Radar-Based Detection and Classification of Vehicles and Pedestrians

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February 3, 2025

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Chapter 1

Introduction

This report presents an overview of the work conducted by Mishay Naidoo during his 2024 winter Erasmus exchange at the University of West Attica. The project, undertaken as part of his Master's degree, focused on radar-based detection and classification of vehicles and pedestrians.

1.1 Background

Road traffic monitoring is key to infrastructure planning and typically involves counting the number of vehicles driving on a road at a given point in time, recording their velocities, and identifying the class of vehicle [1]. A traffic monitoring system should be capable of performing this task automatically, allowing the user to obtain traffic information easily and reliably. Such a system is useful in assisting municipal authorities by providing them with a better understanding of the number and class of vehicles travelling on their roads throughout the day. This information can help identify areas needing road upgrades, plan road maintenance around traffic, and provide insights into pollution emissions. A successful traffic monitoring system in a city requires several sensor nodes to be deployed in various locations which form part of a larger system of sensors. Having multiple sensor subsystems communicating to a central location allows the user to monitor many roads in a city simultaneously. Considering the financial cost of a multi-sensor system, the individual sensors should be low-cost.

1.2 Objectives

This project aimed to evaluate existing printed circuit boards (PCBs), designed by Mishay and Ryan Jones (another UCT student) before the Erasmus exchange, for interfacing with the IPM-165 continuous-wave (CW) Doppler radar. The IPM-165 was chosen as the primary sensor for data capture due to its affordability. The IPM-165's output signal requires amplification due to its weak output signal (10mVpp range) and an analog-to-digital converter (ADC) to sample the data for processing.

The first PCB was designed to evaluate different amplifiers to identify the one that provided the best signal amplification while minimizing added noise. This board included three amplifiers for testing:

- AD620 by Analog Devices
- AD8422 by Analog Devices
- MCP6024 by Microchip Technology

The second PCB was designed to evaluate different ADCs to find the chip that maintained the original signal's integrity when performing the conversion whilst minimizing added noise. Three ADCs were included on the board:

- ADAU1979 by Analog Devices
- STM32H7 by ST
- PCM2900 by Texas Instruments

Fig 1.1 and Fig 1.2 show 3D renders of both boards.

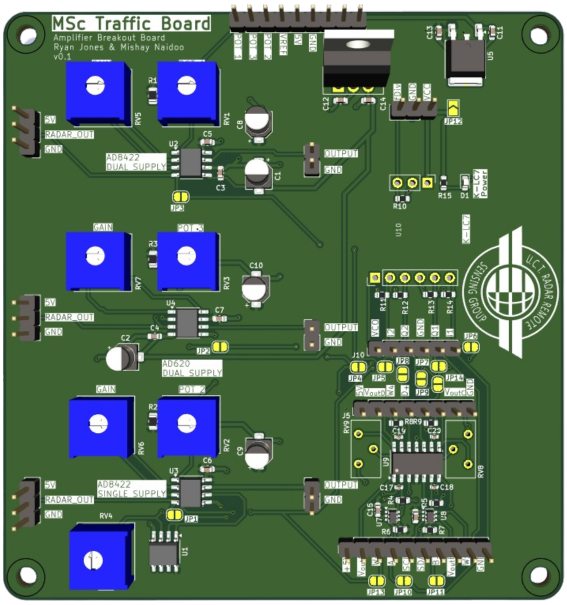

Figure 1.1: 3D Render of Amplifier PCB

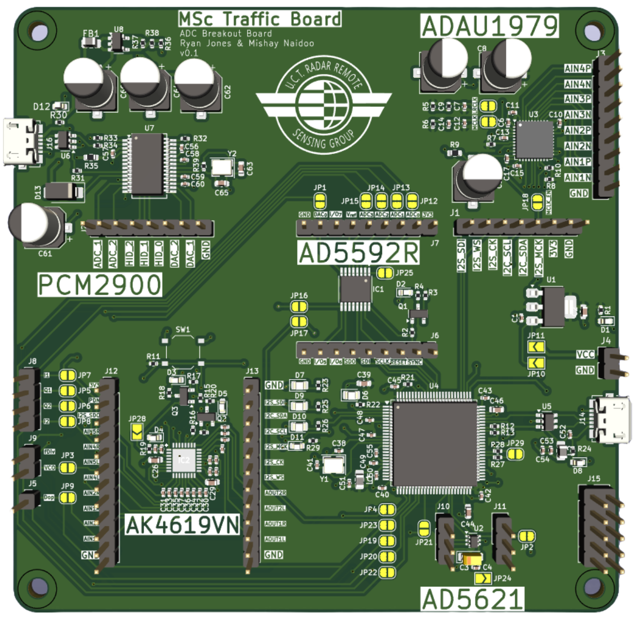

Figure 1.2: 3D Render of ADC PCB

Upon evaluation of the two boards, the selected ADC and amplifier had to be deployed to capture preliminary traffic data to evaluate the performance of the system in a real sensing scenario. Lastly, a final PCB with the selected components was required to combine all of the devices onto a single board for easy deployment.

Chapter 2

Methodology and Results

This chapter provides an overview of the testing procedures for the amplifier and ADC boards, along with the resulting plots. It also details the process for capturing traffic data using the selected components and presents the captured data. Finally, the design process for the final board is shown.

2.1 Amplifier Board

The amplifiers were each tested by feeding an ideal 1khz sinusoid waveform into each amplifier and plotting the frequency domain plots of the amplified data. Each amplifier was compared to the others to analyze the harmonics and noise introduced by each. Figure 2.1 displays the frequency domain plots of all three amplifiers overlaid on top of each other.

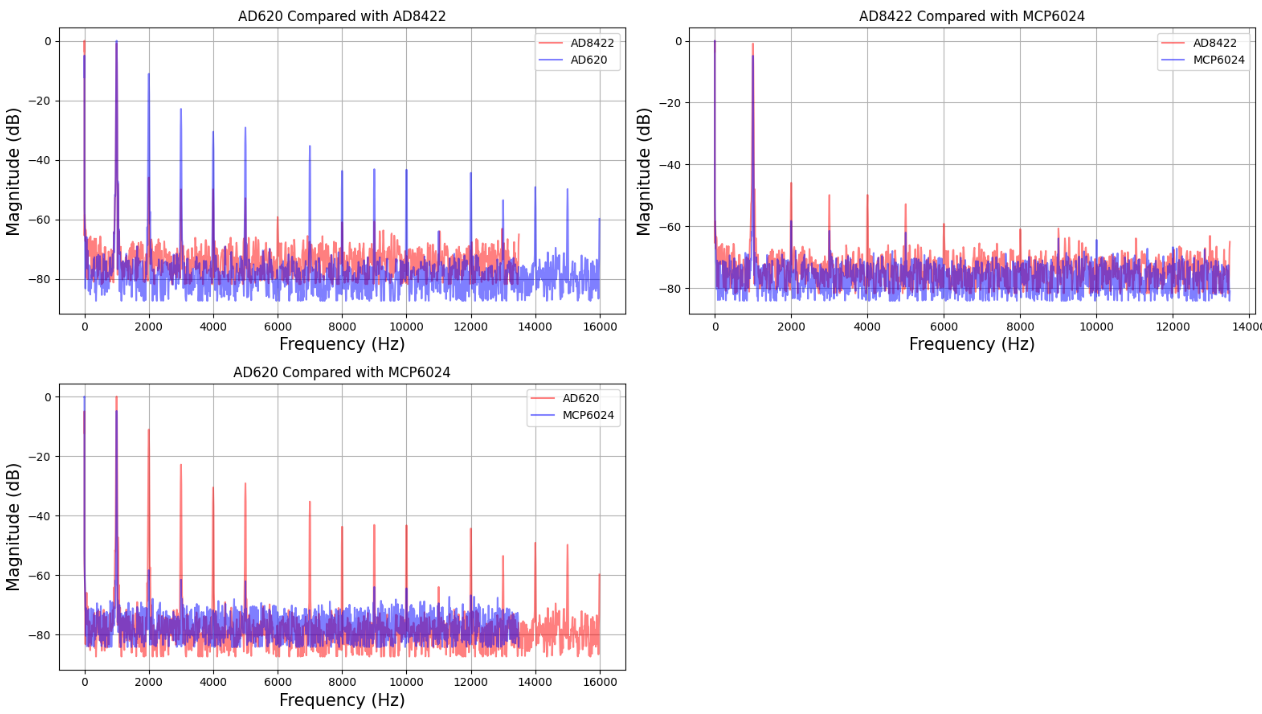

Figure 2.1: Amplifier Plots with 1khz Sinusoid

Fig 2.1 demonstrates that the AD620 performed poorly compared to the other two amplifiers. The harmonics generated by the 1kHz wave were more pronounced in the AD620 plots, and the power at each harmonic was higher. Both the MCP6024 and AD8422 showed good performance with low-power harmonics and a strong signal-to-noise ratio (SNR). However, the MCP6024 outperformed the AD8422 as the power of the harmonics is significantly less. Additionally, a frequency sweep test was done on the AD8422 and MCP6024 to observe the amplifier's performance at various frequencies. This was done by feeding in sinusoids of varying frequencies and observing the frequency domain plots of the captured data.

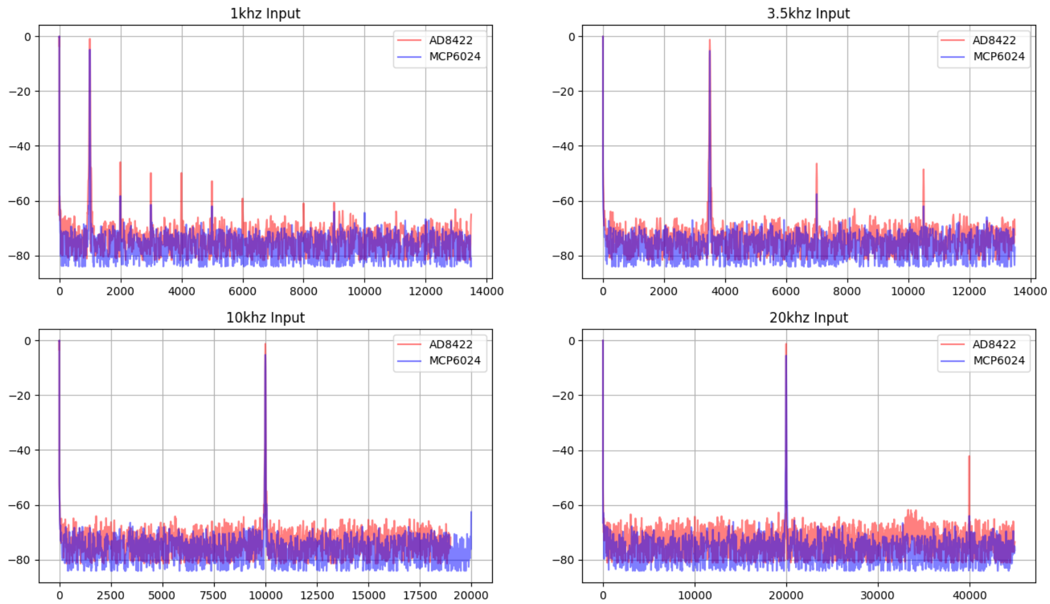

Figure 2.2: Amplifier Plots with Frequency Sweep

Fig 2.2 shows that both amplifiers performed similarly at different frequencies with the MCP6024 still outperforming the AD8422. In conclusion, the MCP6024 was selected as the best-performing amplifier.

2.2 ADC Board

The ADCs were tested by feeding in an ideal 1khz sinusoid and plotting the frequency domain of the sampled data. Each ADC was compared with an off-the-shelf soundcard (the Xonar U3) and the performance was evaluated.

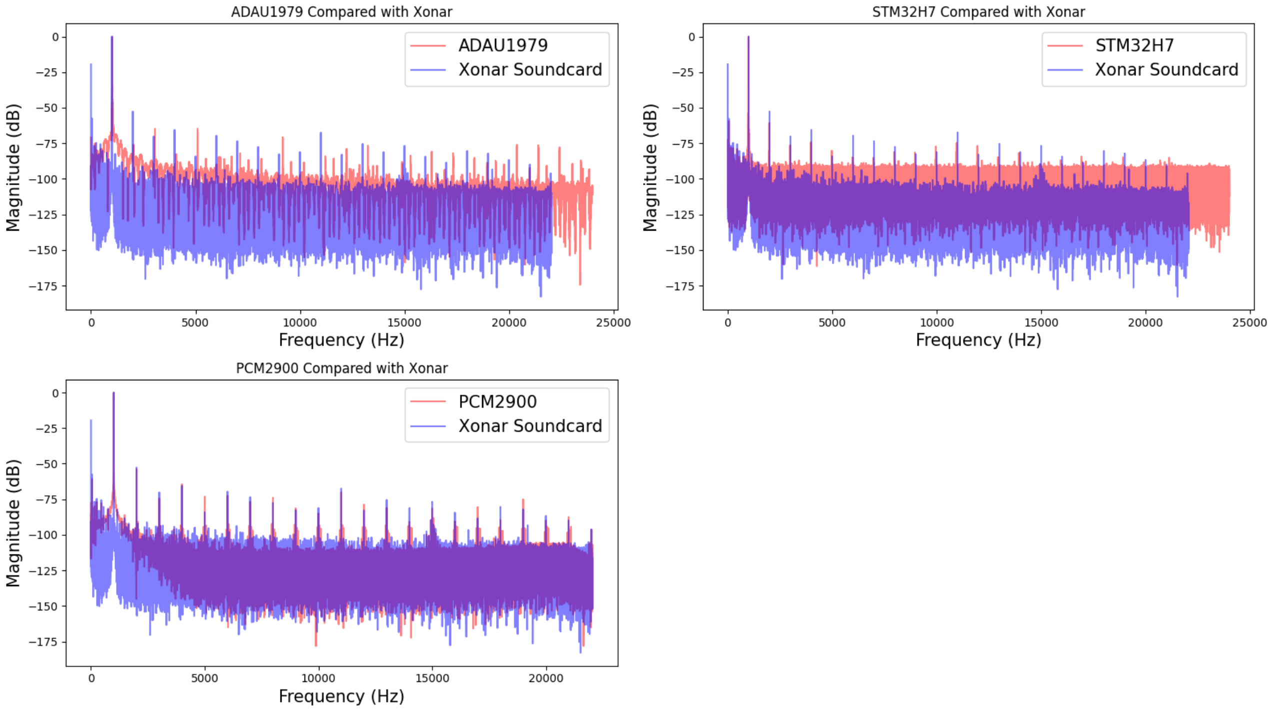

Figure 2.3: ADC Plots with 1khz Sinusoid Input

Fig 2.3 shows that the STM32H7 had a significantly worse SNR when compared with the Xonar making it unsuitable for this application. The harmonics created by the PCM2900 are more pronounced than the ADAU1979 and the Xonar however the SNR excluding the harmonics is marginally better than the ADAU1979. Ultimately, the ADAU1979 was selected due to its low SNR and low power harmonics as well as its 24-bit resolution which is significantly better than the 16-bit resolution of the PCM2900.

2.3 Data Capture

The two PCBs were combined to make a temporary data capture device. The selected amplifier and ADC were connected and the entire system was powered using a 12V battery. The system was deployed on a curb on the University of West Attica campus and used to capture vehicle data. The captured data can be visualised using a spectrogram plot.

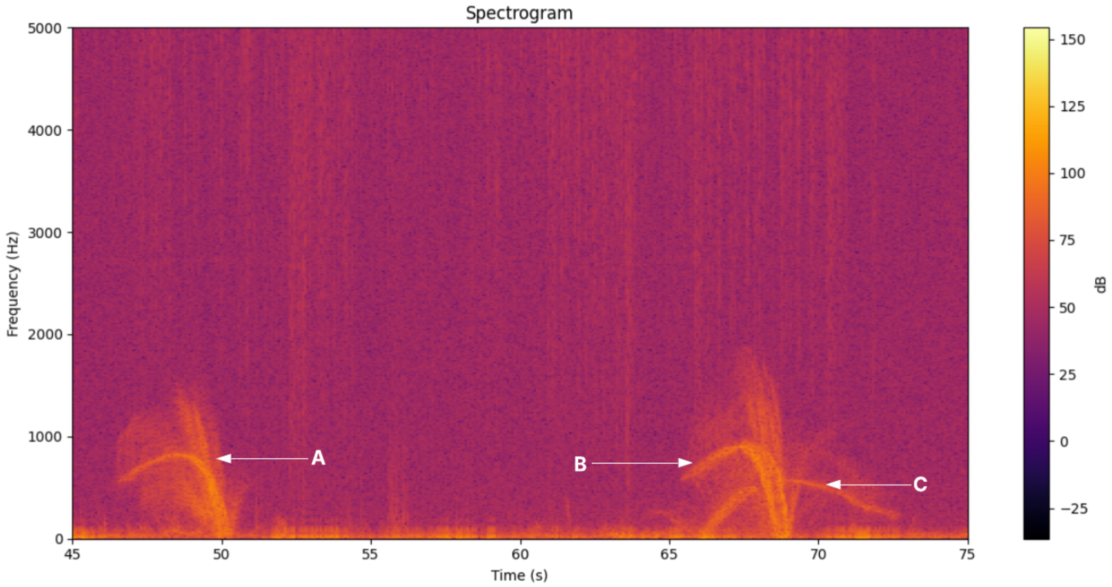

Figure 2.4: Captured Traffic Data

Fig 2.4 shows the captured data. Three vehicles can be identified in the plot with the vehicles labelled *A* and *B* driving towards the sensor and *C* driving away from the sensor. Each target can be clearly identified in the plot indicating a strong SNR.

2.4 Final Board Design

The final board design included the MCP6024 amplifier tested on the amplifier board. The ADAU1979 was substituted for the ADAU1372 because this includes a built-in digital-to-analog converter (DAC) allowing the system to interface with frequency-modulated continuous wave radars as well as the IPM-165. The system also included an STM32H7 microcontroller to interface with the DAC and other systems on the board. An SD card reader was added to allow for data storage. Lastly, various environmental sensors were included on the board to give the user more information about the location of data capture. The sensors included were:

- CO2 Sensor
- Temperature and Humidity Sensor
- GPS
- Light Intensity Sensor
- VO2 Sensor
- Real-time Clock (RTC)

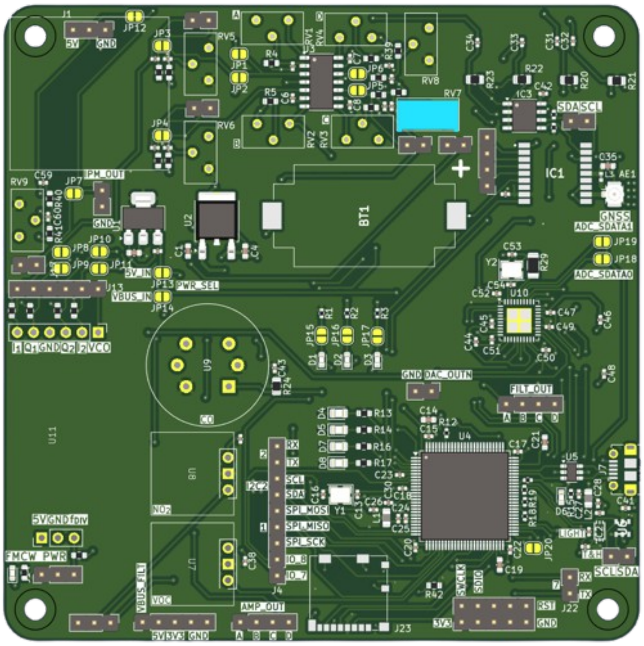

Figure 2.5: Final Board 3D Render

The board seen in Fig 2.5 was ordered just before the end of Mishay's Erasmus.

Chapter 3

Conclusion

This work has made significant progress toward the development of a fully functional traffic monitoring system. The amplifier and ADC PCBs were successfully tested, and the most suitable components were selected based on their performance. These components were deployed in a real-world setting, successfully capturing traffic data. However, due to time constraints, pedestrian data collection was not conducted.

The validated components were integrated into a final board, which, upon arrival, will be used for large-scale data collection. This will enable further advancements in data processing and vehicle classification, bringing the system closer to full implementation.

Bibliography

[1] M. Bernas, B. Płaczek, W. Korski, P. Loska, J. Smyła, and P. Szymała, "A survey and comparison of low-cost sensing technologies for road traffic monitoring," *Sensors*, vol. 18, no. 10, 2018. [Online]. Available: https://www.mdpi.com/1424-8220/18/10/3243