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# PWM SIGNAL GENERATION FOR EV MOTOR CONTROL BY VEHICLE CONTROL UNIT

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## Abstract

The progressive electrification of the transportation sector has necessitated the development of advanced, efficient, and centralized electronic control systems in Electric Vehicles (EVs). This paper addresses the growing demand for intelligent powertrain management. This paper demonstrates a practical implementation of a centralized control architecture capable of managing traction, illumination, and signalling functions simultaneously, thereby reflecting real-world automotive engineering practices.

The core problem addressed is the fragmentation and inefficiency of decentralized vehicle electronics. Traditional architectures require separate control modules for each subsystem, resulting in heavy wiring harnesses, multiple failure points, and poor adaptability. The objective is to consolidate traction control, dashboard illumination management, and indicator blinking into a single microcontroller-based VCU using multi-channel PWM.

***Keywords:*** Dead time insertion, Carrier Wave, Modulation index, Duty Cyle, Switching Frequency

## 1. INTRODUCTION

The global automotive industry is undergoing a paradigm shift from internal combustion engine (ICE)-based vehicles to electrically driven platforms. Electric Vehicles (EVs) offer zero tailpipe emissions, high torque density at low speeds, quiet operation, and reduced maintenance requirements due to fewer moving components[1]. At the core of every EV is its powertrain electronics, which must deliver precise, controllable energy from the battery pack to the traction motor under all operating conditions[2].

Pulse Width Modulation is the industry-standard technique for converting a fixed DC supply into a variable effective voltage by rapidly toggling a switching device between its fully ON and fully OFF states[3]. By varying the fraction of time the switch remains ON (the duty cycle, D), the average power delivered to the load is controlled without wasting energy in series resistors. Modern MOSFET-based inverters achieve efficiencies exceeding 97% under nominal operating conditions[4].

Extensive research has been conducted in the domain of PWM-based motor drives for electric vehicles. Mohan, Undeland, and Robbins [5] established the foundational theory of switch-mode power converters and PWM techniques for DC and AC motor drives. The relationship between duty cycle and average output voltage forms the basis for all modern motor controllers[6].

## 2. ARCHITECTURAL ANALYSIS

The EV prototype is built around a centralized VCU architecture in which a single microcontroller serves as the command hub for all electrical subsystems. The driver interacts through the throttle pedal and drive mode selector[7]. The VCU processes these inputs and issues multi-channel PWM commands to the traction motor driver, dashboard display, and indicator LED arrays[8]. High-voltage power flows directly from the 48 V battery to the motor driver, while all control signals operate at 3.3 V or 5 V logic levels[9]. Table-1 gives the technical specifications of the EV Prototype system.

Table 1 Technical Specifications of the EV Prototype System

| **Parameter** | **Specification Value** | **Engineering Justification** |
|---|---|---|
| Battery System | 48V DC Nominal (54.6V charged), 30Ah<br>Li-Ion | Driver safety + sufficient energy for EV chassis |
| Dataic Motor | 2000W Continuous / 3000W Peak | Thermal capacity for Sport mode testing |
| Traction PWM Freq. | 16.384 kHz | Above audible range; prevents motor whine |
| Dashboard Dimming | 1.000 kHz Square Wave | Above flicker-fusion threshold; smooth dimming |
| Indicator Blink Rate | 1.2 Hz (72 flashes/min), 50% D | Automotive lighting regulation compliant |
| VCU Logic Voltage | 3.3V / 5V (mode dependent) | Standard microcontroller logic levels |
| Throttle Input Range | 0.8V – 4.2V (Hall-effect analog) | Industry-standard throttle range |
| Eco Mode Duty Cycle | 0% – 50% | Max range, minimum current draw |
| **Parameter** | **Specification Value** | **Engineering Justification** |
| Normal Mode Duty Cycle | 0% – 80% | Balanced city driving performance |
| Sport Mode Duty Cycle | 0% – 100% | Full traction power, peak performance |

The motor driver acts as the power amplification stage between the VCU's low-voltage

PWM signal and the Dataic motor. It consists of a MOSFET or IGBT-based H-bridge (DC motors) or three-phase inverter bridge (BLDC). The VCU's PWM drives transistor gates through opto-isolators[10]. During ON state, transistors connect battery voltage to motor windings. During OFF state, built-in flyback diodes provide current continuation, protecting transistors from inductive voltage spikes.

Selection criteria: continuous current rating >50 A, voltage rating ≥80 V (margin above 54.6 V peak charge), R <15 mΩ to minimize conduction losses, and bootstrap gate ds(on) driver circuits for high-side MOSFET gate drive above the supply rail.

## 3. MATHEMATICAL MODELLING

Pulse Width Modulation (PWM) is a switching technique in which a periodic rectangular waveform of fixed frequency is generated, and the width of its active (HIGH) pulse within each period is varied to control the average value of the signal delivered to the load. In power electronics, PWM drives a power transistor (MOSFET/IGBT) between saturation (ON) and cut-off (OFF) states, achieving variable effective voltage with minimal resistive power dissipation. Table 2. gives the Drive Mode PWM Duty Cycle Limits and Characteristics.

Table 2. Drive Mode PWM Duty Cycle Limits and Characteristics

| Mode | Scaling Function | Max Duty Cycle | Max V_avg (48 V) | Characteristic |
|---|---|---|---|---|
| Eco | D_out = 0.50 × x | 50% | 24.0 V | Soft accel., max range, low current |
| Normal | D_out = 0.80 × x | 80% | 38.4 V | Linear response, balanced performance |
| Sport | D_out = 1.00 × x | 100% | 48.0 V | Full power, fast ramp, max torque |

x = empirically derived distance exponent (depends on equipment class; typical x ≈ 1.0–1.5 in the regression — use value from standard).

Figure 1 presents the PWM waveforms for the three traction modes and peripheral control channels. In Eco mode, the duty cycle is limited to 50% (T_on = T_off = 31.25 µs). In Sport mode, D reaches 100% (continuous conduction). The motor's inductive windings smooth the switching waveform into a near-DC current in all three modes.

Figure 1 shows the PWM Waveforms – Eco / Normal / Sport Modes & Peripheral Control

Figure 1: PWM Waveforms – Eco / Normal / Sport Modes & Peripheral Control

## 4. SYSTEM DESIGN AND IMPLEMENTATION

The hardware implementation is organized around three distinct electrical domains: the high-voltage power domain (48 V), the low-voltage logic domain (3.3 V/5 V), and the intermediate-voltage peripheral domain (12 V for indicators). Each domain is kept galvanically isolated at the signal interface level, with energy transfer occurring only through intentional gate-drive and power-output stages.

The 48 V lithium-ion battery pack connects to the motor driver through a main fuse and a software-controllable contactor. The motor driver's output connects directly to the Dataic motor phase windings. The low-voltage VCU supply is derived from a 48 V to 5 V DC-DC buck converter rated at minimum 2 A continuous output, providing stable logic voltage despite switching transients on the main bus.

Figure 2 shows the implified Circuit Connection Diagram – EV VCU System.

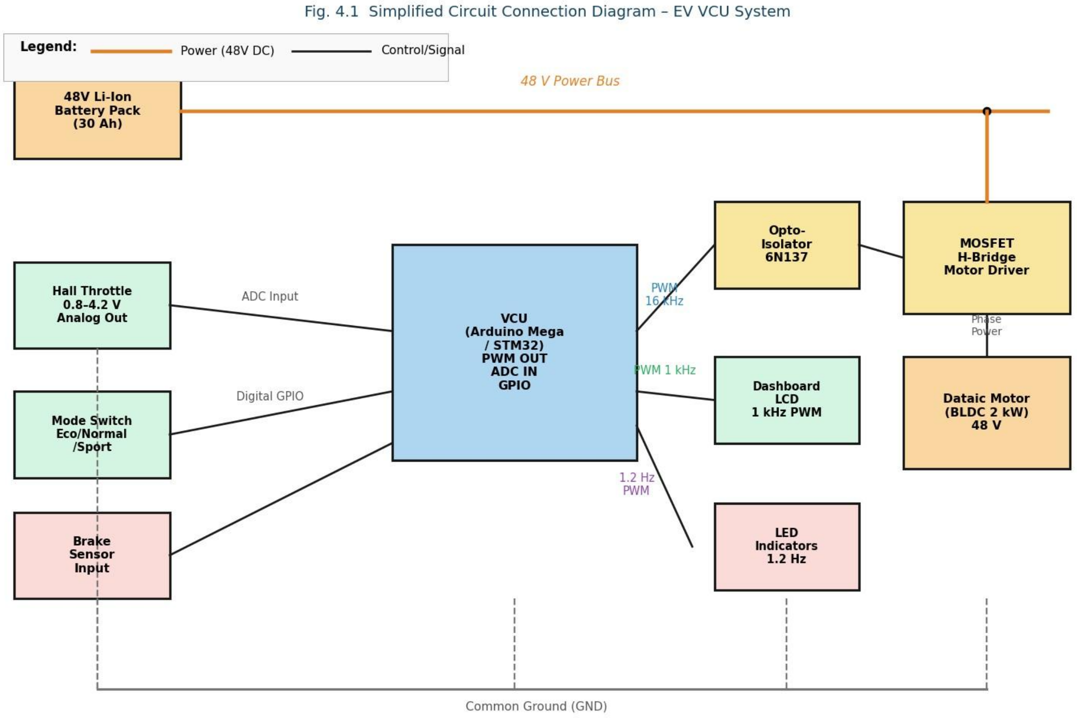

Figure 2: Simplified Circuit Connection Diagram – EV VCU System

## 5. CONCUSIONS

The VCU firmware employs a continuous polling loop (super-loop architecture) executing the following sequence each iteration:

1. Read the 3-position drive mode switch state (debounced GPIO).
2. Read the Hall-effect throttle sensor via ADC (averaged over 8 samples).
3. Normalize ADC value to $x \in [0, 1.0]$ and apply mode-specific scaling: D_target = D_max[mode] × x.
4. Apply slew-rate limiter: increment D_current by a maximum step ΔD per iteration toward D_target.
5. Write D_current to the hardware timer capture-compare register (motor PWMupdate).
6. Check dashboard brightness level and update secondary 1 kHz PWM channel.
7. Check turn signal stalk; indicator toggling handled by background ISR at 1.2 Hz.

PWM-based control is demonstrably superior to analog resistance-based methods forelectric motor speed regulation, offering efficiency gains of 40–50 percentage points at partial duty cycles.

Software-defined drive modes allow a single hardware platform to exhibitfundamentally different performance characteristics, enabling range-performance optimization without any physical hardware modification.

## Declaration of Conflicting Interests

The authors declare no potential conflicts of interest with respect to the research, authorship and publication of this article.

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