ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

Applications des Amplificateurs opérationnels

7.1 Applications linéaires

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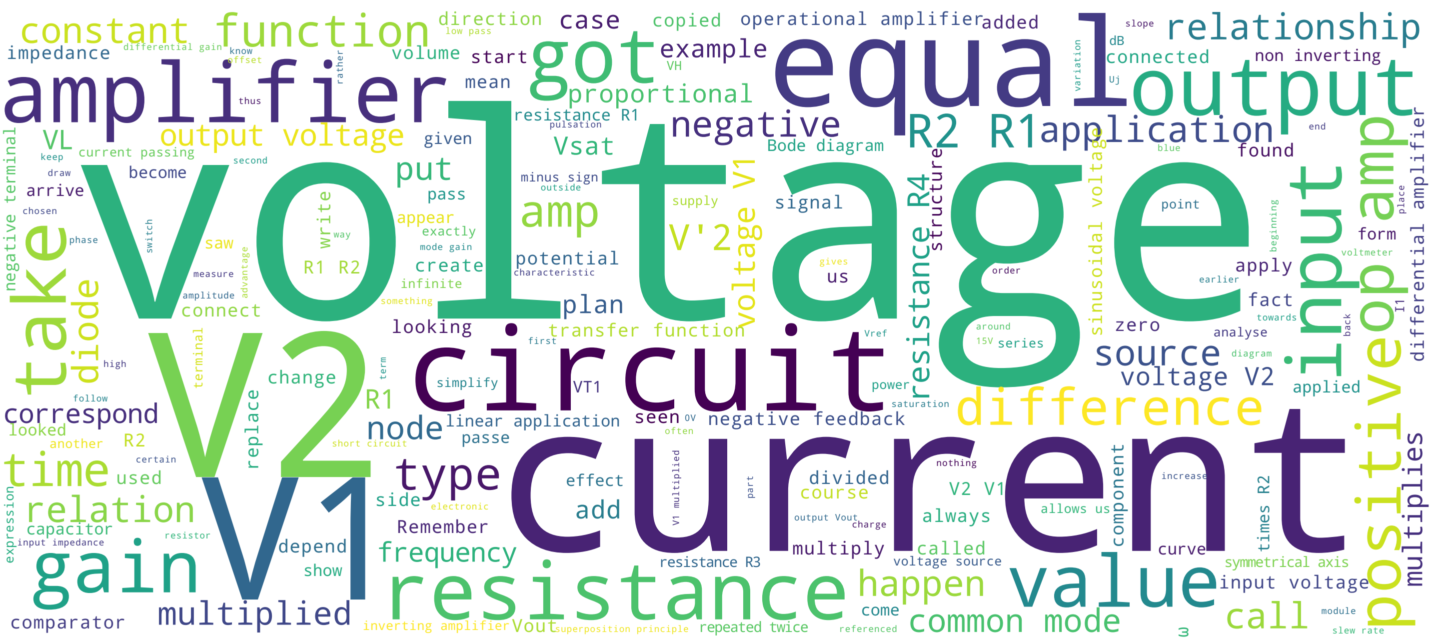


EPFL

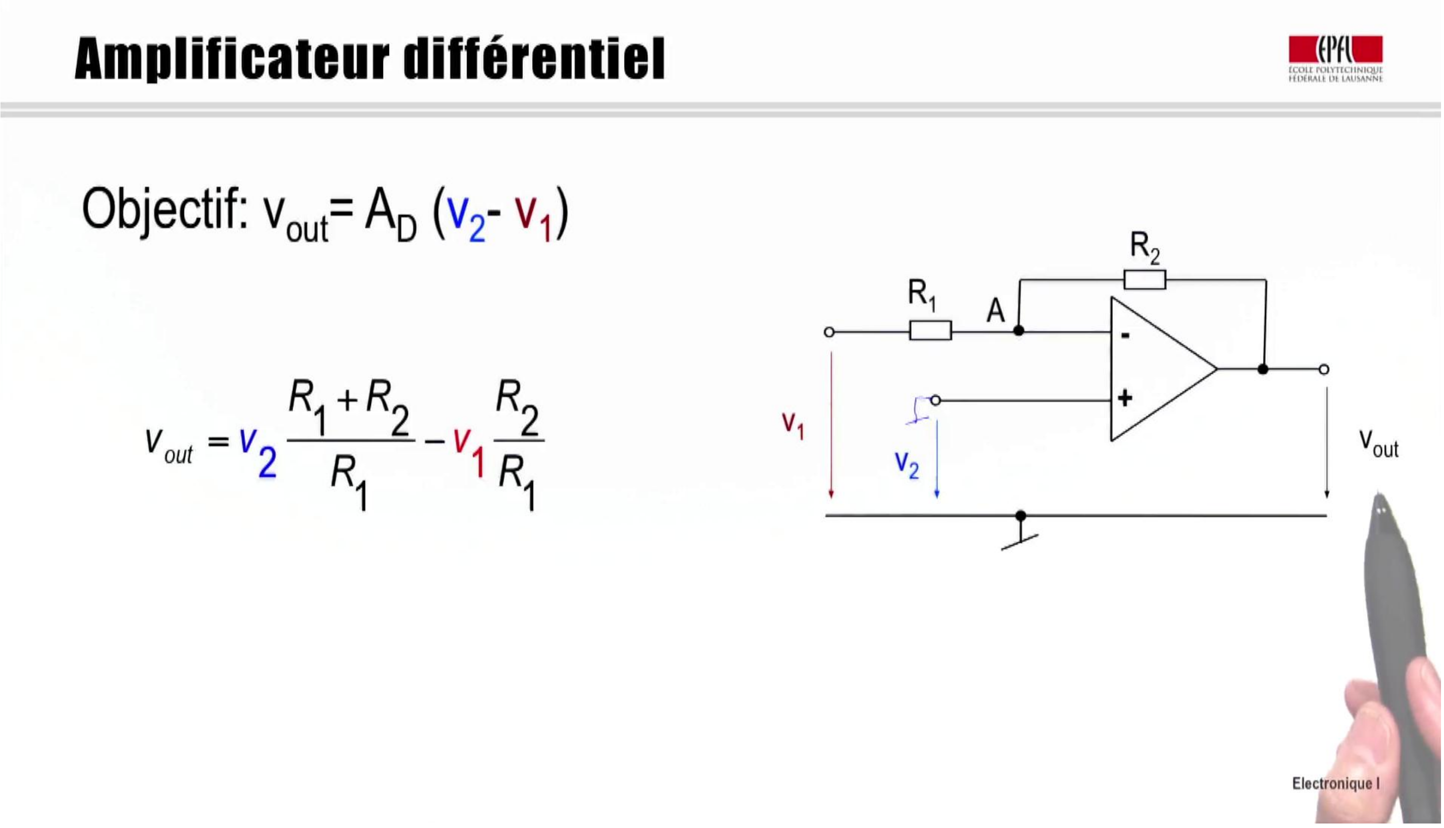
Video

Hello everybody. Today we're going to look at applications for operational amplifiers, or op-amps. We've already covered some of them. Today, we're going to look at a whole series. We're going to start with linear applications. Then we'll go on to look at a series of non-linear applications. Then we'll finish with an application that is quite specific that requires a signal generation circuit at the output that we call a signal generator.

Notes

Summary

0m 04s



For the first application of an op-amp in the series of linear applications, I'd like to look again at a plan that we've already studied. It's a plan that we've seen where the op-amp is in negative feedback. So we've got the two resistances, with a return from the output to the negative terminal. And a positive input used directly by a signal, we'll call it an op-amp with two inputs with a negative feedback. And I'd like to use it for an application in which the voltage output Vout is proportional at the same time to V1 and V2, which is the case in this example. But I'd like to find a relationship that corresponds to a voltage Vout which is equal to a constant that multiplies the difference of or of. The plan that is represented here has already been looked at. It has an output that depends on V2 and V1. Remember, we've already covered this, we applied it to the superposition principle: we took the voltage V2 and we connected it to the volume. And we saw that by connecting the voltage V2 to the volume we found that there was a relationship, or circuit, that is the inverting circuit. So Vout = V1 times R2/R1 with a minus - sign in front, that we find here.

Notes

Summary

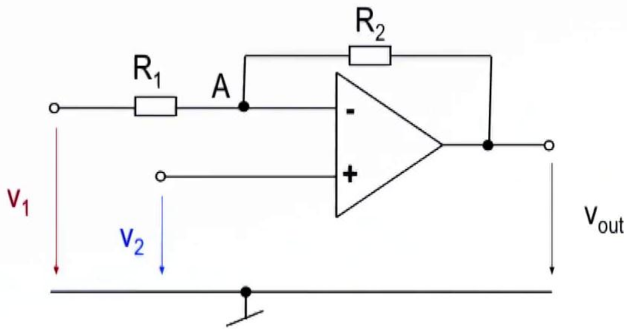
0m 31s

Amplificateur différentiel

Objectif: $v_{out} = A_D\,(v_2 - v_1)$

$$V_{out} = V_2\,\frac{\cancel{R_1+R_2}}{R_1} - V_1\,\frac{R_2}{R_1}$$

$$\ast\ \frac{R_2}{\cancel{R_1+R_2}}$$



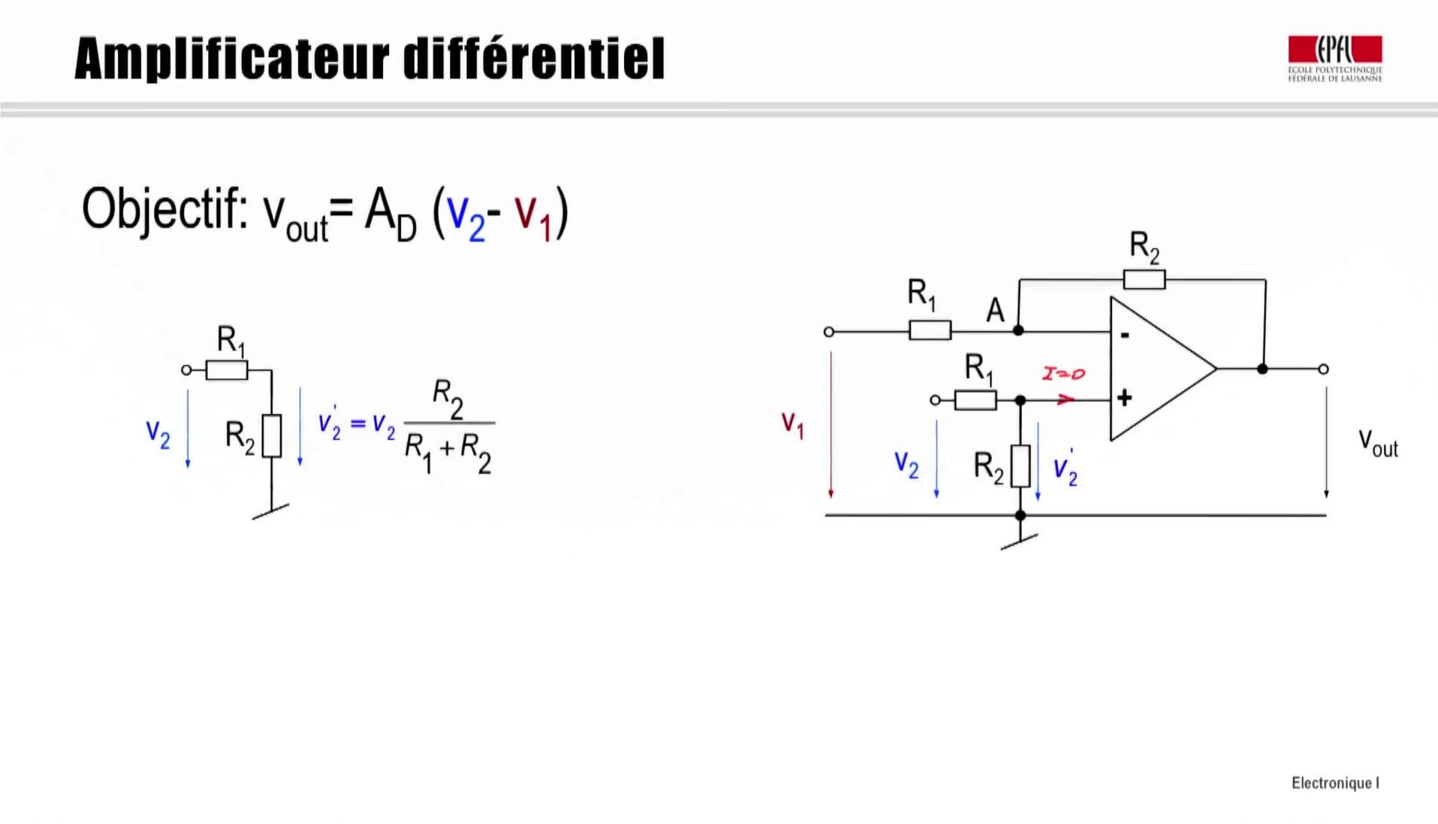
Electronique I

We can take the same plan but this time connect the V1 to the volume. So I connect this to the volume. And I see that Vout = f, and I will find that it's a plan of a non-inverting p-amp that is equal to 1+R2/R1 that multiplies V2 and sends it back to the output to arrive at a voltage V2 proportional to /R1. So, I'll take the same plan but this time I'll modify it, by adding something so that in the end instead of having /R1 and R2/R1, each constant multiplies the variable V2 and the variable V1. I'd like to reduce it to a constant that multiplies the difference. By looking here, we notice something simple. If I come here, I multiply this by R2/, and I'll be able to simplify it to R1+R2 and I find R2/R1 which multiplies V2 and R2/R1 which multiplies V1. and now I've got Vout = R2/R1 that corresponds to this A which is here, and that multiplies the difference between the voltages V2-V1. The advantage of such a circuit is that I've a voltage V1 in relation to V2 and V2 in relation to V1, that gives me a floating voltage with a common-mode at the input, so it's the difference between these two voltages. It's very useful compared to the two circuits that we looked at before.

Notes

Summary

1m 55s



Each time that we had an input, and the input was in relationship to the volume. Here, I can't see where the volume is, I see a common-mode, and this common-mode is the voltage at the terminals from which I will be able to pivot V1 in relation to V2. And we call it an op-amp, with a voltage proportional to the difference in the voltages V2-V1, therefore : differential amplifier. Here's the cell to add. You will have soon realised that to find a voltage that is multiplied by R2/, it corresponds to adding a divisive resistance R1 and R2, and the voltage achieved at the output will be the voltage at the input V2 that is multiplied by this constant, on the condition that there was no current at all coming from this node here, which is the case. Because the current that we see here, is a current i = 0 so there's no chance that I falsify the value of V'2 in relation to V2, and that is simply R2/. And there you have it, our circuit is called a differential amplifier that will apply a voltage V1 in relation to V2 and multiply it by the constant that we're now going to calculate that will be Vout proportional to this.

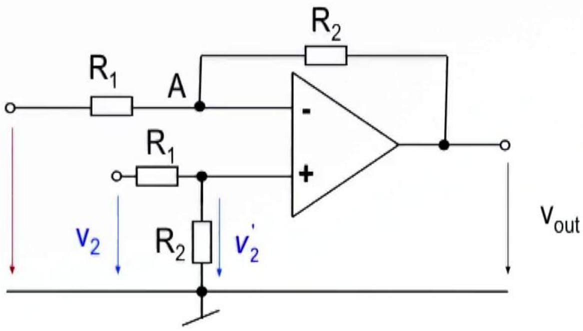
Notes

Summary

3m 42s

Amplificateur différentiel

Objectif: $v_{out} = A_D\,(v_2 - v_1)$



$$v_{out} = v'_2\,\frac{R_1+R_2}{R_1} - v_1\,\frac{R_2}{R_1}$$

$$v_{out} = v_2\,\frac{R_2}{\cancel{R_1+R_2}}\,\frac{\cancel{R_1+R_2}}{R_1} - v_1\,\frac{R_2}{R_1} = \frac{R_2}{R_1}(v_2 - v_1)$$

Electronique I

The same explanation, but this time in relation to the amplifier with its voltage V1 but this time on the positive terminal, the voltage that we've got is V'2. And I replace V'2 that multiplies the /R1 - V1R2/R1*, that we've just looked at. We just need to replace V'2 by its value. So the V'2 will become V2R2/. Once I've replaced the V'2 with this value here, so it's the V'2 that's here, I replace it with its value, and voila, I can simplify it by R1+R2 and I get V2 times R2/R1 minus V1 times R2/R1 so now I can put R2/R1 in evidence and I can find V2-V1 which multiplies a constant. There you go, I've found that A is equal to R2/R1.

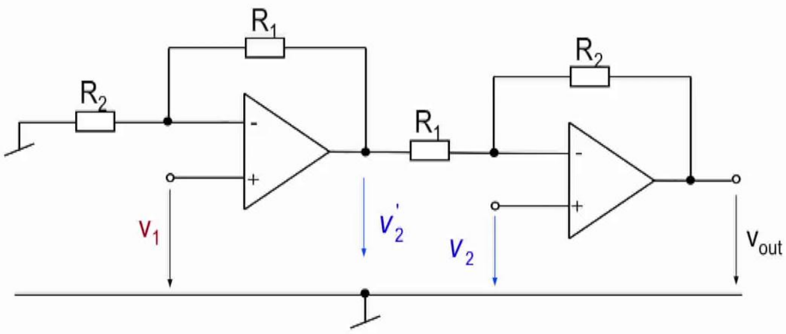
Notes

Summary

5m 04s

Variante à impédance d'entrée infinie

$$V_2' = V_1 \frac{R_1 + R_2}{R_2}$$



$$R_{in} = \infty \;\; !!!!$$

Electronique I

To summarise, we've got something that looks like this. So, we've found the output voltage proportional to the difference between the input voltage. For sure, there isn't a negative or positive voltage. You just have to inverse V1 and V2 or V2 and V1 and the output Vout will change phase in function to the nature of the voltages that we've put at the input V1 and V2. I just need to mention one more thing about this circuit. A current will pass through here and a current will pass through there. We can see that there's an impedance R1 on this track here. The voltage A and A is the same, So with an infinite gain, the amplifier will equalise this node here and this node here. And we've got a differential amplifier with an input resistance equal to twice this resistance R1. So, we've got a current that will be debited by the source. It's not an infinite input, it's a finite input that is falsified or impacted by the value of the resistance R1 that we've chosen to put here. And yes, we're going to solve this problem of impedance at the input of a differential amplifier. We would like one of the voltages to have an infinite input impedance, meaning no current here, i = 0.

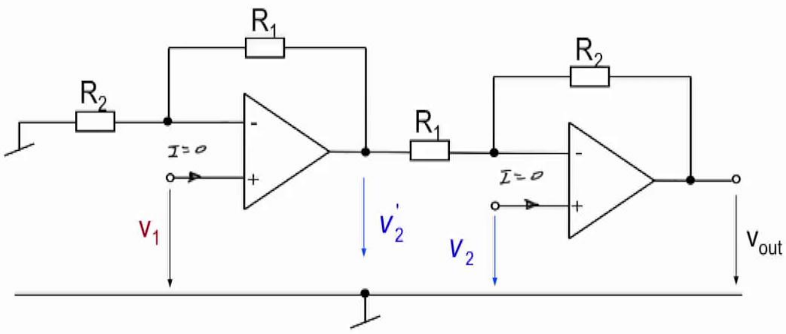
Notes

Summary

6m 16s

Variante à impédance d'entrée infinie

$$V_2' = V_1 \frac{R_1 + R_2}{R_2}$$



$$R_{in} = \infty \;\; !!!!$$

Electronique I

And the same for the voltage source V2, we're going to do something so as to not take any current from the source that happened before. We've chosen this circuit, it's a well-known but not well-used circuit. I'll tell you why it's not very well-used later on. However, there is this characteristic of being very didactic. It allows us to see that when we take a non-inverting amplifier such as this one, we see that the voltage that we have at the output V'2 in function to the voltage that we have at the input, which is V1. Which is what is written down here. The voltage V'2 is nothing other than the voltage V1 multiplied by the gain of this amplifier which is 1+R1/R2, and there it is. We take this voltage and we apply it to the op-amp's input where we're going to use both inputs V2 and V'2. So, the second op-amp which is here will take the voltage V'2 which is here as well as the voltage V2 and it will behave as does this type of op-amp with two inputs, it will give us a voltage output Vout proportional to the voltage V2, which is here, multiplied by the gain.

Notes

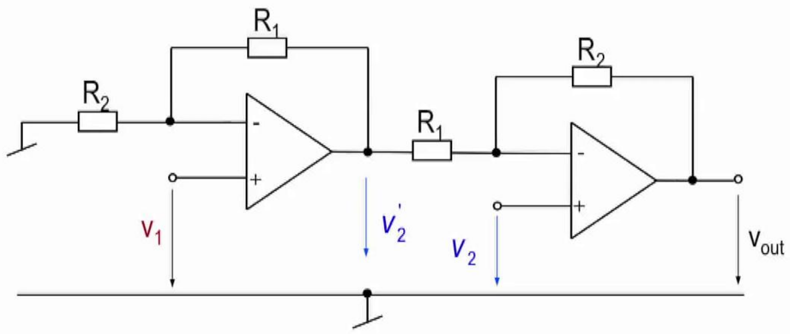
Summary

7m 34s

Variante à impédance d'entrée infinie

$$V_2' = V_1 \frac{R_1 + R_2}{\cancel{R_2}}$$

$$V_{out} = V_2 \frac{R_1 + R_2}{R_1} - V_2' \frac{\cancel{R_2}}{R_1}$$



$$R_{in} = \infty \;\; !!!!$$

Electronique I

So as usual, we've applied the superposition principle, we cancel V'2 and then we will cancel V2 and we'll have an inverting amplifier that will give us V'2 times R2/R1. And V'2, in effect, is the voltage that we've got here. So the V'2 connected here will be multiplied by R2/R1. And V'2 being proportional to V1, you just have to replace this with this, and you see, you can simplify by R2 and you find the expression that we've been looking for, this one here. Here's the solution that we're looking for, it's a solution in which we've got a constant. This constant is proportional to a differential gain because it will multiply V2-V1. And, exactly what we're looking for, it's a difference of voltage, one referenced to the other, so it's floating, multiplied by a differential constant, that we'll determine in function to the two resistances R1 and R2. But the most interesting thing about this example is that Rin, in this case, is infinite. Why don't we use this circuit very often? This circuit isn't very easy to apply to silicon, because very often we prefer to use symmetrical circuits, where we've got the same components, where geometrically, by implementing them onto the microchip we've got a symmetrical axis, which isn't the case here.

Notes

Summary

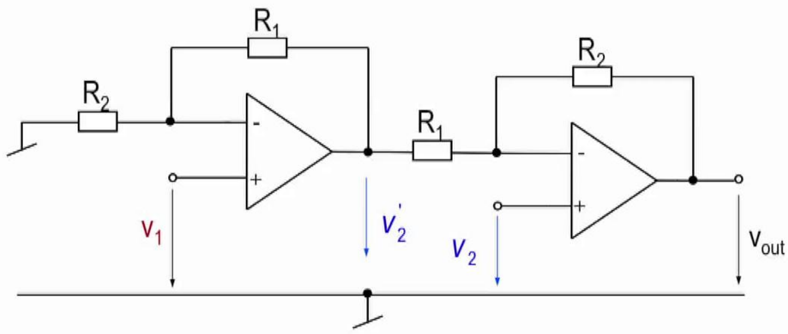
8m 48s

Variante à impédance d'entrée infinie

$$V_2' = V_1 \frac{R_1+R_2}{R_2}$$

$$V_{out} = V_2 \frac{R_1+R_2}{R_1} - V_2' \frac{R_2}{R_1}$$

$$V_{out} = \underbrace{\frac{R_1+R_2}{R_1}}_{AD}(V_2 - V_1)$$



$$\boxed{R_{in} = \infty \;\; !!!!}$$

Electronique I

We've got two op-amps following each other, and two resistances. This resistance is equal to this one, but they are swapped around, they aren't in the same place: the resistance R2 gives a negative feedback here. However, there, it's the resistance R1. So, it's a circuit that gives us matching problems. Later on, if you do microelectronics you'll understand what I mean in terms of matching, because the variability of components is absorbed by the relative value of these components.

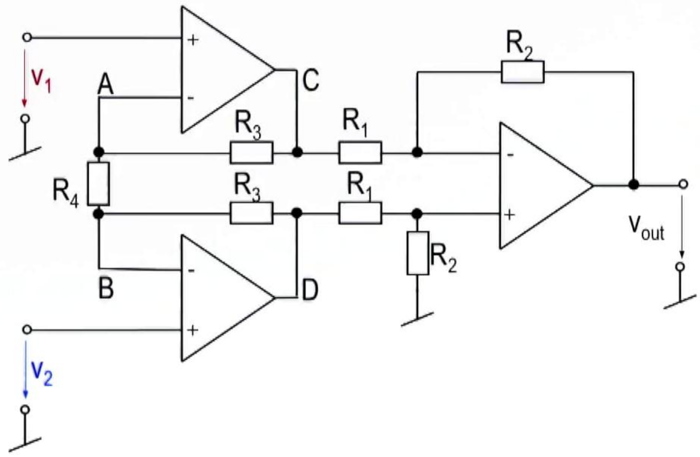
Notes

Summary

10m 27s

Variante à impédance d'entrée infinie et haut CMRR

- Applications: Amplificateurs d'instrumentation, préamplificateur pour microphone, etc.
- Intérêt:
  - Structure symétrique
  - Appariement de R_1 et R_2 moins critique
  - La résistance R_4 pourrait être externe



Electronique I

The circuit that we see here is extremely important with regards to what we've just seen, because of a very interesting characteristic: the ease in which it can be implemented onto silicon and to keep a symmetrical axis by using similar structures. Watch, if we pass a symmetrical axis through here, you'll see that if we do an abstraction of the resistance R4, that R3 is repeated twice, and the same for R1, R2, an op-amp here, the same op-amp repeated twice over, and this one is added at the end which has the possibility to add a symmetrical axis inside. Why do we insist on this notion of symmetry? Because it's a structure that once implemented onto silicon, allows us to create a circuit where absolute error absorption is compensated for by relative errors. We call them matching errors because we can't match the resistances much more when we've got a relative value, so the same resistance R3 repeated twice, even if the absolute value R3 is an error, the resistance R3 is similar on both sides thanks to the fact that it has all been symmetrically repeated twice. This helps us to improve the quality of the amplifier, it allows us to achieve a structure that is guaranteed in common-mode that will be cancelled by the same structure of the amplifier.

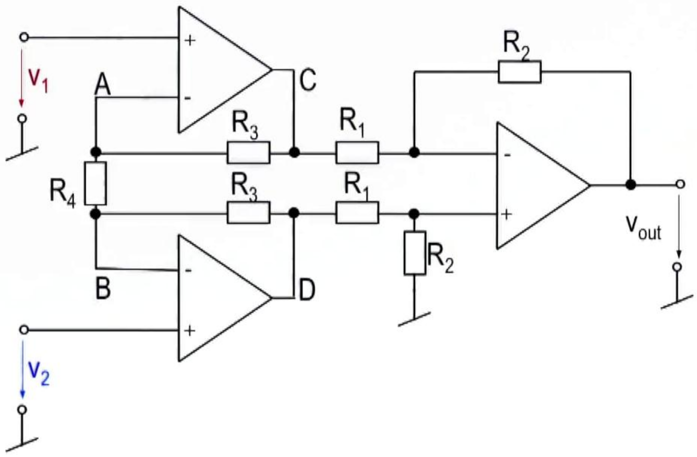
Notes

Summary

10m 56s

Variante à impédance d'entrée infinie et haut CMRR

- Applications: Amplificateurs d'instrumentation, préamplificateur pour microphone, etc.
- Intérêt:
  - Structure symétrique
  - Appariement de R_1 et R_2 moins critique
  - La résistance R_4 pourrait être externe



Electronique I

And we find it on the market as instrumentation amplifiers, it can also be found as a pre-amplifier for a microphone. It's also a structure that is sold in the form of an integrated amplifier with external pins on the chip and an external feed. So, we're going to study this structure, that is widely used for applications with captors.

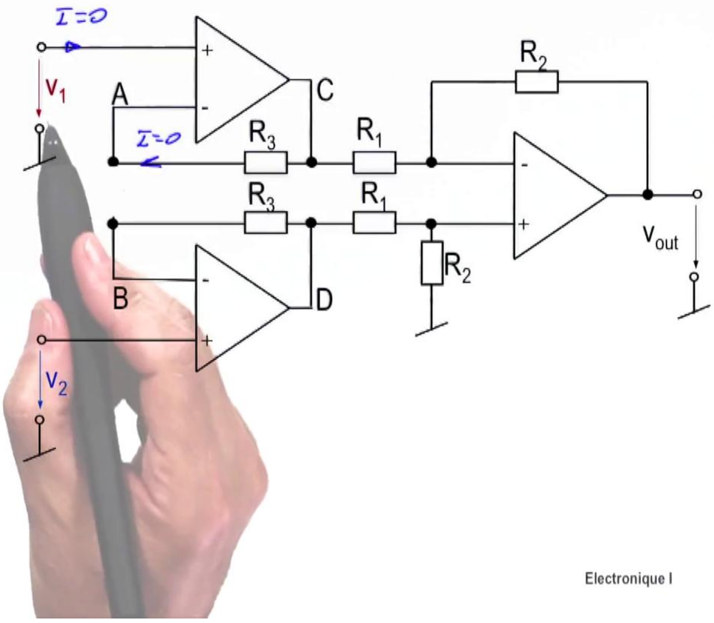
Notes

Summary

12m 33s

Variante à impédance d'entrée infinie et haut CMRR

- Avec $v_2 = v_B$ & $v_1 = v_A$



To start with, I going to make it simpler, just to show what happens if there isn't any resistance R4. Suppose that I take away this resistance here, I remove it from my plan and we see what happens to the circuit once the resistance R4 exists no longer. If you look at the structure here, which is similar to this one, it's a voltage tracker. So the voltage V1, even when the resistance R3 is there, is copied over to A. in any case, the current passing through here is nil, the same on the other side. So R3 doesn't react at all on the signal V1 and copied onto the node A. There isn't any current passing through here, so V1= V and V = V. So we find V1 that appears here. And that, it acts as a buffer, like a plug, that allows the input impedance to be rendered infinitive, no current. The same on the other side. So the voltage V1, or the source that is connected here V1, and that that is connected to V2 or the source that is between V1 and V2 should not supply any current at all to this type of circuit, and we will recognise it as our differential amplifier that we saw at the beginning of this lecture, this amplifier that takes the difference in voltage and multiplies it by a gain, and this gain is returned to the output.

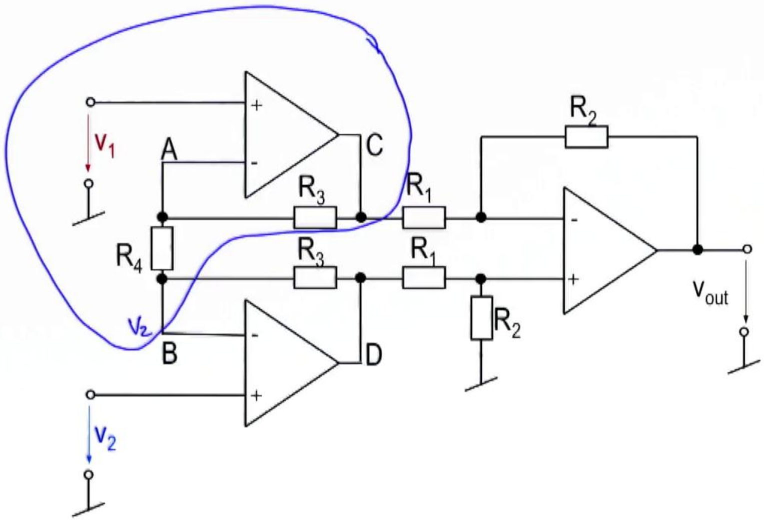
Notes

Summary

13m 02s

Variante à impédance d'entrée infinie et haut CMRR

- Avec $v_2 = v_B$ & $v_1 = v_A$



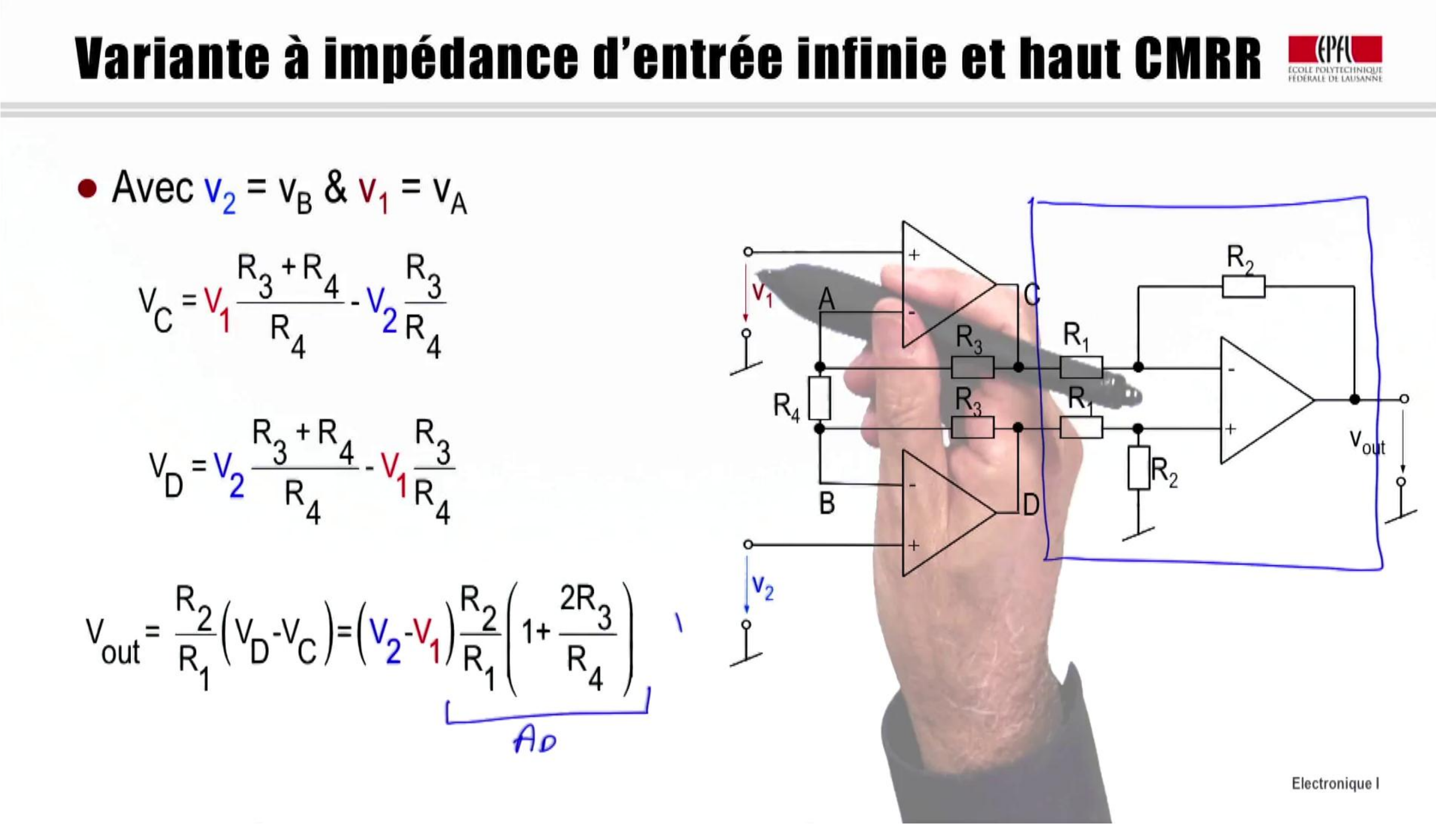
Electronique I

I'm going to take the same circuit, and I'm going to add the resistance R4 that can be external. Some manufacturers sell it with this resistance R4 on the outside to allow a gain on the input stages. Here, we've simply made an input stage without a gain, so the resistance R3 is here and R3 here, we didn't have to use it, it's not doing anything here. Let's suppose now that we take the same circuit, here it is, the same circuit, but this time with the resistance R4. The voltage V2 is equal to the voltage V. The voltage V1 is equal to the voltage V. And we've got an output C and an output D that depends on V1 and V2. It goes without saying that when we've got a negative feedback we always apply the superposition principle. I think that everyone knows that we start by saying V2 = V, so as if I had the voltage V2 here. And if I analyse the amp that is here, I will recognise that it's an amplifier with two inputs, like the one we saw at the beginning of the course. It's got a voltage V1 and a voltage V2, and we just have to write down the relationship V = f. We do the same for the second amplifier. We take the second amplifier which is at the bottom and do the same to that one by saying that V1 is copied over to V and we would have taken this resistance and this one, and we associate them with this op-amp and we'd have expressed V = f. So, we're going to express V and V.

Notes

Summary

14m 36s



Here are the two voltages V and V. Once we've applied V = f as we've just seen, and the same for V, we'll find that V is proportional to V1 multiplied by /R4-V2 times R3/R4. The same for V. And once we've got V and V we'll take our differential amplifier circuit, that's here and apply V and V to it and use the relationship that we found earlier on. So, we'll find Vout = f,V). And, given that V and V will depend on V1 and V2, here's the final relationship that we're going to find between Vout, V2, -V1 multiplied by a constant. Remember that the objective is to find the constant A, it's the differential gain that multiplies the difference in voltage. This type of application allows someone to take the voltage V1 and V2, typically you've got a voltmeter with two sensors, that you connect onto both terminals of the voltmeter, to measure a difference in potential, and these two differences in potential are not at all referenced to the volume, they're referenced to something else. At your voltmeter's input you've got a circuit like this one and you're going to make work a resistance, often it's the resistance R4, that the manufacturer leaves on the outside.

Notes

Summary

16m 30s

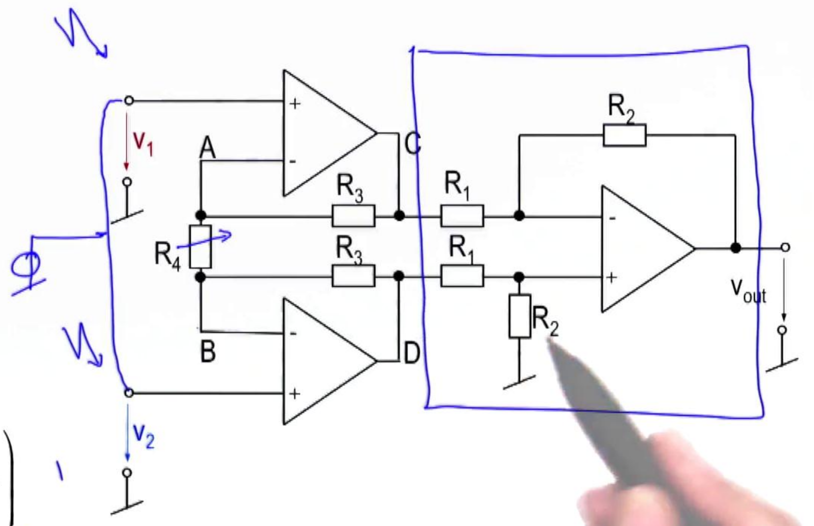
Variante à impédance d'entrée infinie et haut CMRR

- Avec $v_2 = v_B$ & $v_1 = v_A$

$$V_C = V_1 \frac{R_3 + R_4}{R_4} - V_2 \frac{R_3}{R_4}$$

$$V_D = V_2 \frac{R_3 + R_4}{R_4} - V_1 \frac{R_3}{R_4}$$

$$V_{out} = \frac{R_2}{R_1}\left(V_D - V_C\right) = \left(V_2 - V_1\right) \underbrace{\frac{R_2}{R_1}\left(1 + \frac{2R_3}{R_4}\right)}_{A_D}$$



Electronique I

You can modify it in order to change the gain, because we see the resistance R4 here. So, we want to change the gain while having two floating voltages. We get an excellent amplification with this type of application for everything that's done with Wheatstone bridges. So it's with these bridges with captors that measure the differential voltage, and this differential voltage and is multiplied by a certain gain and we find it on an integrated circuit. The advantage of this type of application is that you have a common-mode, meaning that the parasites that arrive in equal quantities on V1 and V2. It's as if we've got a V1 = V2, as if we've got a short circuit with V1 and V2, and we've got a source connected to both of them, that debits a certain amount of voltage. So, remember that we spoke about a common-mode gain. As if V1 is copied here and V2 is copied here, if V1 = V2, so V = V there isn't any current running through the resistance R4. So we'll find our V1 here, we'll find our V2 here. And here, we've got a differential amplifier that sees V1 brought directly to here, V2 brought directly here.

Notes

Summary

18m 05s

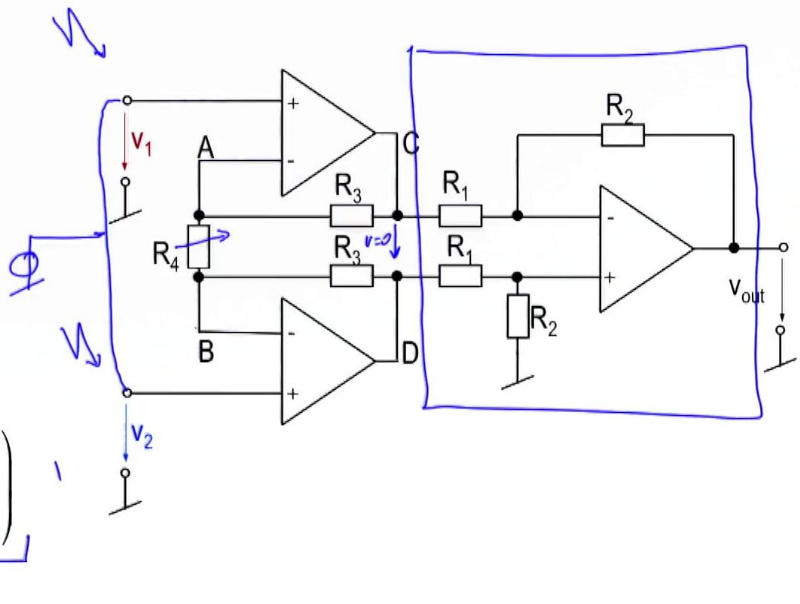
Variante à impédance d'entrée infinie et haut CMRR

- Avec $v_2 = v_B$ & $v_1 = v_A$

$$V_C = V_1 \frac{R_3 + R_4}{R_4} - V_2 \frac{R_3}{R_4}$$

$$V_D = V_2 \frac{R_3 + R_4}{R_4} - V_1 \frac{R_3}{R_4}$$

$$V_{out} = \frac{R_2}{R_1}\left(V_D - V_C\right) = \left(V_2 - V_1\right)\underbrace{\frac{R_2}{R_1}\left(1 + \frac{2R_3}{R_4}\right)}_{A_D}$$



Electronique I

Despite the existence of R4, if the gain of these two amps are high enough, then the common-mode is cancelled out by the fact that there isn't any current going through the resistance R4. And the voltage difference here will be equal to 0, and this voltage here, again, U = 0. And this amp doesn't amplify the tension difference that will be found here, so it will give us a voltage close to 0 and that creates an excellent "common mode rejection ratio", or an excellent common-mode gain in this type of set-up. So, I'm convinced that it's a circuit that is used in linear application in which we want to multiply a difference in voltage by a certain gain, and we find examples of these in the form of integrated amplifiers and it's used by many manufacturers.

Notes

Summary

19m 25s