ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Applications des Amplificateurs opérationnels

8.1 Applications non-linéaires

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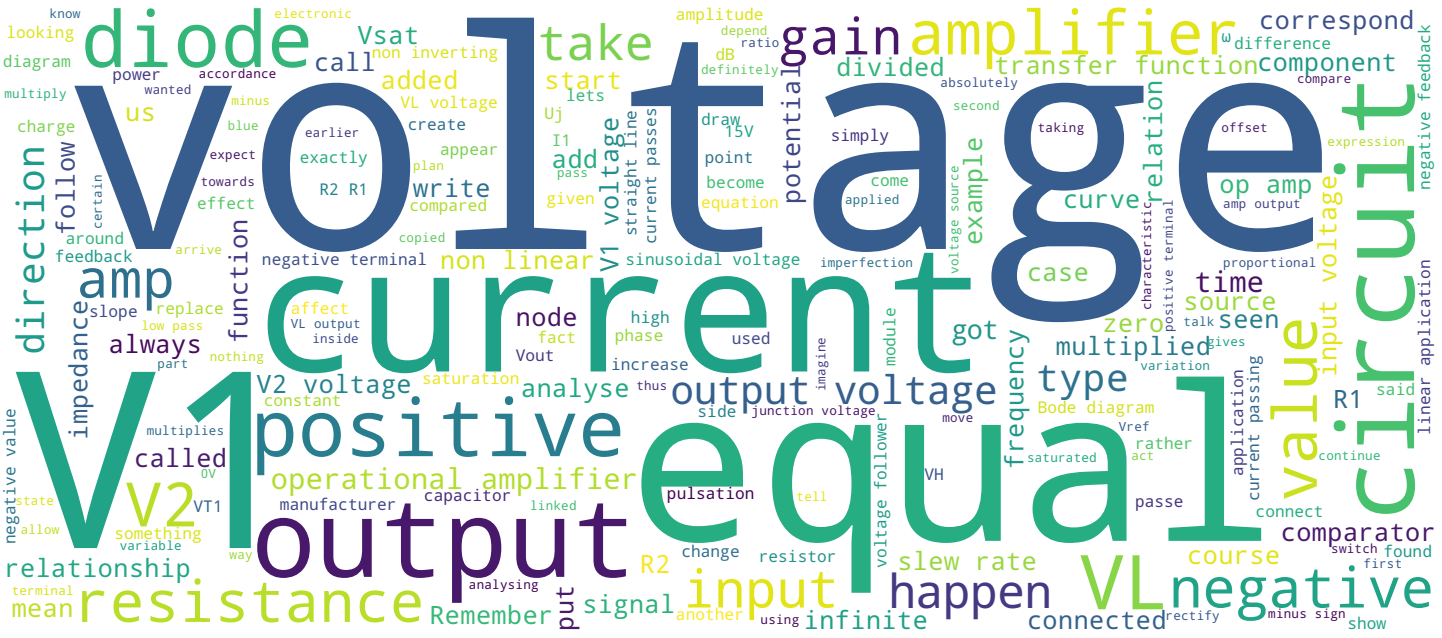


Video

EPFL

Redresseur non-inverseur simple alternance

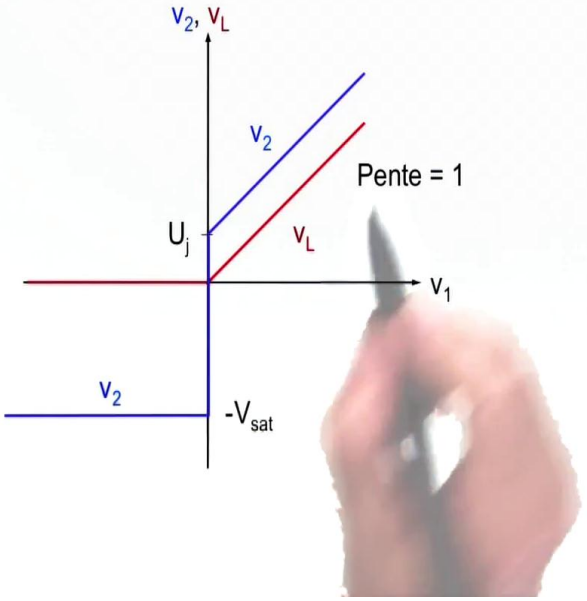
Once we've finished with linear applications, we're going to move on to non-linear applications. A non-linear application means that the relationship between input and output is not linear. It's not y = x. Typically, under non-linear applications we often study rectifiers. So, we take a circuit which manages to replace the famous diode. So this component which lets the current pass in only one direction, we can do it with components such as diodes, but to which we've added an operational amplifier arrangement. So, fulfilling the dream of an engineer is the super diode. Because a diode is unfortunately a passive component. The output voltage, when we leave it, when we use a diode, there's a junction voltage that we lose between the applied voltage and the output voltage, and this junction voltage is around 0.6 to 0.7V, or even less in some types of diode. We'd like to rectify a voltage with an amplitude of 100 mV. We can't use a diode, because the diode needs a certain level of voltage, and above that, it starts to act like a circuit which lets the current pass in only one direction. So, we're going to do it with operational amplifiers and by using diodes.

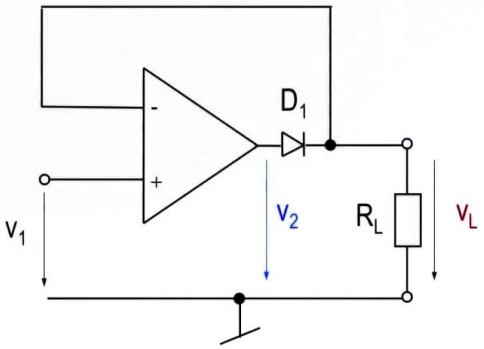
Notes

Summary

0m 04s

Redresseur non-inverseur simple alternance





Electronique I

To begin, I'd like to speak about the non- inverting half-wave rectifier. I'm going to analyse this line here, which shows what this arrangement can give us. The VL output voltage, the V1 input voltage, and we've added a diode. Of course, we have our operational amplifier which is here. This is what we expect of this circuit. I'm going to present and comment on it here, and analyse why we get something like this from this circuit. If you look at what happens to the V1 voltage here, as opposed to the V2 voltage then... Sorry, I rather want to talk about the VL voltage. If you look at what happens with the VL voltage, compared to the V1 voltage, then we can see that VL in accordance with V1, corresponds to this straight line here, where the output voltage, in relation to the input, has a slope = 1, so V1 = VL. This voltage is equal to that, when V1 is positive. The red line corresponds to the output VL. And we see that this red line will only follow the V1 voltage when V1 is positive. If V1 becomes negative, there it is, VL becomes equal to 0. So, VL = 0 if V1 is negative. VL = V1 if the V1 voltage is positive. Therefore it's non-linear. It's a non-linear curve. It's not a straight line.

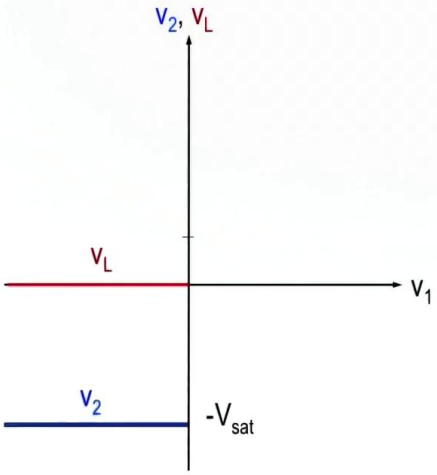
Notes

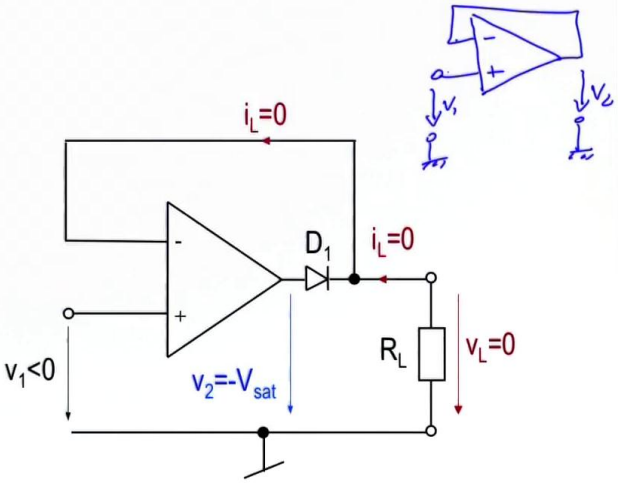
Summary

1m 26s

Redresseur non-inverseur simple alternance

- $v_1 < 0$, $v_2 = -V_{sat}$, $v_L = 0$





Electronique I

That's absolutely not the case. It's simply: look at the sign of the voltage and rectify it. So, if the voltage is positive, we find the component positive. And if the voltage is negative, the output voltage is cancelled out. We're going to analyse this circuit in the following way. I would like to analyse this circuit step by step, and explain how we analyse this type of circuit. So, you've seen that there is a diode. If we disregard this diode, I'm going to draw the circuit which is that without the diode. So, we have an operational amp, we have a voltage follower, and we have an input here, and here, we've connected a V1 voltage. And we're looking at the VL output voltage. So, theoretically, this type of circuit gives V1 = VL, this voltage equals this voltage, this voltage is the same as the output, there's no current passing here, it's the amp which provides the output current. And we have a voltage follower. We add a diode. This diode will be inserted between the amp output and the charge that we connected there. I started first by analysing what happens if the V1 voltage is negative, what happens with the VL voltage at the output. I said if V1 is negative.

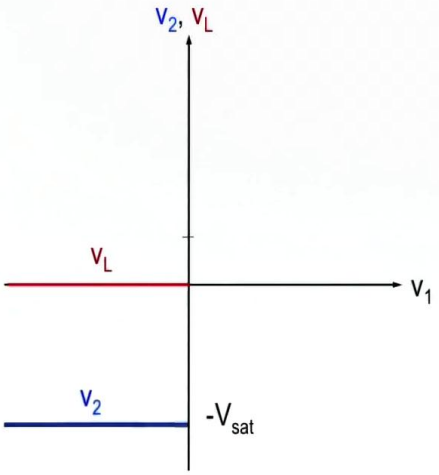
Notes

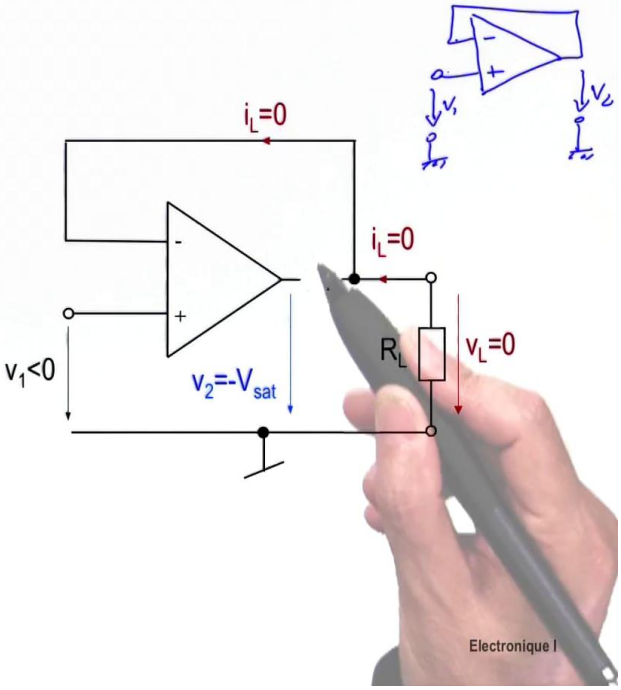
Summary

3m 08s

Redresseur non-inverseur simple alternance

- $v_1 < 0$, $v_2 = -V_{sat}$, $v_L = 0$





Logically, in this circuit, if V1 is negative, VL is negative. When we say: a VL voltage is negative, if that voltage had been negative, the current passes in this direction, I deliberately connected an RL resistor to simplify it and make it easier to understand. So, if you look at what happens with this resistor when it has a negative voltage, we expect there to be a current that passes from the earth and which should come out like that, arrive in this node here. It can't go over here, because the amp doesn't absorb current at the negative terminal. Generally, it passes the amp. It continues its path towards -VCC. But it can't do it, because we added a diode, and this diode blocks in this direction. So, this current can't at all get past this diode to go towards the amp. So, what will happen is that this current arrives, it can't go in this direction, i = 0 here, i = 0 here. And we'll get a voltage VL = 0. If we want to look at this arrangement another way, you just have to imagine it with a blocking diode. The current wants to cross it, so, logic says: it's as if we don't have this diode, as if this diode had disappeared. We have nothing at all here. Look what happens with this circuit.

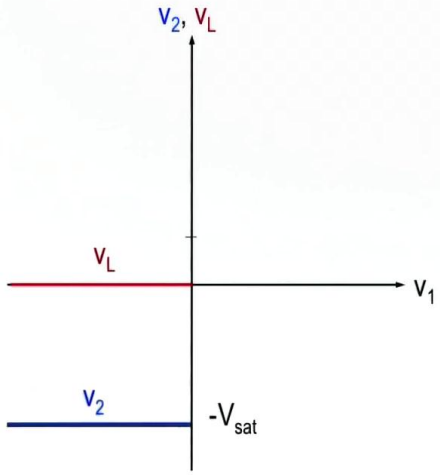
Notes

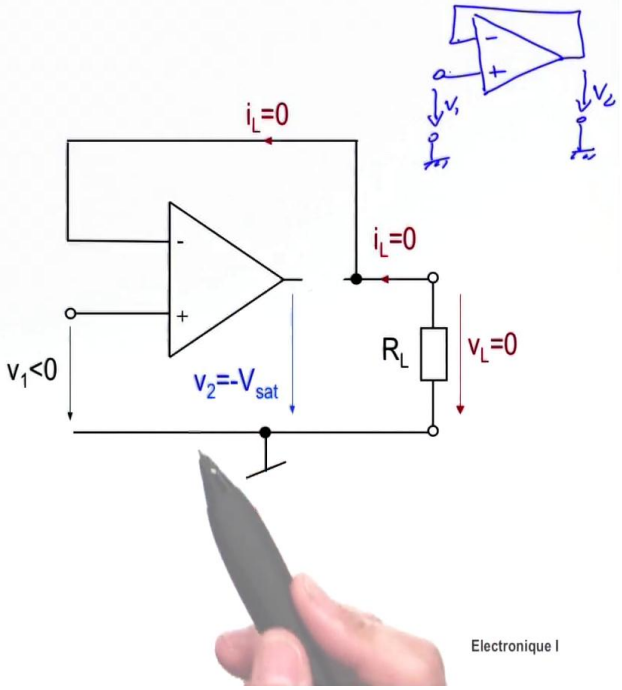
Summary

4m 39s

Redresseur non-inverseur simple alternance

- $v_1 < 0$, $v_2 = -V_{sat}$, $v_L = 0$





You find yourself with a circuit which is exactly this. The diode disappeared, because it has no role to play. The current here can't pass through there. The voltage, here, it finds itself on the positive terminal. But what can be found here as potential? We definitely have an iL = 0. In a charge where there's no current, the voltage VL = 0. So, your terminal or the negative input of your amp is connected to earth, through a resistor that plays no role, because there's a potential difference equal to zero, there's no current passing through anywhere, So you find yourself with a V2 voltage from your amplifier, disconnected from VL, and VL will show you a voltage equal to zero. And this is only applicable when V1 is negative. So analysing that on the curve, it's what I've described there. If V1 is negative, so we're below zero, VL = 0, we can see that here. V2, unfortunately, at that moment sees this potential connected to zero, sees this potential with a negative value, we can imagine at -1. If you have -1 here and 0 there, it's going to tell you that your amp will act as a comparator. It compares the -1 to 0, and it'll find itself with the 0 > -1, so it'll saturate towards Vsat −.

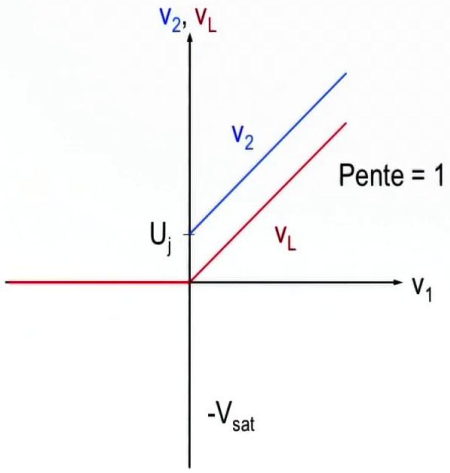
Notes

Summary

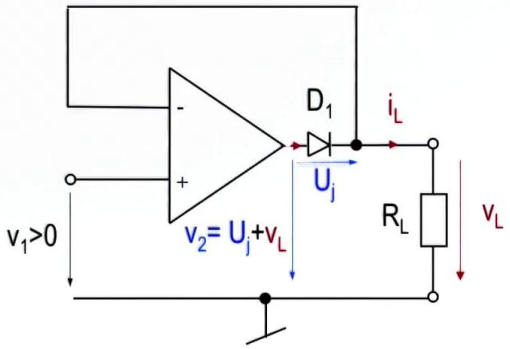
6m 02s

Redresseur non-inverseur simple alternance

- $v_1 > 0$, $v_2 = v_L + U_J$, $v_L = v_1$



$$A(v^+ - v^-) = v_2$$
$$A(v_1 - v_L) = U_J + v_L$$
$$v_L = \frac{A.v_1 - U_j}{A+1} \rightarrow v_L \approx v_1 (A = \infty)$$



Electronique I

The output of your amp will then have V2 = −Vsat. And that corresponds to what we've just seen here. V1 negative, V2, which we can't see, because we subdue it at the output. But at the output, our VL = 0. I'm going to take the same setup and this time analyse the case when V1 is positive. This time, V1 is positive. If you remember, the feedback, when V1 is positive and has a voltage follower, we expect VL to follow V1, so VL will have the value of V1, it'll be positive. A positive voltage means that the current iL is passing in this direction in the RL resistor. That means that there's a current which will come out of my amp through this diode, but this time the diode is in the right direction. And in this direction which lets the current flow, if the current passes through, there will definitely be a threshold voltage equal to Uj. The output of my amp which is there, V2, will see a Uj voltage plus the VL voltage. And we can see it here. So, when this current passes through this diode, the feedback is established. And I'm going to show now that the fact we added a diode won't hugely change what happens with this type of arrangement. We have V1 equal to this node here.

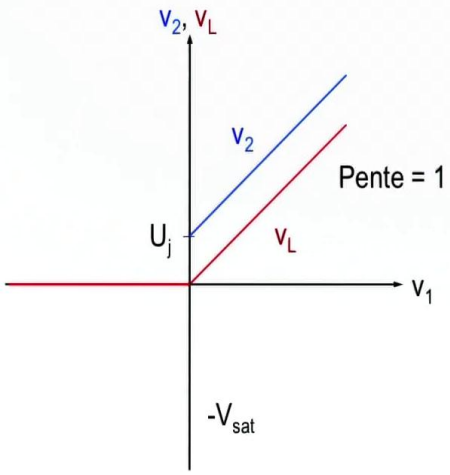
Notes

Summary

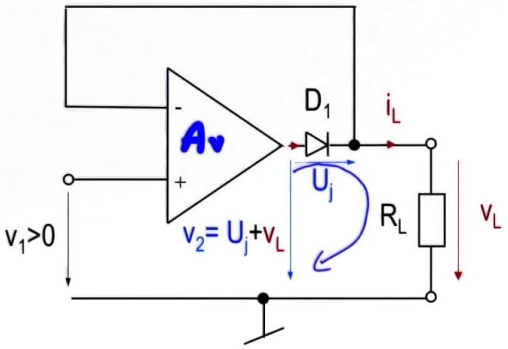
7m 34s

Redresseur non-inverseur simple alternance

- $v_1 > 0$, $v_2 = v_L + U_J$, $v_L = v_1$



$$A(v^+ - v^-) = v_2$$
$$A(v_1 - v_L) = U_J + v_L$$
$$v_L = \frac{A.v_1 - U_j}{A+1} \rightarrow v_L \approx v_1 (A = \infty)$$



Electronique I

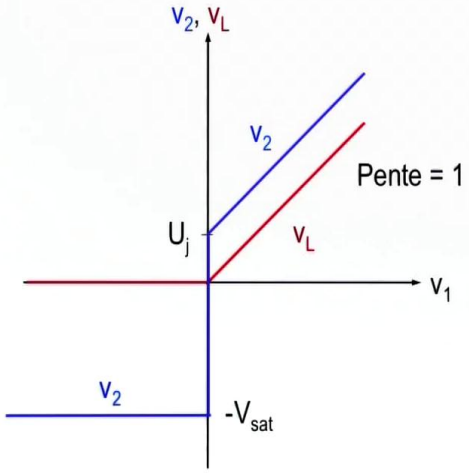
Remember that when an amplifier has feedback, this V1 here is copied there, and if you follow this line, it will go towards VL, so V1 is equal to VL. And that's exactly what we want from this circuit. We want it to become a follower when V1 is positive. So the positive component is returned at the output. I just wanted to give a little demonstration. By taking our operational amplifier, saying, as we've always seen, that the potential on the negative terminal, and the potential on the positive terminal, that's *V+ − V−*, is multiplied by the amplifier's gain, and this gain is infinite. If that gain is infinite, and we have the equation that V2 which is here, equals this infinite gain, which multiplies *V+ − V−*, and that this V2 voltage, I'll write it, this voltage is equal to Uj, if I take the Kirchhoff circuit laws from here to here, I'll say that *V2 = Uj + VL*, which is written here. So, this *V2 = Uj + VL*, and if I replace V+ and V− by their values, V+ = V1, which I put here. V− = VL, connected through here, and I write this equation. And I'd like to look at VL in accordance with the rest. This is saying that *VL = (A.V1 − Uj) / (A + 1)*.

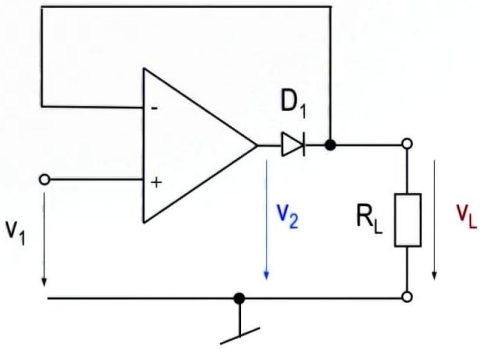
Notes

Summary

9m 10s

Redresseur non-inverseur simple alternance





☹Limité en fréquence (*slew rate*, réponse en fréquence de l'AO)

Electronique I

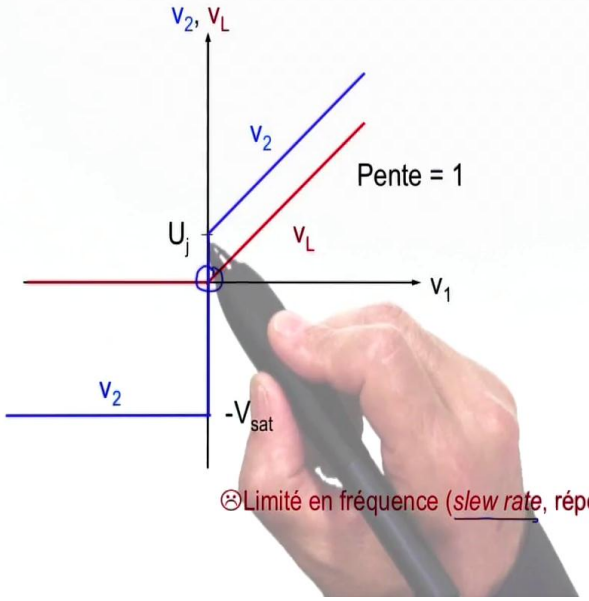
Remember that A is infinite. Remember that if A is infinite, and we look at ∞ + 1, I can easily say that I can discard this 1, in relation to this A. I also have A.V1, minus a certain relatively small amount, which is from around 0.6 to 0.7 V, this is the junction voltage at the diode's terminals. So I can also discard this component here. At that moment, I only have to look at the equation which is left, which is, of course... an estimation. It's *A.V1/A*, so I can eliminate A and A and I get VL = V1, which is exactly what I expected. Definitely this Uj enters into our equation, but compared to *A.V1* with a gain which is extreme, this doesn't affect it at all, or really affects this type of circuit very very lightly. So, with that we've got what we wanted. With that we've got that when the V1 component is positive, the V1 output will follow, or rather the VL output follows the V1 voltage, we see it there. When this is positive, we have a voltage follower with V2 which is still affected by Uj compared to VL, so that corresponds to this straight line here. To summarise, our circuit is this, with the results we got. If the voltage is positive at the input, the output will follow it.

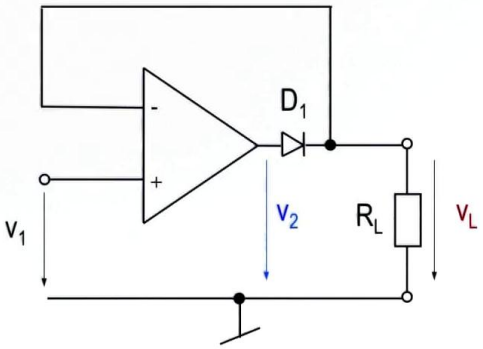
Notes

Summary

10m 43s

Redresseur non-inverseur simple alternance





☹Limité en fréquence (*slew rate*, réponse en fréquence de l'AO)

Electronique I

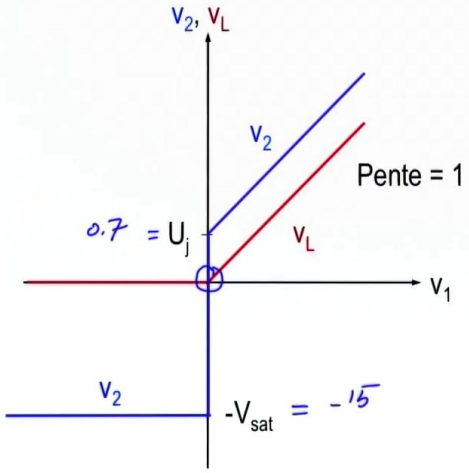
If the voltage is negative, the output will be equal to 0. So, there's another thing which makes this circuit have, or which gives this circuit a factor which could pose a problem when we want to go towards higher frequencies. Remember when we talked about one of the imperfections of the operational amplifier, what we called the *slew rate*. So, the famous *slew rate* of an amp, is this component or rather this effect, which says: unfortunately, the amp output can't vary from one value to another at an extreme speed, and the manufacturer shows us what the maximum speed is at which we can vary V2. And it's linked to an amount of consumption that the manufacturer has already established to make the inside of its amp. And we can find this in this diagram. When V1 passes from a negative value to a positive one, we're here, when V1 passes from a negative value to a positive one, the V2 voltage that you see here, should go from −Vsat to +Uj. If you increase your amp to supply voltages equally as high, such as if we have here something equal to −15V, and you tend towards a voltage of around 0.7V, you have something from −15 to 0.7, which poses quite a danger to our amplifier.

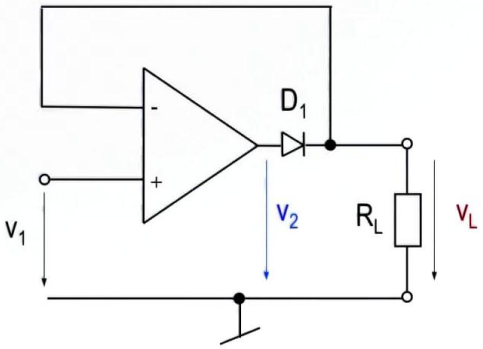
Notes

Summary

12m 23s

Redresseur non-inverseur simple alternance





☹Limité en fréquence (*slew rate*, réponse en fréquence de l'AO)

Electronique I

Every time the voltage we wanted to rectify goes from a negative value to a positive one, the amplifier doesn't manage to follow if the amplitude of the V2 voltage is high. So, remember that the *slew rate* affects the frequency response of the operational amplifier, but the *slew rate*, if you lower the value of V1 so in this case V2, so in this case VL, you perhaps manage to better follow, but this difference is quite excessive, and this has a big impact on the frequencies that we can get when we use a circuit like this. So we have really a big frequency limitation on this type of circuit.

Notes

Summary

13m 57s