MINISTRY OF EDUCATION
TECHNICAL UNIVERSITY
OF CLUJ-NAPOCA, ROMANIA

PWM GENERATOR

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Course: Computer Aided Design

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Introduction

Theoretical support

Pulse-width-modulation signal

The PWM signal generator, translated as pulse-width-modulation is an efficient way to control analog circuits by modifying the duration and the frequency of the signal. Moreover, PWM signals are command signals for power transistors used in switching converters.

A Pulse Width Modulation signal can be created with the use of a comparator circuit. The comparator takes in two input signals, one being the modulating signal and the other being a non-sinusoidal or saw-tooth wave. By comparing the two input signals, the comparator generates a PWM signal as output.

Advantages of PWM

PWM generators are easy to make and the also have a low power consumption and an efficiency up to 90%. Moreover, the have little heat whilst working, the noice interference is less and can utilize very high frequency. Another advantage is that the Synchronization between a transmitter and a receiver is not required unlike pulse position modulation.

Disadvantages of PWM

They are pretty complex and the bandwidth should be large when used in communication. They also have high switching loss due to the high PWM frequency.

Requirements

In order to build a pulse-width-modulation signal, the electrical scheme needs to contain a non-sinusoidal wave generator, in this case, a triangular wave generator, a sinusoidal wave generator and a comparator.

Other requirements:

Freq = 5000Hz

Amplitude = 2-6V

Duty cycle = 20-60%

Triangular wave generator

A triangular wave, also known as a triangle wave, is a waveform that derives its name from its triangular shape. Unlike a sinusoidal wave, it is not a smooth curve but rather a piecewise linear function with a periodic nature.

This particular triangular wave generator from figure 1, contains 2 parts, one called Schmitt trigger which is a comparator circuit with hysteresis, implemented by applying positive feedback to the noninverting input of a comparator and a ramp generator, which is a circuit that creates a linear rising or falling output with respect to time.

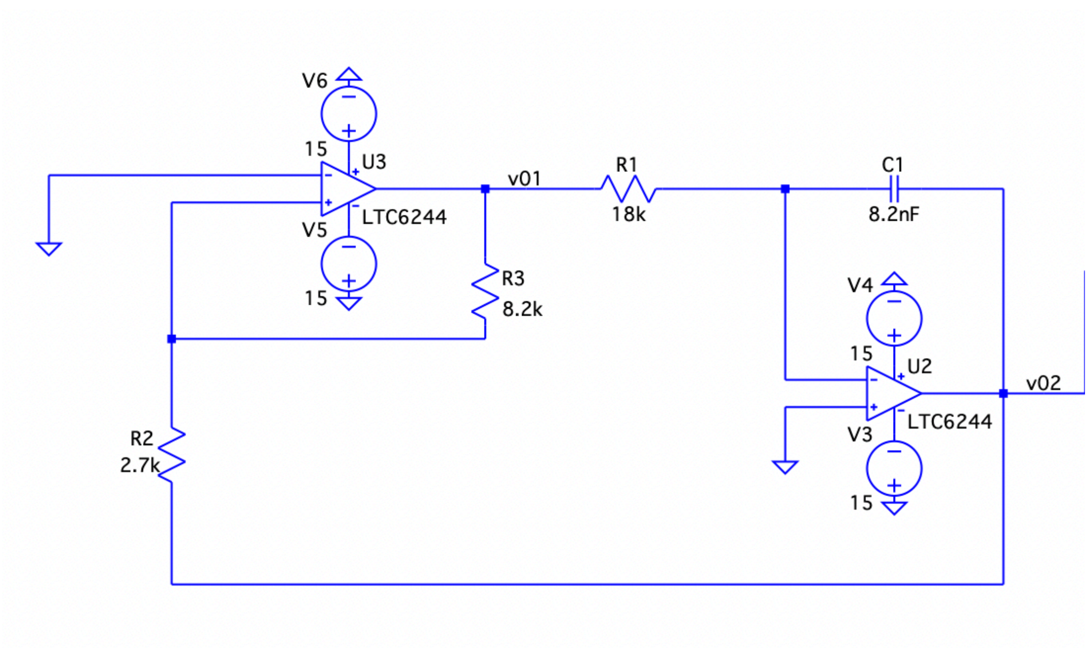


Figure 1

Equations

$$T = \frac{2 \cdot R_1 \cdot C_1}{V_{sat}} \cdot V_{oop} \ \ , \text{(I)} \quad \frac{{}^{-}V_{ramp}}{R_2} = \frac{-{}^{+}V_{ramp}}{R_3} \text{(II)}$$

Wein Bridge

The Wien bridge configuration, from figure 2, is a widely used technique for generating a sine wave using an operational amplifier. It offers a simple electronic circuit design and delivers reliable performance. The op amp Wien bridge oscillator or generator utilizes the Wien bridge network. This network consists of four resistors and two capacitors, forming a specific type of bridge circuit. By leveraging this configuration, the op amp can generate a sine wave output efficiently. There is also a gain limiter that consists of a simple diode-resistor network which has the purpose to control the effective value of R_6 .

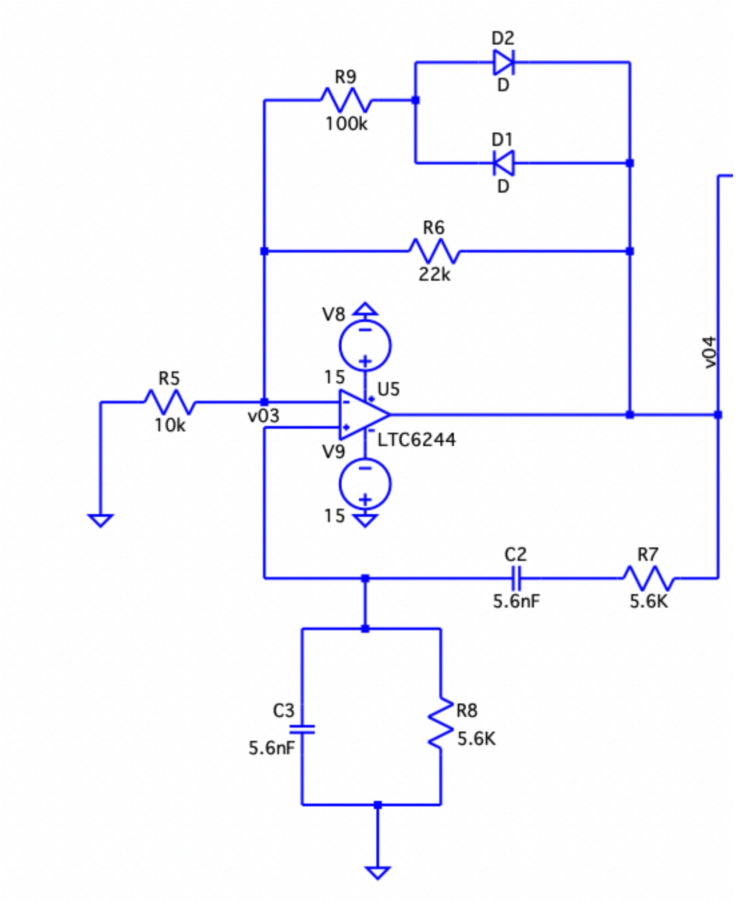


Figure 2

Equations

$$f_{weinbridge} = \frac{1}{2 \cdot \pi \cdot R \cdot C} \quad \text{(III)}$$

$$R_1 = R_2 = R,\ C_1 = C_2 = C \text{ (IV)}$$

$$1 - \frac{R_4}{R_3} > 3 \text{ (V)}$$

Comparator

A comparator, also the one represented in figure 3, is an electronic circuit that compares two input voltages and generates a binary output signal indicating which input voltage is greater. When the voltage at the non-inverting (+) input is higher than the voltage at the inverting (-) input, the output of the comparator goes high. Conversely, when the voltage at the inverting input is greater than the voltage at the non-inverting input, the output of the comparator goes low.

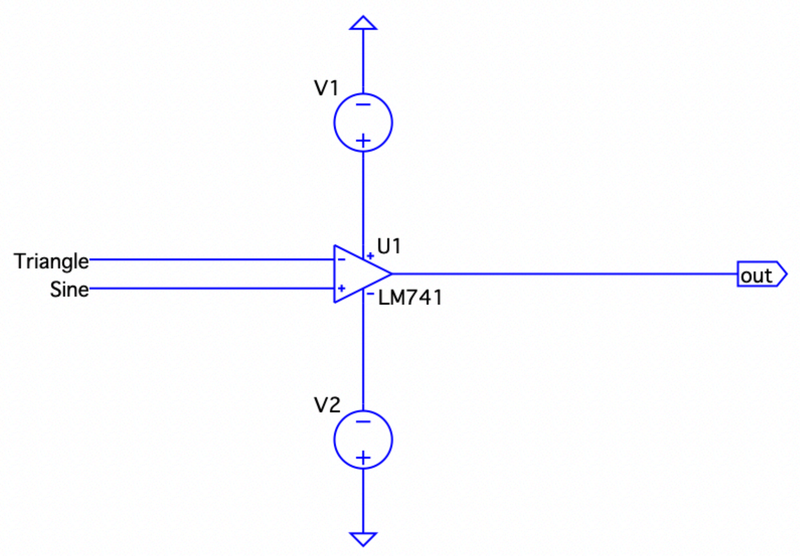


Figure 3

Equations

A buffer amplifier (sometimes simply called a buffer) is one that provides electrical impedance transformation from one circuit to another, with the aim of preventing the signal source from being affected by whatever currents (or voltages, for a current buffer) that the load may impose.

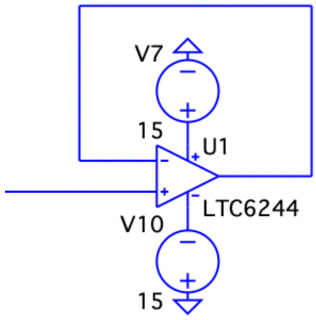


Figure 4

In order to adjust the amplitude, respectively between 2-6V, we need to add a voltage divider(figure 4) at the output of the comparator. In electronics, a voltage divider (also known as a potential divider) is a passive linear circuit that produces an output voltage (Vout) that is a fraction of its input voltage (Vin).

$$V_{out} = \frac{POT_2}{R_1 + POT_2} V_{in} \quad \text{(VI)}$$

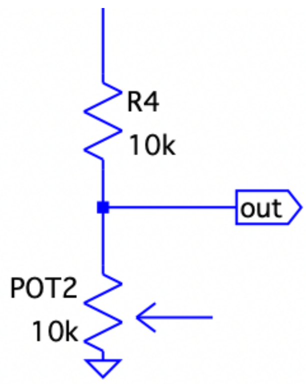


Figure 5

Duty Cycle Adjustment

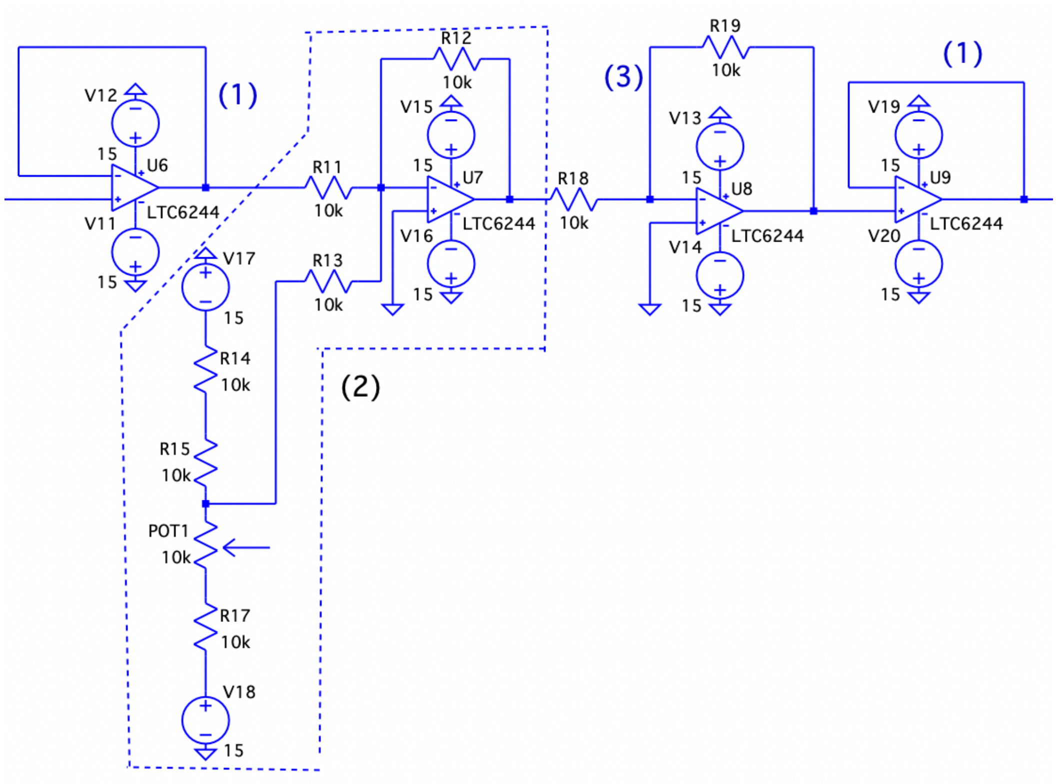


Figure 6

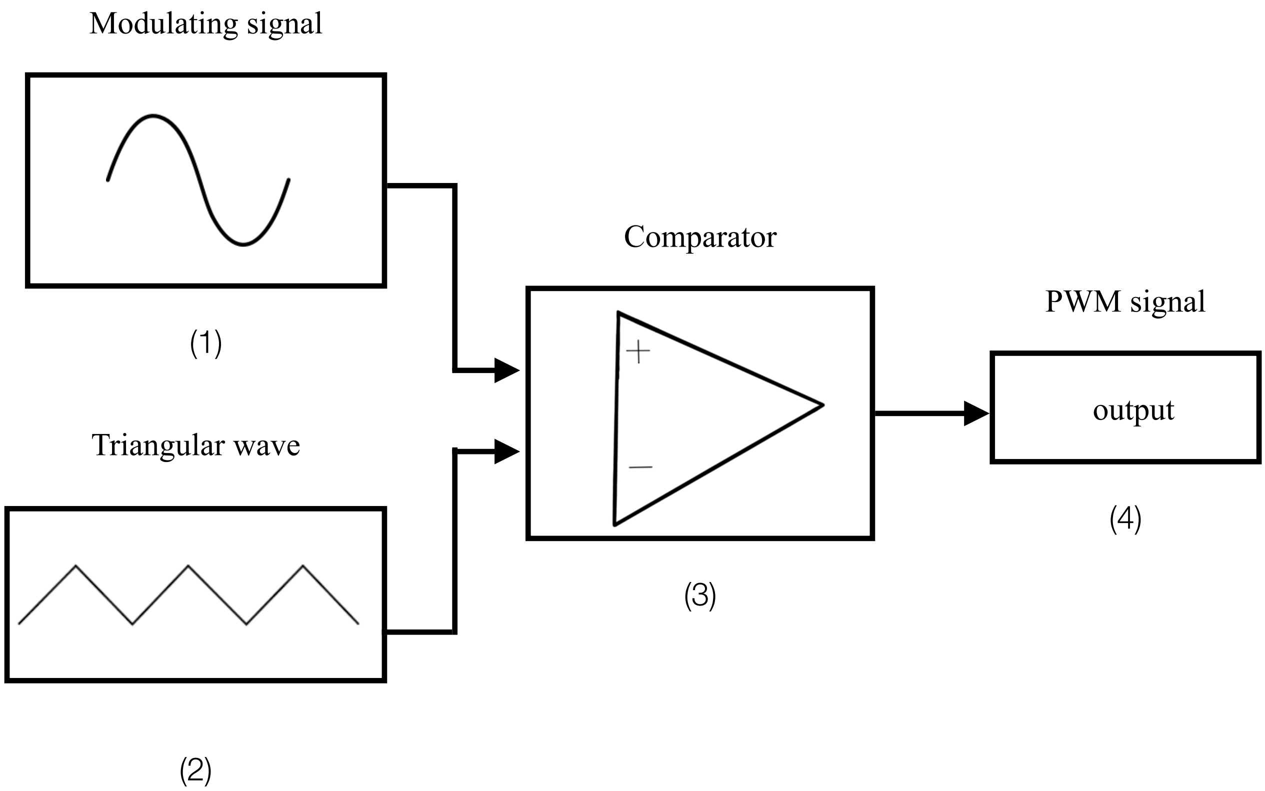
This specific configuration helps move the sinusoidal waveform, in order to achieve the desired duty cycle.

(1) Firstly, there need two buffer amplifiers, one at the begging and one at the end, with the purpose of preventing the signal from being affected.

(2) This configuration adjusts, with the help of a voltage divider, the offset of the signal.

(3) An inverting op amp is an operational amplifier circuit with an output voltage that changes in the opposite direction as the input voltage.

Block Diagram



(1) The first block represents a circuit that generates a modulating signal connected to the (+) of the comparator. The process of adding a low-frequency signal onto a high-frequency carrier signal is known as modulation. The modulation signal used in this process could be various types of signals, such as an audio signal which represents sounds captured by a microphone, a video signal which represents moving images captured by a video camera, or a digital signal which represents a sequence of binary digits, also known as a bitstream, originating from a computer.

(2) In this block we have a circuit that represents a triangular wave which will be connected to the (-) of the comparator. Here we can place any non-sinusoidal wave circuit.

(3) A comparator is an electronic circuit or device that compares two voltages or currents and outputs a digital signal indicating which one is greater. The output signal is typically either high or low, representing a logical 1 or 0, respectively.

(4) The last block represents the output which will show the PWM signal.

Calculus

Wein bridge

From equation (IV) = > $C_2 = C_3 = C, R_7 = R_8 = R$

Fom equation (III) = > $f_{weinbridge} = \dfrac{1}{2 \cdot \pi \cdot R \cdot C}$ => $5kHz = \dfrac{1}{2 \cdot \pi \cdot R \cdot C}$ (1)

Assume: $C = 5.6nF = 5.6 \cdot 10^{-9}F$ (2)

From (1) and (2) =>$R = \dfrac{1}{2 \cdot \pi \cdot f \cdot C} = > R = \dfrac{1}{2 \cdot \pi \cdot 5 \cdot 10^3 \cdot 5.6 \cdot 10^{-9}} = 5{,}686.98 \approx 5.7k\Omega$

From equation (V) = >$1 - \dfrac{R_6}{R_5} = 3 = > \dfrac{R_6}{R_5} = 2 = > R_6 = 20k\Omega, R_5 = 10k\Omega$

Clipping => $R_9 = 100k\Omega$

Figure 7 represents the simulation results for the Wein Bridge oscillator.

Sinusoidal waveform

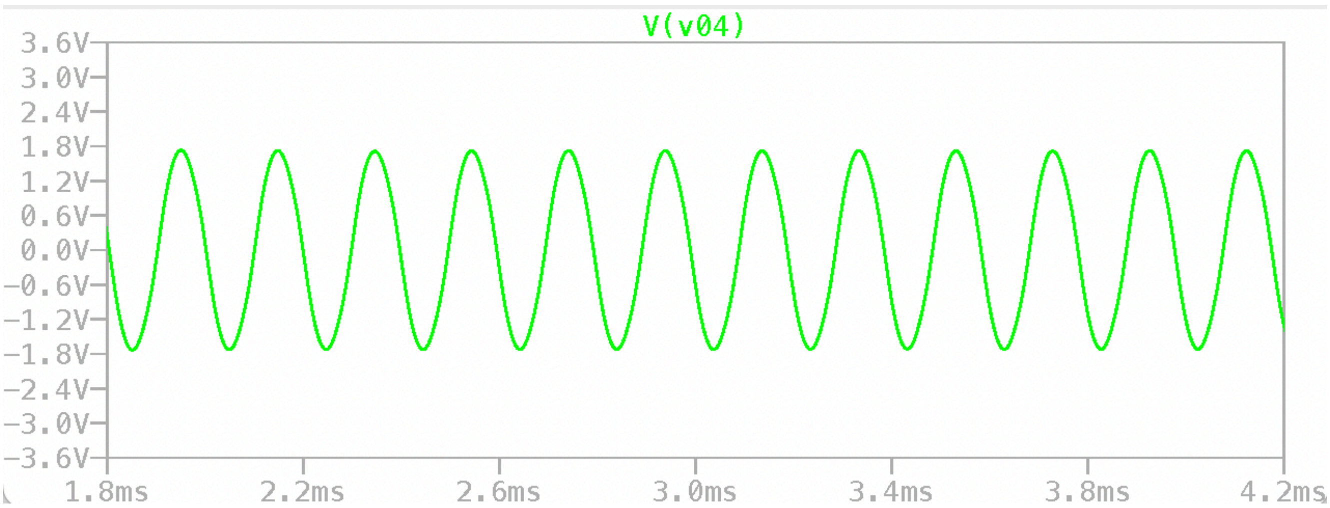


Figure 7

Triangular wave generator

Assume: A = 5V $=> \frac{V_{sat}}{A} = \frac{15}{5} = 3 => \frac{R_3}{R_2} = 3 => R_3 = 3k\Omega\,,\ R_2 = 1k\Omega$

From equation (II) $=> \frac{^{-}V_{ramp}}{R_2} = \frac{-^{+}V_{ramp}}{R_3}$

$$^{-}V_{ramp} = -\frac{R_2}{R_3}\cdot V_{Vsat} = -\frac{10}{30}\cdot 15 = -5\text{V},\quad ^{+}V_{ramp} = -\frac{R_2}{R_3}\cdot -V_{Vsat} = -\frac{1}{3}\cdot -15 = 5\text{V}$$

$$V_{oop} =^{+} V_{ramp} -^{-} V_{ramp} = 5-(-5) = 10V$$

From equation (I) $=> T = \frac{2\cdot R_1\cdot C_1}{V_{sat}}\cdot V_{oop} => T = \frac{2\cdot R_1\cdot C_1}{15}\cdot 10$ (1)

$\frac{1}{T} = f$ (2), Assume: $C_1 = 8.2nF$ (3)

From (1) , (2) and (3)=>

$$f = 5\cdot 10^3 = \frac{15}{2\cdot R_1\cdot C_1\cdot 10} => R_1 = \frac{15}{2\cdot 10^3\cdot 5\cdot 8.2\cdot 10^{-9}\cdot 10} = 18.2k\Omega$$

Figure 8 represents the simulation results of the triangular wave generator.

Triangular waveform

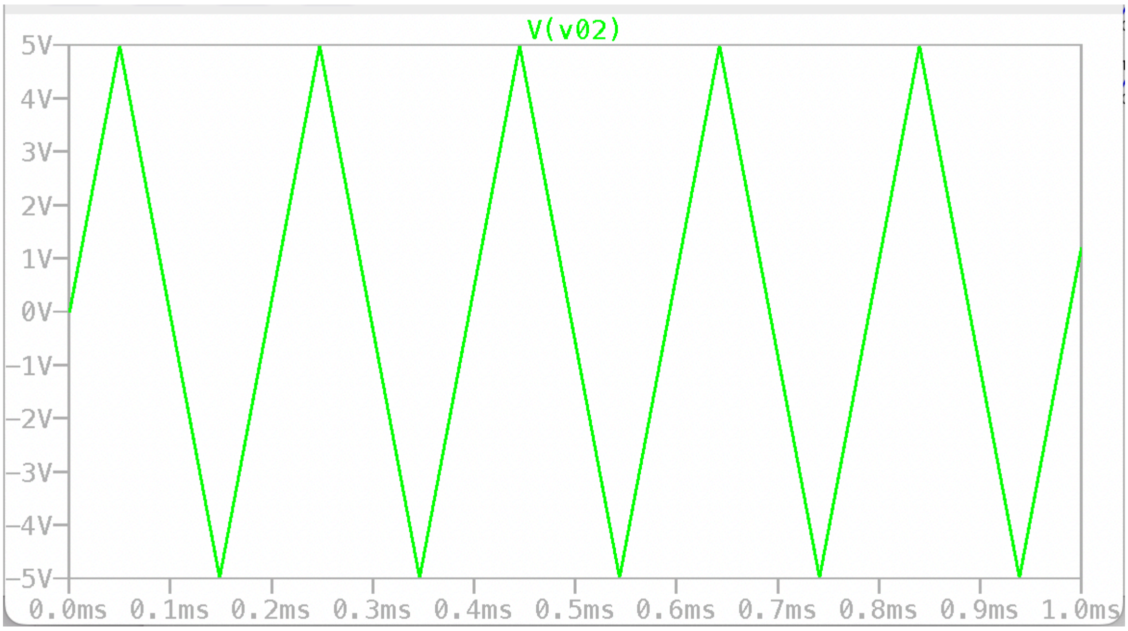


Figure 8

Voltage Divider

A_d = desired amplitude, $A_d = \dfrac{POT}{POT + R} \cdot 15$

Amplitude

$$A_d = \frac{POT_2}{POT_2 + R_4} \cdot 15 => POT_2 \cdot 15 = A_d \cdot (R_4 + POT_2) => POT_2 \cdot 15 - A_d \cdot POT_2 = A_d \cdot R_4 =>$$

$$POT_2 = \frac{A_d \cdot R_4}{15 - A_d}$$

Assume: $R_4 = 10k\Omega$

$$A_d = 2 => POT_2 = \frac{2 \cdot 10 \cdot 10^3}{15 - 2} = 1.5k\Omega$$

$$A_d = 3 => POT_2 = \frac{3 \cdot 10 \cdot 10^3}{15 - 3} = 2.5k\Omega$$

$$A_d = 4 => POT_2 = \frac{4 \cdot 10 \cdot 10^3}{15 - 4} = 3.6k\Omega$$

$$A_d = 5 => POT_2 = \frac{5 \cdot 10 \cdot 10^3}{15 - 5} = 5k\Omega$$

$$A_d = 6 => POT_2 = \frac{6 \cdot 10 \cdot 10^3}{15 - 6} = 6.6k\Omega$$

Duty Cycle

$$A_d = \frac{POT_1}{POT_1 + R_{15}} \cdot 15 => POT_1 \cdot 15 = A_d \cdot (R_{15} + POT_1) => POT_1 \cdot 15 - A_d \cdot POT_1 = A_d \cdot R_{15} =>$$

$$POT_1 = \frac{A_d \cdot R_{15}}{15 - A_d}$$

Assume: $R_4 = 10k\Omega$

$$A_d = 14.5 => POT_2 = \frac{14.5 \cdot 10 \cdot 10^3}{15 - 14.5} = 290k\Omega, => 20\,\%\text{ Duty Cycle}$$

$$A_d = 12.5 => POT_2 = \frac{12.5 \cdot 10 \cdot 10^3}{15 - 12.5} = 50k\Omega => 30\,\%\text{ Duty Cycle}$$

$$A_d = 10 => POT_2 = \frac{10 \cdot 10 \cdot 10^3}{15 - 10} = 20k\Omega => 40\,\%\text{ Duty Cycle}$$

$$A_d = 7.5 => POT_2 = \frac{7.5 \cdot 10 \cdot 10^3}{15 - 7.5} = 8.9k \approx 9k\Omega => 50\,\%\text{ Duty Cycle}$$

$$A_d = 3.5 => POT_2 = \frac{3.5 \cdot 10 \cdot 10^3}{15 - 3..5} = 3k\Omega => 60\,\%\text{ Duty Cycle}$$

Standardization

Wein Bridge

$C_2 = C_3 = 5.6nF => 5.6nF,\ R_7 = R_8 = 5.7k => 5.6k\Omega$
$R_4 = R_5 = R_{11} = R_{12} = R_{13} = R_{14} = R_{17} = R_{18} = R_{19} = 10k => 10k\Omega,\ R_6 = 20k => 22k\Omega$
$R_9 = 100k => 100k\Omega$

Triangular wave generator

$R_1 = 18.2k => 18k\Omega$
$C_1 = 8.2nF => 8.2nF$
$R_3 = 30k => 8.2k\Omega$
$R_2 = 10k => 2.7k\Omega$

Bill of material

BOM

Component	Value	Pieces	Model	Tolerance	Price
R_1	18kΩ	1	10EP51418K0	5 %	0.54$
R_2	2.7kΩ	1	100EP5142K70	5 %	0.06$
R_3	8.2kΩ	1	10EP5148K20	5 %	0.54$
R_6	22kΩ	1	10EP51222K0	5 %	0.54$
R_7, R_8	5.6kΩ	2	10EP5145K60	5 %	0.54$
R_9	100kΩ	1	100EP512100K	5 %	0.06$
$R_4, R_5, R_{11}, R_{12}, R_{13}, R_{14}, R_{17}, R_{18}, R_{19}$	10kΩ	9	10EP51410K0	5 %	0.54$
C_2, C_3	5.6nF	2	1600V562JP15	5 %	0.14$
C_1	8.2nF	1	FKP28200P	2.5%	0.52$
OP-AMP	_	9	LTC6244	-	6.63$
Total	_	28			68,16$

Table 1

Analysis

Transient analysis

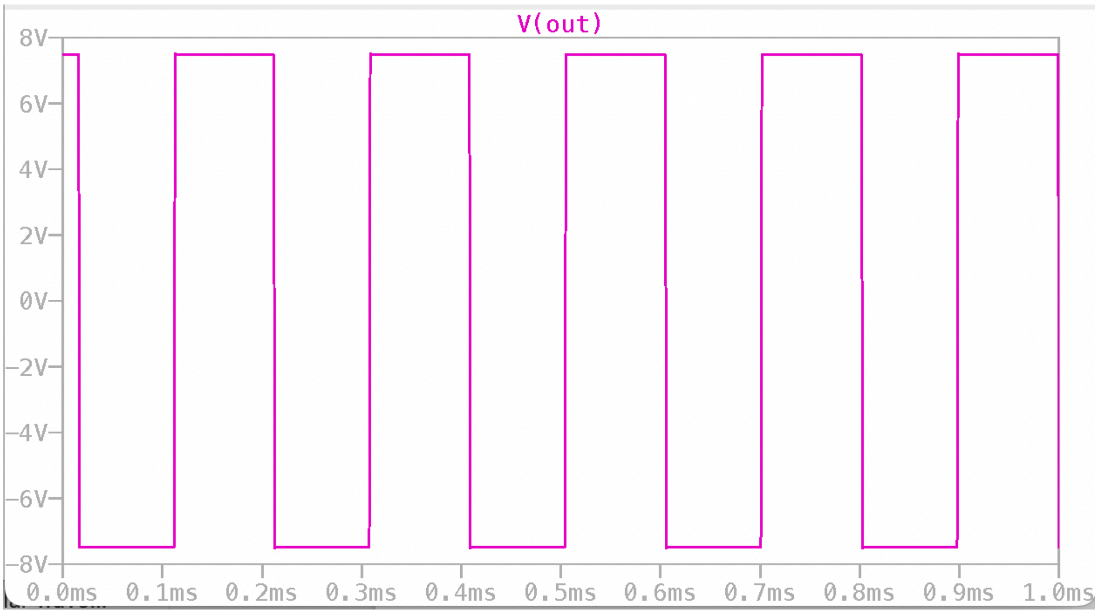


Figure 9

Figure 5 and 6 represent the output voltage of the PWM generator at approximately 5kHz with a period of 0.20ms and a duty cycle of 50%. The analysis has been done using the .TRAN analysis, respectively at 1ms stop time.The transient analysis calculates a circuit's response over a period of time defined by the user.

Frequency

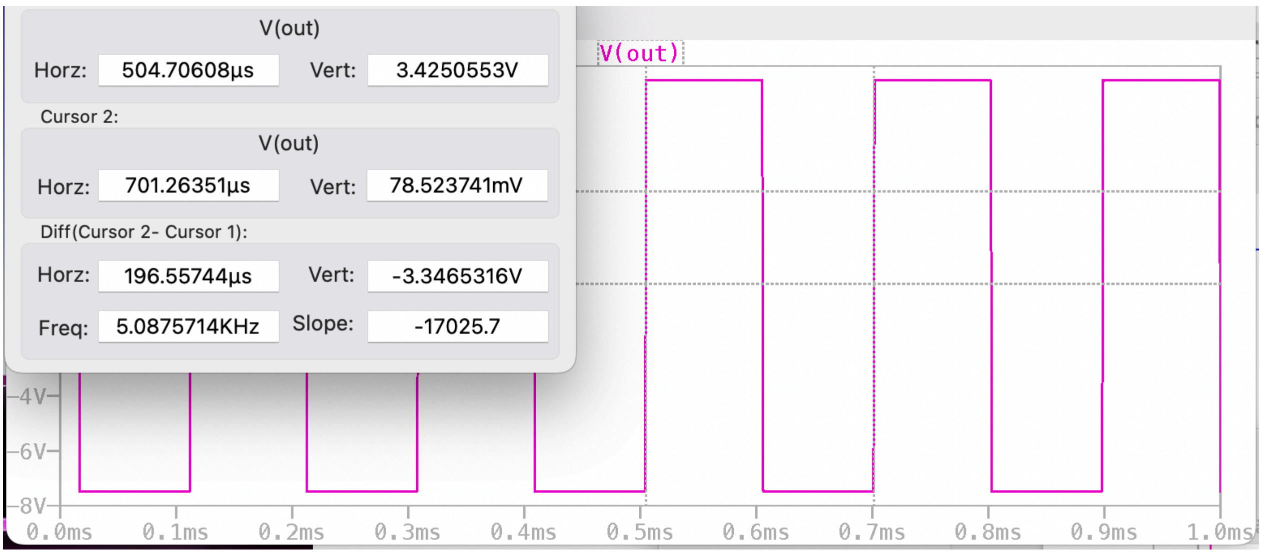


Figure 10

Figure 11 represents the amplitude adjustment analysis, between 2V and 6V, that has been done in LTspice, using the .param command and a voltage divider.

Amplitude adjustment

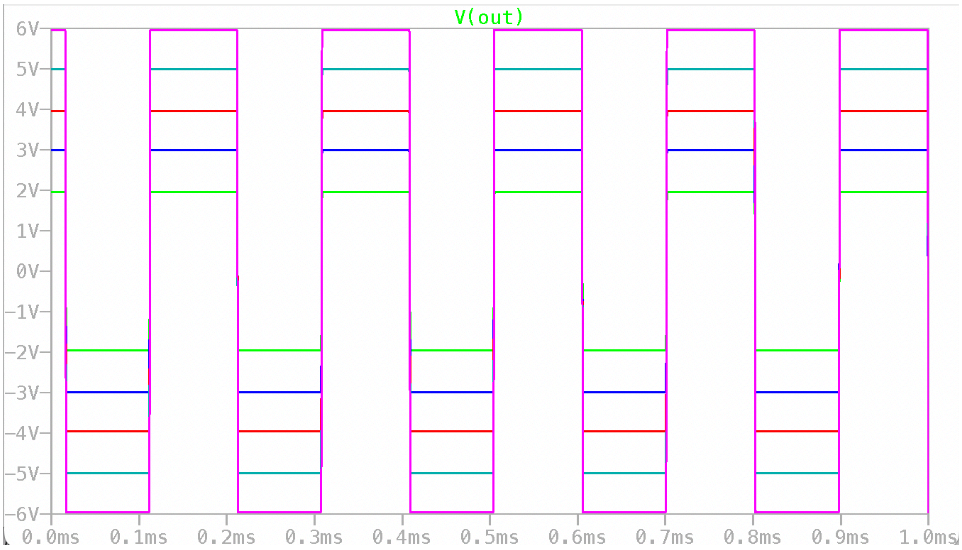


Figure 11

Figure 12 represent the Duty Cycle adjustment analysis that has been done in LtSpice using the .param command, between 20% and 60%.

Duty cycle adjustment

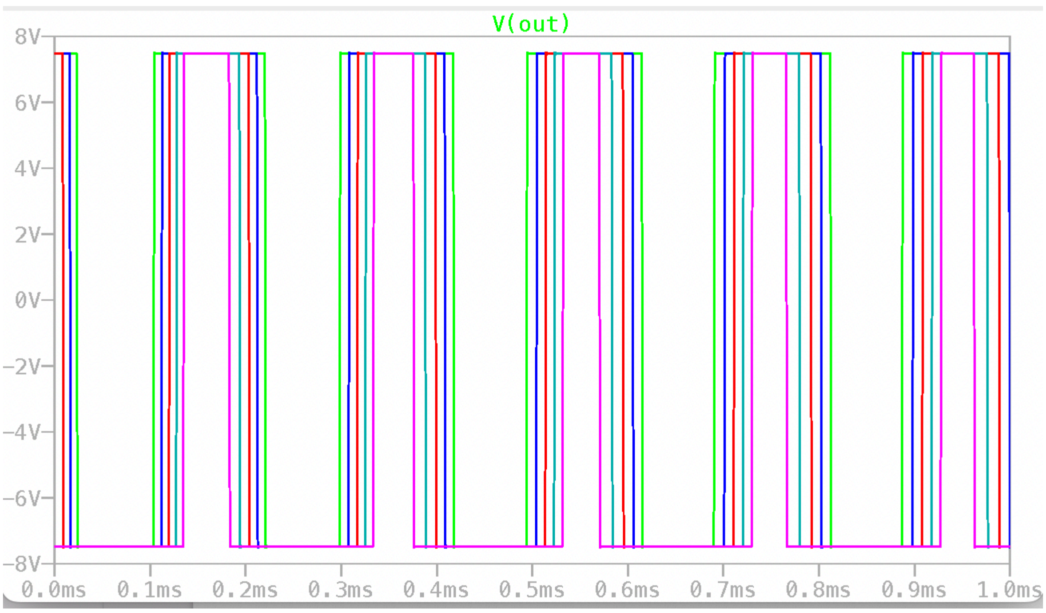


Figure 12

Monte Carlo Analysis

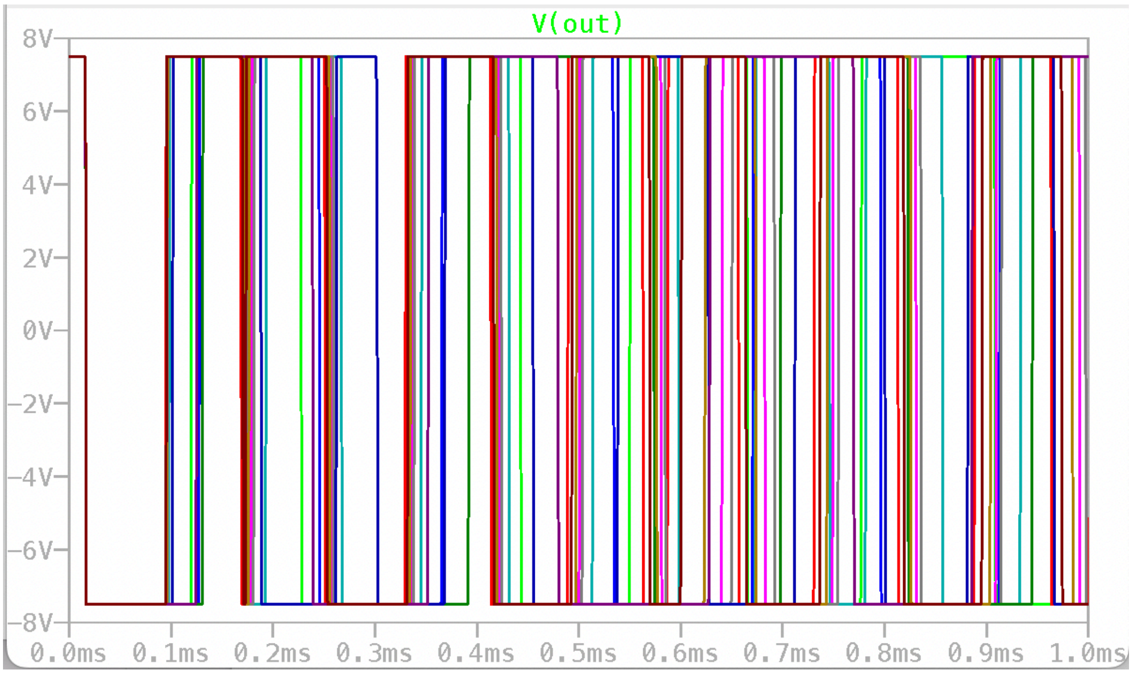


Figure 13

Figure 13 represent the Monte Carlo analysis that is essentially a statistical analysis that calculates the response of a circuit when device model parameters are randomly varied between specified tolerance limits according to a specified statistical distribution.

Temperature Analysis

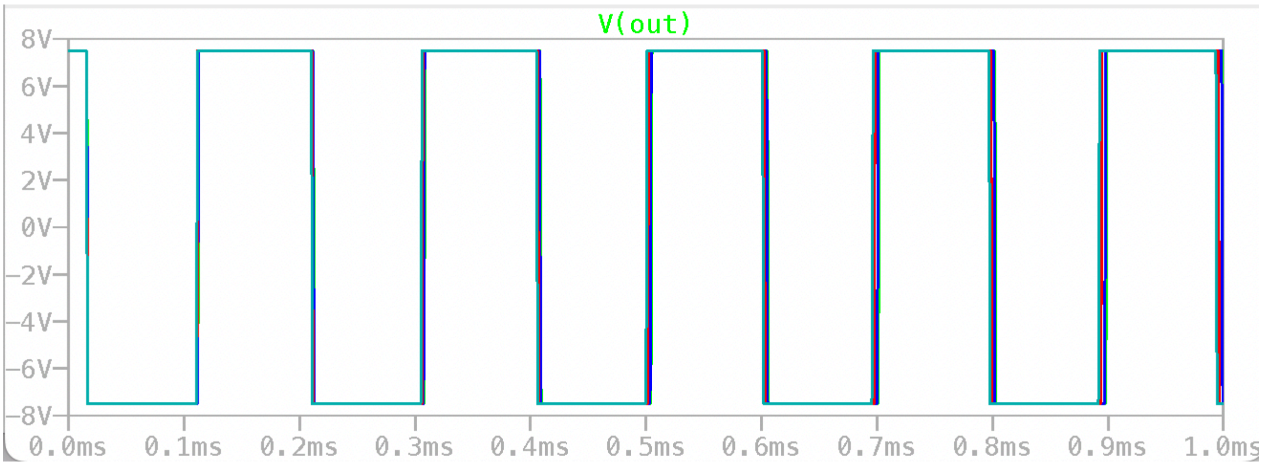
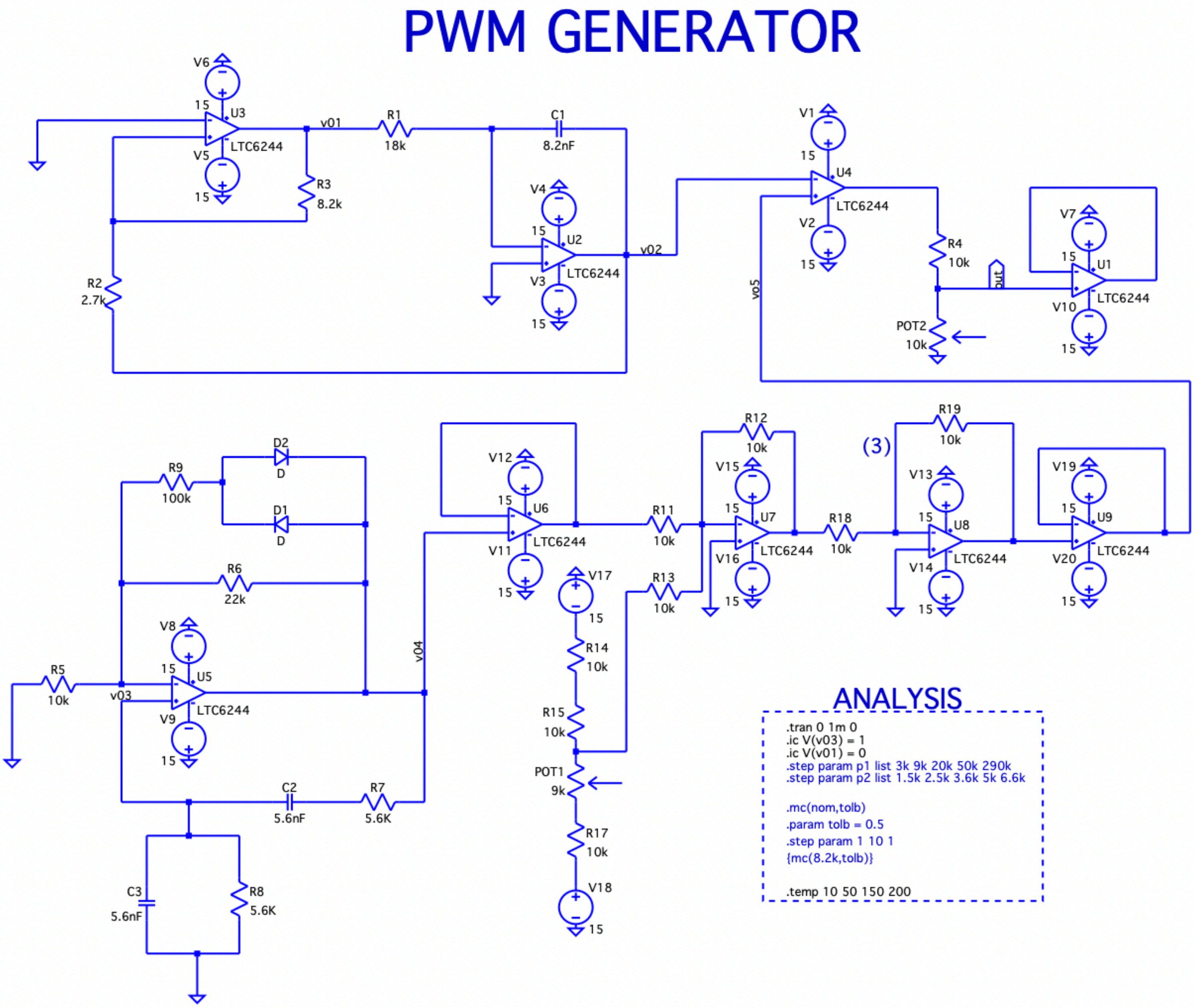


Figure 14

Circuit board thermal analysis techniques aim to predict when and where a board will heat up during operation, as well as how hot the board will get. It is represented in Figure 14.

Schematic


PWM GENERATOR
V6
15
U3
LTC6244
V5
15
v01
R1
18k
C1
8.2nF
R3
8.2k
R2
2.7k
V1
15
U4
LTC6244
V2
15
V4
15
U2
LTC6244
V3
15
v02
R4
10k
out
V7
15
U1
LTC6244
V10
15
vo5
POT2
10k
R12
10k
R19
10k
(3)
R9
100k
D2
D
D1
D
R6
22k
V12
15
U6
LTC6244
V11
15
R11
10k
R13
10k
V15
15
U7
LTC6244
V16
15
R18
10k
V13
15
U8
LTC6244
V14
15
V19
15
U9
LTC6244
V20
15
V17
15
R14
10k
R15
10k
POT1
9k
R17
10k
V18
15
V8
15
U5
LTC6244
V9
15
R5
10k
v03
v04
C2
5.6nF
R7
5.6K
C3
5.6nF
R8
5.6K
ANALYSIS
.tran 0 1m 0
.ic V(v03) = 1
.ic V(v01) = 0
.step param p1 list 3k 9k 20k 50k 290k
.step param p2 list 1.5k 2.5k 3.6k 5k 6.6k
.mc(nom,tolb)
.param tolb = 0.5
.step param 1 10 1
{mc(8.2k,tolb)}
.temp 10 50 150 200

Conclusion

To sum it all up, The PWM (Pulse Width Modulation) generator is an effective technique for managing the average power conveyed by an electrical signal. By swiftly alternating the power supply between 0% and 100% at a frequency faster than the load's significant response time, it becomes possible to regulate the average voltage (and current) provided to the load. As the duration of the switch being in the "on" state increases, the total power delivered to the load correspondingly rises. Moreover, this project has 3 parts, a triangular wave generator composed of a Schmitt trigger and a ramp generator , a wein bridge generator, that creates a sine wave at the oputput and a comparator to compare them.

All in all, the output of the pwm generator generates a square wave signal that hast 5kHz frequency, a period of 0.2ms and a duty cycle of 50%.

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