Development of Power Line Communication for DC Ceiling Fan Control

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***Abstract*—This paper presents the design and development of a power line communication (PLC) system for controlling DC ceiling fans, aiming to replace conventional infrared (IR) remote control. The proposed system transmits control commands via existing AC wiring, addressing key limitations such as remote signal crosstalk, loss, and maintenance overhead. A low-frequency 120 kHz carrier is used to ensure minimal interference while remaining compatible with Malaysia's power line standards. The transmitter modulates control signals onto the power line, while the receiver extracts and decodes these signals to emulate IR commands. Experimental results confirm reliable end-to-end operation with minimal modification to the original fan hardware. This work demonstrates a low-cost, infrastructure-friendly solution for integrating legacy appliances into smart control systems.**

Keywords*—Power Line Communication, DC fan, smart home automation

I. Introduction

Malaysia's hot and humid climate makes electric fans a common appliance in households, schools, offices, and various indoor environments. Electric fans play a crucial role in regulating air circulation and maintaining thermal comfort, especially in buildings without centralized air conditioning such as school or workplace.

In recent years, DC (direct current) fans have gained popularity due to their better energy efficiency and finer speed control [1,2]. Unlike traditional AC (alternating current) fans, which typically use a wall-mounted regulator to adjust speed by varying the voltage through resistive or capacitive control at the live wire, DC fans operate differently. DC fan speed is controlled using Pulse Width Modulation (PWM), a technique implemented within the fan's internal circuitry. As a result, DC fans often come with remote controls that allow users to adjust speed and modes wirelessly, eliminating the need for wall-mounted regulators.

However, several challenges arise when multiple DC fans are used within a confined environment such as offices or classrooms. When relying on infrared or radio frequency remote controls, signal crosstalk can occur, where a single remote unintentionally controls adjacent fan units. Moreover, remote controls are prone to being misplaced or lost introducing maintenance overhead due to periodic replacements.

To address these challenges, a more robust control method is needed. In smart home systems, communication between devices is handled via wirelessly or through power line communication (PLC) [3,4,5]. Wireless solutions, such as Wi-Fi or Zigbee, often suffer from signal interference and limited range, especially in building with thick walls, multiple floors, or high-density electronic environments[6]. These limitations can lead to unstable connections and signal latency which can hinder real-time fan control.

In contrast, PLC offers a significant advantage by using the existing electrical wiring as a communication medium. This eliminates the need for additional infrastructure or implementation cost. PLC is also less susceptible to external electromagnetic interference compared to some wireless protocols, making it more robust in noisy environments [7-11].

However, many off-the-shelf PLC solutions are not well-suited for this application. Most are designed for general-purpose, high-bandwidth data transmission, making them unnecessarily complex and costly for simple control tasks. While PLC is generally more resistant to external electromagnetic interference than wireless systems, commercial PLC modules often operate at high frequencies (e.g., around 1 MHz or higher), which can generate electromagnetic noise affecting nearby electronic devices. Furthermore, many of these systems are developed without consideration for Malaysia's specific power line standard [12].

This paper outlines the design and development of a power line communication system to replace the IR remote control of a DC ceiling fan, focusing on low-bandwidth data transmission in the 100 kHz range. Designed to comply with Malaysia's power line standards, the system utilizes existing electrical wiring to eliminate crosstalk between fans, supports low-data-rate real-time control, and minimizes interference.

II. Proposed System

A. System overview

The proposed system consists of multiple parts as shown in Fig.1. The system can be divided into transmitter and receiver side.

The transmitter functions as a remote controller. Its purpose is to send fan operation signals such as ON/OFF, speed levels, and mode selection. The transmitter can be mounted on the wall near the main fan power switch. The control signal is injected into the live wire, allowing both power and communication signals to propagate toward the receiver (i.e. fan side).

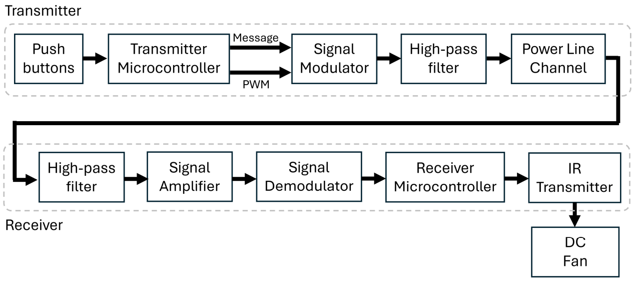

Fig. 1. System block diagram

The signal receiver can be mounted on or within the fan body. It extracts the communication signal from the power line, decodes it, and translates the command into an infrared signal that controls the fan's operation. This allows the system to interface with the existing fan design without internal modification.

The DC ceiling fan is connected to the live, neutral, and earth wires as shown in Fig.2. The live wire is isolated using capacitive coupling on both transmitter and receiver side. The circuit ground (GND) of the microcontroller is kept separated from power ground (E).

The fan's internal circuitry converts the AC supply into DC to power the motor. No changes are made to the fan's power conversion or motor components.

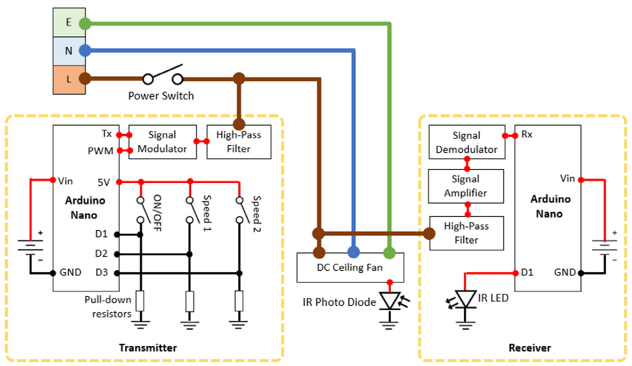

Fig. 2. Overall system diagram

This approach minimizes changes to existing cabling and fan hardware, enabling straightforward integration into current building infrastructure.

B. Transmitter operation

The transmitter consists of several sub-modules. At its core is a microcontroller based on the Arduino Nano platform, powered by a 6 V battery. It functions as a PWM signal generator and produces the control signal (Tx) at a baud rate of 9600, determined by the position of selector switches (e.g., ON/OFF, speed 1, speed 2).

The user interacts with the system by pressing the push button to turn off the fan or change its speed. Each control message is decoded into binary. For this prototype, it is sufficient to encode the message using 8 bits, or a single-byte character.

A 120 kHz PWM signal is used as a carrier wave and is modulated with the control signal using a signal modulator circuit. This modulation is implemented using a simple common-emitter NPN transistor configuration as shown in Fig.3. The modulated signal is then passed through an RC high-pass filter before being coupled to the live wire. An X2-rated 0.1 μF capacitor is used, as it can withstand overvoltage surges. The RC values are selected such that the cutoff frequency is at 120 kHz. This ensures that the high-frequency carrier can be injected onto the power line, while blocking low-frequency 240 V mains voltage from reaching and damaging the transmitter circuitry. The Zener diodes act as protection in case overvoltage happens. The output of this circuit is connected to the live wire.

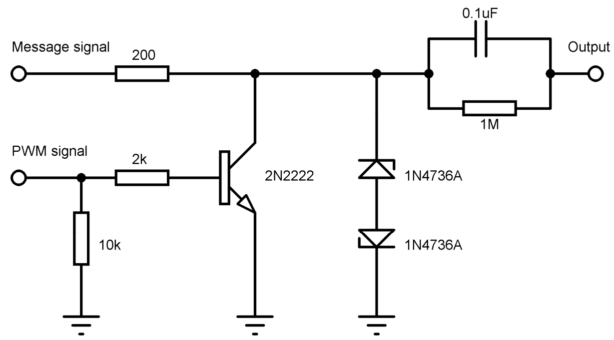

Fig. 3. Signal modulation circuit with high-pass filter

120 kHz is selected as carrier frequency because it is well above the 50 Hz mains frequency and its harmonics, ensuring minimal interference from the power line itself. At the same time, it is low enough to avoid excessive attenuation over typical residential wiring and to prevent interference with other household electronics. The 5V signal design is selected to tolerate the ±10% voltage variation allowed under Malaysia's power line specification (i.e., 216 V to 264 V). By using capacitive coupling and high-pass filtering, the circuit remains isolated from the variable AC amplitude while maintaining consistent high-frequency transmission performance.

C. Receiver operation

At the receiver side, a similar RC high-pass filter is used to isolate the high-frequency communication signal from the 240 V AC power line as shown in Fig.4. The Zener diodes acts as overvoltage protection. Another RC circuit is used to remove low-frequency noise from the signal before being fed into the signal amplifier.

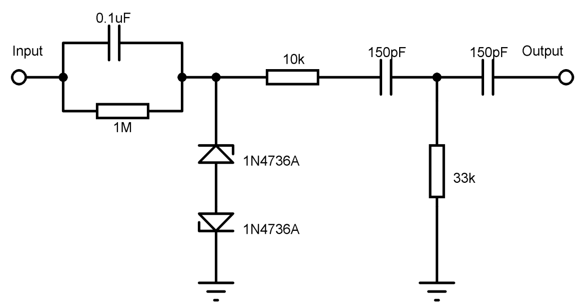

Fig. 4. High-pass filter (receiver-side)

The extracted signal, which is typically weak and noisy need to be amplified using a signal amplifier circuit. The amplifier consists of tuned-amplifier and multi-stage linear amplifier.

The tuned amplifier circuit consist of op-amps, capacitors and inductors as shown in Fig.5. It amplifies signals at a very narrow bandpass frequency centered around the amplifier's resonant frequency. The resonant frequency depends on the capacitance and inductance values, as given in Eq. 1 below.

$$f_c = \frac{1}{2\pi\sqrt{LC}} \tag{1}$$

The values of L and C are selected so that the resonant frequency is 120kHz. This stage suppresses out-of-band noise and reinforces the carrier frequency.

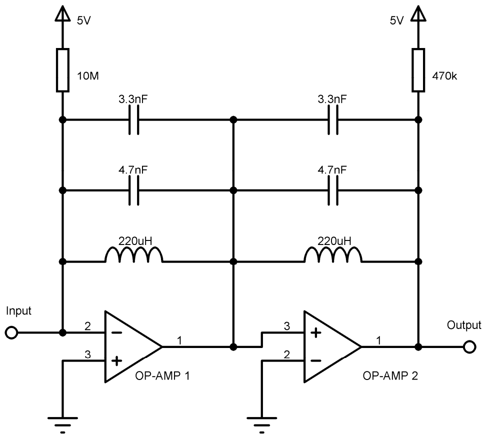

Fig. 5. Tuned-amplifier circuit

The output is then further amplified using multi-stage linear amplifier to ensure sufficient signal strength for reliable demodulation.

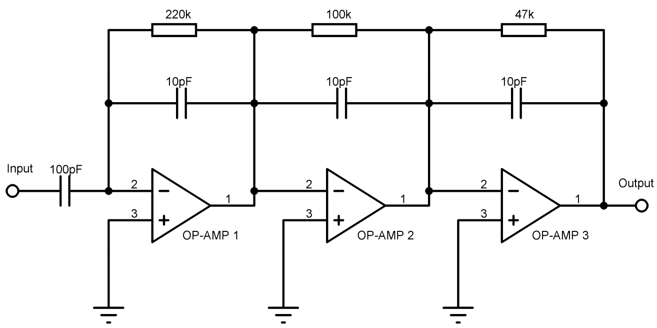

Fig. 6. Signal amplifier circuit

The amplified signal is passed through an envelope detector, which functions as the demodulator, separating the 120 kHz carrier from the embedded control signal as shown in Fig.7. The demodulated control signal is then fed into an Arduino Nano, which interprets the command. The microcontroller is powered by 5V DC taken from DC fan's existing circuitry.

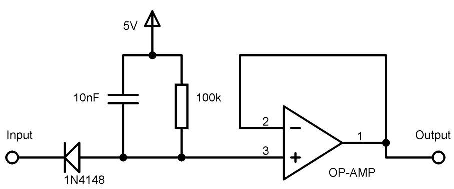

Fig. 7. Envelope detector circuit

Based on the decoded instruction, the microcontroller generates a corresponding IR signal through an infrared LED aimed at the fan's IR receiver. This emulates the function of the original IR remote control.

This architecture allows full remote functionality without requiring any modifications to the internal electronics of the DC fan.

III. RESULTS AND DISCUSSION

The experimental results are presented in Fig.8-11. Fig.8 shows the control signal generated by the Arduino Nano at transmitter side. This is the ASCII symbol 'A', transmitted via UART at 9600 baud. Some high-frequency noise is visible on the signal edges, likely due to parasitic coupling or internal switching noise within the microcontroller circuit.

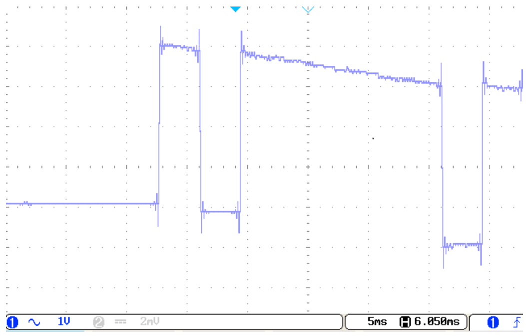

Fig. 8. Control message signal from Arduino Nano

Fig.9 presents the modulated signal, where the control signal is amplitude-modulated onto a 120 kHz PWM carrier. The presence of ripple and high-frequency artifacts is observed, primarily caused by electromagnetic interference (EMI) from nearby AC loads and reflections in the power line.

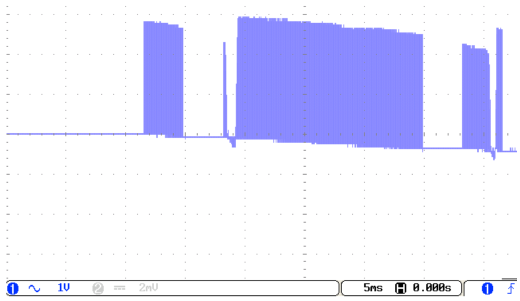

Fig. 9. Modulated signal with carrier wave of 120kHz

Fig.10 shows the signal received after passing through the signal amplifier circuit. While the waveform exhibits some distortion and amplitude fluctuations, the fundamental shape of the modulated control signal is preserved, indicating effective narrow bandpass filtering centered around the 120 kHz carrier frequency.

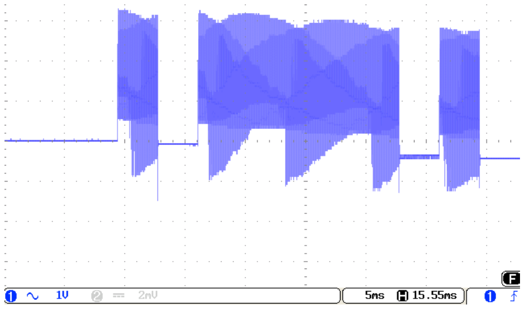

Fig. 10. Output signal from tuned-amplifier

Fig.11 depicts the final demodulated signal output from the envelope detector. Regardless the waveform is slightly distorted, the timing of rising and falling edges is accurately retained. This allows the Arduino Nano at the receiver to successfully decode the signal with no errors as the transmitted symbol 'A' is correctly reconstructed.

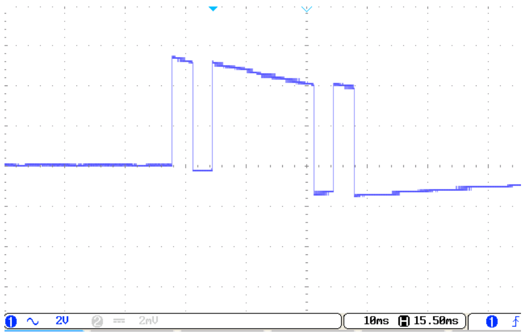

Fig. 11. Output signal from envelope detector

For the final experiment, all system components were connected as described in the previous sections. During testing, the fan blade was removed as a safety precaution. An electrical lamp was connected in parallel with the fan to serve as a visual indicator of live power delivery as shown in Fig.12.

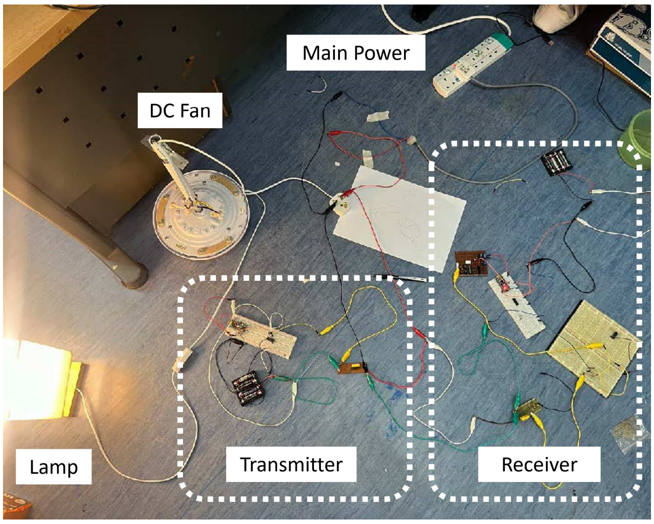

Fig. 12. Experiment setup

A power-on command was transmitted from the transmitter unit. The receiver successfully detected and decoded the signal, subsequently triggering the IR transmitter to activate the fan. The motor movement confirm successful end-to-end operation of the proposed PLC system. This demonstrates the viability of the system in replacing traditional IR remote control with a power line-based communication approach, without modifying the original DC fan circuitry.

The system was further tested by sending a control signal every 1 second for a total of 100 transmissions. The receiver successfully decoded all messages, achieving a 100% success rate.

IV. Conclusion

This paper has presented the design and implementation of a power line communication (PLC) system to replace the infrared (IR) remote control commonly used in DC ceiling fans. The system transmits low-bandwidth control commands over existing AC wiring using a 120 kHz carrier frequency, eliminating the need for additional wiring or major hardware modifications.

It was designed to operate within Malaysia's power line specifications. Experimental results confirm reliable transmission and decoding of control signals, enabling fan control with minimal changes to the original hardware.

This solution demonstrates a practical and infrastructure-friendly approach to integrating legacy appliances into modern smart control systems. Nevertheless, further testing is required under real-world conditions, including evaluation in actual wiring in office, home or school environments to assess noise resilience, setups with multiple fans to examine potential interference, and testing system behaviour under overvoltage surge conditions. These aspects will be addressed in future work.

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