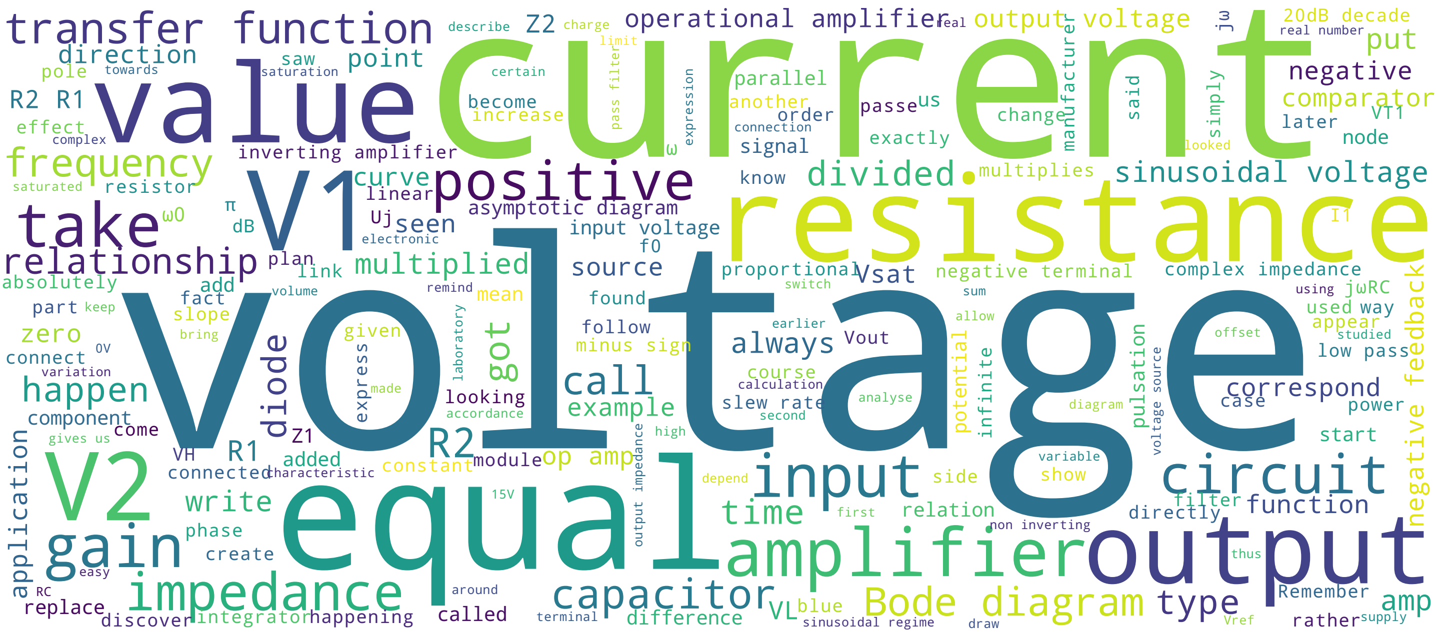
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Amplificateur opérationnel

4.1 Amplificateur à gain dépendant de la fréquence

Prof. Maher Kayal

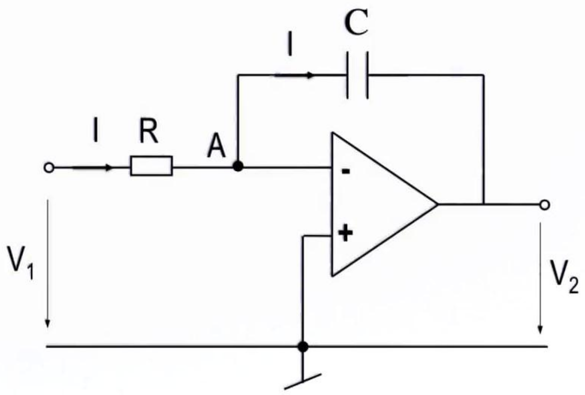
Electronics Laboratory-ELAB



Video

EPFL

Intégrateur inverseur de tension



Electronique I

We've looked at the amplifier for which gain has absolutely no dependence on the frequency. We've seen that in using resistances such as negative feedback, an op-amp's gain is a linear relation between the input and the output, and that there is absolutely no dependence between the frequency and what is happening with the voltage between the input and the output. Today we're going to look at another theme, which will be: what happens if the components which we use to apply negative feedback on the amplifier, for example, have capacitors? So, we have a capacitor and we know for sure that the capacitor has an impedance and that this impedance depends on the frequency. So, we're going to have a look at what's happening and we can see that this leads us to discover that it's just the function of a filter, how we can use the operational amplifier to filter the frequency and work on the Bode diagram that we use to describe the relationship between input and output and to plot the poles and the zeros on the Bode diagram in accordance with our components. Here we have what's called an integrated circuit. You should recall that it's an inverting amplifier.

Notes

Summary

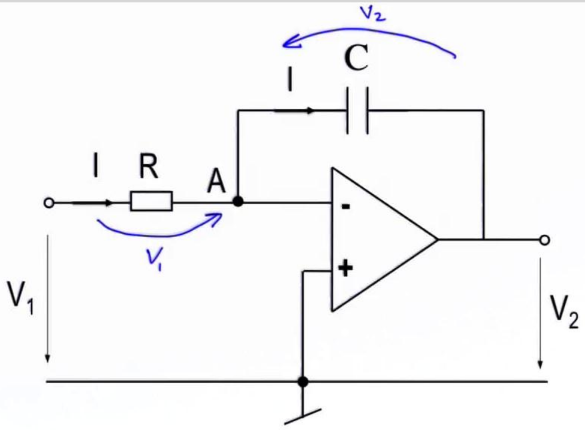
0m 03s

Intégrateur inverseur de tension

$$I = \frac{V_1}{R}$$

$$i = C \cdot \frac{du}{dt}$$

$$i = C \cdot \frac{dV_2}{dt}$$



Electronique I

You've seen that the inverting amplifier has a negative input connected to the volume and that we've got an element of negative feedback that in an inverting amplifier has an independent frequency gain, here, we've put a resistance. Here, we replace the resistance with a capacitor and we keep the resistance that was here. So, we're going to have a look at what's happening. I remind you that the power input *I*, will always be proportional to the voltage, *V1*, divided by the resistance value of the terminals from which I see the current *V1*, I see the same current *I* passing into the capacitor. Here, it's going to change. This current *I* will be equal to *C.du/dt*. In the temporal domain, a capacitor links the power to the voltage of its terminals via a derivative effect from the voltage. In this case, this voltage *du*, is the voltage *V2*. Remember that the voltage *V2*, is this one here, exactly what we saw before, so, this tension *V2*. So, I just have to write that this current *i* is equal to *C.dV2/dt*. And, this current *i* is indeed the same current *I* that we see here, that links *V1* to *R*.

Notes

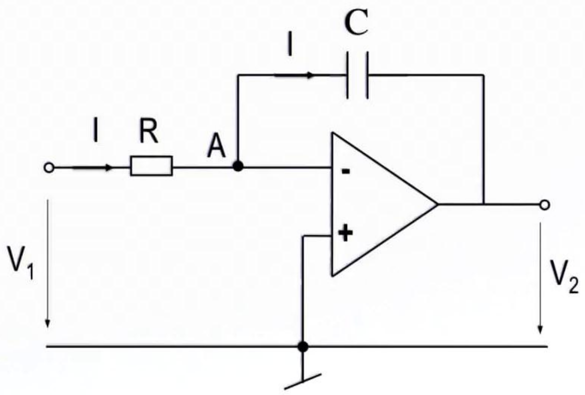
Summary

1m 20s

Intégrateur inverseur de tension

$$I = \frac{V_1}{R} = -C\frac{dV_2}{dt}$$

$$V_2 = -\frac{1}{RC}\int_0^t V_1 dt$$



$R_{in} = R$ $R_{out} = 0$

Electronique I

By analysing what we see in this plan and some of the relationships that are written on it there, we're going to come to the following conclusion: We're going to discover that the voltage *V1/R* equals *-CdV2/dt*. By looking at the value of *V2* in accordance with *V1*, forcibly, we're going to find an integral relationship. Which means that our voltage *V2* sees or depicts in real time the intirety of the voltage *V1dt* multiplied by *1/RC* and therefore, there is always this negative sign due to the fact that the voltage *V2* is positive in this direction and the current *I* is positive in this direction here. The output impedance stays the same as an inversing amplifier, knowing that *R(in)* equals *R*. The output impedance remains equal to 0 because it is governed by your operational amplifier.

Notes

Summary

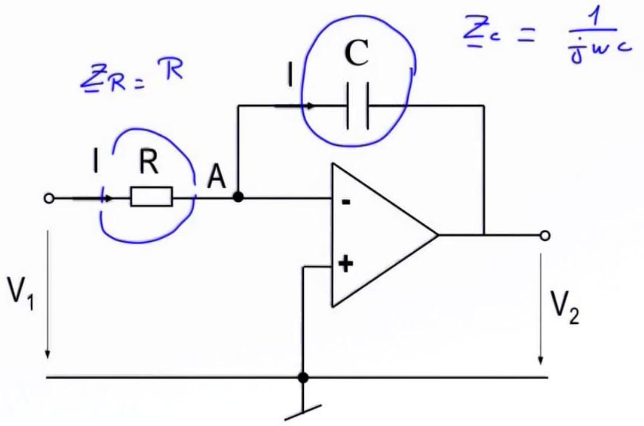
2m 53s

Régime sinusoïdal

$$\frac{V_2}{V_1} = \frac{Z_c}{Z_R} = \frac{1}{j\omega \cdot R \cdot C}$$

$$H = \frac{1}{j\omega \cdot RC} = \frac{1}{j\omega/\omega_0}$$

$$\omega_0 = \frac{1}{RC}.$$



Electronique I

I'd really like to look at the same example but this time look at what happens in a sinusoidal regime. In a sinusoidal regime, we can replace the capacitor with its complex impedance. So, rather than write the temporal relationship of the capacitor that links current to the derived voltage, we're going to replace it by an impedance *ZC*, and this impedance *ZC* = *1/jωC*. It's the same for the resistance *R*. This resistance *R*, I replace with its complex impedance *ZR* which is a real number and which is equal to the value of the resistance *R*. We've analysed the inverter application and we saw that when we want to link the complex voltage output, because we had only a sinusoidal regime for a sinusoidal voltage, to the voltage input *V1*, we wrote, we discovered that it's a relationship between this impedance divided by this impedance. So, I'm going to write down clearly that it's the impedance *ZC* divided by the impedance *ZR*. Which equals *1/jωRC*. So I discover that the relationship between the sinusoidal voltage that I see at the output because of the sinusoidal voltage that I see at the input, it's a transfer function that I will name *H*, I'm in the complex world, that equals *1/jωRC*, that I generally write as though it was *1/jω* over *ω0*, paying particular attention that *ω0* = *1/RC*.

Notes

Summary

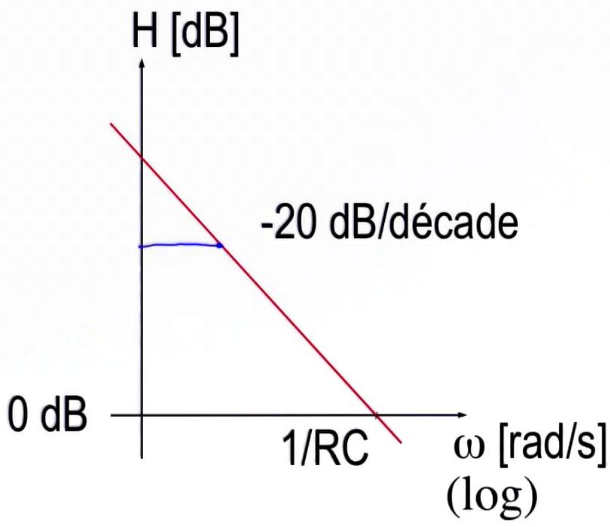
3m 56s

Régime sinusoïdal

- Fonction de transfert :

$$\underline{H}(j\omega) = \frac{\underline{V}_2}{\underline{V}_1} = -\frac{\underline{Z}_2}{\underline{Z}_1} \qquad \underline{Z}_1 = R \qquad \underline{Z}_2 = \frac{1}{j\omega C}$$

$$\underline{H}(j\omega) = \frac{\underline{V}_2}{\underline{V}_1} = -\frac{1}{j\omega RC} \qquad Z_{in} = R_1 \qquad Z_{out} = 0$$



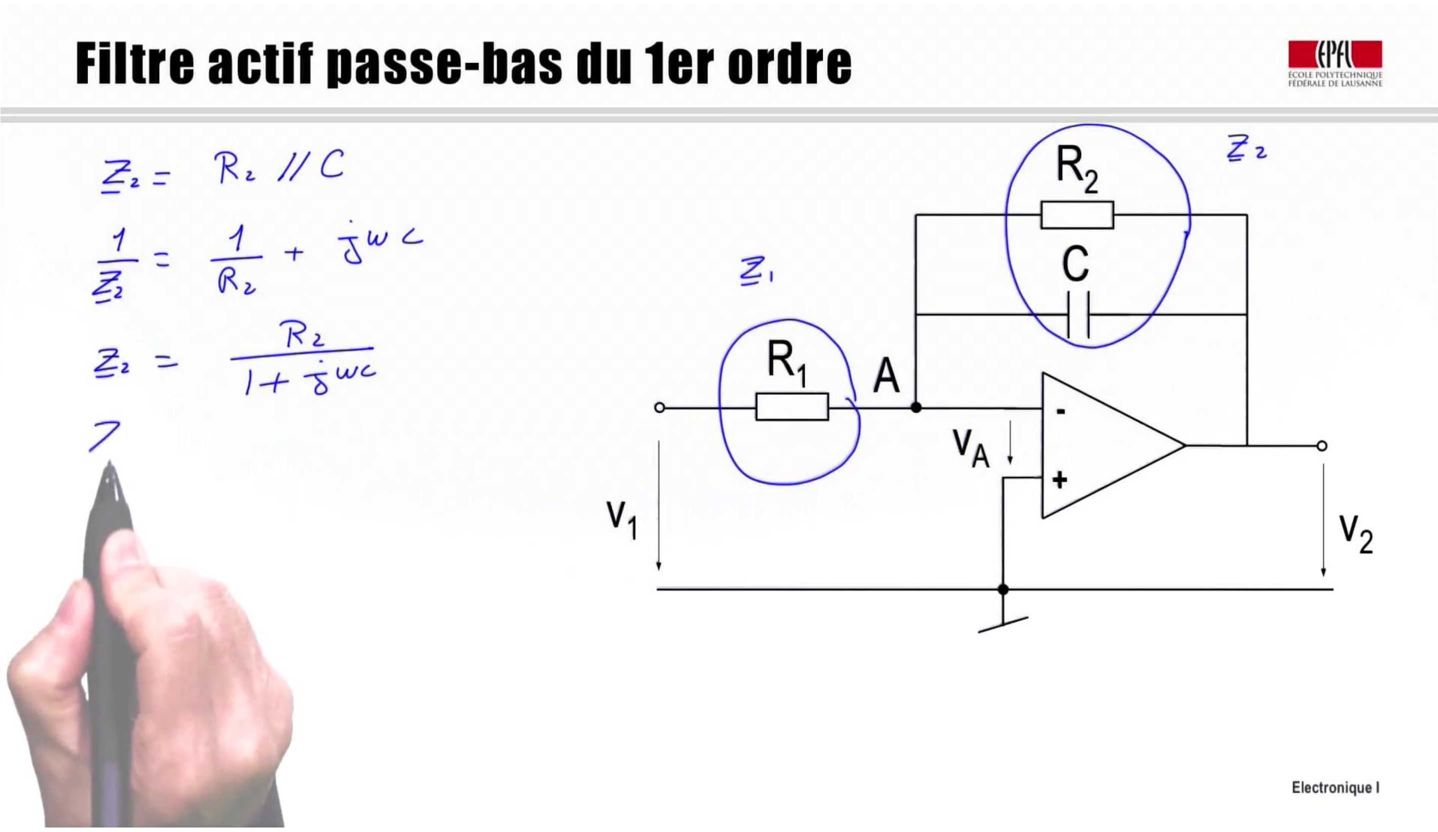
Electronique I

Here's a recap of what we've just seen and the calculations that we've just made. We've got a transfer function *H(jω)* that equals *-1/jωRC*. When we studied the Bode diagram in such a way, if you remember correctly, the Bode diagram functions with pure imaginary. With the imaginary that is found within the denominator, it's a slope that equals -20dB/decade and this corresponds to the integrating effect for a sinusoidal voltage. So, if you would like to see a sinusoidal voltage that is integrated, you need to go right here, where the slope equals -20dB/decade. Why am I pushing this point? Because later on, you'll see that this type of integrator is always used with a resistance that we're going to put in parallel with the capacitor *C*. To achieve a certain gain that we call a gain that will express a plateau in the asymptotic diagram here and this will mean that when I've got this type of functioning the blue curve has a constant value. After I find this slope of -20dB/decade, and yes, you need to go past this pole, in any case, put yourself ten times over the value of the pole from the transfer function, somewhere here to see the integration value of a sinusoidal voltage placed at the input and see the integration at the output.

Notes

Summary

5m 45s

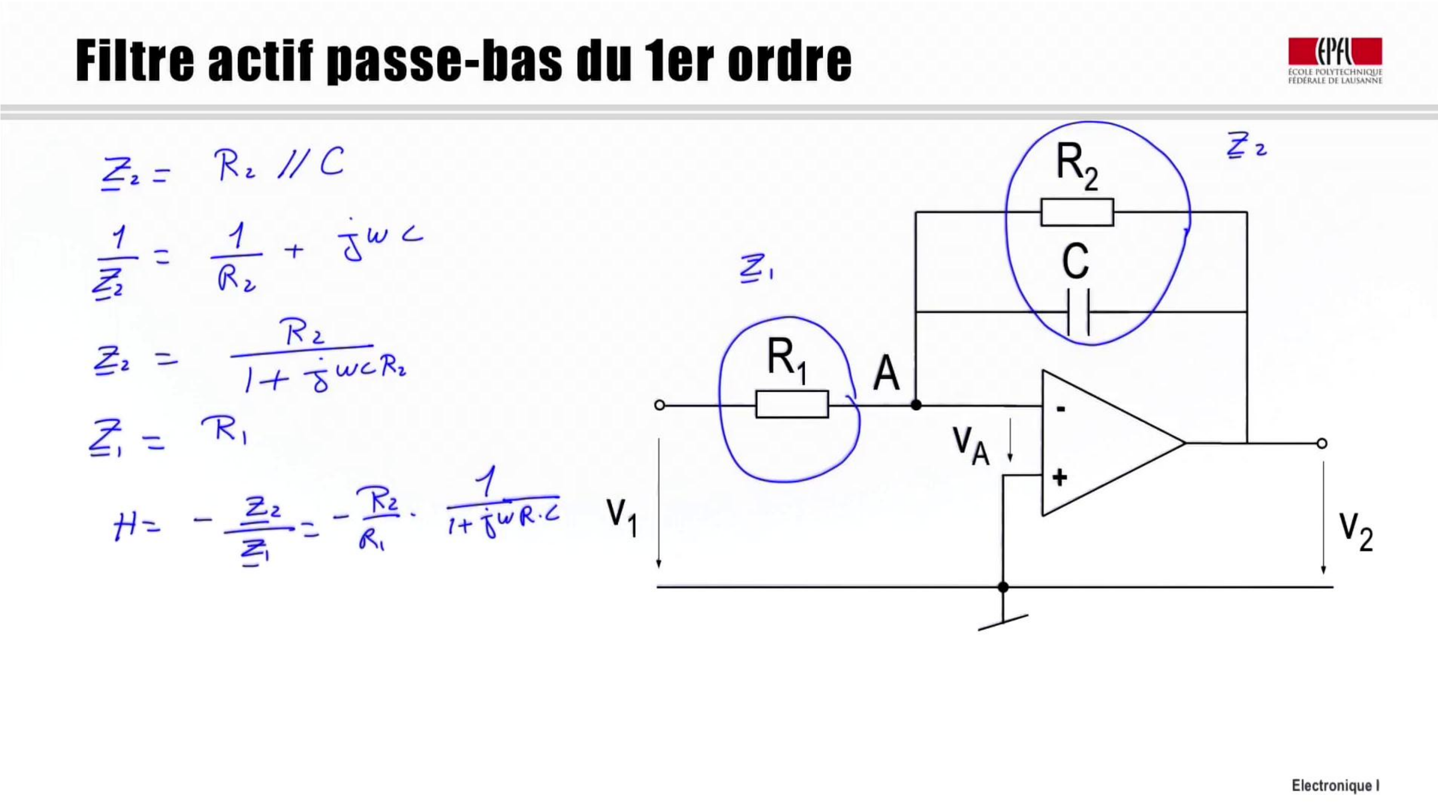


To recap what I've just said. I take my integrator. I see my capacitor in a negative feedback loop between the input and the output and on the negative terminal and I see my resistance *R1*, which is the input resistance on this application. I've added the resistance *R2* in parallel with the capacitor here. I'll write down the transfer function of this. Always, when dealing with this type of application, we take the impedance that is in negative feedback and we express it in the complex domain. We do the same with the impedance here and we express it with its complex impedance. So, I'm going to call this complex impedance *Z2*.. I'm going to call this impedance complex *Z1*. and I'm going to write *Z2* and *Z1*. So here, the complex impedance *Z2*, is an impedance placed in parallel with *R2* parallel with a capacitor. So I'm going to write *1/Z2*, to make things easier, which is simply *1/R2 + jωC*. I've simplified it. Once inverted, I'll find that it's *R2/1 + jωC*. Here's the impedance *Z2* that we've achieved. The impedance *Z1*, is really easy: I get it directly, it's a real number and equals the resistance *R1*.

Notes

Summary

7m 20s



Now all we need to do is make the connection between this impedance and this impedance and I add a minus sign in front in order to find the transfer function *H* which equals -*Z2* divided by *Z1*. So I take *Z2* and *Z1* and I can say equals -*R2* divided by *R1* that multiplies 1 over *1* + *jωRC*. And there, I've forgotten a resistance *R2* that I bring down again before the capacitor *R2* that multiplies *jωC*, that I'd forgotten before.

Notes

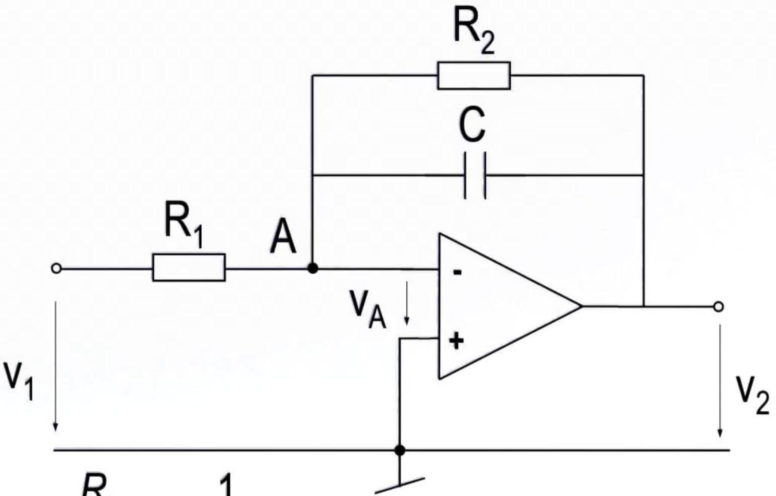
Summary

9m 03s

Filtre actif passe-bas du 1er ordre

$$\underline{Z}_2 = \frac{R_2 \frac{1}{j\omega c}}{R_2 + \frac{1}{j\omega c}} = \frac{R_2}{1 + j\omega R_2 C}$$

$$\underline{Z}_1 = R_1$$



$$\underline{H(j\omega)} = -\frac{\underline{Z}_2}{\underline{Z}_1} = -\frac{R_2}{R_1}\frac{1}{1 + j\omega R_2 C} = -\frac{R_2}{R_1}\frac{1}{1 + j\omega / \omega_0} \text{ avec } \omega_0 = 1/R_2 C$$

Electronique I

To summarise what we've just seen and the calculations that we've just made, written properly with the impedance *Z2*, the impedance *Z1*, the transfer function *-Z2/Z1* we fall on this figure which is a clear and net gain *R2/R1*. So we see the component, or rather the value that is like an inverter, an inverter amplifier, that's the relationship between *R2* divided by *R1* that multiplies the transfert function 1 over *1 + jω* over *ω0* and we replcae *ω0* with *1/R2C* and we call it the transfer function pole. I'm going to take this transfer function and trace the transfer function onto the Bode diagram that's here.

Notes

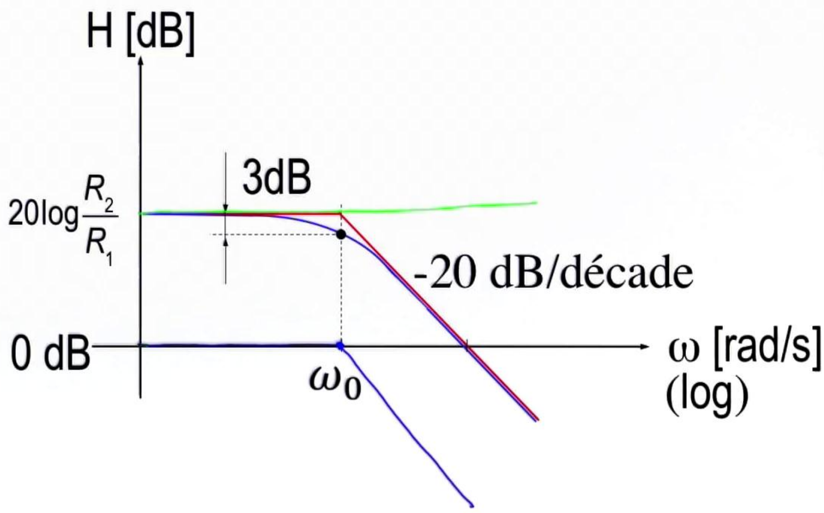
Summary

9m 47s

Comportement en fréquences

$$\underline{H(j\omega)} = -\frac{R_2}{R_1}\frac{1}{1+j\omega/\omega_0}$$

$$Avec\,\omega_0 = 1/R_2C$$



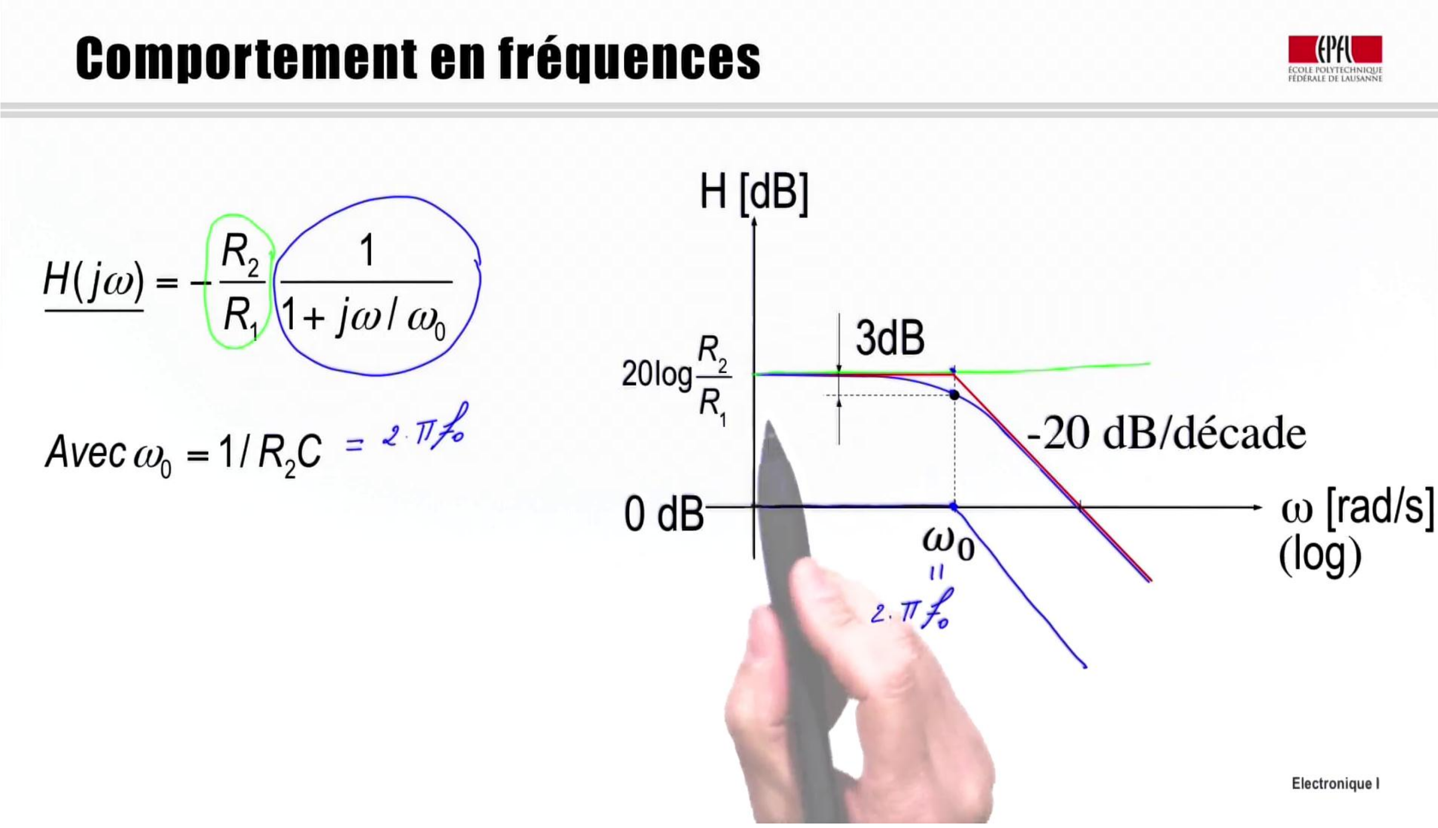
Electronique I

I take the transfer function. I can divide it into two. I take the green part, *R2/R1*. Which is the component without the *ω*, therefore there is no frequency effect on it. Remembering that *ω = 2 x π x f*, therefore it's directly proportional, the pulsation is proportional to the frequency. So, you've got *R2/R1* and you can say that you've 20log of *R2/R1* reported in a Bode diagram to consider the number of decibels. I take the function *1/jω/ω0* again that will give me on a asymptotic diagram something in blue. And I've got the transfer function pole that can be found at *ω0*. Knowing the value *R2* and the value *C*, I'm going to take that up to a point and I'm going to create the asymptotic Bode diagram. You'll find the Bode diagram on this part here, in blue, asymptotic diagram, and you find the independent gain frequency that's in the green part, which is here.

Notes

Summary

10m 42s



And I carry out the addition of this curve with this curve here, and I see that the red curve that corresponds to the sum of the two and the Bode diagram that we will have measured, goes to three decibels in relation to this point, so, there is -3dB between the asymptotic diagram and the diagram that we have measured and that's what we're going to do in the laboratory to take into account the points brought down and the points that we will have traced with the asymptotic Bode diagram. We call that a "Low-pass filter". It's easy to understand what that means. We recognise a pulsation *ω0* that equals *2 x π x f0*, so, *f0* is a frequency, multiplied by *2π*, that gives us this value and that we see is directly proportional to the values *1/R2C*. So, you just need to choose a resistance *R2* and *C* and get directly the *2 π x f0*. In practice, what do we do? We want to limit the frequency range on the asymptotic diagram to a signal with a value of *f0*, and that will give us *w0*, we know that it will follow this type of attenuation so it will be multiplied by the gain.

Notes

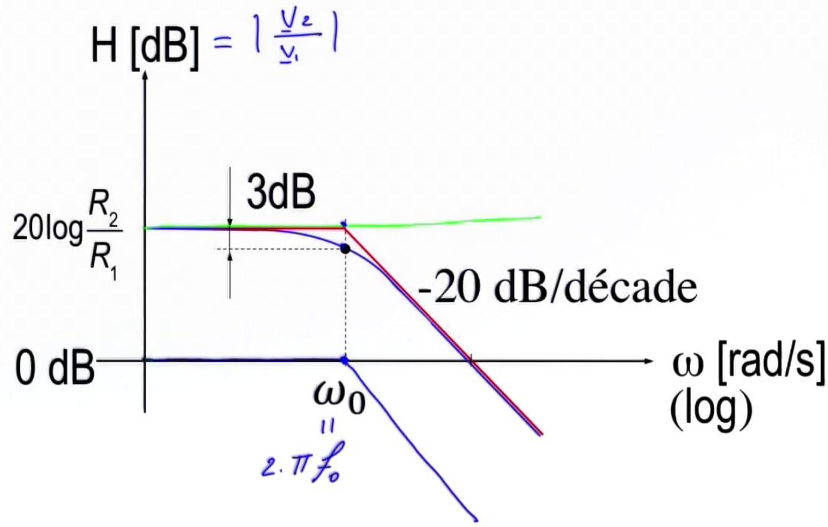
Summary

12m 08s

Comportement en fréquences

$$\underline{H(j\omega)} = -\frac{R_2}{R_1}\frac{1}{1+j\omega/\omega_0}$$

$$Avec\ \omega_0 = 1/R_2C = 2\cdot\pi f_0$$



Electronique I

And from here, it will follow the blue curve, so we see that the output amplitude, remember that it's the relation module of the voltage output over the voltage input, and therefore the module is the output amplitude divided by the input amplitude which will be multiplied by a gain proportional to the resistance *R2/R1* and when you start to go over, on the asymptotic diagram, the value *ω0*, you see, you'll lose 20dB to every ten. So, for each multiplication of pulsation by 10 you'll lose 20dB. You can see it by this relationship and this curve demonstrates it. And we call this a "filtre passe-bass" because the bass frequencies are multiplied by a gain and the high frequencies are obtained according to this curve that we see here.

Notes

Summary

13m 33s