Arbitrary Waveform Generator

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**Concept of Operations**

REVISION – 6

15 September, 2024

Concept of Operations

for

General Arbitrary Waveform Generator

Team <7>

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Prof. Kalafatis Date

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T/A Date

**Change Record**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Rev.** | **Date** | **Originator** | **Approvals** | **Description** |
| **1** | 8/21/24 | Dana Billman |  | Converted to Docs |
| **2** | 9/2/24 | Team 7 |  | Partial completion of data |
| **3** | 9/10/24 | Team 7 |  | Completion of data |
| **4** | 9/12/24 | Team 7 |  | Implement TA Feedback |
| **5** | 9/15/24 | Team 7 |  | Complete formatting |

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# Executive Summary

For our capstone project, we were tasked with creating an arbitrary waveform generator (AWG). A device that generates electrical waveforms used for electronic equipment testing. This project is significant due to the wide range of applications for AWG. The various signal waveforms created by the generator can be used for testing and development in electronics, telecommunications, and signal processing. The main goal of this project is to create a working AWG that can generate customizable waveforms through a mobile app. This feature will allow users to easily input and modify waveforms, making the device highly versatile and accessible. Key stakeholders include our project advisor and potential end-users such as engineers and researchers who will benefit from using the AWG in testing scenarios.

The major components of our AWG will consist of four subsystems:

* **An Android phone app:** This will serve as the user interface, allowing users to input and modify waveforms.
* **A microcontroller:** This will handle communication between the app and the hardware components.
* **An FPGA:** This will be used for the high-speed generation of the waveforms.
* **A PCB board:** This will house various IC components essential for signal processing.

The AWG is designed to be portable, making it suitable for use in engineering labs as well as at display tables during demonstrations.

**Assumptions and Constraints:** We assume access to necessary resources such as hardware components, development tools, and lab facilities. Constraints may include budget limitations and time constraints which could affect overall design and functionality.

**Potential Challenges:** Some challenges we anticipate include ensuring accurate signal generation at varying frequencies and seamless integration between the app and hardware.

In conclusion, if the AWG can successfully generate and display a user-input waveform from a phone app and adjust the output based on input frequency, we will have achieved our project objectives and delivered a functional AWG.

# Introduction

We are developing a general Arbitrary Waveform Generator (AWG) designed to produce a variety of customizable waveforms. This tool is essential for research and development in electronics, telecommunications, and signal processing. By testing various electronic systems and signal applications, we aim to explore and expand the potential uses of these devices, improving their adaptability in different scenarios.

## Background

The initial concept for this project was proposed by Dr. Wright, the original sponsor. His idea was to create a waveform generator specifically designed for use in MRI machines. In MRI technology, radio frequencies (RF) are used with precise timing and phase to generate images. Dr. Wright’s project aimed to allow waveform customization to accommodate different patients’ needs through an app. However, the project encountered difficulties and was not successful. Since, professor Lusher has adapted the original concept into a more versatile waveform generator. This updated version is designed for general use, rather than being specific to MRI applications. The current project focuses on showcasing a personalized AWG that can be applied in a variety of scenarios.

## Overview

The project will consist of an application that includes standard waveforms and a section to draw a waveform. Once the waveform is created, the user will input a frequency, and it will be converted into a file and sent to the microcontroller, this is safe on the hardware and will get converted from digital information to analog. A display will showcase the process currently being completed. Once ready, the wave generator can be connected to the oscilloscope and display two channels. These waveforms will repeat at the input frequency until changed or powered off.

A diagram of a computer program

Description automatically generated

Figure 1: High Level System Overview for AWG

## Referenced Documents and Standards

A diagram of a diagram

Description automatically generated

Figure 2: Project Timeline

Standards

|  |  |  |
| --- | --- | --- |
| Name | Min | Max |
| Frequency | 100kHz | N/A |
| Voltage | -5v | 5v |
| Memory | 16-bit | 16-bit |

Table 1: Project Requirements

Datasheet

|  |  |  |
| --- | --- | --- |
| Name | Description | Datasheet |
| ESP32-DEVKITC-VIE | ESP32-WROVER-IE 8MB FLASH | <https://docs.espressif.com/projects/esp-dev-kits/en/latest/esp32/esp32-devkitc/index.html> |

Table 2: Part Datasheet

|  |  |  |
| --- | --- | --- |
| ESP32-S3-WROOM-1-N16R8 | Bluetooth, WiFi 802.11b/g/n, Bluetooth v5.0 Transceiver Module 2.4GHz PCB Trace Surface Mount | <https://www.espressif.com/sites/default/files/documentation/esp32-s3-wroom-1_wroom-1u_datasheet_en.pdf>  <https://www.espressif.com/sites/default/files/documentation/esp32-s3-wroom-1_wroom-1u_datasheet_en.pdf> |

# Operating Concept

## Scope

For our arbitrary waveform generator (AWG), we have been provided with specific design parameters that guide the development process:

* **Frequency Range:** The AWG is required to operate with a minimum sampling frequency of 100 kHz, ensuring the capability to generate waveforms within this frequency range.
* **Amplitude Range:** The output amplitude of the AWG should be adjustable within a range of -5 V to 5 V, allowing for both positive and negative voltage outputs.
* **Waveform Types:** The AWG must be capable of producing the following waveform types: Sine Wave, Square Wave, Triangle Wave
* **Custom User-Defined Waveform:** The AWG will allow users to input and generate custom waveforms according to their specific needs.
* **Output Resolution:** The output waveform will be displayed on an oscilloscope, enabling precise visualization of the voltage output. The resolution must be sufficient to clearly represent the waveform shapes and ensure accurate monitoring of the generated signals.

This scope outlines the design specifications for our arbitrary waveform generator project. By adhering to these guidelines, we aim to deliver a functional AWG that meets the needs of our users and ensures that the final product will be both reliable and effective in its intended applications.

## Operational Description and Constraints

Our project will be used to output any wave desired by the user. The user can draw a picture of a period (for a periodic signal) or they can choose a basic signal (sine, square, triangle) and provide their desired amplitude and offset. The user will also be able to choose their desired frequency. However the voltage will be set at -5 to +5 and is not adjustable. The project budget limitations and time constraints will also affect the overall design and functionality.

## System Description

**Android App:** The app is designed to personalize waveforms by offering users three options: standard, special, and personalized. If the user selects the “personalized” option, they will be taken to a menu screen where they can draw their custom waveform on a graph with a vertical axis scaled from -5 to 5. The frequency for the waveform can be entered below the graph. An example of a custom waveform is illustrated in Figure 3 below. Once the waveform is drawn, the app will convert it into a series of samples, with each sample consisting of a sample number and its corresponding voltage. This data is then transmitted via Bluetooth to an ESP-32 microcontroller.

A graph with red and blue lines

Description automatically generated

Figure 3: Early waveform design

**Microcontroller:** The arbitrary waveform generator (AWG) system is primarily controlled and coordinated by the microcontroller. Acting as the system's brain, it controls communication between the FPGA, the DAC (Digital-to-Analog Converter) and the user interface (App). User input from the App interface is received and interpreted by the microcontroller via converting to files. It then decodes these commands to figure out what waveform to produce and how to set up the DAC and FPGA in accordance with that. To guarantee that the waveform is generated in accordance with the specified settings, it serves as a mediator between the user and the FPGA. This entire process will be utilized over a Bluetooth connection

**FPGA:** The FPGA serves as the central processing and control unit in the arbitrary waveform generator (AWG). Its primary role is to generate high-precision, programmable waveforms that are output as analog signals through a Digital-to-Analog Converter (DAC). The FPGA coordinates data storage, timing control, and waveform synthesis, leveraging both internal and external memory for waveform storage.

**PCB Board:** The PCB’s primary role is housing and connecting all the components. These components include the AC to DC converter, the microcontroller, the FPGA, and the digital to analog converter.

## Modes of Operations

Based on user requirements, the arbitrary waveform generator (AWG) can be operated in multiple modes, each of which offers a varying degree of control and functionality. The microcontroller and FPGA subsystems oversee managing these modes which are configured via the App interface. These are the following primary operational modes which are supported by the system:

* **Standard Waveform mode**: In this mode, the user can select from a set of predefined standard waveforms such as sine, square and triangle. These waveforms are generated directly within the FPGA, utilizing built-in digital waveform synthesis techniques. The parameters of the waveform, such as amplitude, frequency, and phase, can be adjusted through the App, which communicates the desired settings to the microcontroller. The microcontroller then configures the FPGA to output the corresponding waveform to the DAC, which converts it into an analog signal.
* **Custom Waveform Mode:** In this mode users draw a set of data points using the App to define their own arbitrary waveform. These data points show the intended waveform shape over the given time interval. After processing the incoming data, the microcontroller instructs the FPGA to produce the appropriate digital waveform. After that the digital output is converted into an analog signal by the DAC. This mode enables complete waveform design flexibility meeting the needs of applications requiring non-standard signals.

## Users

The arbitrary waveform generator (AWG) is intended for a wide variety of users that require specific and unordinary periodic electrical signals. The primary users of the AWG are engineers and technicians engaged in the design, development, and testing of electronics. The AWG is excellent for applications like circuit testing, system calibration, and assessing the performance of electronic components. It is necessary for the user to have a foundational understanding of signal processing, waveform theory, and signal generation to install and operate the AWG.

## Support

The arbitrary waveform generator (AWG) will come with a support manual to guarantee users have a seamless and effective experience. The manual will be made by the team to accommodate users with different technical backgrounds, such as students and engineers and will be created to provide help during the system’s installation and operation. The handbook will be sent out detailing the system's physical configuration including the FPGA, MCU and external device connections as well as the initial software installation for the App interface. Users with only rudimentary technical knowledge will be able to understand this guide thanks to its clear and simple writing style.

# Scenario(s)

## Case 1: MRI Machine

MRI machines require an arbitrary waveform generator (AWG) for magnetic resonance imaging. The waveforms produced by the AWG correspond to the RF pulses sent towards the body to generate the resulting image. Customization of the waveforms allows for various imaging techniques and sequences. Parameters are adjusted to improve resolution, target specific tissues, and tailor imaging to individual needs. The AWG works in conjunction with the gradient coils and signal detectors, enhancing the MRI’s system’s capabilities to generate more complex pulse sequences.

## Case 2: Electronics Research

AWGs are crucial to the validation of electronic circuits systems, where large amounts of electricity can produce distortion between components. They are used to simulate various conditions that occur within the systems. Including noise, distortion, and modulation schemes. This ensures that potential issues with electronic distortion are identified and addressed, leading to higher-quality results.

## Case 3: Telecommunications Testing

In situations where companies need to test the performance of new signal processing equipment, our AWG offers a valuable solution by generating complex waveforms and custom signals to simulate real-world scenarios. This allows engineers to evaluate how well their equipment handles various signal types, ensuring robust performance and reliability

## Case 4: Educational Purposes

In learning environments such as classrooms, electronics labs, even in live demos. Our AWG can be used as a teaching tool for people learning about waveform generation and signal processing. The intuitive mobile app interface allows students to experiment with basic and custom waveforms and modulation techniques easily, enhancing their understanding of signal generation concepts.

# Analysis

## Summary of Proposed Improvements

Our system focuses on an app that allows users to personalize their waveforms. It will have multiple options for standard waveforms, non-standard waveforms, and then a category for drawn waveforms. The drawn waveforms will include a high accuracy (16 bits) to ensure the user's input can be fully processed. A crucial improvement of our AWG is that it will be paired with an Android application that will allow the user to draw a picture of their desired period.

## Disadvantages and Limitations

Our system has balanced the processing time, power consumption, accuracy, and wave personalization. Our team will focus on the accuracy of the waveform with a maximum of 16 bits, as well as the personalization for the wave. As a result, the processing time and power consumption of our device will increase. Our waveform will be limited to a voltage of -5 to 5, and a minimum frequency of 100kHz. Our AWG will not include the ability to adjust the output in real time based on an input, such as a trigger from an oscilloscope

## Alternatives

Other arbitrary waveform generators will not have an Android application paired with the hardware to draw a picture of a period, and include different methods of obtaining the desired waveform from the user. Some alternatives include the feature to be either repetitive (periodic) or single-shot (one pulse only). Some AWG models include detection schemes to adjust the output in real time based on different kinds of measurement results obtained by signal demodulation, photon counting, or triggering with an oscilloscope.

## Impact

The implementation of our AWG will have significant impacts across several domains.

**Technical Impact:** One of the standout features of this arbitrary waveform generator (AWG) is its integration with a mobile application for data input. This innovative approach significantly enhances user experience by simplifying the process of waveform configuration and manipulation. The mobile app allows users more convenience and accessibility. Users can easily configure and control the AWG remotely via their smartphones or tablets. This eliminates the need for physical interaction with the device, making the system more accessible and user-friendly, particularly in lab environments where ease of use is crucial.

**Educational Impact:** The project has contributed to the technical and problem-solving skills of the team, particularly in digital circuit design, FPGA programming (using Verilog/VHDL), and signal processing. The detailed documentation and design methodology can serve as a learning tool for future students undertaking similar projects, enhancing their understanding of complex waveform generation and FPGA applications. Additionally, this project emphasizes the importance of debugging and iterative testing in electronic system design.

**Industry Impact:** The versatility of the AWG, with its ability to produce a wide range of arbitrary signals, opens up potential applications in various industries such as telecommunications, biomedical engineering (e.g., for ECG/EKG signal simulation), and electronics testing. By offering a cost-effective and adaptable tool, this project could lower the barrier for companies requiring specialized signal generation tools without the need for expensive commercial alternatives. Moreover, the modular nature of the design allows for future enhancements and adaptations for more complex industrial requirements.

**Ethical Impact:** We need to ensure that the design and software do not infringe on existing patents or intellectual property rights. This is achieved by implementing a phone app in tandem with the AWG. As a result, any potential issues of plagiarism in both hardware and software designs will be avoided.