Pulse Width Modulation Generator

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Documentation&Research

Requirements

The signal of this PWM generator will have a duty factor between 10% and 50%, a variable amplitude between 3 and 6 Volts and a frequency of 3500Hz.

Theoretical approach

A PWM generator produces a square wave output (digital), where the width of the pulse (the duration the signal is "high") is modulated to produce an output with a varying average voltage. This output is used to control the power delivered to a load, such as a motor or an LED, by adjusting the amount of time the signal is "on" versus "off". Some applications of the generator are in a wide range of electronic devices and systems, including motor control, lighting control, power supply regulation, and audio signal processing. They are also used in renewable energy systems, such as solar and wind power systems, to control the power delivered to the grid or to a battery bank.

The pulse can be obtained with a simple comparator, which has at its imputs two diffrent shapes of signals, in order for the duty cycle to vary and a voltage divider with a potentiometer at its output, so that the amplitude could be adjustable.

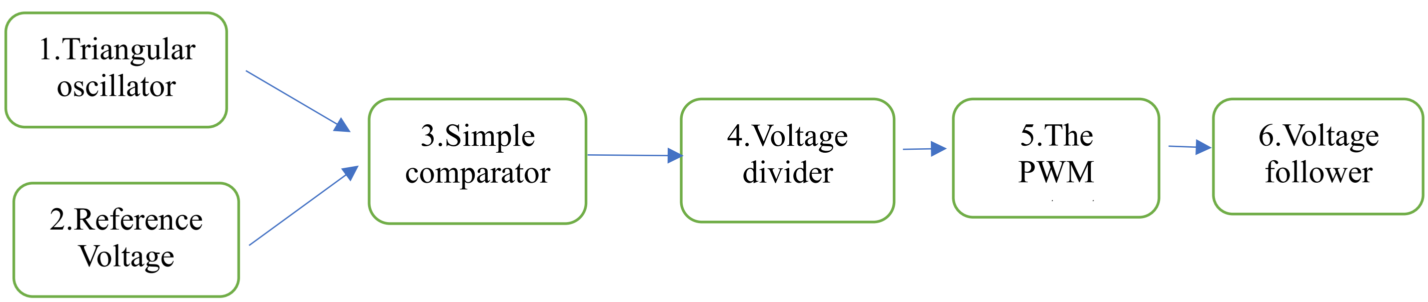


Fig.1 PWM generator block diagram

1.The triangular oscillator can be realised with an astable multivibrator and an integrator;

2. The reference voltage represents a DC level voltage, adjustable with the help of a potentiometer;

3.Both signals are connected to an operational amplifier’s inputs;

4.The voltage divider made of a potentiometer and two resistors;

5. The output should be a pulse with variable duty factor;

6.For the circuit to be isolated, a voltage follower will be connected to the output.

Here is a draft for the electrical scheme:

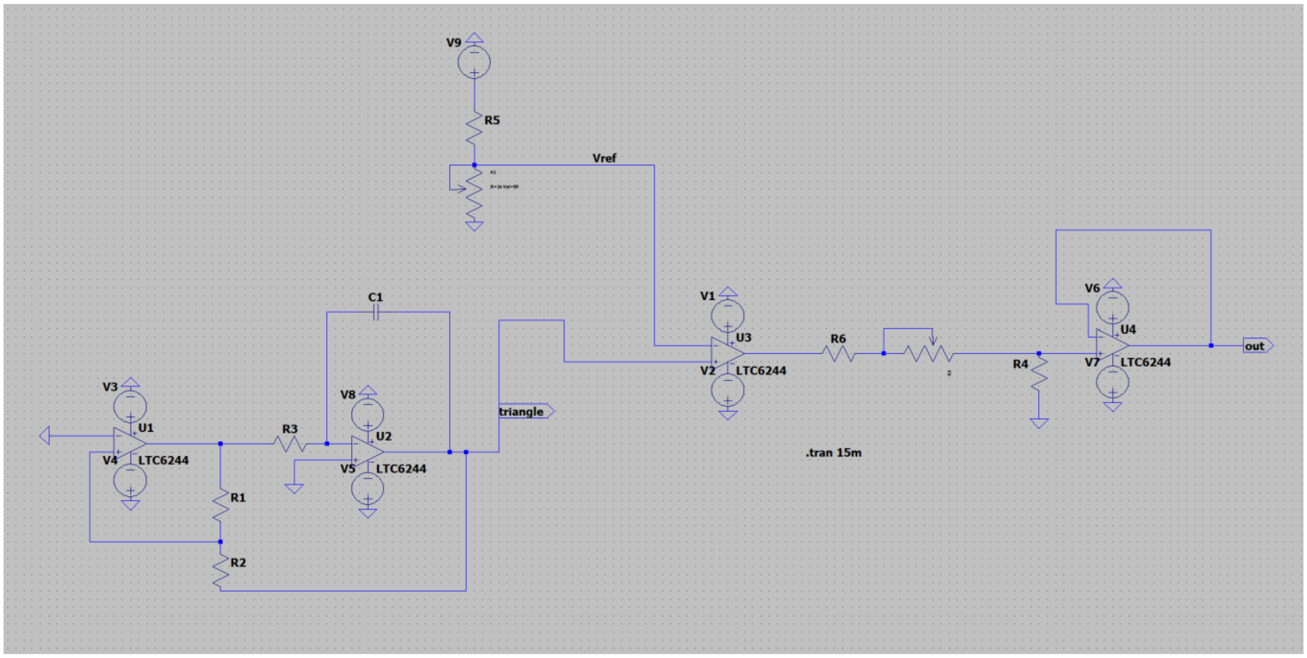


Fig.2 First draft electrical scheme

And the waveforms that show that a rectangular signal can be obtained from a triangular and a DC voltage:

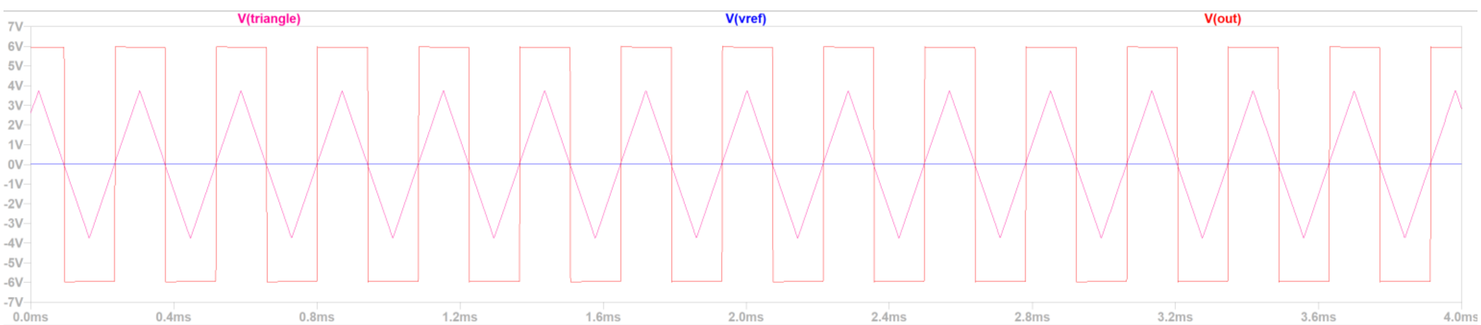


Fig.3 Waveforms to demonstrate the initial idea

When the reference voltage is below the triangular one, the output signal is “on”(logic ‘1’) and when it is above the triangular wave, the output signal is “off”(on logic ‘0’).

Calculus

Firstly, for the calculus part, we must start with the desired result, which is a pulse signal with constant frequency and variable duty factor and amplitude. In order for this to happen, I have chosen to create the triangular signal having the wanted output frequency and an adjustable reference DC voltage for varying the duty cycle . The amplitude will also be controlled with the help of a potentiometer.

Triangular wave generator

It generates the triangular wave by integating a rectangular one.

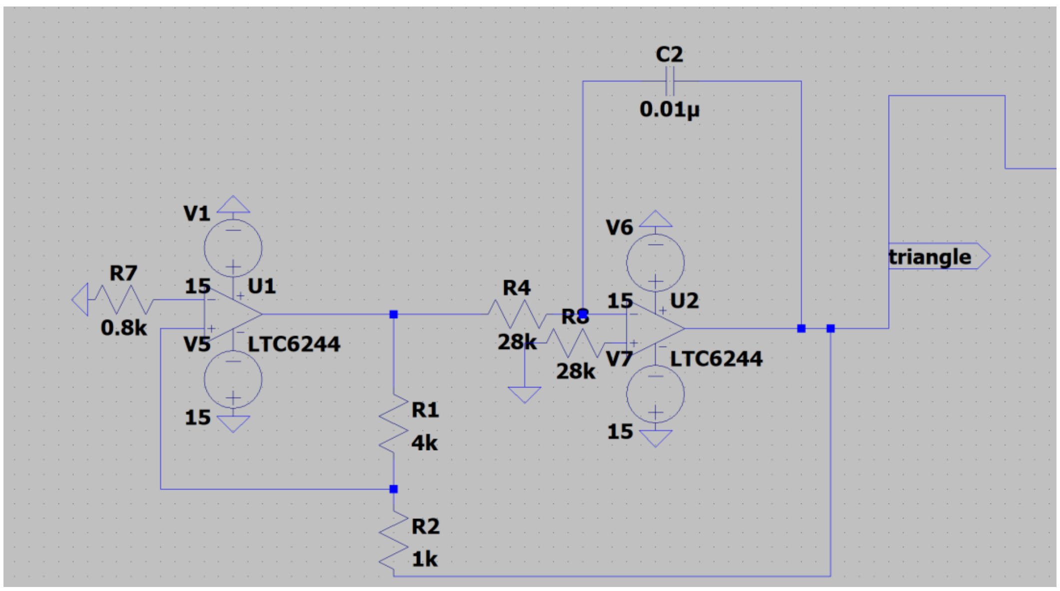


Fig.4 Triangular wave generator

$$Vpp = -\frac{1}{RC}\int_0^{\frac{T}{2}} Vin(t)dt \quad (1)$$

$$f = \frac{R1}{4R2R4C2} \quad (2)$$

$$Vpp = 2\frac{R2}{R1}Vout1 \Longrightarrow \frac{R1}{R2} = \frac{2Vout1}{Vpp} \quad (3)$$

$$(3), \mathrm{Vout1} = 15\mathrm{V} \Rightarrow \mathrm{Vpp} = 7.5\mathrm{V} \quad (4)$$

$$(4) \Longrightarrow A = 3.75 \quad (5)$$

$$\frac{R1}{R2} = 4 \Longrightarrow R1 = 4k\Omega; R2 = 1k\Omega \quad (6)$$

$$\text{For } C2 = 10nF \text{ and } f = 3500Hz \text{ we obtain:}$$

$$R4 \cong 28.57k\Omega \qquad (7)$$

$Vin = input\ voltage\ for\ the\ second\ opAmp;$

$Vpp = Voltage\ peak\ to\ peak;$

$Vout1 = output\ voltage\ of\ the\ first\ opAmp;$

A=amplitude.

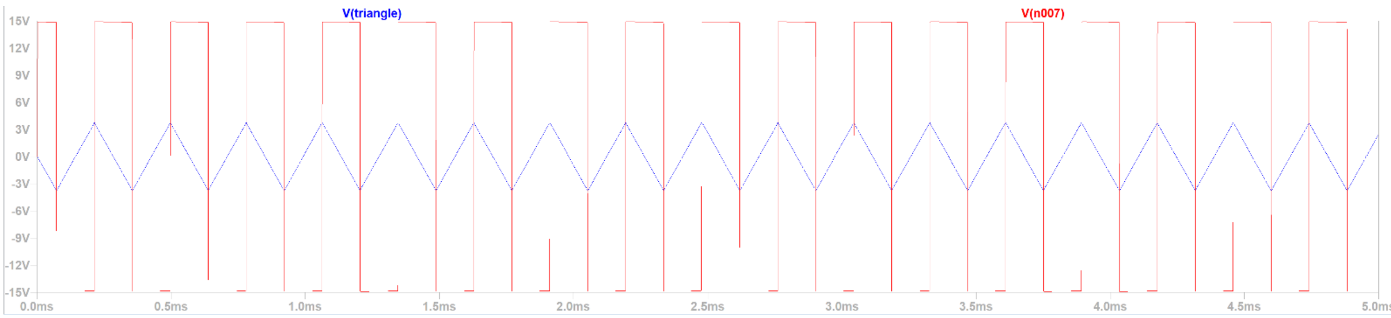
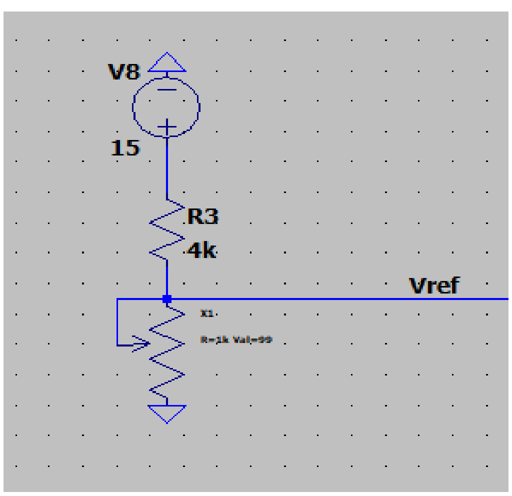


Fig.5 Waveforms for the triangular wave generator

The reference voltage



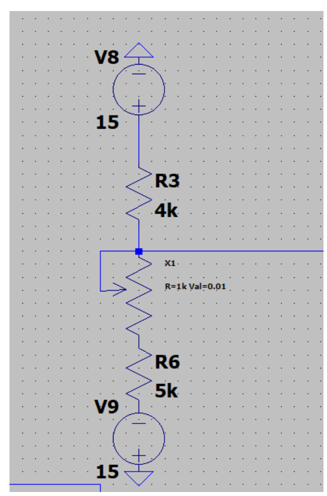


Fig.6 The reference voltage

Fig.7 Solution for higher duty cycle

This voltage is meant to adjust the duty cycle of the output signal, by intersecting with the triangular signal in different points. For calculating the exact level of the Vref for the duty cycle to vary between

10% and 50%, I have calculated the height at which Vref must intersect each triangle (we will consider the first triangle from the figure 5). When intersecting at 0V, the duty cycle is 50%, for higher that 50%, the reference voltage should be below 0V(Figure 7).

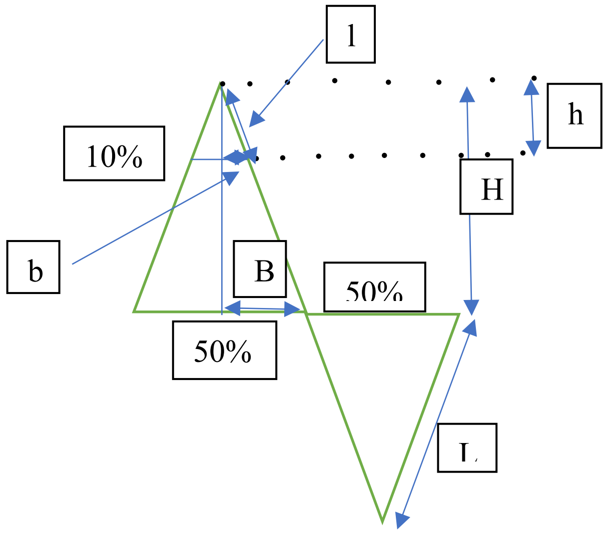


Fig.5 Triangle drawing for duty cycle

$$Fig.5 \Rightarrow B = 25; b = 5 \quad (8)$$

$$H = 3.71 \quad (9)$$

$$Similar\ triangles\ Th, (8) \Longrightarrow \frac{H}{h} = \frac{L}{l} = \frac{B}{b} = 5 \quad (10)$$

$$(9), (10) \Rightarrow h = \frac{1}{5} * 3.71 \quad (11)$$

$$(11) \Longrightarrow h = 0.742 \quad (12)$$

$$(2), (4) \Rightarrow H - h = 3 \quad (13)$$

$$Vref = \frac{Pot}{Pot+R3} * 15V \quad (14)$$

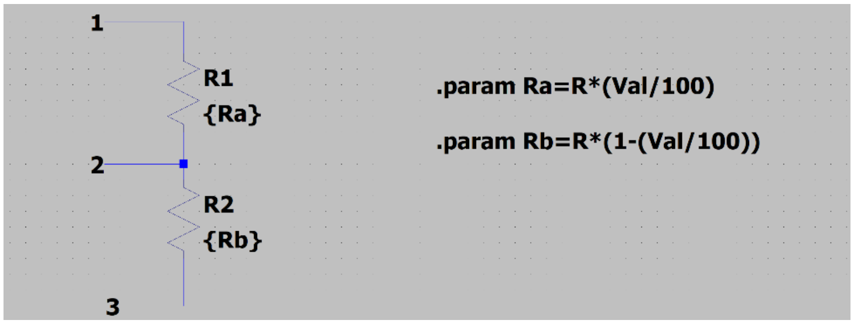
$$For\ Vref = 0V \Longrightarrow Pot = 0\Omega \quad (15)$$

$$(13), (14) \Longrightarrow For\ Vref = 3V \Longrightarrow Potmax = 1K\Omega, \text{R3} = 4\text{K}\Omega \quad (16)$$

Potmax= maximum resistance of the potentiometer.

This means that to obtain the duty cycle of 10%, the reference voltage should be approximately 3V and the Potentiometer should be on its maximum value, 1K Ω.

This project was made in LtSpice, so the potentiometer was created as a voltage divider, with a symbol derived from a resistor one.



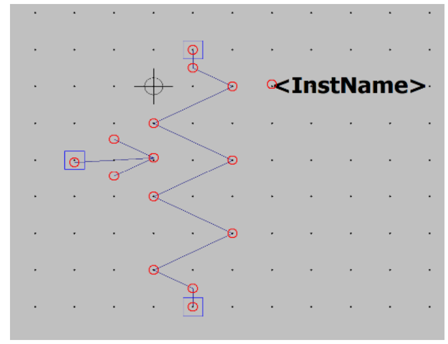


Fig.6 The electrical scheme of the potentiometer

Fig.7 The symbol for the potentiometer

The non-inverting comparator

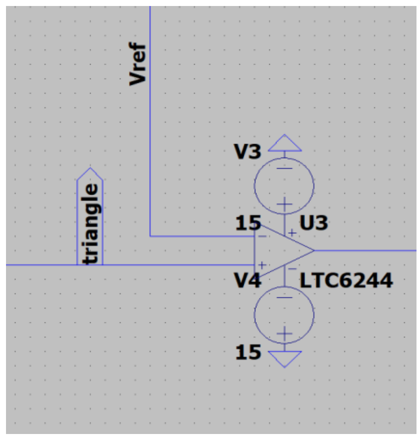


Fig.8 Simple comparator

The triangular signal is connected to the positive input of the comparator and the reference voltage is connected to the negative input. When the reference voltage is less than the voltage of the triangular wave, the output will be “on” (high state).

I have chosen a 15V voltage source to use for all the operational amplifiers and also for Vref. The operational amplifier chosen is an LTC6244 because it performs better regarding the rise and fall times.

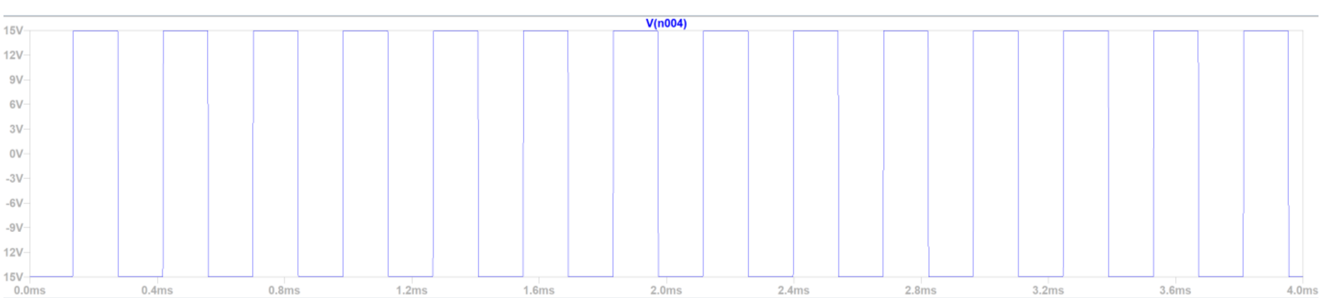


Fig.9 The output of the comparator when Vref=0

Voltage divider

To be able to adjust the amplitude of the output signal, we need a voltage divider with a potentiometer.

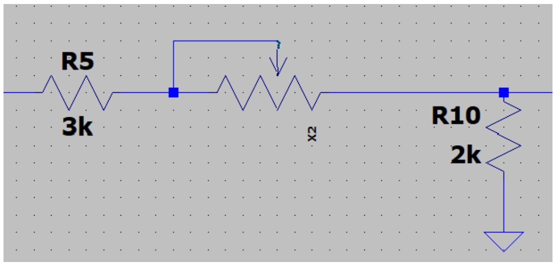


Fig.10 voltage divider for amplitude

$$VoutH = \frac{R10}{R10+R5+Pot}VH;\ VoutL = \frac{R10}{R10+R5+Pot}VL \quad (17)$$

$$VoutH = -VoutL; VH = -VL = 15V \quad (18)$$

$$If\ Pot = 0\Omega \Rightarrow Vout\ is\ max \Rightarrow A = 6V \quad (19)$$

$$If\ Pot\ is\ at\ maximum\ resistance \Rightarrow Vout\ is\ min \Rightarrow A = 3V \quad (20)$$

$$(17), (18), (19) \Rightarrow R5 = 3K\Omega; R10 = 2K\Omega \quad (21)$$

$$(17), (18), (20), (21) \Rightarrow Potmax = 5K\Omega \quad (22)$$

A=amplitude;

Potmax= maximum resistance of the potentiometer.

Because the amplitude of the output signal of the comparator is equal to 15V, we can choose R5=3KΩ, R10=2KΩ and the potentiometer can take values between 0Ω and 5KΩ, in order for the output amplitude to be 6V, respectively 3V.

Voltage follower

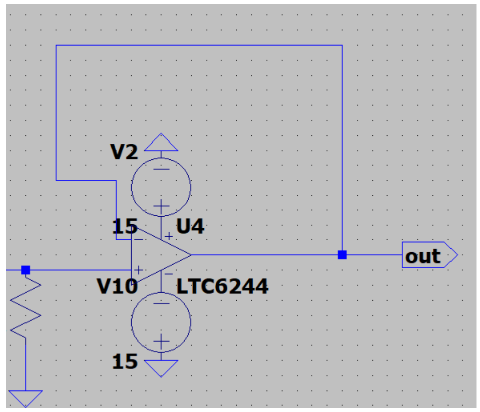


Fig.11Voltage follower

Voltage follower circuit is used to create isolation between two different kind of circuits. Due to high input impedance, so the input current is much lower than the output current while the output voltage follows the input voltage. It is used as a buffer circuit and can be used to isolate the circuit from external impedances.

Standardization

Here is a table with all the components on the scheme and the ones to be used in real life:

Scheme components	Real life components	Tolerance
R7	45F800E	1%
R3	MFR-25FTF52-4k	1%
R8,R4	MFR-25FBF52-28K	1%
R2	MFR-50FRE52-1k	1%
R1	MFR-25FTF52-4k	1%
R10	MFR-W25-2K-HQ	1%
R5	MFR-25FRF52-3K	1%
C2	1210N103J101CT	5%
Potentiometer X1	RS Pro P25 Series Wire-Wound 842-7030-1KOhm	10%
Potentiometer X2	RJ-13SR 5K Ohm (502)	10%
OpAmp	LTC6244	-

Fig.12 Components Table

Bill of Materials

Components	Price(€)/1 component
MFR-25FRF52-3K	3.6
45F800E	2.8
MFR-25FBF52-28K	0.1
MFR-12FTE52-5k	0.094
MFR-W25-2K-HQ	1.1
MFR-50FRE52-1k	0.18
MFR-25FTF52-4k	0.124
MFR-25FRF52-3K	0.1
RS Pro P25 Series Wire-Wound 842-7030-1KOhm	5.67
RJ-13SR 5K Ohm (502)	3.1
1210N103J101CT	0.44
LTC6244	3

Fig.13 The price of materials

Simulation Results

For this circuit i have performed a parametric analysis, for the potentiometers:

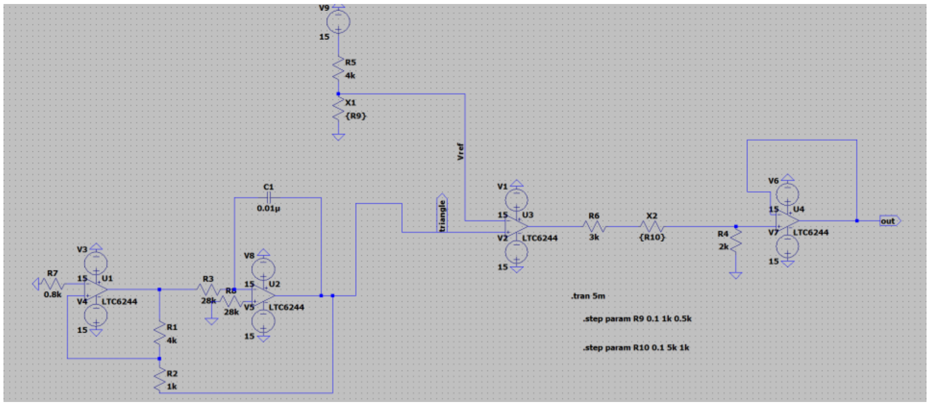


Fig14.Electrical scheme for parametric analysis

Fig.15 Parametric analysis-output result for both potentiometers

This analysis shows that the output amplitude varies between 3V and 6V and the duty cycle between 10% and 50%.

To be able to see the result better, i will vary first the duty cycle at the amplitude of 6V, and then the amplitude at the duty cycle of 50%.

Fig.16 Varying of the duty cycle 10%-50%

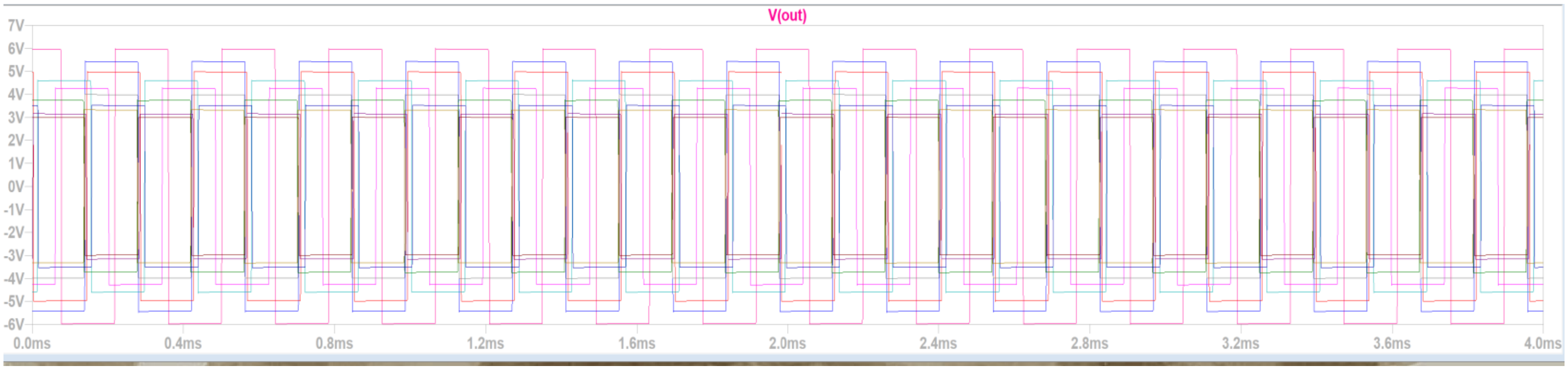


Fig.17 Varying the amplitude between 3V and 6V

The second analysis performed is the temperature one at 3V and 10% duty cycle:

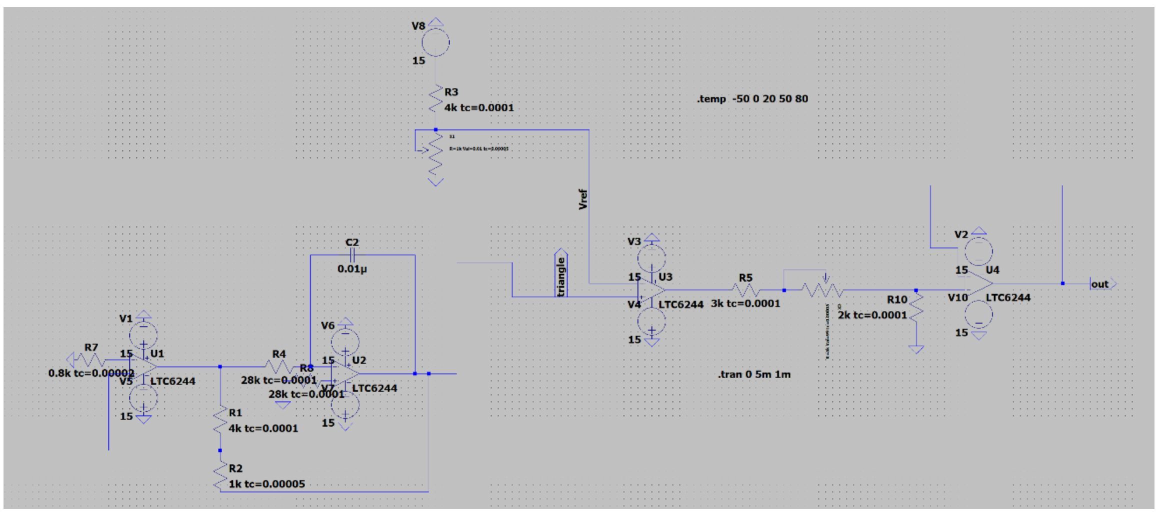


Fig.15 Scheme with temperature coefficients

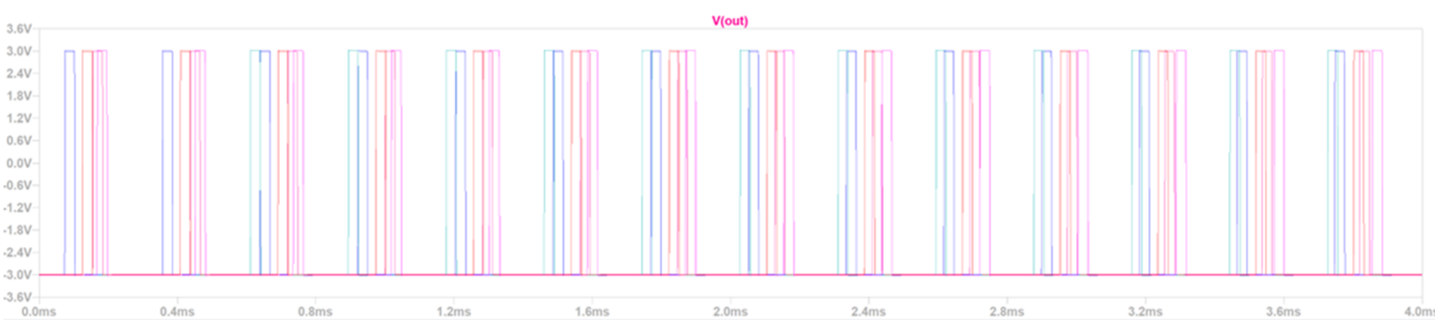


Fig.16 The output after temperature sweep

As it can be seen, the duty cycle, frequency and amplitude ar not affected, online the time that the pulses start is changed.

The third analysis is Monte Carlo: it determines, statistically, the circuit behavior when the components values are changed in their tolerance domain.

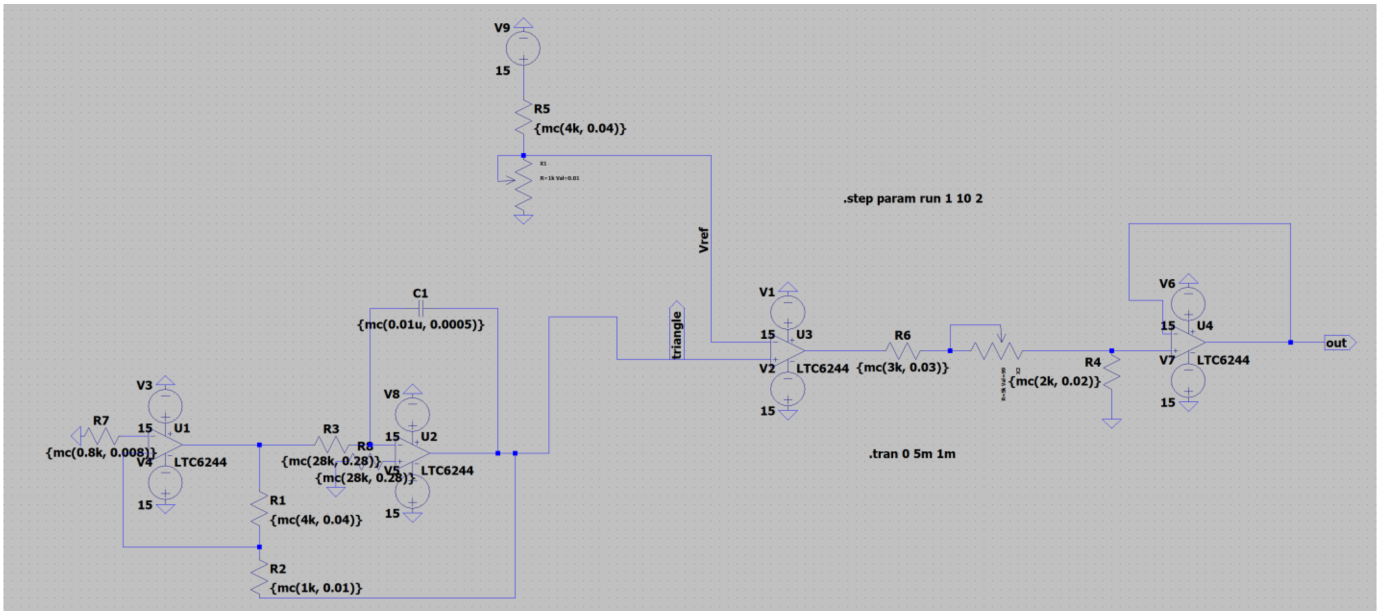


Fig.17 The electrical scheme with tolerances

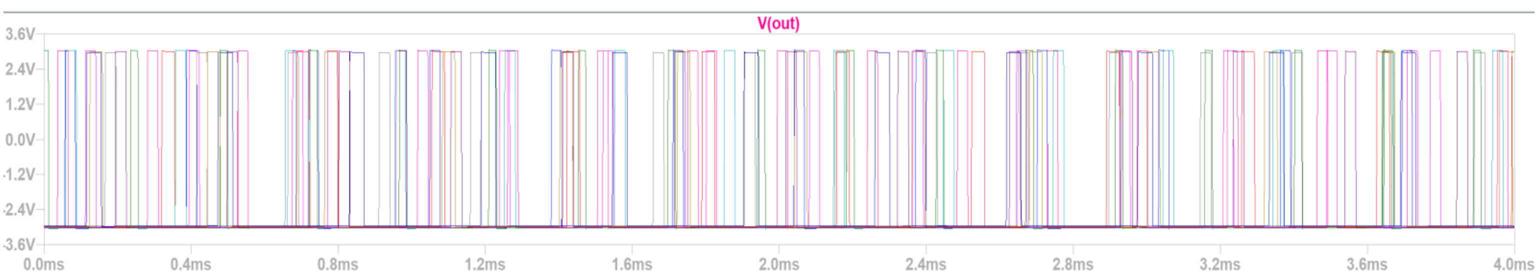


Fig.18 The output after Monte Carlo analysis with 10% duty cycle

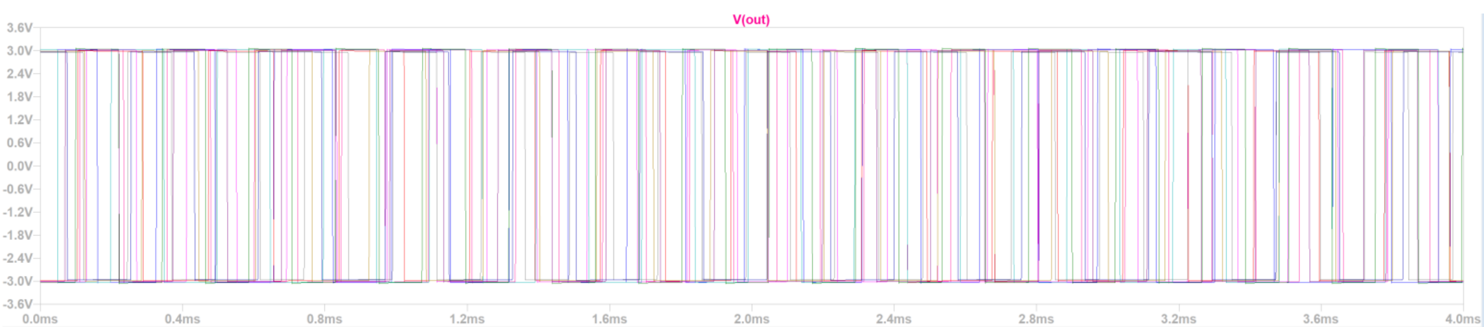


Fig.20 The output after Monte Carlo analysis with 50% duty cycle

It can be observed that the starting time changes, but the frequency and amplitude are not greately affected.

Conclusion

The PWM generator respects the requirements: the amplitude varies between 3V and 6V due to the potentiometer, the duty cycle varies in time from aproximately 50% to 10% and the frequency is 3,53kHz, which represents 100.57% of the required frequency. What is more, the simulations performed have satisfying results.

Proof that the frequency is respected:

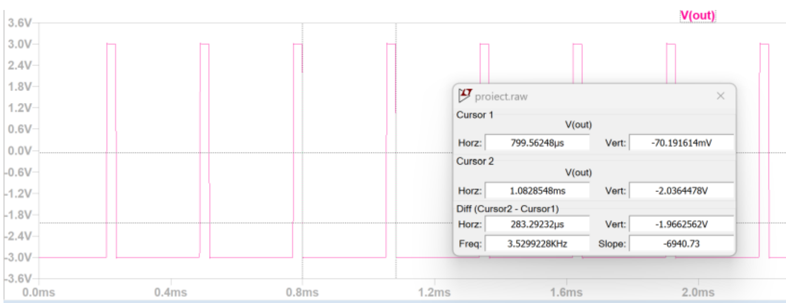


Fig.21The frequency at 10% duty cycle

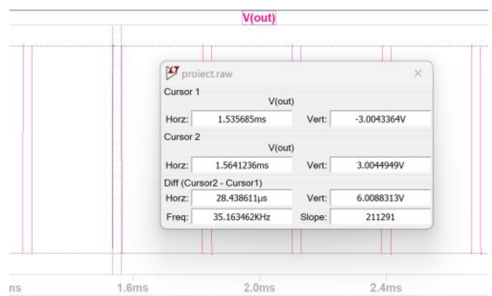


Fig.22Proof for 10% duty cycle=28.5ms

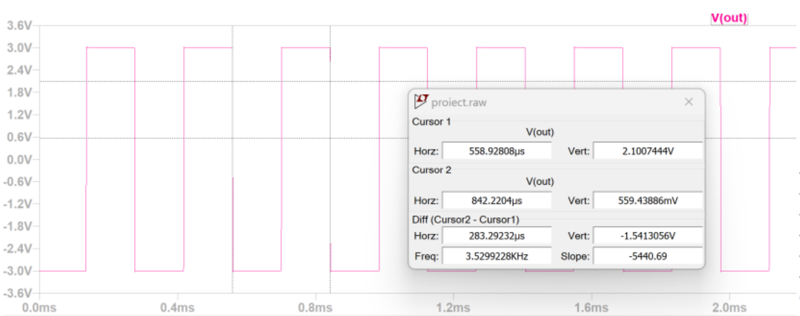


Fig.23The frequency at 50% duty cycle

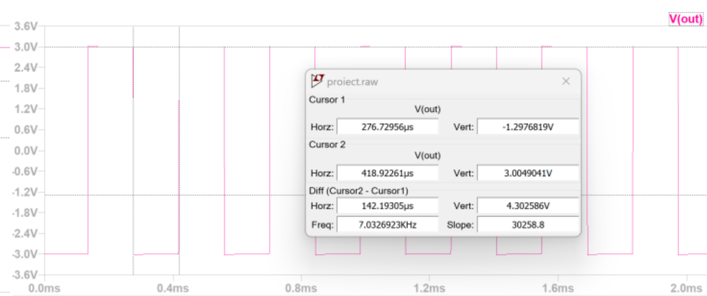


Fig.24 Proof for 50% duty cycle=142ms

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