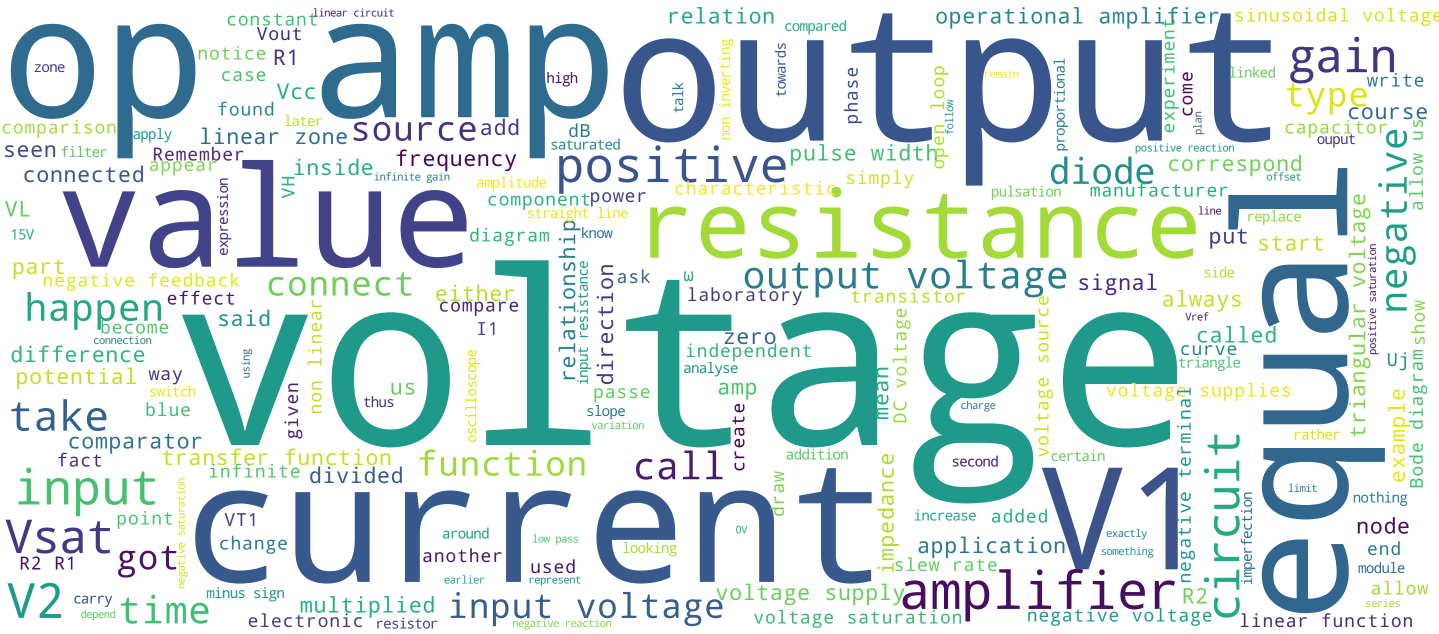
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Amplificateur opérationnel

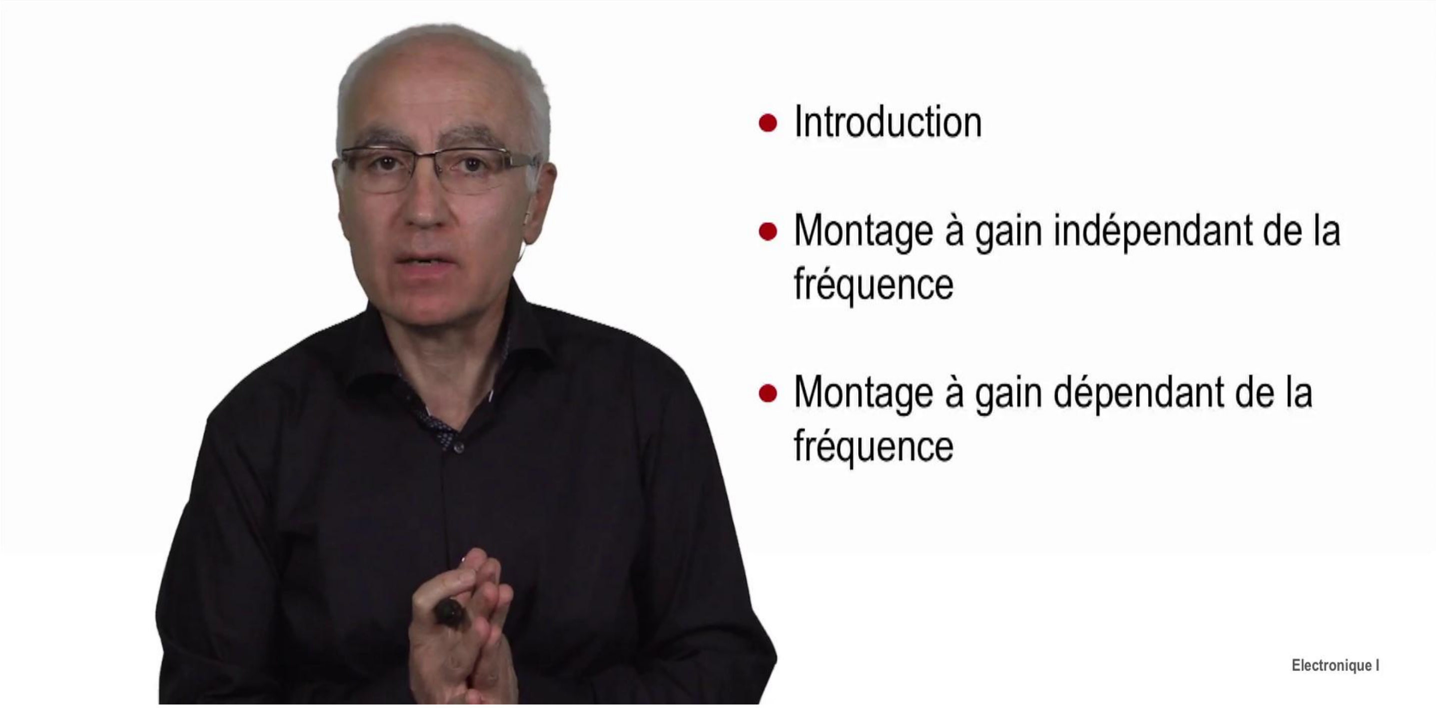
1.1 Introduction

Prof. Maher Kayal
Electronics Laboratory-ELAB



Video

Amplificateur opérationnel



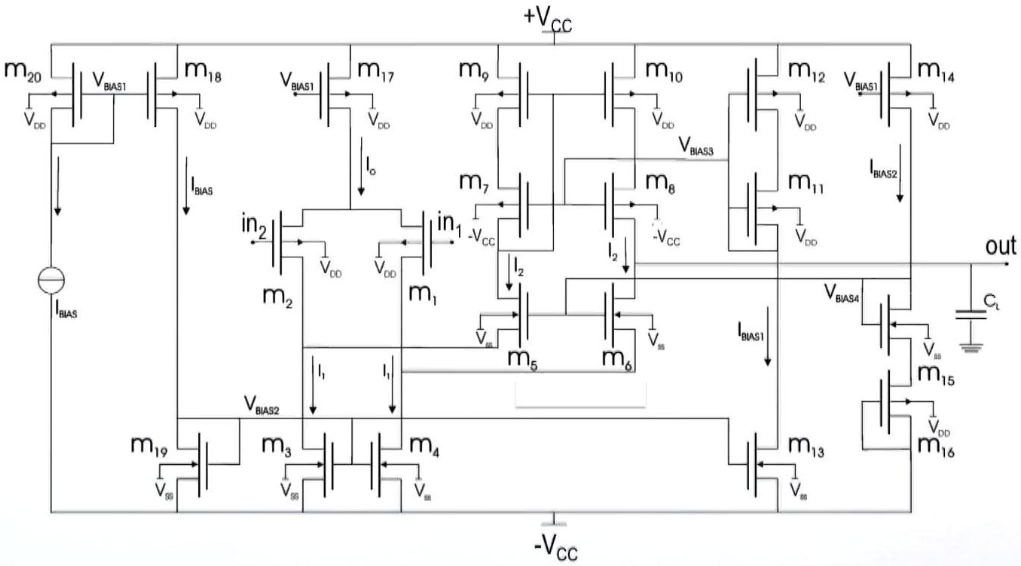
The first lesson about operational amplifiers consists in describing the circuit itself. Then, we'll talk about the negative reaction followed much later on by what is called the positive reaction. We will start with a short introduction and we'll go over all of the symbols, look at voltage and the flow of electric current, and how to power an operational amplifier (op-amp). And straight after this, we'll go on to examine this type of amplifier in a range of circuitries. These circuitries will exemplify what we call a frequency-independent amplifier, which means that once this op-amp has been connected to an electronic circuit, the input and output are independent from frequency variations. This is an example of linear function. This will bring us to consider the topic of filters. Inside the filters, we've got an op-amp which will be connected and which would allow us to vary the amplifier gain in line with frequency variations.

Notes

Summary

0m 04s

Exemple d'un amplificateur opérationnel



Electronique I

Here's an example of an op-amp or rather what we find inside the amp. You can see there are a lot of transistors. All of these transistors will perform a different function to allow this op-amp to display the characteristics which we'll examine as we go through this chapter. So, as you can see, this is a very complex process. These transistors, which inside here are of MOS type display quite a few functionalities This type of circuit would be integrated to a chip or to a silicon base. In the end, we do not show anything about what's inside. We'll have to limit our observation to the input of this op-amp which is here, a second input, to be found is there, two supply voltages which bring power to the circuit, and an output. So, in the end, there will be five tracks to the circuit and this circuit will be later represented by a triangle with two inputs, one output in addition to two voltage supplies.

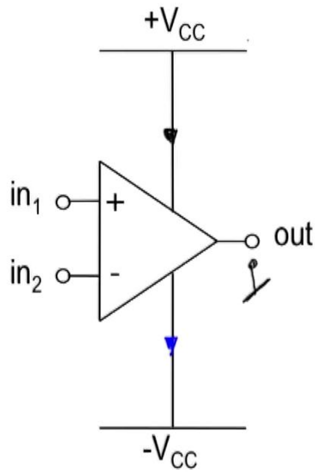
Notes

Summary

1m 06s

Amplificateur Opérationnel

- Généralement deux tensions d'alimentation:
  - $+V_{cc}$ et $-V_{cc}$
- Point milieu des alimentations considéré comme une référence de potentiels (GND)



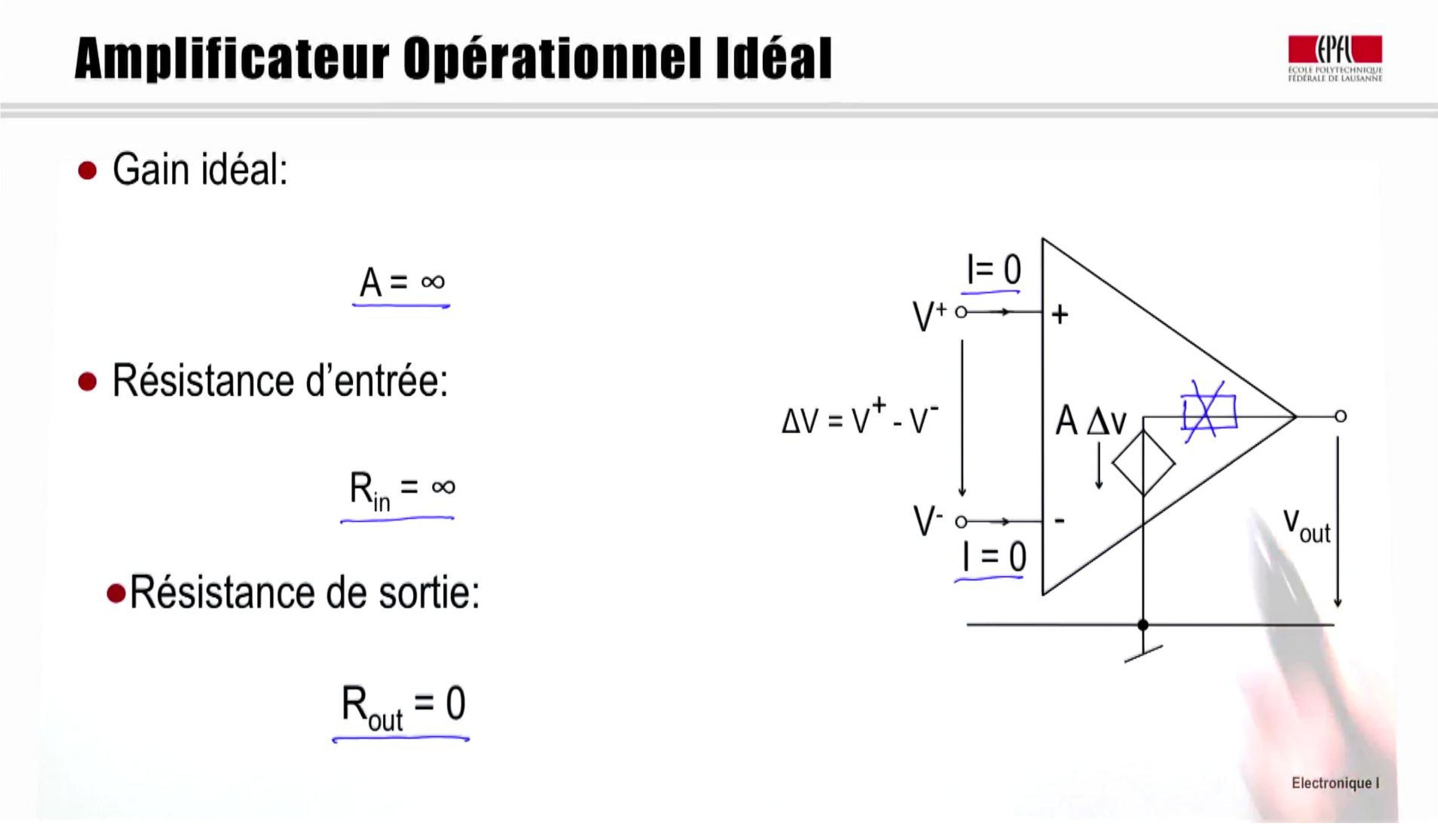
Electronique I

What we will mainly look at is this symbol. Once all of the transistors are marked in this triangle, this triangle comes to represent the op-amp which has one positive imput, one negative input, and an ouput. In addition to one positive and one negative voltage supply, and this is very, very important. These two voltage supplies are going to bring power to the electrical circuit with a positive current going one way, and a negative current going the other, and all of this will work in relation to a reference point between input and output, called the ground. Here we have: a positive voltage supply, a negative voltage supply, and a common point between the input and the output which we call the ground, and this type of diagram outlines everything included in the integrated circuit what is required to power it up and to give it a reference point. However, once we've begun to use this op-amp we'll stop drawing the +Vcc and the -Vcc signs. What remains is the mass potential which is essential. Today, we're simply going to look at this slide, and as soon as we've moved on to the circuits based on the op-amp, you'll see that the +Vcc and the -Vcc will disappear.

Notes

Summary

2m 08s



The perfect op-amp has certain characteristics which allow it to on one hand, amplify to a gain A = ∞; and on the other hand, there is an input resistance which is also infinite. This means that when you look at the current that will be absorbed by the op-amp, it will be summarised as a I=0 current. We've said that there are two inputs. In either of these inputs, no current feeds into the amp. Therefore, this amp merely receives two voltage supplies, V(+) and V(-), and both these voltage supplies will be infinitely multiplied and sent back towards the output. Now, when we look at the output, the output resistance of this op-amp is equal to zero. This means that the resistance which should have been there, in series with this source of controlled voltage supply that you see at the output, this resistance that should be here, just does not exist. So, we've got absolutely no series resistance with a controlled voltage source that picks up a difference in the voltage V(+) - V(-) which is called ΔV and which will be multiplied by a A= V gain.

Notes

Summary

3m 41s

Amplificateur Opérationnel Idéal

- Gain idéal:

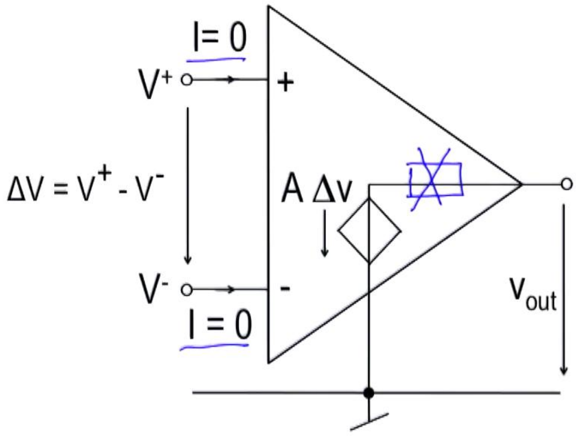
$$A = \infty$$

- Résistance d'entrée:

$$R_{in} = \infty$$

- Résistance de sortie:

$$R_{out} = 0$$



Electronique I

These three characteristics show a typical op-amp with: an infinite gain, an infinite input resistance, and an output resistance that equals zero, This will the type of op-amp that we'll be using throughout this introduction before starting to look at what we refer to as the imperfections the op-amp, when we will see that there are certain characteristics which aren't as ideal as those we see on an ideal op-amp.

Notes

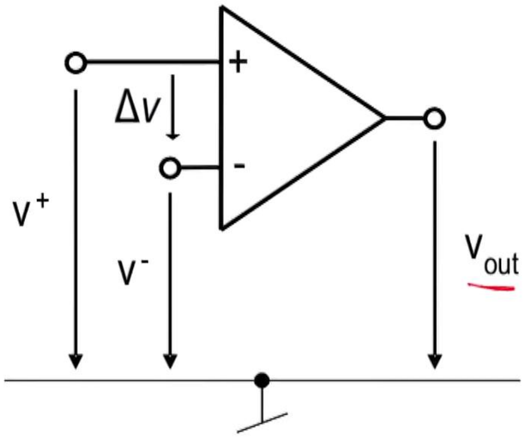
Summary

4m 54s

Amplificateur Opérationnel Idéal

$$V^{-}_{sat} \leq V_{out} \leq V^{+}_{sat}$$

$$V^{+}_{sat} = +V_{CC},\ V^{-}_{sat} = -V_{CC} \quad \text{(valeurs par défaut)}$$



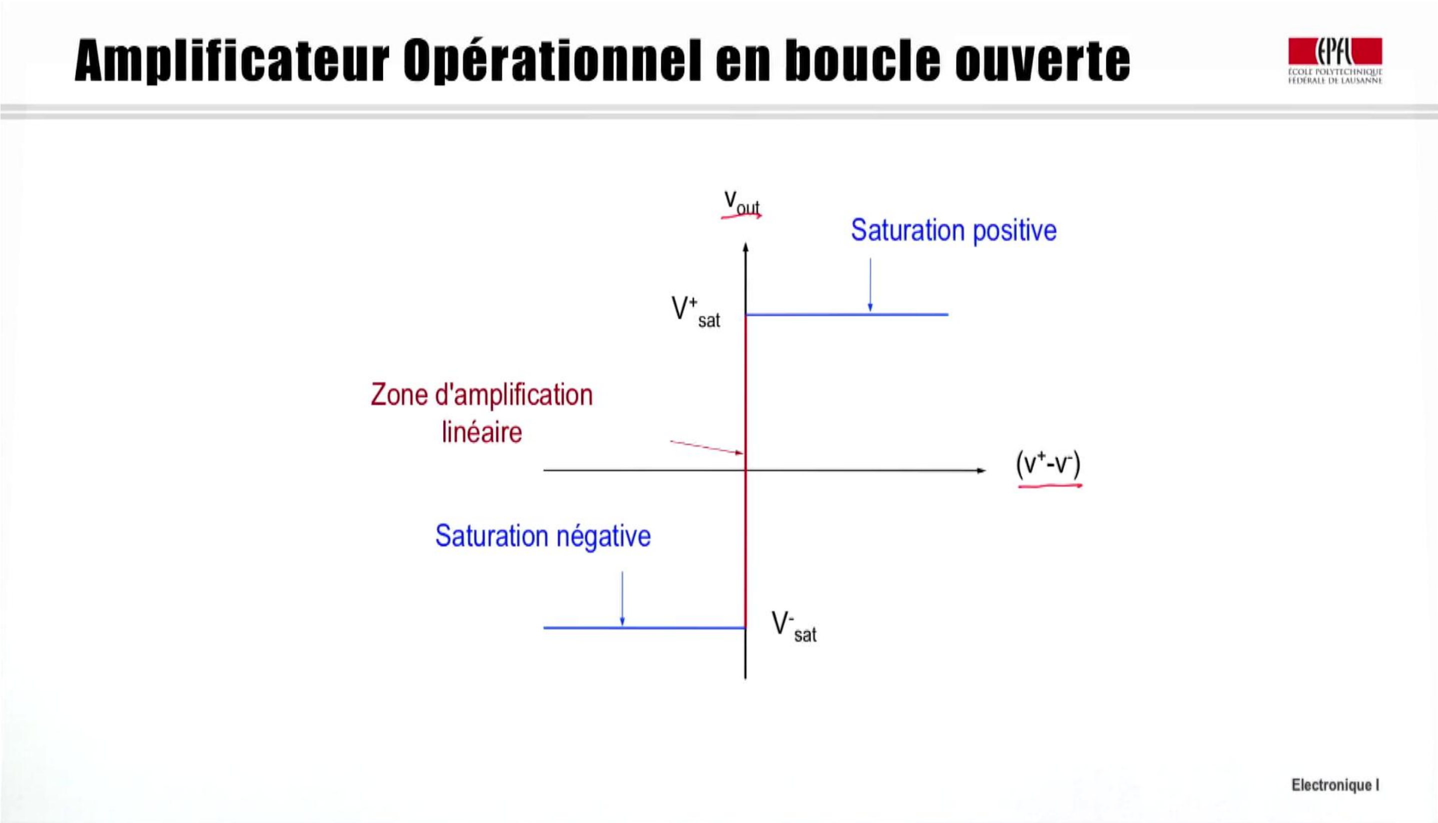
Electronique I

Let's look a bit closer at how this amp works. Unluckily, or rather luckily, the voltage output is saturated Unluckily, or rather luckily, the voltage output is saturated The voltage ouput V(out) can't in anyway exceed the positive voltage supply and the negative voltage supply. This means that V(out) is limited by what we call Vsat(+) and Vsat(-) which are nothing more than voltage saturation values, which in the first case, have been equalised by the voltage supply. It goes without saying that we find op-amps on the market that have a positive and negative voltage saturation that are not at the same levels as the voltage supply.

Notes

Summary

5m 26s

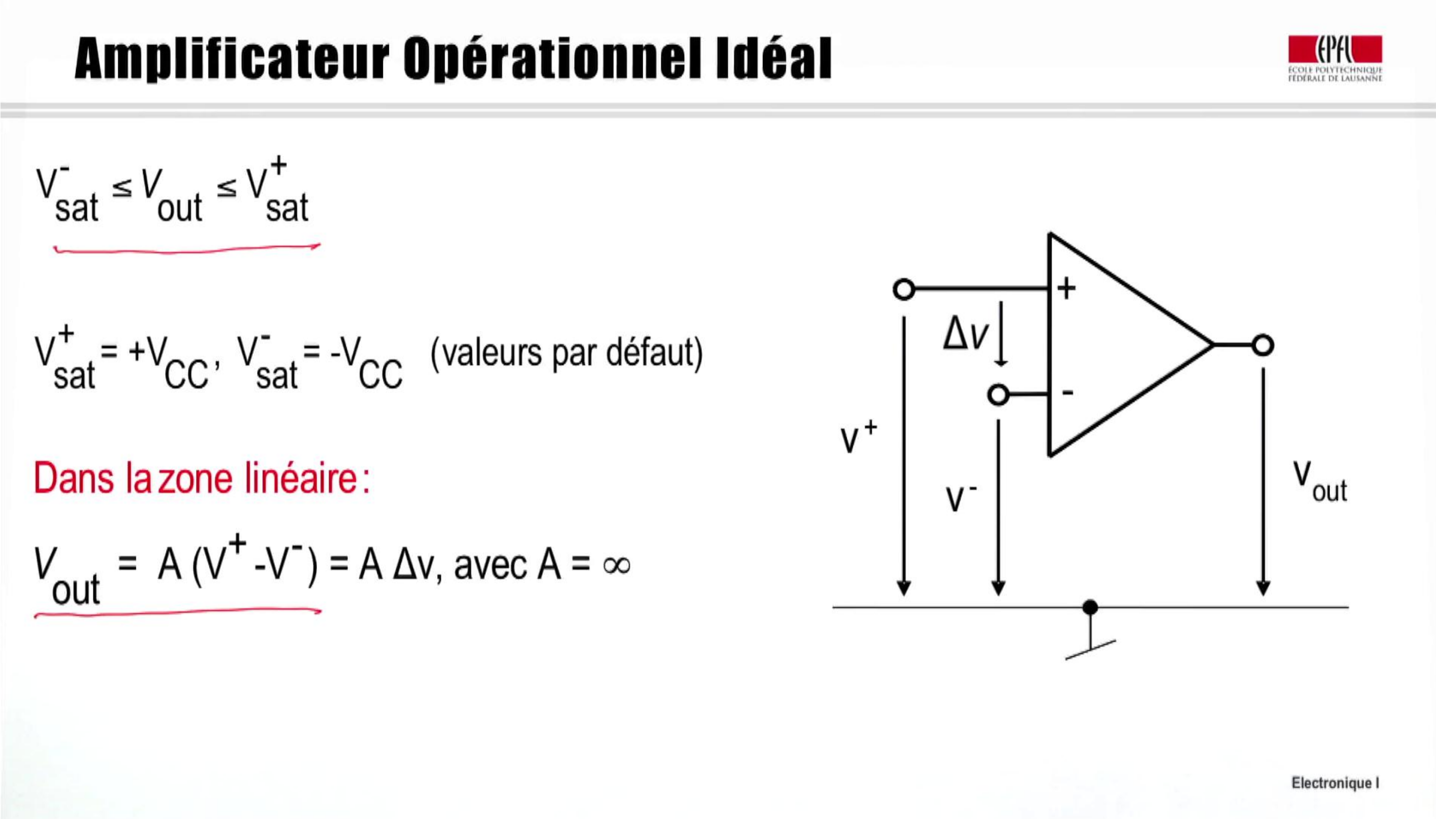


Here is the characteristic which connects the input voltage V(+) - V(-) to the voltage output V(out). We can distinguish two zones. One positive saturation zone, and a negative one, we call it saturation, we've just had a look at it just now, and a very interesting feature of this op-amp which will constitute the topic of how to use this op-amp in linear circuits, which is referred to as the linear amplification zone. If you look now at how an op-amp reacts to a signal.

Notes

Summary

6m 15s

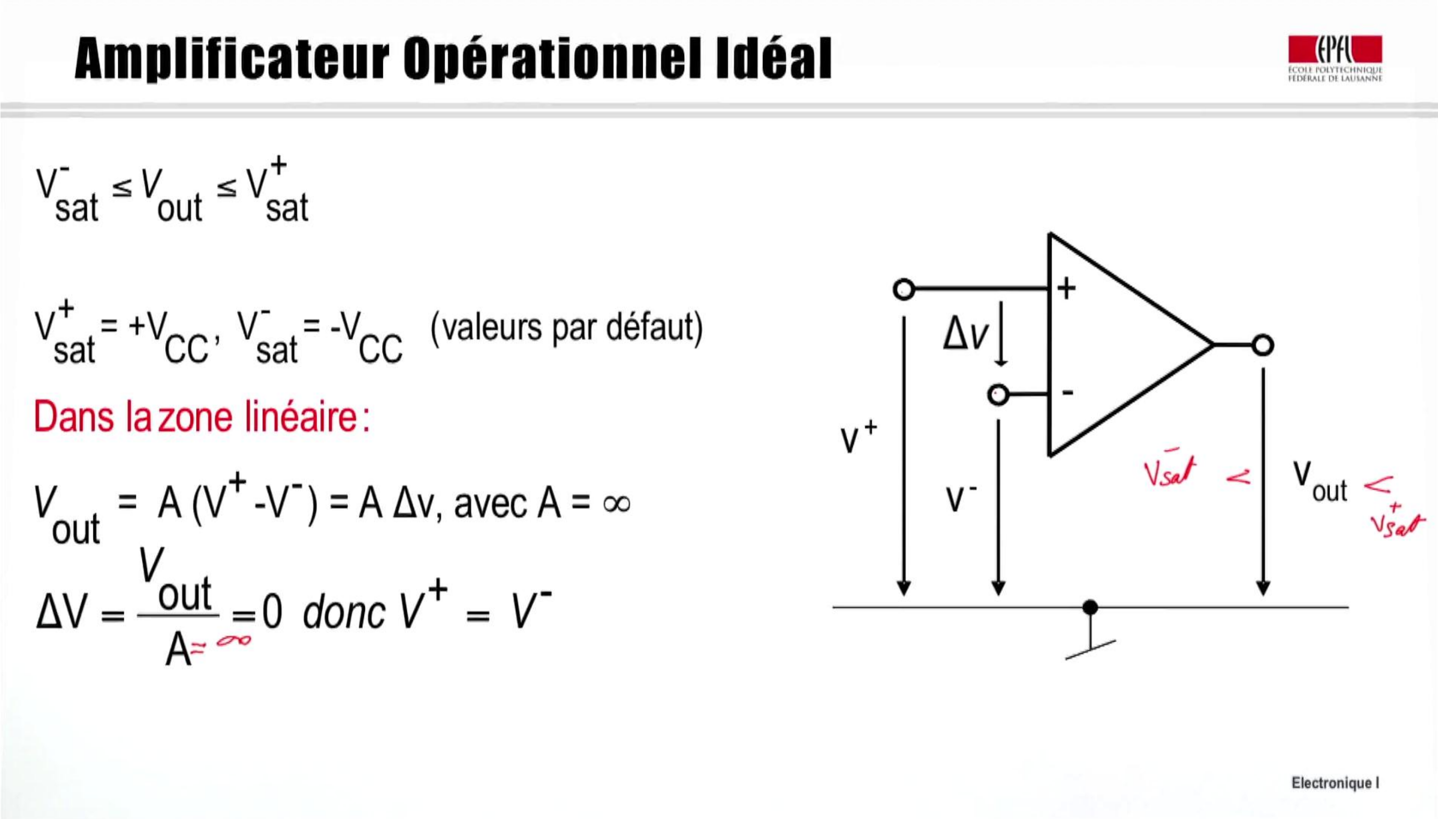


We just said that there are two voltage saturations, Vsat(+) and Vsat(-), and here, it's about non-linearity because we can't go any further than that. We lose the linearity. and, between these two voltage saturations, we have a straight line. And this straight line here, we call it the linear zone, and it's this linear zone that creates the amplification function of this op-amp. Let's see how all this interacts into a circuit. Let’s just summarise what we've just said. We've just said that the voltage an op-amp cannot go over the two voltage supplies, that we represent by +Vcc et -Vcc. We've also said that the linear zone is a zone where the voltage output is linked to the difference between V(+) - V(-) that we call ΔV and which is multiplied by a gain. We've also said that the gain is infinite. We've said that this part here, is the part that interests us the most when we want to create linear circuits. It is inside this linear zone that the op-amp should create, within a given circuit, a connection between V(out) and a input voltage V(in) which we're going to look at next. If we don't have this linear zone, the op-amp is basically non-linear, il will be torn between two voltage levels that will cause it to block.

Notes

Summary

6m 47s

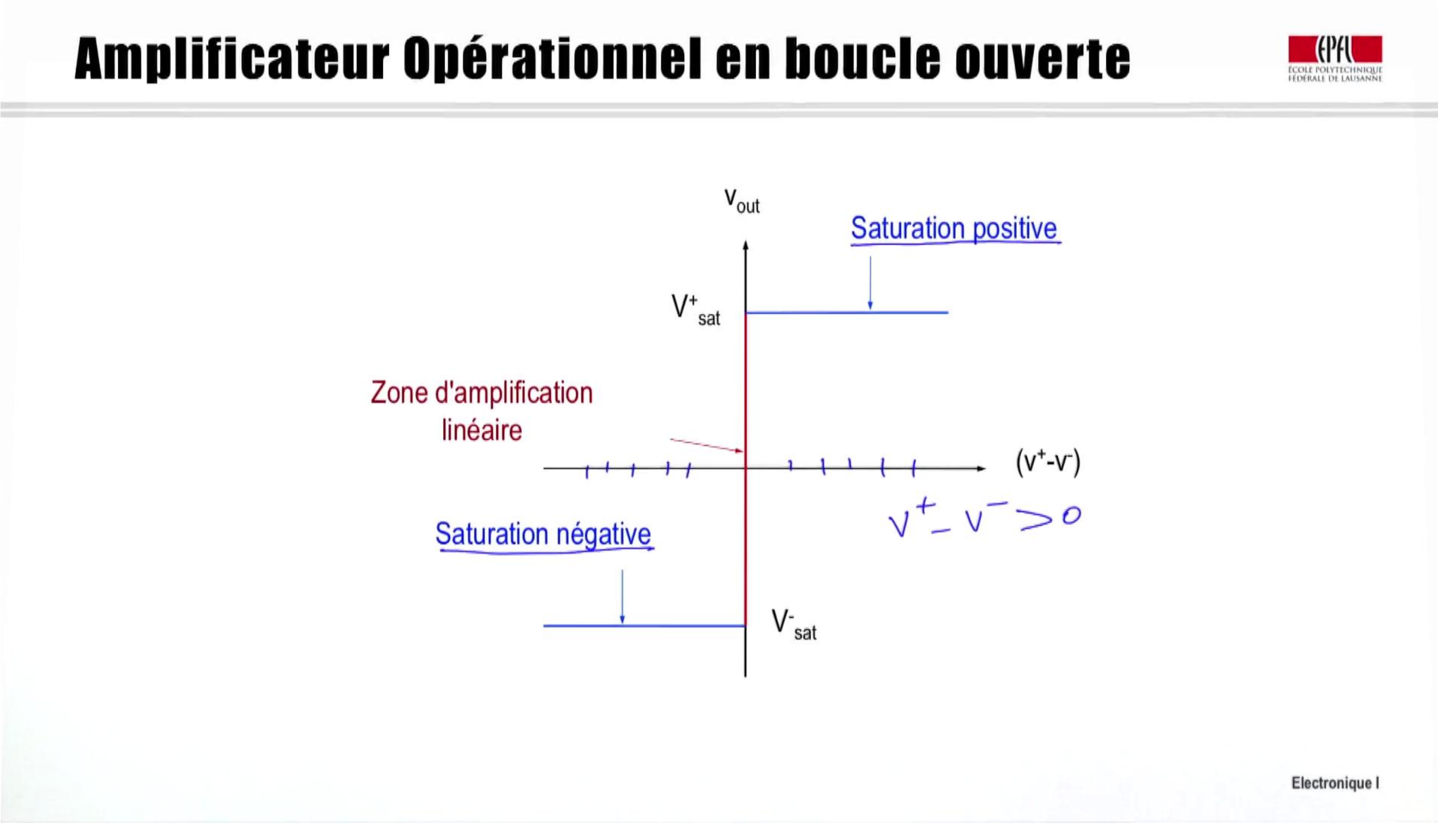


So, these are power supply tracks. So within the linear zone that we've just seen, we can formulate it like this in English: if the op-amp output is neither Vsat(+) nor Vsat(-) and the output voltage is strictly below Vsat(+) and strictly more than Vsat(-), then yes, we can say that our op-amp is fixed in this relation here, it is in the linear zone. And here we can draw an interesting conclusion, that when the op-amp, which has infinite gain, because this A here is equal to infinity, when this gain is equal to infinity, independently from the output voltage knowing that the voltage can't ever go over Vsat(+) et Vsat(-), Of course, the difference in voltage is zero. So, if this difference equals zero, the potential in this node here is equal to the potential in that node there. And it's this characteristic that will allow us to achieve a wide variety of functions in electronics, and we're going to use the op-amp in a purely linear function, and a direct relation y = x will connect V(out) to V(in). We're going to see how this will be confirmed within the context of a negative feedback circuit, caused by a negative reaction.

Notes

Summary

8m 14s

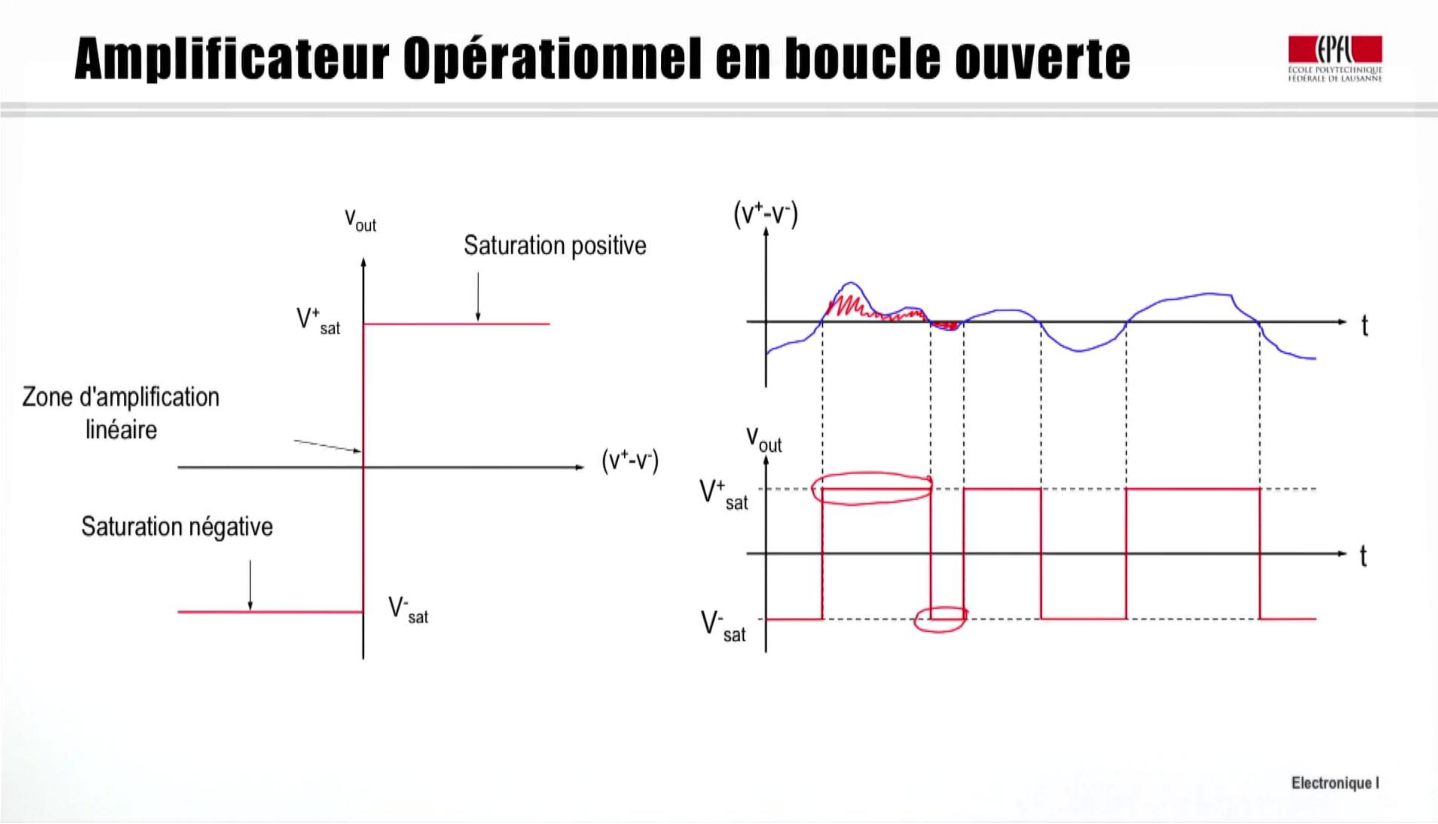


Let's see if I can use my op-amp within the positive or negative saturation zones, therefore in a non-linear function. For any input value V(+) - V(-), independent of this value, we have a unique output value, which can be either here or there, independent of this value, we have a unique output value, which can be either here or there, it's a detector signal from the op-amp that is called the comparator. So, if V(+) - V(-) is positive, in other words, if V(+) > V(-), or, if V(+) < V(-), we'll find ourselves with a saturated output, either a positive saturation, or a negative saturation, which will lead us to use the op-amp in a non-linear function.

Notes

Summary

9m 42s



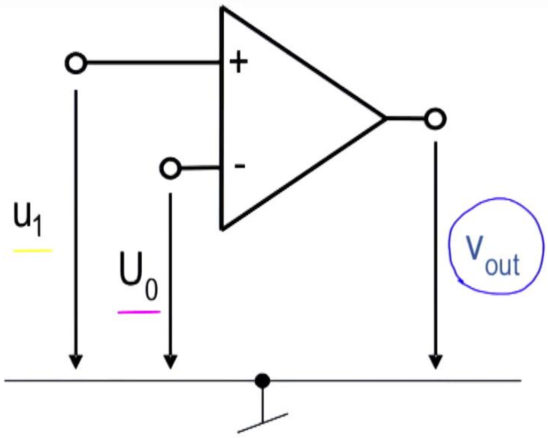
Here's an example that demonstrates this characteristic. Take a completely variable signal, that varies over time, and watch how the op-amp reacts at the ouput to detect whether the signal is positive, so all of this part here will allow us to source a voltage at the output that is always equal to Vsat(+). And all of this part here will lead us to find a voltage that is always negative. So with a binary voltage, if it's Vsat(+), we can say that the voltage is positive, and if it's Vsat(-), we can say that the voltage is negative. So, with this, we have a detection signal at the input which will tell us if V+ > V- or if V+ < V-. Of course, there are many ways of applying this. We can see here that we're analysing the op-amp in open-loop with the op-amp applications, or when we use the op-amp in positive reaction.

Notes

Summary

10m 28s

Exemple: Modulation PWM



u_1 : tension triangulaire

U_0 : tension continue

Electronique I

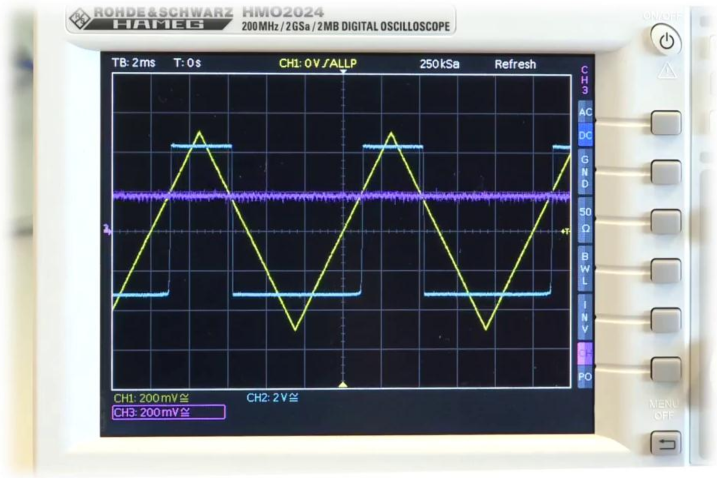
And this brings us on to look at some of these applications: There's a technique called Pulse-width modulation, that uses an op-amp open-loop. Here's the diagram of an op-amp loop where we are interested in the voltage output. When we compare the continuous input voltage, U(0), that is connected to the negative charge in purple, and on the positive charge, voltage U(1) I'm going to connect a triangular voltage. We're going to look at what happens at the output, and here, in blue, we've got the output voltage V(out). What I would ask you to do, is to go and connect this in a laboratory I've prepared this for you, so just here, you will notice, or carry out an experiment, just to see what happens. I've prepared this for you, so just here, you will notice, or carry out an experiment, just to see what happens. What I would ask you to do, is to go and connect this in a laboratory that when we compare a continuous voltage with a triangular voltage What I would ask you to do, is to go and connect this in a laboratory that when we compare a continuous voltage with a triangular voltage and look at the pulse-width at the output of an op-amp which will become increasingly wide or narrow depending on the comparison value to apply a well-known modulation technique that's called the PWM, or "Pulse-width modulation".

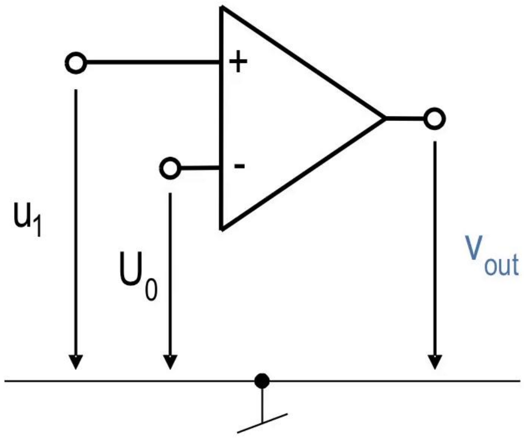
Notes

Summary

11m 36s

Exemple: Modulation PWM





u_1 : tension triangulaire

U_0 : tension continue

Electronique I

And so, we have here now in purple, the DC voltage, which is compared to the triangular voltage, that is in yellow, and you'll notice that at the output we find the voltage in blue, that corresponds to V(out). So, we can clearly see that if the triangular voltage is greater than the DC, the output is Vsat(+) ou à Vsat(-). We are moving the input voltage, and we see the pulse-width V(out) reacting exactly in comparison to the triangular voltage and the DC voltage that is at the input. Therefore, the pulse-width becomes increasingly narrow, And, when we lower the DC voltage, you'll notice straight away that the pulse-width modulates in comparison, and this can be easily observed on the screen of an oscilloscope.

Notes

Summary

13m 01s