Doppler Wheel for Emulation of Automotive Radar Target
Abstract

Automotive radar is an emerging field of research and development. Technological advancements in this field will improve safety for vehicles, pedestrians, and bicyclists, and enable the development of autonomous vehicles. Usage the Automotive radar are expanding in car and road areas to reduce collisions and accident. Automotive radar developers face a problem to test their radar sensor in the street, since there are a lot of interferences signals, noise and unpredicted situations. This thesis provides a part of solution for this problem by designing a device can demonstrate a different speeds value. This device will help the developer to test their radar sensor inside an anechoic chamber room that provides accurate control of the environmental conditions. This report shows how to build the measuring setup device, step by step to demonstrate the people and vehicle’s speed in the street by a Doppler emulator using the wheel for millimetre FWMC radar. Linear speed system needs a large space for testing, but using the rotational wheel allow the developer to test the radar sensor in a small area. It begins with the wheel design specifications and the relation between the rotational speed (RPM) of the wheel and the Doppler frequency. The Doppler frequency is changed by varying the speed of the wheel. Control and power circuit was carefully designed to control the wheel speed accurately. All the measuring setup device parts were assembled in one box. Also, signal processing was done by MATLAB to measure the Doppler frequency using millimetre FMCW radar sensor. The measuring setup device was tested in the anechoic chamber room for different speeds. the manual and automatic tests show good results to measure the different wheel speeds with high accuracy.
Project Reference

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**Project name:** Combined Radar-Based Communication and Interference Mitigation for Automotive Applications Funded by Vinnova FFI.

The project will focus on developing expertise in the area of joint radar and communication as well as the realization of a demonstrator. Moreover, the project will provide inputs to regulatory bodies for future radar standards in the 60 GHz band. The project will last for 2 years and will be coordinated by Chalmers University of Technology and includes as academic partner Halmstad University and as industrial partners Volvo Car Corporation (Volvo Cars), Autoliv, QAMCOM, and SAAB.

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<thead>
<tr>
<th>Acronym</th>
<th>Full Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC</td>
<td>Alternating Current</td>
</tr>
<tr>
<td>ADC</td>
<td>Analog-to-Digital Converter</td>
</tr>
<tr>
<td>CMOS</td>
<td>Complementary Metal–Oxide–Semiconductor</td>
</tr>
<tr>
<td>CW</td>
<td>Continuous Wave</td>
</tr>
<tr>
<td>DC</td>
<td>Direct Current</td>
</tr>
<tr>
<td>FFT</td>
<td>Fast Fourier Transform</td>
</tr>
<tr>
<td>FM</td>
<td>Frequency Modulation</td>
</tr>
<tr>
<td>FMCW</td>
<td>Frequency Modulated Continuous Wave</td>
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<tr>
<td>FT</td>
<td>Fourier Transform</td>
</tr>
<tr>
<td>IC</td>
<td>Integrated Circuit</td>
</tr>
<tr>
<td>IF</td>
<td>Intermediate Frequency</td>
</tr>
<tr>
<td>ITS</td>
<td>Intelligent Transportation Systems</td>
</tr>
<tr>
<td>LCD</td>
<td>Liquid Crystal Display</td>
</tr>
<tr>
<td>PC</td>
<td>Professional Computer</td>
</tr>
<tr>
<td>PCB</td>
<td>Printed Circuit Board</td>
</tr>
<tr>
<td>PWM</td>
<td>Pulse Width Modulation</td>
</tr>
<tr>
<td>RF</td>
<td>Radio Frequency</td>
</tr>
<tr>
<td>RPM</td>
<td>Revolutions Per Minute</td>
</tr>
<tr>
<td>RX</td>
<td>Receiver</td>
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<tr>
<td>SNR</td>
<td>Signal to Noise Ratio</td>
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<td>TX</td>
<td>Transmitter</td>
</tr>
<tr>
<td>UART</td>
<td>Universal Asynchronous Receiver-Transmitter</td>
</tr>
<tr>
<td>USB</td>
<td>Universal Serial Bus</td>
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<tr>
<td>UWB</td>
<td>Ultra-Wideband</td>
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<td>Symbol</td>
<td>Description</td>
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<td>----------</td>
<td>---------------------------</td>
</tr>
<tr>
<td>$\nu$</td>
<td>Linear velocity</td>
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<td>Radial speed</td>
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<td>$R$</td>
<td>Radius</td>
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<td>$\lambda$</td>
<td>Wavelength</td>
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<td>Speed of light</td>
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<td>Frequency</td>
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<td>Voltage</td>
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<td>Resistance</td>
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<td>Flux</td>
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<td>Average voltage</td>
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<tr>
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<td>Beat frequency</td>
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<tr>
<td>$f_{bd}$</td>
<td>Beat frequency from down chirp</td>
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<tr>
<td>$f_{bu}$</td>
<td>Beat frequency from up chirp</td>
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Chapter 1
Introduction

Radar sensor used in many applications nowadays, especially in cars and roads to prevent collisions and save people lives. Developing radar sensors are required to improve the safety-relevant systems. This chapter talking about the problem that faces the radar developer, and the thesis contributions to solving this problem. Also, the outline of the thesis shows the project block diagram and the report organization as well.

1.1 Background

Driving a car is a dangerous task! There are too many fatalities every year because of car accidents. Human beings have many limitations in the ability to precisely measure the distance and the difference of speeds between the cars which results in high accident rates [1].

Speeds between the cars can be measured using Millimeter-wave frequency-modulation continuous wave (FMCW) radar. This type of radar has been more commonly used in safety-relevant systems over the past decade because of its simplicity in system architecture, small system components and high-frequency reuse features. Moreover, it can also be used in adverse weather conditions. The FMCW technique enables information regarding the range and relative velocity of multiple targets to be easily obtained by estimating the corresponding range and Doppler beat frequencies. These advantages of the millimeter-wave FMCW radar make it a favorable candidate for automotive applications; therefore, an increasing number of intelligent transportation systems (ITSs) such as adaptive cruise control, blind-spot detection, and lane-change assistance have been developed. render the millimeter-wave FMCW radar a promising candidate for automotive applications [2-9].
1.2 Problem statement

Automotive radar such as FMCW radar plays an important role to prevent accidents and save people lives, because of that developing this radar technology is required to increase the radar ability to measure different persons and vehicles speeds on the road. Developing radar sensors technology required a perfect testing environment for testing the radar sensor, and that cannot be done in the real street because it has a different problem like noisy environment and interfering signals, and that makes hard to test the radar sensor feature because it is already under development. The best solution for the developer to test their radar sensor is making the test inside the anechoic chamber room because they have the ability to control the environment of testing as they want. But still need some kind of device that can demonstrate the different objective speeds on the street, instead of using real cars and persons.

1.3 The goal of this Thesis

The main goal of this thesis is to design and fabricate a small device that can demonstrate a different speed of the people and vehicles on the street. This device will help the developer to test their radar sensor in the anechoic chamber room with the ability to demonstrating any speed in the range from 3m/s to 10m/s with high accuracy and without needs to any additional tools. This Measurement setup device designed in this thesis has different advantages like:

- The ability to demonstrate different real speed using the Doppler effect.
- The device has a small size so it easy to use in camber room.
- High precision speed demonstration with 0.6% average error.
- The device can be controlled manually or by PC for automotive measurements.
1.4 Previous studies

Because of the millimetre wavelength radar sensor is started to be used recently in safety applications, there are few studies of Doppler emulator designs. One of these studies has used the Measured Doppler spectra of tracked and wheeled vehicles to guide the development of moving target emulators, made from "switchable" reflectivity panels. The geometry of the panels was electrically percolating surfaces. The percolating patterns provided 10:1 bandwidth, satisfying ultra-wideband radio UWB criteria for frequency response with minimal modulating elements. A potential problem is a number of modulating elements on a panel that are required to synthesize the complex Doppler waveform measured on a ground vehicle [10]. This emulator design is working perfectly for a few of GHz frequency, but when it goes to high-frequency radar sensor (more than 20GHz) it will not be working perfectly anymore, because the wavelength in the high-frequency radar sensor is in millimetre scale. That is mean small vibration in the device will cause a big shift in the reflected signal. And that what has been taken into consideration in this thesis work.

Another study used the Elementary electronics building blocks as a low-cost baseband Doppler simulator for developing the post-detector processing parts of millimetre wave pulsed radars, employing amplitude and phase channels. Narrow pulses converted to low Doppler frequencies by CMOS switches and normal function generator ICs [11]. The similar technique used in another research to generate a fake doppler effect, an electronic component used to change the received intermediate frequency and transmitted it back to the radar sensor [12-14]. These studies succeeded to simulate the Doppler effect for different speeds values using an electronics component to generate a fake doppler effect, but it is not taking the mechanical structure of the target in the account. Reflected signals interference - as will explain later - can be constructive or destructive interference, due to the reflection of the signal from different parts of the same target. The emulator device designed in this thesis has a real movement wheel part generate a real doppler frequency, so the reflected signals are actually reflected from different parts of the wheel and can demonstrate the constructive interference as well.
1.5 Thesis outline

1.5.1 Project block diagram

A block diagram, shown in figure 1.1 illustrates the basic structure of all parts, worked in this thesis. The signal processing commands using MATLAB program will contact the speed controller circuit and sending the required speed data to it. Also, it will collect data from the radar sensor by a serial communication using UART protocol. Speed controller circuit will control the DC motor using a PWM signal. Also, it will measure the DC motor feedback sensor for closed-loop control. The Radar sensor transmitted 60 GHz signal and the received echo signal reflected from the circular plate in the DC motor. Subsequently, the data is sent to MATLAB to go through signal processing code to estimate the circular plate speed.

Figure 1.1: Project block diagram.
1.5.2 Project parts

Figure 1.2 shows the different parts of the system

1. Doppler emulator Measurements setup device.
2. Radar sensor.
3. MATLAB program.

![Figure 1.2: All project parts.](image)

1.5.3 Project steps achievements

In the beginning, information about the project was collected, followed by studying the theoretical principle behind the project idea with project supervisor. Then the electronics circuit was designed and simulated. Afterwards, the microcontroller firmware programming code was written using C programming language. Later, the schematic and the layout designed using OrCAD program. Subsequently, the electronic board was fabricated and the whole Doppler emulator measuring setup device assembled together in one box. At the end of the first task, the emulator device was testified successfully. The next task was to write a MATLAB code that connects the radar sensor and the emulator device, to measure the Doppler frequency. Finally, the system tested and the speed measurement were done in the anechoic chamber room successfully.
1.5.4 Report Organization

This report consists of five chapters. Introduction chapter defines the problem statement and the thesis solution. The methods that thesis follow to solve the problem discourse in chapter two and three. The measurement setup device has been discussed in chapter two including, the wheel design and the circuit design (both control and power system design). The radar and the signal processing have been studied in chapter three including, the working principle of radar, FMCW radar, the target range and the velocity calculations. Chapter four covers the Result and discussion of the whole system testing and system accuracy calculations. At the end of this report, the conclusions and the future outlooks have been provided.
Chapter 2
Measurement Setup Device

2.1 Circular wheel

It is very hard to use a linear speed measuring tool, to demonstrate the objects speed. It is need a large space to move. Also, does not give the accurate measurement due to the distance limitation of movement, and different acceleration due to the start and the stop procedures. The circular wheel is shown in figure 2.1 using to solve these problems and get more realistic results.

![Circular wheel](image)

**Figure 2.1:** Doppler emulator wheel.

The idea of introducing this measurement tool is the potential ability to measure a continuous object’s movements in a small space without any linear movement. Also, it can show the different linear speed $v(m/s)$ by varying the radial speed $\omega(RPM)$ of the wheel. Using the below formula 2.1 for converting from RPM to m/s.

$$v = \frac{2\pi R \omega}{60}$$  \hspace{1cm} (2.1)
Where $v$ is the linear velocity (m/s), $\omega$ is the revolution per minute (RPM) of the circular plate, and $R$ is the radius of the circular plate. Many things need to be considered during the design of this wheel.

### 2.1.1 Material and dimensions

One of the successes keys for this demonstration is to have a good interaction between the radar sensor and the wheal. To be sure that this will happen, the wheal material should be made from high reflector material such as aluminium, leading to increase the signal to noise ratio SNR. Also, it should have a small diameter so it can be in the far field regime, in just a few meters away from the radar sensor. As shown in figure 2.2, the wheal diameter is 10 cm and with 3 cm thickness.

![Figure 2.2: Circular wheel dimensions.](image)

### 2.1.2 Increasing target cross section

Strengthen of the echo signal depends on wave interference phenomena and the phase shift between the interferer signals. Wave interference occurs when two waves meet while travelling along with the same medium. Which, it means that they can be in the same place at the same time. The amplitudes of the waves can simply be added together.
Interference is referred to the interaction of waves which have constant phase difference and the same frequency.

Constructive wave interference is a wave interference which occurs when two in-phase waves with the same frequency meet at the same place at the same time. The amplitudes of the two waves are simply added together. The resultant wave amplitude is greater than that of the original waves. In figure 2.3 the two interference waves are the blue and green, and the result of the interference is the red colour wave. The number one represents two waves in the same phase, and the result is the same frequency wave but with double amplitude. The case number two represents two waves with a 90-degree phase shift ($\lambda/4$), and the resultant wave is the same frequency and the same amplitude. Wave interference can have the same or higher amplitude if the phase shift between the two signals from 0 to 90 degree (0 to $\lambda/4$), or from 180 to 270 degree ($\lambda$ to $3\lambda/4$).

![Figure 2.3: Wave interference illustrating graph (1-2) constructive interference. (3-5) Destructive interference.](image-url)
Destructive wave interference occurs when the two wave signals meet in out of phase, forming a new wave with lower amplitude or zero amplitude as shown in figure 2.3. The interference wave can have lower or zero amplitude if the phase shift between the two signals is in the range of 90 to 180 degree or from (λ/4 to λ/2), or from 270 to 360 degree (3λ/4 to λ).

As previously explained, the constructive signal leads to adding the amplitudes of the interference signals. The wheal teeth pattern designed in a way to give a constructive signal. As shown in figure 2.4, the distance between the parallel planes of the two close teeth has a half wavelength distance separation.

Figure 2.4: The wheel teeth distance (pitch) designed to generate a constructive wave.

The frequency value of 60GHz of the radar sensor was used in this test. The wavelength can be calculated using the below formula 2.2:

\[
\lambda = \frac{c}{f} \tag{2.2}
\]

where, \(C=3\times10^8\)m/s is the speed of light, \(f=60\times10^9\)Hz is the radar sensor central frequency. Consequently, \(\lambda\) is 5mm.

Referring to figure 2.4, the radar transmitted signal A, and B, hitting the wheal tooth. Because of the distance between two teeth is half wavelength (2.5mm), the reflected signal A is the same phase of the reflected signal B plus (5mm is the full wavelength
distance). It means 360-degree shift between reflected signals A and B, leading to constructive interference between the signals. In the end, all the reflected signals interference from the wheal tooth, resulting in one constructive signal with high amplitude and large SNR.

### 2.1.3 Speed limitations

The range of speeds, needed in our system is about 2.7m/s to 9.5m/s. Formula 2.1 was modified to calculate the RPM speed limitation of the wheal:

\[
\omega = \frac{60v}{2\pi R}
\]

\[
\omega = \frac{60 \cdot 2.7}{2\pi \cdot 0.05} \approx 500\text{RPM}
\]

\[
\omega = \frac{60 \cdot 9.5}{2\pi \cdot 0.05} \approx 1800\text{RPM}
\]

Since the wheal tooth has a 30-degree angle alignment, the Doppler speed \(v_{\text{doppler}}\) can be calculated by the below formula 2.3:

\[
v_{\text{doppler}} = v \cdot \cos (30) \quad (2.3)
\]

That is leading to modify the wheal speed limitations from 600RPM to 2100RPM.

### 2.2 DC motor

There is a lot of different kind of motors for a different purpose. For example, DC motor, AC motor, stepper motor, …etc. DC motors are chosen in this project for different reasons:

- Easy to control the motor speed.
- Stable.
- High speed.
- Smooth transition.
A DC motor is a machine that converts DC power to mechanical energy. The principle of DC motor works, is very simple. When the current flow in the conductor placed in a magnetic field, a mechanical force will be generated in the conductor. The direction of the force can be determined by Fleming’s left-hand rule as shown in figure 2.5.

![Figure 2.5: Fleming’s left-hand rule [15].](image1)

Every DC motor has 6 main parts. Axle, Rotor, Commutator, Field magnets, and Brushes. As shown in figure 2.6 the current pass through the armature when it is connected to the power supply through the commutator segment and brushes. A magnetic field will be formed between two permanent magnetic that armature is placed between them [16].

![Figure 2.6: The six parts of the DC motor [16, p95].](image2)
The applied direct current converts the electrical energy into mechanical energy because of the interaction of two magnetic fields. One field is produced by the permanent magnet and the other is produced by the electric current flowing through the armature winding. Because of the interaction of these two fields, the armature experiences a force which tends to rotate the rotor [15].

### 2.3 DC motor speed control

The main advantage of a DC motor is its speed that can be changed over a wide range by different simple methods. In fact, fine speed control is one of the reasons for the strong competitive position of DC motors in the modem industrial applications.

To understand the effect of parameters in the speed of a DC motor, the DC motor speed formula 2.3 is given:

\[ \omega_{RPM} = \frac{V - I}{\phi} \]  

(2.3)

Where:

- \( V \): the DC applied voltage.
- \( R \): the resistance in the armature circuit.
- \( \phi \): the flux.

By changing one of these parameters, DC motor speed will change, flux parameter can increase the number of motors pole, and that is can be done in the fabrication process. In the other side, the DC motor speed can also be controlled by the parameters after the fabrication process. By adding series resistance as shown in figure 2.7, it is an easy way, but it is low efficiency due to the power losses in the resistor.
The last method is the most effective one. Controlling the DC motor speed by varying the DC power supply voltage, by decreasing the voltage the DC motor speed decrease, and increasing the voltage increasing the DC motor speed. There are two control methods to be used for motor control. The first one is an open loop control and the other is a closed loop control method.

### 2.3.1 Open loop control

Open loop control method depends on the mathematical calculation of the relation between the motor speed and the voltage (refer to formula 2.3), and by knowing the desired speed, the required DC voltage can be calculated. This method has some disadvantages such as low precision. It did not take it into account that the other parameters can be affected by the speed of the DC motor, e.g. varying the load can increase or decreases the motor torque, leads in changing the motor speed.
2.3.2 Close loop control

Despite the open loop speed control, the closed loop speed control is very accurate, because it uses a feedback system as shown in figure 2.8. The feedback system can tell the controller the real-time speed values of the DC motor. The feedback system usually is an encoder sensor that is connected to the shaft motor that can recognize the motor speed and sending it to the controller in the form of pulses or analogue voltage.

As shown in the previous figure 2.8, the required speed value is given to the controller, which calculated the required voltage. It is sent to the power converter that giving the exact value to the DC motor. Now the motor sends the feedback of it is real time speed to the controller through the encoder sensor. The controller can be detecting the error between the desired value and the real value and convert it to a DC voltage to correct the error.

Figure 2.8: Closed loop control system block diagram.
2.4 Control circuit

The measurement setup control unit block diagram shown in figure 2.9 contains several parts, the brain of the control system is a PIC18F4550 microcontroller[17]. It takes two different kinds of inputs; manual inputs by the user through the knob, or serial inputs through a UART serial communication. The PWM technique is used to control the DC motor speed and finally, the encoder sensor gives the real speed of the motor to the microcontroller.

![Measurement setup control unit block diagram.](image)

**Figure 2.9:** Measurement setup control unit block diagram.

2.4.1 Microcontroller

A microcontroller is a small computer on a single integrated circuit, containing a processor core, memory, and programmable input/output peripherals. There are different companies that manufacturing microcontroller like:

- Microchip.
- Atmel.
- ARM.

Microcontrollers are used in automatically controlled products and devices, such as automobile engine control systems, implantable medical devices, remote controls, office machines, appliances, power tools, and toys.
PIC18f4550 microcontroller from Microchip Company was used and is shown in figure 2.10 to control the DC motor for many reasons:

- Large memory
- High speed
- More stable
- PWM channel
- Multi-channels of ADC
- Several Timers.
- UART support.

![PIC18f4550 microcontroller](image)

**Figure 2.10:** PIC18f4550 microcontroller.

### 2.4.2 UART

A Universal Asynchronous Receiver/Transmitter (UART) is a hardware component that can transmit and receive binary data (digital data) serially. A UART transmits bytes of data over a single wire one bit at a time to be received by another UART at the other end. The receiving UART reconstitutes the bits back into bytes. A UART communicates using a pair of wires, one for transmitting data (TX wire) and one for receiving (RX wire) [18].

In most computers, a UART is responsible for handling communications over the serial ports, commonly via an RS-232 serial port. Most microcontrollers include a UART serial communication interface.
When not transmitting any data, the wire voltage is held high. When the transmitting UART is ready to transmit a byte, it must first transmit a start bit as shown in Figure 2.11. The start bit is always 0. This tells the receiver that a byte is incoming, the next bit will be the first bit of the byte being transmitted. Bits are transmitted starting with the least significant digit finishing with the most significant. After the 8th bit, a stop bit is transmitted which always has a value of 1. At least one stop bit is required. If no more bytes are pending transmission, the transmitter will go idle with a high voltage level same as the stop bit [19, 20].

![UART Signal Format](image)

**Figure 2.11**: UART signal format [20].

Some commonly used in UART serial communication bit rates (or baud rates), in bit/s:

- 9600
- 19200
- 38400
- 57600
- 115200

### 2.4.3 PWM

Pulse Width Modulation (PWM) is a powerful way of controlling DC voltage value, using the digital outputs of the microcontroller. PWM signal shown in figure 2.12 contains three parameters time on, time off, and total time (higher than 20ms).
The average DC voltage generated from the PWM signal can be calculated using the following formula 2.4

\[ V_{AVG} = V_{max} \frac{t_{on}}{t_{total}} \]  \hspace{1cm} (2.4)

Figure 2.12: PWM signal parameters.

The maximum voltage is converted to average DC voltage by changing the on time. The motor coil will filter the PWM signal and take the average voltage from zero to the maximum voltage as shown in figure 2.13.

Figure 2.13: Average voltage generated from the PWM signal [41].
2.4.4 Isolation

The microcontroller is a sensitive component to noise that can be stuck easily if it is not protected well from large noise and reverse current. DC motor generates an electromagnetic wave, causing reverse currents that can affect microcontroller badly. An Optocoupler showed in figure 2.14 used in this case to solve the problem by providing complete electrical isolation between the control unit and the motor using led and phototransistor for transferring the signal.

Figure 2.14: Optocoupler component used for electrical signals isolation.

The 6N139 [21] optocoupler was used to fully electrical isolation between the control unit and the power unit. A common mistake is using optocoupler component and keep the same ground for both the controller and the power unit. Every unit should have it is own voltage source completely separate from the other sources.
2.4.5 Schematic design

Schematic design was done by OrCAD program, below figure 2.15 shows the main parts of the control circuit:

1. Pic18f4450 Microcontroller.
2. Selecting a mode switch.
4. Encoder sensor feedback connection.
5. LCD.
6. Reset pushbutton.
7. PWM output signal.
8. Serial to USB cable connection.

Figure 2.15: Control circuit schematic.
2.5 Power circuit

Many considerations need be taken during the design of the power circuit for any electronic device. In this design the power circuit as shown in figure 2.16 contains four main parts:

1. Rectifier circuit.
3. Overcurrent protection.
4. Reverse voltage protection.

![power circuit schematic](image)

Figure 2.16: power circuit schematic.

2.5.1 Rectifier circuit

A rectifier is an electrical device that converts alternating current (AC), which periodically reverses direction, to direct current (DC). Two types of rectifier are existed [23]:

1. Half wave rectifier: this is the simplest rectifier and uses one diode only
2. Full wave rectifier: this rectifier has two types
   (a) centre-tapped transformer
   (b) full bridge rectifier which uses four diodes. The circuit and the waveform are shown in figure 2.17.
Rectifier circuit contains three main parts shown in figure 2.18:

1. Stepdown transformer.
2. Full-wave bridge rectifier.
3. Smoothing unit.

A step-down transformer [24] reduces the main AC voltage 220 V to 42V AC. After that, the full bridge rectifier [25] converts the AC voltage to DC voltage as shown in figure 2.17. The DC voltage values can be calculated using the below formula 2.5.

\[ V_{DC} = V_{AC} \cdot \sqrt{2} \]  \hspace{1cm} (2.5)

\[ V_{DC} = 42V \cdot \sqrt{2} = 60V \]

After the rectification, the signal needs to be smoothed to provide pure DC voltage, using a capacitor. The capacitor value is calculated based on the following formula 2.6.

\[ c = \frac{\text{Current} \cdot \text{Half cycle time}}{\text{Acceptable voltage drop}} \]  \hspace{1cm} (2.6)
Where:

- The Max. current required for the DC motor is 2A.
- Half cycle time = $\frac{1}{2 \cdot \text{frequency of the AC voltage}} = \frac{1}{2 \cdot 50} = 0.01 \text{ sec.}$
- Acceptable voltage drop = 2V.

\[ e = \frac{2 \cdot 0.01}{2} = 0.01F = 10000\mu F \]

Finally, pure 60V\text{DC} was generated to operate the DC motor.

### 2.5.2 Power electronic drive component

A Darlington transistor [26] is shown in figure 2.19, used as a switching electronic component to switch the DC voltage according to the PWM signal which was generated from the control unit to control the speed.

![Darlington transistor used as an electronic power switch.](image)

**Figure 2.19:** Darlington transistor used as an electronic power switch.

### 2.5.3 Overcurrent protection

An overcurrent occurs when the current exceeds the current capacity of the electrical circuit. Any power circuit should have an overcurrent protection, to protect the circuit from damage if the overcurrent situations. Many reasons can cause overcurrent:
- Wrong connection.
- Heavy load.
- Ground fault.
- Arc fault.

A simple way for overcurrent protection is to connect a fuse with the same or clothe to the current capacity of the circuit between the power source and the power circuit, as shown in figure 2.16-3.

2.5.4 Reverse voltage protection

Normally when a magnetic load, such as a motor is used, a reverse voltage can be generated when the power is disconnected. The motor becomes a generator for a moment. This can be sufficient to damage some electrical components. Adding a fly back diode [27] pin parallel with the motor as shown in figure 2.20 provides a path for the dissipation of stored energy when the switch is opened, and it protects the circuit.

![Figure 2.20: Fly back diode connected to DC motor for reverse voltage protection.](image)

2.6 Circuit layout and PCB

A layout OrCAD program was used to design the layout of the full circuit control and power unit. As shown in figure 2.21, the grounded power and the control unit are separated from each other. And all the component connections are done in one layer.
The final electronic board, after assembling the components and soldering them on the PCB circuit, is shown in figure 2.22.
Chapter 3
Radar and Signal Processing

3.1 Radar history

Radar stands for radio detection and ranging. Radar started with Heinrich Hertz’s experiments in the late 19th century that showed that radio waves were reflected from metallic objects. This possibility was suggested in James Clerk Maxwell's seminal work on electromagnetism. However, it was not until the early 20th century that systems were able to use these principles to become widely available. A German inventor Christian Hülsmeyer was the first who used them to build a simple ship detection device intended to help to avoid collisions in fog. Numerous similar systems, which provided directional information to objects over short ranges, were developed over the next two decades [28]. The invention of the radar started within the military field for aero planes detection before their strikes which provided a strategic added value and privilege against the enemy.

Over the years, the radar concept exceeded the military application to be included in the weather forecast, traffic system detection, ground structure detection as geological applications, car radar, etc.

3.2 Radar work principle

The principle of radar is simple, radar sending electromagnetic waves from the transmitter antenna, then the wave propagates through space and hitting the object (target) causes reflected wave from the object. The received antenna of radar detects the reflecting waves from the object within the antenna range that can be estimated from below formula 3.1.

\[
P_r = \frac{P_t \cdot G_t \cdot G_r \cdot \sigma \cdot \lambda^2}{(4\pi)^3 \cdot D^4} \quad (3.1)
\]
Where

\( D \): Distance between antenna and target.

\( P_t \): Transmitted signal power.

\( P_r \): The received signal power.

\( G_t \): Transmitted antenna gain.

\( G_r \): Received antenna gain.

\( \sigma \): The radar cross section represents the intersection object area with the transmitted signal.

\( \lambda \): Electric wavelength, and it is depending on signal frequency.

The received signal is processed into different stages e.g. filtering, amplifying and processing. By using signal processing certain information about the reflecting object can be extracted for instance the range, velocity, angle etc.. [29].

### 3.3 Types of radar systems

Radar systems are classified under various categories depending on the functions and the purposes. For examples, Bistatic radar, Continuous wave (CW) radar, pulse radar, weather radars, mapping radar, etc.…

#### 3.3.1 Continuous wave (CW) radar

CW radar depends on continuously transmits of the electromagnetic waves with a constant frequency. If the object is a static object, the reflected signal will be around the same transmitted frequency. If the object is dynamics or moving object, then the reflected signal will be shifted due to the Doppler effect. The velocity of the object can be measured by evaluating this shift. However, since the signal is not modulated it is impossible to detect the target range [30,31].
3.3.2 FMCW radar

Frequency Modulated Continuous Wave (FMCW) radar, is a special type of radar sensor which combined the CW radar with frequency modulation (FM) technique. As previously discussed, the disadvantage of the CW radar devices, without frequency modulation, is the disability of determining the target range. Because it lacks the timing mark necessary to allow the system to time accurately the transmit and receive cycle and to convert this into the range [32]. The FMCW radar transmits a continuous carrier, modulated by a periodic function such as a sinusoid or saw-tooth wave to provide range data [33]. The signal frequency is increased or decreased in periodic time as shown in figure 3.1. And that is called chirp signal or chirp pulse.

![Figure 3.1: Chirp signal.](image)

The main advantages of FMCW radar are:

- Ability to measure very small details of the target by using high frequency transmitted signal.
- Ability to measure the target range and its relative velocity.
- Very high accuracy of range measurement.
- Signal processing after mixing is performed at a low-frequency range.
3.4 FMCW Radar - Range detection

In chirp pulse, the frequency is an increase in specific bandwidth range, and that is happening in periodically time called time sweep. The larger chirp bandwidth gives better range resolution [32].

![Diagram showing FMCW radar intermediate frequency.]

When the reflected signal is received as shown in figure 3.2, the change of frequency gets a delay of \( \tau \), measured by the difference in the phase or the frequency between the transmitted and the received signal. The frequency difference between TX chirp and RX chirp \( \Delta f \), is called intermediate frequency IF or beat frequency \( f_b \). The range can be calculated from the following formula 3.2:

\[
D = \frac{IF \cdot C}{2S} \tag{3.2}
\]

Where

- \( IF \): intermediate frequency value.
- \( D \): the distance between the target and the radar sensor.
- \( C \): speed of light = 3x10^8 m/s
- \( S \): the slope of the chirp line.
3.5 FMCW Radar – Speed detection

Speed detection in radar system depends strongly on Doppler effect, and by using signal processing, the target speed can be measured.

3.5.1 Doppler effect

The Doppler effect is the change in frequency or wavelength of a wave in relation to an observer who moving relative to the wave source [34]. It is named after the Austrian physicist Christian Doppler, who described the phenomenon in 1842.

An ambulance running in a street between two persons as shown in figure 3.3, is a common example of the Doppler effect. The voice getting higher for the person that the ambulance moving toward him. And getting lower for the person that the ambulance moving far away from him.

![Figure 3.3: Example of a Doppler effect [35].](image)

If the body is approaching the observer (reference target), then the wavelength shrinks and increases the frequency and become the main frequency $f_0 + f_d$ (Doppler frequency). If the body is moving away from the observer, then the wavelength gets stretched and frequency decreases $f_0 - f_d$. The source of sound always emits the same frequency. Therefore, for the same period of time, the same number of waves must fit between the source and the observer. If the distance is large, then the waves can be spread apart, but if the distance is small, the waves must be compressed into the smaller distance.
It is important to note that the effect does not result because of an actual change in the frequency of the source. The source transmitted the same frequency, but the observer only receives a different frequency because of the relative motion between them. The Doppler effect is a shift in the apparent or observed frequency and not a shift in the actual frequency at which the source vibrates.

3.5.2 Triangular chirp Modulation pattern

There are several possible modulation patterns as shown in figure 3.4, which can be used for different measurement purposes [32, 36]. For example, a popular saw-tooth is used to detect large distance and triangular shape is usually used to detect the velocity of the target. Because it is easier to calculate the Doppler effect from the reflected signal.

![Modulation patterns shapes](image)

**Figure 3.4:** Modulation patterns shapes [32].

In a triangular-shaped frequency changing, a distance measurement can be performed on both, the rising and the falling edges. In Figure 3.5, an echo signal was shifted to the right due to the running time compared to the transmission signal.
When the target is fixed (only static objects in range), the amount of the frequency difference $\Delta f_{up}$ during the rising edge is equal to the $\Delta f_{down}$ measurement during the falling edge, and both equal beat frequency $f_b$ [32]. In this case, the range of the object can be detected from the frequency difference as shown previously in formula 3.2.

If the reflecting target is moving towards or away from the radar, the echo signal, unlike the fixed target, will be shifted. The beat frequency from up chirp $f_{bu}$ is no longer equal the beat frequency from down chirp $f_{bd}$ as shown in figure 3.6. In the fixed target case, there is no Doppler shift, but in moving target, there is a Doppler shift generated in the echo signal.
The beat frequency from up chirp $f_{bu}$ as shown in formula 3.3, contains the Doppler frequency $f_{doppler}$ plus the beat frequency $f_b$.

$$f_{bu} = f_b + f_{doppler} \quad (3.3)$$

Beat frequency from down chirp $f_{bd}$ as shown in formula 3.4, contains the Doppler frequency $f_{doppler}$ subtracting from the beat frequency $f_b$.

$$f_{bd} = f_b - f_{doppler} \quad (3.4)$$

The Doppler frequency and beat frequencies can be separated using the following formulas 3.5 and 3.6.

$$f_b = \frac{f_{bu} + f_{bd}}{2} \quad (3.5)$$

$$f_{doppler} = \frac{|f_{bu} - f_{bd}|}{2} \quad (3.6)$$

Target velocity can be calculated using below formula 3.7:

$$v = \frac{\lambda}{2} f_{doppler} \quad (3.7)$$

The direction of movement can be detected from the sign of the difference between $f_{bu}$ and $f_{bd}$. If it is positive, the target is moving toward the radar. If it is negative, the target is moving away from radar as shown in figure 3.7.

![Figure 3.7: Effect of Doppler shift on frequency peaks when the target is either moving towards or away from the radar [37, p.23.]](image-url)
3.6 Signal processing

Data signal processing was done by the MATLAB program. It contained many stages as seen in figure 3.8. The radar sensor sends the data to the MATLAB program through a USB cable and the serial port. These data contain the I and Q values for up and down chirp for both receivers. Applying fast fourier transform (FFT) leads to finding the Doppler frequency of the target. Finally, using some average algorithm and equation, the speed will be measured.

![Signal processing stages](image)

**Figure 3.8:** Signal processing stages.

3.6.1 Fourier transform

Fourier transform (FT) helps in breaking down an incoming signal into its frequency building [37]. Figure 3.9 showed that any periodic signal \( s(t) \) in the time domain, can be written as a sum of sine waves with various amplitudes, frequencies and phases in frequency domain \( s(\omega) \).

![Signal in time and frequency domains](image)

**Figure 3.9:** Signal in time and frequency domains [38].
Let’s take an example. In figure 3.10, signal number 1 is a sin wave signal with a frequency of 50Hz. The second signal is a sin wave with a frequency of 200Hz. The third signal is the result of adding signal 1 to signal 2. All signals 1, 2, and 3, are represented in the time domain. The Fourier transform result of the signal number 3 is shown in number 4, and it is clear to represent the signal in the frequency domain instead of the time domain. The result shows that signal number 3 is a combination of two sin wave signals, one with the 50Hz frequency with amplitude value 1, and the other with the 200Hz frequency with amplitude value 2. And that is the magic of Fourier transform.

Figure 3.10: Modulation patterns shapes.
3.7 Radar sensor

The used radar sensor in this project is responsible for signal generation and frequency sweep bandwidth between 57 - 64GHz, and a 20ms time sweep for up chirp and also a 20ms time for the down-chirp. This part was achieved by using one chip solution provided by the supplier [39]. The IC allows multiple functions to be programmed, including the delivery of analogue or digital (I/Q) baseband signals. The design does not require any difficult RF/microwave board design, just simple low-frequency components suffice to complete the application. The chip provides with 2 receivers antenna [40]. Main feathers of the radar sensor illustrated in table 3.1 below.

<table>
<thead>
<tr>
<th>Center frequency</th>
<th>60GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum range</td>
<td>35m</td>
</tr>
<tr>
<td>Chirp bandwidth</td>
<td>7GHz</td>
</tr>
<tr>
<td>Chirp time sweep</td>
<td>20ms</td>
</tr>
<tr>
<td>Number of receivers</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 3.1: Radar sensor specification.
Chapter 4

Results and Discussion

Testing and measurement for the measurement setup device (Doppler emulator) have been discussed in this chapter. The full system testing and the result of the experimental verification were done in the anechoic chamber room is discussed in the second half of this chapter with the spot result for the accuracy of the system.

4.1 Measurement setup

4.1.1 Measurement setup assembly

After the design and fabricate the control and power circuits for the measurement setup device completed. All the parts were assembled in a single metal box as shown in figure 4.1. The numbers refer to:

1. Electronic board circuit.
2. The transformer as a power source for power circuit.
3. The small transformer as a power source for the control circuit.
4. DC motor.
5. DC motor shaft, where the wheel should place.

Figure 4.1: Measurement setup device parts.
4.1.2 Measurement setup interface panel

As previously mentioned, the DC motor speed can be controlled manually or by a serial mode using a USB cable. Figure 4.2 shows the interface panel for the measurement setup device, where every number is referred to:

1. Power cable 220V.
2. Fuse for protection from overcurrent.
3. Power switch.
4. Reset button.
5. Selection mode switch.
6. Manually speed input knob.
7. Serial to USB cable used in serial mode.
8. Input pins for PICKit3 Microchip Programmer to update PIC18f4450 firmware.

Figure 4.2: Measurement setup interface panel.
The final measurement setup device after placing the wheel is shown in figure 4.3.

![Measurement setup device with the wheel.](image)

**Figure 4.3:** Measurement setup device with the wheel.

### 4.1.3 Experimental result

Measurement setup device was tested to obtain the system accuracy and the error percentage. Tachometer RPM speed measurement tool shown in figure 4.4 used to measure the real RPM speed of the DC motor.

![Tachometer used to test the Real motor speed.](image)

**Figure 4.4:** Tachometer used to test the Real motor speed.
Table 4.1 shows the experimental measurement values for different RPM speed values also shows the calculation of the error percentage for every reading.

<table>
<thead>
<tr>
<th>Speed required ((\omega_{\text{rpm}}))</th>
<th>Real speed ((\omega_{\text{rpm}}))</th>
<th>Error %</th>
</tr>
</thead>
<tbody>
<tr>
<td>600</td>
<td>600</td>
<td>0</td>
</tr>
<tr>
<td>650</td>
<td>649</td>
<td>0.15</td>
</tr>
<tr>
<td>700</td>
<td>701</td>
<td>-0.14</td>
</tr>
<tr>
<td>750</td>
<td>749</td>
<td>0.13</td>
</tr>
<tr>
<td>800</td>
<td>799</td>
<td>0.13</td>
</tr>
<tr>
<td>850</td>
<td>848</td>
<td>0.24</td>
</tr>
<tr>
<td>900</td>
<td>899</td>
<td>0.11</td>
</tr>
<tr>
<td>950</td>
<td>948</td>
<td>0.21</td>
</tr>
<tr>
<td>1000</td>
<td>1001</td>
<td>-0.10</td>
</tr>
<tr>
<td>1050</td>
<td>1049</td>
<td>0.10</td>
</tr>
<tr>
<td>1100</td>
<td>1100</td>
<td>0.00</td>
</tr>
<tr>
<td>1150</td>
<td>1148</td>
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</tr>
<tr>
<td>1200</td>
<td>1197</td>
<td>0.25</td>
</tr>
<tr>
<td>1250</td>
<td>1247</td>
<td>0.24</td>
</tr>
<tr>
<td>1300</td>
<td>1297</td>
<td>0.23</td>
</tr>
<tr>
<td>1350</td>
<td>1345</td>
<td>0.37</td>
</tr>
<tr>
<td>1400</td>
<td>1398</td>
<td>0.14</td>
</tr>
<tr>
<td>1450</td>
<td>1447</td>
<td>0.21</td>
</tr>
<tr>
<td>1500</td>
<td>1497</td>
<td>0.20</td>
</tr>
<tr>
<td>1550</td>
<td>1549</td>
<td>0.06</td>
</tr>
<tr>
<td>1600</td>
<td>1596</td>
<td>0.25</td>
</tr>
<tr>
<td>1650</td>
<td>1647</td>
<td>0.18</td>
</tr>
<tr>
<td>1700</td>
<td>1697</td>
<td>0.18</td>
</tr>
<tr>
<td>1750</td>
<td>1746</td>
<td>0.23</td>
</tr>
<tr>
<td>1800</td>
<td>1795</td>
<td>0.28</td>
</tr>
<tr>
<td>1850</td>
<td>1846</td>
<td>0.22</td>
</tr>
<tr>
<td>1900</td>
<td>1896</td>
<td>0.21</td>
</tr>
<tr>
<td>1950</td>
<td>1946</td>
<td>0.21</td>
</tr>
<tr>
<td>2000</td>
<td>1995</td>
<td>0.25</td>
</tr>
<tr>
<td>2050</td>
<td>2046</td>
<td>0.20</td>
</tr>
<tr>
<td>2100</td>
<td>2095</td>
<td>0.24</td>
</tr>
</tbody>
</table>

Table 4.1: Experimental results for the measurement setup device test.

The experimental result shows high accuracy of the measurement setup device to reach the required RPM speed with a maximum error equals 0.37%, and an average error
value equals 0.17%. That is because the control algorithm applied in the microcontroller and the feedback system as well.

4.2 Doppler speed measurement

The aim of this project as previously explained is to demonstrate the people and the speeds of the vehicles for radar sensor testing and development purpose. To be sure that our goal was achieved, the Doppler frequency should be observed clearly and the RPM speed should be measured successfully using the Radar sensor.

4.2.1 Measurement environment

A millimetre radar sensor needs a special environment setup to do an accurate measurement without any outside environment interference. As shown in figure 4.5, the measurement setup device was placed in the anechoic chamber room, 2.75 meters away from the radar sensor. Radar Lenz used to focus the radar sensor beam and increase the signal to noise (SNR) ratio. The PC is connected to both of the measurement setup device and the radar sensor to control the output and the input data, and also for processing the signal.

Figure 4.5: Testing environment setup.
4.2.2 Result expectation

The result graph expectation is shown in figure 4.6. The results should show the wheel location (the distance between the radar sensor and the wheel) and also the Doppler frequency is related to the half distance between the two peaks surrounding the wheel location.

![Figure 4.6: Doppler Emulator Result expectation.](image)

When the wheel is rotating anticlockwise as shown in figure 4.7, the right teeth will be moving further away from the radar sensor. The left teeth will move toward the radar sensor, and since both of them has the same speed of rotation, they will have the same Doppler frequency with opposite signs.

![Figure 4.7: The direction of wheel rotation relative to the radar sensor.](image)
After the FFT process complete the output data format for the X-axis arranged in range scale (the distance between the radar sensor and the target). The relation between the wheel speed and the distance can be calculated below.

Using formulas of (2.1), (2.3), and (3.7), the relation between the RPM speed and Doppler frequency can be calculated as follows:

\[
\frac{2\pi R \cdot \omega (RPM)}{60} = \frac{\lambda}{2 \cos(30)} f_{\text{doppler}}
\]

\[
\omega_{RPM} = \frac{60\lambda}{2 \cos(30) \cdot 2\pi R} f_{\text{doppler}}
\]

To find the relation between the Doppler frequency and the distance scale, the formulas of (3.2) and (3.6) were used:

\[
D = \frac{f_b \cdot C}{2 S}
\]

\[
f_b = \frac{D \cdot 2S}{C}
\]

\[
f_{\text{doppler}} = \frac{|f_{bu} - f_{bd}|}{2}
\]

\[
f_{\text{doppler}} = \frac{2S}{2C} \Delta D
\]

By solving the previous equations, the relation between the RPM speed and the distance difference is calculated:

\[
\omega_{RPM} = \frac{60\lambda}{2 \cos(30) \cdot 2\pi R} \frac{2S}{2C} \Delta D
\]

Where:

- \( \lambda = 0.005m \)
- \( R = 0.05m \)
- \( S \) (chirp slope) = 358588134

\[
\omega_{RPM} = \frac{0.005 \cdot 60}{2 \cdot 2\pi \cdot 0.05} \frac{2S}{2C} \Delta D
\]

Finally, the relation between the RPM speed and the range difference (the distance between the two peaks) is represented by formula 4.1.

\[
\omega_{(RPM)} = 0.659 \cdot \Delta D_{(mm)} \quad (4.1)
\]
4.2.3 Manual mode testing

In manual mode testing, specific speed will be chosen manually to test. In this experiment, different speeds were taken to cover different ranges.

- **610 RPM**

As shown in figure 4.8, the large peak appeared in the middle was the location of the measurement setup device. It was 2.75m away from the radar sensor. The other two peaks represent the Doppler effect generated from the wheel.

![Figure 4.8: Doppler frequency generated from 610 RPM wheel speed.](image)

measured speed by radar sensor can be calculated from the distance between the small two peeks using formula (4.1):

\[
\text{Distance between two peaks (\(\Delta D\))} = 936.75\text{mm}
\]

\[
\text{Measured speed} = 0.659 \cdot 934.75 = 616\text{RPM}
\]

Error = 0.98%

- **1200 RPM**

Figure 4.9 shows the output result from the required speed 1200RPM. Notice that the large peak still fixed, because the wheel is still at the same distance from the radar sensor, but the distance between two small peaks was increased due to speed increasing.
Distance between two peaks ($\Delta D$) = 1830mm
Measured speed = $0.659 \cdot 1830 = 1206$RPM
Error = 0.47%.

- **1800 RPM**

Figure 4.10 shows the output result from the required speed 1800RPM. It is clear that the distance was increased more again due to increasing speed.

Distance between two peaks ($\Delta D$) = 2749mm.
Measured speed = $0.659 \cdot 2749 = 1812$RPM.
Error = 0.68%.
4.2.4 Automatic Measurement

Using the serial mode of the measurement setup device allows MATLAB to take control of all measurement process, by sending the required speed to the measurement setup device using a USB cable. Also, controlling the reading data from the radar sensor for every different speed, then it is calculated the speed automatically using signal process code to find the measuring speed for every speed. Automatic measurement has many advantages like:

- High accuracy.
- Ability to take large data.
- Easy to storage the data.
- Less time.

Automatic measurement required different inputs of values from the user. The parameter set to this testing operation is shown in figure 4.11.

```matlab
%%% Automatic measurements
start=650;       % start speed
finish=2100;     % stop speed
step=50;
AV=6;            % average point
Delay_s=2;       % time between two steps

Figure 4.11: Parameter required for Automatic testing.
```

Where:

- Start: the speed that the user wants to start the measurements from it.
- Finish: the speed that the user wants to finish the measurements with it.
- Step: the speed that the user wants to increase in every measurement.
- AV: number of averaging taken for each measurement.
- Delay_s: time delay between two steps to give the motor chance to be stable.
Table 4.2 shows the testing result related to the required parameters in figure 4.12.

<table>
<thead>
<tr>
<th>Motor speed ((\omega_{\text{rpm}}))</th>
<th>Measured speed ((\omega_{\text{rpm}}))</th>
<th>Error %</th>
<th>Motor speed ((\omega_{\text{rpm}}))</th>
<th>Measured speed ((\omega_{\text{rpm}}))</th>
<th>Error %</th>
</tr>
</thead>
<tbody>
<tr>
<td>650</td>
<td>644</td>
<td>0.92</td>
<td>1400</td>
<td>1385</td>
<td>1.10</td>
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<tr>
<td>700</td>
<td>690.6</td>
<td>1.35</td>
<td>1450</td>
<td>1428</td>
<td>1.54</td>
</tr>
<tr>
<td>750</td>
<td>740</td>
<td>1.35</td>
<td>1500</td>
<td>1503</td>
<td>0.21</td>
</tr>
<tr>
<td>800</td>
<td>793.3</td>
<td>0.84</td>
<td>1550</td>
<td>1538</td>
<td>0.74</td>
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<tr>
<td>850</td>
<td>837.3</td>
<td>1.50</td>
<td>1600</td>
<td>1585</td>
<td>0.91</td>
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<tr>
<td>900</td>
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<td>1.16</td>
<td>1650</td>
<td>1637</td>
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<tr>
<td>950</td>
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<tr>
<td>1000</td>
<td>988.1</td>
<td>1.19</td>
<td>1750</td>
<td>1743</td>
<td>0.38</td>
</tr>
<tr>
<td>1050</td>
<td>1041</td>
<td>0.82</td>
<td>1800</td>
<td>1793</td>
<td>0.36</td>
</tr>
<tr>
<td>1100</td>
<td>1092</td>
<td>0.73</td>
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<td>1837</td>
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<td>1150</td>
<td>1144</td>
<td>0.53</td>
<td>1900</td>
<td>1886</td>
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<tr>
<td>1200</td>
<td>1200</td>
<td>0.01</td>
<td>1950</td>
<td>1937</td>
<td>0.66</td>
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<tr>
<td>1250</td>
<td>1237</td>
<td>1.05</td>
<td>2000</td>
<td>1987</td>
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<tr>
<td>1300</td>
<td>1284</td>
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<td>2050</td>
<td>2039</td>
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<tr>
<td>1350</td>
<td>1360</td>
<td>0.75</td>
<td>2100</td>
<td>2082</td>
<td>0.85</td>
</tr>
</tbody>
</table>

Table 4.2: Experimental results for the measurement setup device test (Automatic test).

From the previous table, the average percentage error can be calculated, and the maximum error percentage can be found:

Maximum error = 1.54%

Average error = 0.84%

Also, another automatic testing was taken with the following parameters:

- Start: 610RPM
- Finish: 2100RPM
- Step: 10RPM
- AV: 6
- Delay_s: 2Sec

This testing experiment for 150 different speeds (seen in appendix C) has the following system accuracy result:

Maximum error = 1.29%

Average error = 0.54%
Chapter 5
Conclusion and Future Work

5.1 Conclusion

Within this thesis, we tried to demonstrate the speeds of different objects in the road to generate a Doppler emulator for different speed ranges from 3m/s to 9.5m/s. We discovered that the designed linear speed demonstration device has many disadvantages e.g. need of a large space that causes impossible demonstration of continuous run speed for a long time. The system needs to be stopped when it reaches the end. This problem was solved by using wheel rotate with different RPM speeds instead of the linear system. Since it does not need to move linearly, and it can be run forever. The wheel was designed to strengthen the echo signal and to have constructive interference.

To investigate different speeds, we need to have a speed controller. The project was continued by designing a measurement setup device that can have a manual and a computerized option to control the motor speed. A DC motor was chosen in this project because it can reach a high speed with smooth running speed. The control system was designed as a closed loop control for more accuracy. The microcontroller used as the brain of the control system and programmed to have a full speed control of the DC motor using PWM according to the required speeds. A power circuit was designed to provide the DC motor with the required power and protect it from overcurrent and reverse voltage problems. In addition, the control unit and the power unit were fully electrical isolated by an optocoupler component to protect the control circuit and the microcontroller. Subsequently, all the system was assembled in one box. A MATLAB program was used to write the signal processing code to measure the Wheel speed and control the measurement setup device by a USB cable for automatic measurements. The measurement setup device was tested and it showed less than 0.6% error percentage.
Testing and measuring for the whole system were done in the anechoic chamber room. First, the manual test with specific speed values showed a high accuracy of emulating the Doppler speed with a low error percentage in every speed. Also, the automatic test was done using 150 different speeds, showing promising results with 0.54% as an average error percentage.

5.2 Future work

We look forward to further improve the system to cover more speed values (higher and lower). In that case, we can demonstrate, for example, two cars in the railway with high speed. Also increasing the ability to use this device for radar development area by increasing the accuracy, and programming the device to have also acceleration curves that can demonstrate a lot of situation that might be happening in the road, for example, a car stopped suddenly or someone is walking then suddenly start to run. All these ideas can be done in future and it will help to develop the automotive radar field to predict the accidents and saves lives.
References


Appendix A

Electronic circuit schematic design

Figure 01. Electronic circuit schematic design
PCB layout design

Figure 02. PCB layout copper plane

Figure 03. PCB Top layer
## List of components

<table>
<thead>
<tr>
<th>Designator</th>
<th>Description</th>
<th>Value</th>
<th>Qty</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1, C4, C5, C8</td>
<td>Capacitor</td>
<td>100nF</td>
<td>4</td>
</tr>
<tr>
<td>C2</td>
<td>Capacitor</td>
<td>100uf</td>
<td>1</td>
</tr>
<tr>
<td>C3, C7, C12</td>
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<td>3</td>
</tr>
<tr>
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<td>Capacitor</td>
<td>10uf</td>
<td>1</td>
</tr>
<tr>
<td>C9</td>
<td>Capacitor</td>
<td>33pf</td>
<td>1</td>
</tr>
<tr>
<td>C10</td>
<td>Capacitor</td>
<td>33pf</td>
<td>1</td>
</tr>
<tr>
<td>C11</td>
<td>Capacitor</td>
<td>10000uf</td>
<td>1</td>
</tr>
<tr>
<td>D1, D2</td>
<td>LED</td>
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<td>2</td>
</tr>
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<td>F1</td>
<td>FUSE</td>
<td>1A</td>
<td>1</td>
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<tr>
<td>J1</td>
<td>LCD</td>
<td>16 pin connectors</td>
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</tr>
<tr>
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<td>Connector</td>
<td>2 pins</td>
<td>1</td>
</tr>
<tr>
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<td>Connector</td>
<td>2 pins</td>
<td>1</td>
</tr>
<tr>
<td>J4</td>
<td>Connector</td>
<td>2 pins</td>
<td>1</td>
</tr>
<tr>
<td>J5</td>
<td>Connector</td>
<td>3 pins</td>
<td>1</td>
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</tr>
<tr>
<td>J7</td>
<td>Connector</td>
<td>2 pins</td>
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</tr>
<tr>
<td>J8</td>
<td>Connector</td>
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<td>Transistor</td>
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<td>R1, R6, R7, R8, R10</td>
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<td>10k</td>
<td>5</td>
</tr>
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<td>R2, R5</td>
<td>Potentiometer</td>
<td>10k</td>
<td>2</td>
</tr>
<tr>
<td>R3, R4</td>
<td>Resistor</td>
<td>Depends on feedback voltage*</td>
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<td>V1</td>
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<td>1A</td>
<td>1</td>
</tr>
<tr>
<td>V2</td>
<td>Rectifier</td>
<td>1A</td>
<td>1</td>
</tr>
<tr>
<td>V3</td>
<td>Rectifier</td>
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<tr>
<td>Y1</td>
<td>Crystal</td>
<td>4MHz</td>
<td>1</td>
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</tbody>
</table>

Table 0.1: List of components

* R3 and R4 values depends on the encoder sensor maximum analog voltage. In this project it was from 0 to 24V, so these two resistors act as voltage divider to convert the feedback analog voltage to 0-5V.
Appendix B

Microcontroller C program software

int voltage, voltage1, voltage2, voltage3, k;
int lower, upper, nn, result, g;
int t, cnt, speed, pot, duty, newspeed;
int feedback_in, feedback_volt;
int real_speed, feedback_in1, feedback_in2, feedback_in3, feedback_in4,
feedback_in5, feedback_in6, feedback_in7, feedback_in8;
int speed_lower, speed_upper, center, low, upp;
float pwmvol, test, duty_float, real_speedf;
float timereq, delay;
int timerreg;
char txt[7], txt2[7], txt3[7], txt4[7];
int receive[5], mspeed[5];

void interrupt()
{

    if(INTCON.TMR0IF == 1)
    {
        // set the initial value to the Timer0
        // program
        // optimisation

        if((real_speed-speed) >= 100 || (speed-real_speed) >= 100)
            k = 2;

        if((real_speed-speed) >= 400 || (speed-real_speed) >= 400)
            k = 5;

        if((real_speed-speed) >= 900 || (speed-real_speed) >= 900)
            k = 8;

        if((real_speed-speed) >= 1300 || (speed-real_speed) >= 1300)
            k = 10;

        if((real_speed-speed) >= 1600 || (speed-real_speed) >= 1600)
            k = 15;

        if (real_speed == speed)
duty=duty;

if (real_speed<speed)
duty=duty+k;

if (real_speed>speed)
duty=duty-k;

if (duty>=255)
duty=255;

if (duty<=0)
duty=0;

cnt++;
if(cnt==5)
cnt=1;
tmr0h=upper;
tmr0l=lower;
INTCON.TMR0IF = 0;  // clear tmr0 flag 

///////////////////////////////////////////////////////////////////////////////////UART received inturept///////////////////////////

if(RCIF_bit == 1)
{
  nn++;  
  receive[nn]=UART1_Read();
  RCIF_bit = 0;  //Flag bit, RCIF, will be set when reception is complete

  mspeed[1]=(receive[1]-48)*1000;
  mspeed[2]=(receive[2]-48)*100;
  mspeed[3]=(receive[3]-48)*10;
  mspeed[4]=(receive[4]-48);

  if (nn==5)
  {
    nn=0;
  }
}
}
// LCD module connections
sbit LCD_RS at RB4_bit;
sbit LCD_EN at RB5_bit;
sbit LCD_D4 at RB0_bit;
sbit LCD_D5 at RB1_bit;
sbit LCD_D6 at RB2_bit;
sbit LCD_D7 at RB3_bit;

sbit LCD_RS_Direction at TRISB4_bit;
sbit LCD_EN_Direction at TRISB5_bit;
sbit LCD_D4_Direction at TRISB0_bit;
sbit LCD_D5_Direction at TRISB1_bit;
sbit LCD_D6_Direction at TRISB2_bit;
sbit LCD_D7_Direction at TRISB3_bit;
// End LCD module connections

void main()
{

cmos = 0xff;
trisb.f0=1;
trisd.f7=0;
adcon1=0b00000111;
CMCON=0b00000111;

UART1_Init(9600);               // Initialize UART module at 9600 bps
Delay_ms(100);                  // Wait for UART module to stabilize

receive[1]=0;
receive[2]=0;
receive[3]=0;
receive[4]=0;

Lcd_Init();
Lcd_Cmd(LCD_CLEAR);              // Clear display
Lcd_Cmd(LCD_CURSOR_OFF);         // Cursor off
Lcd_Cmd(LCD_CLEAR);

// Timer configuration
RCIE_bit = 1;   // EUSART Receive Interrupt Enable bit
GIEL_bit=1;     //Peripheral Interrupt Enable bit
intcon.gie=1;
intcon.tmr0if=0;
intcon.tmr0ie=1;
lower = 0b11011000;
upper = 0b11110110;
tmr0h=upper;
tmr0l=lower;
t0con=0b10000111;
duty=0;
portd.f7=0;
Pwm1_Init(3000);
PWM1_Set_Duty(0);

nn= 0;
cnt=1;
Lcd_Out(1, 1, "Mode:");
Lcd_Out(2, 1, "Speed:");
while(1)
{
    if(portd.f0==1)
    {
        Lcd_Out(1, 8, "Manual");
        // read the analog signal from RA0 for determine the speed manually
        pot = ADC_Read(0);
        voltage = (pot*2.05);      //scale from 0 to 2046 rpm
        // Moving Filter
        voltage3=voltage2;
        voltage2=voltage1;
        voltage1=voltage;
        if(voltage==0 || voltage1==0 || voltage2==0 || voltage3==0 )
            speed=voltage;
        else
            speed=(voltage+voltage1+voltage2+voltage3)/4;
    }
    if(portd.f0==0)
    {
        Lcd_Out(1, 8, "Serial");
            speed=0;
        else
    }
    // speed limitation values.
if(speed>=2101)
speed=2100;
if(speed<=100)
{
speed=0;
Lcd_Out(2, 8, " OFF");
duty=0;
t0con.TMR0ON=0;
}

if(speed>=100 && speed<=2100)
{
    k=1;
t0con.TMR0ON=1;
}

// feedback
feedback_in = ADC_Read(1);
// Moving Filter
feedback_in8=feedback_in7;
feedback_in7=feedback_in6;
feedback_in6=feedback_in5;
feedback_in5=feedback_in4;
feedback_in4=feedback_in3;
feedback_in3=feedback_in2;
feedback_in2=feedback_in1;
feedback_in1=feedback_in;

if(feedback_in1==0 || feedback_in2==0 || feedback_in3==0 || feedback_in4==0 || feedback_in5==0 || feedback_in6==0 )
feedback_in=feedback_in1;
else
feedback_in=(feedback_in1+feedback_in2+feedback_in3+feedback_in4+feedback_in5+feedback_in6+feedback_in7+feedback_in8)/8;

//measured with direct DC voltage
real_speedf=feedback_in*2.161;
if(real_speedf<=0)
real_speedf=0;

real_speed=real_speedf;

PWM1_Set_Duty(duty);
PWM1_Start();
if(cnt==1)
{
    intToStr(speed,txt2);
    Lcd_Out(2,7,txt2);
    cnt++;
}
}
## Appendix C

### Automotive measurement results

<table>
<thead>
<tr>
<th>Wheel speed (ω\text{RPM})</th>
<th>Measured speed by radar (ω\text{RPM})</th>
<th>Error %</th>
</tr>
</thead>
<tbody>
<tr>
<td>610</td>
<td>615.8</td>
<td>0.94</td>
</tr>
<tr>
<td>620</td>
<td>623.9</td>
<td>0.62</td>
</tr>
<tr>
<td>630</td>
<td>638.1</td>
<td>1.29</td>
</tr>
<tr>
<td>640</td>
<td>642.4</td>
<td>0.37</td>
</tr>
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<td>650</td>
<td>654.2</td>
<td>0.65</td>
</tr>
<tr>
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<td>662.9</td>
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<td>670</td>
<td>675.7</td>
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</tr>
<tr>
<td>680</td>
<td>685.7</td>
<td>0.84</td>
</tr>
<tr>
<td>690</td>
<td>694.6</td>
<td>0.67</td>
</tr>
<tr>
<td>700</td>
<td>704.4</td>
<td>0.62</td>
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<td>710</td>
<td>715.7</td>
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<td>0.43</td>
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<tr>
<td>730</td>
<td>733</td>
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<tr>
<td>740</td>
<td>745</td>
<td>0.67</td>
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<tr>
<td>750</td>
<td>755.7</td>
<td>0.76</td>
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<tr>
<td>760</td>
<td>765.7</td>
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<td>770</td>
<td>778.6</td>
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<td>790</td>
<td>797.8</td>
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**Table 0.2:** Automotive measurements test result.
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Master of Science, Electronics Design
Bachelor of Electrical Engineering.
rimawi2002@hotmail.com
mohalr18@student.hh.se