ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Imperfections des Amplificateur opérationnel

6.2 Imperfections

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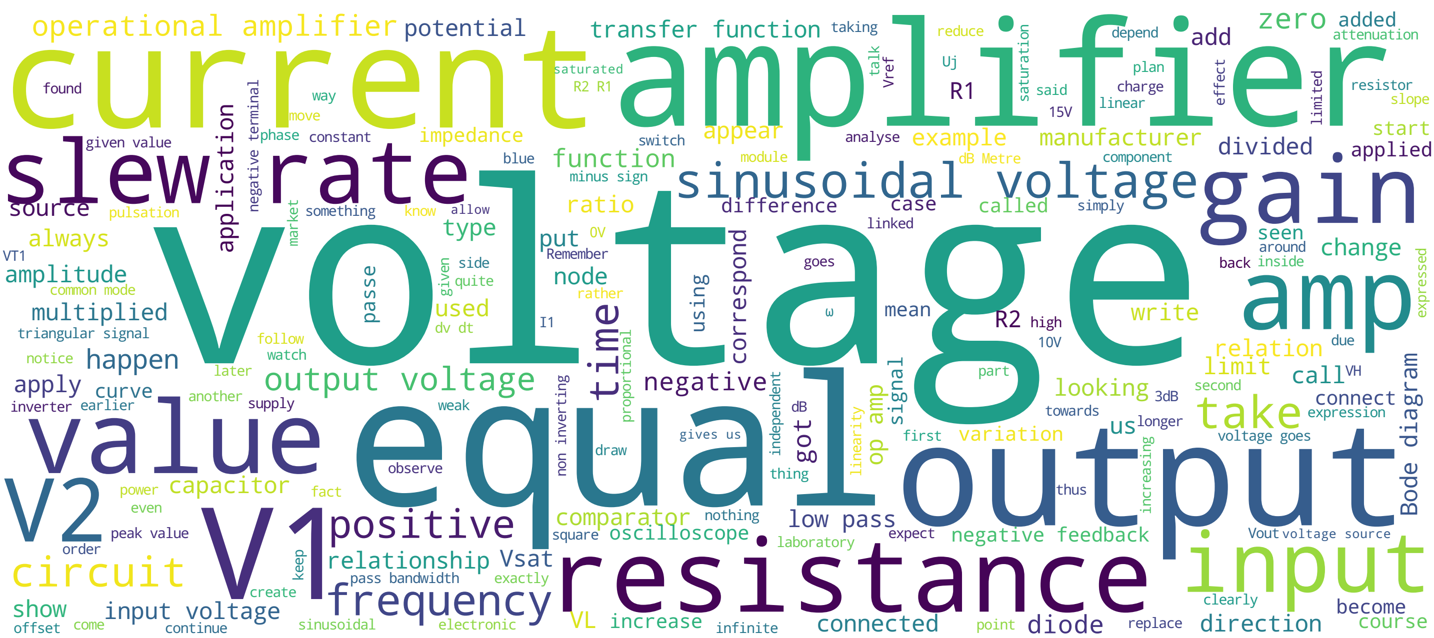
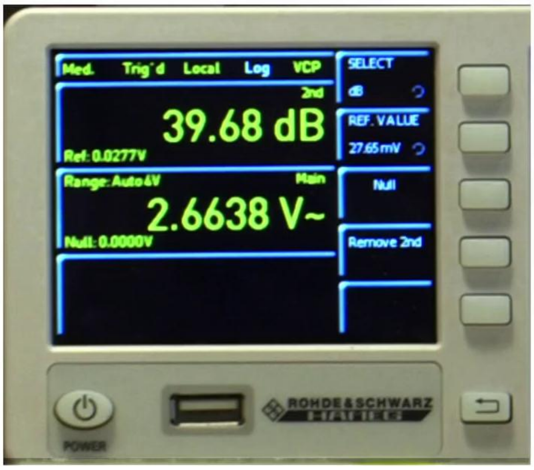


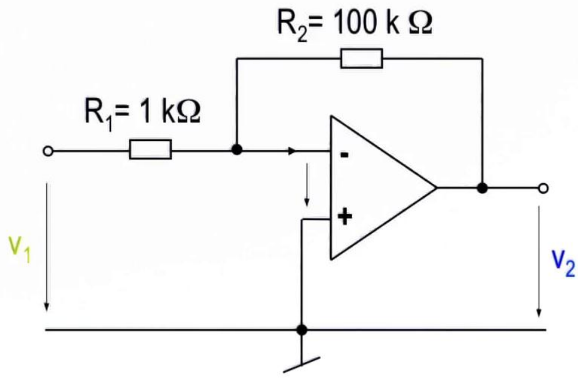
Video

EPFL

TP: Observation de la bande passante de l'AO

$$\underline{A} = -\frac{R_2}{R_1} = \frac{\underline{v}_2}{\underline{v}_1}$$





Electronique I

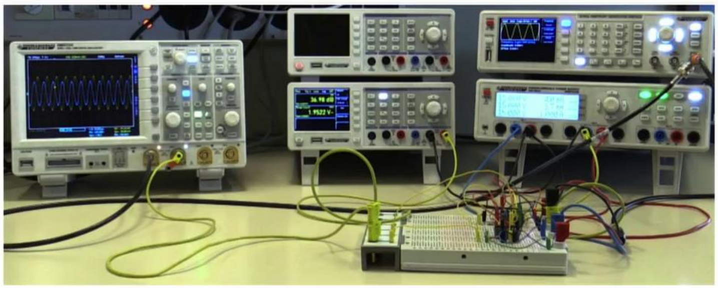
Now, I would like you to into the laboratory, and connect an operational amplifier which produces a gain equal to 100, So, an amplifier producing a gain of 100 connected in this way Remember that this is a closed-loop gain A equals resistance R2 divided by resistance R1 with a minus sign. This gain represents the ratio between voltage v2 divided by voltage v1. If we talk about a sinusoidal function, we're referring to a transfer function, involving complex numbers, We can observe that this gain corresponds to an amplification of voltage v2 and voltage v1 through a relationship based on resistance and resistance in this example, is equal to 100. What you see here, is simply a dB Metre which has been connected to show the ratiov2/v1. If we're given 20 log for R2/R1\ and we know that the gain is equal to 100 so it's 20 times log to base, 10 of the value 100 that will give us a magnitude of 40 decibels. So we are looking at the gain in the low-pass bandwidth of our amplifier and we can see that it is perfectly within the magnitude range expected from these two resistances. Of course, the minor error that you notice here, is due to issues of tolerance between the resistances in this experiment as in lab conditions, we take accurate readings.

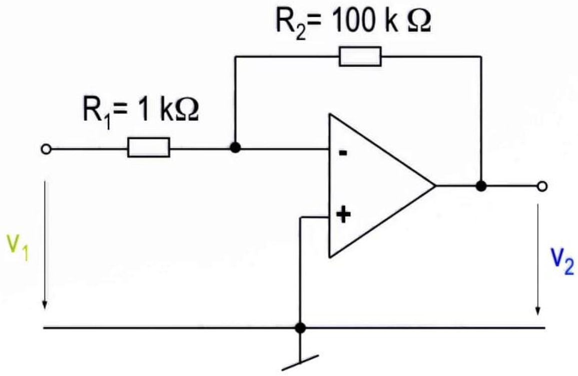
Notes

Summary

0m 03s

TP: Observation de la bande passante de l'AO





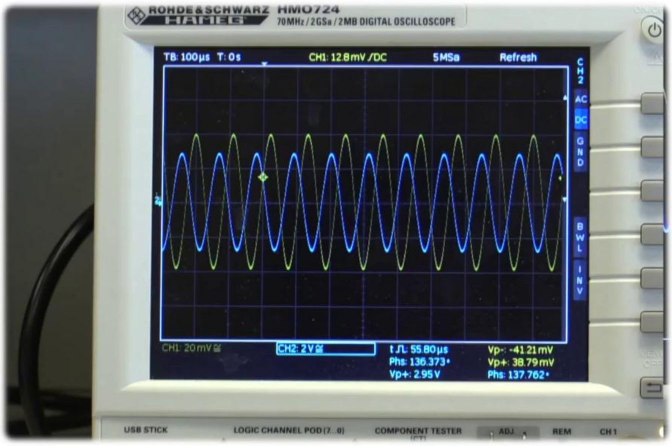
Electronique I

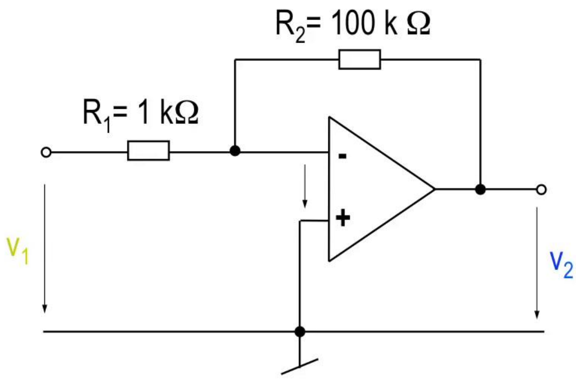
Here is the same montage in the actual experiment So our amplifier has been connected We have an oscilloscope that shows the voltage ratio v2/v1. and a dB Metre which gives us a reading of the gain of our amplifier, plus our function generator which injects a sinusoidal voltage, and we can clearly see that the voltage is sinusoidal. So now, we will demonstrate that by taking the value or more accurately the connected signal v1, and we're going to change its frequency. And when the frequency changes, you will notice that R2 and R1 remain unchanged we keep the same gain. When we increase the v1 frequency, this will be mirrored by the v2 frequency you'll see on the oscilloscope that the voltage will v2 go down. and will follow the Bode diagram that we saw earlier on and corresponds to the low-pass filter. By keeping the same gain and by increasing the v1,frequency you'll see that v2 will go down and tend towards a value, which, were we to carry on, would become so weak that it wouldn't even be registered on the oscilloscope.

Notes

Summary

1m 41s



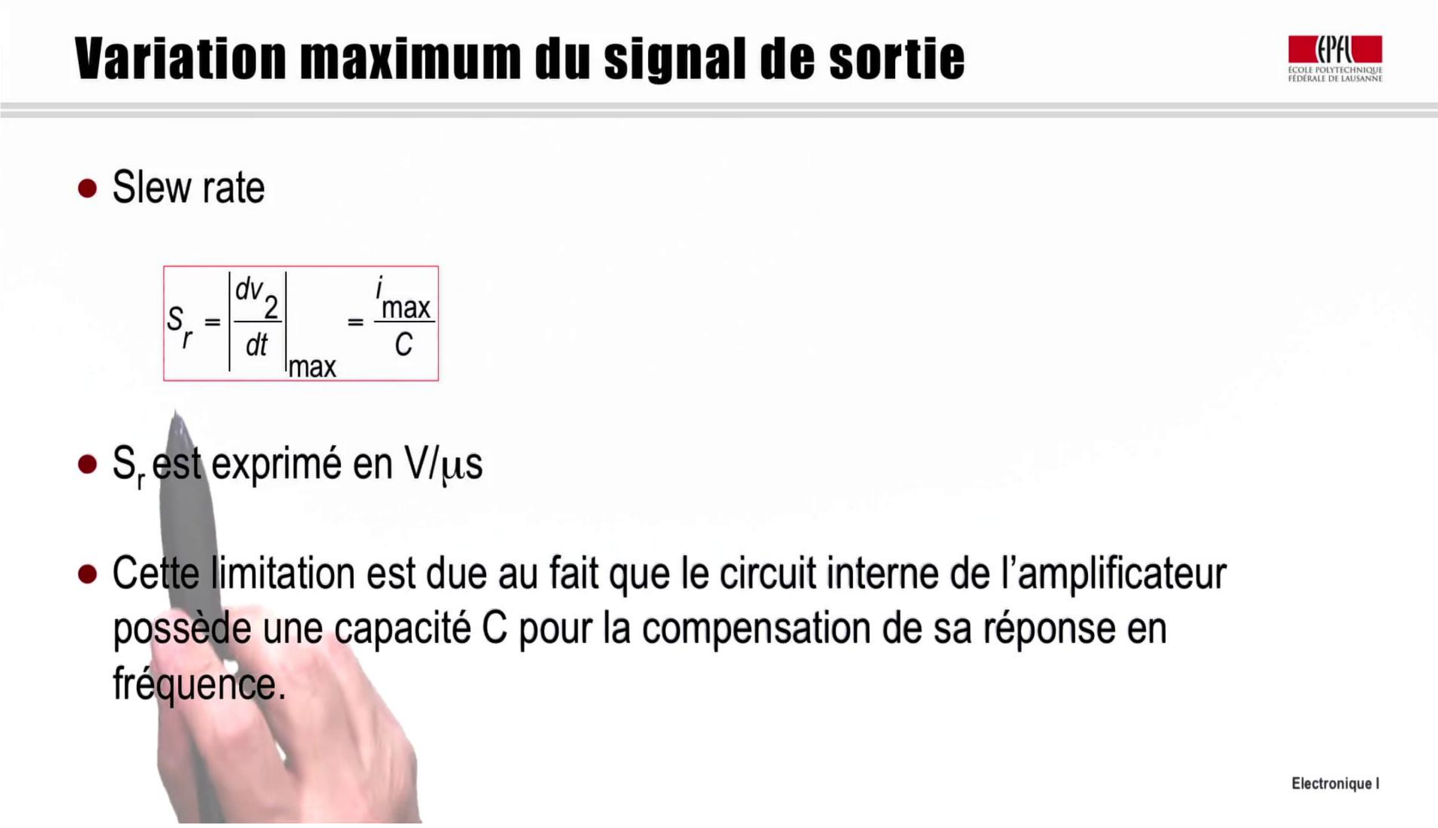


We can see this fT frequency At the input and output, we have two voltages which are phase-inverted in relation to each other that's an inverter. We're increasing the frequency of the input voltage. Watch the voltage in blue, which is the output one and is disappearing. as a result of the amplifier's action. and we can see it completely disappear because of the transfer function that we have just seen before. Now, let's go back in the other direction and look for the -3dB to find out the dominant pole. Let's change the frequency of our input voltage and we'll go up to an attenuation of 3dB. You will see that the output voltage has reached an attenuation of 3dB, it's the operational amplifier's natural pulsation at which the amp has now reached a slope of 20dB/décade. So this is a well-known phenomenon in amplifiers which is linked to its internal structure.

Notes

Summary

2m 59s



Another limitation of the operational amplifier, is the maximum variation of the output voltage. Unfortunately, to achieve stability of the operational amplifier, we have to add a capacitor which we find inside, we'll see it in the microelectronics course, but it doesn't appear in the integrated circuit, because it's integrated into the microchip. A certain amount of time is required for this capacitator to charge up, which limits the voltage change at the output. So, this is not linked to an issue of frequency but rather to the variation in voltage. When the voltage goes up from one value to another, we'll see that it will take this voltage a certain time and we're talking about the slew rate of an operational amplifier. And here's the explanation of the maximum variation of the output signal, that we call the slew rate of an amplifier. It's also a value of the output signal provided by the manufacturer which is determined by a ratio of the internal current of our amp, we can't see it, it's not up to us to decide its value, it has been used by the manufacturer to polarise the transistors inside the amplifier, divided by a capacitor, that has been added by the manufacturer to compensate for the frequency of an amp that will be used in negative feedback.

Notes

Summary

4m 02s

Variation maximum du signal de sortie

- Slew rate

$$\boxed{S_r = \left|\frac{dv_2}{dt}\right|_{max} = \frac{i_{max}}{C}}$$

- S_r est exprimé en V/µs

- Cette limitation est due au fait que le circuit interne de l'amplificateur possède une capacité C pour la compensation de sa réponse en fréquence.

Electronique I

So, even if you don't fully understand what this here means, Remember that the curve that we've just looked at on the Bode diagram corresponds to a low-pass filtre, is achieved like this, and the low-pass bandwidth is limited due to an internal capacitor. The slew rate is expressed in volts per microsecond. Therefore, it's a time variation. So we're looking at the ouput voltage of an amp and how long it takes for this voltage to change from one value to another. So, it's a ratio of a voltage variation divided by time which we can observe on a square or triangular signal and we'll try and analyse it particularly in relation to a sinusoidal voltage, to show that there's a link whose formulation may seem a little odd because it will be expressed in relation to frequency and yet, it's a variation which is no other than a variation in output voltage.

Notes

Summary

5m 30s

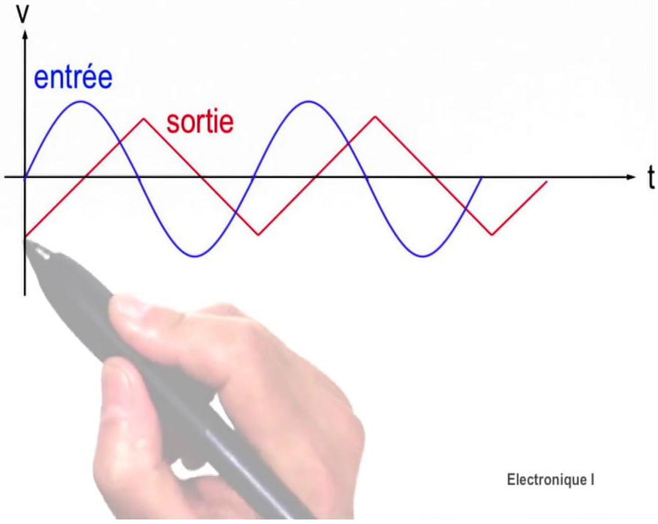
Conséquence de l'imperfection

- Pour une tension sinusoïdale:

$$v(t) = \hat{U}\sin(\omega t)$$

$$S_r = \left|\frac{dv_2}{dt}\right|_{max} = \left|\frac{dv_2}{dt}\right|_{t=0} = \omega\hat{U}$$

$$f_{max} = \frac{S_r}{2\pi\hat{U}}$$



Exemple numérique:
$S_r = 2\ V/\mu s$
$\hat{U} = 10\ V$

$$f_{max} = \frac{S_r}{2\pi\hat{U}} = \frac{2\times10^6}{2\pi\times10} = 31.8\ kHz$$

Electronique I

We're now going to have a look at the consequences of the slew rate on a sinusoidal voltage applied to an operational amplifier. If you take a sinusoidal voltage and apply it to an op-amp that has a slew rate supplied by the manufacturer. So, you've got an amp with a slew rate of a given value and you provoke a negative feedback in your amp and you apply this voltage. The voltage that appears at the input should be multiplied by a gain or transformed in a certain way but it should stay remain linear with the output voltage, it's a linear application. So, the slew rate will have the following effect. There's a limit that prevents your amp from registering a sharp variation in voltage. So there is a limit that is equal to a given value of a number of volts over a unity of time and that these volts over a unity of time, that are supplied by the manufacturer, will react in such a way that when the voltage wants to move or sharply increase, the amp will resist. So, when looking at a sinusoidal voltage and looking for the point at which the sinusoidal voltage does a dv/dt - the blue - sharp, we will notice that it's when it goes through zero.

Notes

Summary

6m 25s

Conséquence de l'imperfection

Electronique I

- Pour une tension sinusoïdale:

$$v(t) = \hat{U}\sin(\omega t)$$

$$S_r = \left|\frac{dv_2}{dt}\right|_{max} = \left|\frac{dv_2}{dt}\right|_{t=0} = \omega\hat{U}$$

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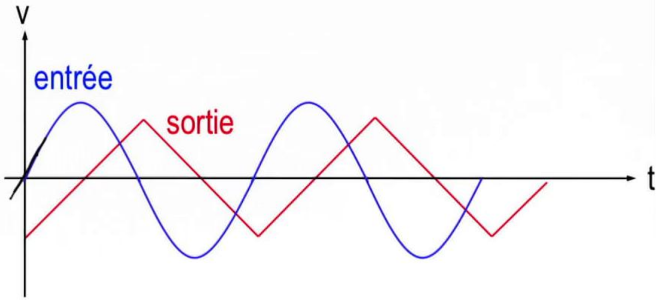

Exemple numérique:
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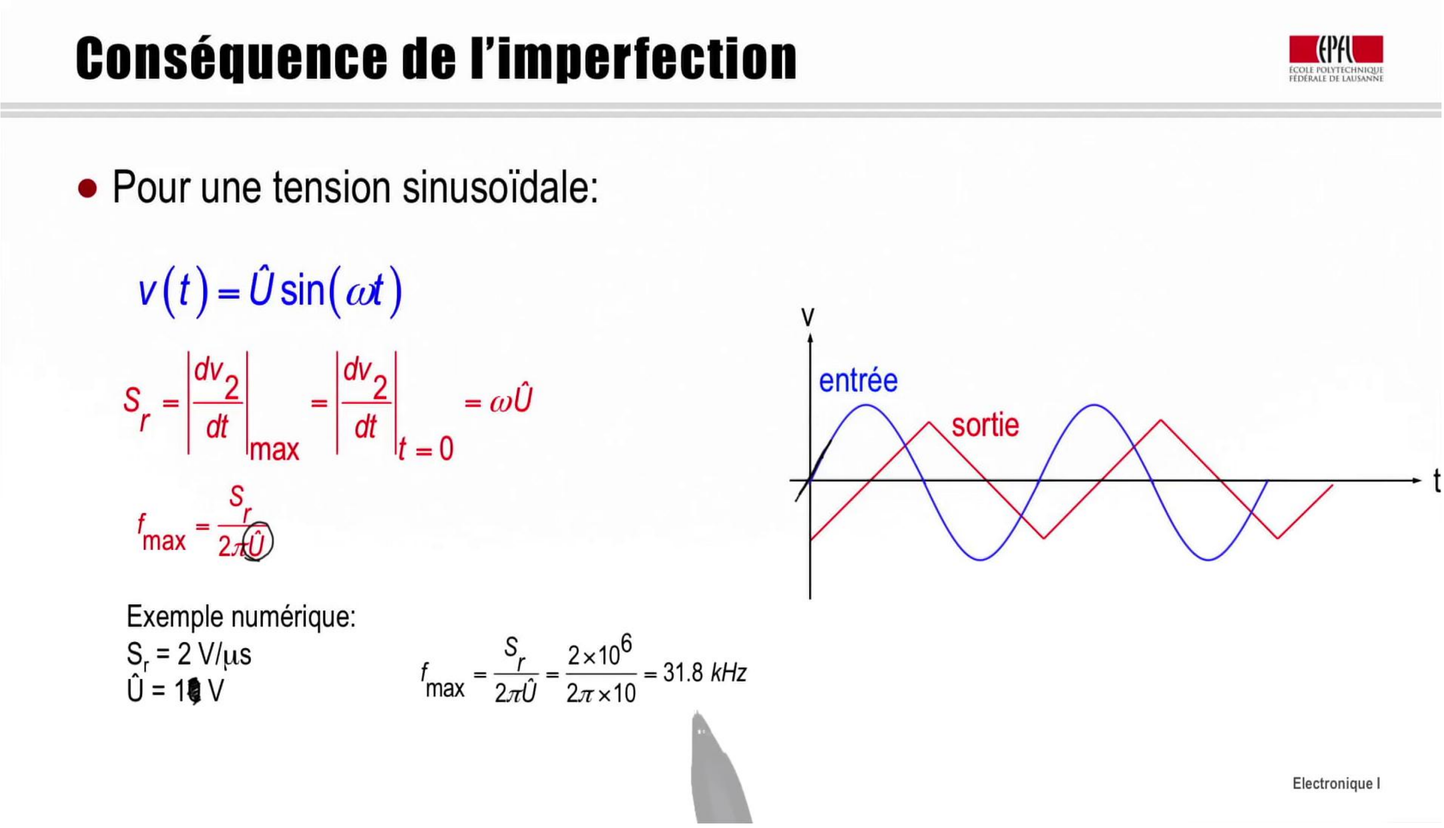
Each time the sinusoidal voltage goes through zero, we notice that it's when it passes through zero. Each time the sinusoidal voltage goes through zero, there's a higher dv/dt ratio. In other cases, it will continue, the voltage will continue to rise, until a certain time when dv/dt is equal to zero. So, if you take this sinusoidal voltage and look for the voltage or rather the impact of this slew rate on the voltage you just have to derive it when it goes through zero because it's that's the highest impact of the slew rate. So, let's derive. Ûsin at the instant t equals 0 which will give us ωÛ. So ωÛ corresponds to the frequency ω = 2πf and if you write down this ratio like this, you get a maximum frequency limited by this slew rate, which is equal to slew rate, the given value, divided by 2 x π x Û*. So we can clearly see that in this denominator, we've got the amplitude of the sinusoidal voltage that we've applied. which means that the more we increase the input voltage, the more you limit the utilisation frequency of your amplifier and that the voltage that you've applied, that is a sinusoidal voltage, doesn't have the time to change at the amp's output, because it's being held back by the slew rate and that transforms more or less into something that looks like a triangular signal.

Notes

Summary

7m 44s



So, we can't keep the linearity between the input and the output and the amp or the application that you've used, as it is not at all performing its function. So we just need to reduce the peak value to get back to a sinusoidal voltage between the input and the output. Let's look at a digital example. Let's assume that you've bought an amp, or that you're using an amplifier bought on the market, Let's assume that you've bought an amp, or that you're using an amplifier bought on the market, which has a voltage, or a slew rate equal to 2V/μs, a value supplied by the manufacturer, and that you're applying a voltage with a peak value equal to 10V and you're using this ratio. This ratio will tell you that you can use your amplifier up to the order of magnitude 31.8kHz because over this value, you will no longer see a sinusoidal output voltage, you'll see something that doesn't even have the time to get to the higher value. because It's limited by your amp's internal dv/dt Now, if you simply change the peak value of the voltage that you apply at the input, and you select 1V instead of 10V, Let's look at what happens here. You'll see that fmax equals 318kHz.

Notes

Summary

9m 18s

Conséquence de l'imperfection

- Pour une tension sinusoïdale:

$$v(t) = \hat{U}\sin(\omega t)$$

$$S_r = \left|\frac{dv_2}{dt}\right|_{max} = \left|\frac{dv_2}{dt}\right|_{t=0} = \omega\hat{U}$$

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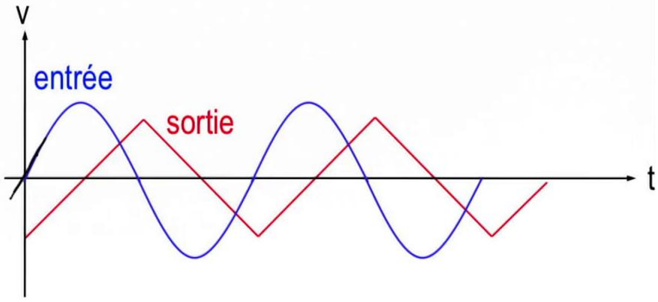


Exemple numérique:
$S_r = 2\ V/\mu s$
$\hat{U} = 10\ V$

$$f_{max} = \frac{S_r}{2\pi\hat{U}} = \frac{2\times10^6}{2\pi\times10} = 31.8\ kHz$$

Electronique I

So you've increased the utilisation frequency of your amplifier by the power of 10. There's a fundamental difference between a limitation caused by the slew rate of an amp and the frequency limitation of an amp, that we had analysed before and brought back to the low-pass bandwidth of an amp We had spoken about the frequency of fGBW that we also call the transition frequency. There is no direct link between one or the other. One, limit in the variation amplitude, that is the slew rate, the other one is independent of the amplitude but it is limiting the amplifier's frequency. That said, if you are tracing the Bode diagram of an amplifier and you apply a sinusoidal voltage, if you don't watch the voltage output and that, by chance, you were applying a voltage or a voltage amplitude that caused the slew rate to start reacting on your signal frequency, you haven't got a sinus at the output, so you won't be able to trace a Bode diagram of it and your amplifier isn't performing its role.

Notes

Summary

10m 39s

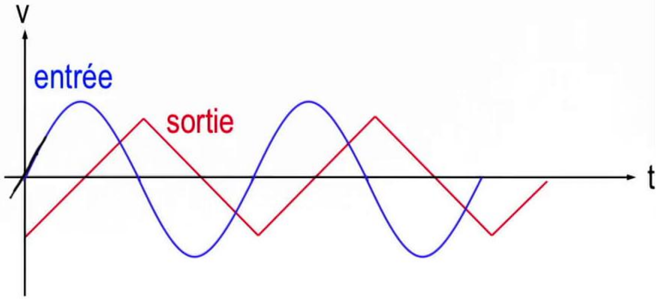
Conséquence de l'imperfection

- Pour une tension sinusoïdale:

$$v(t) = \hat{U}\sin(\omega t)$$

$$S_r = \left|\frac{dv_2}{dt}\right|_{max} = \left|\frac{dv_2}{dt}\right|_{t=0} = \omega\hat{U}$$

$$f_{max} = \frac{S_r}{2\pi\hat{U}}$$



Exemple numérique:
$S_r = 2\ V/\mu s$
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$$f_{max} = \frac{S_r}{2\pi\hat{U}} = \frac{2\times10^6}{2\pi\times10} = 31.8\ kHz$$

Electronique I

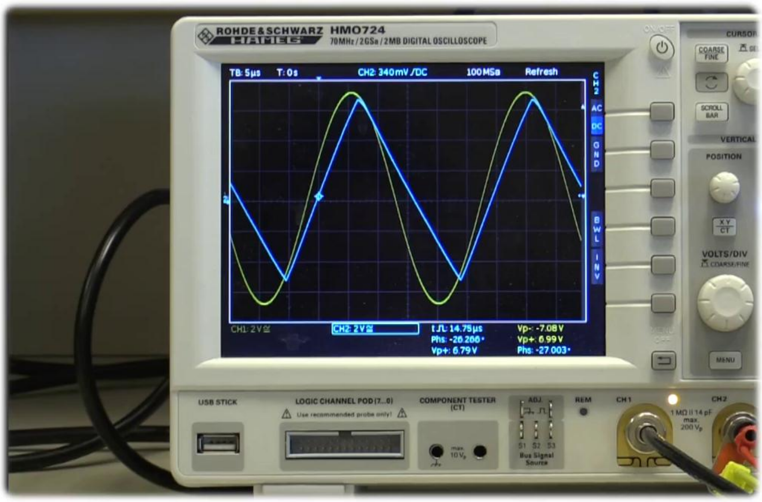
So, I recommend that you always connect an oscilloscope at the output of your amp and check that your amplifier has a sinusoidal voltage at the input, and is transforming it to a sinusoidal voltage by multiplying it by a certain gain or by filtering it, but always keeping this linear relationship between one and the other, because, if by chance, you have applied a peak value at the input that causes the amp to be limited byits slew rate, you'll loose your output voltage. So take care that the output isn't affected by an operational amplifier's excessive slew rate.

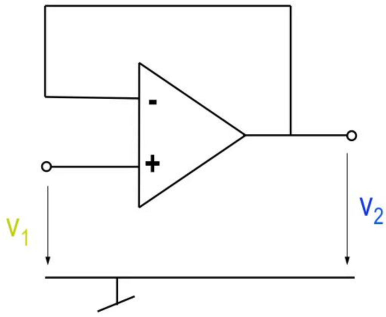
Notes

Summary

11m 48s

TP: Observation de l'effet de S_r





Electronique I

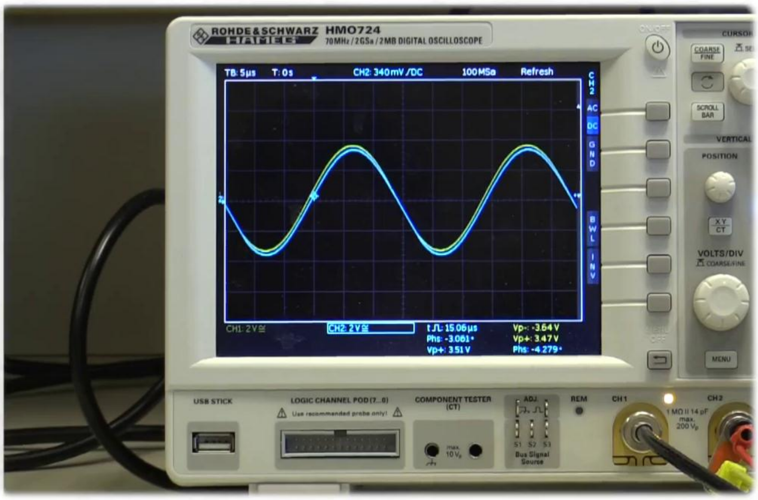
So, at the input of the amp, we apply a square wave signal, that's marked in yellow, and we're going to look to see what happens at the output. We're looking at a positive slew rate that isn't at all the same thing as a negative slope, that is a negative slew rate. In this respect, manufacturers give us different values. In this type of behaviour, we see that there isn't any symmetry in this structure. The negative slew rate seems to be completely different. And we can also see that there's quite a special reaction happening due to the fact that our amplifier is in tracking mode and later, you'll learn about a limitation which is called the common-mode range, It's an unusual phenomenon that appears at the input. Now we apply a sinusoidal voltage, which is a tracker, so we expect the output to be the same. And we're going to modify the amplitude of our input voltage and look at the output, how it is being modified. The blue curve, the sinusoidal voltage, is no longer a sinusoidal voltage. It's almost a triangular signal. And this triangular signal corresponds to the tangent slope of our sinus when going through zero. So the linearity that we'd expect from an amplifier has gone.

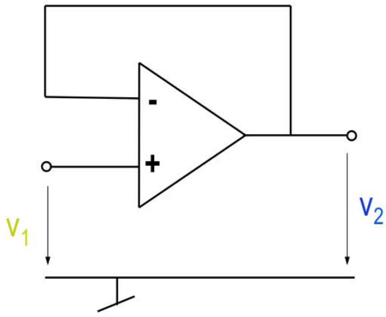
Notes

Summary

12m 27s

TP: Observation de l'effet de S_r





Electronique I

And this limitation is due to the amp's slew rate, it's nothing to do with the frequency. We haven't changed the frequency. And now we'll see what happens in the other direction. We start to reduce the amplitude and again, we get our sinusoidal voltage at the output and the amp's linearity has been restored. So, if you're looking at a Bode diagram with a system where the amplitude is limited by the slew rate, your dB Metre won't read the correct values.

Notes

Summary

13m 46s