Birla Institute of Technology and Science, Pilani

EEE F377: Design Project

Design of Direct LED Modulator for VLC Transmitter

Under the guidance of,

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Abstract

The automotive industry is evolving with the integration of advanced technologies, including Vehicle-to-Vehicle (V2V) communication, to enhance road safety and traffic management. This project focuses on developing a Visible Light Communication (VLC) system tailored for automotive applications. Methodology involves establishing half-duplex and full-duplex communication setups using Arduino microcontrollers, LED arrays, and photodetectors. ASCII encoding and On-Off Keying (OOK) modulation are used to enable bidirectional communication. Integration of a JML-LV22754 5V LED strip allows us to simulate a car's Daytime Running Lights (DRL) system, showcasing full-duplex communication in realistic vehicular scenarios. Future work includes designing a Direct LED Modulator for transmitter optimization and integrating the system with a car's DRLs to enable advanced communication features. Overall, this project contributes to the development of robust VLC-based V2V communication systems, promising improved road safety, traffic management, and automotive efficiency.

Birla Institute of Technology and Science, Pilani

Department of Electrical and Electronics Engineering

CERTIFICATE

This is to certify that "SARANSH GAUTAM" of Dual Degree M.Sc. Mathematics and B.E. Electrical and Electronics has submitted project report entitled "Design of Direct LED Modulator for VLC Transmitter" for fulfilment of EEE F377 - Design Project in 2nd semester of academic year 2023-24. The report has been reviewed and found satisfactory for evaluation.

Dr. Rahul Singhal

(Associate Professor, EEE Deptt.)

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Introduction

In recent years, the automotive industry has been witnessing a transformative shift towards the integration of cutting-edge technologies aimed at enhancing vehicle safety, efficiency, and connectivity. One such technology gaining considerable attention is Vehicle-to-Vehicle (V2V) communication, which holds the promise of revolutionizing road safety and traffic management by enabling vehicles to exchange vital information in real-time. However, the existing V2V communication systems primarily rely on radio frequency (RF) communication, which poses challenges such as limited bandwidth, susceptibility to interference, and regulatory constraints.

To overcome these limitations and unlock the full potential of V2V communication, researchers and engineers are increasingly exploring alternative communication technologies. Among these, Visible Light Communication (VLC) emerges as a promising candidate due to its distinct advantages, including high bandwidth, immunity to electromagnetic interference, Safety on human skin and compatibility with existing lighting infrastructure.

Despite its immense potential, the practical implementation of VLC for V2V communication in real-world scenarios poses several technical challenges. These challenges encompass issues such as signal attenuation due to environmental conditions, mobility-induced variations in signal strength, and the design of robust modulation schemes capable of accommodating dynamic vehicular movements.

This report seeks to address these challenges and contribute to the development of a robust and efficient VLC-based V2V communication system tailored for automotive applications. Special emphasis will be made in this report towards investigating the design of direct LED Modulator for the VLC transmitter.

Literature Review

Goto, Y. et al, A New Automotive VLC System Using Optical Communication Image Sensor (2016)

The paper introduces a novel approach to Vehicle-to-Vehicle (V2V) communication utilizing an Optical Communication Image Sensor (OCIS). This system enables vehicles to exchange information via modulated light signals, enhancing communication reliability and security compared to traditional RF-based systems. The OCIS captures optical signals emitted by nearby vehicles, allowing for robust data transmission even in challenging environmental conditions. The paper outlines the design, implementation, and experimental validation of the proposed VLC system, highlighting its potential to revolutionize automotive communication by offering high-speed, interference-resistant connectivity between vehicles.

Amjad, M. et al, An IEEE 802.11 Compliant SDR-based System for Vehicular Visible Light Communications (2023)

The paper "An IEEE 802.11 Compliant SDR-based System for Vehicular Visible Light Communications" presents a Software-Defined Radio (SDR) based system designed to enable Visible Light Communications (VLC) in vehicular environments while adhering to the IEEE 802.11 standard. This system aims to enhance communication between vehicles by leveraging VLC technology, which utilizes modulated light for data transmission. By integrating SDR technology, the system offers flexibility and adaptability to varying communication scenarios. It ensures compatibility with existing IEEE 802.11 infrastructure, allowing seamless integration into vehicular networks. The paper discusses the architecture, implementation, and performance evaluation of the proposed system, demonstrating its feasibility and effectiveness in supporting high-speed, reliable VLC communication among vehicles.

Kim, Y. et al, Experimental Demonstration of LED-based Vehicle to Vehicle Communication under Atmospheric Turbulence (2015)

The research paper "Experimental Demonstration of LED-based Vehicle to Vehicle Communication under Atmospheric Turbulence" presents a comprehensive examination of the performance of LED technology in facilitating vehicle-to-vehicle (V2V) communication, particularly in environments characterized by atmospheric turbulence. Atmospheric turbulence can introduce fluctuations in signal propagation, impacting the reliability of communication systems, especially in outdoor settings like vehicular environments.

Methodology

Half-Duplex Communication: In order to validate the effectiveness of the Visible Light Communication (VLC) Vehicle-to-Vehicle (V2V) system, an illustrative setup was created. This setup consisted of two Arduino microcontroller boards, LED array transmitters, and photodetectors. Message transmission involved the utilization of ASCII encoding combined with On-Off Keying (OOK) modulation protocol. The communication arrangement was devised to operate in both directions, allowing for the transmission and reception of signals. The LED array emitted light pulses based on the binary representation of ASCII characters, where a logic of 1 corresponded to LED activation and 0 indicated LED deactivation. Following this, the transmitted signals were captured and interpreted by photodetectors, and the received data underwent decoding using Arduino-based algorithms.

Transmission Protocol: Figure 1 illustrates the Transmitter Communication Protocol, where the data is encoded in ASCII format and transmitted using the On-Off Keying (OOK) protocol. By default, the transmitter operates in the ON state. Prior to initiating message transmission, the transmitter remains in a low state for one period. Each character, consisting of 8 bits, is transmitted according to its ASCII representation. Subsequently, after transmitting the 8 bits, a high output is maintained for at least one period. If the transmitted character was the final one in the message, the LED remains illuminated. However, if it wasn't the last character, the same protocol can be repeated for the subsequent character.

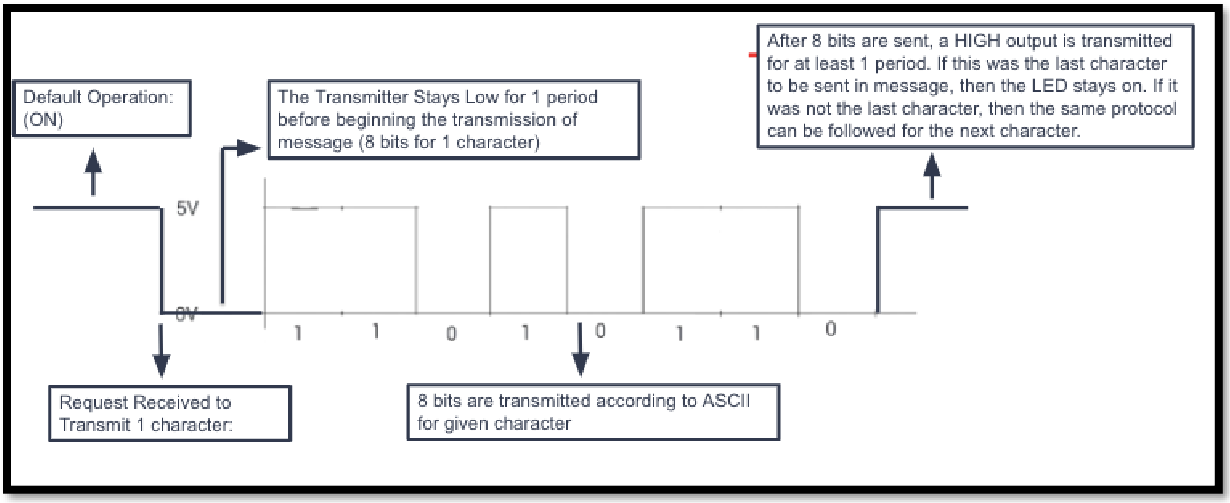

Figure 1: Transmission Protocol

Receiver Protocol: In Figure 2, the Receiver Communication protocol is depicted. The detection mechanism initiates signal detection upon identifying a descending edge. Subsequently, it waits for 1.5 periods after this detection. The photodiode then captures input signals eight times, with each period lasting 1 period for 8 bits. Each received bit is determined to be either 0 or 1 based on a predetermined threshold. The detection process halts until the occurrence of the next descending edge.

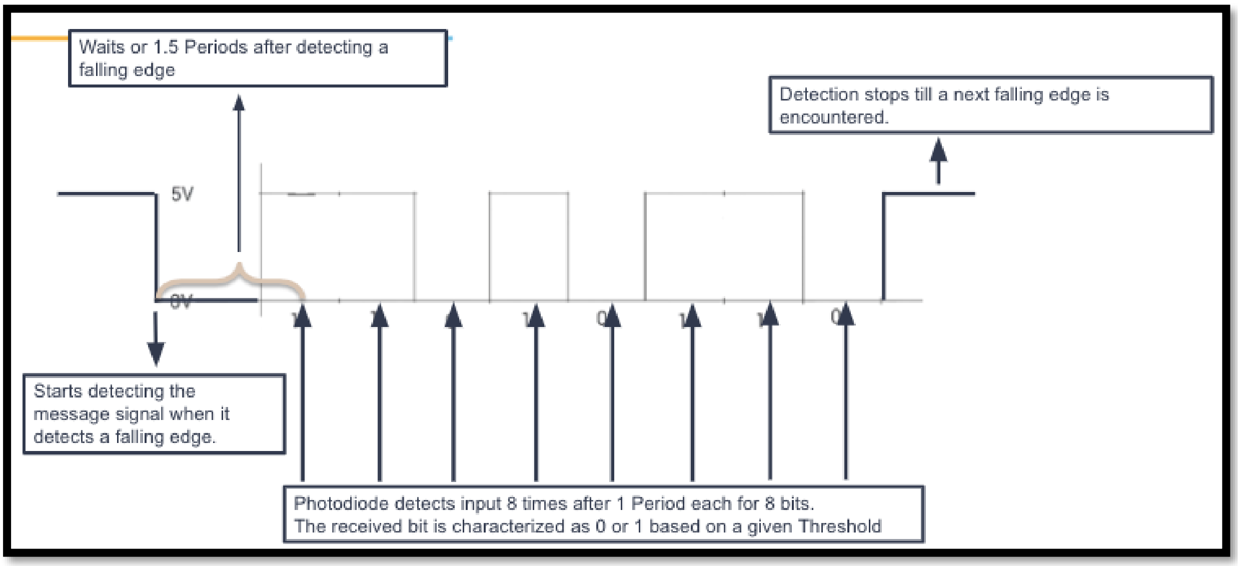

Figure 2: Receiver Protocol

Full Duplex Communication:

Full-Duplex Communication: Building upon the foundation of the established half-duplex Visible Light Communication (VLC) Vehicle-to-Vehicle (V2V) system, full-duplex communication was achieved by augmenting the setup with an additional pair of Arduino microcontroller boards. This expanded configuration now comprises four Arduino microcontroller boards, divided evenly between two communicating sides. Each side is equipped with one Arduino board dedicated to LED transmission and another for photodiode reception. The transmission and reception protocols remain consistent with those employed in the half-duplex setup, utilizing ASCII encoding and On-Off Keying (OOK) modulation. This augmentation enables simultaneous bidirectional communication, allowing for the transmission and reception of signals concurrently. The LED arrays continue to emit light pulses encoding binary representations of ASCII characters, while the photodiodes capture and interpret the transmitted signals. Decoding of received data is conducted using Arduino-based algorithms, ensuring seamless and efficient full-duplex communication within the VLC V2V system.

Integration of JML-LV22754 5V LED Strip to simulate a Car’s DRL system:

We have worked on the integration of a JML-LV22754 5V LED strip with our setup to simulate a car's Daytime Running Lights (DRL) system. This addition allowed for the demonstration of full-duplex communication within the context of vehicular environments. By leveraging the LED strip as a means of transmission, bidirectional communication was achieved concurrently with the transmission and reception of signals. This milestone showcases the adaptability of the VLC technology for practical automotive applications.

Results and Discussions

1. **Established Half Duplex Communication:** The initial phase of our experimentation focused on establishing half-duplex communication within the Visible Light Communication (VLC) Vehicle-to-Vehicle (V2V) system. Utilizing the devised setup comprising Arduino microcontroller boards, LED array transmitters, and photodetectors, we successfully demonstrated bidirectional communication. Through the implementation of ASCII encoding paired with On-Off Keying (OOK) modulation protocol, messages were effectively transmitted and received between the two communicating sides. This achievement laid the groundwork for further enhancements in our communication system.

2. **Established Full Duplex Communication:** Building upon the success of the half-duplex communication setup, we enhanced our system to achieve full-duplex communication capability. By augmenting the setup with an additional pair of Arduino microcontroller boards on each side, we successfully realized full-duplex communication. The transmission and reception protocols remained consistent with the half-duplex setup, ensuring compatibility and efficiency. Furthermore, through optimization and fine-tuning of our system parameters, we achieved a transmission speed of 50 bits per second, enabling rapid and seamless exchange of data between communicating vehicles.

3. **Attempted Establishment of Multi-Channel Communication:** In an effort to further enhance the versatility and robustness of our communication system, we explored the possibility of implementing multi-channel communication. This involved utilizing different wavelength ranges as distinct channels to facilitate simultaneous transmission of multiple streams of data. However, despite our efforts, we encountered challenges in establishing multi-channel communication due to latency issues observed in the multi-colour photodiode. The latency issue posed significant hurdles in synchronizing and coordinating the reception of signals across different channels, ultimately rendering our attempt unsuccessful. Nonetheless, this exploration provided valuable insights into the complexities of multi-channel communication within VLC V2V systems, highlighting areas for future research and development.

4. **Integration of JML-LV22754 5V LED Strip:**

   The successful integration of a JML-LV22754 5V LED strip to emulate a car's Daytime Running Lights (DRL) system marked a significant achievement in our study. This integration facilitated the demonstration of full-duplex communication in realistic vehicular scenarios. Utilizing the LED strip for transmission, we achieved bidirectional communication simultaneously transmitting and receiving signals. This milestone not only highlights the feasibility of VLC technology for practical automotive applications but also emphasizes its potential impact on improving road safety and traffic management.

Conclusion

The development and implementation of the Visible Light Communication (VLC) system for Vehicle-to-Vehicle (V2V) communication has shown promising results for the automotive industry. Through the utilization of Arduino microcontroller boards, LED arrays, and photodetectors, we successfully established both half-duplex and full-duplex communication setups. By employing ASCII encoding and On-Off Keying (OOK) modulation, we achieved efficient bidirectional communication, laying the groundwork for further enhancements.

The integration of a JML-LV22754 5V LED strip to simulate a car's Daytime Running Lights (DRL) system marked a significant milestone, showcasing the adaptability of VLC technology in realistic vehicular scenarios.

Future work includes the design of a Direct LED Modulator to enhance transmitter performance and reliability. Ideas such as Pulse Width Modulation (PWM), Huffman encoding, and adaptive modulation schemes hold promise for optimizing data transmission. Integrating the communication system with a car's DRLs presents opportunities to enhance road safety and enable advanced features like collision avoidance and traffic management.

Overall, this project contributes to the development of robust and efficient VLC-based V2V communication systems tailored for automotive applications. By addressing technical challenges and exploring innovative solutions, we aim to improve road safety, traffic management, and automotive efficiency.

Future Work

Design of a Direct LED Modulator for VLC transmitter: In the development of a Visual Light Communication (VLC) system, the efficiency and reliability of the transmitter play a crucial role in ensuring robust communication. One key component of the transmitter is the LED modulator, which directly influences the modulation and transmission of data through light pulses. Here, we explore some ideas for designing a Direct LED Modulator to enhance the performance of the transmitter:

1. **Pulse Width Modulation (PWM):** Implementing PWM techniques can enable precise control over the intensity of light emitted by the LED array. By varying the duty cycle of the PWM signal, different brightness levels can be achieved, facilitating the encoding of binary data efficiently. This method offers flexibility in adjusting the modulation depth according to the specific requirements of the communication system.

2. **Huffman Encoding:** To further enhance transmission efficiency, the integration of Huffman encoding techniques could be explored. Huffman encoding, by assigning variable-length codes to input characters based on their frequencies, enables more frequent characters to be represented using shorter codes. Implementing Huffman encoding in conjunction with the VLC transmitter can effectively compress data before transmission, optimizing bandwidth usage and potentially increasing the effective bit rate of the communication system.

3. **Adaptive Modulation Schemes:** Incorporating adaptive modulation schemes based on the ambient light conditions can improve the reliability of data transmission. By dynamically adjusting the modulation parameters such as modulation depth and frequency in response to changes in ambient light levels, the system can maintain optimal performance under varying environmental conditions. Adaptive modulation ensures robust communication even in challenging lighting environments.

4. **Digital Signal Processing (DSP) Techniques:** Leveraging DSP techniques can enhance the signal processing capabilities of the LED modulator, enabling advanced modulation schemes such as Quadrature Amplitude Modulation (QAM) or Frequency Shift Keying (FSK). DSP algorithms can be employed to preprocess data, optimize signal-to-noise ratio, and mitigate distortion effects, resulting in higher data rates and improved spectral efficiency.

5. **Feedback Control Mechanisms:** Implementing feedback control mechanisms based on received signal quality metrics can enhance the reliability of communication. By continuously monitoring the received signal strength and error rates, the transmitter can adapt its modulation parameters in real-time to optimize performance. Feedback control mechanisms enable autonomous adjustment of modulation parameters, ensuring reliable communication even in dynamic channel conditions.
6. **Optical Filtering Techniques:** Introducing optical filtering techniques such as spectral shaping and wavelength division multiplexing (WDM) can mitigate interference and improve spectral efficiency. By selectively filtering out unwanted spectral components and optimizing the spectral bandwidth of the transmitted signal, the LED modulator can minimize crosstalk and enhance the signal-to-noise ratio, thereby improving the overall performance of the communication system.

Incorporating these innovative ideas into the design of the Direct LED Modulator can significantly enhance the performance, reliability, and efficiency of the transmitter in a Visual Light Communication system, enabling seamless and robust data transmission in various applications.

Integration with a Car’s DRL System:

As part of our ongoing efforts, we have integrated a JML-LV22754 5V LED strip, emulating the DRL system's functionality, with our system. By leveraging the existing infrastructure of DRLs, we aim to expand their role beyond traditional visibility enhancement during daylight hours. Integrating our communication system into DRLs offers a seamless and efficient means of vehicle-to-vehicle (V2V) communication, thereby enhancing overall road safety and enabling advanced features such as cooperative collision avoidance and traffic management. This integrated approach not only demonstrates the practical applicability of our communication system in real-world automotive environments but also paves the way for widespread adoption of V2V communication technologies in the automotive industry.

References

1. Goto, Yuki & Takai, Isamu & Yamazato, Takaya & Okada, Hiraku & Fujii, Toshiaki & Kawahito, Shoji & Arai, Shintaro & Yendo, Tomohiro & Kamakura, Koji. (2016). A New Automotive VLC System Using Optical Communication Image Sensor. IEEE Photonics Journal. 8. 1-1. 10.1109/JPHOT.2016.2555582.

2. Amjad, Muhammad & Tebrügge, Claas & Memedi, Agon & Kruse, Stephan & Kress, Christian & Scheytt, J. & Dressler, Falko. (2019). An IEEE 802.11 Compliant SDR-based System for Vehicular Visible Light Communications. 10.1109/ICC.2019.8761960.

3. Kim, Yong-hyeon & Cahyadi, Willy & Chung, Yeon-Ho. (2015). Experimental Demonstration of LED-based Vehicle to Vehicle Communication under Atmospheric Turbulence. 10.1109/ICTC.2015.7354759.

4. Kruse, Stephan & Kress, Christian & Memedi, Agon & Tebrügge, Claas & Amjad, Muhammad & Scheytt, J. & Dressler, Falko. (2018). Design of an Automotive Visible Light Communications Link using an Off-The-Shelf LED Headlight.

5. Takai, Isamu & Harada, Tomohisa & Andoh, Michinori & Yasutomi, Keita & Kagawa, Keiichiro & Kawahito, Shoji. (2014). Optical Vehicle-to-Vehicle Communication System Using LED Transmitter and Camera Receiver. IEEE Photonics Journal. 6. 1-14. 10.1109/JPHOT.2014.2352620.

Appendix

1. **Transmitter Code:**
   https://drive.google.com/file/d/1rWqUWqkqC_ez3mFfTZbMreD5guWu6Hx2/view?usp=sharing

2. **Receiver Code:**
   https://drive.google.com/file/d/1_Ax616KfTjRxRMjeyOuaXywy-2I0xLyL/view?usp=sharing

3. **Half Duplex Communication Code:**
   https://drive.google.com/file/d/1OO3wAy0NJJY2JiDj0bwYUCi4YBluYbVc/view?usp=sharing

4. **5V LED Transmitter: JML-LV22754**

   Product Link:
   https://www.aliexpress.com/i/1005004093060842.html#nav-specification

   Specifications:

   Colour: cold white.
   Size: 5.8*1.8*0.9cm/10.1*1.8*0.9cm.
   Bead: LED5730 *3/8 beads.
   Input Voltage: 3-5V.
   Working Current: 500mA.
   Lighting: 200LM.
   Colour temperature: 3000K

5. **Photodetector: TEMT 6000**
   Product Link:
   https://learn.sparkfun.com/tutorials/temt6000-ambient-light-sensor-hookup-guide/all

   Datasheet:
   https://drive.google.com/file/d/1k4mA0KSBx_SrL4S3f25jGMPbGzBwwTaJ/view?usp=sharing