team14m2

by 01fe21 bec154

School of
Electronics and Communication Engineering

Minor Project-2 Report

on

GPS Disciplined Oscillator

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SCHOOL OF ELECTRONICS AND COMMUNICATION ENGINEERING

CERTIFICATE

This is to certify that project entitled **"GPS Disciplined Oscillator"** is a bonafide work carried out by the student team of **"Tarun Divatagi (USN: 01FE21BEC196), Rahul Hegde (USN: 01FE21BEC219), Anirudh Nayak (USN: 01FE21BEC154), Rahul Katigar (USN: 01FE22BEI409)"**. The project report has been approved as it satisfies the requirements with respect to the mini project work prescribed by the university curriculum for BE (VI Semester) in School of Electronics and Communication Engineering of KLE Technological University for the academic year 2023-2024.

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ABSTRACT

The GPS, or Global Positioning System, is a worldwide system of navigation satellites used to establish the location of any target by measuring the time delay of signals transmitted from the satellites to the GPS receiver. GPS was initially designed for military use, such as positioning, navigation, and weapon targeting.

A GPS device is a receiver that picks up signals transmitted by Global Positioning System satellites. These satellites broadcast their location and precise time using atomic clocks. By measuring the time taken for the signals to reach the GPS receiver, the distance to each satellite can be estimated. When the receiver has information from at least four GPS satellites, it can use this data to determine its latitude, longitude, and elevation.

Our main goal is to minimize any potential inaccuracies in a GPS device, which works by receiving signals from satellites via the GPS Neo-6M module for data logging. To achieve this, our project focuses on collecting and storing GPS data to improve timing accuracy. We incorporate a PLL (Phase-Locked Loop) circuit that uses a 1 PPS (one pulse per second) signal as a trigger. This signal is generated by the GPS module and is used to synchronize the PLL circuit.The objective of the analysis is to improve the GPS data gathering procedure by carefully evaluating the two circuits and analyzing any possible variations. This project aims to refine the synchronization process, thereby enhancing the accuracy and precision of the timing in GPS data logging.

Keywords : GPS System,GPS Receiver,Timing inaccuracies,PLL circuit, GPS Data Gathering

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Chapter 1

Introduction

The Global Positioning System (GPS) is a network of 24 satellites orbiting the Earth that provide users with accurate location, velocity, and time information anywhere in the world. The system is composed of three segments: the space segment, which includes the satellites; the control segment, which monitors and manages the satellites; and the user segment, which includes GPS receivers that collect signals from the satellites.

In this project, we leverage the precise timing information provided by GPS to generate a one-pulse-per-second (1 PPS) signal, which is crucial for synchronization in various applications. We set up two identical systems, each with an Arduino UNO, a GPS module, and a Phase-Locked Loop (PLL) circuit. The Arduino processes the time data from the GPS module, generating a 1 PPS signal that is fed into the PLL circuit. By comparing the outputs from both systems, we aim to evaluate the accuracy and reliability of the GPS modules in generating synchronized timing signals. This comparison will provide valuable insights into their performance, especially for applications requiring precise time synchronization.

1.1 Motivation

The GPS is a navigation system that utilizes satellites to provide location and other information, and it is commonly used to track vehicles or objects with attached tracking devices. To ensure accurate positioning of these objects, a GPS receiver is necessary to receive data transmitted by multiple satellites using the NMEA protocol. The NEO-6M GPS module and Arduino are commonly used to extract latitude, longitude, and altitude data from GPS signals. However, there are various factors that can impact the transmission and reception of GPS signals as they travel from space to Earth.

In our project, we focus on the critical aspect of time synchronization using the 1 pulse-per-second (1 PPS) signal generated by GPS modules. This signal is vital for applications requiring precise timing, such as telecommunications, data centers, and navigation systems. By comparing two GPS-based systems generating 1 PPS signals, our motivation is to analyze the precision and consistency of these signals under different conditions. The integration of a GPS-disciplined oscillator with a phase-locked loop (PLL) circuit aims to enhance the accuracy and stability of the timing signals. This project seeks to minimize errors and improve the reliability of time synchronization in various technological and communication infrastructures, thereby contributing to advancements in research and applications that depend on precise timing.

1.2 Objectives

1. Extract a 1PPS (pulse per second) signal from a GPS module (NEO-6M).
2. Design and implement a frequency oscillator using a PLL (Phase-Locked Loop) IC.
3. Trigger the PLL circuit using the extracted 1PPS signal.
4. Accurately analyze the timing data obtained from the NEO-6M GPS sensor.

1.3 Problem statement

The aim of this project is to develop a sophisticated system that can accurately extract timing signals from a NEO-6M GPS module and utilize these signals to generate a precise 1PPS (pulse per second) signal. This 1PPS signal will serve as a triggering input for a Phase-Locked Loop (PLL) circuit, designed to function as a highly stable frequency oscillator. The project encompasses the design and implementation of the PLL circuit to ensure it can effectively lock onto the 1PPS signal, thereby maintaining synchronization and frequency stability. In addition, the system will be replicated to perform comprehensive analysis of timing errors and evaluate synchronization accuracy across multiple units. This analysis will verify the reliability and precision of the generated timing signals, ensuring they meet the requirements for high-accuracy timekeeping applications. Through this project, we aim to demonstrate the feasibility and effectiveness of using GPS-derived timing signals for precise oscillator control and synchronization.

1.4 Literature Survey

Boehmer and Bilén highlight the exorbitant expense of chip-scale atomic clocks while discussing the high-accuracy timing needs of sensor systems such as distributed wireless sensor arrays. Although they draw attention to the excessive power consumption of conventional GPS-disciplined oscillators, they investigate the use of GPS signals to discipline local oscillators for long-term stability. Their suggested solution, which uses only 45 mW and provides an accuracy of 5 µs RMS, is appropriate for low-power applications like the geoPebble system used in glacial reflectometry. [1]

Lombardi discusses the use of clocks and GPS-disciplined oscillators (GPSDOs) as time and frequency standards in metrology and calibration labs. These devices are essential in many different businesses because they are calibrated using GPS satellites to match Coordinated Universal Time (UTC). The study offers techniques for assessing GPSDO uncertainty and traceability, highlighting the measures' intrinsic correctness while also pointing out the difficulties in substantiating them to laboratory assessors. [2]

Lombardi et al.'s research describes the use of GPS signals in time and frequency metrology. It describes how to use GPS receivers as reference signals for time synchronization and frequency calibrations. It also covers how to measure different things, like carrier phase and direct reception. The way GPS signals provide traceability to national and international standards is also discussed. [3]

Using a temperature range of -40°C to +82°C and substantial vibration, McClelland et al. describe a rubidium (Rb) oscillator intended for demanding situations. With a GPS receiver input signal of one pps, this oscillator maintains lock by combining a quartz oscillator with vibration compensation based on a MEMS accelerometer. With less than 24 hours of time error accumulation, the device's quick warm-up and well-thought-out design elements improve performance under holdover conditions. [4]

Plumb and co-authors tackle the calibration challenges of geodetic-quality GPS receivers and their equipment for time transfer. They conducted tests using a dual-frequency GPS simulator and calibrated the antenna and cables with a vector network analyzer. Their findings show calibration stability within 1 nanosecond for pseudoranges on GPS frequencies, with results corroborated by in situ measurements and comparisons to other time transfer techniques. This calibration process ensures minimal errors and high precision in GPS-based time transfer.[5]

1.5 Organization of the report

The report is mainly divided into the following parts.

Chapter 1 : Introduction contains the information about the entire problem statement. It gives an insight about the different image quality metrics.

Chapter 2 : Description about the frame work followed and and flow of the project.

Chapter 3 : Implementation details contain a brief explanation about the methods and platform used during the project.

Chapter 4 : Optimization technique talks about the selected image quality analysis method and its justification

Chapter 5 : Results are discussed

Chapter 6 : Conclusion and future scope is discussed.

References provides the information about all the research papers used in the entire project. The basic and functional block of the proposed system and their explanation is detailed in the following chapter.

Chapter 2

GPS Data and Error Correction

Accurate localization is essential for navigation, and GPS modules may have different levels of positioning accuracy. The NEO-6M GPS module is used to collect raw NMEA data, including latitude, longitude and altitude values. However, this collected value is not highly accurate and contains errors. One of the major error causes is ionospheric error, resulting from the signal's interaction with free electrons in the ionosphere, which causes considerable refraction effects. The earth's surface and hardware errors during usage and manufacturing are also causes of error. These errors result in variations in the GPS positioning and methods to reduce such errors are employed.

Figure 2.1: NEO 6M GPS Module

NEO-6M GPS Module: The NEO-6M GPS module as shown in figure 2.1 is basically a receiver that receives signals sent by GPS satellites to pinpoint its location. The NEO-6M module has to be attached to an external antenna in order to receive signals from the GPS satellites. The NEO-6M module trilaterates the signals it has received in order to determine the location of the

GPS receiver. Trilateration includes calculating the distance to each satellite and timing the passage of GPS signals from the satellites to the receiver. When the NEO-6M module receives data from at least four GPS satellites, it may calculate its latitude, longitude, and elevation and output this data in the form of NMEA statements.

2.1 System design

2.1.1 Quantifying GPS signal occurrence error at trigger moment and analyzing arrival interval errors for precision assessment:

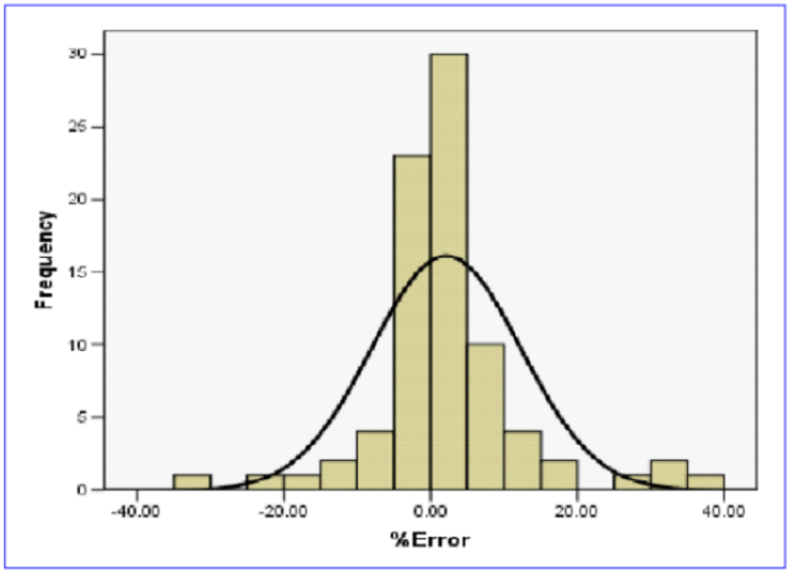

Figure 2.2: Example of Histogram.

It is important to analyse GPS signal trigger time or arrival interval inaccuracy since it helps to increase the precision of GPS positioning, navigation, and timing systems. It guarantees accurate and trustworthy location information for a variety of applications, including transportation, surveying, and time synchronisation, by comprehending and fixing these flaws.

The objectives of analyzing the trigger time or arrival interval error of GPS signals are to:

1. Identify and quantify the timing errors in GPS signals.
2. Understand the factors contributing to these errors, such as atmospheric conditions or satellite clock discrepancies.
3. Improve the accuracy and reliability of GPS positioning, navigation, and timing systems.

The scope of the analysis includes:

1. Collecting and analyzing data from GPS receivers.

Reference Time

1. The reference time used in this analysis is obtained from the Arduino Serial Monitor timestamp.
2. When the trigger time or arrival interval data for GPS signals was collected, the corresponding timestamp from the Arduino Serial Monitor was recorded as the reference time for each data point.
3. The Arduino Serial Monitor provides a time source that can be used as a reference due to its ability to provide timestamps with reasonable accuracy.

Steps to plot histogram:

1. Import Necessary Libraries: Incorporate the necessary libraries, such as Mat plotlib and NumPy, into the Python script to enable numerical calculations and data visualisation.
2. Prepare Data: Establish the "data" dataset variable, which will hold the numerical values that the histogram will display. Ascertain that the data is prepared correctly for analysis.
3. Generate Histogram Bins: To automatically identify the bin edges for the histogram based on the provided dataset, use NumPy's histogram bin edges function. For the data to be represented appropriately, this step is essential.
4. Create Histogram: To create a histogram, use the hist function in Matplotlib. As input parameters, supply the dataset and the calculated bin edges. As a result, the frequency distribution of the data will be represented visually.
5. Label and Display: Identify the histogram's x and y axes and give the reader some background. Additionally, give the histogram a title that expresses the main idea or concept. Finally, use Matplotlib's show function to see the resulting histogram.

This methodology offered our team an effective and accurate approach for extracting GPS time using the NEO 6M sensor, leveraging the precision provided by satellite signals. By logging the data in an Excel sheet, we ensured its organization and ease of analysis, particularly when dealing with a large dataset. The utilization of algorith to generate histogram has enabled us to narrow down the dataset to the most significant values for our analysis. Finally, by using Google Colab, we efficiently generated a histogram, enabling us to visualize the distribution pattern and facilitate the interpretation of the data's characteristics.

2.1.2 One PPS (Pulse Per Second):

1PPS stands for "One Pulse Per Second". It is a timing signal generated by a device, such as a GPS module, that provides a precise reference point for timing measurements. The signal consists of a single pulse that occurs once every second, which can be used to synchronize clocks, measure time intervals, and maintain precise timing in various systems.

The 1PPS signal as shown in figure 2.4 is commonly used in a variety of applications, such as telecommunications, navigation systems, and scientific experiments. In navigation systems, for example, the 1PPS signal can be used to synchronize a receiver's clock with GPS time, ensuring accurate location data. In telecommunications, the 1PPS signal can be used to synchronize the clocks of different network devices, ensuring that data is transmitted and received at the same rate. Overall, the 1PPS signal provides a precise reference point for timekeeping and synchronization, making it a critical component in many systems where timing is essential.

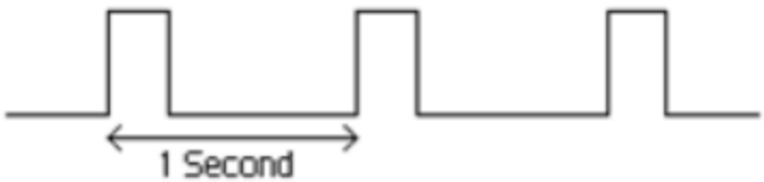

Figure 2.3: One PPS Signal

2.1.3 PLL as Oscillator

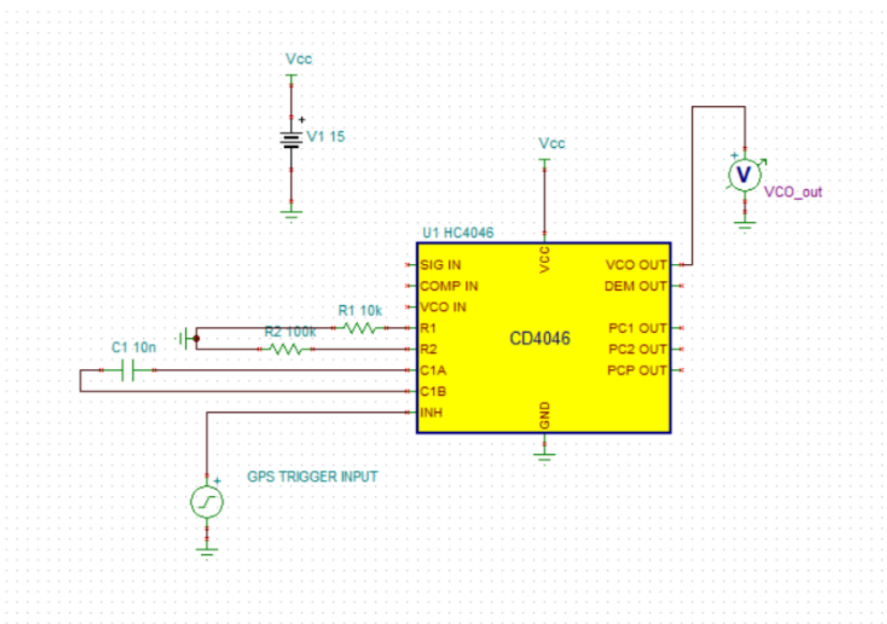

Figure 2.4: PLL Circuit Diagram

Voltage-Controlled Oscillator (VCO) integrated circuit, Phase-Locked Loop (PLL) design, CD4046. We are using the VCO independently in our setup to provide a constant frequency output in the absence of an external input signal. To obtain the desired oscillation, the connections and parts needed for this setup are carefully chosen.

The power supply connections are the most important first. The positive supply voltage, which might be +5V, +12V, or +15V depending on the demands of the particular application, is connected to the VDD pin (pin 16) of the CD4046; in our example, we utilize a +15V supply. To complete the circuit, the VSS pin (pin 8) is connected to the power supply's ground (GND).

After that, the components that determine frequency are attached to the corresponding pins. Pin 11 (R1) is connected to ground through a 10k resistor, and pin 12 (R2) is connected to ground through a 100k resistor. Additionally, a 10nF capacitor is placed between pins 6 (C1A) and 7 (C1B). These components collectively determine the oscillation frequency of the VCO.

Pin 4 (VCO OUT) provides access to the VCO's output. To measure and see the frequency that is created, attach an oscilloscope or frequency counter to this pin. Pin 5, often known as the INHIBIT pin, is essential for managing the VCO. The VCO can oscillate because this pin is connected to ground, which activates the VCO. The oscillation is stopped if the INHIBIT pin is left unconnected or is coupled to a high voltage, deactivating the VCO.

2.1.4 Calculation for PLL Circuit

The external resistors and capacitor attached to the pins of the VCO of the CD4046 control its operation. The values of the resistors R1 and R2, the capacitor C1 and the resistor R2 define the frequency f_{VCO} , which is created by the VCO, using the following formula:

$$f_{VCO} = \frac{1}{2.2 \cdot R1 \cdot C1} + \frac{R2}{2.2 \cdot R1 \cdot R2 \cdot C1}$$

The formula to calculate the time period is

$$t = \frac{1}{f}$$

Where F: Frequency of the circuit (measured in Hertz)
R1: Resistance of the first resistor (measured in Ohms)
R2: Resistance of the second resistor (measured in Ohms)
C1: Capacitance of the first capacitor (measured in Farads)
T: Time period of the circuit (measured in seconds)

The VCO will begin oscillating as soon as the circuit is switched on and configured, resulting in a square wave output at pin 4. The interactions between the connecting resistors and capacitor determine the frequency of this output. Software like TINA-TI may be used to simulate the circuit and observe the time-domain response by doing a transient analysis in order to confirm the functioning. After accounting for any small component tolerances, the observed frequency should nearly match the theoretical value that was estimated.

2.1.5 CD 4046 PLL IC

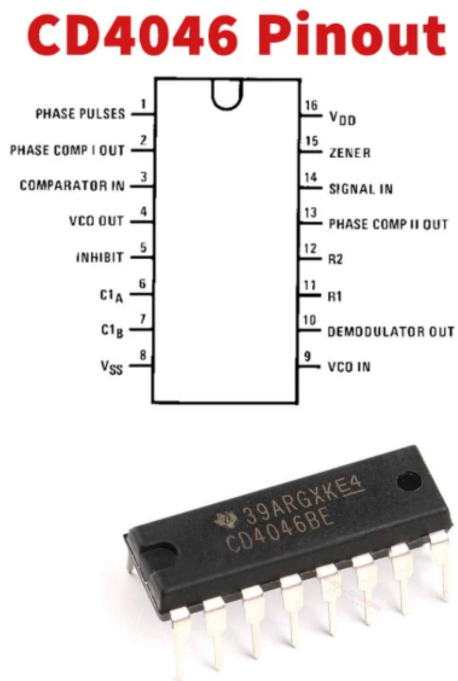

Figure 2.5: PLL IC

The CD4046 is a versatile Phase-Locked Loop (PLL) integrated circuit that includes a Voltage-Controlled Oscillator (VCO) and two phase comparators. It is widely used in various applications such as frequency synthesis, modulation, and demodulation, and frequency multiplication or division. The IC is known for its flexibility, low power consumption, and the ability to operate over a wide range of supply voltages.

2.1.6 Functional Block Diagram

The system starts with the NEO 6M GPS Module, which receives and extracts the NMEA data from GPS satellites. This data includes the precise timing information required to generate a 1 PPS signal.

The Arduino Uno processes this NMEA data, extracting the timing information. When the timing information indicates the start of a new second, the Arduino generates a 1 PPS trigger signal. This trigger signal is essential for ensuring that the rest of the system remains synchronized with the GPS time.

The PLL Frequency Synthesizer receives the 1 PPS trigger signal from the Arduino. It uses this signal to lock its output oscillations to the precise timing provided by the GPS data. This ensures that the output frequency is highly accurate and synchronized with the GPS timing.

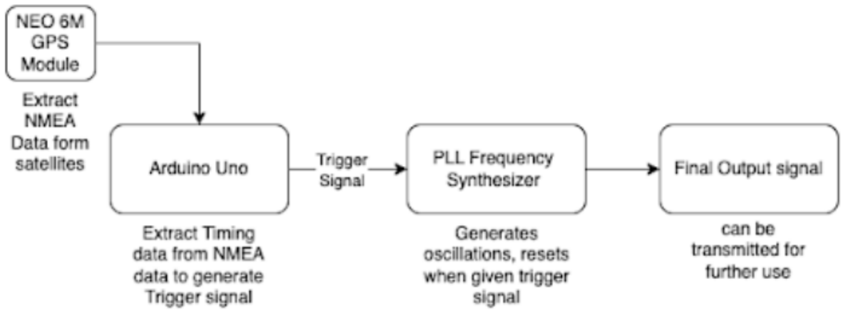

Figure 2.6: Block diagram for GPS based timing system

Finally, the Final Output Signal from the PLL is available for further use. This signal can be used in any application requiring precise timing, such as synchronization of systems, time-sensitive communications, and other high-accuracy timing applications.

Chapter 3

Implementation details

3.1 Specifications and final system architecture

1. **Hardware and software requirements**: GPS Neo-6 module, Arduino UNO, Digital oscilloscope, wires, breadboard, power supply, resistors, capacitors, and other passive components required for the circuitry and interface. Software required are Arduino IDE, TinyGPS Library.
2. **System design and architecture diagrams**
   (a) **GPS Neo-6 module**: The module will be the primary component for receiving GPS signals.
   (b) **Arduino board**: It will be used to interface with the GPS module and process the received data.
   (c) **Digital oscilloscope**: It will be used to measure and visualize the output of the oscillator circuit.
3. **Input/output specifications:**The GPS Neo-6m module provides NMEA statements with GPS time information to the Arduino board through the serial UART interface. The Arduino board will process the GPS time data also generates a 1pps signal. This 1pps will be input for Phase lock loop circuit and output of two oscillator circuit will be compared and visualized using a digital oscilloscope.

3.2 Algorithm

1. **Setup Initialization**:
   (a) **T**he Serial Monitor at a baud rate of 57600.
   (b) **T**he GPS module's serial communication at a baud rate of 9600
   (c) The pin for the 1PPS signal (ppsPin) as an output and ensure it starts low.
2. **Main loop**:
   (a) Clear any remaining data in the GPS module's serial buffer.
3. **Reading GPS Data**:
   (a) Check for the presence of the GPRMC, string in the incoming GPS data stream.
   (b) If found, read the remaining NMEA sentence until the newline character.

(c) Parse the NMEA sentence by splitting the string at each comma and store the values in the nmea array.

(d) Update the updates counter.

(e) Convert latitude and longitude from NMEA format to decimal degrees using ConvertLat and ConvertLng functions.

(f) Print the parsed GPS data (Time, Status, Latitude, Hemisphere, Longitude, Hemisphere, Speed, Track Angle, Date) to the Serial Monitor.

4. **Generate 1PPS Signal**:

(a) Check if the time (nmea[0]) has changed from the last read.

(b) If the time has changed, call generatePulse to create a 1PPS pulse on ppsPin and update the lastTime.

(c) Record the current timestamp using recordTimestamp.

3.3 Flowchart

The flowchart begins with the initialization of the GPS module NEO-6M, which is crucial for starting the reception of signals from GPS satellites. Once the module is initialized, the system continuously checks for the receipt of the GPS signal. Upon successful reception, the system gathers precise timing data from the GPS module, specifically focusing on the 1PPS (Pulse Per Second) signal. This 1PPS signal, which provides a highly accurate timing reference, is then used as a trigger for further processing.

The trigger signal from the 1PPS is directed to the 4046 PLL (Phase-Locked Loop) oscillator circuit. This circuit uses the precise timing provided by the 1PPS signal to generate a high-frequency oscillation that is synchronized with the GPS timing. The behavior of the PLL circuit is dictated by the edges of the pulse: during the rising edge, the circuit is pulled down to ground, and during the falling edge, the circuit resets. This mechanism ensures that the oscillations are accurately timed according to the GPS signal. The output from the PLL oscillator circuit is then displayed on a digital oscilloscope, which allows for visual analysis and verification of the signal's timing and frequency characteristics. This display is the final step in the process, confirming the accurate synchronization and functioning of the system.

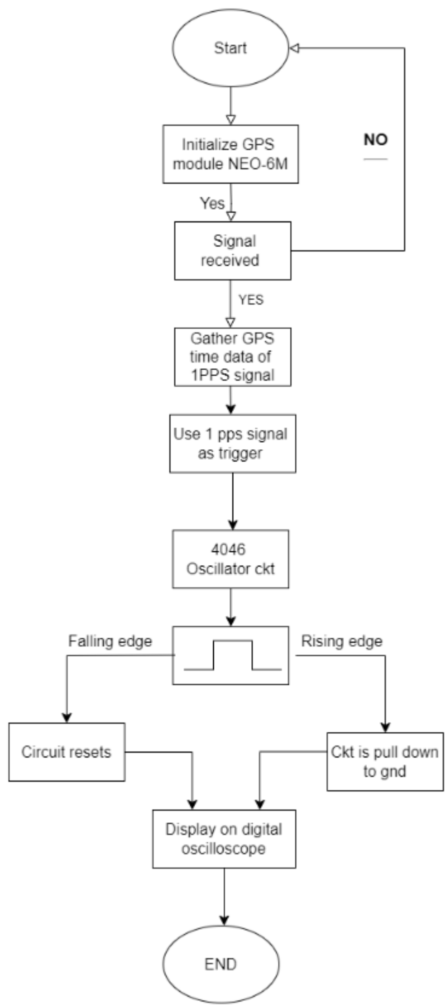

Figure 3.1: Flowchart for GPS based timing system

Chapter 4

Results and discussions

In this section we discuss about the result obtained from the GPS module, the output of PLL circuit and also the results after integration of these two systems. The hardware setup involved using an Arduino Uno to extract the 1PPS signal from a NEO-6M GPS module. For the PLL frequency synthesizer, a CD4046 IC was utilized.

4.1 GPS System Output

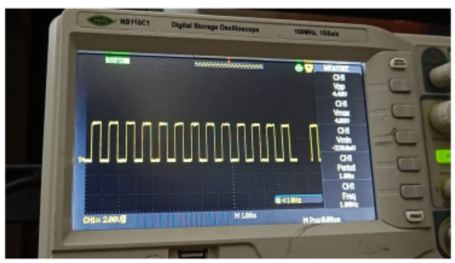

Figure 4.1: 1pps output waveform in Digital storage oscilloscope

The oscilloscope image shows a 1 Hz square wave generated by the Arduino algorithm. The signal has a peak-to-peak voltage (Vpp) of 4.48V, a maximum voltage (Vmax) of 4.86V, and a minimum voltage (Vmin) of -328.9mV. The period of the wave is 1.0s, indicating that the generatePulse function is correctly producing a pulse on the ppsPin every second. This confirms the Arduino code is functioning as intended, generating a precise 1PPS (one pulse per second) signal.

4.2 PLL System Output

The CD4046 Phase-Locked Loop (PLL) integrated circuit was employed as a frequency synthesizer to generate a stable 2.5 MHz frequency signal. The PLL operates by locking the phase of the output signal to the phase of a reference signal, ensuring high precision and stability. The output waveform was observed and verified using a Digital Storage Oscilloscope (DSO), confirming the successful generation of the desired 2.5 MHz signal. The DSO capture shows a clear and stable sinusoidal waveform, indicating the effective performance of the CD4046 IC in frequency synthesis applications. The consistent frequency and amplitude of the signal demonstrate the reliability of the setup for applications requiring precise frequency generation.

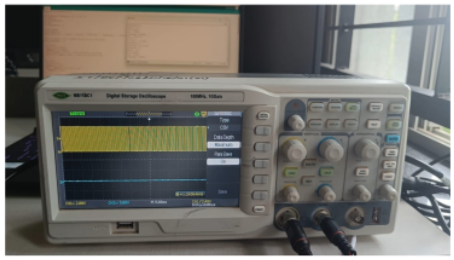

Figure 4.2: PLL frequency synthesizer output in DSO

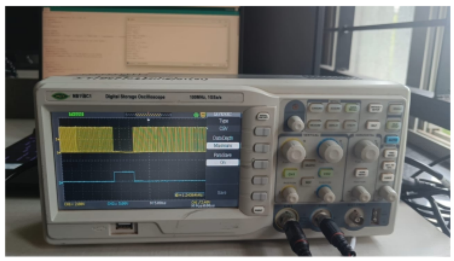

Figure 4.3: Yellow waveform indicates the oscillations of the 1pps and the blue waveform indicates GPS sensor .

The 1PPS signal extracted from the GPS module was used as a triggering input to the PLL, ensuring synchronization with the GPS's accurate timekeeping. On the rising edge of the 1PPS signal, the circuit is pulled to ground, effectively resetting the PLL. This synchronization ensures that the PLL's oscillations restart on the falling edge of the 1PPS signal, maintaining the accuracy and stability of the generated 2.5 MHz frequency signal. This integration of the GPS-derived 1PPS signal with the PLL circuit enhances the overall precision of the frequency synthesis, providing a robust solution for applications requiring high timing accuracy.

Chapter 5

Conclusion

This project successfully demonstrates the development and implementation of a GPS-based timing system using the NEO-6M GPS module and Arduino Uno. By extracting precise timing information from GPS satellites, we generated a reliable 1 PPS (Pulse Per Second) signal to trigger a PLL (Phase-Locked Loop) frequency synthesizer. The comparative analysis of two setups, each using different GPS modules, provided valuable insights into the performance and error margins of GPS-disciplined oscillators. This project underscores the importance of precise timing in modern technology and highlights the potential of GPS technology in achieving high-precision timing solutions. The findings and implementation offer a foundation for further advancements in GPS-based timing and synchronization, ensuring improvements in accuracy and reliability across various applications.

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