

Low-Cost MOSFET H-Bridge Driver for DC Motor Control: Design and Experimental Evaluation

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ARTICLE INFO	ABSTRACT
Published Online: 30 September 2026 Corresponding Author: Minh Bui Vu KEYWORDS: h-bridge, dc motor, pwm control, arduino board, power electronics	This paper presents a DC motor speed control model using an H-bridge and an Arduino Uno R3. The H-bridge driver circuit is designed based on four IRF540 N-channel MOSFETs. Two IR2104 ICs are responsible for controlling these MOSFETs. The pulse width modulation (PWM) method is implemented on the Arduino Uno R3 board to drive these two IR2104s. The control signal is a square pulse with a frequency of 490.2 Hz, and the duty cycle is modulated from 3.9% to 98%. Experimental results show that this model operates accurately, reliably, and safely, with motor speed varying from 112 RPM to 2845 RPM. Furthermore, the experimental measurements achieve over 98% agreement with MATLAB simulation results, confirming the circuit's stability and effectiveness under loaded conditions.

I. INTRODUCTION

In modern industry, designers are concerned with optimizing the control of electric motors in production lines as a top priority. They control DC motors, which is essential in this context. The DC motor is highly reliable and widely used. Efficient DC motor control ensures flexible production lines, smooth operation, reduced operating costs, lower power loss, and high-quality finished products. Direct DC motor control methods are considered obsolete as they fail to meet technical requirements [1], [2]. An effective control system must allow for easy speed adjustment and directional control. The DC motor is driven by a direct current (DC) or controlled by a DC voltage. Once powered, it rotates, converting electrical energy into mechanical energy. DC motors are commonly used in low-voltage and high-starting-torque applications. The DC motor features an armature circuit with inherent inductance. It has proven its advantages over extensive use, including easy control, efficient energy use, strong starting/stopping/reversing capabilities, fast acceleration, high torque, and an absence of harmonics.

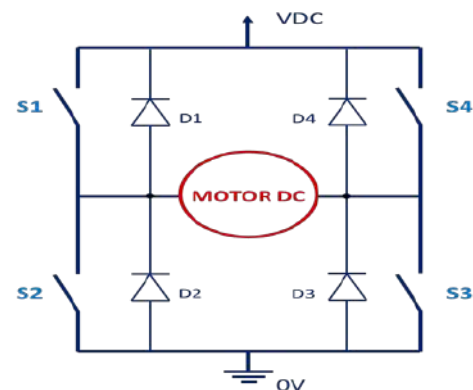


Figure 1: The H-bridge driver circuit architecture

Due to these benefits, DC motor control remains a key area of interest. The authors propose an H-bridge driver circuit for this purpose (Figure 1). The H-bridge driver circuit consists of multiple switches with fast switching capabilities controlled by a pulse width modulation (PWM) signal [3], [4]. It alternately connects and supplies voltage to the motor. In addition, freewheeling diodes are integrated into this circuit [4]. These switches operate in a predefined sequence to control the current flowing through the motor (Table 1). Thanks to these control components, DC motors operate reliably, safely, and responsively.

Table 1: The S-switches control the current through the DC motor

Closed Switches (S)	Motor DC Voltage State
S1, S3	Positive (forward rotation)
S2, S4	Negative (reverse rotation)
S1, S4	Zero
S2, S3	Zero
S1, S2	Short circuit
S3, S4	Short circuit
None or one	Open circuit

A unipolar power supply supplies power to the H-bridge driver circuit. The S-switches are controlled by pulse width modulation (PWM) signals. The PWM signals are generated by a microcontroller. These S-switches are central to controlling the DC motor; therefore, they have been designed, calculated, and selected to ensure high reliability. The S-switches operate in saturation mode, resulting in a lower voltage drop and minimal heat dissipation. These switches are typically selected as MOSFETs or IGBTs [4]. The current through the DC motor depends on whether these switches are turned on or off.

Additionally, switching states not specified in the table will cause a short circuit and must be avoided.

One method used to control these S-switches is based on PWM. PWM is a digital signal widely used in various applications, ranging from simple to complex ones [1], [5]. PWM allows for both fixed and variable durations of the high and low signal states. One pulse period is the sum of the high and low times of the signal. If a PWM signal has equal high and low durations, it has a duty cycle of 50% and resembles an ideal square wave (Figure 2). If the duty cycle exceeds 50%, the signal remains in the high state longer than in the low state, and vice versa.

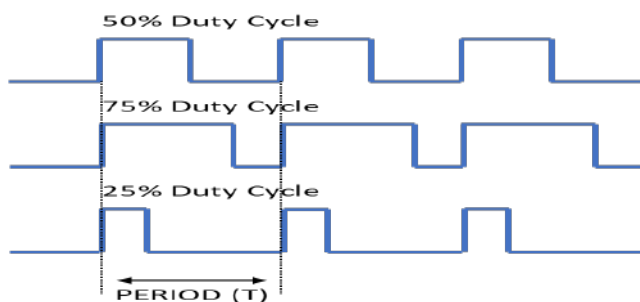


Figure 2: The model describes the duty cycle of the PWM signal in one pulse cycle

If the duty cycle of the PWM is 100%, the digital signal will be constantly high. Conversely, if the duty cycle of the PWM is 0%, the digital signal will be constantly low.

II. METHODOLOGY

1. Circuit Simulation

A Buhler DC motor with model code 1.13.018 is selected (Table 2). It offers proven advantages such as fast starting and stopping, high starting torque, reversing capability, adjustable speed, simple input voltage control, and low cost.

The DC motor speed control model using the PWM method is implemented in MATLAB [6]. The specifications of the DC motor are imported from the Buhler 1.13.018 model. The PWM control signal is set to a frequency of 490.2 Hz, where a 0% duty cycle corresponds to 0 V, and a 100% duty cycle corresponds to 5 V. The H-bridge unit is configured with an output voltage of 24 V. Parameters such as armature current (IM), motor voltage (VM), and motor speed (SM) under load are displayed.

Table 2: Specifications of the Buhler DC motor

Specifications	Value	Units
Rated Voltage	24	V
Rated Power	56	W
Rated Speed	2500	RPM
No Load Speed	3000	RPM
Armature Inductance	1.5	mH
Rotor inertia	$0.25e^{-5}$	$\text{Kg}\cdot\text{m}^2$
Rotor damping	$0.7e^{-5}$	$\text{N}\cdot\text{m}/(\text{rad/s})$

In the first case, with a duty cycle of 3.9%, the DC motor speed is 114.6 RPM, the voltage is approximately 0.9 V, and the current is very low (Figure 3).

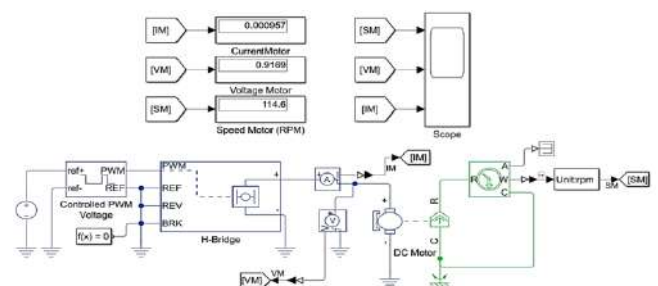


Figure 3: DC motor speed control model with a 3.9% duty cycle

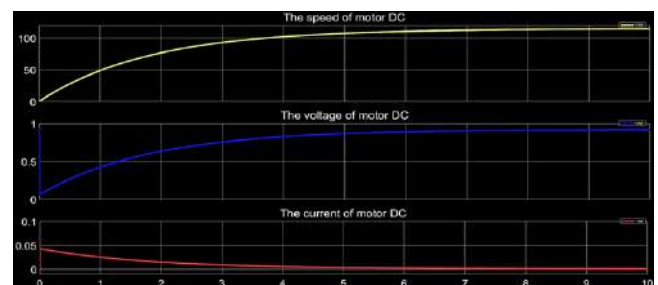


Figure 4: Graph of speed, voltage, and current at a pulse width of 3.9%

In the second case, with the duty cycle set to 98%, the motor speed reaches 2890 RPM, the voltage is approximately 23 V, and the current is approximately 0.02 A (Figure 5).

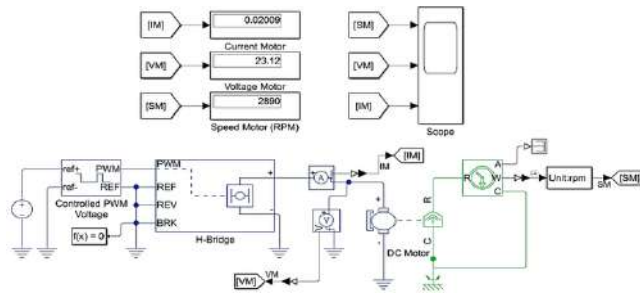


Figure 5: DC motor speed control model with a 98% duty cycle

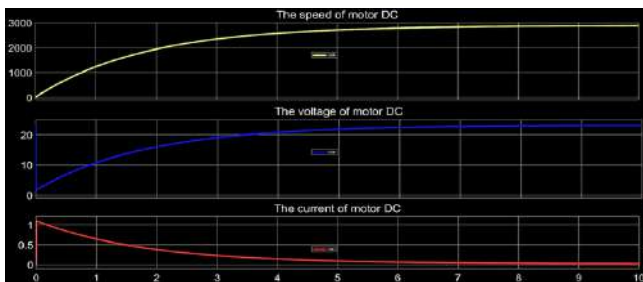


Figure 6: Graph of speed, voltage, and current at a pulse width of 98%

The signal waveforms during DC motor operation, along with the speed, voltage, and current parameters, are graphically shown in Figures 4 and 6.

2. Circuit Design

The authors used the Arduino Uno R3 board to generate the control signals for the S-switches in the H-bridge driver circuit [2], [7]. The Arduino Uno R3 is the third-generation board based on the AVR ATmega328P microcontroller architecture. It is capable of handling a wide range of applications, offering the advantages of low cost and high efficiency [8], [9]. Furthermore, low-cost DC motor control circuits integrating microcontrollers have been widely researched and applied in practice, demonstrating rapid response to PWM control signals as well as effective control of motor speed and direction [10], [11]. Additionally, embedded closed-loop remote control systems for DC motors have proven effective in validating experimental models against theoretical ones [12]. The board is powered via a 5V DC supply, either through the USB port or an external DC power supply. The recommended DC voltage is between 7V and 12V. The Arduino Uno R3 generates two PWM signals using the Arduino IDE software to control the S-switches. The duty cycle of these PWM signals can be adjusted via externally connected buttons.

The H-Bridge driver circuit is designed using four IRF540 N-channel MOSFETs. These MOSFETs function as S-switches, offering the advantage of handling high load currents [4]. They can drive loads up to 23 A and voltages up to 100 V DC. Additionally, they are capable of high-speed switching, making the IRF540 suitable for a wide range of applications.

During the operation of the H-bridge circuit, these MOSFETs require fast switching to ensure safety, accuracy, and reliability. The intermediate component chosen to drive these MOSFETs is the IR2104 gate driver IC [3]. Two IR2104 ICs are responsible for controlling the MOSFETs. The IR2104 is optimally designed to control the conduction of the MOSFETs. In the H-bridge circuit design, driving the high-side N-channel MOSFETs (Q1 and Q3) requires a gate voltage V_G higher than the DC supply voltage V_{DC} . The IR2104 IC works in conjunction with bootstrap diodes D5 and D6 to provide the high-side floating supply voltage V_{BS} , elevating the gate drive level above V_{DC} for proper MOSFET conduction. Pulse width modulation (PWM) control is programmed on the Arduino to drive the two IR2104 ICs.

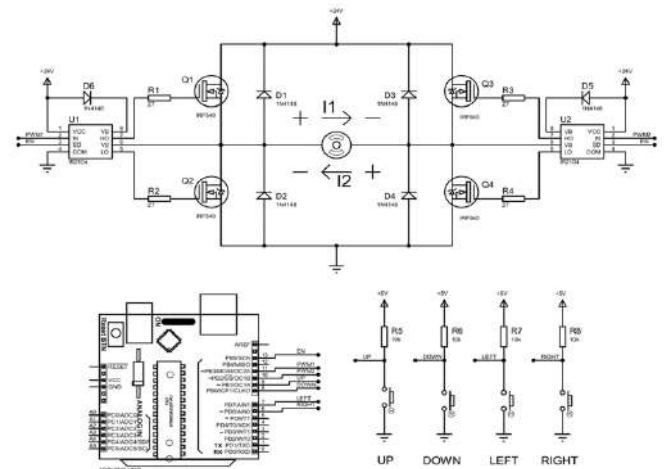


Figure 7: Schematic of the H-bridge driver circuit using MOSFETs to control the DC motor

A schematic of the H-bridge driver circuit using MOSFETs to control a DC motor is proposed (Figure 7). The H-bridge driver circuit is powered by a 24 V DC supply. The PWM signals, generated by the Arduino Uno R3, drive the IR2104 ICs. The IR2104 is responsible for fast and precise control of the switching of the IRF540 MOSFETs. With this configuration, the DC motor can be reliably controlled to change both its speed and direction of rotation.

III. RESULTS

The prototype hardware model of the H-bridge driver circuit using MOSFETs to control the DC motor is presented (Figure 8). In this case, a Buhler brushed DC motor is selected as the load.

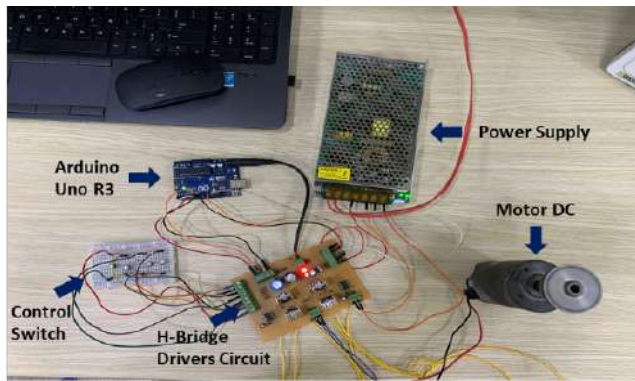


Figure 8: The prototype hardware model of the H-bridge driver circuit using MOSFETs to control the DC motor

For low-speed rotation of the DC motor, the voltage across it is approximately 1 V. The PWM signal has a peak voltage of 3.52 V, a frequency of 490.2 Hz, and a duty cycle of 3.9% (Figure 9). This PWM signal is observed on an oscilloscope, and under these conditions, the speed of the DC motor reaches 112 RPM.

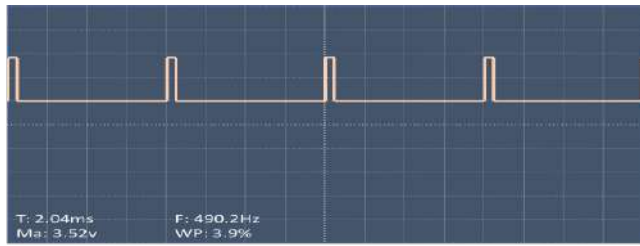


Figure 9: The PWM signal in case of low voltage on the load

In the opposite case, when the motor speed increases, the voltage across the DC motor is high, approximately 23 V. The PWM signal has a peak voltage of 3.6 V, a frequency of 490.2 Hz, and a duty cycle of 98% (Figure 10). At this point, the speed of the DC motor reaches 2845 RPM.

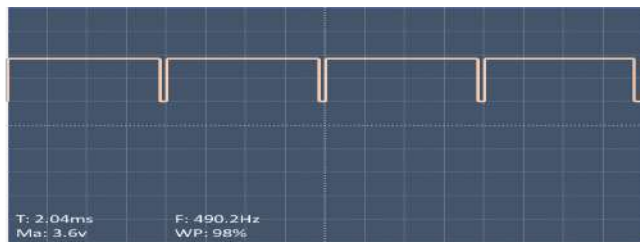


Figure 10: The PWM signal in case of high voltage on the load

The voltage across the DC motor varies from 1 V to 23 V. During the process of increasing or decreasing speed, or changing the direction of rotation, the frequency of the PWM signal remains constant. Equations (1) and (2) describe the relative error (ϵ) and correlation accuracy (A).

$$\epsilon = \frac{|S_{sim} - S_{exp}|}{S_{sim}} \times 100\% \quad (1)$$

$$A = 100\% - \epsilon \quad (2)$$

At low speed with a 3.9% duty cycle, the experimental motor speed of 112 RPM deviated by only 2.27% from the predicted 114.6 RPM, achieving an accuracy of 97.73%. Conversely, at high speed with a 98% duty cycle, the experimental speed of 2845 RPM deviated by only 1.56% from the predicted 2890 RPM, achieving an accuracy of 98.44%. These minor discrepancies are primarily attributed to unmodeled mechanical friction, parasitic resistance within the H-bridge circuit, and slight fluctuations in the DC power supply during operation. Overall, the experimental results demonstrate an average correlation exceeding 98% with the simulation results, thereby confirming the validity of the proposed H-bridge circuit (Table 3).

Table 3: Compare the DC motor parameters from simulation and experiment

Case	Simulation (S_{sim})	Experiment (S_{exp})	Relative Error (ϵ)	Accuracy Ratio (A)	Duty Cycle (%)
Speed _{min}	114.6 RPM	112 RPM	2.27%	97.73%	3.9%
Speed _{max}	2890 RPM	2845 RPM	1.56%	98.44%	98%

IV. CONCLUSIONS

In this study, an H-bridge circuit model using MOSFETs for DC motor speed control is proposed. Experimental results show that the H-bridge driver circuit operates stably with high accuracy, with the DC motor's speed changing smoothly. It is easy to control the motor according to technical requirements. The PWM signal varies from 3.9% to 98%, with a frequency of 490.2 Hz. At the same time, experimental results also showed similarities with simulations using MATLAB, achieving a speed correlation of 97.73% at the minimum speed (112 RPM vs 114.6 RPM) and 98.44% at the maximum speed (2845 RPM vs 2890 RPM). With an overall accuracy exceeding 98%, the proposed low-cost MOSFET H-bridge driver proves to be highly reliable and precise for practical DC motor control applications, maintaining parameter stability during loaded operation.

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