International Journal of Computational and Electronic Aspects in Engineering
Vol. 5, Issue 4, December 2024, pp 131 - 140
https://doi.org/10.26706/ijceae.20241101

Generate Different Frequencies and Voltages Based on OP-AMP

Dhuha Abdulmunem Mohammad [1,*], Sawsan N. Abdullah [2]

[1] Computer Engineering Techniques, Northern Technical University, Mosul, Iraq
[2] Electrical Engineering Techniques, Northern Technical University, Mosul, Iraq

dhuha.abdulmunem@ntu.edu.iq [1], sawsannajeebabdullah@ntu.edu.iq[2]

***Correspondence:** dhuha.abdulmunem@ntu.edu.iq

Article – Peer Reviewed
Received: 14 Aug 2024
Accepted: 2 Nov 2024
Published: 2 Dec 2024

Cite this article: Dhuha Abdulmunem Mohammad, Sawsan N. Abdullah, "Generate different Frequencies and Voltages Based on OP-AMP", *International Journal of Computational and Electronic Aspects in Engineering*, RAME Publishers, vol. 5, issue 4, pp. 131-140, 2024.
https://doi.org/10.26706/ijceae.5.4.20241101

Abstract: A signal generator is used in many applications in electronic measurement and teaching. Many types of signal generators are in a fixed operating mode with limited utilized signals. This research aims to design a highly accurate multi-functional, multi-waveform economic signal generator based on an Operational Amplifier (OP-AMP) that can provide waveforms commonly used in electronics experiments. The output values of the waveforms of the signal generator are square, triangle, and sine wave, and the output frequency was obtained in the range of (50 Hz- 4 kHz). The signal generator designed in this paper is a simple, practical experiment with low-cost features and an important application. A circuit of generator based on OP-AMP employs resistors and capacitors to shape the output signals. Additionally, a volume control component is integrated to allow for easy adjustment of the frequency. The research achieved good results for sinusoidal, triangle, and square waves, where multiple frequencies up to 4KHz and different voltage peaks at +5V, +10V, and +15V were obtained.

Keywords: OP-AMP, Sinusoidal, Frequency, Square, Triangle, Multi-functional

1. Introduction

Different signal shapes can be generated at the output by a signal generator. The most common signal shapes are sine waves, triangle waves, and sawtooth waves. The frequencies of these signals range from a fraction of a hertz to hundreds of kilohertz. Signal generators are very versatile because they provide different waveforms at different frequencies and are used in a variety of applications [1] [2]. As a result of the rapid progress witnessed by modern technology, which led to the development of signal generators that provided functions and ease of use. When choosing a signal generator, the following criteria must be taken into account [3] [4]:

- Frequency range: This description represents the range of frequencies produced by the signal generator. Frequency ranges range from a few hertz (Hz) to high megahertz (MHz).
- Types of waveforms: Different types of waves can be generated according to requirements through signal generators.
- Accuracy: Signal generators are more expensive as they provide higher accuracy.

The most prominent uses of signal generators are:

- Scientific research and development: Signal generators are used in laboratories to develop and test electronic devices and devices.
- Education: Signal generators are an essential tool for teaching electronics and electrical engineering concepts in academic scientific institutions.
- Quality control: They are used in manufacturing units to monitor the quality of electronic products.

- Repair and maintenance: In service and maintenance centers, faults are inspected, detected and repaired in electronic devices using signal generators.

The previous examples represent a small part of the applications that use signal generators, and these applications are increasing with the increase in technological progress [1].

2. Methodology

This section is the main part of this research regarding methods and approaches that must be achieved to proceed with this research. The methodology of creating a function generator circuit using an operational amplifier (Op-Amp) involves the following key steps:

i. Selection of Operational Amplifier (Op-Amp): Choosing a suitable Op-Amp for the circuit. LM741 general-purpose Op-Amps was utilized.
ii. Circuit Configuration: Designing the circuit using operational amplifiers, resistors, and capacitors. The configuration may include a stable multivibrator circuits to generate specific waveforms such as square waves.
iii. Adjustable Parameters: Incorporate adjustable components such as potentiometers or variable resistors to control key frequency.
iv. Implementation: the overall circuit consists of two parts power supply and function generator. EAGLE CAD software is used to design PCBs.

The block diagram of system is shown in Fig.1 below this block diagram is to explain further details of the hardware that will be used for this system.

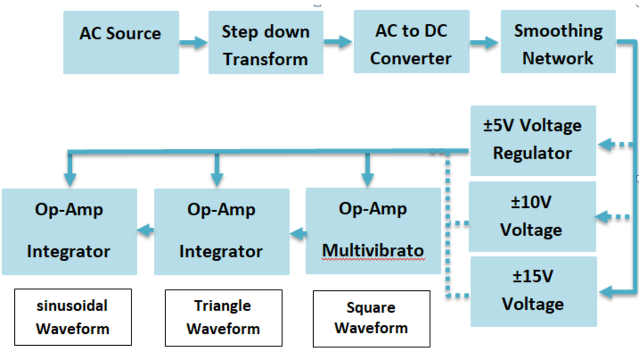


Figure1. A block diagram of system.

A. *System Summary*

An analog function generator system is operated through a 220V and 50Hz supply. The AC–DC converter produces a pulsating DC When the system is connected to the current by its power cord, the AC – DC converter produces a pulsating DC voltage of minimal ripple content due to the presence of a capacitance of 1000uF after the bridge rectifier.

A dual power supply circuit is utilized to provide the necessary power supply for a function generator circuit requiring both positive and negative voltages (±VCC). This configuration employs voltage regulator ICs, specifically the LM7805, LM7810, and LM7815, to generate +5V, +10V, and +15V, respectively. Simultaneously, the LM7905, LM7910, and LM7915 voltage regulator ICs produce -5V, -10V, and -15V, ensuring a symmetrically balanced dual power supply. This setup caters to the requirements of the signal generator circuit, allowing it to operate effectively with both positive and negative voltage values[6].

In a dual power supply configuration, the circuit incorporates voltage regulators such as LM7815, LM7915 for +15V/-15V, and LM7810, LM7910 for +10V/-10V, providing a symmetric power supply. This dual power supply is then connected to a signal generator circuit.The system generates three distinct waveforms:

1. Square Wave: The circuit produces a square wave by controlling the timing of signal transitions using electronic switches.

2. Triangle Wave: Utilizing a combination of capacitors, resistors, and operational amplifiers integrator circuits, the circuit shapes a triangular waveform.

3. Sine Wave: Achieved through another integrator circuit, that is used to integrate triangular waveform to get sinusoidal waveform. Fig. 2 illustrates system overview [6].

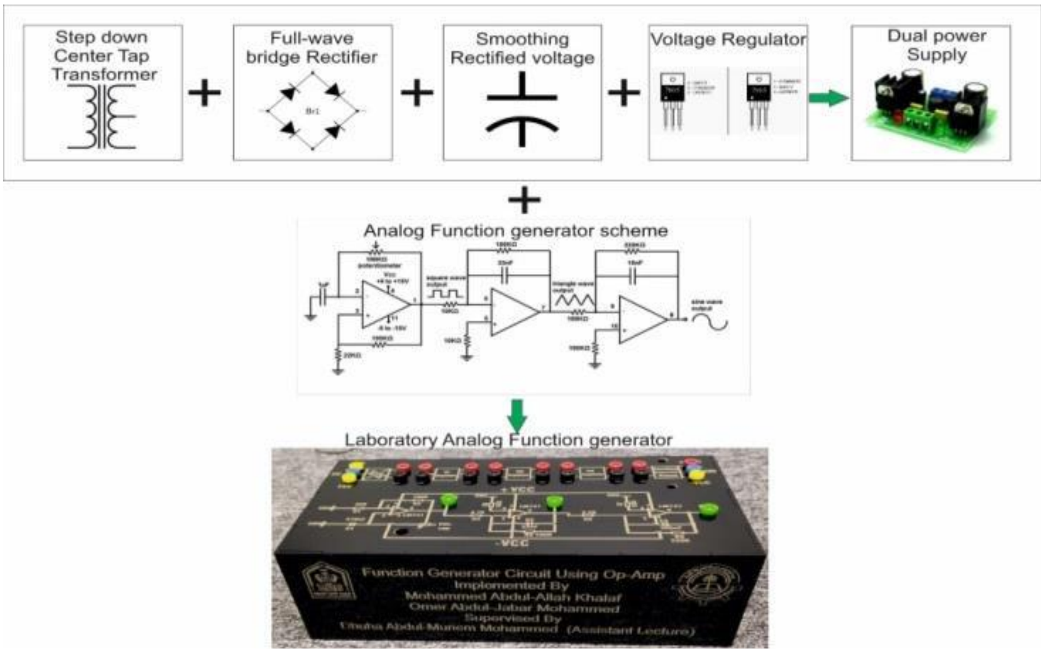


Figure 2. System Overview.

B. Center-Step Transformer

The working principle of a center-step transformer is similar to that of a normal transformer. The difference between the two types is that its secondary windings are divided into two parts, thus two individual voltages can be obtained across the two ends of the lines. As shown in Fig. 3, this type of configuration gives two phases across two parts of the secondary coil, and the total wires composing it are three wires, where the middle wire, the center-step wire, and the neutral wire are the same. Hence, this center-step connection is also known as a two -phase, three -wire transformer system. The voltages, between line A and neutral and between neutral and line B are called V_A and V_B respectively. Both voltages depend on the primary voltage as well as the turns ratio of the transformer [7].

$$V_A = \frac{N_A}{N_P} V_P \qquad (1)$$

$$V_B = \frac{N_B}{N_P} V_P \qquad (2)$$

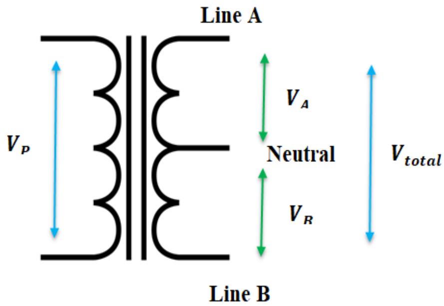


Figure 3. Center Tapped Transformer symbol.

C. AC to DC Converter

This converter is known as a linear rectifier and capacitor. The line rectifier is a full-wave bridge rectifier unit (KBU810) as shown in Fig.4 and consists of four diodes. This type of silicon rectifier was chosen in our design because of some of its unique properties. It can hold high voltage from the mains well without dissipating much heat.

This converter has a maximum recurring reverse voltage of 1000 V, a maximum average forward output current of 8 A , and a maximum forward voltage drop of 1 V at 4.0 A DC per element. The operating and storage temperature range of the KBU810 bridge rectifier is -65 to +150 °C. The rectifier converts the AC input voltage to a pulsating 100 Hz DC voltage. The output voltage of the rectifier can be expressed by an equation as follows [8]:

$$V_{dc} = \frac{2V_m}{\pi} \qquad (3)$$

$$V_m = \sqrt{2} \times V_{r.m.s} \qquad (4)$$

The root means square voltage, $V_{r.m.s} = 15V$

So,

$$V_{dc} = \frac{2 \times \sqrt{2} \times V_{r.m.s}}{\pi} = \frac{2 \times \sqrt{2} \times 15}{\pi} = 13.504V$$

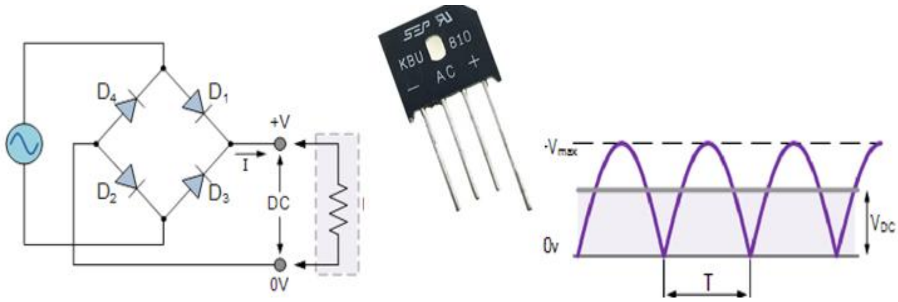


Figure 4. AC to DC Full Bridge Rectifier.

Smoothing capacitor are used to filter and smooth the waveform which is improve the average DC output of the rectifier while reducing the AC variation of the rectified output. Smoothing capacitors or tanks connected in parallel with the load increases the average DC output level to a larger value where the capacitor acts as a strong device as shown in Fig. 5 [8].

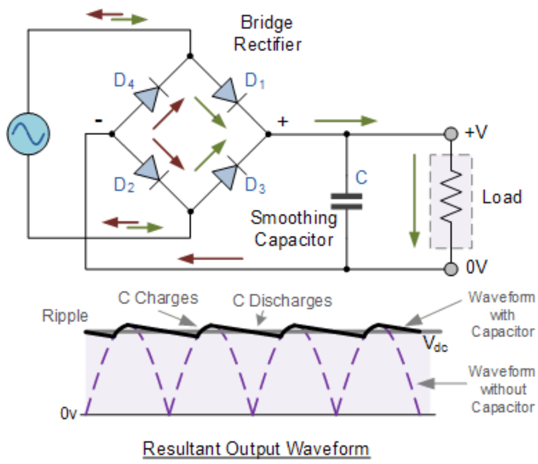


Figure 5. Full bridge rectifier with smoothing capacitor.

The maximum ripple voltage for a Full Wave Rectifier circuit is not only determined by the smoothing capacitor but also by the frequency and load current, and is calculated as follows:

$$V_{ripple} = \frac{I_{DC}}{2fC} \quad (5)$$

Where:
I_{DC}: represent the DC load current in Amps,
f: The frequency of the ripple or twice the input frequency in Hz,
C: The capacitance in Farads.

The operation of electronic and electrical devices requires a dual power source as it provides negative and positive voltage with the ground. Operational amplifiers are electronic equipment that require a dual power source. One of the most important applications in which the dual power source is used is [9]:

1. A Dual Power Supply in OP-AMPs

OP-AMPs generally need to swing bipolar output voltages. One of them goes either positively or negatively in response to the normal input signal range. Thus, OP-AMPs have two rails. So, to provide power to the OP-AMPs, a Dual power supply is needed.

2. A Dual Power Supply in Generators

When running two different power circuits on the same Power Supply without taking it offline, a dual power supply is needed. A dual power supply allows one to perform maintenance and other work on electrical equipment without taking the device offline. The electronic equipment requires a DC power source in the range of 5 -15V. Most circuits have individual step-down transformers and voltage regulators as shown in Fig. 6. For indication purposes, LED can add.

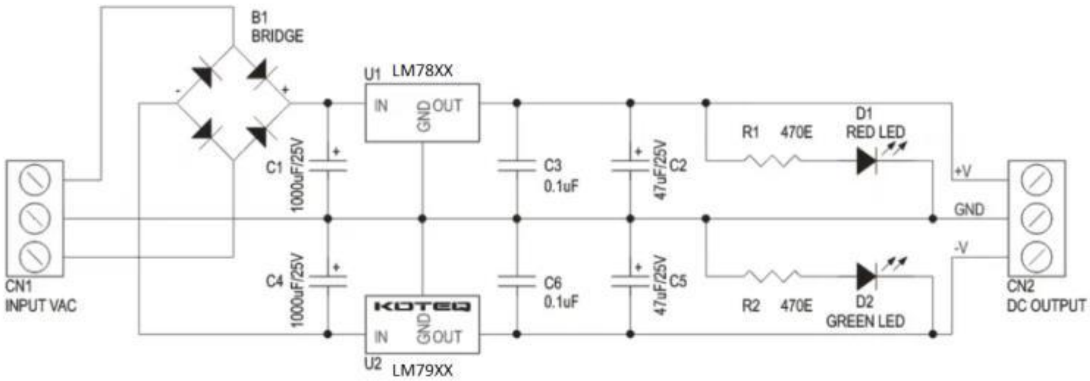


Figure 6. Dual power supply.

D. General Purpose Operational Amplifier LM741

An Operational Amplifier, or op-amp, is an amplifying device designed to be used with external feedback components between its output and input terminals. The feedback components determine whether resistance, capacitance, or both, the amplifier can perform different operations, giving rise to its name of "Operational Amplifier"[12].

An Op-AMP is a three-terminal device that consists of two high-impedance inputs. One of the inputs is called the Inverting Input. The other input is called the Non-inverting Input. A third terminal represents an output port voltage or a current. In a linear operational amplifier, the output signal is the amplification factor, Called the amplifier gain (A) multiplied by the value of the input signal. and depending on the nature of these input and output signals, there are four different classifications of OP-AMP gain depending on the nature of input and output [13], Voltage, Current, Transconductance and Transresistance. The output voltage from an Op-AMP is represent the difference between the signals being applied to its two individual inputs. Fig. 7 shows the pin out of LM741 and the equivalent circuit [13].

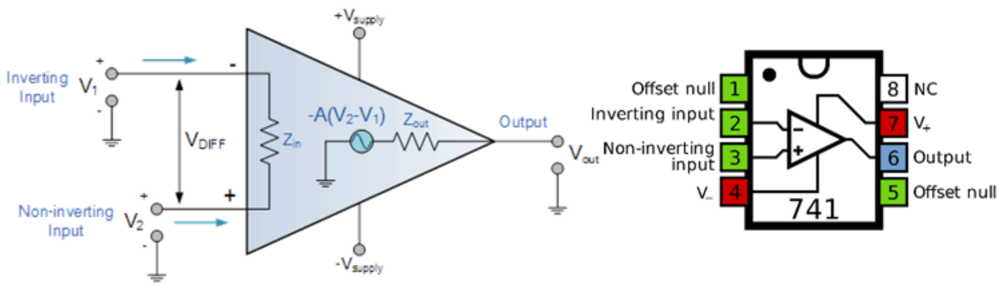


Figure 7. LM741 pinout and Equivalent Circuit.

E. Operational Amplifier as Multivibrator

The type of Op-amp Multivibrator is an astable oscillator circuit generates a rectangular output waveform using a component RC that is connected to the Inverting input of the OP-AMP and a voltage divider connected to the other Non-inverting input[14-17]. The OP-AMP is used in multivibrator circuits to remove uncontrolled switching operations. The circuit in Fig.8[14] shows the multivibrator.

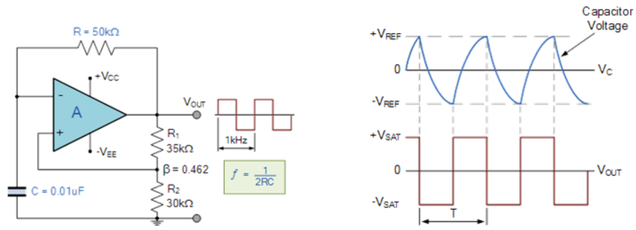


Figure 8. Op-amp Multivibrator Voltages.

The reference voltage, Vref will therefore depend on the fraction of Vout fed back to the non- inverting input. This feedback (β) is given by the following [14][18]:

$$\beta = \frac{R_2}{R_1+R_2} \qquad (6)$$

$$V_{OUT} = V_{SATURATION}$$

$$V_{REF} = V_{OUT} \times \frac{R_2}{R_1+R_2} = V_{SAT} \times \beta \qquad (7)$$

Therefore:

$$+V_{REF} = +\beta V_{SAT} (8)$$

$$-V_{REF} = -\beta V_{SAT} (9)$$

t1 = t2, if the positive and negative values of the amplifier's saturation voltage has the same magnitude and the equation that gives the period of oscillation is:

$$T = 2RC \times \ln \frac{1+\beta}{1-\beta} \qquad (10)$$

$$f = \frac{1}{T} \qquad (11)$$

F. Op-AMP as Integrator

An operation amplifier is used for differentiation and integration. In an integrated circuit, the output is integrated with the input voltage. A passive integrator uses resistors and capacitors [19]. An ideal OP-AMP integrator usees a capacitor Cf, the connected between the output and the OP-AMP inverting input terminal, as illustrated in Fig. 9 [1].

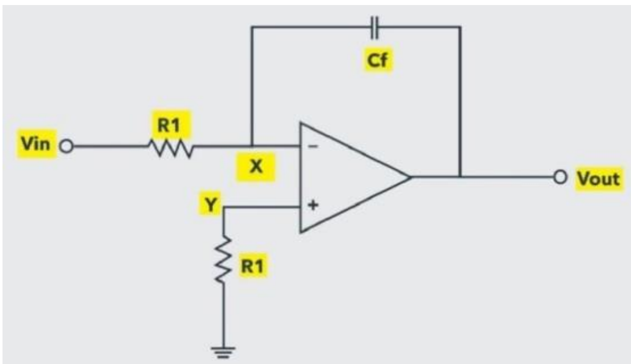


Figure 9. ideal OP-AMP integrator.

From the circuit display in Fig.9, it is shown that point Y is grounded by a compensating resistor R1. Node X will also be at ground potential, due to the virtual ground [17][20].

$$V_x = V_y = 0 \qquad (12)$$

The input current to an OP-AMP is ideally zero, for the current flowing through the input resistor, due to Vin, also flows through the capacitor C_f is given as: [9] [12]

$$I = \frac{V_{in} - V_x}{R_1} = \frac{V_{in}}{R_1} \qquad (13)$$

$$I = C_f \frac{d(V_x - V_{OUT})}{dt} = -C_f \frac{d(V_{OUT})}{dt} \qquad (14)$$

When equating the two equations of I, we find:

$$\frac{V_{in}}{R_1} = -C_f \frac{d(V_{OUT})}{dt} \qquad (15)$$

Then Integrating both the sides of the above equation, as below:

$$\int_0^t \frac{V_{in}}{R_1}.dt = -C_f \int_0^t \frac{d(V_{OUT})}{dt}.dt$$

$$\int_0^t \frac{V_{in}}{R_1}.dt = -C_f.V_{OUT}$$

Therefore:

$$V_{OUT} = \frac{-1}{R_1 C_f} \int_0^t V_{in}.dt \qquad (16)$$

The important advantage of an integrator is the large-constant, which results in the accurate integration of the input signal [20]. Because the current flowing into the OP-AMP internal circuitry is zero, effectively all of the current flows through the feedback capacitor Cf. This current charge the capacitor [21-24]. Because the capacitor is connected to the virtual ground, the voltage across the capacitor is the output voltage of the OP-AMP [25]. Figure 10 shows an integrated square waveform.

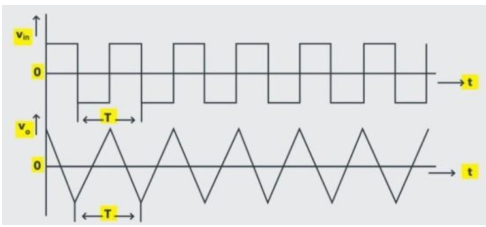


Figure 10. :Input and Output square Waveform of an Integrator.

By adding another inverting integrator, whereas the triangle-waveform is the input signal, the output signal is sinusoidal but it will not be a sine function [26-30]. It will just be connection of multiple $y = x^2$ as shown in Fig. 11.

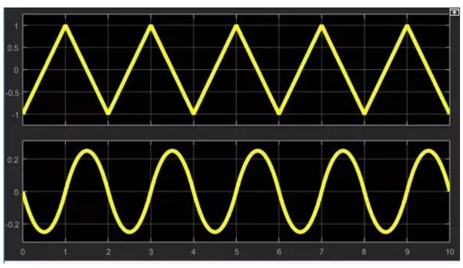


Figure 11. Input and Output Waveform of an Integrator (Triangle Wave Input)

3. Project implementation

A printed circuit board (PCB) is designed and implemented to simplify wiring by using EAGLE. The EAGLE is defined as an electronic design automation (EDA) software that lets printed circuit board (PCB) designers seamlessly connect schematic diagrams, component placement, and PCB routing. Fig. 12 shows the system's schematic and layout.

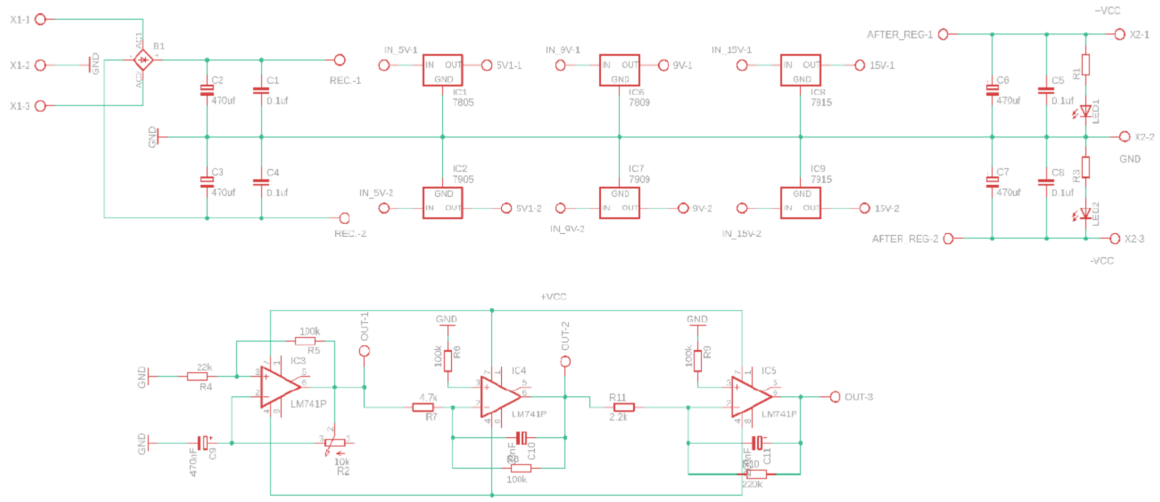


Figure 12.:Project's schematic.

After that, the electronic circuit of the system is manufactured in several steps. Finally, the PCB board is drilled and the electronic components are on it. As shown in Fig. 13.

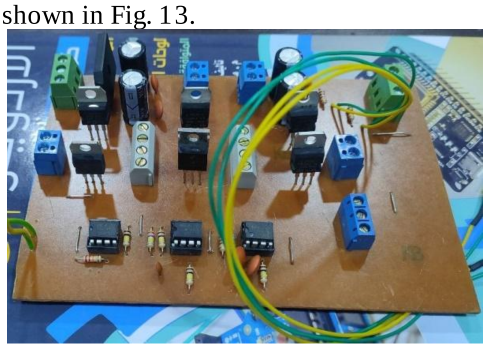
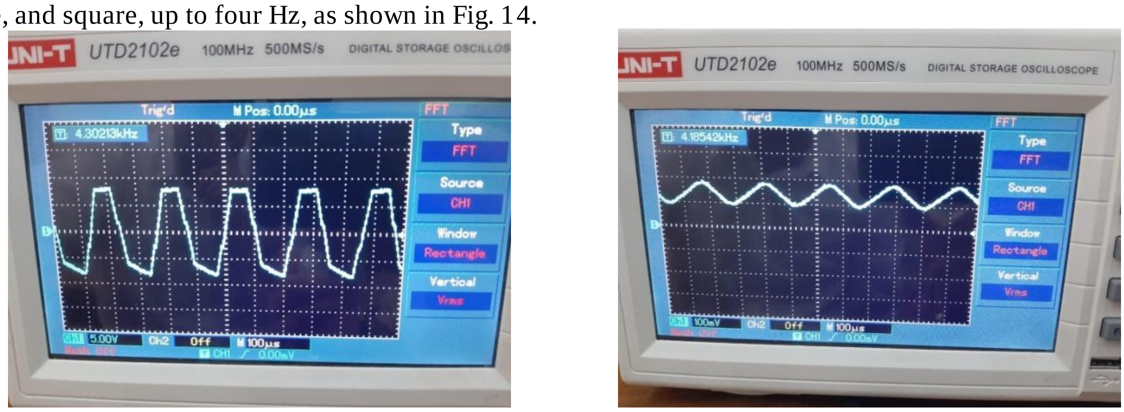


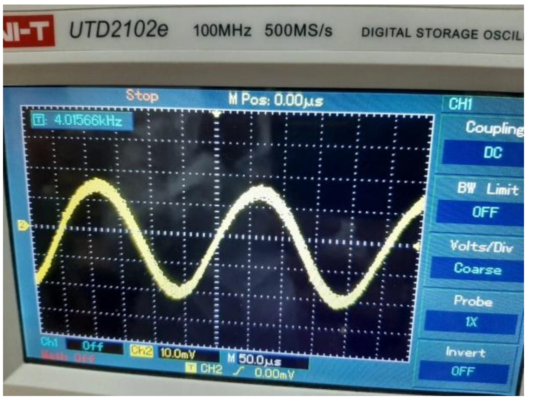
Figure 13. System component installed on PCB

4. Results and Discussion

After soldered electronic components on the PCB, the project is tested. The results obtained in this project are considered satisfactory because it is low cost. A wide range of frequencies was obtained for the three waves, sinusoidal, triangle, and square, up to four Hz, as shown in Fig. 14.



(a) (b)



(c)

Figure 14. (a)square, (b)Triangle, and (c)sinusoidal waveforms of the function generator.

5. Conclusions

The system that employs a 741 operational amplifier and a dual power supply circuit based on the 78XX and 79XX ICs has proven to be a practical and affordable solution for waveform generation For the sinusoidal, a frequency range of up to 4 kHz was obtained. For the triangle wave, a frequency range of up to 4.1KHz was demonstrated. Finally, the frequency range of the square wave was investigated, where a maximum frequency of 4.3KHz was achieved.

Briefly, the signal generator incorporating the 741 operational amplifier and dual power supply circuit with three choices of dual power supply has demonstrated efficiency, affordability, and versatility in waveform generation, making it a valuable tool for electronics enthusiasts and hobbyists.

6. Recommendations

To enhance the performance and expand the capabilities of the system designed, here are recommendations.

- Frequency Range Expansion:

Explore options for expanding the frequency range of the function generator to cater to a broader range of applications.

- Compact Design:

Optimize the layout and design of the circuit for a more compact by replacing LM741 which contains a single Op-AMP in single chip by LM324 which contains Quad Op- Amp in a single chip.

References

[1] O. Nelles and J. Belz, "Function Generator Application," in *Proc. 25th Workshop Computational Intelligence*, Scientific Publishing, 2015, pp. 1614-5267.

[2] JOJO, "Function Generators," *Circuitstoday*, Aug. 13, 2017. [Online]. Available: https://www.circuitstoday.com/functiongenerators.

[3] D. Peterson, "Function Generator and Arbitrary Waveform Generator," *Metrixelectronics*, 2010.

[4] M. S. R. Mohite, M. P. S. Mali, M. A. Suryavanshi, and M. A. H. Tirmare, "FPGA BASED FUNCTION GENERATOR," *Int. Res. J. Eng. Technol. (IRJET)*, vol. 2, no. 9, pp. 2394-2399, Dec. 2015.

[5] H. Schmid, "Combined Analog/Digital Computing Elements," *Western Joint IRE-AIEE-ACM Computer*, pp. 299–314, May 1961.

[6] H. Bonekamp, "Magzdb," Apr. 1995. [Online]. Available: https://magzdb.org/file/599413/dl.

[7] N. Takaoka, H. Takahashi, and J.-i. Itoh, "Isolated Single-Phase Matrix Converter Using Center-Tapped Transformer for Power Decoupling Capability," *IEEE Trans. Ind. Appl.*, vol. 54, no. 4, pp. 1523-1531, 2018.

[8] B. Singh et al., "A review of single-phase improved power quality AC-DC converters," *IEEE Trans. Ind. Electron.*, vol. 50, no. 6, pp. 962-981, 2003.

[9] T. Sebastian and S. B. Dewan, "Comparison of dual-converter-based power supply systems," *IEEE Trans. Ind. Appl.*, vol. 25, no. 2, pp. 339-347, 1989.

[10] "IB Diagram," *Fairchild Semiconductor International*, 2001. [Online]. Available: https://img2.cleverworldnet.com/tmp/MC7806CT__001.pdf.

[11] S. Dinata, H. Kusnadi, T. Wibawa, and S. Bakhri, "The development of tools for power electronics virtual laboratory for maintenance personnel," *AIP Conf. Proc.*, vol. 2484, no. 1, 2023.
[12] S. Bhattacharjee, S. Mukherjee, A. Roy, and A. Mallick, "Experimental Study of Howland Current Source using General Purpose Operational Amplifier and its Application to Bio-impedance Measurement," 2019.
[13] "SPN NAD0010A," *Boston University*, May 1998. [Online]. Available: https://www.bu.edu/peaclab/files/2019/08/lm741.pdf.
[14] Hung-Chun Chien, "Three-mode controllable master-slave monostable multivibrators using current-feedback operational amplifiers," *The Institution of Engineering and Technology*, vol. 8, no. 6, pp. 543–553, Jun. 2014.
[15] K. Swain and M. K. Sahoo, "Design and Implementation of Equiripple FIR High Pass Filter on FPGA," *Int. J. Comput. Electron. Aspects Eng.*, vol. 1, no. 1, pp. 1-4, Mar. 2020.
[16] A. L. Rane and N. Patil, "Voice Control Elevator for Prevention of Physical Touch," *Int. J. Comput. Electron. Aspects Eng.*, vol. 1, no. 4, pp. 95-100, Dec. 2020.
[17] A. M. Nory, "Influence of doubling the concentration of InP/InGaAsP laser diode layers on power and photon density using Silvaco program," *Int. J. Comput. Electron. Aspects Eng.*, vol. 5, no. 2, pp. 61-72, Jun. 2024.
[18] A. Tamasevicius and K. Murali, "The Common Multi-Vibrator Family," in *Proc. 15th IEEE Int. Workshop Nonlinear Dyn. Electron. Syst.*, Jul. 2007.
[19] M. Ahmed, H. U. Zaman, M. A. N. Rafiya, and H. Hossain, "A Comparative Study of Various Simulation Software for Design and Analysis of Operational Amplifier Based Integrator Circuits," in *Proc. 2017 8th Annu. Ind. Autom. Electromech. Eng. Conf. (IEMECON)*, Bangkok, Thailand, 2017.
[20] S. Michael and W. Mikhael, "Inverting Integrator and Active Filter Applications of Composite Operational Amplifiers," *IEEE Trans. Circuits Syst.*, vol. 34, no. 5, pp. 461–470, May 1987.
[21] T. R. Brown and B. Carter, *Handbook of Operational Amplifier Applications*, Texas Instruments, 2001.
[22] J. K. Roberge, *Operational Amplifiers: Theory and Practice*, John Wiley & Sons, Inc., 2007.
[23] W. Mikhael and S. Michael, "Composite operational amplifiers: Generation and finite-gain applications," *IEEE Trans. Circuits Syst.*, vol. 34, no. 5, pp. 449–460, May 1987.
[24] A. Gupta, C. Mithlesh, and P. Tapashetti, "Design and Simulation of Op Amp Integrator and Its Applications," *Int. J. Eng. Adv. Technol. (IJEAT)*, vol. 1, no. 3, pp. 12-19, Feb. 2012.
[25] S. Winder and G. B. Clayton, *Operational Amplifiers*, Oxford, 2003.
[26] A. M. Nory, O. I. Alsaif, and Z. R. Mahmood, "Improving the Emission Spectrum Performance of InP/InGaAsP Laser Diode Using Silvaco TCAD," *Int. J. Microw. Opt. Technol.*, vol. 19, no. 2, pp. 226–235, 2024.
[27] S. Yawale and S. Yawale, *Operational Amplifier Theory and Experiments*, Springer, 2022.
[28] S. Franco, *Design with Operational Amplifiers and Analog Integrated Circuits*, McGraw-Hill, 2002.
[29] N. M. Samad, F. G. Beshaw, and I. K. Saleh, "Calculations of the effect of photovoltaic renewable resources on the power generation grid continuity," *Int. J. Comput. Electron. Aspects Eng.*, vol. 4, no. 1, pp. 1-10, Jan.–Mar. 2023.
[30] R. Pochhi, R. Chede, and S. Thakare, "Design and Development of Solar Powered Compost Bin – A Review," *Int. J. Comput. Electron. Aspects Eng.*, vol. 2, no. 1, pp. 1-5, Mar. 2021.