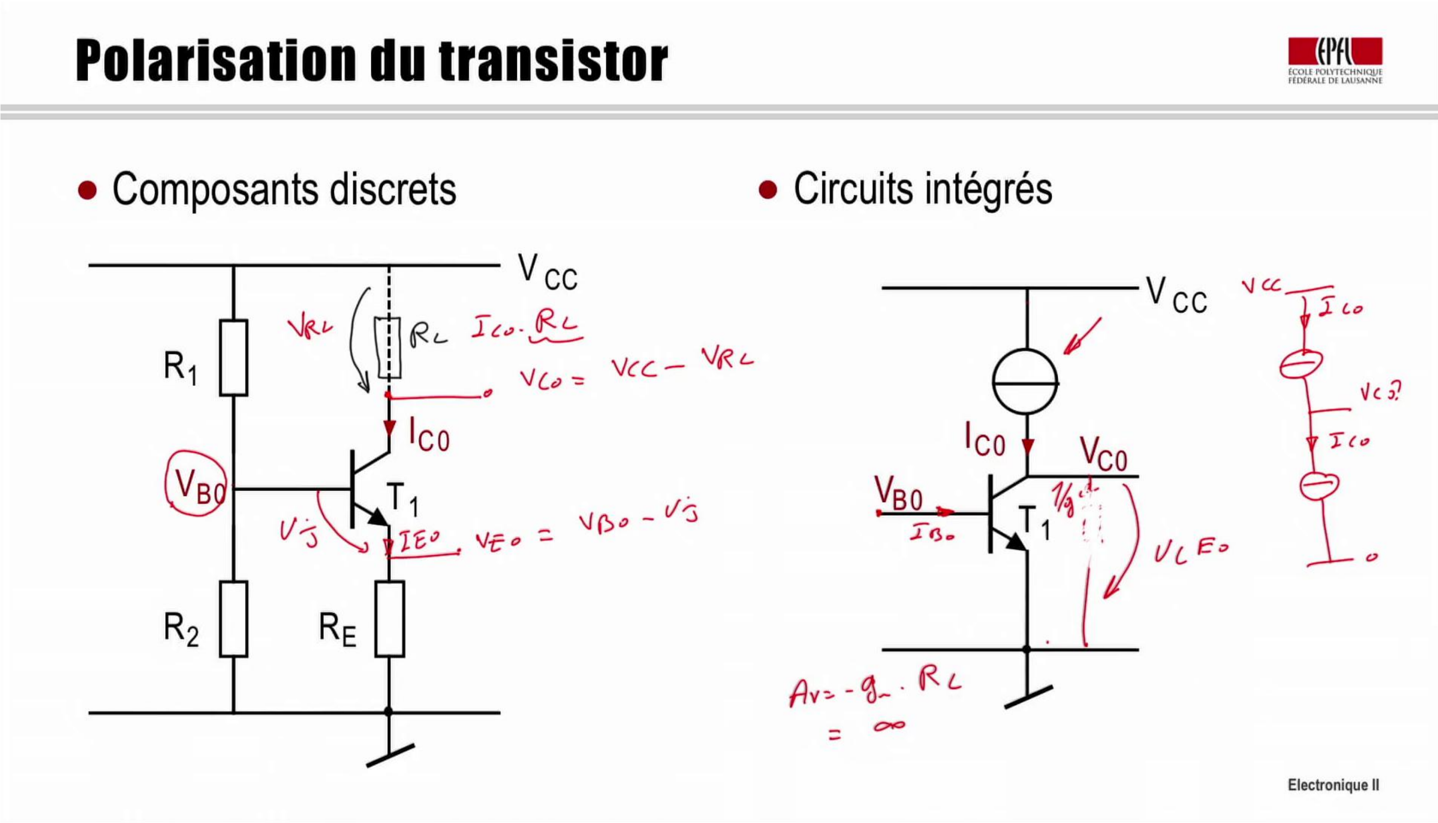


You could not say. Because this tension, it could not be defined it can be anywhere in that range. It may actually go up and down anywhere within this range. Actually this kind of assembly exists, it is used in integrated circuits and usually when you make an output this way we add a circuit to fix what is called the common mode output. So the tension VC0 contrary to what you see there, that we directly see in this assembly there, it could not be known, it will depend on what you will connect yourself on that side. If it's a similar assembly as we said here, if you come here to connect a transistor like this, this tension from here to there if it is a PNP transistor, it will be of a voltage junction nature. But for the moment, nobody could tell you what is the VC0 tension. One can of course ignore or make a guess that there here I have a resistance which is the output transistor of that resistance which is 1 / GCE and this resistance there allows me to find the test potential that is at output. But what I want to said there comparing these two approaches, that's an assembly which takes into account the discrete components in which I had to use: a resistance to impose IC0 current, two resistors to impose the potential VB0 and there, I had to use a component which is a current source, we will see just now how we will do it to impose the IC0 current.

Notes

Summary

12m 44s



In this case, when I write the gain, it is really the gain of a common transmitter assembly, So this is the gain which will be equal minus GM times a load resistor. I consider that this resistance there, it is infinite so it does not exist, I erase this. There, there is no resistance here and there it is an infinite resistance, we have just seen it. So what is the gain of this circuit? Well the gain of this assembly, it can only be infinite, because RL is infinite. We have just seen that a power source it's great, I just realized an assembly whose the gain is infinite. I remind you that in an operational amplifier when you take an ampiOP, it displays theoretically an infinite gain if not very very large. So it's probably inside, we used an assembly in the integrated circuit which mold the operational amplifier, we used an assembly of that nature here. And it is absolutely the case because we use active charges because thanks to that, we have the very high resistance if not infinite, and we can cascade 2 stages which lead us to extremely high gains.

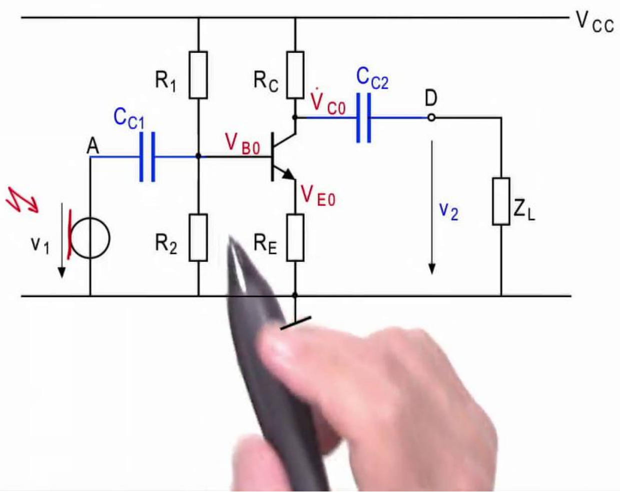
Notes

Summary

14m 20s

Couplage et découplage AC

- Couplage



Electronique II

I go back to the analysis of this circuit we just saw before. That is to say the assembly, I hide these 2 parts, I show it like this, It is the famous montage where it was necessary to polarize I points back potentials VB0 - VE0 - VC0 that we called resting points or operating points. An operating point, is that, at rest, when you plug it and you take a voltmeter according to ground and measure that point, it displays the VB0 voltage, we measure this, it displays VE0 and here we see VC0. But when you take an alternative signal so this which is in red represents the DC components. Suppose that here you have a sensor which varies over time, we can take an example of an audio signal coming from a microphone. So suppose that is a microphone and then you bring a signal and you want to amplify, you want to amplify the signal that arrives here this signal is of AC nature in this node A which is an AC signal therefore which varies in time. That is a source of tension. How could we connect this tension there on a DC point? If the capacity that you see here does not exist, so if you're in that situation, so I'll delete this capability and I will replace it with a short-circuit If I do not have that capacity and look what will happen to you.

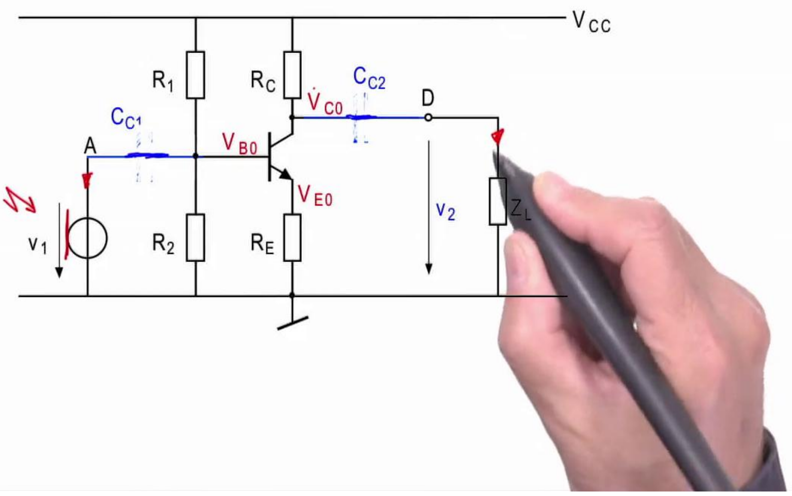
Notes

Summary

15m 43s

Couplage et découplage AC

- Couplage



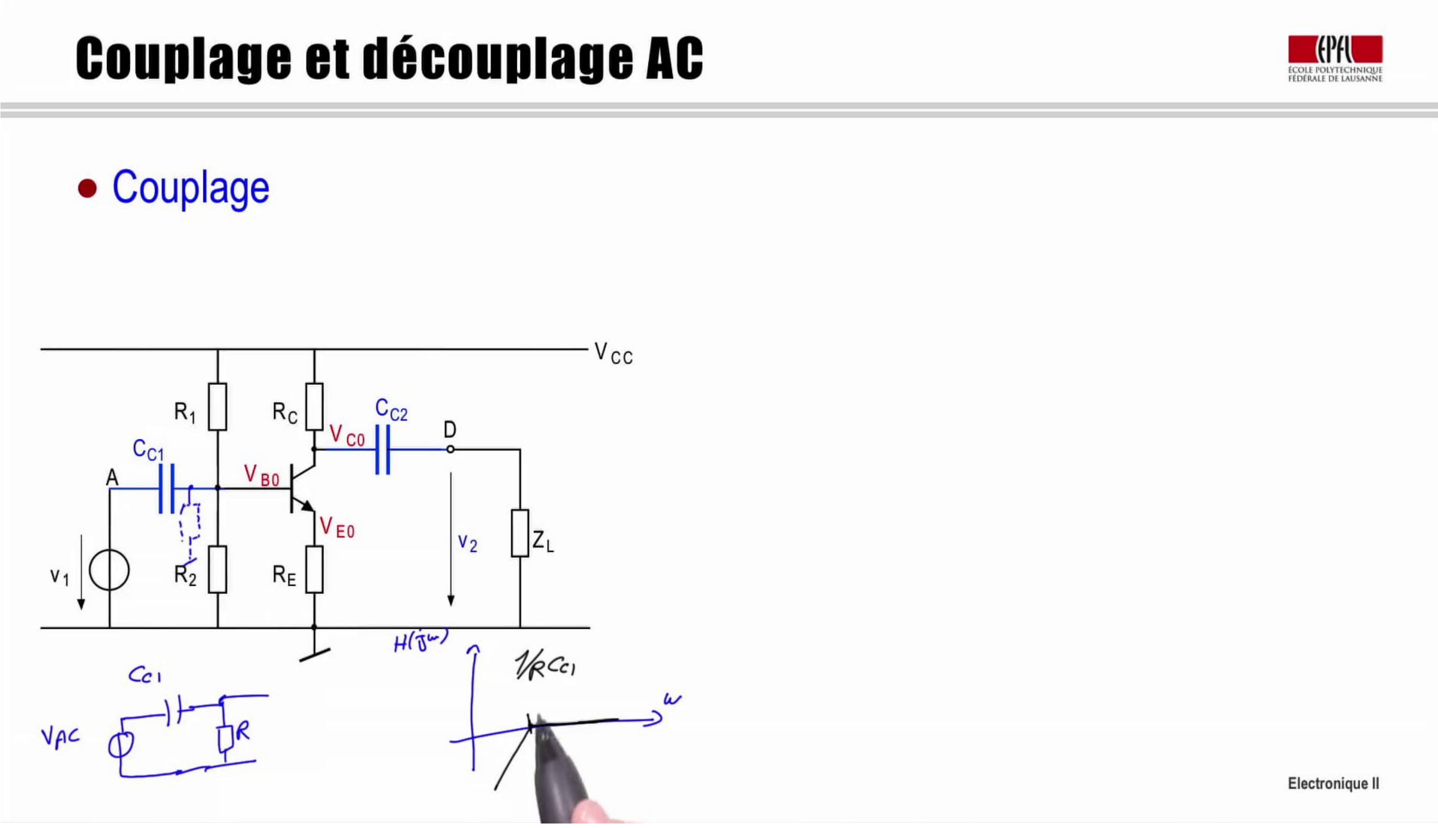
Electronique II

You take this, you plug this line directly like that, you find that the VB0 appears across your source. If it were a microphone, your microphone it will never work because it will have a DC potential which is imposed so it will have a current that will go through it that goes in that direction there, it comes a current that goes into your microphone that comes from that connection here. So that, that's wrong! Same, if you come this way and you connect, we will say a loudspeaker to facilitate the task and you put a signal transducer which will convert the audio signal and that the capacity which is there doesn't exist and well you find yourself with this capacity which is again replaced by a short circuit. So as if your speaker, it is connected to a DC potential. So I take my signal here and I connect it to that, So this: the VC0, it will tackle a DC voltage on your speaker. So a scheme of this style, there to which you connected a resistance which comes to putting on a DC potential will be covered by a DC current of course. So in a speaker, it'll make a hell of a noise when you plug it because it will pull the membrane and it will make passing a constant current and there on that side, your microphone it will also be browsed by a constant current and this assembly it could not be used.

Notes

Summary

17m 18s

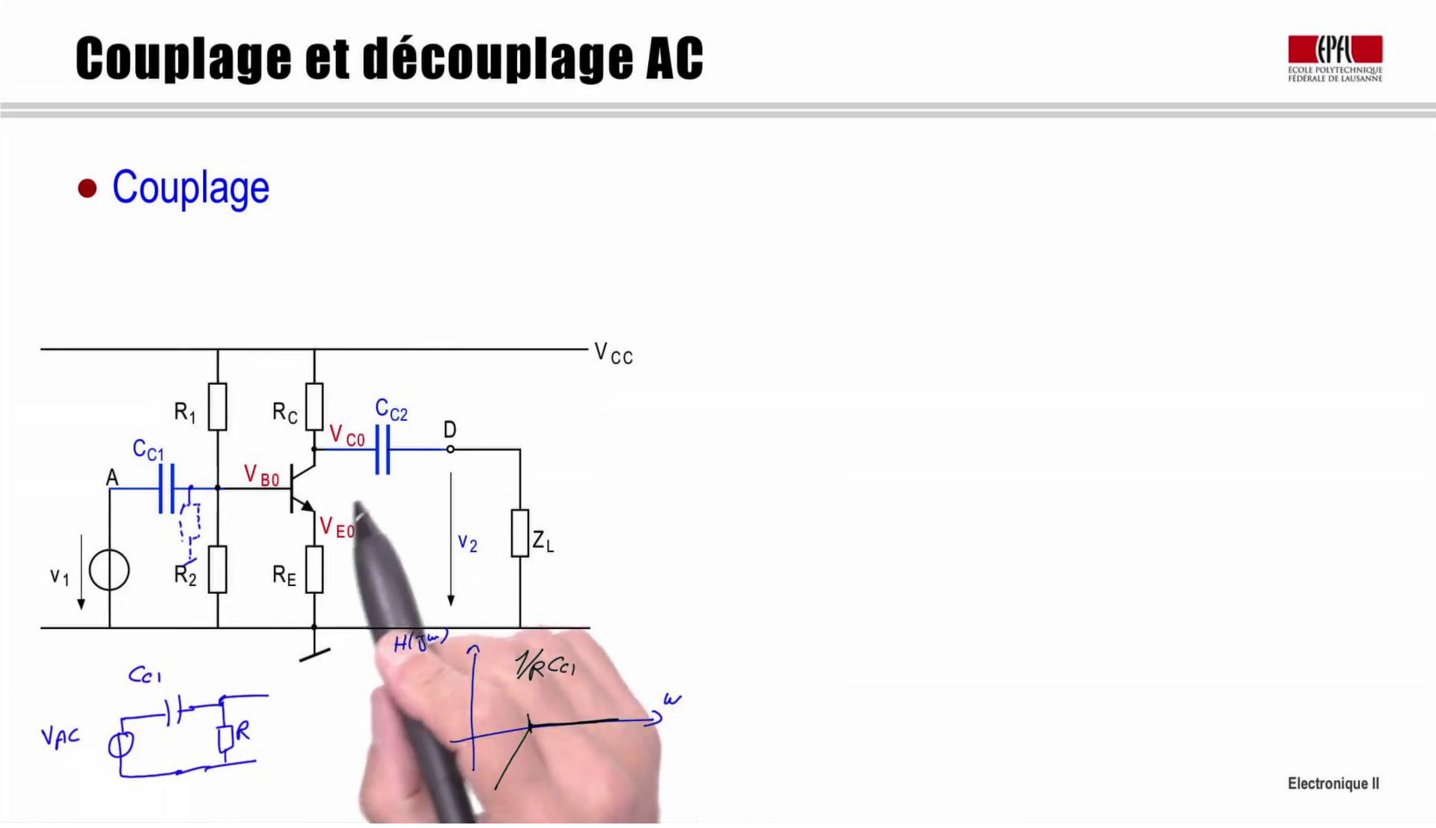


So what we can do,I return to the previous diagram, I put my capacities back and I observe what happens. If I look at this capacity and I imagine that there, I have an impedance, we will consider that it is purely resistive. I will draw what I see there, I hide all this part there and I say all this, it is equivalent to a resistance, this is something that appears as a resistance. And if I look at this circuit which is there, so this whole part there comes down to that resistance there. And I draw below what I see. I see a capacity CC1 and an impedance which appears here. I apply here a variable AC source and I go into this kind of circuit. Well it's this kind of circuit, this is typically a circuit of high-pass nature. I see that the C and R, I represent them in a Bode diagram So H of J omega module according to omega, it would give me something of this style with a point here that is equal To 1 / R x CC1. Therefore knowing the resistance R, I can calculate the capacity CC1 and deciding that from a point, I strongly attenuates the low frequencies and I have a bandwidth in which I transit my AC signal.

Notes

Summary

18m 48s



So when I take an AC signal, I correctly calculate my capacity, which couples the increases through this assembly, the DC voltage can not pass in this direction there, there is no DC current which crosses my capacity it is well known. So my capacity, it will act on the alternative current that will cross it in this direction and it will come in my assembly and it will overlap with the component VB0 which is here. So I find myself with a high-pass circuit where low frequencies have been eliminated so the DC components as well. And I can do the same on that side. From that side, I put a coupling capacity, This capacity it will take the alternative signal here which is superimposed on VC0. When I vary the tension there, I will vary the tension there. And the capacity, it will behave as a closed circuit for variations and it will decouple the DC voltage, so the DC voltage does not appear on that side except of course the index response when I have a voltage jump and I put in tension all of this. So the capacity is loading to this potential VC0, on the other hand, the signal AC passes through and again, here if you analyze what you observe here, it is again a circuit of CZL nature and there you have a high-pass filter if this is a resistor.

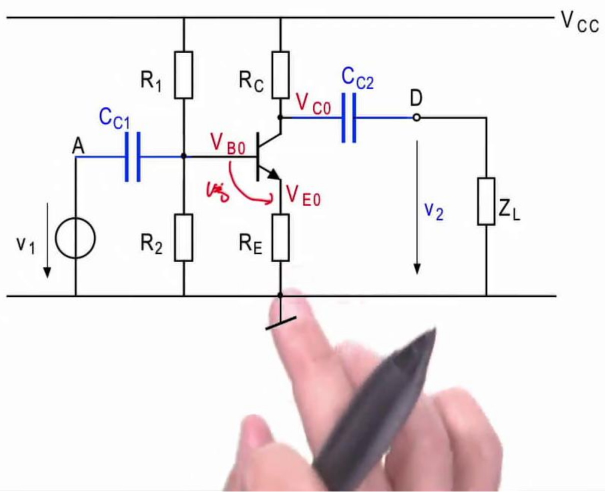
Notes

Summary

20m 30s

Couplage et découplage AC

- Couplage



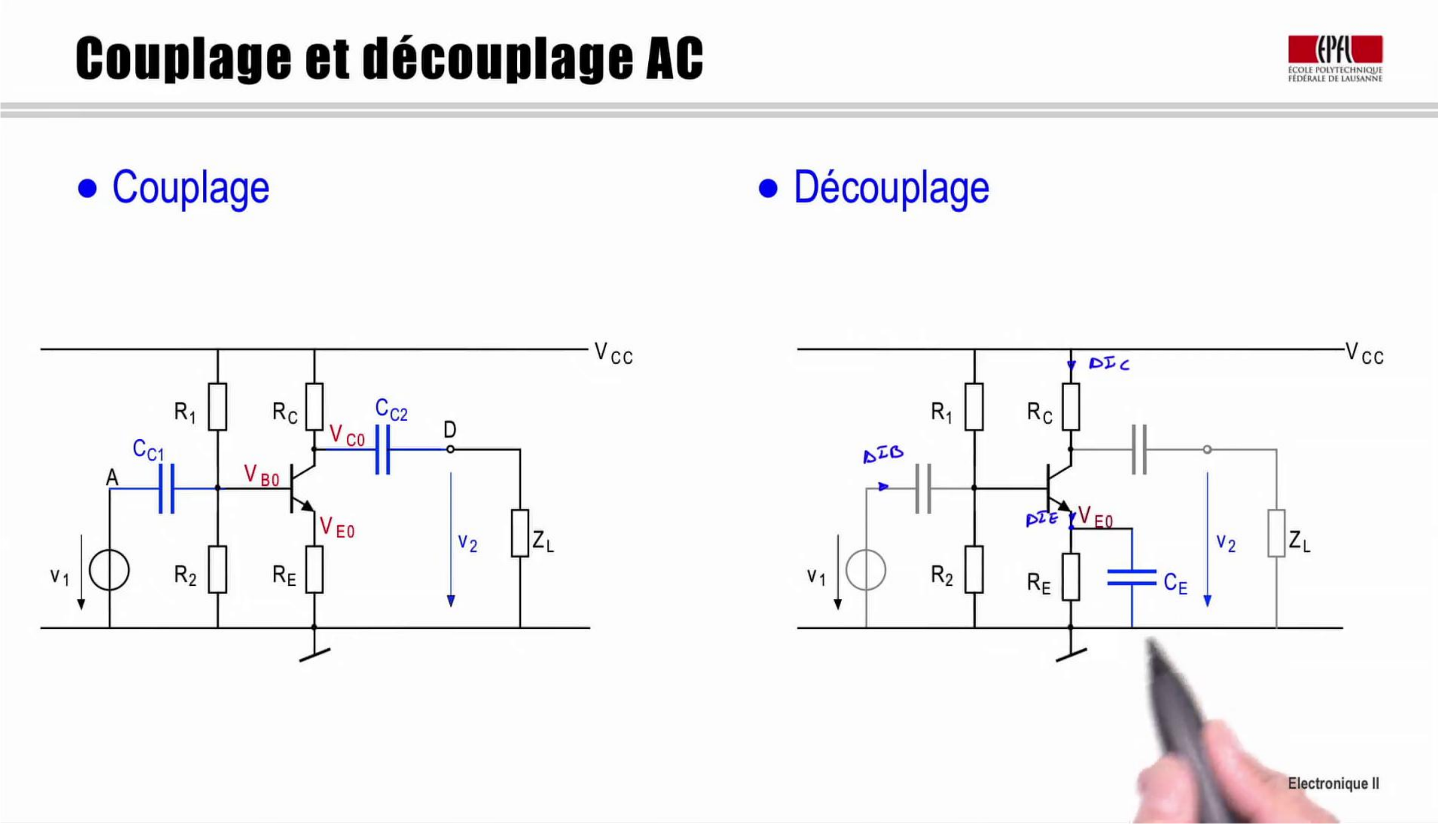
Electronique II

So we realise a filter on that side, a filter on that side and these 2 filters are of this nature to pass the high frequency components. I return to the assembly. So I think we located the capacity used to prevent the AC signal to be shorted or rather the DC signal to come on our source and load and we decoupled the variation by capacities, it was called capacity-decoupling or capacities-decoupling. When we studied the common transmitter assembly, the transistor transmitter was connected to ground and there, we had to add it the resistance RE, so the transmitter is not connected to ground. If you have a variation here and you have a variation, you have an almost constant drop voltage which is UJ there, so you will end up with your variation which moves and turns on EV. The variations there and the variations there are the same if tensions between the two, the voltage is constant. So you will end up with that tension there copied here. So on this resistance there you have a varying voltage. Same on VC0, you'll have a tension that varies. When the transmitter has been grounded, there wasn't this resistance RE and it was considered that the gain of this assembly, The gain of this assembly was calculated and we had seen that this gain equaled less GM times the load resistance.

Notes

Summary

22m 02s

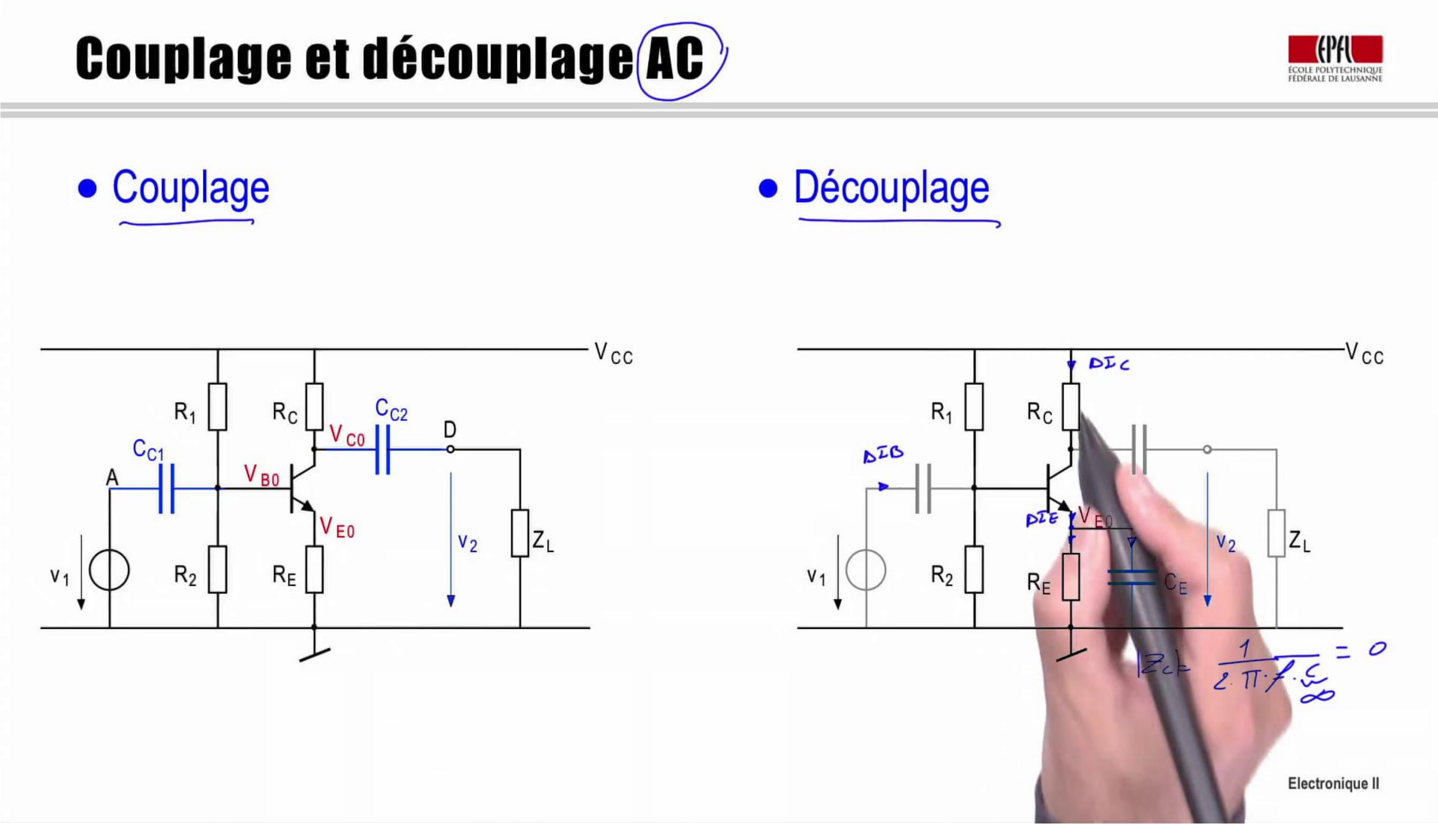


Is this is the case? when I add a resistor in the transmitter This is valid when the transmitter was to the grounded. Now I'll add him a resistance and well that is not the case. You will do this in an exercise and you will see that the gain of this assembly When we put a resistance, this gain is not this, the gain will be of the order of less RC divided by RE. So we do not have the high gain we will have a gain which is relatively low compared to this. so how do we do? How to bring the transmitter to the ground? Well what we're going to do, We will do the following: we will add in the same way a capacity which would short-circuited the resistance RE for the alternating current to pass By capacity not by resistance and again from the AC point of view this resistance is short-circuited. And here it is! this is the assembly when using a decoupling of the transmitter. so if you have an AC current that happens here, I will get a current here, a IB delta which will generate a IC current delta. This current is approximately the same IE delta, this current arrives in this node there, it has a capacity in parallel and it has a resistor in parallel. The impedance of the ZC capacity is proportional to 1/2 x Pi x F x C.

Notes

Summary

23m 38s



So if you consider that it is infinite or a very very high capacity this ZC it will be equal to 0. and the impedance of the capacity ends to 0 or when the frequency is high, the ability is high. So what IE delta, he sees himself in a node where it can go here and there and of course it will go through the lowest impedance in this case the impedance of the capacity, so the capacity which is there will short-circuit your RE resistance. And from the AC point of view, from the point of view Alternating current, it will rather by your ability. which brings you back to say That the transmitter goes to ground by a short circuit performed by a decoupling capacitor. And here are two names: coupling and decoupling that will allow us to create assembly in which one will superimpose of the DC components and AC components and in which we removed the effect of the RE resistor which is essential to the DC. And when there is a variation, It is shorted-circuited despite the current continues, continues to cross it because the direct current, the one we had seen, that we would see red here. If I put a DC here IC0 which is pretty much the same here it will go through the step resistance capacity because it is continuous in nature and capacity is an open circuit because F equal to 0 for a direct current.

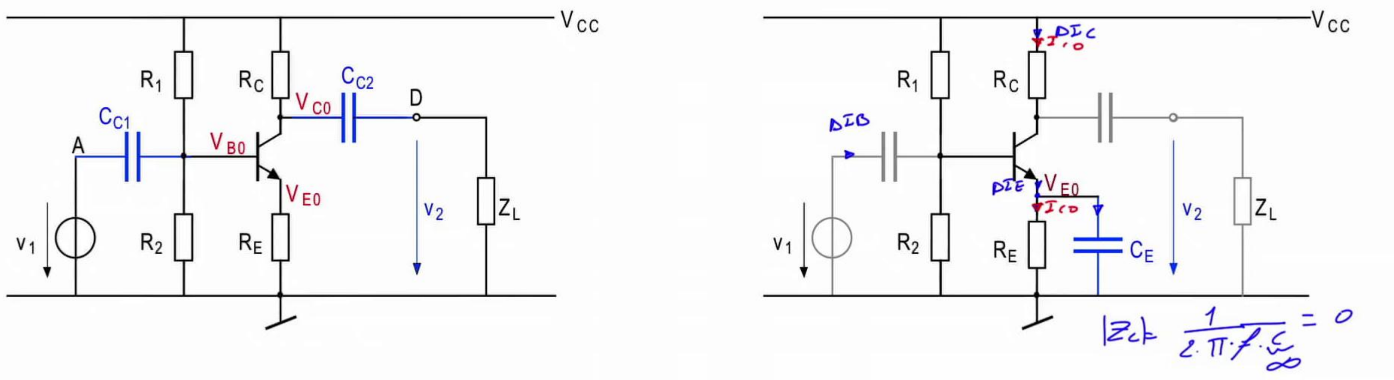
Notes

Summary

25m 20s

Couplage et découplage AC

- Couplage
- Découplage



Electronique II

So the DC goes through there, Alternative here and there it is, we arrive on a diagram complete assembly which amplifies The AC signals while superimposing them to DC components and improving the assembly by placing a decoupling capacitor to eliminate the effect of polarization.

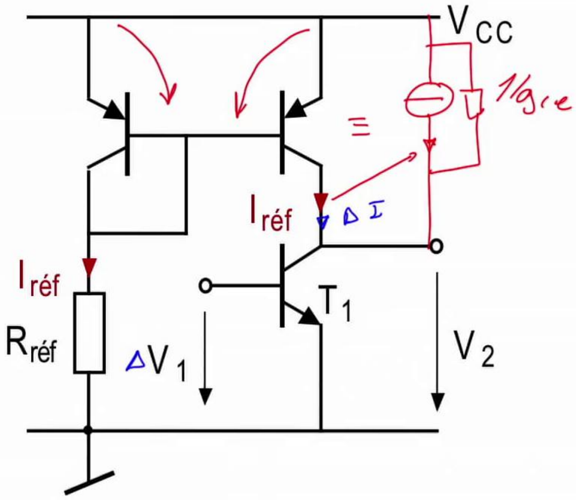
Notes

Summary

26m 57s

Couplage direct en circuits intégrés

- Assurer que la source ou l'étage précédent fournissent le courant de base du transistor



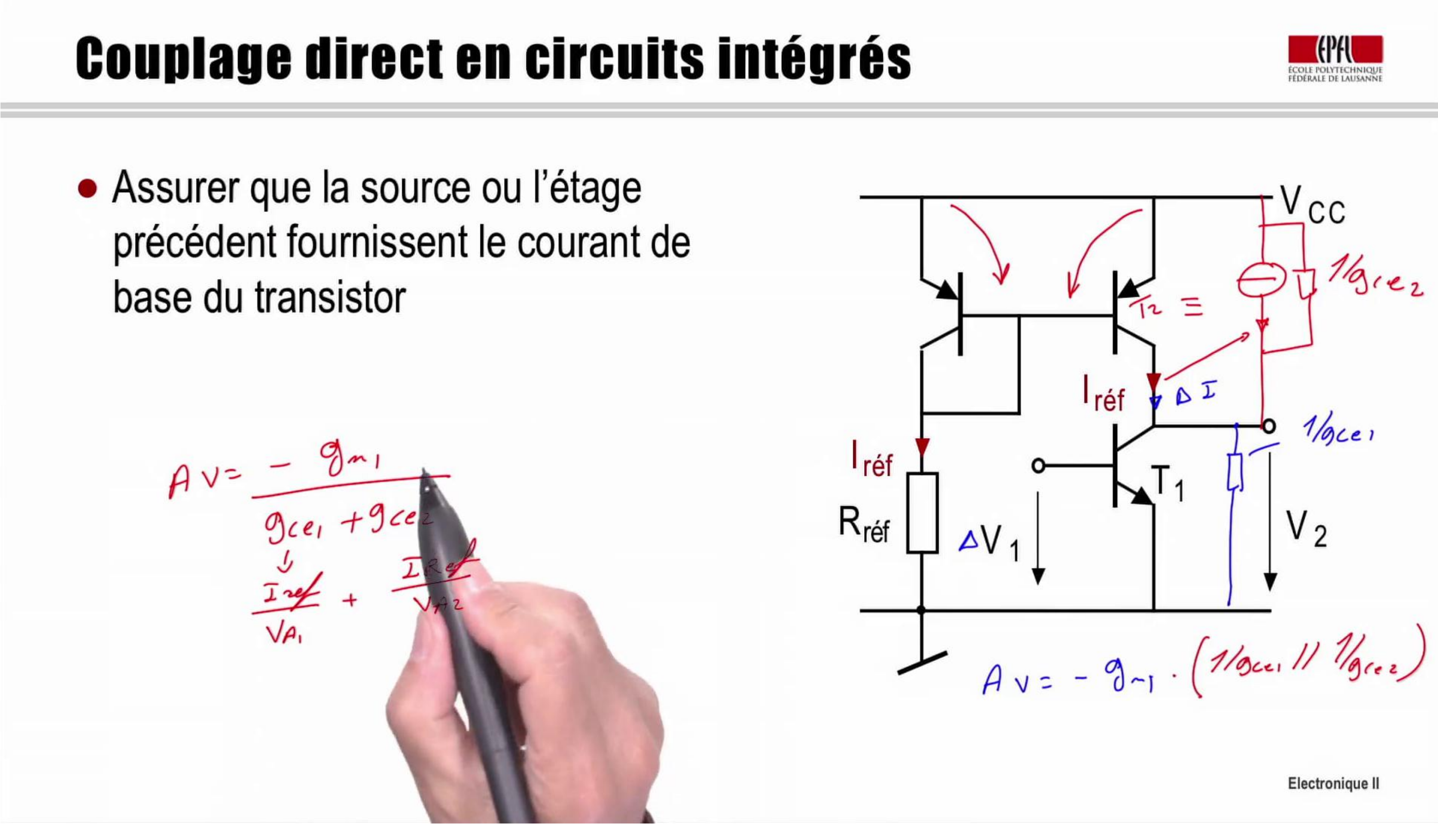
Electronique II

I come now on the same assembly but I'm replacing all that I have just seen before by a current source. so I remind you that this assembly which has a current mirror, this is identical to a current source here having a parallel impedance which is equal to 1 on GCE of this transistor. So it's a pretty high impedance in parallel with a current source whose value of the flow of this current is this, that's the Iref. So we fall back on what has been discussed and has been called the active load. This part I refer you to the course on the mirrors of the currents, it simply serves to impose Iref and which would generate a voltage VEB here who is copied the same here. So it will spark this current and impose it on the other side. And this transistor there, it will have a delta V variation, so I could put in blue to talk about a variation. And this change will generate a current in delta I. Here the delta I, it will see as an open circuit for the current source, it will stay to it 1 / GCE that is to say it will remain to it a great resistance, so it will realize a gain AV equals minus GM1.

Notes

Summary

27m 18s

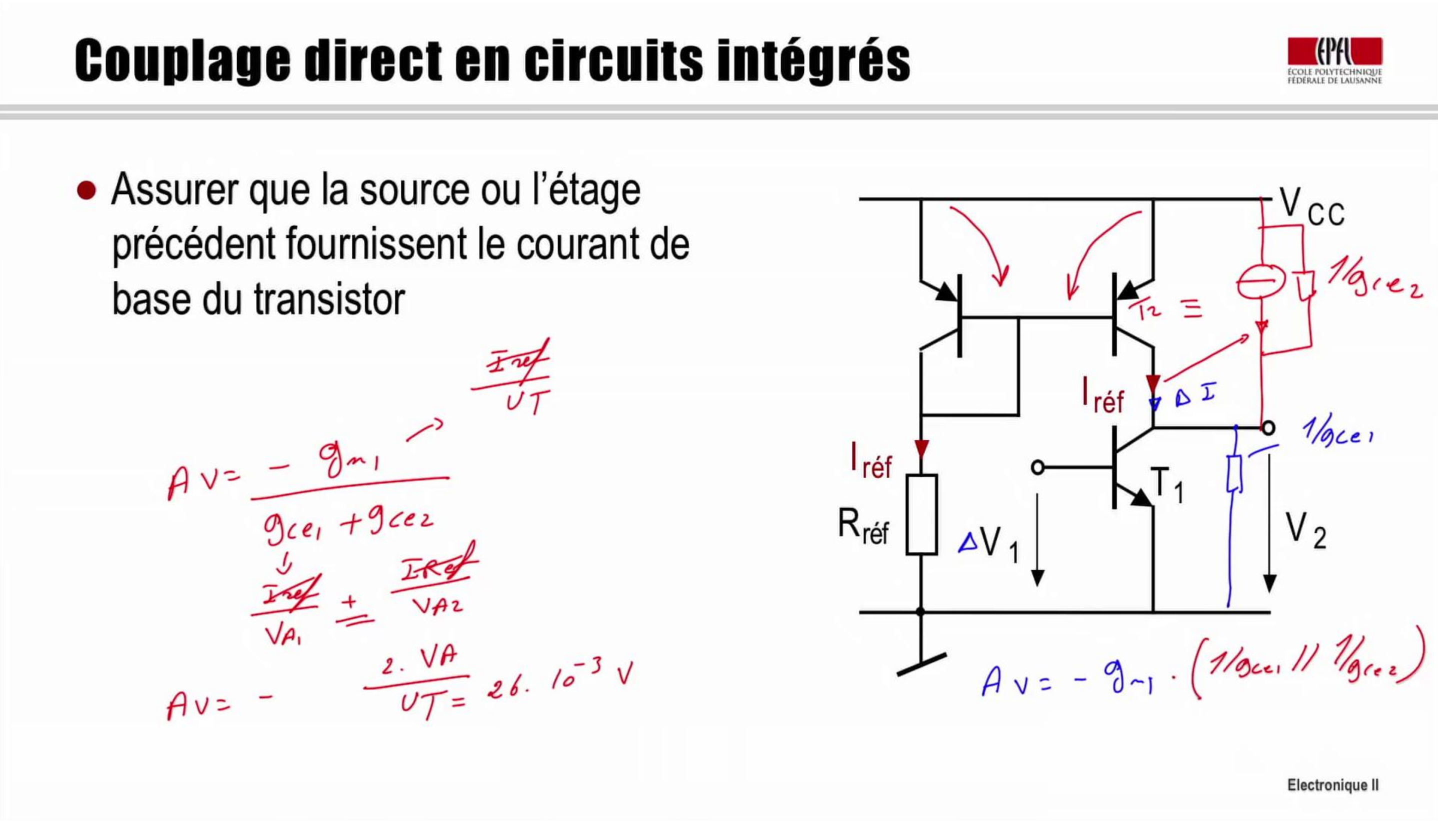


If we consider that this transistor has no output impedance or even if you consider it, you would have drawn here an impedance of a value 1 / GCE1, 1 / GCE1 and here we would have written 1 / GCE2 and there I call it transistor T2 therefore the gain of such an assembly would become minus GM1 multiplied by the parallel setting. You remember that I must short-circuited VCC to ground, so I would put 1 / GCE1 parallel to 1 / GCE2. and this would give me an AV gain equal minus GM1 divided by GCE1 plus GCE2. And this kind of installation, we will also make a simplified abstraction, suppose that GCE1 is Iref divided by the Early voltage of transistor 1 and the other is Iref, it is the same current in both divided by VA2 which is the Early voltage of the transistor 2. And the GM1, this transistor it has a current Iref which passes through it divided by UT and look what will happen with this kind of montage: if you consider that VA1 and VA2 is the same value, that the two transistors have the same tensions of Early and that the same currents cross it therefore the Iref, Iref, Iref will disappear.

Notes

Summary

28m 53s

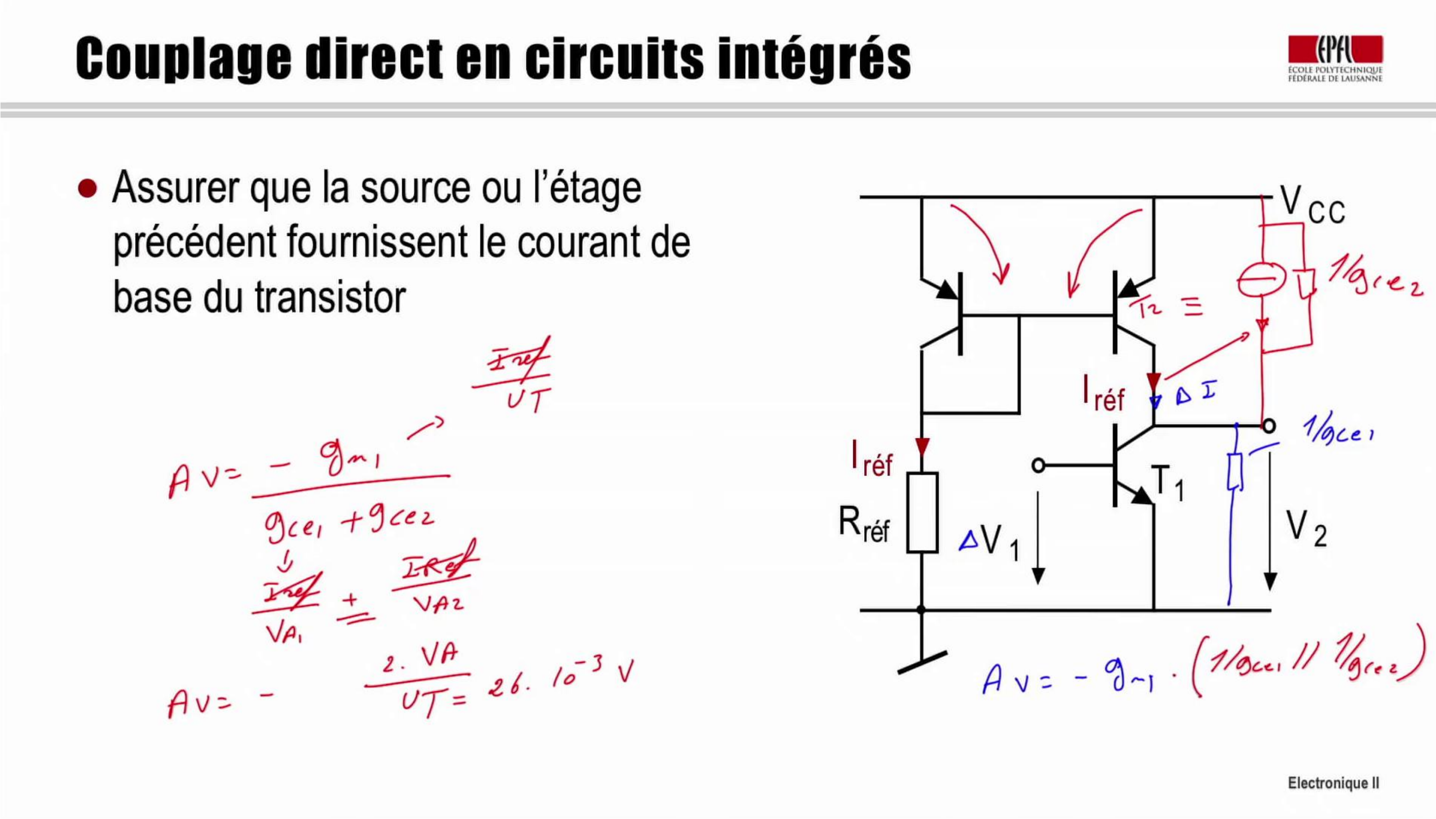


Look at what's going on: you end up with a gain which is proportional to, if we replace VA1 equal to VA2, therefore you are with 2 times, so that the AV gain would become less than 2 VA divided by the thermodynamic voltage UT. And you can do what you want with this assembly, you do not change the gain. It depends on the Early voltage and you remember in the bipolar transistor, it is linked to the width of the base and it's not you who are going to do it, it is part of the characteristic of your transistors and the thermodynamic voltage this is the 26 millivolt. So here it is a constant value at room temperature and there it is a value related to your transistor, so you can not change it, it would give you a fairly high gain independent of your design. but then you will tell me: "It's great!" Yes, it's great. It makes a gain. As soon as you plug it in, technology that you would use impose the Early voltage to you. It is linked to the physical law, you can not change it and you get a gain. And this gain is quite high because you have at the denominator 10 minus 3, therefore there is a factor 1000 that will multiply the ratio of VA / UT multiplied by 2 and the Early voltage is of the order of hundred volts for a low power transistor and there it is you find your self with a gain that automatically is high.

Notes

Summary

30m 40s



And I repeat the comments: that tension is not defined, it is defined by what you are going to put behind this transistor. To summarize what we have just seen now, I retraced again the use of transistor and I used the common transmitter assembly to explain and I demonstrated that when I take passive components to achieve an amplifier. My amplifier, it needs 2 resistors to polarize the base, it needs a strength in the transmitter for imposing a current in the transmitter and all this independent of the load because once you have added the load plus the active component which is the transistor, you will need 3 resistances to polarize. But unfortunately, the fact of having polarize, t was necessary to add also 3 capacities for your assembly can be used. Therefore, a montage by passive components needs 3 resistors, 3 capacity To realize it and the capacities And the resistors are components large, bulky when it is done with circuits and discrete elements. If you take the same assembly and you integrate, you will need a current source that is realized by a current mirror, so everything revolves around the transistor and becomes extremely small size that can be integrated on silicon and make very very high gains which would bring you later to do counter-reaction, so use that in context of a feedback amplifier and adjust the feedback gain.

Notes

Summary

32m 17s