ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

Applications des Amplificateurs opérationnels

8.4 Bascules et générations de fonctions

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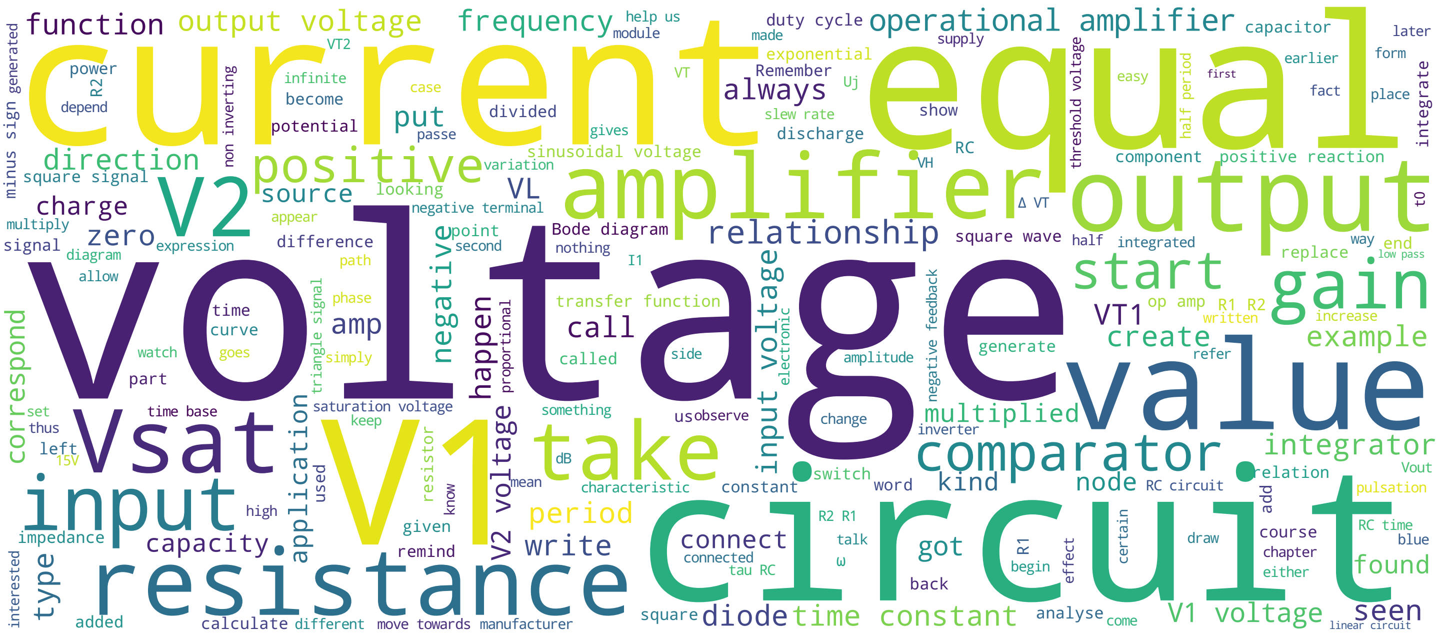


Video

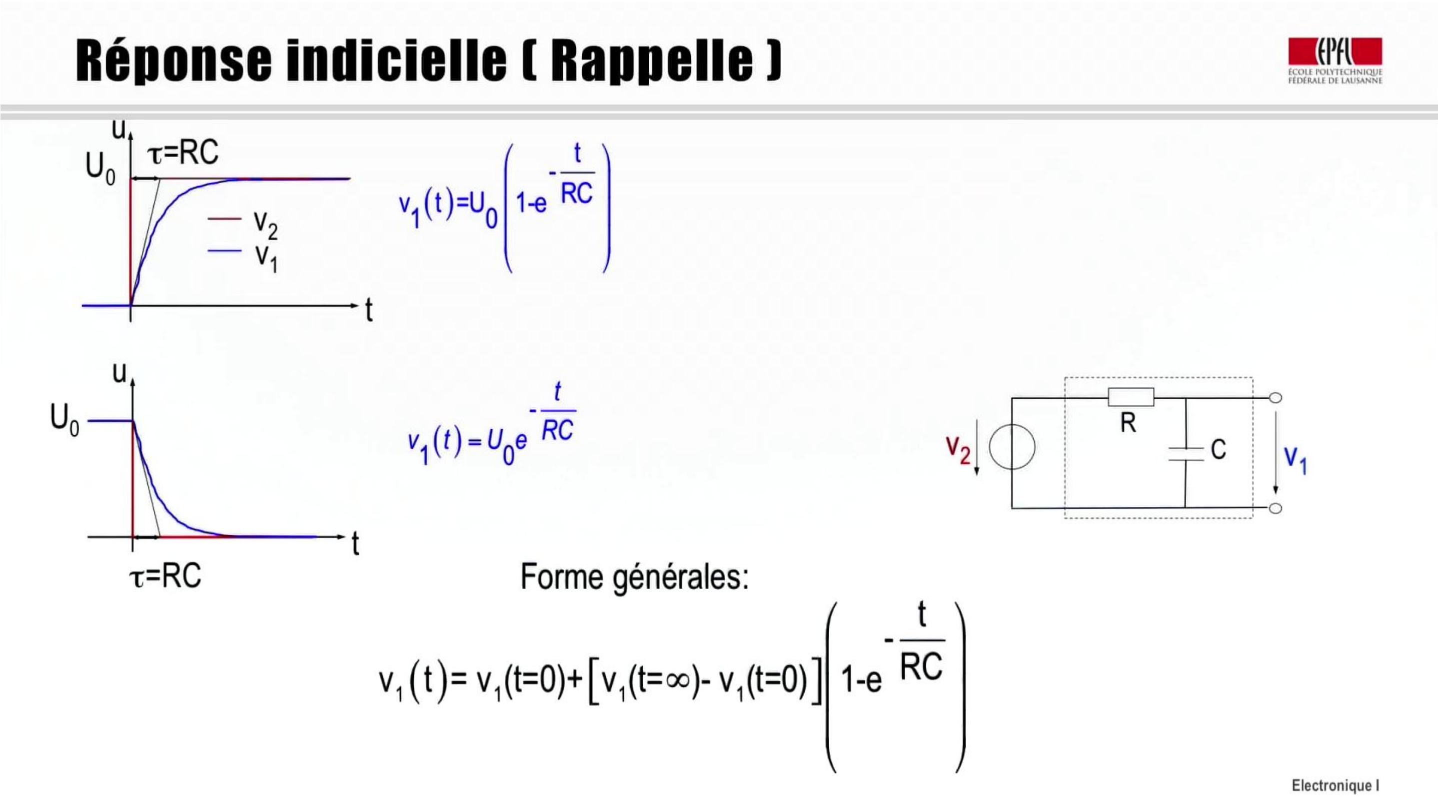
EPFL

Among the applications of operational amplifiers, there's a fairly well-known one: they have no input voltage, just an output voltage. Sometimes we have to design a time basis, in other words, we have to create a wave, typically a square wave, which has a well-established frequency. Sometimes, we need a triangle wave. We can push to have a sinusoidal voltage, called an oscillator. So these kinds of functions carried out by operational amplifiers, of course we'll consider comparators as well, allow for a variety of applications where there is no input, but where there is an output. This output is a deterministic voltage called a function generator. These are the sorts of devices which can be found on laboratory benches, and which generate a square wave with a variable duty cycle, or with a variable frequency generating a variable amplitude. The same goes for a triangle wave, and for a sinusoidal voltage. I'm now going to immediately introduce these kinds of functions, just to show how we synthesise them and how we create them with operational amplifiers and comparators. We need a time base. And so, we need certain parameters which help us to create a certain time that we can control.

Notes

Summary

0m 04s

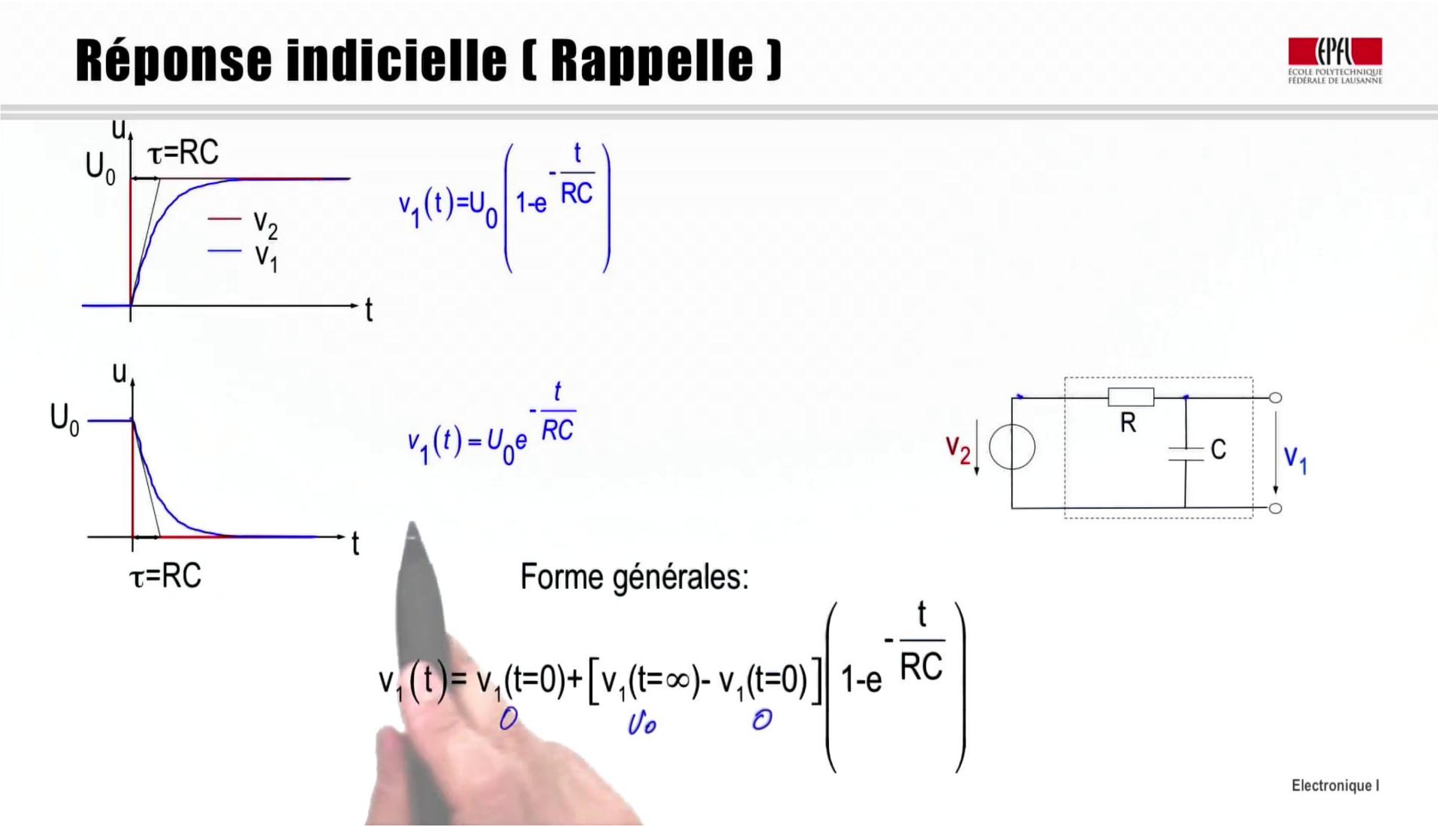


The most important aspect of these time bases, but one not addressed in this chapter, is quartz. We can use quartz which can be added and which would help to stabilise a frequency. Here, I'm predominantly going to use an *RSC* time constant which, within the Time domain, and knowing the \tau = RC time constant, would help us to generate simple functions which are very easy to wire in a laboratory and are easy to check. Before starting to talk directly about the electronic diagrams, I would like to remind you of how we deal with these resistances and capacitances to create a \tau = RC time constant. And just to remind you what this \tau time constant is, if you take a resistance and a capacitance, and if you generate a voltage here, a Dirac impulsion, would later become a square wave. Whenever there's a voltage jump, this circuit will not react immediately. Instead, it will move towards the maximum value of the U0 voltage that we applied to the input. There would be no sudden change in the input voltage. An exponential function would be generated. The objective, just as a reminder, is not to go into the details about how we found these relationships, you will have no doubt studied them in lessons on physics, basic electronics, or basic electro-technology.

Notes

Summary

1m 24s



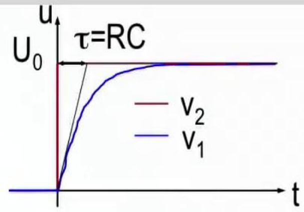
There's a general form here which will always help us to write the exponential voltage. Wherever we start from... We create a voltage jump from a given value: here I've given two examples. One example is where we start from a U0 value at the moment equal to 0. Here, we start from a value of 0, and we make a jump, which is in red, and in blue, we can see that we're going to end up with the V1 voltage at the output. Therefore, the V1 voltage would be written as V1 voltage at time t = 0, like this. In this instance, t = 0, and in this curve, it's equal to zero. V1 starts from zero and V1 ad infinitem will move towards the maximum value of the input voltage, namely U0. Why? Because this capacity will create a charge and it will be charged by the value. It will reach the value of the maximum voltage found here. When the U0 is here, appearing from the other side, well, the resistance R stops the current from passing, because there's a difference in potential equal to zero. By writing this relationship V1(t = 0) = 0 V1(t= ∞), we get the U0 voltage. And here again, we have zero, multiplied by 1 - e, to the power of -t/RC, and we end up with that relationship. We can do the same with this.

Notes

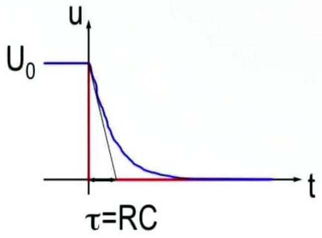
Summary

2m 44s

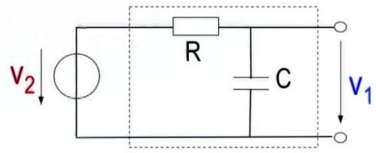
Réponse indicielle (Rappelle)



$$v_1(t)=U_0\left(1-e^{-\frac{t}{RC}}\right)$$



$$v_1(t)=U_0 e^{-\frac{t}{RC}}$$



Forme générales:

$$v_1(t)=\underset{U_0}{v_1(t=0)}+\left[\underset{0}{v_1(t=\infty)}-\underset{U_0}{v_1(t=0)}\right]\left(1-e^{-\frac{t}{RC}}\right)$$

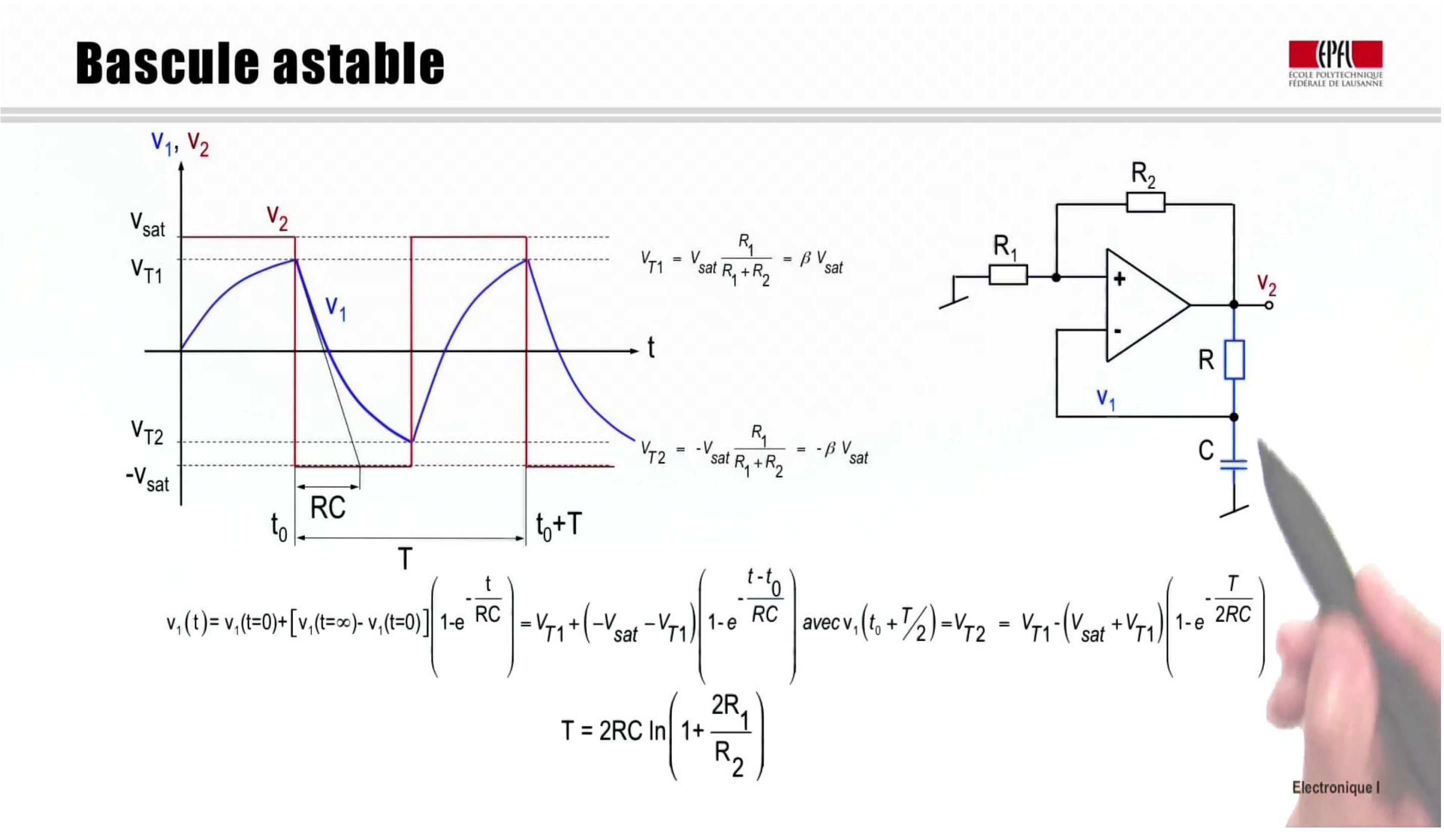
Electronique I

So, I'd like to find this, and I say that when t = 0, I start from U0. So I write U0 here. Eventually, I should find this voltage, which will move towards zero. So I would put zero here. And here, when t = 0 = 0, I get this, and I would find V1(t) = U0e to the power of -t/RC. To say that with this form that I just showed you there, you can always start at a specified time that you declare as t = 0, and you either carry on or write down this relationship. That would give you the analytical expression of the exponential that we would have seen at the output, when applying a Dirac jump and, later on, there will be a square voltage.

Notes

Summary

4m 20s

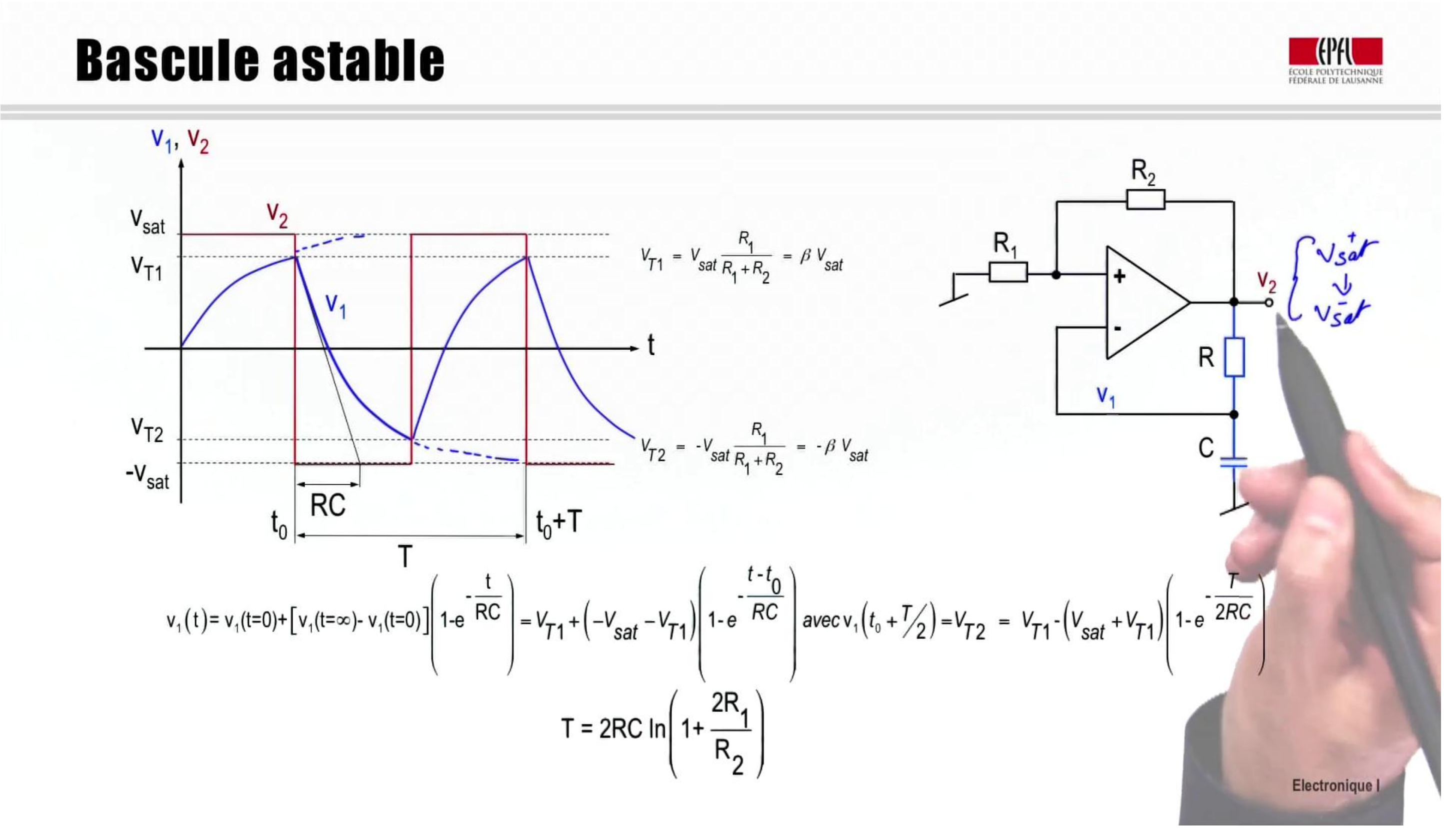


I'd like to show you a typical example of a stable switch. In other words, the V2 voltage will become established when you connect this circuit here. And this V2 voltage will be a square wave. Really square. A 50% duty cycle. A 50% duty cycle is this half period that you can see from here to here. That really is the half period because the period that we find here is the complete period. The half period ends up being t/2. So, we call that a duty which is equal to 50% and we will ignore whatever happens at the beginning when we start this kind of circuit. So how would this type of circuit start? For this kind of circuit, you take an amplifier which is used as a comparator. Here, there will be some sort of comparator with a positive reaction. I refer you back to the lesson on hysterisis switches to recognise this kind of connection. You get a positive reaction, so we return with a component of the output voltage on the positive band. We can compare this node to the V1 node generated by an RC circuit, such as the one we have just seen. So, this RC circuit that we saw earlier has a V1 voltage which is exponential.

Notes

Summary

5m 02s



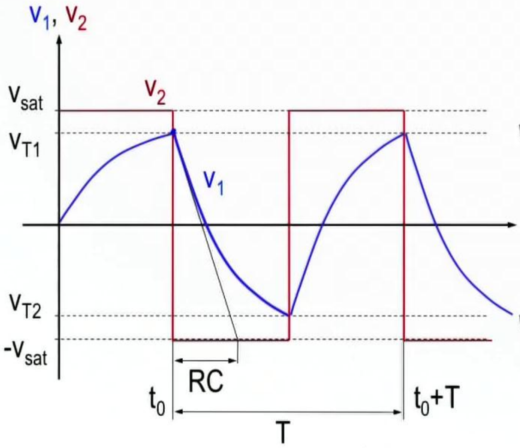
Let's say you connect this circuit, and power the whole circuit, and let's say that the capacity was fully discharged, there would be no charge on the capacity. If the capacity is discharged, V1 will start from zero. And this V1 will move towards a saturation voltage, because the V2 voltage, in a hysterisis comparator, will either be Vsat+ or Vsat-. And this V1 voltage on the negative terminal of this comparator will cause it to trip. So this voltage which starts from zero will go in search of the Vsat voltage, but as soon as it reaches the VT1 value, which is the trip threshold, your comparator will change state. So the V2 voltage is an inverter and a comparator with a hysterisis inverter. In other words, when the voltage reaches VT1, it will switch from a positive saturation voltage to a negative saturation voltage. So now, V2 will switch from Vsat+ to Vsat-. So when this Vsat- voltage appears, the capacity will discharge through the resistance. We will end up with this exponential, and this exponential will theoretically continue here until Vsat-. It will always look for the value found here. We said V2 is equal to Vsat-, so the capacity will discharge itself and we will be left with V1 which will keep on decreasing until we're left with V2 again.

Notes

Summary

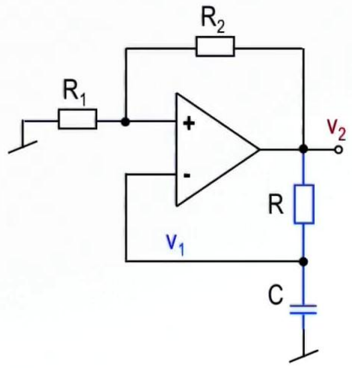
6m 29s

Bascule astable



$$V_{T1} = V_{sat}\frac{R_1}{R_1+R_2} = \beta\, V_{sat}$$

$$V_{T2} = -V_{sat}\frac{R_1}{R_1+R_2} = -\beta\, V_{sat}$$



$$v_1(t) = v_1(t{=}0) + \left[v_1(t{=}\infty) - v_1(t{=}0)\right]\left(1-e^{-\frac{t}{RC}}\right) = V_{T1} + \left(-V_{sat} - V_{T1}\right)\left(1-e^{-\frac{t-t_0}{RC}}\right) \quad \text{avec}\ v_1\left(t_0 + T/2\right) = V_{T2} = V_{T1} - \left(V_{sat} + V_{T1}\right)\left(1-e^{-\frac{T}{2RC}}\right)$$

$$T = 2RC\ln\left(1+\frac{2R_1}{R_2}\right)$$

Electronique I

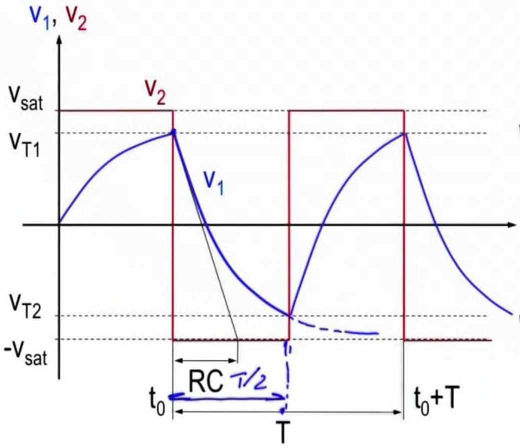
This will... sorry, the V1 voltage, which we'll be left with is equal to Vsat-. But that's where we have to stop it. Why? Because we're in the middle of intercepting the same voltage and we will change the Vsat state. Instead of Vsat-, we will take it back to Vsat+. So, when this V1 voltage is dropping, we will read its value upon the input of our comparator which will then switch again. So that's it, we go back and we reverse the charge cycle which will start around Vsat+. These periodic changes of voltage will generate a square wave, and it's a square wave which is characteristic of a stable switch which could generate a time base with a given frequency, Now we will see how this frequency is calculated. So, it's a square wave generator and the frequency depends on R1, R2 and RC values. To analyse this kind of circuit, we'll take the relationship that we've just seen, this famous relationship typical of an RC circuit, and I'm going to begin from this point here. I will not take into account the transient response. This is the first time, but once we have generated this impulsion, we will always start between VT1 and VT2.

Notes

Summary

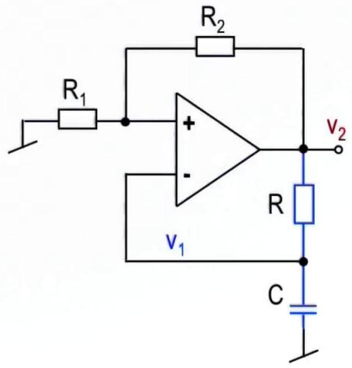
8m 15s

Bascule astable



$$V_{T1} = V_{sat}\frac{R_1}{R_1+R_2} = \beta V_{sat}$$

$$V_{T2} = -V_{sat}\frac{R_1}{R_1+R_2} = -\beta V_{sat}$$



$$v_1(t) = \underbrace{v_1(t=0)}_{V_{T1}} + \left[\underbrace{v_1(t=\infty)}_{-V_{sat}} - \underbrace{v_1(t=0)}_{V_{T1}}\right]\left(1-e^{-\frac{t}{RC}}\right) = V_{T1} + \left(-V_{sat} - V_{T1}\right)\left(1-e^{-\frac{t-t_0}{RC}}\right) \text{ avec } v_1\left(t_0+T/2\right) = V_{T2} = V_{T1} - \left(V_{sat}+V_{T1}\right)\left(1-e^{-\frac{T}{2RC}}\right)$$

$$T = 2RC\ln\left(1+\frac{2R_1}{R_2}\right)$$

Electronique I

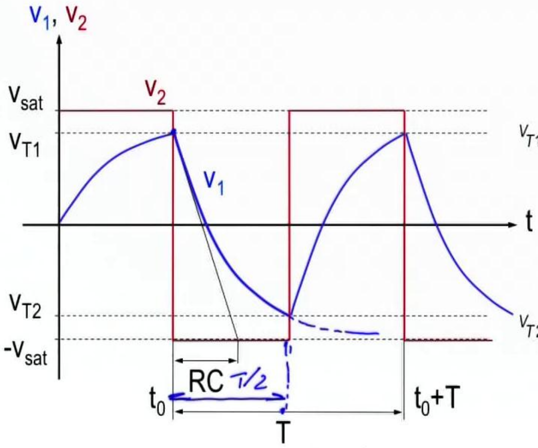
So, there's the exponential which will always be stuck by VT1 and VT2 and we'll be left with V2 which will always be generated by the charge and the discharge of these RC circuits. So, you can see that there's no input, there are only power supplies. You're going to assemble this circuit and straightaway at the input you'll see a voltage which will establish itself and which has a square function. So, it's a circuit which doesn't have an input, it only has an output. I'm going to write the voltage V1(t) starting from here. I start from VT1, and I need to go towards Vsat-. So, when t = 0, I start from VT1. When t is equal ad infinitem, I'm going to go towards Vsat which is negative because it's -Vsat. Again, when t = 0, I have VT1 which I'm going to multiply by this, what I've written here. VT1 between brackets -Vsat, the voltage -VT1 -- because I have a minus sign here -- multiplied by -- because I started at this point -- I noted 1-e, to the power of -t/t0, divided by RC. With t0 + t/2, I'm interested in what is going to happen, just here. So, I take here to here, from here to here, and I have half of the period. So, I'd like to watch what happens to the V1 voltage when t = t0, the initial time to which I added half of the period.

Notes

Summary

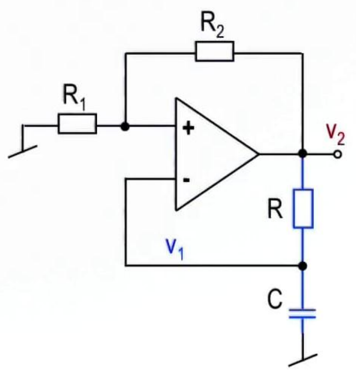
9m 41s

Bascule astable



$$V_{T1} = V_{sat}\frac{R_1}{R_1+R_2} = \beta V_{sat}$$

$$V_{T2} = -V_{sat}\frac{R_1}{R_1+R_2} = -\beta V_{sat}$$



$f = \frac{1}{T}$

$$v_1(t) = \underbrace{v_1(t=0)}_{V_{T1}} + \left[\underbrace{v_1(t=\infty)}_{-V_{sat}} - \underbrace{v_1(t=0)}_{V_{T1}}\right]\left(1-e^{-\frac{t}{RC}}\right) = V_{T1} + \left(-V_{sat} - V_{T1}\right)\left(1-e^{-\frac{t-t_0}{RC}}\right) \text{ avec } v_1\left(t_0 + \tfrac{T}{2}\right) = V_{T2} = V_{T1} - \left(V_{sat} + V_{T1}\right)\left(1-e^{-\frac{T}{2RC}}\right)$$

$$T = 2RC\ln\left(1+\frac{2R_1}{R_2}\right)$$

Electronique I

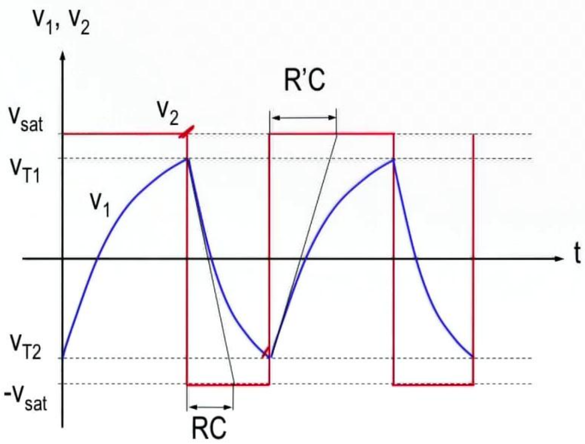
I replace it with this relationship. I replace t with t0 + t/2, and I'm going to be left with this relationship that you can see here. So I get this relationship, and what I'm interested in is the time T, or the period. I remind you that the frequency is the inverse of the period, so if you give me the period, I can get you the frequency and, with this expression, I can calculate the time T which is equal to 2RC logarithm 1+ 2R1/R2. To calculate the dimensions of this kind of circuit, I only have to set a value of R2, for example, a value of R and a value of R1, and find value C for which I have the period that I'm looking to calculate, or the frequency that I'm looking to calculate. And here's a typical example of a square sign generator. You put a diode in the output, you rectify this signal, you establish a rectifying amplifier, and you're going to find that the positive or negative component --it depends on what you want to do with it, but you have a signal in the time base -- depends on a /tau RC time constant. You set one of the values and then you find the other. Of course this type of calculation requires knowledge because there are standardised values that we must choose in the ranges that we find in the market.

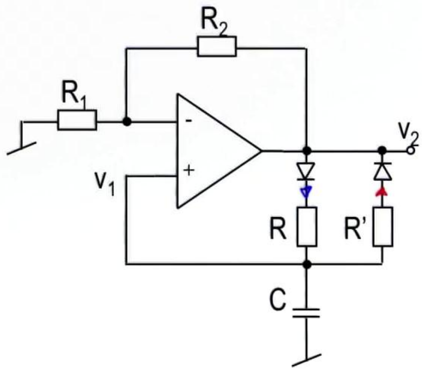
Notes

Summary

11m 27s

Bascule astable , sortie asymétrique





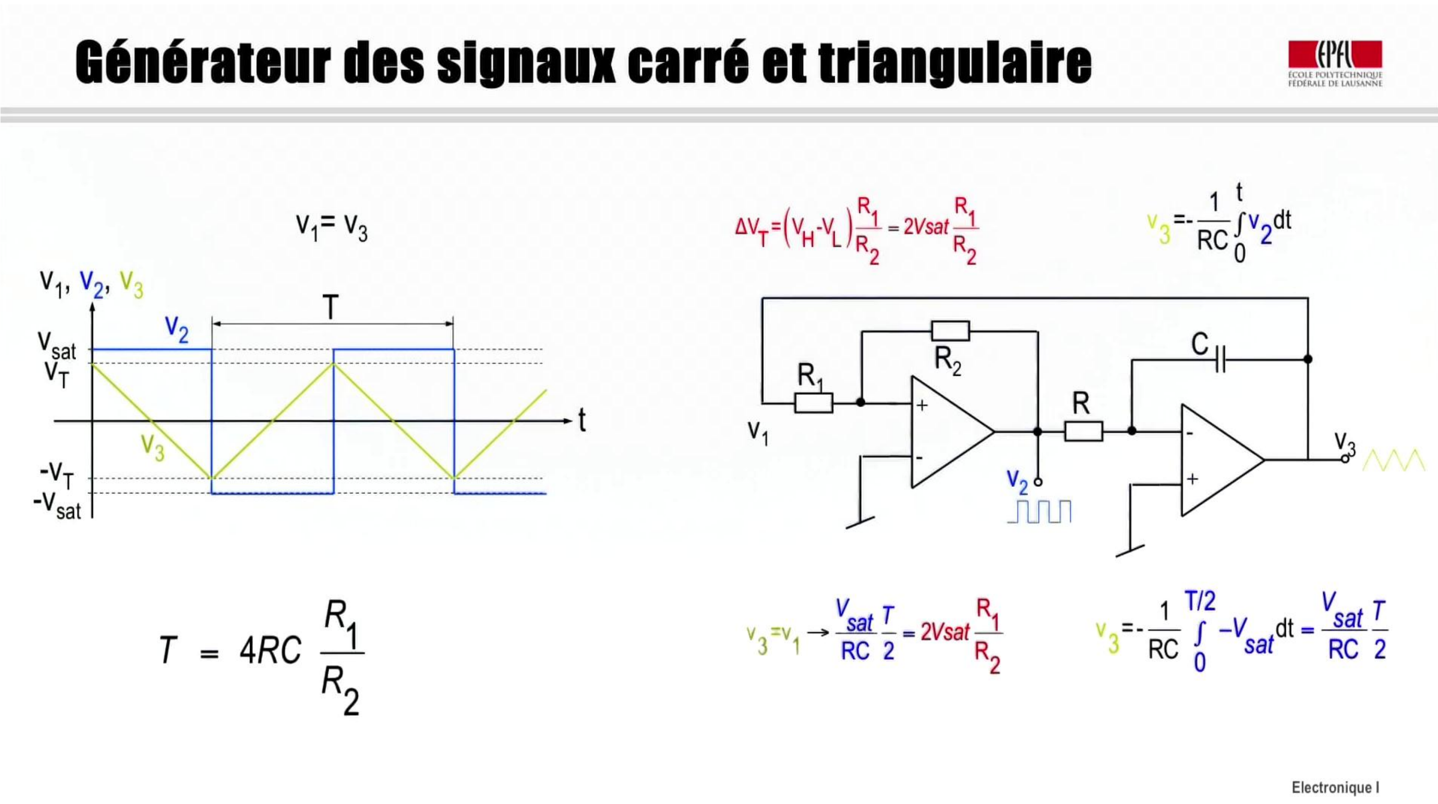
Electronique I

Take the same circuit, you can add in place of an RC resistance -- so I remind you, earlier, that there was a resistor and a capacitor. Here, I added two resistors and two diodes. I created a path for the charge in the direction of the capacity. And there's a path for the discharge of the capacity in this direction. So, I charge through RC, and I discharge through R'C. Why? Because this diode, set in this direction, lets the current pass through in only this direction here. This diode, set in this direction, lets the current pass through in the other direction. Therefore, I can form a circuit which has two-time constants: an RC time constant, and an R'C time constant, which breaks the 50% duty cycle. And now we'll talk about a switch with an asymmetric output. We don't have a 50% duty cycle. Half of the period is divided by one part, and a second part where the charge and the discharge don't have the same time constant. Once it was RC, another time it was R'C. It's another variant to help generate a V2 voltage which is not a square signal. It's a signal in the duty cycle, which is different to 50%.

Notes

Summary

12m 50s

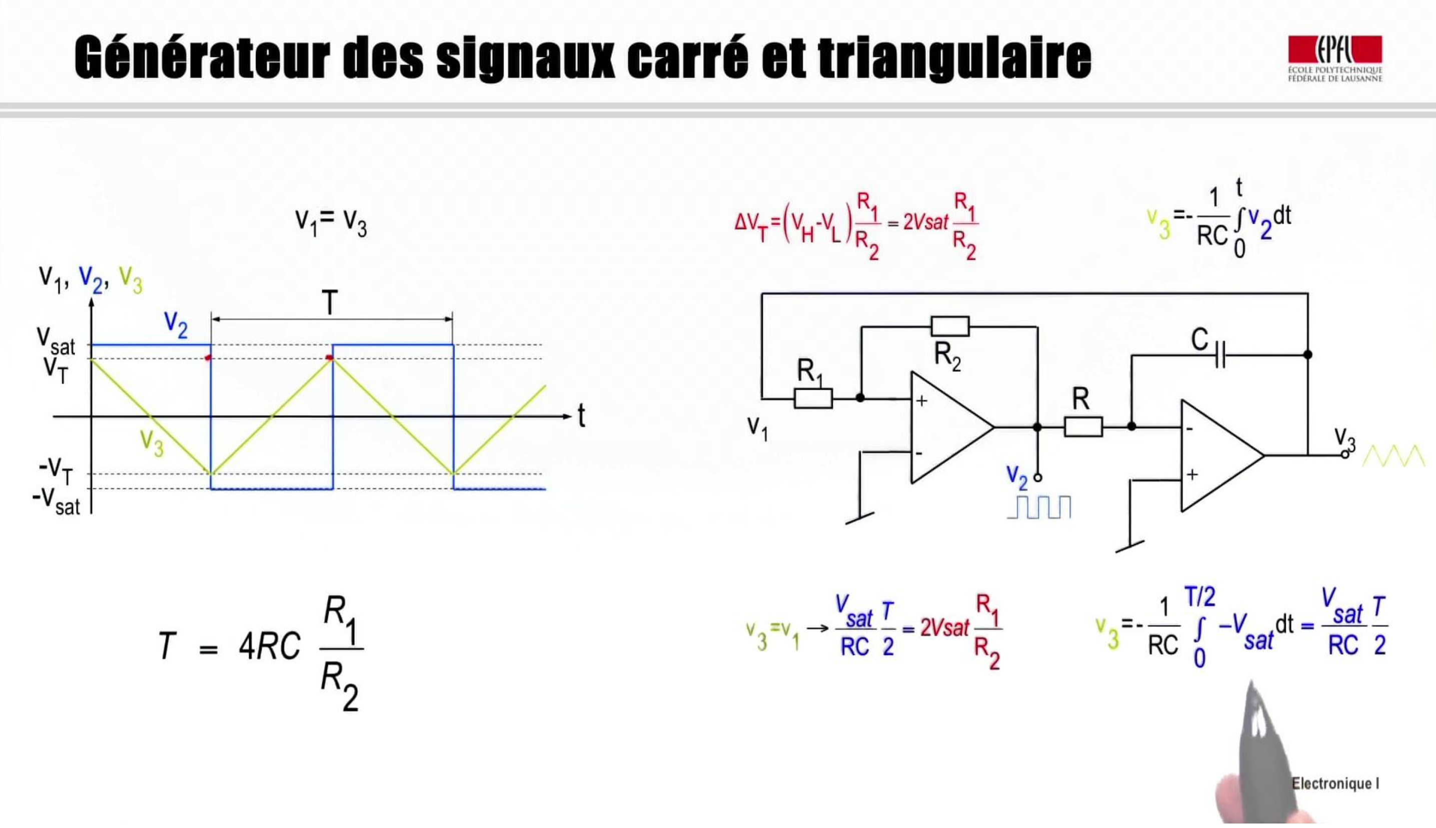


To finalise, we're going to analyse a square and a triangle signal generator. They are made of two operational amplifier circuits: one circuit with a positive reaction, the other with a negative reaction. This circuit with the positive reaction is a circuit which makes a VT1 and VT2 threshold voltage. It's the famous comparator with hysterisis and an integrator which is going to create a square signal and integrate it. With that, we will see a square signal generated on a V2 voltage and a triangle signal, which is the integral of this voltage squared, which had been injected inside this integrator circuit. So, we integrate the square, and it gives us a triangle. To recap, the output voltage of an integrator is 1/RC with a minus sign. The integral of the voltage is nothing other than a square voltage. So we will get the same frequency for both. On the one hand, it's a square signal, and on the other a triangle signal. The comparator hysterisis has a Δ VT. We already studied this. I refer you to the part where we analysed this type of circuit. You're going to see that this circuit has two threshold voltages: VT and -VT. These two threshold voltages, in this example here, are centred around zero.

Notes

Summary

14m 18s

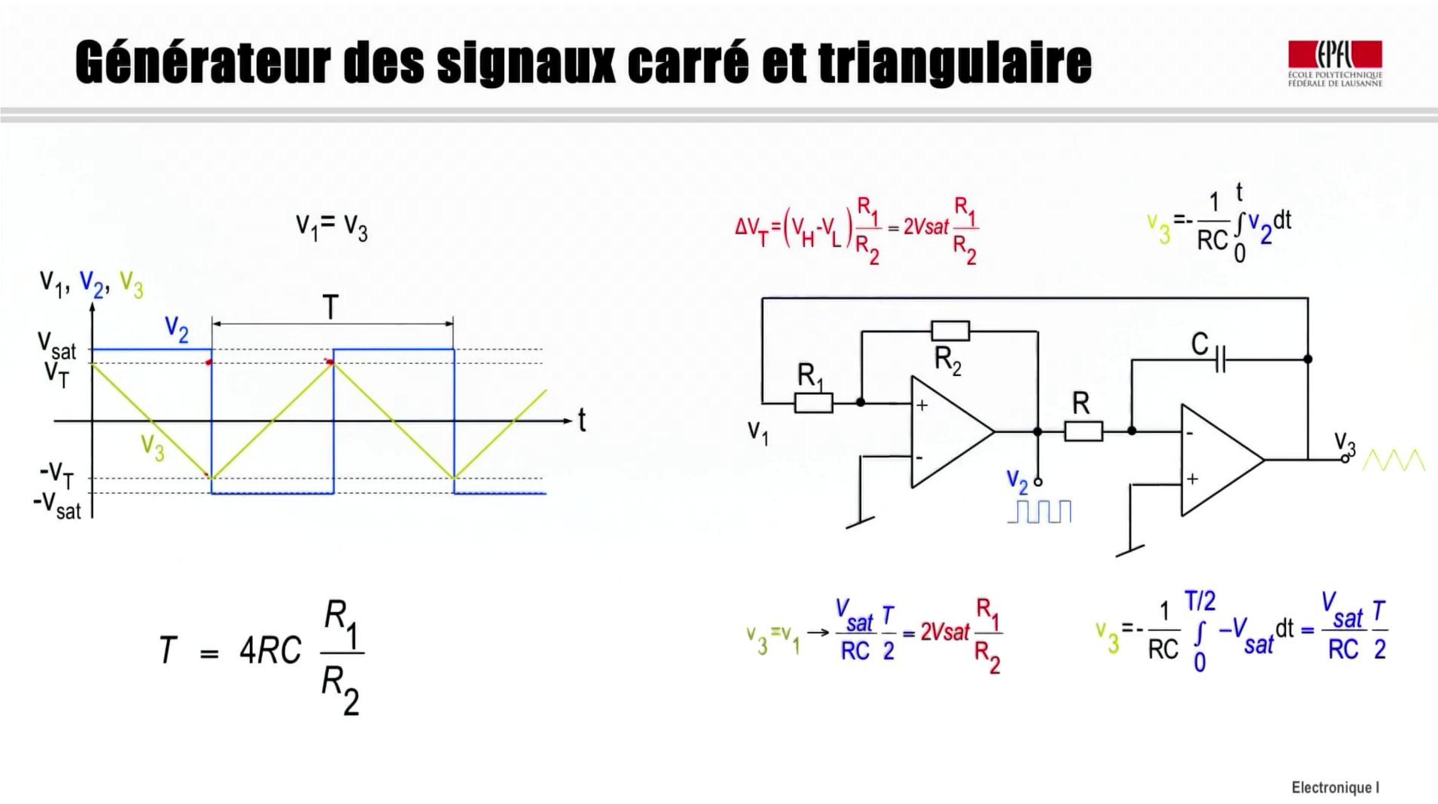


The Δ VT = 2Vsat R1/R2. You can have a look at this chapter and remind yourself about this subject. Let's take this V2 voltage which only has two values. The V2 voltage will have +Vsat and -Vsat. When it has Vsat+, it can be integrated between zero and T/2. So, if we take this voltage here and put it in our integrator, it will be integrated with a minus sign. This integration with a minus sign will give us a negative slope like that. And we'll stick it between a VT and -VT threshold voltage, because we'll take the V3 voltage and return it to the input of this comparator. In other words, when this voltage touches the switch voltage of this comparator, this comparator immediately changes state. It either goes from -Vsat to +Vsat or from +Vsat to -Vsat. And the integrator is always stuck on these VT voltages. So there's a time trip equal to T/2. If we look from here to here, we can see half of the period because the period goes from here to here. So, it's best to write the relationship of the integrator which will integrate by starting either here or here, whatever you prefer. Here, I start from a -Vsat voltage, and so I end up here. I replace V2 by -Vsat. I integrate between 0 and T/2.

Notes

Summary

15m 55s

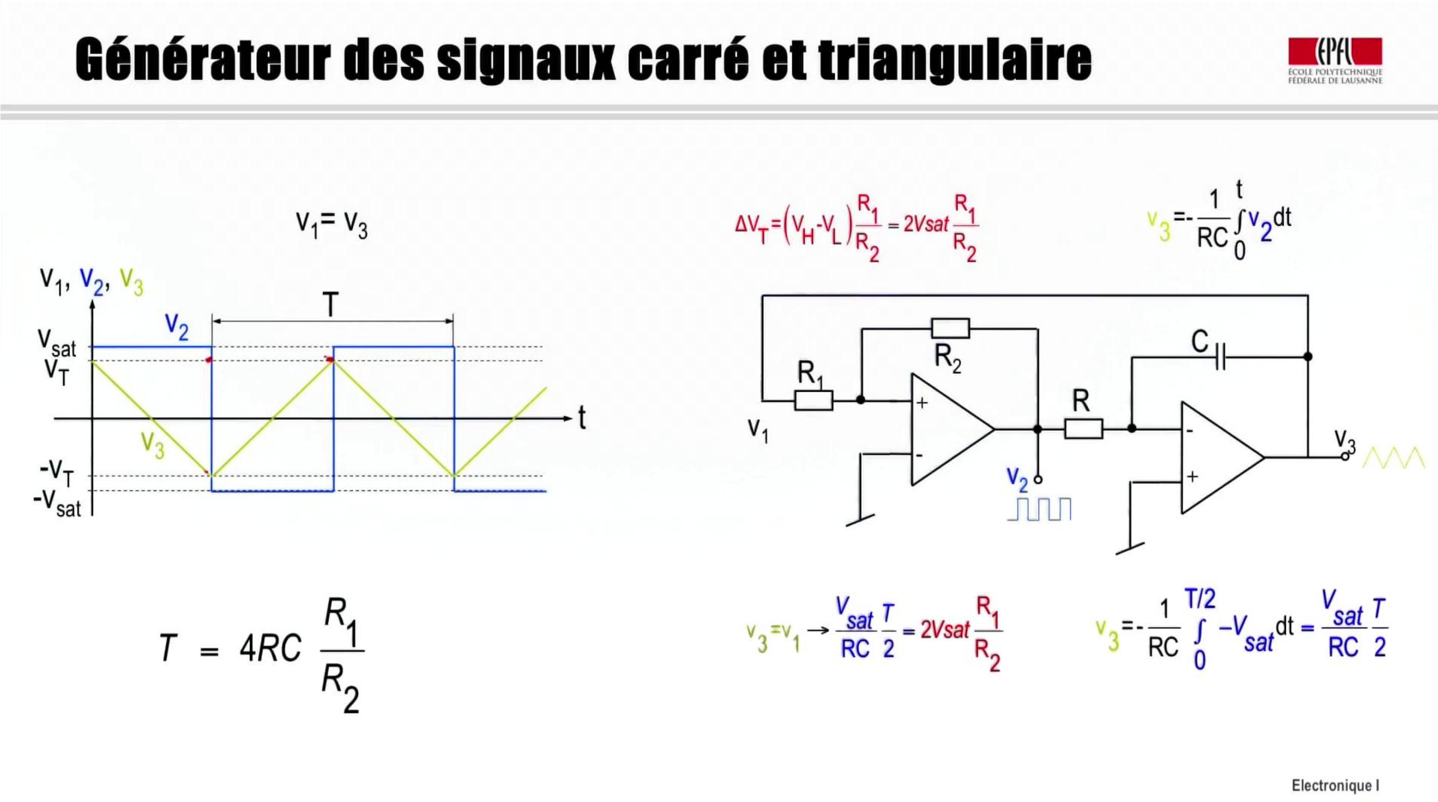


Therefore, I integrate between 0 and T/2 in the relationship of this integrator, and I'll discover that it's Vsat, divided by RC, and multiplied by T/2. The time needed to go from here to here corresponds to this Δ VT, because I start with +VT minus -VT, which gives me Δ VT. Therefore, the time needed for this integrator to pass through half of the period, which is what I've just done here, is equal to this 2Vsat R1/R2 relationship. This helps me to extract the frequency of this circuit, so I can extract T according to what I have just found here. And that will give me a period equal to 4RC R1/R2. Once again, it becomes a circuit as soon as you give it power. It will begin to generate a square signal here, and a triangle signal here, and you'll have both of these until you turn the power supply off. So, it's something which has two outputs yet doesn't have an input, apart from the power supplies. You can, of course, calculate the dimensions of these components, then go and connect them, and watch, and observe. The circuits which work very, very well have market operational amplifiers and the circuits which have low power behaviour have some very very good amplifier qualities or comparators.

Notes

Summary

17m 26s



Therefore, these signals here correspond to what we would find in basic practical exercises and we would definitely find what I've just explained. This calculation gives some extraordinary results according to the period that we calculated here. Good. We've just finished a number of comparator applications and of operational amplifiers, by discussing linear circuits, non-linear circuits, and the use of an amplifier like a signal generator. We could also observe or analyse the oscillators. I think we've mastered the use of an operational amplifier with this chapter. We've seen its applications, and we've managed to carry out some practical exercises which demonstrate that some very well-known market applications use these operational amplifiers. There are no secrets for students when they use these circuits for everyday applications.

Notes

Summary

18m 54s