RYERSON UNIVERSITY

Faculty of Engineering, Architecture and Science

Department of Electrical and Computer Engineering

Course Number	ELE504
Course Title	Electronic Circuits II
Semester/Year	F2021

Instructor	Dr. M.S. Kassam

ASSIGNMENT No. 5

Assignment Title	Major Project Formal Technical Report

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Due Date	November 3, 2021

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Student ID	500959286
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Abstract

The objective of this project is to design, simulate, implement and test a linear voltage-controlled multi-function waveform generator using only op-amps and discrete components while meeting certain provided specifications. The design was created by integrating intermediate designs, taking the foundational circuits and putting them together to achieve the desired outcome. The resultant circuit consists of a variety of components, with a DC converter, inverting integrator, and inverting bistable comparator at the center of it all. It is shown how different values of threshold voltages, saturation limits, frequencies, etc. can be found and how voltage supplies, resistors, capacitors and so on can affect these outcomes. The design was built for the user to be able to select and toggle through different options and control the circuit's frequency and gain, providing a controllable circuit for the user to play and test with. This project was completed by the designer, Muhab Hasan, based on the knowledge provided by Dr. Kassam.

Objective

The objective of this project is to design, simulate, implement and test a linear voltage-controlled multi-function waveform generator using only op-amps and discrete components. The design should meet certain specifications, which include the following; the ability for the user to select either triangular or square waveform output, as well as two frequency ranges (provided as $f_X$and $f_X/5$. The circuit should also have an input d.c voltage,V_C range for the user to control, an output amplitude control range for both waveforms, and the d.c power supplies should be 10V.

Introduction

In general, a function waveform generator is meant to generate waveforms (sine, triangular, square, etc.) for a certain device. They also are able to apply a DC offset to the signal, while giving you the ability to control the frequency of the waveform. They can be created by integrating different components and pieces together as shown in the next section. For this design, the function waveform generator will be built using a DC converter, an inverting integrator, and an inverting bistable comparator. Before building the final linear voltage-controlled multi-function waveform generator with all the required components, a series of circuits were built and analyzed leading up to the final design, which will also be further examined in the next section. These circuits help identify what each component is actually doing and how it can be altered or played with, and ultimately by integrating certain parts of these circuits the final design was achieved.

Theory

From Milestone #1, the threshold voltages (V_{TL}, V_{TH}) were chosen as -4.25V and 4.25V, respectively. The ratio of R1 and R2 for the bistable comparator was found using the equation $\frac{R1}{R2} = \frac{-V_{TH}}{L^{-}}$(1), which gave a result of R2=2R1, therefore the values of R1 and

R2 were chosen to be 10kΩ and 20kΩ respectively. In order to find an appropriate value for the capacitance of the inverting integrator, C1, the equation $f_x = \frac{L^+}{2(V_{TH}-V_{TL})RC}$(2a) was rearranged into $C = \frac{L^+}{2(V_{TH}-V_{TL})Rf_x}$(2b), where the resistance of the integrator, R, was chosen to be 50kΩ and the frequency f_x was provided as 3700 Hz. In Milestone #2, the saturation values were wanted as $L^+ = 6V$ and $L^- = -6V$. The threshold voltage values were altered to 3V and -3V. The voltage of the Zener diodes in the limiter circuit integrated with the bistable comparator was chosen as 5.3V in order to achieve a saturation voltage of 6V (5.3V + 0.7V from the normal diode). The resistance at the output of the bistable comparator, R_o, was found using the equation $R_o = \frac{V_i - V_o}{I_Z}$(3). The resistance of the resistors in the DC converter, R_{4a}, R_{4b}, R_{4c}, was chosen to be 20kΩ. In Milestone #3, the DC converter was integrated into the function waveform generator and the non-inverting bistable comparator was changed to inverting. In Milestone #4, the frequency range control component was placed between the DC converter and the inverting integrator. This component consists of a switch and two resistors, allowing the user to toggle between frequency range 1 (f_x) and frequency range 2 (f_x/5). The value of the resistor, R, was already chosen as 50kΩ and is relabelled as Rf1. Looking at equation (2a), if the frequency is divided by a factor of 5, the resistance will go up by a factor of 5 since they are indirectly proportional to one another. Therefore, the value of the resistor for frequency range 2, Rf2, is chosen as 250kΩ. For the gain control requirement, an amplitude control circuit consisting of a buffer circuit connected to a potentiometer was implemented. This allows the user to toggle between a triangular waveform output and a square waveform output.

Design analysis

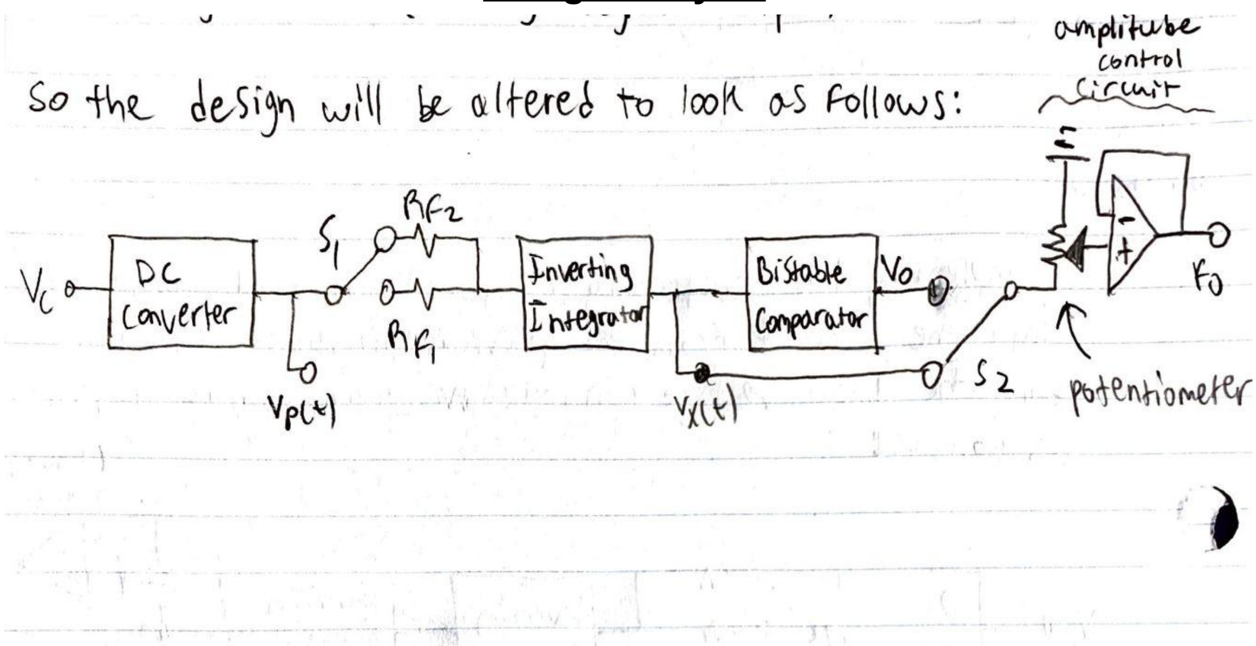

Image 1: Concept diagram of the final design for the Major Project
The image above represents the schematic of the final design of the circuit for the Major Project. The DC converter, integrator, and bistable comparator are all inverting and consist of LM741CN Op-Amps.

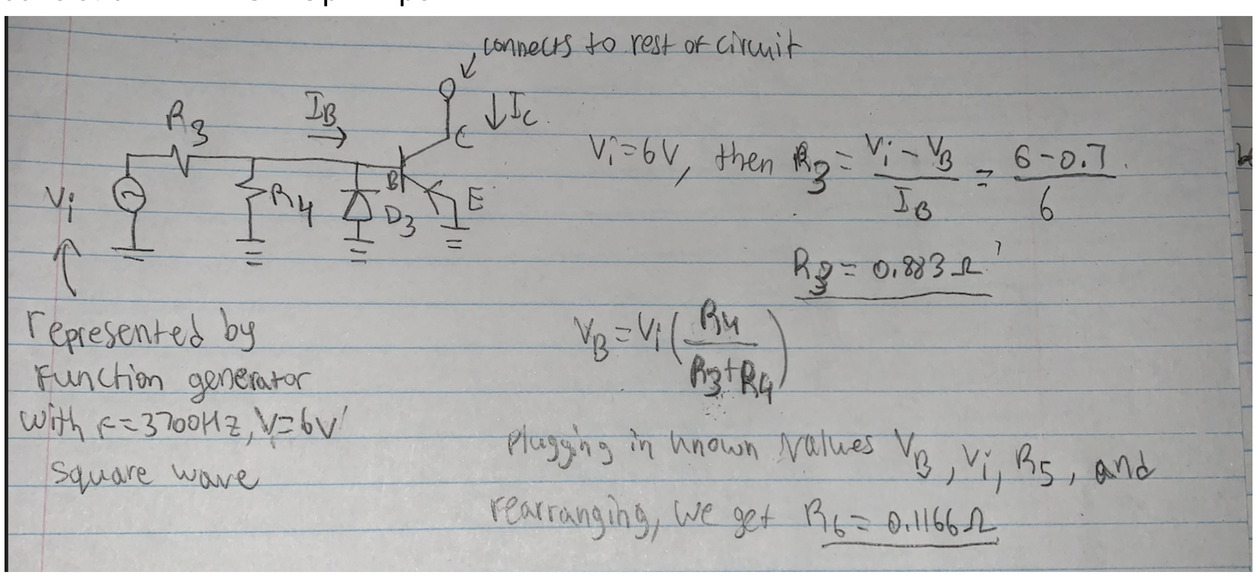

Image 2: Schematic of the switch in the DC Converter
The image above represents the schematic of the switch implemented in the DC converter. It consists of a BJT connected to a diode, which is in parallel with a resistor which is also in parallel with a resistor and a power supply. A switch is placed after the DC converter and before the integrator, which allows the user to connect the output of

the DC converter to one of the two resistors based on which frequency range they would like. A triangular waveform can be found from the output of the inverting integrator, Vx, while the square waveform can be achieved from the output of the inverting bistable comparator, Vo. The user can select which one using the switch which is connected to the gain control component consisting of the amplitude control circuit.

Experimental Procedure

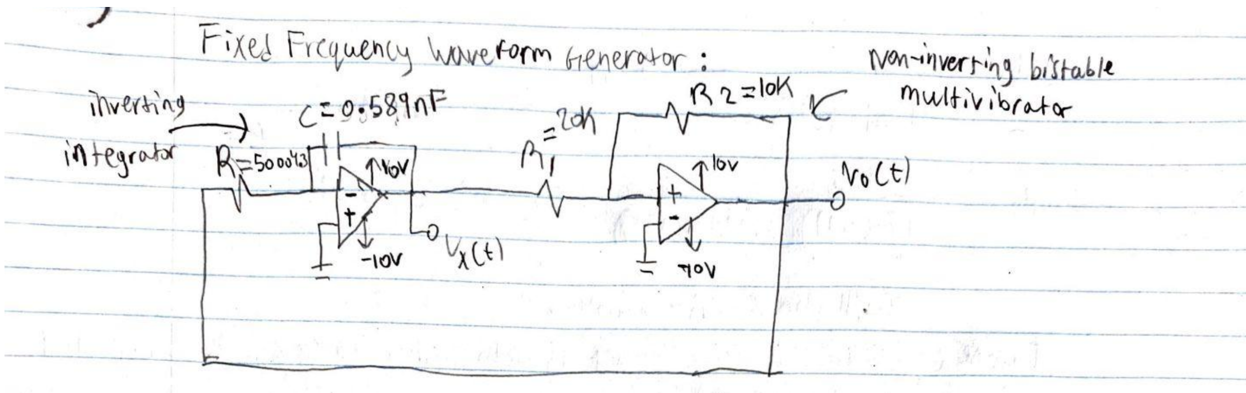

Image 3: Schematic of circuit from Milestone #1

The image above represents the schematic of the circuit from Milestone #1. This is the most basic circuit of all the milestones, but is very crucial to how the rest of the circuit was designed as this set the foundation for the entire project. After this design, the rest of the circuit was built by slowly adding different components and making some adjustments.

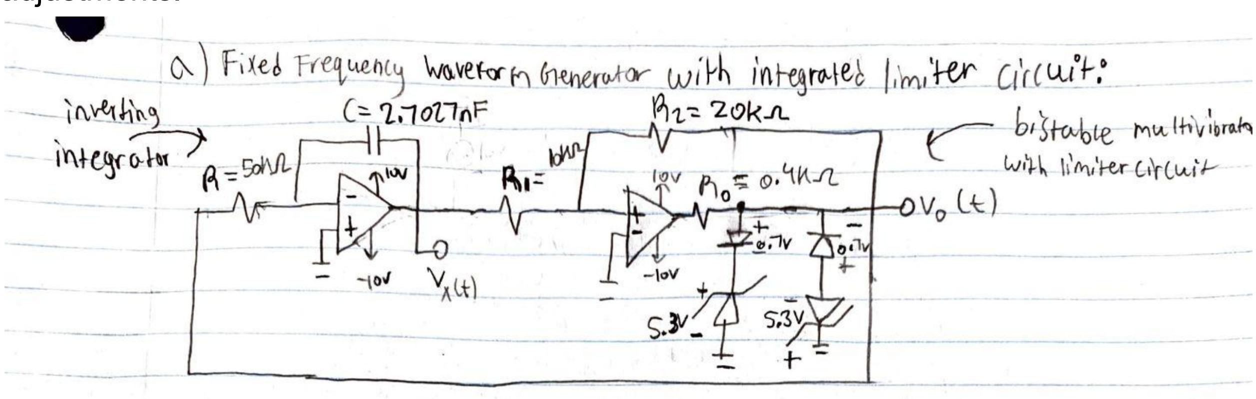

Image 4: Schematic of circuit from Milestone #2

Image 4 displays the schematic of the circuit from Milestone #2. This circuit is similar to that shown in **Image 3**, however this time there is a limiter circuit, consisting of diodes and Zener diodes, that is placed at the output of the bistable comparator in order to lower the saturation levels.

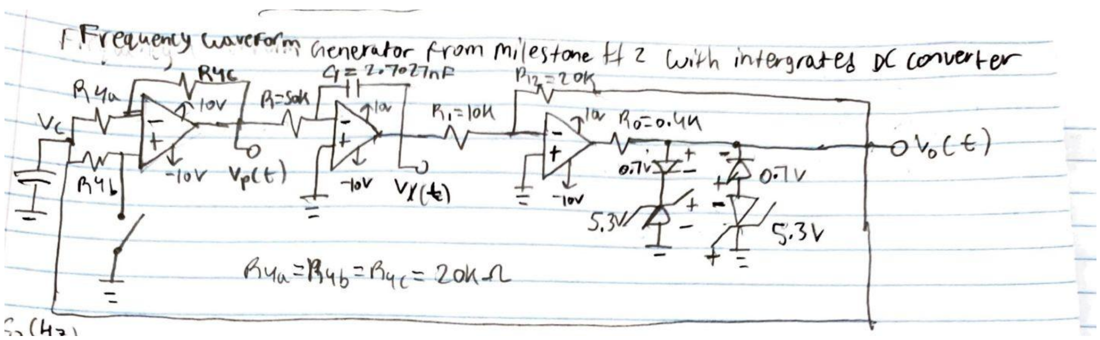

Image 5: Schematic of circuit from Milestone #3

In Milestone #3, the waveform generator displayed in **Image 4** was adjusted by making the bistable comparator inverting instead of non-inverting, and the DC converter was added as well. The switch of the DC converter shown in the schematic actually represents the design made in **Image 2.** The final design was made in Milestone #4, represented in **Image 1,** and is essentially the same circuit as that in Milestone #3 but with the frequency range and gain control components implemented as required. Therefore, these intermediate steps helped pave the path towards the final design wanted in the Major Project.

Results and Observations

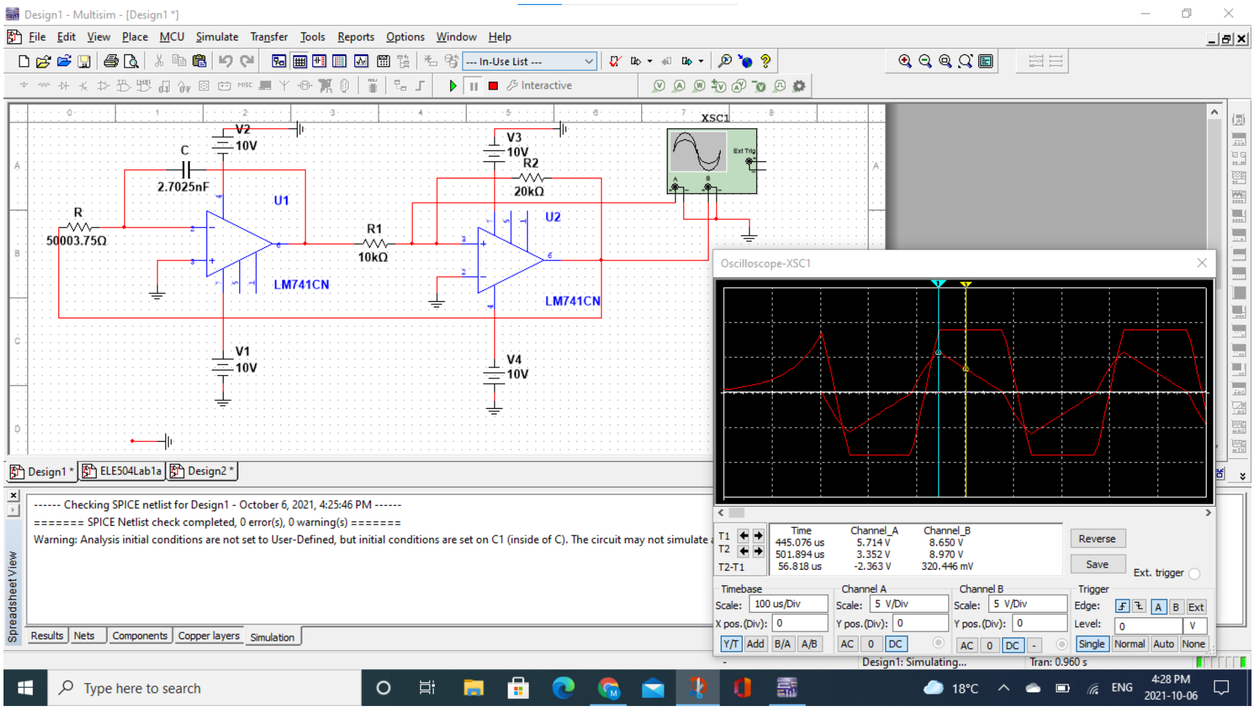

Image 6: The simulated circuit of the schematic from **Image 3** (Milestone #1)

	Pre-Lab	Results
Saturation Voltage (L+,L-)	8.5V, -8.5V	8.97V, -8.97V
Threshold Voltage (Vth, Vtl)	4.25V, -4.25V	5.737V, -5.887V
Frequency Fx	3700 Hz	2855.2134 Hz

Table 1: Theoretical Vs Experimental values for saturation and threshold voltages and frequency

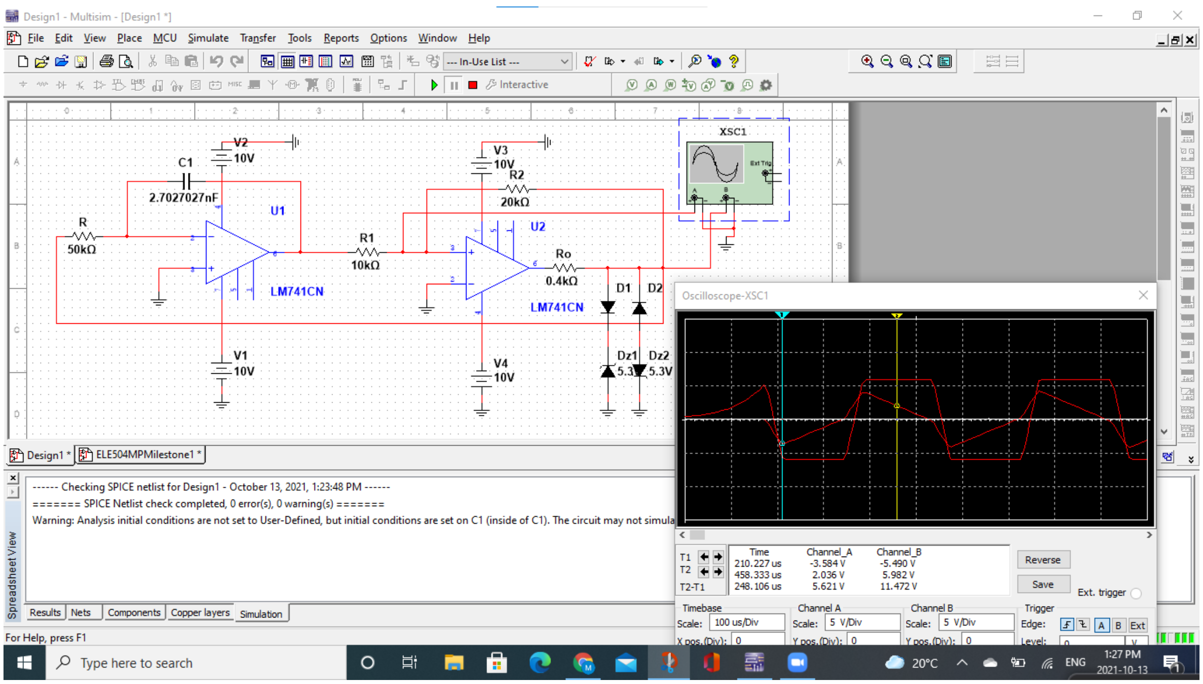

Image 7: Multisim Circuit of Waveform Generator with limiter circuit (Milestone #2, **Image 4**)

	Pre-Lab	Results
Saturation Voltage (L+,L-)	6V, -6V	5.982V, -5.982V
Threshold Voltage (Vth, Vtl)	3V, -3V	3.584V, -3.584V

Table 2: Theoretical Vs Experimental values for saturation and threshold voltages

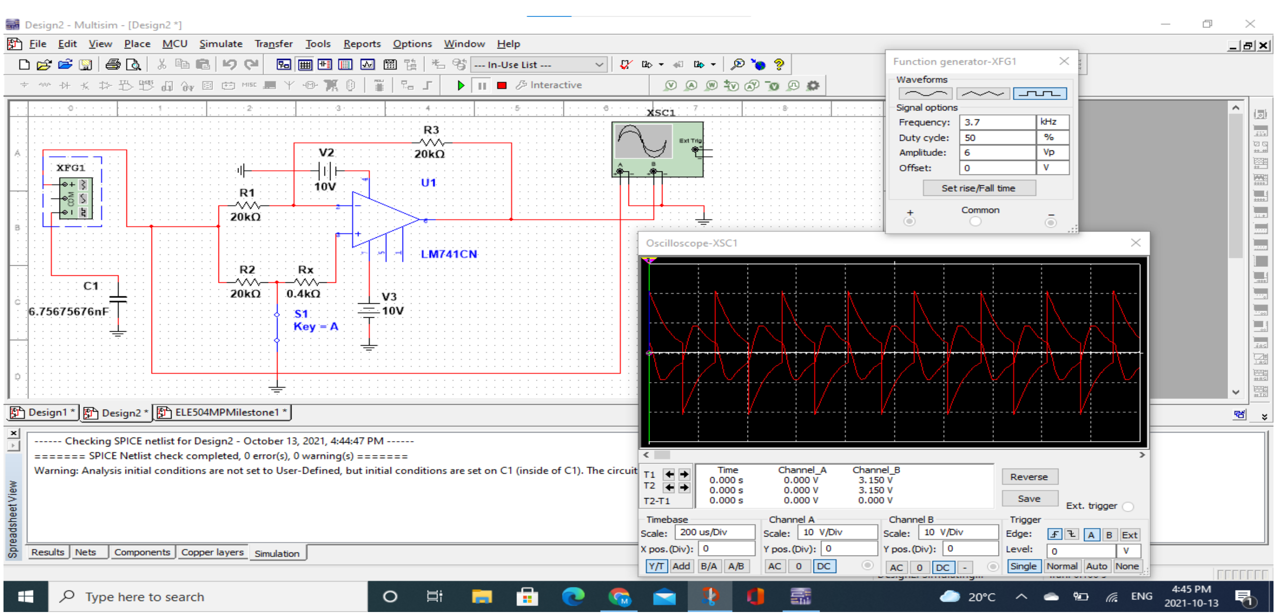

Image 8: Multisim circuit of DC converter schematic (Milestone #2)
The capacitor seen in this circuit should be ignored as it was not included in the final design.

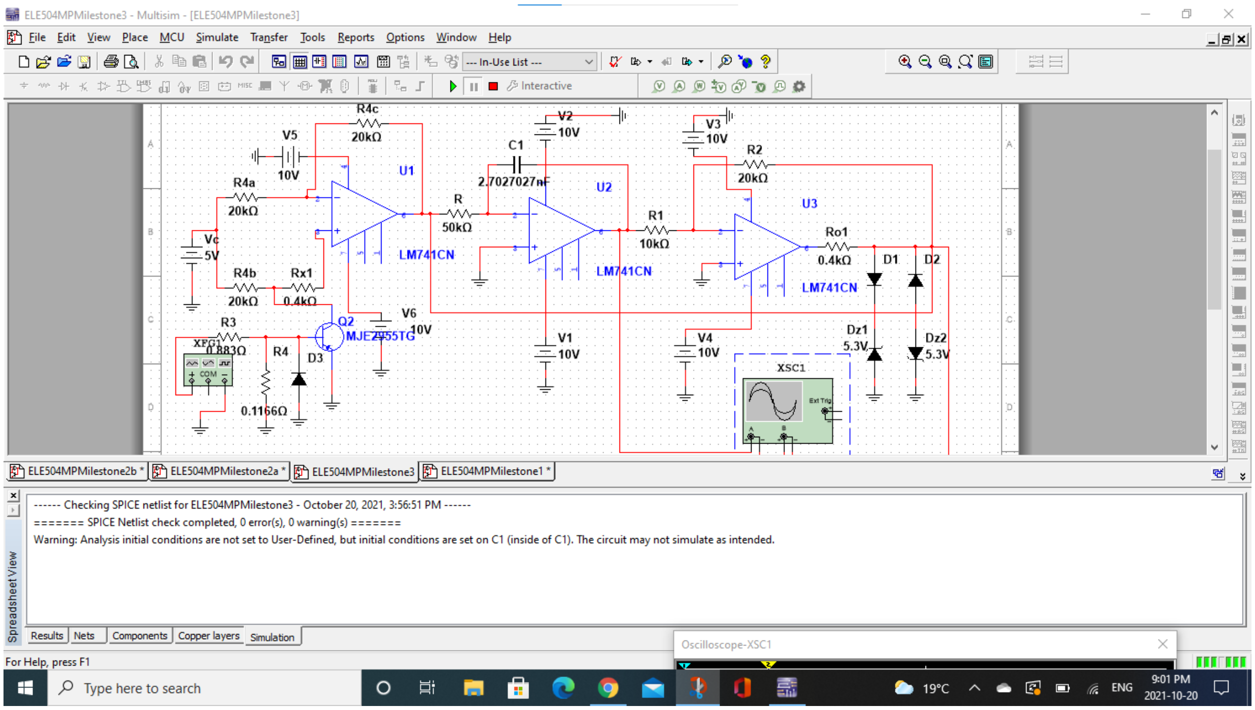

Image 9: Multisim circuit of **Image 7** implemented with **Image 8** (Milestone #3)
This circuit represents the circuit used for the final design without the gain and frequency control components.

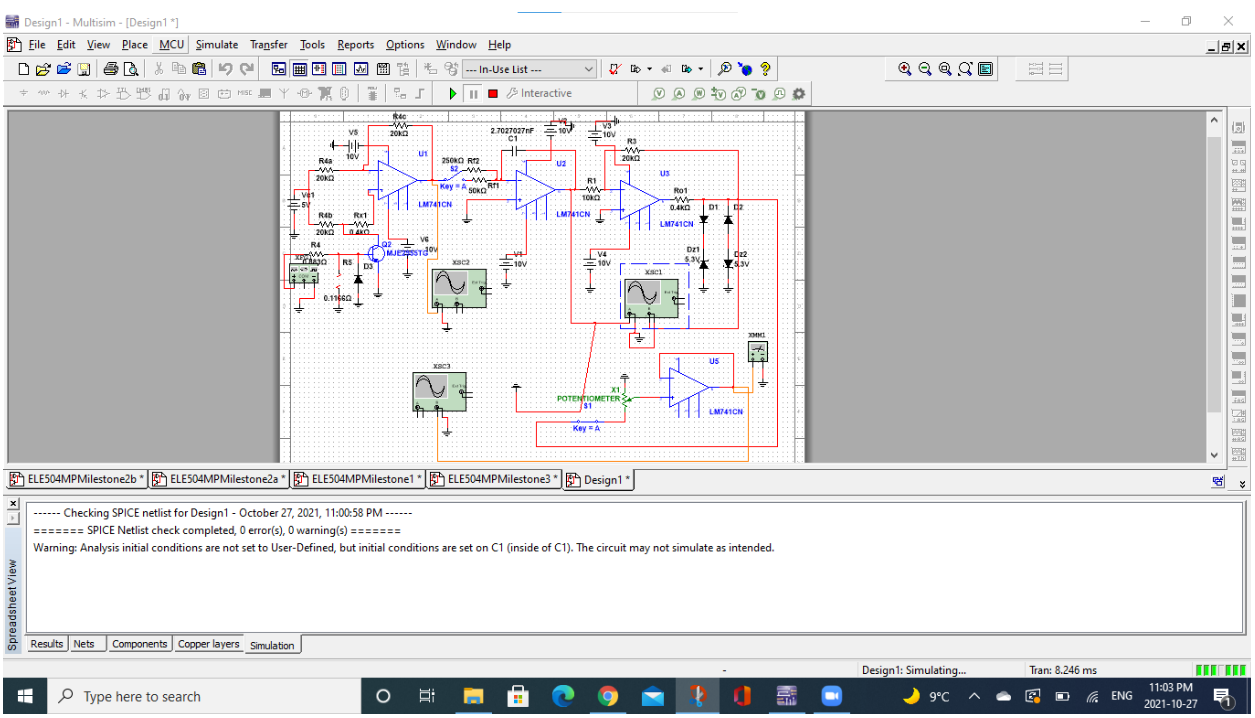

Image 10: Multisim circuit of the final design of the Major Project

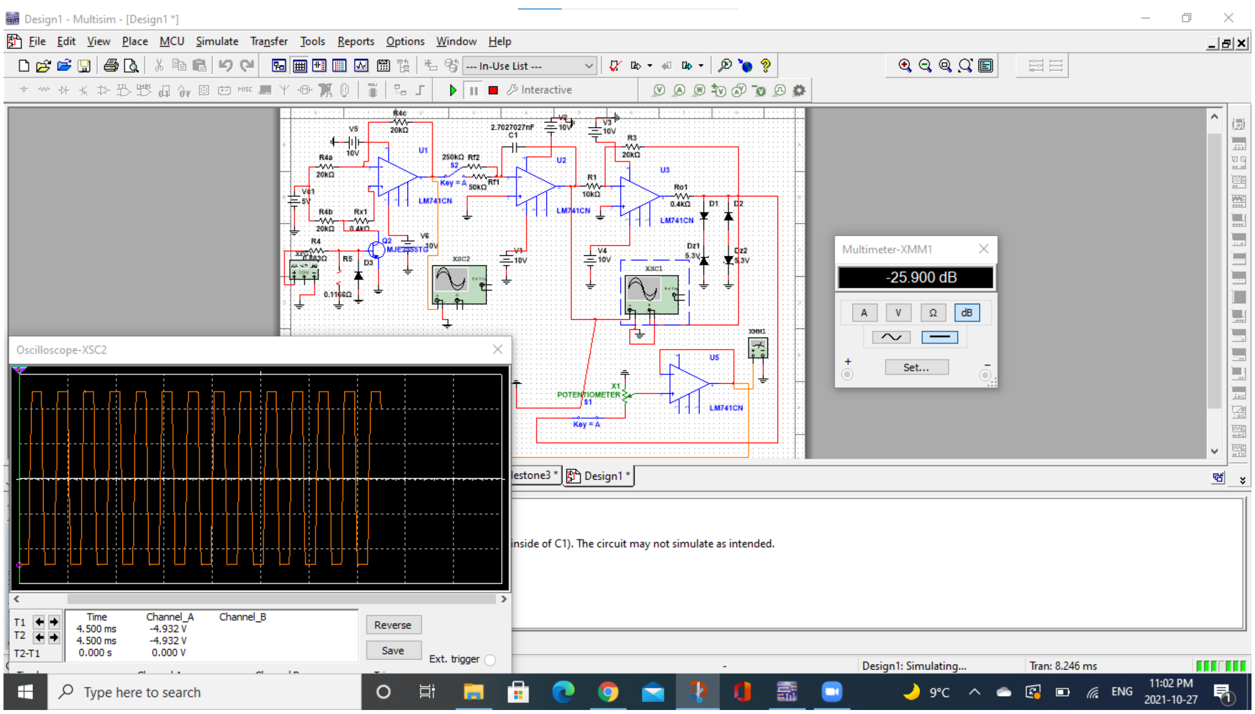

Image 11: Output range 2 frequency in dB and resultant oscilloscope reading for square wave

Conclusions and Recommendations

In **Image 6,** the simulated circuit of the schematic for Milestone #1, the output square waveform looked relatively well, however the triangular waveform was quite distorted. The experimental results slightly differed from the theoretical values. Also, the calculated value for the capacitance C1 of the inverting integrator was found using equation (2b) to be 2.7025 nF.

For the circuit from Milestone #2, the resistance at the output of the bistable comparator, R_o was calculated using equation (3) as 0.4kΩ. Again, the experimental values slightly differed from the theoretical values. The resultant oscilloscope reading is not what was expected, which makes sense as the circuit was thrown off by the misplaced capacitor, which is why it was indicated that it should be ignored since it should not be there and was not included in the final design.

For the circuit in **Image 9,** the polarity of the output voltage is dependent on the switch of the DC converter being open or closed. When open, it is at the upper saturation limit, and when closed it is at the lower saturation limit.

In **Image 10**, the final circuit design, it displays how exactly the user would be able to use the switch to toggle between frequency ranges as well as the other switch to toggle between either square or triangular output waveform. Frequency range 1 is equal to 3700 Hz, while frequency range 2 is equal to 740 Hz.

Image 11 represents how the user can choose to see the square wave output of the range 2 frequency. The user would also be able to change it around and see the triangular waveform for this range, or even to see either waveform at range 1 frequency. Errors and discrepancies in the results can be credited to human error and miscalculation, as well as issues with the design of the circuit.
In conclusion, the intermediate circuits from the milestones leading up to the final design allowed the designer to see how each component works and what it contributes to the circuit, and indicates how all the components can be incorporated together to work as a linear voltage-controlled multi-function waveform generator.

References

Lectures and notes provided by Dr. M.S. Kassam during the Fall 2021 Semester at Ryerson University.

Appendix

List of components for final design:

- 4 LM741CN Op-Amps
- 1 function generator
- 11 resistors
- 6 10V DC voltage supplies
- 1 controlled DC voltage supply
- 1 BJT
- 3 diodes
- 2 Zener diodes
- 1 capacitor
- 2 switches
- 1 potentiometer

All Progress Reports

Documents will be submitted, unable to add in this document

All Multisim files

Documents will be submitted, unable to add in this document