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H-Bridge Motor Driver Circuit for Control of Brushed DC Motors

Süleyman Erdoğan[1*] and Serhat Çindemir[1]

[1] *Rollmech Automotive, Research and Development, Bursa, Turkey*

Abstract

Brushed DC motors are used in many applications today. Brushed DC motors should be controlled to operate at the desired speed, forward or reverse, and for the desired duration in their applications. In this study, a motor driver circuit that includes the control of the brushed DC motor with a door driver using an H-Bridge and the configuration of the door driver, controlling the brushed DC motor operating current, speed and position control of the brushed DC motor with a Hall sensor, and CAN-BUS communication is explained in detail in the rest of the article. An experimental circuit board block diagram, software flow diagram, and 3D images of the circuit board that will serve as an example according to the automotive industry requirements are shared. The results of the experimental application are shared and the mentioned Brushed DC motor H-Bridge driver circuit will contribute to a better understanding of motor control.

Keywords: CAN-BUS communication, H-bridge, Gate driver, Motor current, direction and speed control.

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1. Introduction

Brushed DC motors are used in many applications, including automotive control systems, robotics, and different industrial fields. Brushed DC motors have become an indispensable sub-component due to their easy operation and low cost [1]. Brushed DC motors must be controlled to operate at the desired speed, forward or backward direction and for the desired times in their application. To control these parameters, a driver circuit needs to be designed. It is advantageous that brushed DC motor drives, which are used to provide speed, position and direction control in the automotive industry, have low cost and features that can be applied to different components (e.g. steps, trunks, doors, mirrors, seats, towbars, etc.) using the existing design. Furthermore, according to automotive industry requirements, these motor drives are required to meet durability standards. Because automotive applications are often exposed to harsh conditions such as temperature fluctuations, vibrations, and moisture. They are also expected to perform reliably over long-term use without requiring frequent maintenance or replacement [9–10].

In past studies, there is a lot of research on DC brushed motor speed control. However, most of these driver circuits are designed to operate in only one direction. In order to change the direction of rotation of the motor, the polarity of the applied voltage must be changed [3-6]. In many control applications, such as H-Bridge motors, DC/DC converters, or class-D amplifiers, it is a power device that is often used to drive inductive load [7]. H-Bridges are well-known structures that are typically used to connect a load to a voltage source in either a forward or reverse direction. Some of the most common applications include controlling DC motors, stepper motors, solenoids, and many applications in power electronics [11]. Therefore, it has become an important driving component for motor control. The basic structure of the H-Bridge is formed by 4 power transistors such as BJT, MOSFET or IGBT that work as electronic switches [8]. However, the main problem with this control method using transistors is the heating of the transistors. Due to heating, transistors lose energy, which reduces the efficiency of the motor drive system. To eliminate this disadvantage, it is possible to use the Pulse Width Modulation (PWM) method. PWM controls motor speed with short pulses. The occupancy rate of these pulses is called the "Duty Cycle". The motor speed can be adjusted according to the Duty Cycle. If the Duty Cycle is high, the motor will spin faster, and if it is low, the motor will spin slower [2]. When both the upper and lower power transistors on the same side are turned on simultaneously, the jumping phenomenon can occur due to the transition delay of the power transistors. As a result, the generation of dead time is necessary and important for the H-Bridge drive [12].

The purpose of this study; To develop a circuit and software design that will control the direction, position, speed, current and communication of the brushed DC motor by using the H-Bridge and gate driver. The design includes Schmitt triggering with hysteresis to prevent magnetic fluctuations from causing unwanted transitions of the signal from the hall effect sensors, status information with the switch, warning beep, light-emitting diode (LED) indicator, CAN-BUS communication, reverse battery protection with continuous current up to 62A, direction control using a high-side switch with H-Bridge motor driver, current control. The MOSFET used provides up to 30 Amps of drive current for one brushed DC motor.

In the following parts of the article; This study will be explained in detail and the results of the experimental studies will be discussed and evaluated. This study will contribute to a better understanding of brushed DC motor control processes with the H-Bridge in automotive and industrial applications.

2. Method

2.1. Circuit Board Design

As seen in the block diagram in Figure 1 the yellow boxes represent the 12V operating voltage and the blue colored boxes represent the 3.3V operating voltage. Figure 2 and Figure 3 show a 3D image of the front and back of the circuit board design.

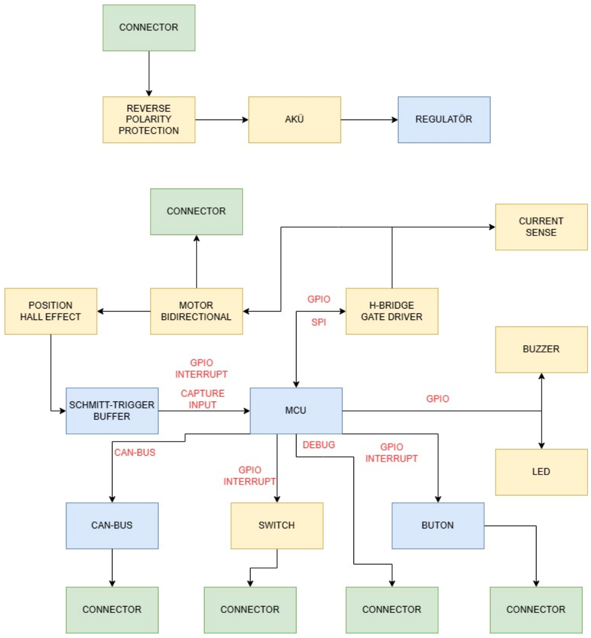

Figure 1. H-Bridge Brushed DC Motor Driver Circuit Board Block Diagram

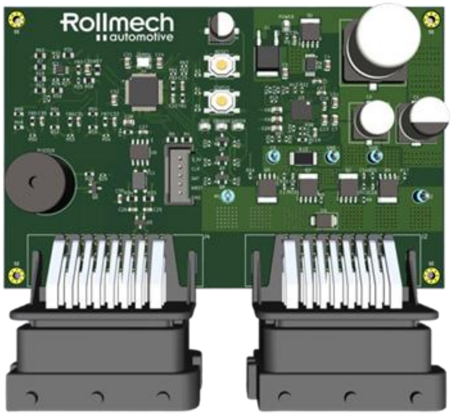

Figure 2. H-Bridge Brushed DC Motor Driver Circuit Board Front Side 3D Image

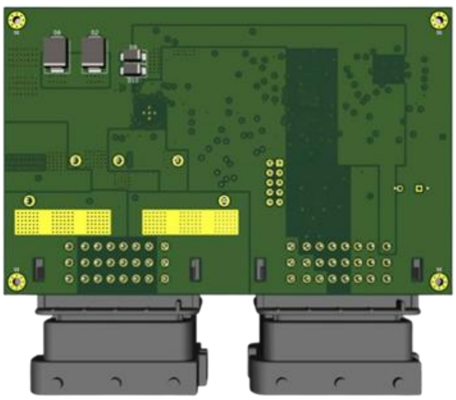

Figure 3. H-Bridge Brushed DC Motor Driver Circuit Board Back Side 3D Image

2.2. Power

Most systems, whether in automotive or industrial applications, require fast-response reverse polarity protection at the input stage. Schottky diodes, or p-channel MOSFETS, are often used in most power systems to maintain the charge in the event of negative polarity. The main disadvantage of using diodes is the voltage drop that occurs on the P-N junction during forward conduction, which reduces the available voltage and increases the associated power losses. PFET solutions are inefficient for handling high load current at low input voltage. A diode controller has been used for reverse power protection, compliant with the requirements of the ISO-7637 and ISO-16750 standard, which has zero standby current coupled with an external N-channel MOSFET to replace a diode or PFET reverse polarity solution in power systems, withstanding up to 62A continuous current [14-16]. The system supply is provided from the battery. It is powered by 3.3V, which is regulated using a linear voltage regulator to power the IC components within the circuit.

2.3. Microcontroller

To process signals, a 32-bit ARM Cortex-M0-based microcontroller with an operating voltage range of 2.5 V to 5.5 V was used, capable of generating 24 channels of 16-bit 100MHz high-resolution PWM designed for automotive applications needing CAN communication, operating at speeds up to 50 MHz.

2.4. H-Bridge Gate Driver

The H-Bridge gate driver are H-Bridge gate drivers that use four external N-channel mosfets targeted to drive the bidirectional brushed DC motor. The PH/EN independent H-Bridge or PWM interface provides simple interfacing to the controller circuit. It provides adjustable current control thanks to its built-in amplifier. The gate driver contains circuits to regulate the winding current using a PWM current cut-off method. With boost rate control, it helps improve MOSFET efficiency and reduce switching ripples. It provides overcurrent protection (OCP), undervoltage lockout (UVLO), and thermal shutdown.

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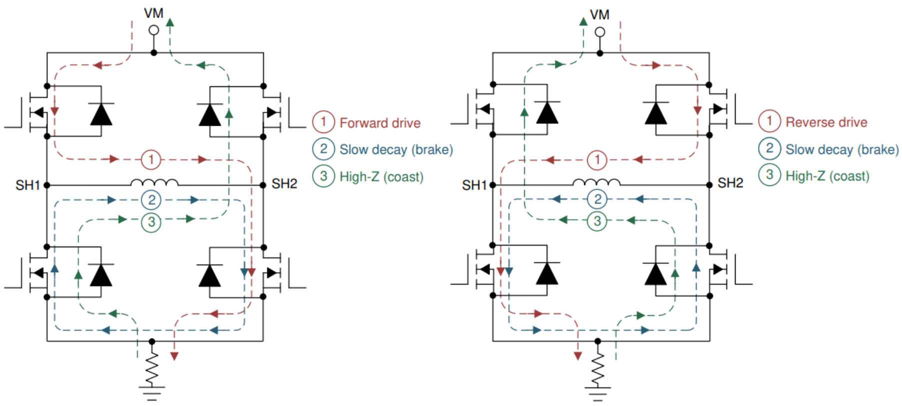

Figure 4. Bi-Directional Rotation Using H-Bridge

$$Duty\ Cycle(\%) = \frac{On - Off\ Time}{Period} x100 \tag{1}$$

$$PWM\ Frequency = \frac{1}{Period} \tag{2}$$

$$T_{DEAD} = \frac{VCC}{I_{Pik} x R_{DS(on)}} \tag{3}$$

As seen in Figure 4 in another control method with the DC brushed motor in both directions with the H-Bridge gate driver; It is made high impedance by setting the mode pin as input or by leaving floating idle. In this configuration, it is controlled by a single PWM signal. The PWM signal is applied to the IN2/EN pin by calculating Equation (1) and Equation (2) PWM frequency and duty cycle value. Dead time is calculated as seen in Equation (3). The gate driver has programmable dead-time options of 120, 240, 480, 960 ns. If IN1/PH is selected as "1" to provide directional control, the motor will move in the forward direction. The current will provide direct current from SH1 to SH2. If IN1/PH is selected as "0", the motor will move in the opposite direction. The current will provide direct current from SH2 to SH1. This control method allows the motor to maintain precise speed control and if it is not actively fed or braked, it will release and turn in its own inertia and then stop. Brake control can also be used if necessary [13].

2.5. Current Control

The H-Bridge gate driver incorporates current regulation to limit the maximum current flowing through the motor winding. When the H-Bridge is activated, current rises through the winding. The winding's DC voltage and inductance determine the rate of rise of the current. The cut-off current is set by a comparator. The comparator compares the voltage across a current-sense resistor connected to the gate driver's pin to a reference voltage from the V_{REF}(Referance Voltage) pin by multiplying it by the factor A_V(Shunt Amplifier Gain).

$$R_{Sense} = \frac{V_{REF} - V_{IO}}{A_V x I_{Max}} \tag{4}$$

As seen in Equation (4), the gate driver V_{REF}(Reference voltage) voltage is taken as 3.3V. The V_{IO}(Input reference offset) value is taken as 10mV. In the H-Bridge gate driver, the A_V(Amplifier gain) value is selected as 39.4V in the control registers. The gate driver's 12V maximum current value is 30A. The I_{Max} (Maximum current) value is taken as 30A. The R_{Sense}(Current measurement resistance) value is found here to be approximately 0.0018Ω.

$$I = \frac{V_{REF} - V_{IO}}{A_V x R_{Sense}} \tag{5}$$

As seen in Equation (5), if the R_{Sense}(Current measurement resistance) value is selected as 0.0018Ω, the I value is found as 29.3A.

$$P = I^2 x R \tag{6}$$

As seen in Equation (6), the I^2 value is 900 A. With a resistance value of 0.0018 Ω, the power value is 1.62W

$$I_{OCP} = \frac{V_{DS}}{R_{DS(on)}} \tag{7}$$

As seen in Equation (7), the V_{DS}(Drain-source voltage difference) value in the I_{OCP}(Overcurrent Protection) H-Bridge gate driver is selected based on the MOSFET's $R_{DS(on)}$(Drain-source open state) resistance value. For example, if the V_{DS} (Drain-source voltage difference) value in the control registers is selected as 0.06V in the H-Bridge gate driver, the MOSFET's $R_{DS(on)}$(Drain-source open state) resistance value is 0.0040Ω, and the overcurrent protection will cut off the current at approximately 15A. The nFault pin will be driven low.

2.6. Brushed DC Motor Speed Lap Angle Measurement With Hall Sensor

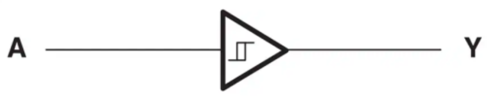

Figure 5. Schmitt Triger Buffer

Schmitt Buffer trigger is used in order to minimize the noise that may occur in the electrical fields in the connection between the Hall effect sensors and the control board, as shown in Figure 5. This function prevents noise from causing multiple transients. It reduces electrical noise in signals from Hall effect sensors.

$$\text{RPM} = \frac{60000000.0(\mu s)}{\text{Pulse Range}(\mu s) x Gear\ Ratio} \tag{8}$$

RPM (revolutions per minute) is 60000000.0 as seen in Equation (8); It represents minutes in microseconds. Pulse range; It represents the time between two pulses in microseconds. The gear ratio represents the brushed DC motor reducer ratio.

The rotational speed of the motor on the gear is calculated as in Equation (8).

$$\text{Reducer Ratio} = \frac{\text{Input Turnover(RPM)}}{\text{Output Turnover(RPM)}} \tag{9}$$

$$\text{Total Rounds} = \frac{\text{Total Pulses}}{\mathit{Reducer\ Ratio}} \tag{10}$$

The total number of turns represents the total number of pulses read from the hall sensor as seen in Equation (10). As seen in Equation (9), the reducer ratio is the term that indicates how much the speed of the output shaft of a reducer is reduced to the speed of the input shaft.

The number of revolutions of the motor on the gear is calculated as in Equation (9) and Equation (10).

2.7. Software Flow Diagram

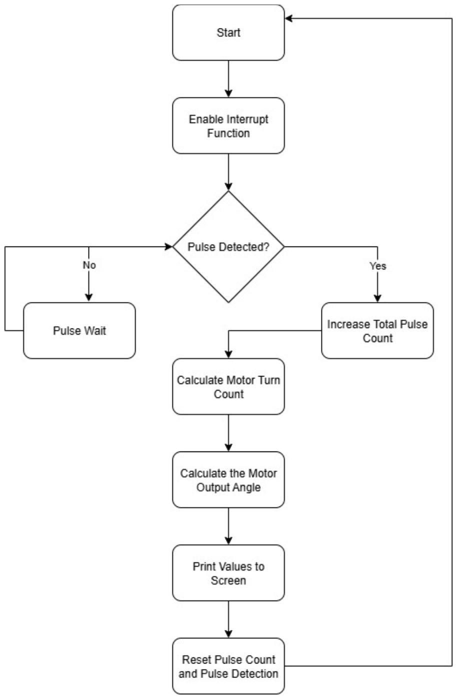

Figure 6. Software Flow Chart

As seen in Figure 6. the software flow chart that will serve as an example for the H-Bridge motor driver circuit board is seen.

2.8. Can-Bus Communication

For the communication of the signals with another ECU system, a CAN-BUS IC with thermal shutdown protection was used, which complies with the requirements of the ISO 11898 standard [17]. In terms of EMC (Electromagnetic compatibility), common mode coil, TVS diode, termination resistor according to the number of nodes in the network, and capacities depending on the termination resistor are used in parallel to the termination resistor are used to filter electromagnetic interference and suppress noises emitted from the electronic control module (ECU).

3. Conclusions

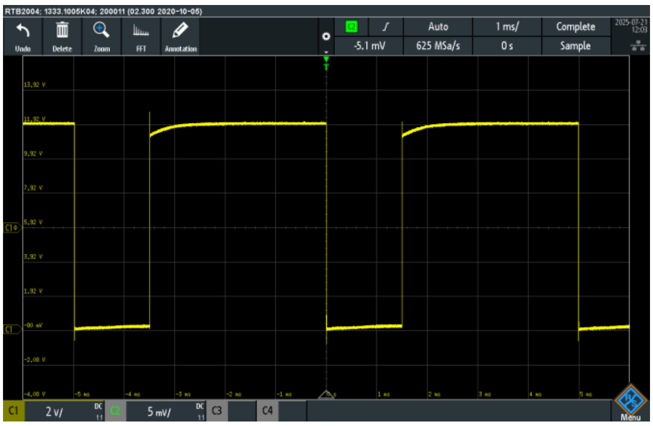

Figure 7. Motor End PWM Signal – Forward Direction

Figure 7 shows the PWM signals of the H-Bridge motor drive circuit and the motor output voltage at 12V DC supply voltage, indicating that the motor is running in a forward direction.

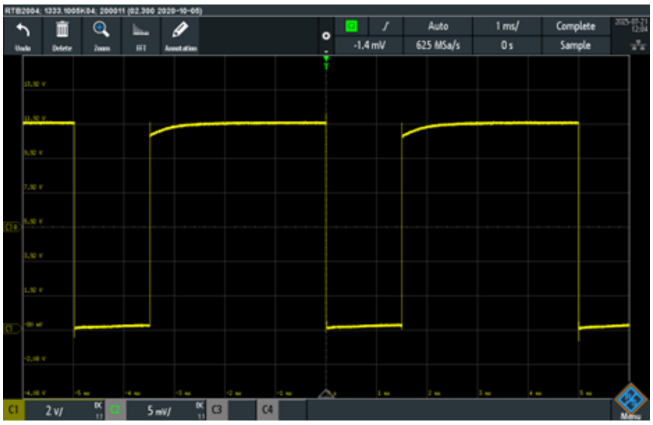

Figure 8. Motor End PWM Signal-Reverse Direction

Figure 8 shows the PWM signals of the H-Bridge motor drive circuit and the motor output voltage at 12V DC supply voltage, indicating that the motor is running in reverse.

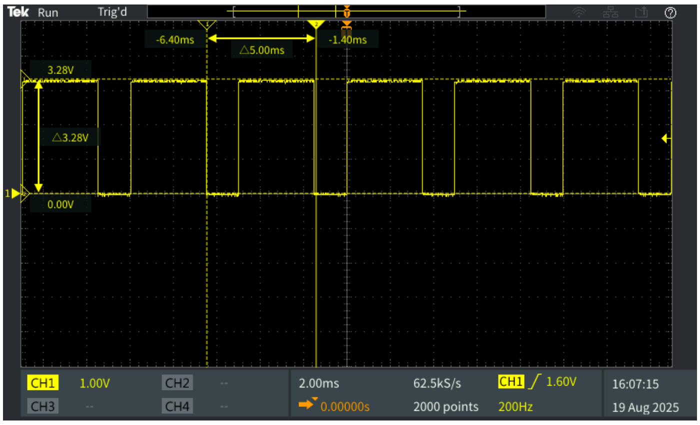

Figure 9. PWM Signal Applied by Microcontroller to IN2/EN Pin

Figure 9 shows the oscilloscope image of the PWM signal with a 200 Hz 70% duty cycle rate applied to the IN2/EN pin of the H-Bridge motor driver circuit produced by the microprocessor

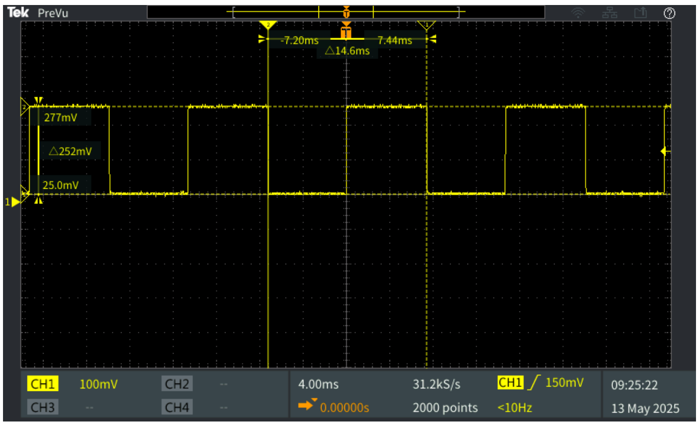

Figure 10. Two Pin Latch Hall Sensor Signal of Brushed DC Motor in Forward and Reverse Direction

As can be seen in Figure 10 the two-pin latch hall sensor was measured as Δt 14.6ms in one period.

Within the scope of this experimental study, studies such as H-Bridge and gate driver for the control of the brushed DC motor and forward or backward control, current control, speed measurement, position information, CAN-BUS communication for the brushed DC motor were successfully carried out and the experimental oscilloscope measurement results were shared. The motor control unit design has been shared in detail, providing flexibility for the control of the brushed DC motor in many applications. This study will contribute to a better understanding of brushed DC motor control.

Acknowledgment

We would like to thank all Rollmech Automotive employees and the Rollmech Automotive R&D Team for their support.

Nomenclature

Δt	Time difference between two signal repeats
3D	Three-dimensional
A	Amperage
A_V	Shunt amplifier gain
BJT	Bipolar-coupled transistor
DC	Direct current
ECU	Electronic control unit
EMC	Electromagnetic compatibility
Hi-Z	High impedance
I	Current
I_{Max}	Maximum current
I_{OCP}	Overcurrent protection
I_{Pik}	Instantaneous maximum current
IC	Integrated circuit
IGBT	Bipolar transistor with isolated control
IN1/PH	First input phase
IN2/EN	Second login activation
mV	Milivolt
MHz	Megahertz
MOSFET	Metal-oxide-semiconductor field-effect transistor
n	Negative
NFET	N-channel field-effect transistor
ns	Nanoseconds
P	Power
p	Positive
PFET	P-channel field-effect transistor
PWM	Pulse width modulation
R	Resistance
$R_{DS(on)}$	Drainage source open state
R_{Sense}	Current measurement resistor
RPM	Revolutions per minute
SH	Switch
T_{DEAD}	Dead time
TVS	Transient voltage suppressor
µs	Microseconds
UVLO	Undervoltage lockout
V	Volt
V_{DS}	Drain source voltage difference
V_{IO}	Offset with input reference
V_{REF}	Reference voltage
VCC	Supply voltage
W	Watt

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