Technical University of Cluj-Napoca

Faculty of Electronics, Telecommunications and Information Technology

2021

Computer Aided Design

Signal Generator

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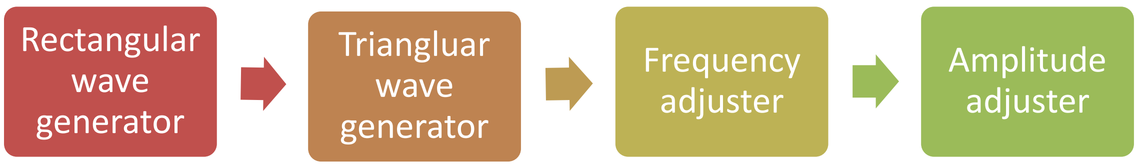
Group: 2023

1 Documentation part

1.1 Requirements

Design a signal generator that provides a rectangular signal of variable amplitude {4V, 7V}, and a triangular signal of 4V amplitude. The frequency of the signal should range between [2400; 9100][Hz], the power supply has the amplitudes [-15;+15] [V] and the load resitance has a value of 10[Ω].

1.2 Block Diagram



1.2.1 Block 1: Rectangular signal generator- Positive feedback comparator

The first block represents an Op-amp multivibrator or attenuation oscillator (positive feedback comparator), which will give at the output a rectangular signal, having the amplitude equal to the saturation voltage of the power supply.

An oscillator is a circuit that uses only a dc voltage supply as input, to produce a periodic waveform on its output. A relaxation oscillator is part of a major category of oscillators, that work based on an RC timing circuit and a device that changes states.

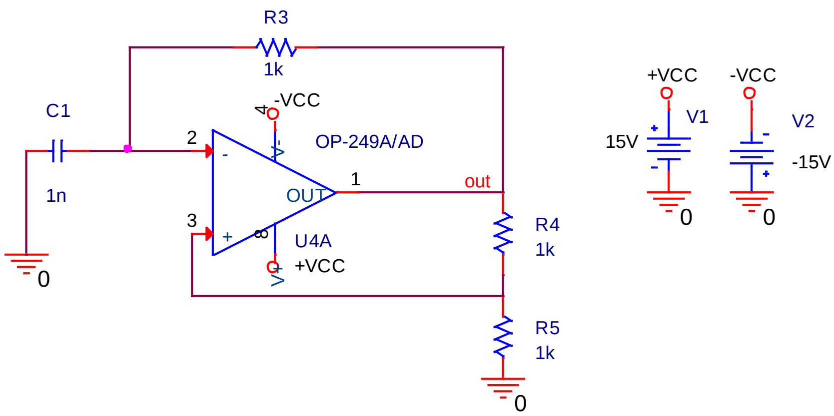


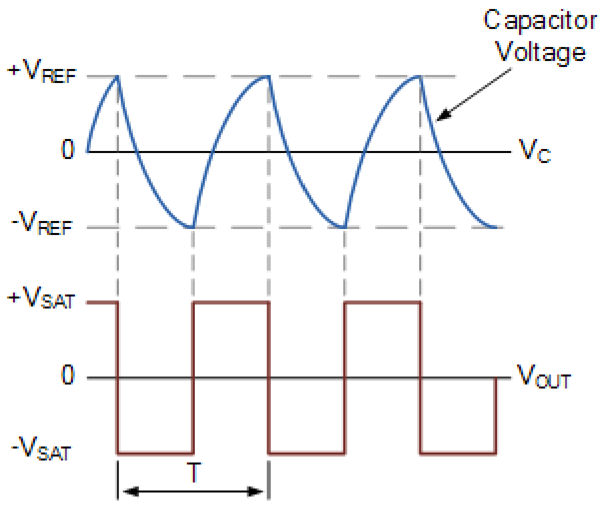
Figure 1- Astable multivibrator (Positive feedback comparator)

That device will be a positive feedback comparator- an op-amp circuit that compares two input voltages and delivers at the output its maximum or minimum saturation voltage provided, depending on the relationship between the inputs. Because the op-amp has a high open-loop voltage gain, it is very sensitive to the voltage changes on its inputs, and the output can switch uncontrollably between its positive, +V(sat) and negative, -V(sat) supply rails whenever the input voltage being measured is near to the reference voltage, V_{REF}, as in Graph 1 . In figure 1, V_{REF} is the voltage divider between R4 and R5, and it's value can be computed using formulas (1) and (2).

The RC timing network is connected to the inverting input of the operational amplifier and the voltage divider network is connected to the non-inverting input.

The Op-Amp is constantly switching between two states with the time spent in each state controlled by the charging or discharging of the capacitor through the resistor.

At the beginning, when the circuit is turned on, the capacitor is not charged, therefore the inverting output will have 0V, and the noninverting input will have a greater voltage, making the circuit to deliver a maximum voltage at the output. The capacitor begins to charge through resistance R3, until it reaches a certain voltage that is equal or greater than the voltage of the noninverting input, Vref. In that moment, the op-amp will switch to its minimum value, and the capacitor will be fed with a negative voltage, making it to discharge until it reaches –Vref. This process repeats infinitely, and a rectangular wave will be obtained at the output.



Graph 1-Voltage on the capacitor (Vc), voltage at the output (Vout)

Formulas:

$$-V_{REF} = \frac{R5}{R4+R5} * (-V_{SAT}) \quad (1)$$

$$+V_{REF} = \frac{R5}{R4+R5} * V_{SAT} \quad (2)$$

We denote: $$\beta = \frac{R5}{R4+R5} \quad (3)$$

Period of the signal: $$T = 2C_1R_3 ln\frac{1+\beta}{1-\beta} \quad (4)$$

Frequency of the signal: $$f = \frac{1}{T} \quad (5)$$

R is Resistance, C is Capacitance, ln( ) is the Natural Logarithm, T is periodic time in seconds, and f is oscillation frequency in Hz. Formulas from above are presented in [5].

1.2.2 Block 2. Triangular waveform-Integrator-Active LowPass Filter

To obtain a triangular waveform, we can enhance the astable multivibrator circuit presented before, making the voltage on the capacitor while charging/discharging, linear. By knowing the formula for the voltage on the capacitor:

$$v_c(t) = \frac{1}{C}\int_{t1}^{t2} i_C\, dt \tag{6}$$

We can deduce that if the current through the capacitor is constant, the voltage will be a linear variation in time, which is exactly what we want to obtain:

$$v_c(t) = \frac{1}{C} I_c t|_{t1}^{t2} \tag{7}$$

As shown above, an op-amp integrator simulates the mathematical process of integration, determining in this way the instantaneous rate of change of a function. Practical integrators often have an additional resistor or other circuitry in parallel with the feedback capacitor to prevent saturation.The circuit can be seen in figure 2.

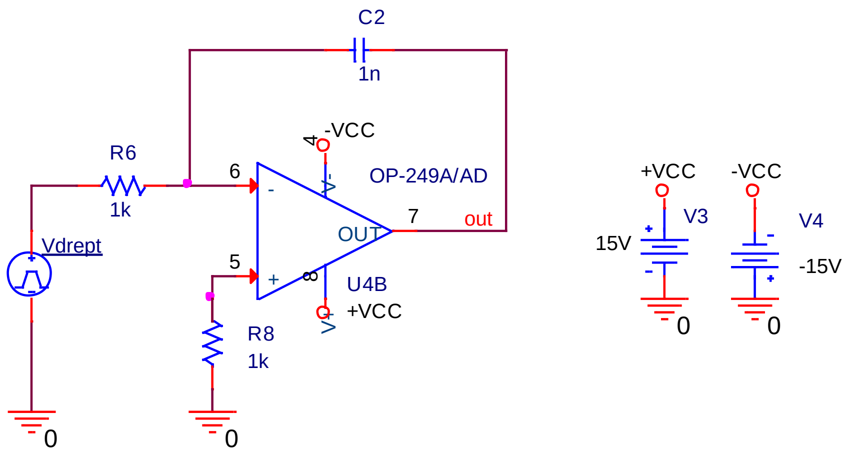


Figure 2-Integrator

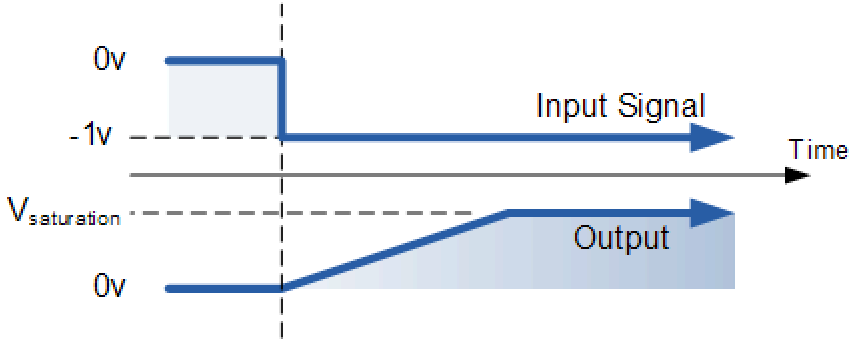
Considering V_{drept} a rectangular voltage that is applied to the input of an integrating amplifier. At the beginning: the capacitor C2 is uncharged and acts as a short circuit, maximum current is drawn by the input resistance Rin. Since no current flows into the Op-Amp, the non-inverting input is connected to the ground, and the voltage at point 6, V^- ,is equal to the voltage at point 5, V^+; the point 6 will be a virtual ground, resulting in zero at the output.

As the capacitor starts to slowly charge due to the influence of V_{drept}, the voltage on the negative side of the capacitor, which is also the output of the Op-Amp, decreases linearly from 0, until the capacitor is fully charged. This voltage is called negative ramp, and is a consequence of a constant positive input.

The rate of change of the output is the rate of change at which the capacitor charges, determined by the RC time constant, described by formula (8), presented in [1].

$$\frac{\Delta V_{out}}{\Delta t} = -\frac{V_{drept}}{R_6 C_2} \tag{8}$$

When it is fully charged, the capacitor acts as an open circuit, blocking any flow of DC current. The ratio of capacitor reactance to input resistance is now infinite resulting in infinite gain. The result of this high gain is that the output of the amplifier goes into saturation as shown in graph 2.



Graph 2- Output signal of an integrator in comparison with the input voltage

If we apply a constantly changing input signal such as a square wave to the input of an integrator amplifier then the capacitor will charge and discharge in response to changes in the input signal, as in graph3.

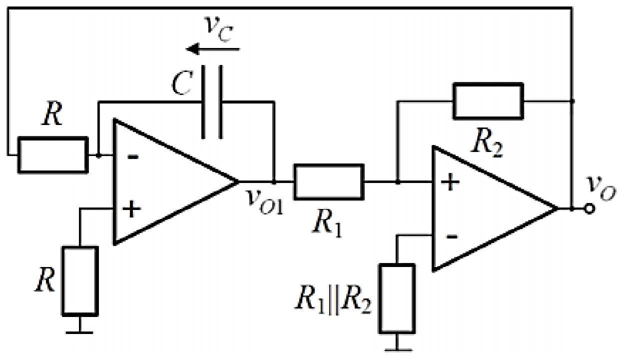
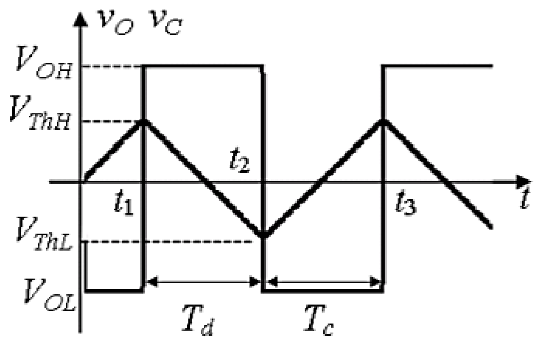


Figure 3- Integrator circuit



Graph 3-Output signal of an integrator, when is fed with a rectangular voltage

The output of the first amplifier in the picture above, which is also the voltage on the capacitance, Vo1, will have the amplitude equal to:

$$V_{ThL} = -\frac{R1}{R2}V_{OH} \tag{9}$$

$$V_{ThH} = -\frac{R1}{R2}V_{OL} \tag{10}$$

Discharge time: $$T_d = RC\frac{V_{ThH}-V_{ThL}}{V_{OH}} \tag{11}$$

Charge time: $$Tc = RC\frac{V_{ThH}-V_{ThL}}{-V_{OL}} \tag{12}$$

In general : V_{OH} =-V_{OL}

Period of a triangle wave: $$T=Tc+Td=2RC\frac{V_{ThH}-V_{ThL}}{V_{OH}} \tag{13}$$

1.2.3 Block 3 -Frequency Adjuster

In order to adjust the frequency of the oscillator, we have to change the time constant of the circuit, which means to change either the capacitor value, either the resistance. I plan to use a structure based on a potentiometer and a resistor, seen by the resistance on the inverting input of the integrator. The full circuit at this stage should look like in figure 4.

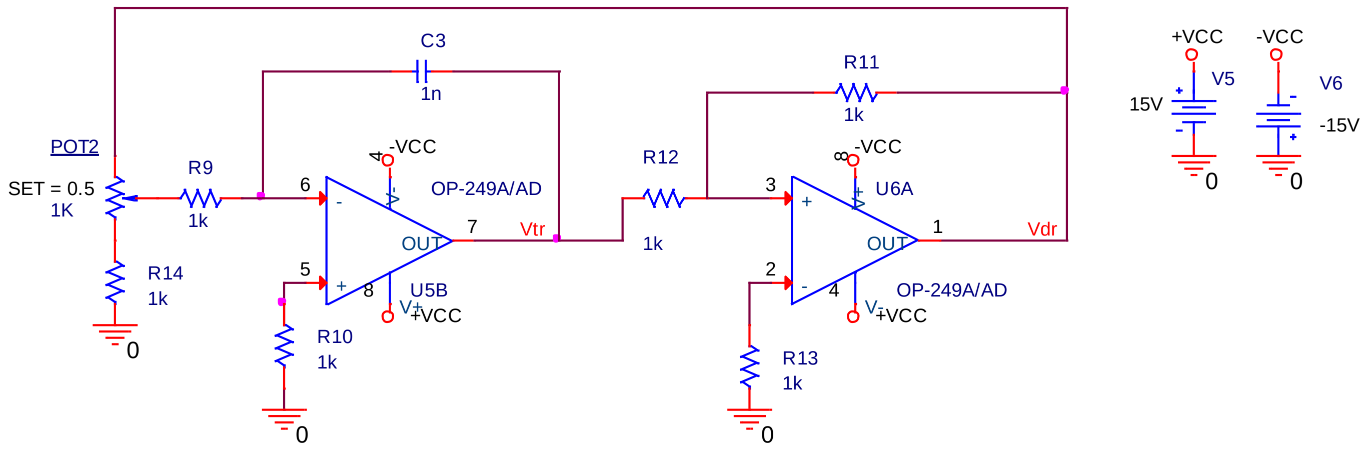


Figure 4-Triangle signal generator with adjustable frequency

In this way, we can compute the frequency range of the circuit, using the formulas presented in [5].

$$f_{max} = \frac{1}{4R_9C_3}\frac{R_{11}}{R_{12}} \tag{14}$$

$$f_{min} = \frac{1}{4R_9C_3}\cdot\frac{R_{11}}{R_{12}}\cdot\frac{R_{14}}{R_{14}+POT_2} \tag{15}$$

1.2.4 Block 4-Amplitude adjustment

The amplitude of the rectangular wave at the output of the positive comparator is approximately 15V. Therefore, we need to adjust this voltage to either 4 V, or 7V.

I plan to do this by using a structure based on a potentiometer, two resistors, and a voltage follower to match the impedances of the resistors to the load.

The gain of the Op-Amp is 1, and the voltage of the noninverting input is going to be the same as the voltage at the output, it does not affect the signal's amplitude.

In this circuit, in order to obtain the desired amplitude of the signal, the resistances used have a smaller impedance compared to the one of the load, and this may cause impedance mismatching. The usefulness of the buffer comes from that it's input impedance is really high, while the impedance at the output is low, solving the impedance problem.

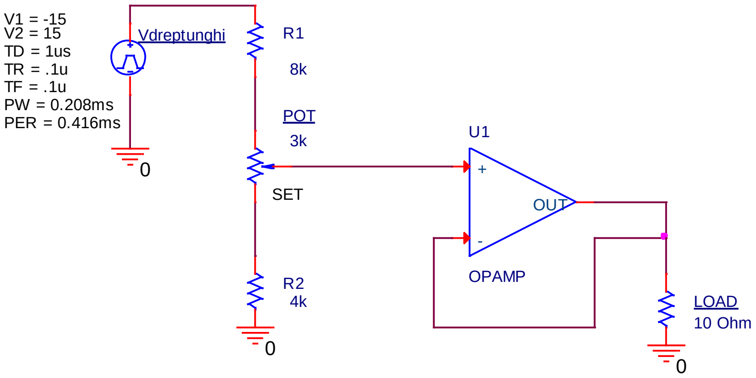


Figure 5-Amplitude adjuster

The formulas for the output voltage, depending on the position of the potentiometer:

Set=0: $$Vout_{min} = \frac{R2}{R1+POT+R2} * Vdrept \tag{16}$$

Set=1: $$Vout_{max} = \frac{POT+R2}{R1+POT+R2} * Vdrept \tag{17}$$

1.2.5 Block5- power amplifier

The current at the output of the Op-Amp should be about 400mA when the output voltage is 4V and about 700mA when the output voltage is 7V. But because a the UA741 opAmp can't provide such a bif current, I used a Class AB power amplifier with a shortcircuit protection for higher currents.

The amplifier works like this: on the positive half of the input signal, the npn transistor Tn is in conduction, and it uses 0.7V from the input signal VI, for its VBE, base to emitter voltage. To make the output signal to get back the 0.7V lost on the transistor Tn, I placed a diode D1 that will provide the biasing voltage to this part of the circuit. Tp and D2 work for the negative half of the input voltage VI, symmetrically.

The current in the diodes and transistors are the same, building a current mirror that eliminates the crossover distortion appeared in class B amplifier. To prevent a higher current flow through the diodes, resitors R are added to alleviate the thermal runnaway.

Using the formulas from [1],the diode current is the same as ICQ, the collector current in the transistor Tn:

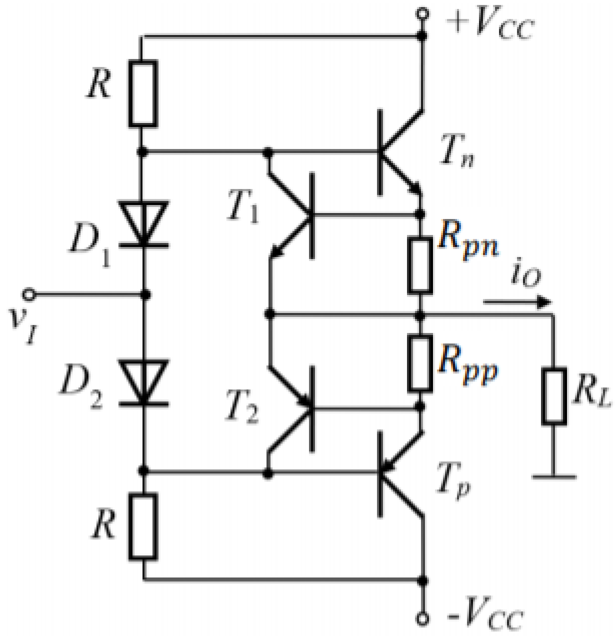


Figure 6-Class AB power amplifier

$$I_{CQ} = \frac{V_{CC}-0.7V}{R} \quad (18)$$

The ideal maximum peak output voltage is

$$V_{outPeak=}V_{CEQ} = V_{CC} = 15V \quad (19)$$

The ideal maximum peak current is:

$$I_{outPeak} = I_{Csat} = \frac{V_{CC}}{R_L} = \frac{15}{10} = 1.5A \quad (20)$$

The elements responsible for the short-circuit protection are: **T1,T2, Rpn, Rpp**.

When the output voltage Vo is positive and the voltage drop on the resistance Rpn is $R_{pn} * I_o < 0.7$V, then T1 is off and I_o is given bythe formulas from [9] :

$$I_o = \frac{V_o}{R_L} \tag{20}$$

When $I_o$increases, and when the voltage drop $R_{pn} * I_o$ =0.7V, then T1 will enter conduction and

$$I_o max = \frac{V_{BE}}{R_{pn}} = \frac{0.7V}{R_{pn}} \tag{21}$$

To compute the resistances R from fig 6, I used formulas from [10]:

$$V_{CC} = 2 * R * I_{bias} + 2 * V_{BE}$$

$$R = \frac{V_{CC} - 2 * V_{BE}}{2 * I_{bias}}$$

$$I_{bias} = 0.02 * ICsat = 0.02 * \frac{V_{CC}}{2R_L}$$

The testing block from ORCAD: The amplifier magnifies the output current of the OpAmp

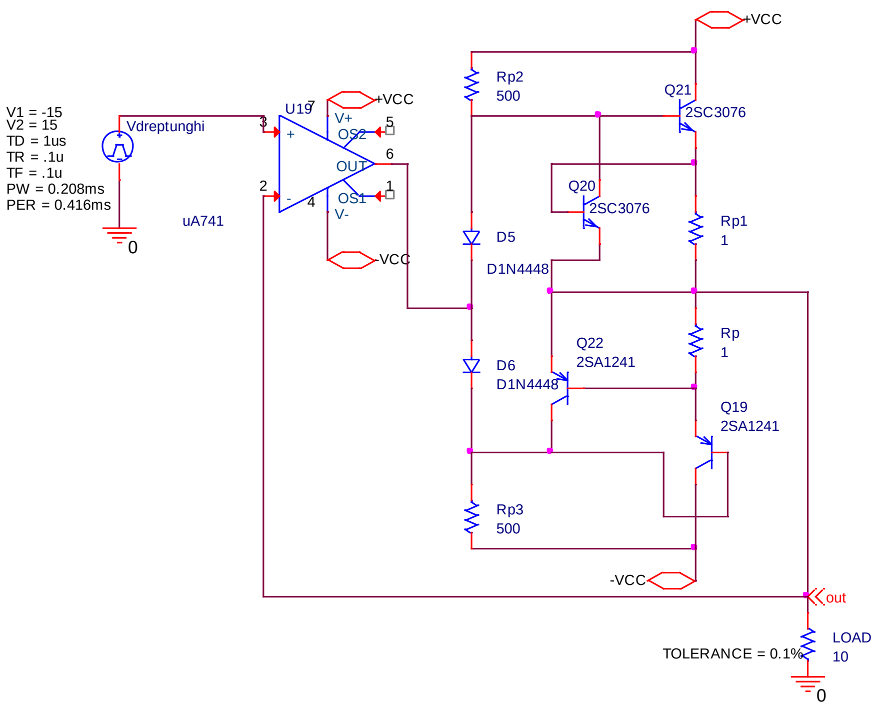


Figure 7-Class AB Power Amplifier - ORCAD

2 The final circuit

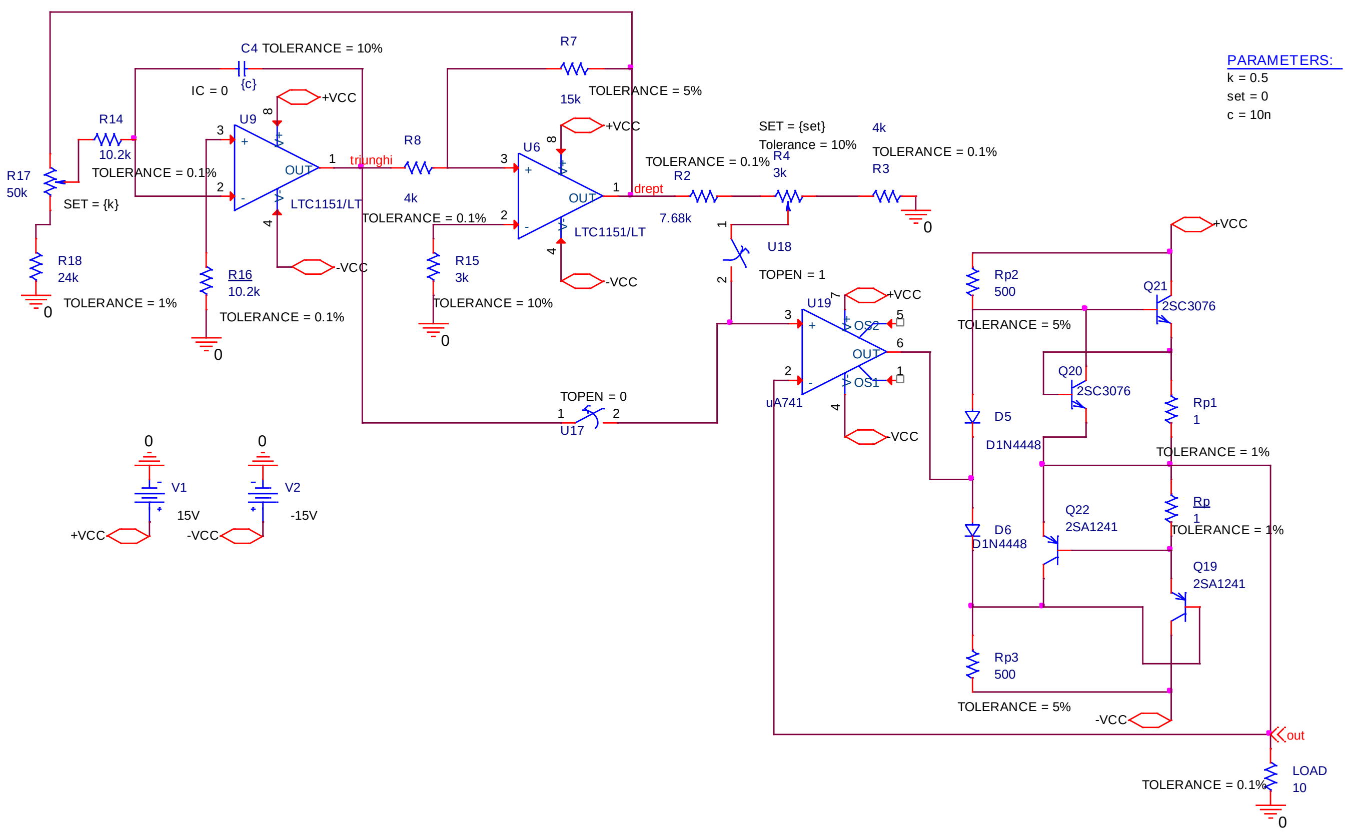


Figure 8-FINAL CIRCUIT-ORCAD

3 Calculus

<u>Compute the amplitude of the triangle wave</u>:

$$\boldsymbol{V_{triunghi}} = \frac{R8}{R7} V_{OH} = \frac{R8}{R7} 15 = \mathbf{4\ V} \qquad \Rightarrow \textbf{R7=15k}\Omega\textbf{; R8=4k}\Omega$$

R15=R8||R7=3kΩ (for stabilizing the opamp)

<u>Compute the amplitude of the rectangular wave:</u>

$\boldsymbol{V_{load}(rectangle)}$ has to be either **4V** or **7 V**

Set=0: $$Vload_{min} = \frac{R3}{R2+R4+R3} * 15 = 4V$$

Set=1: $$Vload_{max} = \frac{R4+R3}{R2+R4+R3} * 15 = 7V$$

$$R2 + R4 + R3 = \frac{R3 * 15}{4} = \frac{(R4 + R3) * 15}{7}$$

7R3=4R4+4R3=> 3R3=4R4=> **R3=4kΩ ; R4=3kΩ**

$$R2 + R4 + R3 = \frac{4k*15}{4} = 15k = R2 + 3k + 4k \quad => \boldsymbol{R2 = 15k - 7k = 8k\Omega}$$

Compute the frequency of the signal:

$$\mathrm{f_{max}} = \frac{1}{4R_{14}C_4}\frac{\mathrm{R_7}}{R_8} = \frac{1}{4R_{14}C_4}\frac{15\mathrm{k}}{4k} = 9100\ Hz \quad => R14 * C4 = \frac{15}{4*9100} = 103\ u \quad =>$$

$$\boldsymbol{R14 = 10.3k\Omega};\ \boldsymbol{C4 = 10nF}$$

R16=R14=10.3kΩ (for stabilizing the opamp)

$$\mathrm{f_{min}} = \frac{1}{4R_{14}C_4}\frac{\mathrm{R_7}}{R_8}\cdot\frac{\mathrm{R_{18}}}{\mathrm{R_{18}+R_{17}}} = 2400\ Hz \quad => \quad \frac{\mathrm{R_{18}}}{\mathrm{R_{18}+R_{17}}} = \frac{2400}{9100} \quad =>$$

$$91R18 = 24R18 + 24R17 \quad => 67R18 = 24R17 \quad => \boldsymbol{R18 = 24k\Omega};\ \boldsymbol{R17 = 67k\Omega}$$

Sizing the elements of the power amplifier:

The OpAmp U19 used is an **uA741**. The diodes D5 and D6 are fast switching diodes **D1N448**

Using the formulas (21) we can compute the protection resistances Rpn, Rpp from fig6:

$$R_{pn} = R_{pn} = \frac{0.7V}{I_o max}$$

If we choose the maxim output current 0.8A

Rpn = Rpp = $\boldsymbol{\frac{0.7V}{0.8A} \sim 1\Omega}$

To compute the resistances R from fig 6:

$$I_{bias} = 0.02 * ICsat = 0.02 * \frac{V_{CC}}{2R_L} = 0.02 * \frac{15}{2 * 10} = 15mA$$

$$\boldsymbol{R = \frac{15 - 2 * 0.7}{2 * 0.015} = 453 \sim 450\Omega}$$

As for the transistors, I used **2SC3076** for the NPN and **2SA1241** for the PNP, because the maximum collector current I_C=2A, which is greater than 1.5A ($_{IoutPeak}$).

TOSHIBA TRANSISTOR SILICON NPN EPITAXIAL TYPE (PCT PROCESS)

2SC3076

POWER AMPLIFIER APPLICATIONS

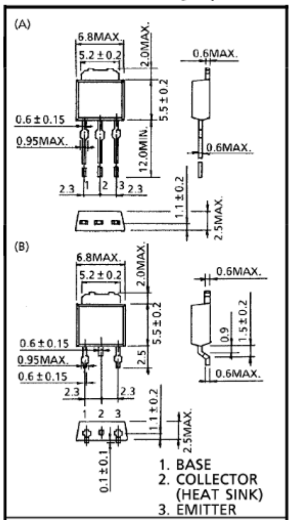
POWER SWITCHING APPLICATIONS

- Low Collector Saturation Voltage
  : $V_{CE\,(sat)} = 0.5$ V (Max.) ($I_C = 1$ A)
- Excellent Switching Time : $t_{stg} = 1.0\ \mu s$ (Typ.)
- Complementary to 2SA1241

MAXIMUM RATINGS (Ta = 25°C)

CHARACTERISTIC		SYMBOL	RATING	UNIT
Collector-Base Voltage		V_{CBO}	50	V
Collector-Emitter Voltage		V_{CEO}	50	V
Emitter-Base Voltage		V_{EBO}	5	V
Collector Current		I_C	2	A
Base Current		I_B	1	A
Collector Power Dissipation	Ta = 25°C	P_C	1.0	W
	Tc = 25°C		10	
Junction Temperature		T_j	150	°C
Storage Temperature Range		T_{stg}	−55~150	°C

Unit in mm



JEDEC	—
EIAJ	—
TOSHIBA	(A) 2-7B1A (B) 2-7B2A

Weight : 0.36 g

Figure 9 -Datasheet of the NPN transistor

For the block that give rectangular and triangular waveforms, I used an operational amplifier **LTC1151/LT** which gives an output voltage swing of +-14.99V

List of real components:

Component	Theoretical value	Real value	Tolerance	From where to buy	Price
Resistor	24kΩ	24k Ω	+/-1%	https://ro.farnell.com/multicomp/mf25-24k/res-24k-1-250mw-axial-metal-film/dp/9341609	0.19lei/pcs Min 10pcs
Resistor	10.3kΩ	10.2k	+/-0.1%	https://ro.farnell.com/te-connectivity/rp73pf1j10k2btdf/res-10k2-0-1-0-166w-0603-thin/dp/2116785	2.71lei/1pcs
Resistor	4kΩ	4k	+/-0.1%	https://ro.farnell.com/multicomp/mcknp03uj0402b00/wirewound-resistor-4kohm-3w-5/dp/1602143	4.31lei/pcs **x2=8.62**lei
Resistor	15kΩ	15k	+/-5%	https://ro.farnell.com/w/c/passive-components/resistors-fixed-value/prl/rezultate?resistance=15kohm&packaging=each	0.65lei/pcs
Resistor	3kΩ	3k	+/-5%	https://ro.farnell.com/multicomp/mcknp03uj0302b00/res-3k-5-3w-axial-wirewound/dp/1903845	3.14lei/pcs
Resistor	8kΩ	7.68k	+/-0.1%	https://ro.farnell.com/neohm-te-connectivity/yr1b7k68cc/res-7k68-0-10-250mw-axial/dp/1083350	3.18lei/pcs
Resistor	10Ω	10	+/0.1%	https://ro.farnell.com/neohm-te-connectivity/yr1b10rcc/res-10r-0-10-250mw-axial/dp/1083036	3.39lei/pcs
Resistor	500Ω	500	+/-5%	https://ro.farnell.com/multicomp/mcknp01wj0501a10/res-500r-5-1w-axial-wirewound/dp/1903699	0.91lei/pcs **x2=1.82lei**
Resistor	1Ω	1	+/-1%	https://ro.farnell.com/vishay/mbb02070c1008fc100/res-1r-1-600mw-axial-thin-film/dp/2614375	0.59lei/pcs **x2=1.2lei**
Potentiometer	67k Ω	50k	+/-20%	https://ro.farnell.com/bourns/3310p-001-503l/potentiometer-50k/dp/1156136	12.75lei/pcs
Potentiometer	3k Ω	3k Single turn	+/-10%	https://ro.farnell.com/bourns/3362p-1-302lf/trimmer-pot-3kohm-10-1turn-th/dp/2328607	5.35lei/pcs
Capacitor	10nF	0.01uF	+/-10%	https://ro.farnell.com/vishay/mkt1813310635g/cap-0-01-f-630v-10-pet/dp/1166871	13.85lei/pcs

OpAmp	Model: LTC1151			https://www.ebay.com/p/661301885	53.94lei/pcs X2=108lei
OpAmp	UA741ID			https://ro.farnell.com/stmicroelectronics/ua741id/op-amp-single-1mhz-0-5v-s-8/dp/1842613?st=ua741	18.5lei/pcs
Diode	1N4148TA			https://ro.farnell.com/on-semiconductor/1n4148ta/diode-ultrafast-300ma-100v-do/dp/2322485?st=1n4148	0.73lei/pcs **x5=3.65lei**
Transistor	2SC3076			https://store.americanmicrosemiconductor.com/2sc3076y.html?mcid=7	2.34lei/pcs **x2=4.68lei**
Transistor	2SA1241			https://www.utsource.net/itm/p/752906.html?digipart=1	3.52lei/pcs **x2=7.04lei**

4 Analyzes

a. Transient Analysis

- **The Triangle of 4V**

Frequency:

- for the potentiomenter **R17 with k=0.5**

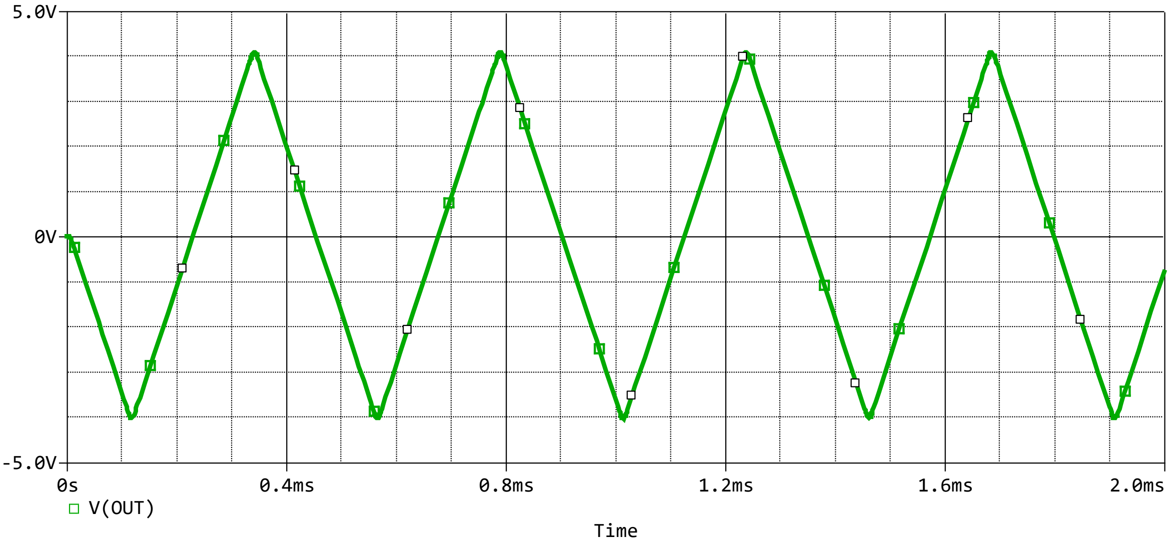


Figure 10-Triangle wave-frequency of 2237Hz

Evaluate	Measurement	Value
☑	Period(V(triunghi))	447.92366u
☑	Period(V(load:2))	447.92350u

$$f = \frac{1}{T} = \frac{1}{447u} = 2237Hz$$

- for the potentiomenter **R17 with k=0**

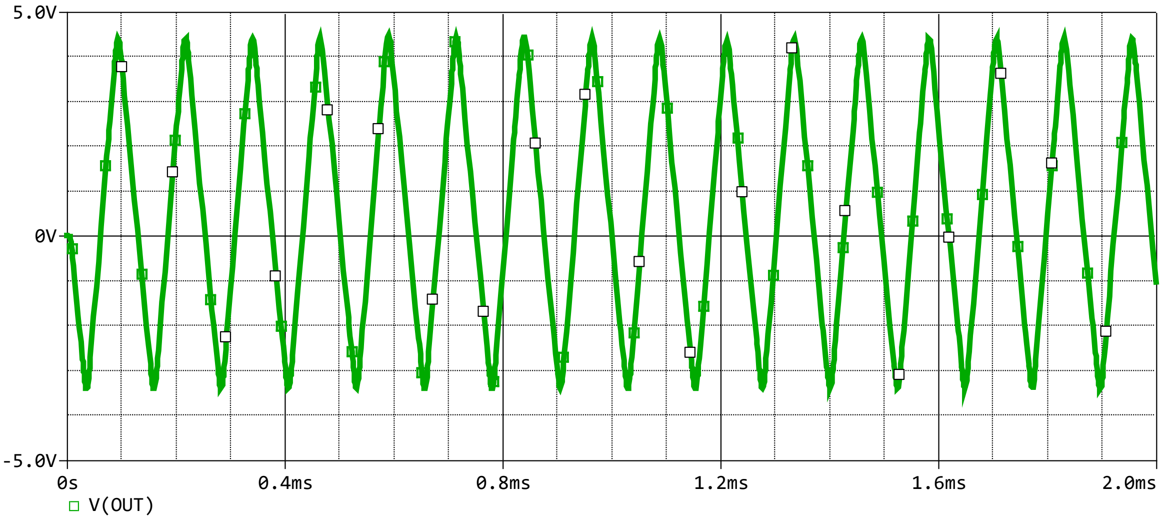


Figure 11-Triangle wave-frequency of 8130

Evaluate	Measurement	Value
☑	Period(V(triunghi))	123.44171u
☑	Period(V(load:2))	123.44088u

$$f = \frac{1}{T} = \frac{1}{123u} = 8130Hz$$

- **The Rectangle**

The setting **Set=0** will ensure an amplitude of 4V

Frequency:

- for the potentiomenter **R17 with k=0**

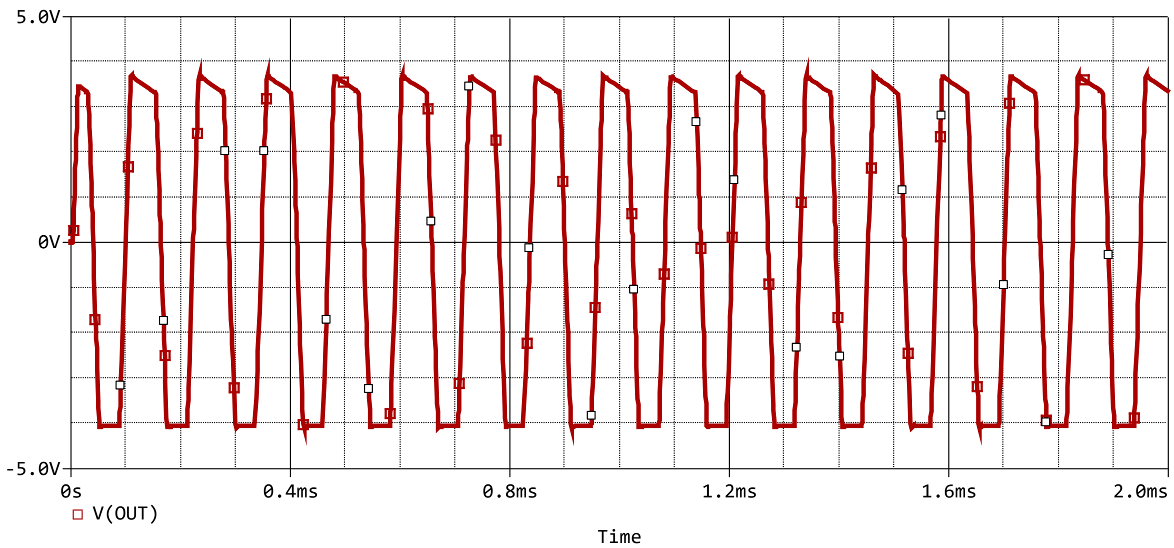


Figure 12-Rectangular-4V-frequency 8130Hz

Evaluate	Measurement	Value
☑	Period(V(drept))	123.53691u
☐	Period(V(triunghi))	
☑	Period(V(load:2))	123.55814u

- for the potentiomenter **R17 with k=0.5**

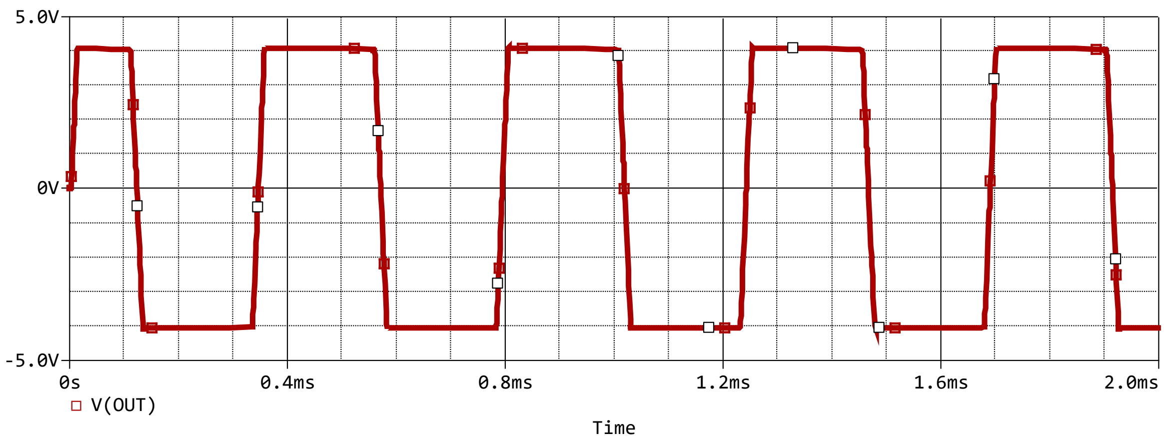


Figure 13-Rectangular-4V-frequency 2237Hz

Evaluate	Measurement	Value
☑	Period(V(drept))	339.67462u
☐	Period(V(triunghi))	
☑	Period(V(load:2))	448.04571u

The setting **Set=1** will ensure an amplitude of 7V

- for the potentiomenter **R17 with k=0.5**

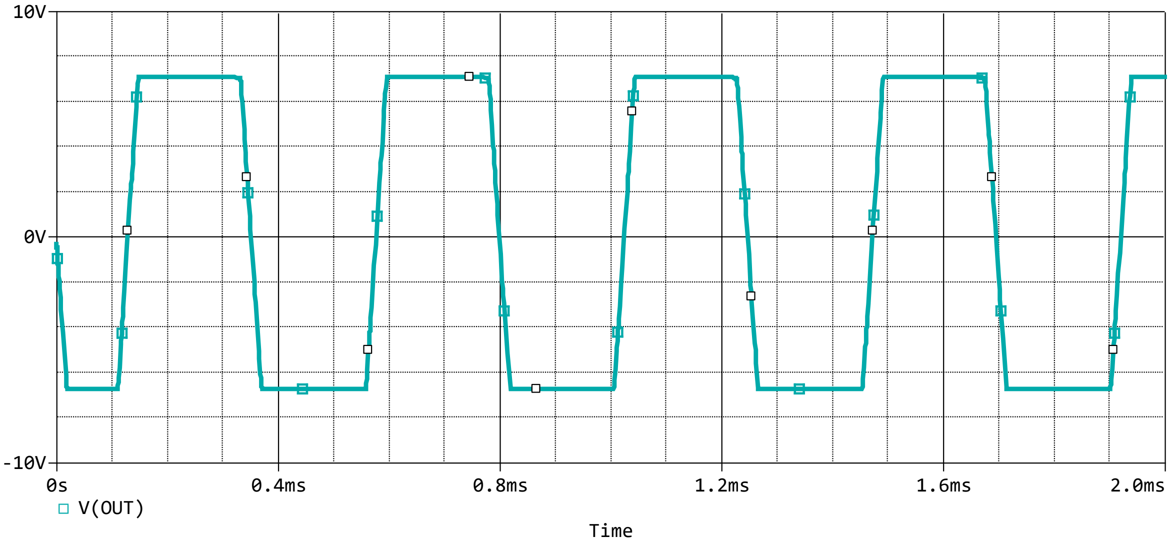


Figure 14-Rectangular-7V-frequency 2237Hz

Evaluate	Measurement	Value
☐	Period(V(triunghi))	
☑	Period(V(load:2))	447.79941u
☑	Max(V(out))	7.09081

- for the potentiomenter **R17 with k=0**

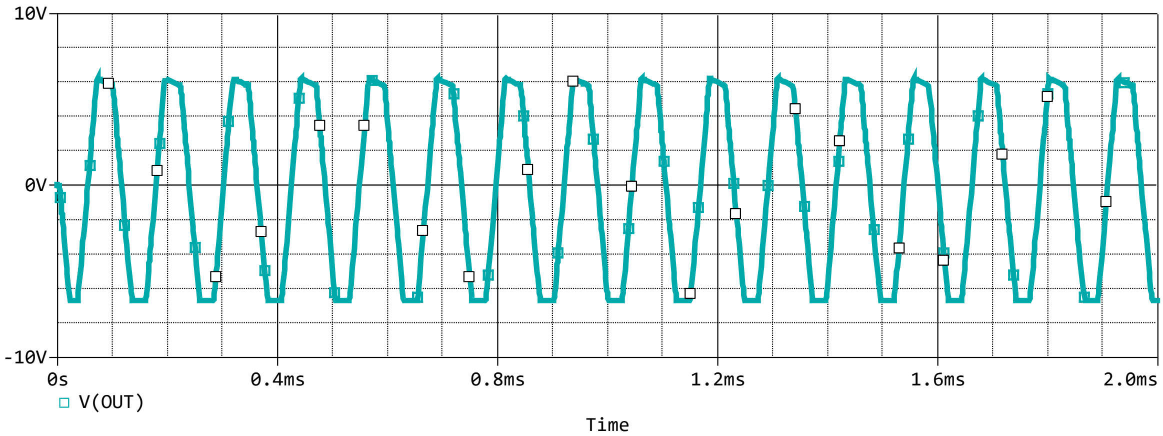
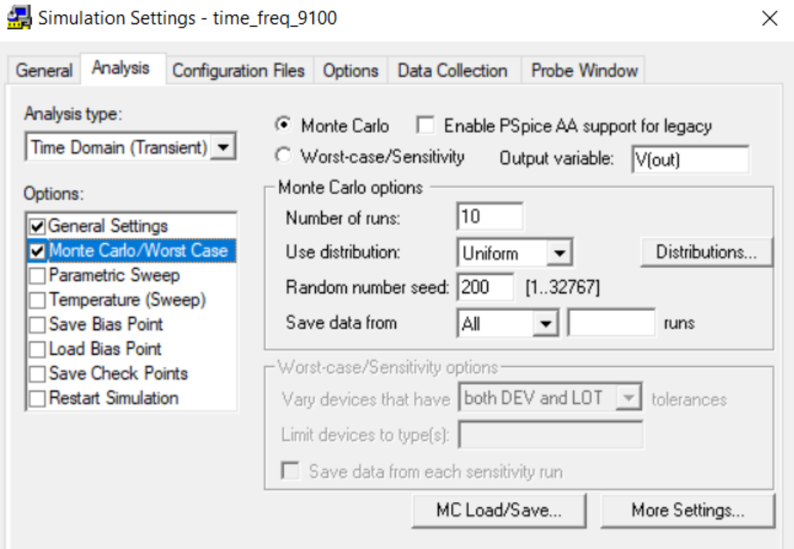


Figure 15-Rectangular-6.21V-frequency 8130Hz

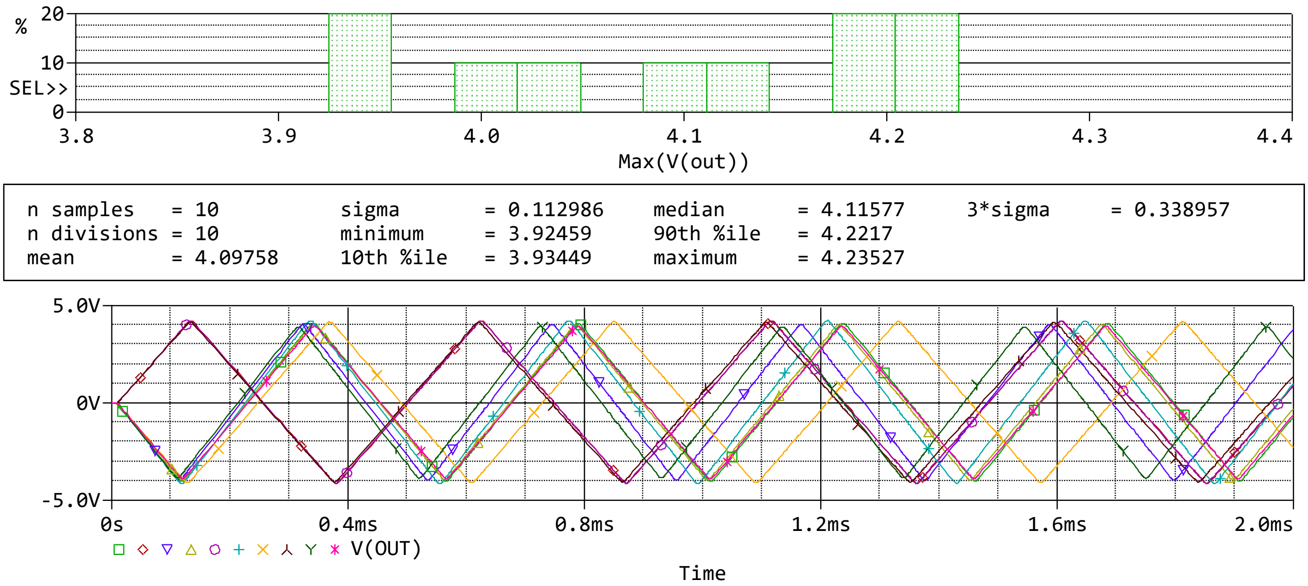
Evaluate	Measurement	Value
☑	Period(V(load:2))	123.80873u
☑	Max(V(out))	6.21063

b. Sensitivity Analysis

Results of running a **Monte Carlo Analysis** to test the **tolerances of the components**:



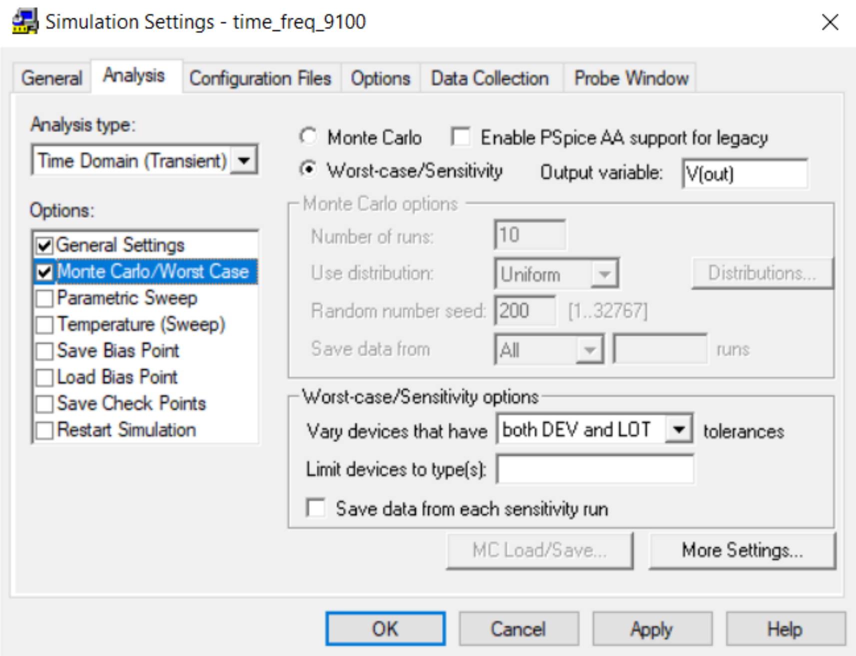
Simulation setting 1- Monte Carlo



Graph 4- Monte Carlo Analysis

The results of the Monte Carlo analysis show that the maximum value of the voltage at the output that can be obtained is 4.23V, wheareas the minimum value is 3.92V, and the mean value is 4.098V, which is satisfying the desired conditions.

Results of running a **Worst Case sensitivity analysis** on the **triangle wave** :

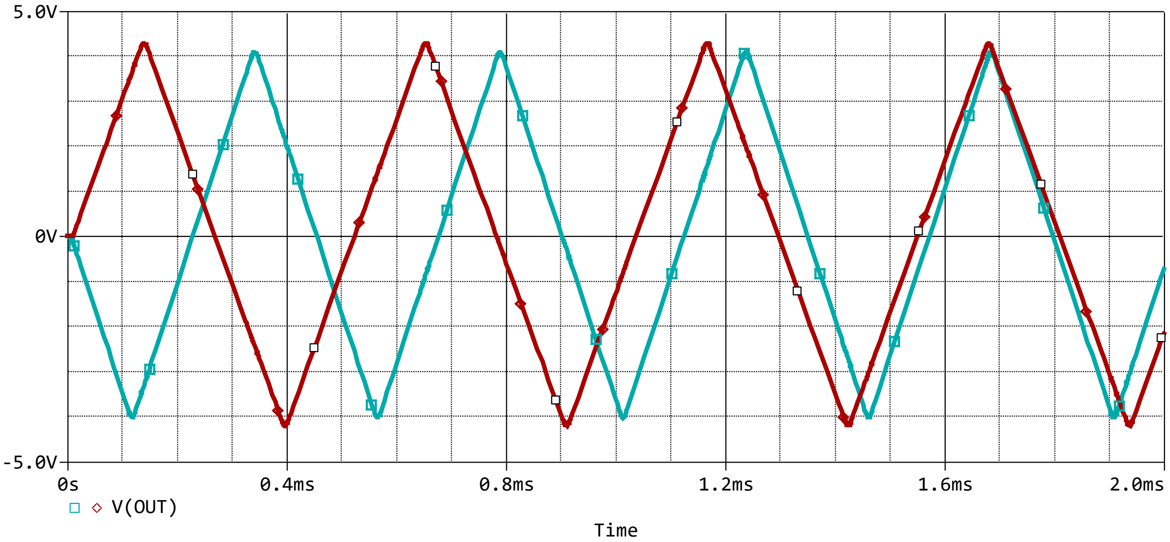


Simulation setting 2-Worst Case

Output file of the simulation:

```
                      WORST CASE ALL DEVICES

******************************************************************************


Device        MODEL         PARAMETER     NEW VALUE
C_C4          C_C4          C                1.1            (Increased)
R_R8          R_R8          R                 .999          (Decreased)
R_R3          R_R3          R                 .999          (Decreased)
R_R2          R_R2          R                1.001          (Increased)
R_R14         R_R14         R                 .999          (Decreased)
R_R18         R_R18         R                1.01           (Increased)
R_LOAD        R_LOAD        R                1.001          (Increased)
R_R7          R_R7          R                 .95           (Decreased)
R_R15         R_R15         R                 .9            (Decreased)
R_R16         R_R16         R                1.001          (Increased)
R_Rp2         R_Rp2         R                 .95           (Decreased)
R_Rp3         R_Rp3         R                 .95           (Decreased)
R_Rp          R_Rp          R                 .99           (Decreased)
R_Rp1         R_Rp1         R                 .99           (Decreased)

**** 06/02/21 17:25:48 ****** PSpice 17.2.0 (March 2016) ****** ID# 0 ********

 ** Profile: "SCHEMATIC1-time_freq_9100"  [ d:\cad\signal_generator-pspicefiles\schematic1\time_freq_9100.sim ]

 ****     SORTED DEVIATIONS OF V(OUT)      TEMPERATURE =    27.000 DEG C

                      WORST CASE SUMMARY

******************************************************************************
```

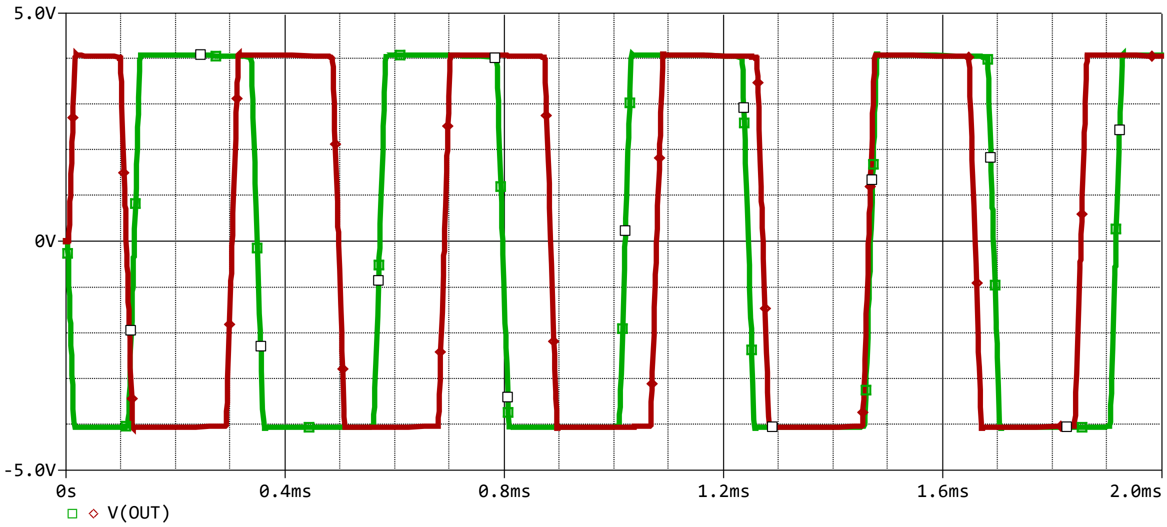
It can be seen that the most significant modifications were done regarding the capacitance, and resistors R2,R18,R16 and also at the load, although the load has a small tolerance, of 0.1%.



Graph 5-Worst Case analysis on the triangle wave

Results of **running worst case analysis** when v(out)= **rectangular of 4V**

```
                      WORST CASE ALL DEVICES

****************************************************************************


Device        MODEL         PARAMETER    NEW VALUE
C_C4          C_C4          C                .9            (Decreased)
R_R8          R_R8          R                .999          (Decreased)
R_R3          R_R3          R                .999          (Decreased)
R_R2          R_R2          R               1.001          (Increased)
R_R14         R_R14         R               1.001          (Increased)
R_R18         R_R18         R               1.01           (Increased)
R_LOAD        R_LOAD        R                .999          (Decreased)
R_R7          R_R7          R               1.05           (Increased)
R_R15         R_R15         R                .9            (Decreased)
R_R16         R_R16         R                .999          (Decreased)
R_Rp2         R_Rp2         R               1.05           (Increased)
R_Rp3         R_Rp3         R                .95           (Decreased)
R_Rp          R_Rp          R                .99           (Decreased)
R_Rp1         R_Rp1         R                .99           (Decreased)

**** 06/02/21 17:31:58 ****** PSpice 17.2.0 (March 2016) ****** ID# 0 ******

 ** Profile: "SCHEMATIC1-time_freq_9100"  [ d:\cad\signal_generator-pspicefi


 ****     SORTED DEVIATIONS OF V(OUT)      TEMPERATURE =   27.000 DEG C
```



Graph 6-Worst Case of rectangular of 4V

With green is the output resulted by using the nominal values, and with red is the output considered in the worst case possible.

Results of **running worst case analysis** when v(out)= **rectangular of 7V**

WORST CASE ALL DEVICES

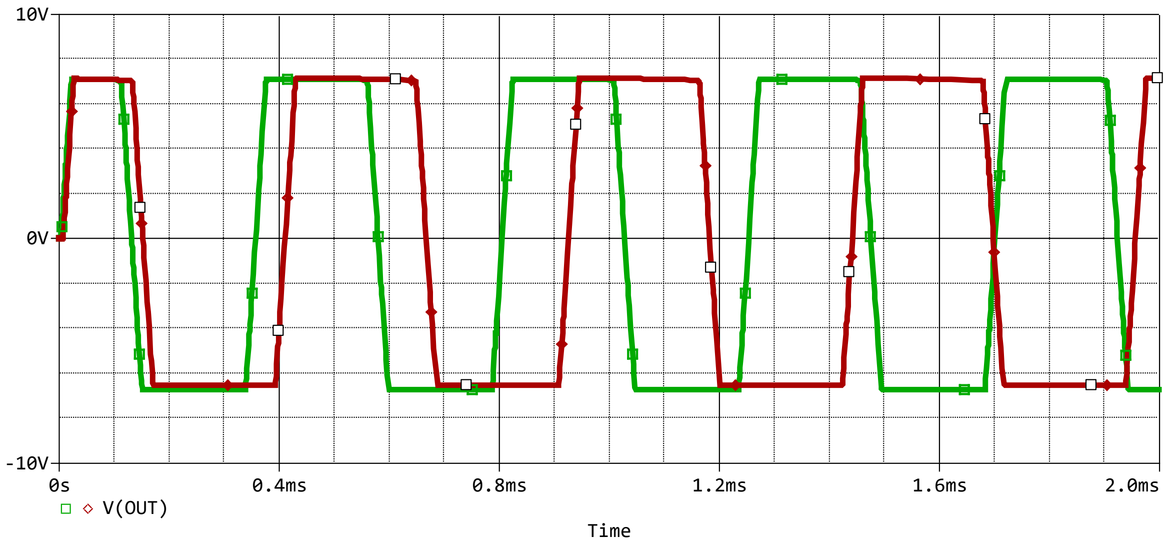
****

Device	MODEL	PARAMETER	NEW VALUE	
C_C4	C_C4	C	1.1	(Increased)
R_R8	R_R8	R	1.001	(Increased)
R_R3	R_R3	R	1.001	(Increased)
R_R2	R_R2	R	.999	(Decreased)
R_R14	R_R14	R	1.001	(Increased)
R_R18	R_R18	R	.99	(Decreased)
R_LOAD	R_LOAD	R	.999	(Decreased)
R_R7	R_R7	R	.95	(Decreased)
R_R15	R_R15	R	.9	(Decreased)
R_R16	R_R16	R	.999	(Decreased)
R_Rp2	R_Rp2	R	.95	(Decreased)
R_Rp3	R_Rp3	R	1.05	(Increased)
R_Rp	R_Rp	R	1.01	(Increased)
R_Rp1	R_Rp1	R	.99	(Decreased)

**** 06/02/21 17:29:35 ****** PSpice 17.2.0 (March 2016) ****** ID# 0 *****

** Profile: "SCHEMATIC1-time_freq_9100" [d:\cad\signal_generator-pspicef

**** SORTED DEVIATIONS OF V(OUT) TEMPERATURE = 27.000 DEG C

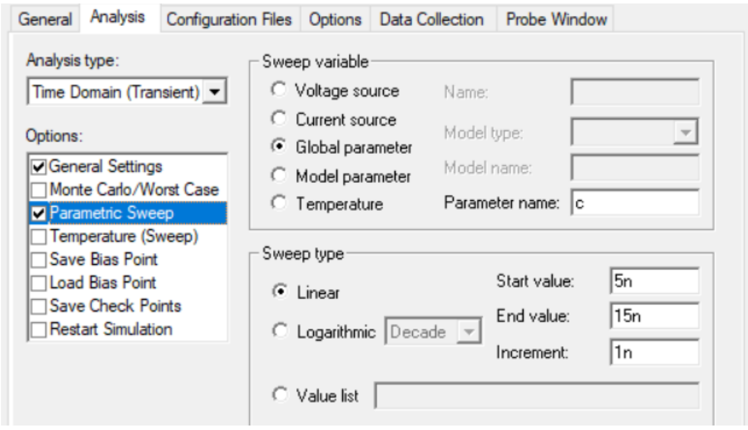


Graph 7-Worst Case- Rectangular of 7V

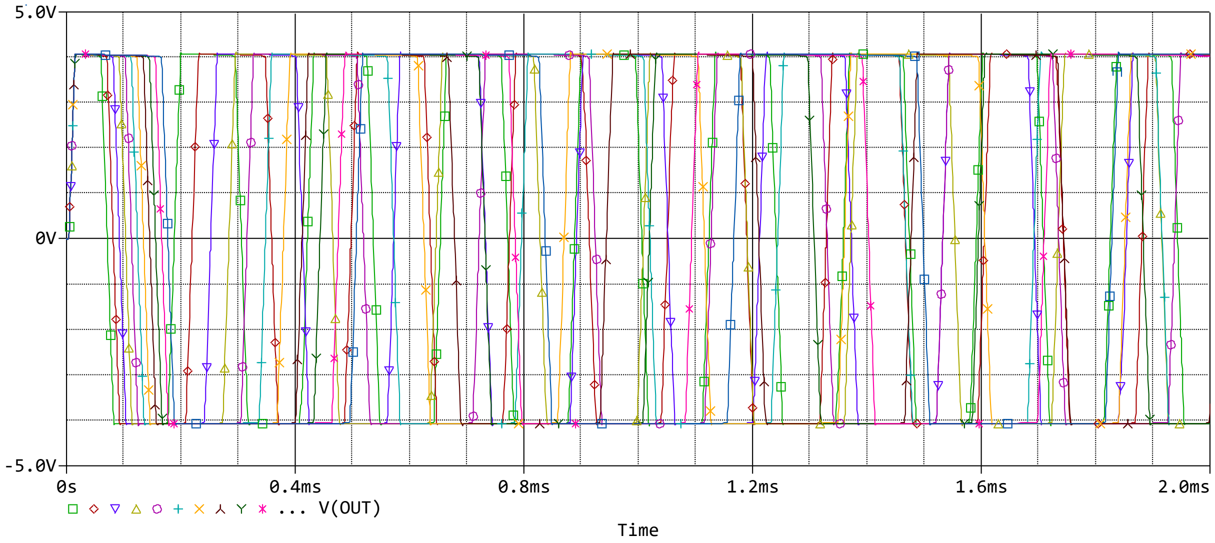
With green is the output resulted by using the nominal values, and with red is the output considered in the worst case possible. In this case, it deviates to much from the nominal value, in comparison when a signal of 4V needs to be obtained.

c. Parametric Analysis

- Below is the variation of the output signal when it is swept over the **capacitance** :



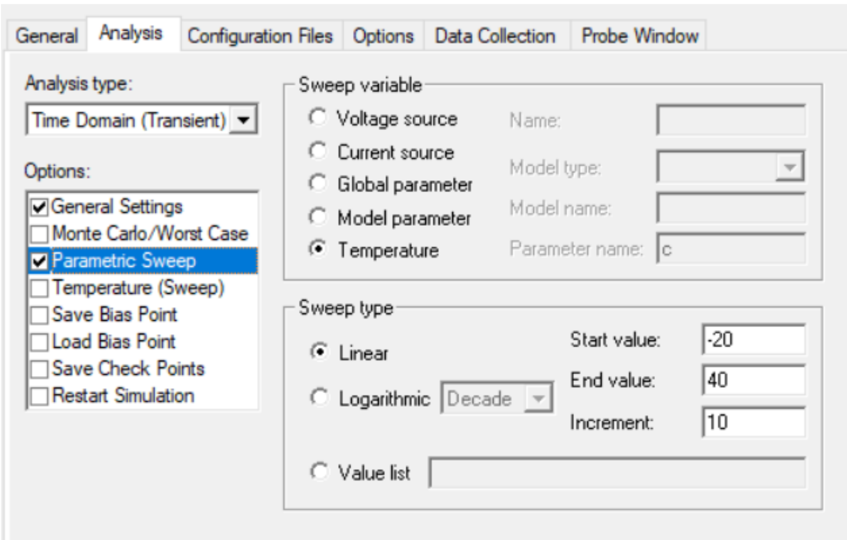
Simulation setting 3-Capacitance sweeping



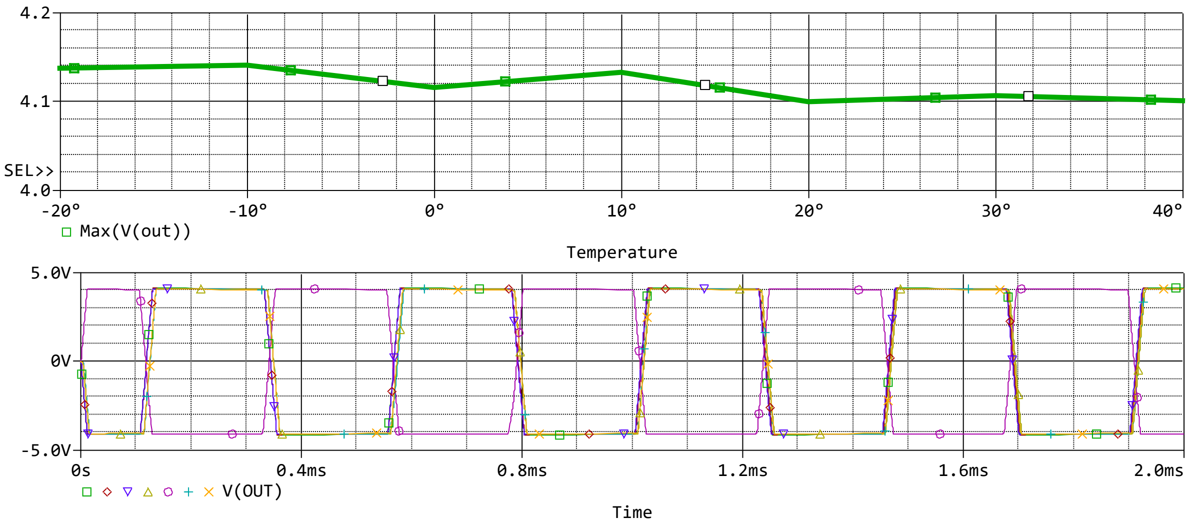
Graph 8-Output swept over the capacitance

It can be seen that the signals are not perfect rectangles, but they reach +-4V.

- Below is the variation of the output signal when it is swept over the temperature:



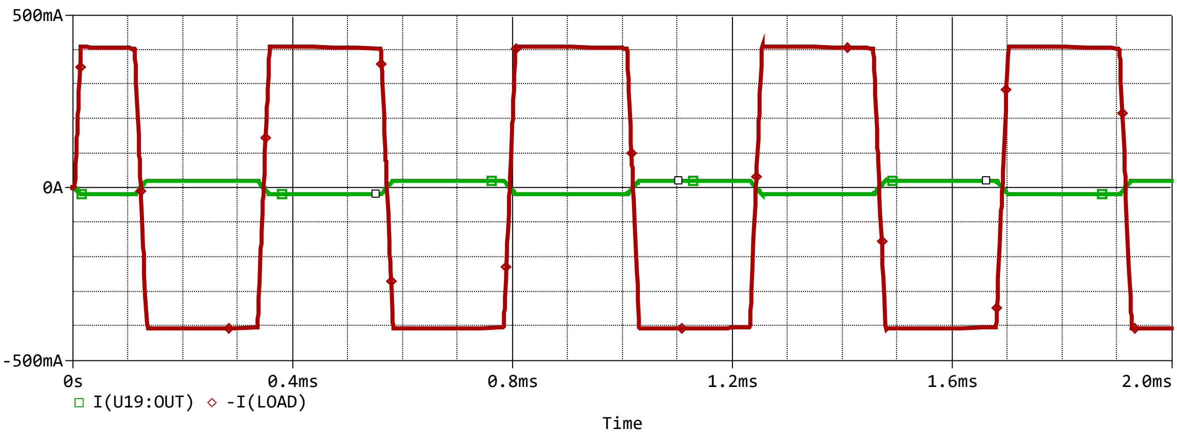
Simulation setting 4-Temperature sweeping



Graph 9-Output swept over the temperature

It can be seen that the output varies between **4.14V** at **T=-20°** and **4.1V** at **T=40°,** which is not such a great deviation, so the circuit behaves good in standard temperature conditions.

Also, to prove the functioning of the power amplifier of the circuit I established another transient analysis in which I compared the current at the output of the UA741 OpAmp with the current through the load .



Graph 10-Currents through the load and the output at the OpAmp

✓	Max(I(LOAD))	410.32528m
✓	Max(I(U19:OUT))	20.80018m

As expected, the UA741 can only provide 20mA, while the load needs around 400mA to function properly.

5 Conlusions

As an overview, the triangle wave manages to achieve +/-4V as expected, and the waveform is a perfect triangle at the frequency of 2237Hz. The range of desired frequencies was 2400Hz and 9100Hz, but this signal generator can only output waves of a maximum of 8130Hz, due to inappropriate resistance biasing.

The rectangle wave behaves best when it has an amplitude of 4V. The wave has a good shape and the amplitude doesn't deviates too much from the required one. It can achieve as the triangle, frequencies between 2237Hz and 8130Hz. When the potentiometer is set to provide an amplitude of 7V, the signal looks more like a trapeze, probably it is due to the time constant. When the frequency is 8130Hz, the rectangular signal has a greately deviated shape at both 4V and 7V.

Overall, I can say that the performance of this signal generator is acceptable. Although the frequency range is not the one required, and the waveforms may vary, it still reaches the amplitudes for which it was designed in standard conditions.

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