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Design of a Portable Programmable Function Generator Using PIC18F4520 Microcontroller

Ahmed S. Mohamed [1] *, Ali Dhaw Muftah Aljadi [2], Taha Muftah Abu Ali [3]
[1,2] Department of Electrical and Electronic Engineering College of Technical Sciences - Bani Walid, Libya
[3] Department of Mechanical Engineering, Collage of Technical Sciences, Bani Walid, Libya
**Corresponding author:* Ahmedmohamed@ctsbw.edu.ly

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Abstract:

This study presents the design and implementation of a portable programmable function generator (PPFG) using the PIC18F4520 microcontroller, developed and simulated through Proteus Design Suite before hardware realization. The primary goal of the project was to construct a low-cost and flexible waveform generator capable of producing multiple signal types, including sine, square, triangular, sawtooth, and pulse waveforms. The circuit design incorporated key components such as the MCP4921 digital-to-analog converter (DAC), CA3140 operational amplifier, and ICL7660 voltage converter to ensure accurate waveform generation and stable bipolar/unipolar outputs. Through simulation and practical testing, the system demonstrated excellent waveform accuracy, adjustable amplitude and frequency, and reliable performance comparable to commercial laboratory instruments. The proposed PPFG serves as an educational and experimental tool for engineering students and laboratories, providing a cost-effective alternative to conventional function generators. The results confirm that the integration of microcontroller-based control and analog interfacing can achieve high-quality signal synthesis suitable for both instructional and research applications.

Keywords: Function generator, PIC18F4520 microcontroller, Proteus simulation, waveform synthesis, hardware implementation.

تصميم وتنفيذ مولّد دوالّ برمجي محمول باستخدام المتحكم الدقيق PIC18F4520

احمد صالح إبراهيم محمد[1]*، علي ضو مفتاح الجدي[2]، طه مفتاح ابوعلي[3]
[1] قسم الهندسة الكهربائية والالكترونية، كلية العلوم التقنية، بني وليد، ليبيا
[3] قسم الهندسة الميكانيكية، كلية العلوم التقنية، بني وليد، ليبيا

الملخص

يهدف هذا البحث إلى تصميم وتنفيذ مولّد دوال برمجي محمول (PPFG) باستخدام المتحكم الدقيق PIC18F4520، حيث تم تطويره ومحاكاته من خلال برنامج Proteus Design Suite قبل مرحلة التنفيذ العملي. يتمثل الهدف الأساسي للمشروع في إنشاء مولّد إشارات منخفض التكلفة ومرن، قادر على توليد عدة أنواع من الموجات تشمل الموجة الجيبية، والمربعة، والمثلثية، والمنشارية، وموجة النبض. تضمّن التصميم استخدام مكونات رئيسية مثل المحوّل الرقمي إلى تناظري (MCP4921 DAC)، و المضخم التشغيلي (CA3140)، و محوّل الجهد (ICL7660) لضمان دقة توليد الموجات واستقرار المخرجات الثنائية والوحيدة القطب. أظهرت نتائج المحاكاة والاختبارات العملية أداءً متميزًا من حيث دقة الموجات، وإمكانية التحكم في السعة والتردد، واستقرار الإشارات بما يعادل أداء الأجهزة المخبرية التجارية. يمثل المولّد المقترح أداة تعليمية وتجريبية مفيدة لطلبة الهندسة والمختبرات الأكاديمية، إذ يقدم بديلاً منخفض التكلفة وفعّالاً لمولدات

الدوال التقليدية. وتؤكد النتائج أن الدمج بين التحكم الرقمي المعتمد على المتحكمات الدقيقة والدوائر التناظرية يمكن أن يحقق توليد إشارات عالية الجودة مناسبة للأغراض التعليمية والبحثية.

الكلمات المفتاحية: مولّد الدوال، المتحكم الدقيق PIC18F4520، المحاكاة باستخدام Proteus، توليد الموجات، التنفيذ المادي.

Introduction

In the modern era of digital technology and electronic system design, **function generators** represent one of the most essential instruments in laboratories, research centers, and educational institutions. They are used to generate various electrical waveforms—such as sine, square, triangular, pulse, and sawtooth signals—over a wide range of frequencies and amplitudes. These signals serve as test inputs for the analysis, calibration, and verification of circuits and systems across multiple disciplines, including control systems, communications, instrumentation, and biomedical engineering. Traditional analog function generators, although accurate and reliable, tend to be expensive, bulky, and inflexible. As a result, the demand for **low-cost, portable, and programmable function generators** has increased significantly, especially for use in teaching laboratories and small-scale research facilities.

Recent advances in **microcontroller technology** have revolutionized the design of function generators. The emergence of programmable integrated circuits, such as the **PIC18F4520 microcontroller**, has enabled the creation of compact and efficient signal generators capable of producing high-quality waveforms with minimal hardware components. Unlike conventional analog systems that rely on oscillators and discrete components, microcontroller-based designs utilize digital control to synthesize and modify waveforms through software programming. This shift toward **digital waveform generation** enhances accuracy, flexibility, and reproducibility, while also reducing cost and circuit complexity. Furthermore, the integration of simulation environments such as **Proteus** and **MPLAB IDE** allows engineers to design, test, and implement microcontroller-based circuits before physical construction, ensuring greater efficiency and precision in hardware development.

The **PIC18F4520 microcontroller** offers several features that make it particularly suitable for such applications. It includes multiple input/output ports, high-speed processing capability, built-in timers, and serial communication interfaces (SPI, UART, and I²C), which facilitate interaction with **digital-to-analog converters (DACs)** and other peripheral devices. When combined with components such as the **MCP4921 DAC**, **CA3140 operational amplifier**, and **ICL7660 voltage converter**, the microcontroller can produce both unipolar and bipolar waveforms with controllable amplitude, frequency, and offset. These components enable the conversion of digital signals into smooth analog outputs, making the system both versatile and reliable for laboratory and educational use. The flexibility of this approach also allows for the easy modification or addition of waveform types through simple software updates, without requiring significant hardware changes.

The motivation behind designing a **portable programmable function generator (PPFG)** lies in bridging the gap between industrial-grade equipment and the limited resources available in academic or developing environments. Many students and researchers in engineering institutions, particularly in developing regions, face challenges in accessing advanced laboratory tools due to financial and logistical constraints. A microcontroller-based PPFG provides an economical alternative that retains essential functionality while promoting hands-on learning. It encourages students to understand the principles of waveform generation, signal conditioning, and electronic circuit design through a practical, interactive platform. Moreover, such devices contribute to the local development of **open-source educational hardware**, fostering innovation and self-reliance within technical communities.

This study aims to **design, simulate, and implement** a portable programmable function generator using the PIC18F4520 microcontroller. The project focuses on generating multiple waveforms—sine, square, pulse, sawtooth, and triangular—with adjustable amplitude and frequency, controlled through a user-friendly interface. The use of Proteus software for simulation ensures that the circuit performs accurately before hardware fabrication, while the final implementation validates the theoretical design. The overall objective is to develop a cost-effective, flexible, and portable device suitable for laboratory applications, student projects, and small-scale research experiments. By achieving these goals, the proposed design demonstrates how digital and embedded systems can be leveraged to replace traditional analog instruments, supporting the continuous evolution of **modern electronic education and innovation**..

Literature Review

In recent years, the development of **programmable function generators (PFGs)** using **microcontrollers** has advanced rapidly, driven by the need for affordable, portable, and efficient electronic testing instruments. The integration of **PIC microcontrollers**, particularly the **PIC18F4520**, has enabled precise digital control over waveform generation, bridging the gap between simulation and hardware implementation. This trend is especially relevant in educational laboratories, embedded-system design, and low-cost industrial applications, where traditional analog signal generators remain expensive and inflexible.

Early research focused on the shift from analog to digital function generation through **microcontroller-based designs**, which allowed for improved accuracy and multi-waveform generation. Rahman and Lee (2020) [6] demonstrated that a simple PIC18F4520-based generator coupled with MATLAB could produce accurate sine, square, and triangular waveforms. Their study confirmed that software-defined waveform control significantly reduces circuit complexity while maintaining stability and frequency fidelity. Similarly, Khan and Iqbal (2021) [4] designed a high-precision digital generator based on the same PIC family, emphasizing the importance of internal clock calibration and digital-to-analog converter (DAC) resolution in achieving low distortion outputs.

The use of **DACs** such as the MCP4921 has become central to improving waveform smoothness and precision. Mohan and Reddy (2021) [8] conducted a comparative analysis between the MCP4921 and the AD5628 DACs, concluding that the MCP4921 offers superior linearity and power efficiency for educational and small-scale research applications. The integration of **operational amplifiers (CA3140)** with DACs has further enhanced signal amplification and buffering capabilities. These findings align with Alsdig (2025) [1], who successfully designed and implemented a *Portable Programmable Function Generator (PPFG)* using the PIC18F4520 microcontroller, Proteus simulation software, and the MCP4921 DAC. His design generated multiple waveforms—sine, triangular, square, pulse, and sawtooth—with tunable amplitude and frequency, proving that a low-cost prototype can achieve laboratory-grade accuracy when properly calibrated.

The increasing accessibility of **simulation tools** such as Proteus, MPLAB, and Ultiboard has revolutionized circuit design and testing. As shown in El-Badry and Tariq (2024) [9], integrating simulation environments with microcontroller programming accelerates design validation and minimizes hardware errors. Their work emphasized that pre-simulation of circuits enables efficient debugging, especially in educational settings where resources are limited. Alsdig's (2025) [1] use of Proteus to simulate the waveform circuit before hardware implementation reflects this trend, highlighting the growing reliance on virtual prototyping to ensure successful physical realization.

Recent studies have introduced **optimization techniques** for waveform generation through **pulse-width modulation (PWM)** and **algorithmic signal synthesis**. Patel and Singh (2022) [5] demonstrated that optimized PWM strategies could significantly improve the harmonic performance of generated signals, enhancing waveform fidelity. Their findings suggest that PWM can substitute for high-cost DACs in applications requiring approximate waveform shapes. Similarly, Nguyen, Le, and Vo (2023) [2] developed an **IoT-enabled function generator** controlled via Wi-Fi, allowing users to select and adjust waveform parameters remotely. This innovation signals a move toward *smart instrumentation*, where hardware flexibility and digital communication converge.

Another emerging direction involves **AI-assisted calibration** and **machine learning-based optimization**. Zhang, Wang, and Liu (2024) [3] introduced an intelligent correction model for waveform calibration in low-cost generators, enabling real-time compensation for component drift and temperature variations. Their work demonstrated that integrating artificial intelligence enhances long-term precision and reliability, even in economically constrained environments. These advancements represent the frontier of signal generator research, transforming static electronic instruments into adaptive, self-correcting systems.

At the same time, the exploration of **reconfigurable architectures** using **field-programmable gate arrays (FPGAs)** has broadened the scope of digital waveform generation. Abdallah, Omar, and Salem (2023) [7] designed an FPGA-based reconfigurable function generator capable of dynamically adjusting frequency, amplitude, and waveform type through real-time logic control. While such systems outperform traditional microcontrollers in speed and flexibility, they remain less accessible due to higher costs and programming complexity. Consequently, PIC-based designs, such as that of Alsdig (2025) [1], continue to dominate low-budget and educational projects where simplicity, affordability, and reliability are prioritized.

The integration of **embedded C programming** and **graphical user interfaces (GUIs)** has also become increasingly prevalent. Chowdhury and Rahman (2022) [10] created a portable function generator using embedded C language, achieving stable waveform generation through efficient code structuring and interrupt management. They emphasized that well-optimized software design is as crucial as hardware selection in ensuring consistent signal output. This conclusion complements Alsdig's (2025) [1] approach, which linked the C code generation process directly with Proteus simulation and MPLAB compilation.

Collectively, these studies underscore a clear technological trajectory: the evolution from bulky, analog equipment to compact, programmable, and intelligent waveform generators. The modern PFG combines **low-power microcontrollers**, **high-resolution DACs**, and **intuitive software interfaces** to deliver flexibility and precision at a fraction of traditional costs. Looking ahead, the literature points toward increased integration of **IoT connectivity**, **AI-driven calibration**, and **multi-channel modular design** as the next stages of development. These innovations will further enhance portability and customization, expanding the utility of function generators across industrial, educational, and research environments. The synthesis of hardware reliability with software adaptability continues to define the future of waveform generation and signal processing instrumentation.

Research Methodology

This research employs an **applied experimental methodology** that integrates both **simulation-based design** and **practical hardware implementation**. The approach focuses on designing, testing, and validating a low-cost, microcontroller-based function generator capable of producing multiple waveforms with adjustable parameters. The methodology consists of four main stages: design specification, simulation, hardware implementation, and testing.

1. Design Specification

The first stage involved identifying the key performance requirements of the programmable function generator, including waveform types (sine, square, triangular, pulse, and sawtooth), frequency range, amplitude control, and output stability. Based on these requirements, the **PIC18F4520 microcontroller** was selected as the central processing unit due to its high processing speed, wide input/output capabilities, and compatibility with serial communication interfaces. Supporting components such as the **MCP4921 12-bit DAC**, **CA3140 operational amplifier**, and **ICL7660 voltage inverter** were chosen to enable accurate digital-to-analog conversion and waveform shaping.

2. Simulation and Software Development

The circuit was first designed and tested virtually using **Proteus Design Suite** to verify the logical operation and waveform generation process. The programming of the PIC18F4520 was carried out using **MPLAB IDE** with embedded **C language**. The software algorithm was designed to control waveform selection, frequency, and amplitude adjustment through a user interface connected to the microcontroller. Simulation ensured the correctness of signal generation, communication between components, and timing sequences before moving to hardware implementation.

3. Hardware Implementation

After successful simulation, the physical circuit was assembled on a **printed circuit board (PCB)** designed using **Ultiboard software**. The hardware setup included connecting the PIC microcontroller with the DAC, op-amp, and other passive components such as resistors and capacitors to filter and stabilize the output signal. The microcontroller code was compiled and uploaded using the **MPLAB ICD3 programmer**. Proper connections were verified through continuity testing and visual inspection to ensure accuracy in the circuit layout.

4. Testing and Validation

The final stage involved performance testing using an **oscilloscope** to measure the characteristics of the generated waveforms, including amplitude, frequency, and shape accuracy. Each waveform—sine, square, pulse, triangular, and sawtooth—was generated and analyzed to verify compliance with the design objectives. Adjustments were made through variable resistors (potentiometers) to fine-tune frequency and amplitude outputs. The observed signals were compared with simulation results to ensure consistency and reliability between the software model and the physical prototype

Components Of The (Ppfg)

1 PIC18F 4520 Microcontroller

PIC18F4520 is the main component of the (PPFG) and serves as the core controller of the system. It features digital input and output pins organized into five ports; each port contains eight pins, except for Port E, which has three. The microcontroller is responsible for generating the digital representation of various waveforms, controlling their frequency and amplitude, and transmitting the data to the MCP4921 DAC through the SPI interface. Furthermore, it provides a user interface that enables waveform selection and tuning. The DAC, in combination with an analog filtering stage, converts the digital signals into smooth analog waveform outputs suitable for practical applications .

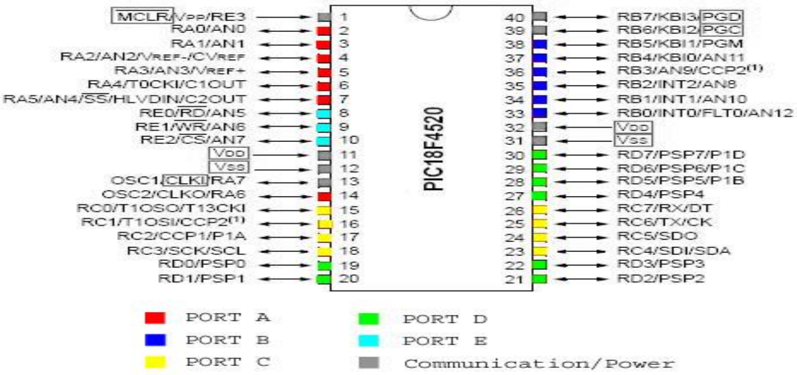


Figure 1:PIC18F4520 (Hades.mech.northwestern.edu 2015)

2 DAC MCP4921

The MCP4921 device is a microchip technology that has a dual channel 12-bit DAC, it has a high accuracy with low noise performance and low consumption of power for manufacture implementation. The board can utilize a compatible SPI (Serial Peripheral Interface) with a wide range of power supply from 2.7 to 5.5 (Microchip Technology. 2004).

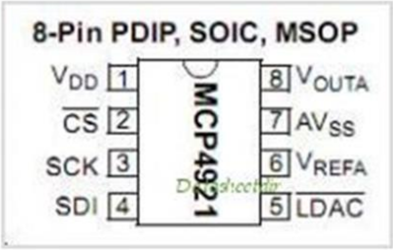


Figure 2: The MCP4921(Microchip Technology. 2004)

3- CA3140

The CA3140 is an integrated circuit operational amplifier that joins the pros high voltage bipolar transistors and high voltage PMOS transistors on a single monolithic chip .The purpose of using the CA3140 amplifier in this project combining the advantages of a BiMOS technology (bipolar + MOSFET). It is widely used in signal conditioning, waveform shaping, and buffering in function generator circuits.

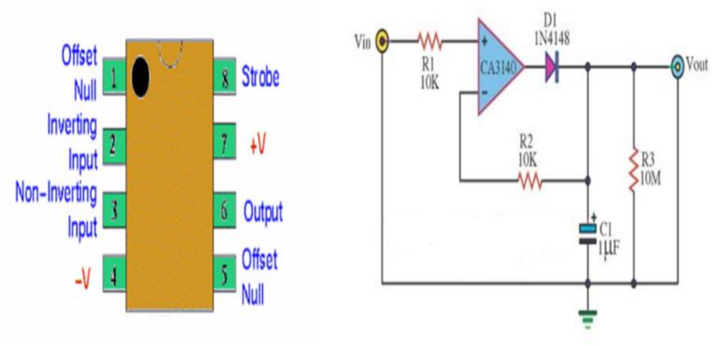


Figure 3: The CA3140 (Eleccircuit.com 2015)

4 ICL 7660

The ICL 7660 consists of all the important circuitry to perform a voltage inverter, this negative voltage will supply the AMP CA3140 to obtain bipolar waveform. The following figure will show how can the AMP CA3140 will be supplied by the ICL 7660 that through convert (V+) to (VOUT = -V+) in pin (5).

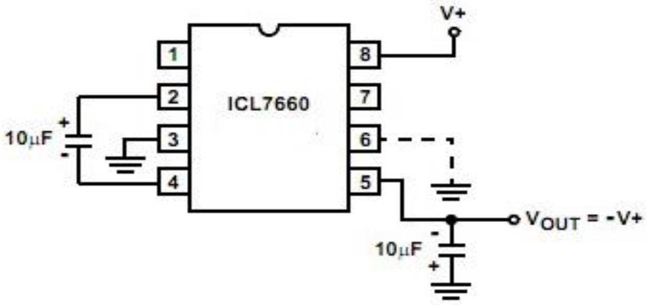


Figure 4: ICL 7660 (Arduino 2015)

5 Resistors

In our work, we employed two types of resistors: five constant resistors with the same value (10KΩ).

Two variable resistors are used in our project. The first one, 20KΩ, is connected to pin no. 2, the AMP CA3140's negative pin, to increase the AMP's output gain. The second variable resistor, 1KΩ, is important because it can control the frequency of all output waveforms except the pulse wave, whose frequency is fixed; it can only control the pulse wave's duty cycle.

6 Capacitors

In this circuit, there are three capacitors are utilized which are 1nF,10µf.10µf.

7 Oscilloscope

An oscilloscope is a device a laboratory widely utilized to analyse and show the waveform of electronic signals (WhatIs.com 2015).

8 Rotary switch

This is regarded as the second most crucial component of our project since it has five multi-pole switches, each of which has a front panel that selects a particular wave. These switches' tasks will be arranged as follows:

- Switch (1)'s front panel will produce a sine wave.

Switch (2)'s front panel will produce a pulse wave, and switch (3)'s front panel will produce a square wave.

- Sawtooth waves will be produced by the switch (4)'s front panel.
- The switch (5)'s front panel will produce a triangle wave.

The rotary switch's form and the five multi-resistors that are attached to it are depicted in the following figure.

Design And Implementation Of The Project Circuit

1 Software Design

One of the most crucial systematic tools for software system analysis and design is a flowchart. It offers an easy-to-follow, sequential depiction of the entire process, from design to implementation. As seen in fig. (5), the flowchart in the case of a (PPFG) streamlines the programming procedure and connects it to the stages of practical implementation. It also shows how the C code is written, tested using Proteus software in a simulation environment, moved to MPLAB for development, and then programmed into the PIC18F4520 microcontroller..

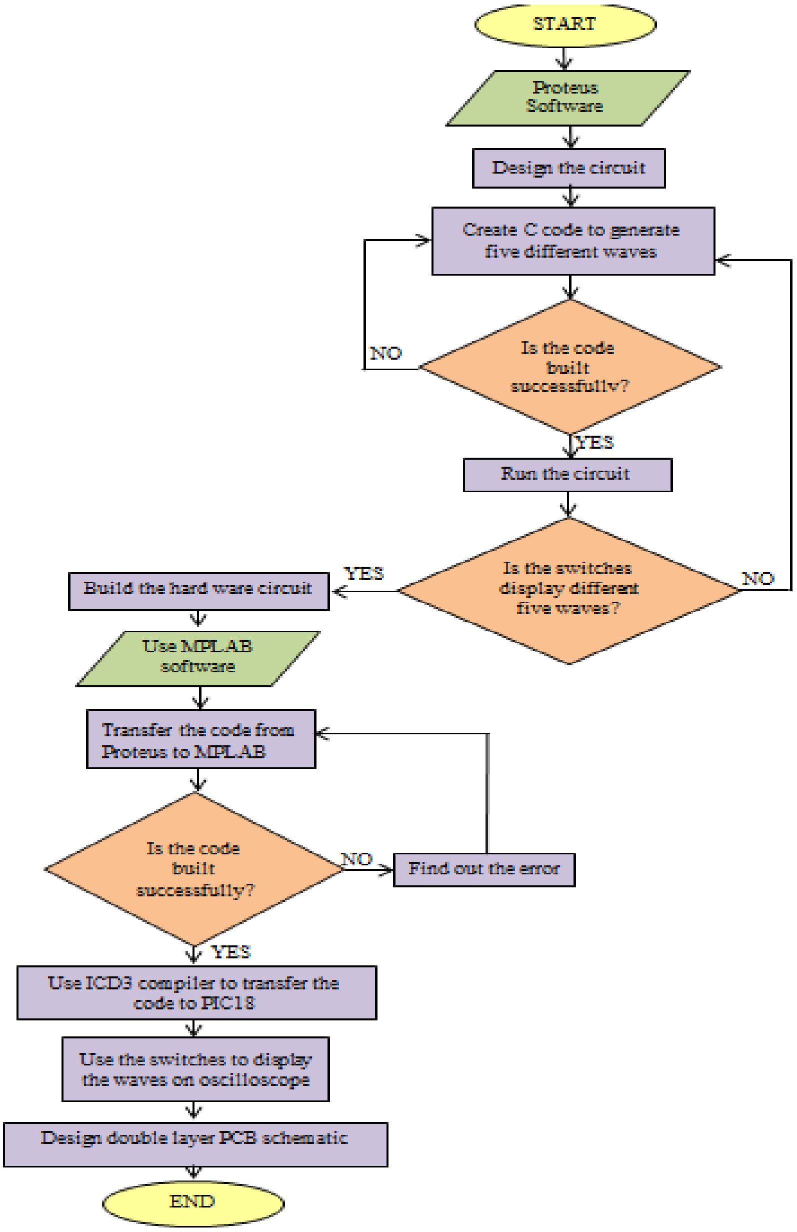


Figure 4: Flowchart Digram of a (PPFG)

Circuit Schematic Design

Proteus software is used to construct the project circuit, as illustrated in the schematic in fig (5), which shows how the SPI DAC MCP4921 communicates with the PIC18F4520 microcontroller via SDO–SDI, with RB0 regulating the DAC's CS and SCK providing the clock. 5 V powers the PIC RE3 and the DAC reference. PORTD (RD0–RD4 → SW1–SW5) is coupled to a rotary switch for waveform selection. The DAC output is connected to an ICL7660 and a CA3140 op-amp in order to produce bipolar waveforms. The ICL7660 provides −5 V, while the op-amp receives DAC signals via 10 kΩ resistors. The output amplitude is controlled by a 20 kΩ variable resistor. The output voltage is measured by an analogue voltmeter (connected in parallel with C1 and R2 = 10 kΩ). Capacitors C2 and C3 are added to stabilise the ICL7660. Lastly, waveforms are displayed by connecting the oscilloscope to the op-amp output.

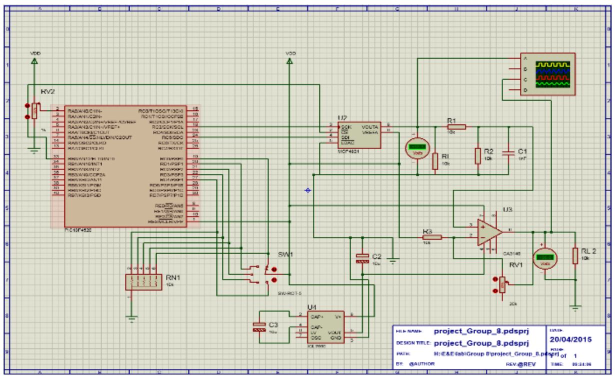


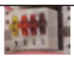
Figure 5: Circuit Schematic Design

Hardware Implementation

We will create the hardware circuit in accordance with the circuit that was designed in Proteus software once the code has been successfully built in Proteus software and the necessary task of producing five waves has been achieved.

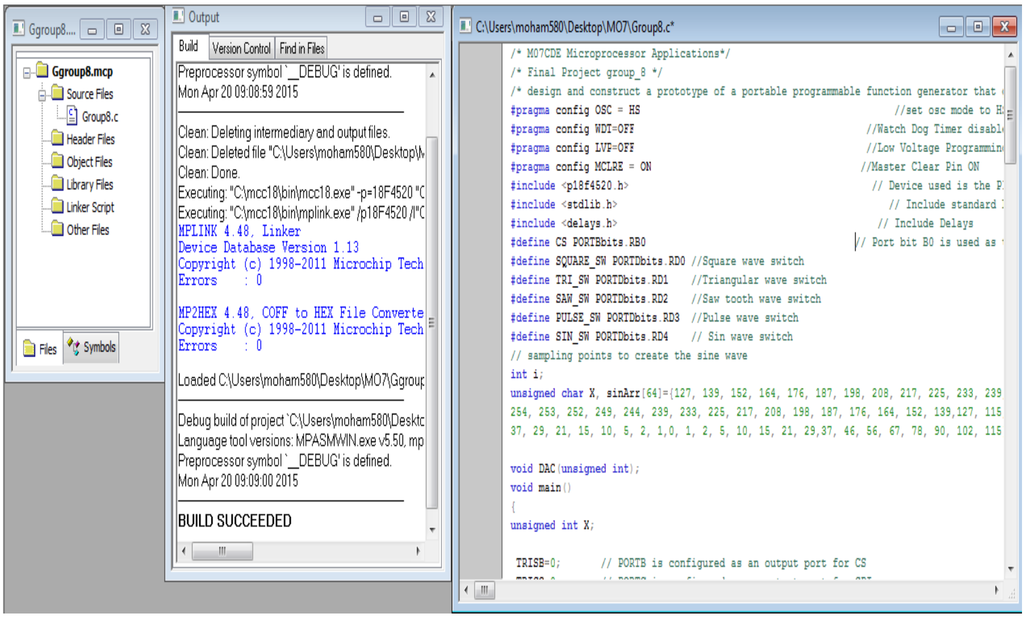
Hardware Components Requirements

TABLE1: HARDWARE COMPONENTS REQUIREMENTS

The name of components	The image of components
PIC 18F4520	
DAC 4921	
ICL 7660	
Rotary switch	
ICD3 compiler	
5V DC Supply source	
Bread board	
Connection wires	
Resistor 10 KΩ	
Oscilloscope	
Potentiometer	
Logic probe	

Testing the hardware

Firstly, we need to build the code in MPLAB software, as shown in figure 19 below:



```
Preprocessor symbol `__DEBUG' is defined.
Mon Apr 20 09:08:59 2015
----------------------------------------------------------------------
Clean: Deleting intermediary and output files.
Clean: Deleted file "C:\Users\moham580\Desktop\M
Clean: Done.
Executing: "C:\mcc18\bin\mcc18.exe" -p=18F4520 "C
Executing: "C:\mcc18\bin\mplink.exe" /p18F4520 /l"C
MPLINK 4.48, Linker
Device Database Version 1.13
Copyright (c) 1998-2011 Microchip Tech
Errors    : 0

MP2HEX 4.48, COFF to HEX File Converte
Copyright (c) 1998-2011 Microchip Tech
Errors    : 0

Loaded C:\Users\moham580\Desktop\MO7\Ggroup
----------------------------------------------------------------------
Debug build of project `C:\Users\moham580\Desktc
Language tool versions: MPASMWIN.exe v5.50, mp
Preprocessor symbol `__DEBUG' is defined.
Mon Apr 20 09:09:00 2015
----------------------------------------------------------------------
BUILD SUCCEEDED
```

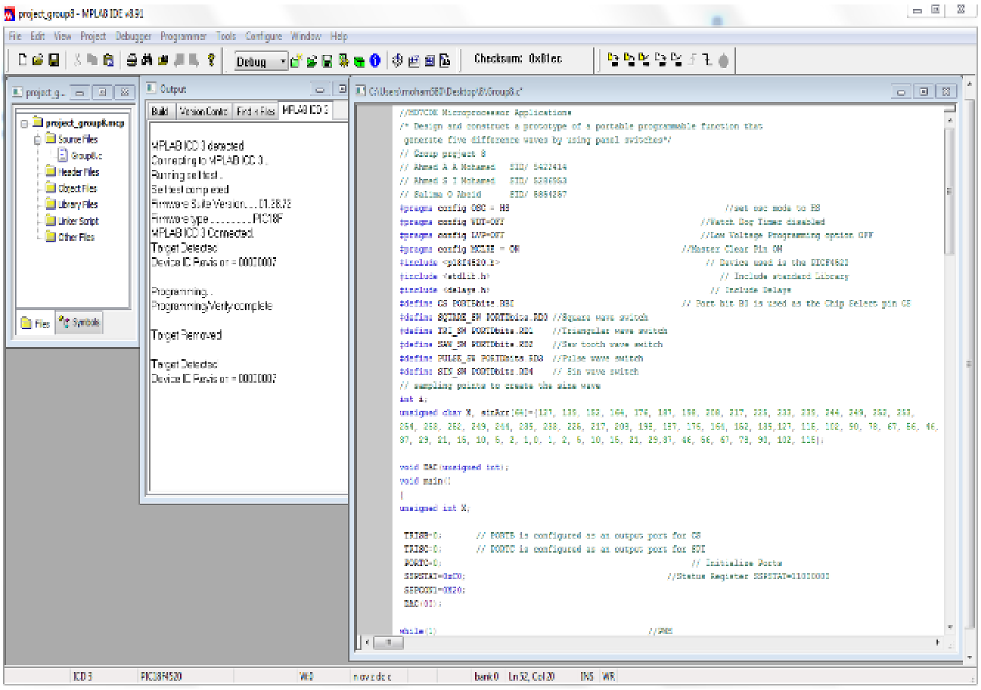
```c
/* M07CDE Microprocessor Applications*/
/* Final Project group_8 */
/* design and construct a prototype of a portable programmable function generator that 
#pragma config OSC = HS                                              //set osc mode to H
#pragma config WDT=OFF                                            //Watch Dog Timer disabl
#pragma config LVP=OFF                                            //Low Voltage Programmin
#pragma config MCLRE = ON                                        //Master Clear Pin ON
#include <p18f4520.h>                                              // Device used is the P
#include <stdlib.h>                                                  // Include standard 
#include <delays.h>                                                // Include Delays
#define CS PORTBbits.RB0                                     // Port bit B0 is used as 
#define SQUARE_SW PORTDbits.RD0 //Square wave switch
#define TRI_SW PORTDbits.RD1    //Triangular wave switch
#define SAW_SW PORTDbits.RD2    //Saw tooth wave switch
#define PULSE_SW PORTDbits.RD3  //Pulse wave switch
#define SIN_SW PORTDbits.RD4    // Sin wave switch
// sampling points to create the sine wave
int i;
unsigned char X, sinArr[64]={127, 139, 152, 164, 176, 187, 198, 208, 217, 225, 233, 239
254, 253, 252, 249, 244, 239, 233, 225, 217, 208, 198, 187, 176, 164, 152, 139,127, 115
37, 29, 21, 15, 10, 5, 2, 1,0, 1, 2, 5, 10, 15, 21, 29,37, 46, 56, 67, 78, 90, 102, 115

void DAC(unsigned int);
void main()
{
unsigned int X;

 TRISB=0;       // PORTB is configured as an output port for CS
```

Figure 6: The code is built successfully in the MPLAB

Secondly, we need to compile the code and download it to the PIC18F4520 by using ICD3 compiler, as shown below:



```
MPLAB ICD 3 detected
Connecting to MPLAB ICD 3 ...
Running self test ...
Self test completed
Firmware Suite Version.....01.28.72
Firmware type..............PIC18F
MPLAB ICD 3 Connected
Target Detected
Device ID Revision = 00000007

Programming...
Programming/Verify complete

Target Removed

Target Detected
Device ID Revision = 00000007
```

Figure 7: MPLAB window illustrates the code has downloaded to the PIC successfully

Thirdly, we need to connect whole the components. As shown below:

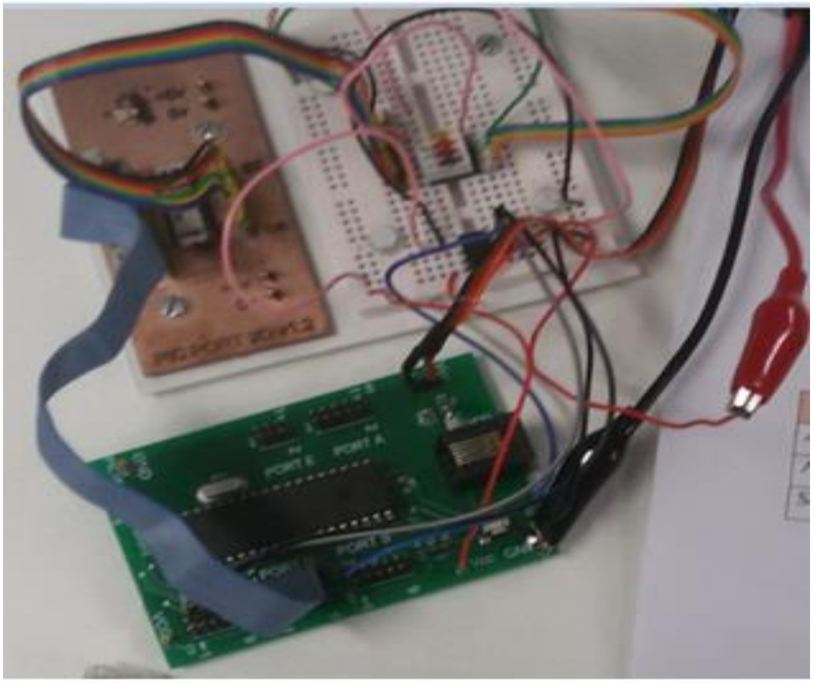


Figure 8: Final Hardware Circuit Connection

After connecting the whole components, we are going to use the five switches to check the results of the five waves on the Oscilloscope.

The Sine wave is selected by using switch (1) as shown on the screenshot below:

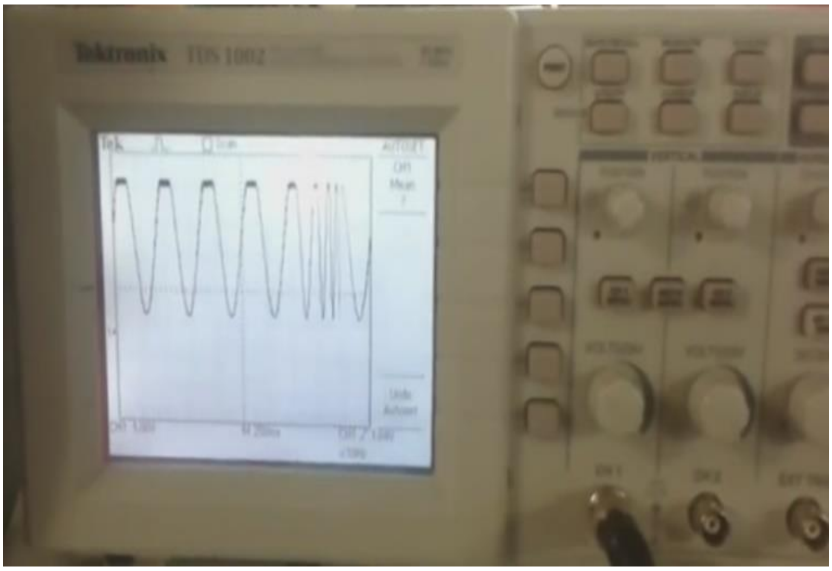
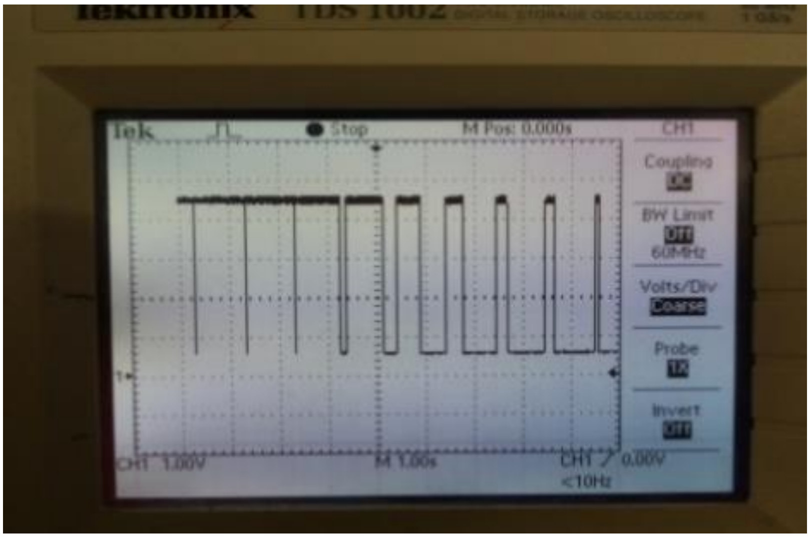


Figure 9: Sine wave

As illustrated in figure(22) above it can be seen that we can control the frequency of the Sine wave by using potentiometer
The Pulse wave is selected by using switch (2) as shown on the screenshot below:



M Pos: 0.000s
Coupling DC
BW Limit Off 60MHz
Volts/Div Coarse
Probe 1X
Invert Off
CH1 1.00V
M 1.00s
CH1 0.00V
<10Hz

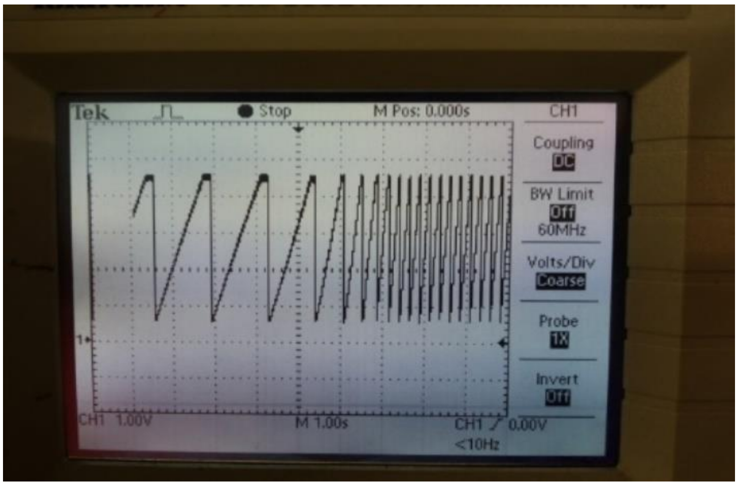
Figure 10: Pulse Wave

As illustrated in figure 10 above it can be seen that the frequency is fixed in the pulse wave, while we can change the duty cycle by using the potentiometer.
The Square wave is selected by using switch (3) as shown on the screenshot below:

M Pos: 0.000s
Coupling DC
BW Limit Off 60MHz
Volts/Div Coarse
Probe 1X
Invert Off
CH1 1.00V
M 1.00s
CH1 0.00V
<10Hz

Figure 11: Square Wave

As illustrated in figure 11 above it can be seen that the frequency of the square wave is adjustable by using potentiometer
The Sawtooth wave is selected by using switch (4) as shown on the screenshot below:



M Pos: 0.000s
Coupling DC
BW Limit Off 60MHz
Volts/Div Coarse
Probe 1X
Invert Off
CH1 1.00V
M 1.00s
CH1 0.00V
<10Hz

Figure 12: Sawtooth Wave

As shown in figure 12 above it can be seen that the frequency of the Sawtooth wave is adjustable by using potentiometer. The triangular wave is selected by using switch (5) as shown on the screenshot below:

Figure 13: Triangular wave

As illustrated in figure 13 above it can be seen that the frequency of the Triangular wave is adjustable by using potentiometer.

The Printed Circuit Board (PCB)

The material of the PCB is non-conductive. It has lines printed or deposited on the substrate, which is an insulating board. Single-layer, double-layer, and multi-layer PCBs are the three varieties available. ULTIBARD software is used in this project to create a double layer PCB that is based on a through hole.

The PCB Specification

The PCB is 40 by 40 mm in size, with two layers being used. The components required to design the circuit's PCB are listed in the following table. The final PCB design layout for the project, as shown in figure (13) below:

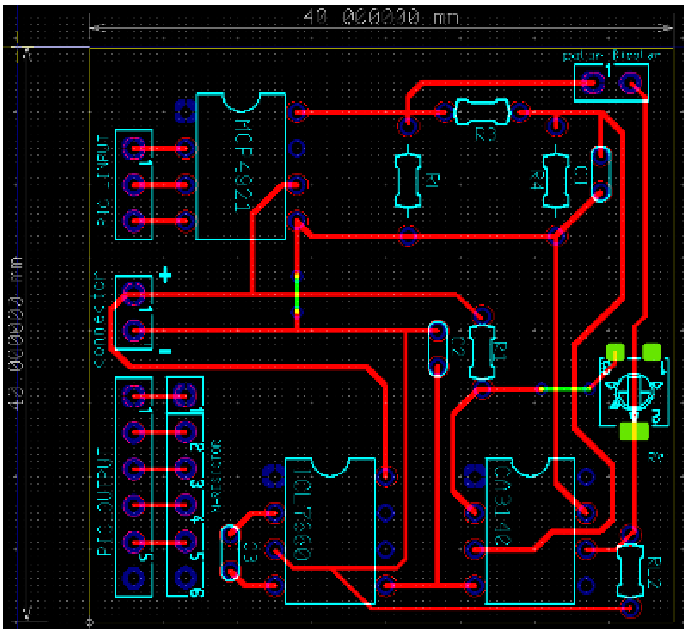


Figure 13: The layout of the PCB design

The 3D view of the top side of the PCB as illustrated in the figure (14) below:

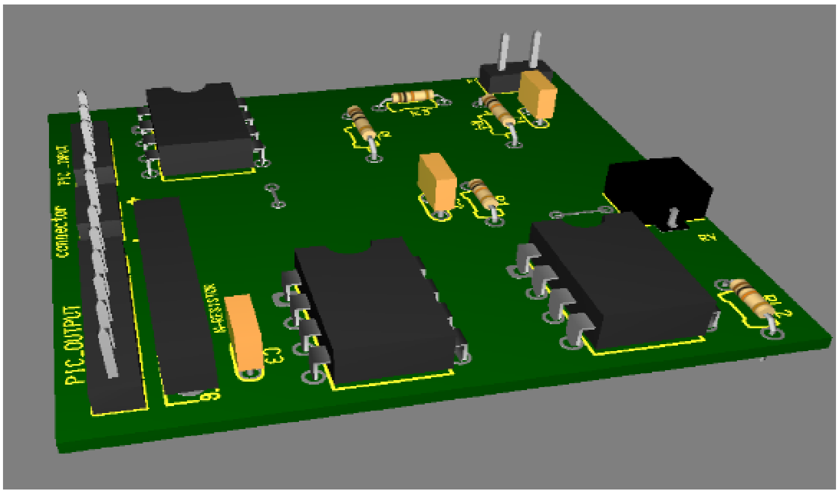


Figure 14: The 3D view of the top side of the PCB

Discussion of Results

The results obtained from both the simulation and hardware implementation confirmed the effectiveness of the designed **portable programmable function generator (PPFG)** in generating multiple waveform types with reliable accuracy and stability. The simulation stage in **Proteus** successfully demonstrated the production of sine, square, triangular, sawtooth, and pulse waveforms, all of which exhibited clean transitions and minimal distortion. During the hardware testing phase, the signals displayed on the **oscilloscope** closely matched the simulated results, indicating a high degree of correlation between the software model and the physical prototype. The **PIC18F4520 microcontroller** effectively controlled waveform selection and frequency adjustment through programmed logic, while the **MCP4921 DAC** provided smooth digital-to-analog conversion, producing stable voltage outputs. The **CA3140 operational amplifier** ensured signal amplification without introducing significant noise, and the **ICL7660 voltage converter** enabled the generation of both unipolar and bipolar outputs. The adjustable **potentiometer** allowed fine control of amplitude and frequency, confirming the flexibility of the design. Overall, the experimental findings validated that the proposed system can replicate the performance of conventional laboratory function generators at a fraction of the cost. Minor deviations in waveform linearity were observed at higher frequencies, which can be attributed to component tolerance and limited DAC sampling speed; however, these effects remained within acceptable ranges for educational and research purposes. Consequently, the developed PPFG prototype demonstrates a practical and efficient solution for low-cost waveform generation, offering an excellent balance between functionality, affordability, and portability.

Conclusion:

This study successfully demonstrated the design, simulation, and implementation of a portable programmable function generator (PPFG) based on the PIC18F4520 microcontroller. The developed system effectively generated five types of waveforms—sine, square, triangular, sawtooth, and pulse—with adjustable amplitude, frequency, and offset parameters. Through the use of Proteus software, the circuit was accurately simulated before hardware implementation, minimizing errors and ensuring efficient performance. The integration of the MCP4921 DAC, CA3140 operational amplifier, and ICL7660 voltage converter provided stable and precise analog outputs with the capability to switch between unipolar and bipolar modes. Experimental results showed a high correlation between simulation and hardware outputs, confirming the reliability and accuracy of the proposed design.

The developed PPFG offers a cost-effective, compact, and educationally valuable alternative to conventional laboratory function generators. Its portability and flexibility make it suitable for academic laboratories, electronic workshops, and research applications where affordability and practicality are essential. Future improvements may include the integration of a graphical user interface (GUI) for easier control, frequency display modules, and communication features such as USB or Wi-Fi connectivity to expand its functionality. Overall, this project proves that microcontroller-based digital systems can effectively replace traditional analog instruments, supporting the advancement of modern electronic education and experimental innovation.

Finally, in this stage we have applied PCB design by used Ultiboard software. The PCB is two layers and its size is (40 ×40 mm). The process of the PCB design was stated and the PCB budget components were illustrated by various resources.

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Compliance with ethical standards

Disclosure of conflict of interest

The authors declare that they have no conflict of interest.