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DC motor control in vehicle body applications as a practical example of a cost competitive CAN networking solution.

DC motor control is the most distributed application in automotive body systems. As the number of DC motors in cars increases, a multiplexed architecture becomes the only viable solution, reducing cost and weight, improving reliability and control efficiency, and significantly increasing passenger convenience. This paper demonstrates in a practical example how products from National Semiconductor help minimize the cost of these applications, using CAN as the state of the art, fault tolerant networking solution.

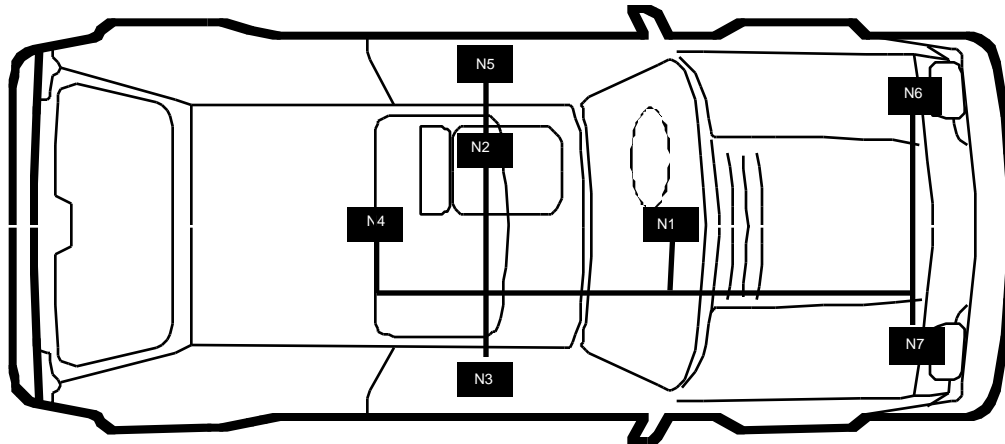
Introduction

This paper describes the issues associated with the implementation of DC motor control systems in automotive applications. It identifies the multiple locations of DC motors in automobiles. With reference to a basic DC motor control system structure it explains the approach National Semiconductor Corporation has taken to implement a system solution onto a single CAN microcontroller.

DC motors in automotive applications

DC motors are used in automobiles to increase the convenience and safety of driving. These functions are distributed throughout the car in various applications. These include modules located in the door like window winders, mirror control or in the driver and passenger seat for seat positioning and functions such as trunk lock or sunroof control. All these systems have the characteristic that control is performed far away from the action. Figure 1 shows various locations of DC-motors and their control systems in cars.

One example is a power seat where the driver wants to have the control buttons in the handrest and the motor is in the seat. Another example are the motors to control the mirror and window of the passenger door. Here again the driver needs to have the control buttons close to hand. Traditionally these systems require a large number of copper wires and a central control system to perform tasks like reading the switches and driving the motor to perform the desired action. The large number of wires used for control introduces a risk of malfunction. In a door module wires have to go through a small hole in the door and bend when the door opens and closes. If one wire breaks, the complete system may not operate any more. Also if the cabling to a motor in the power seat system breaks this could cause unwanted movement introducing a safety risk if this happens while the car is being driven. The solution is to replace the wiring looms with a multiplexed wiring bus. This reduces the cost of wiring and improves system reliability, for example when a fault tolerant protocol, like CAN, is used for control. Moreover, multiplex wiring gives more 'intelligence' to the motor helping to detect malfunctions directly. This can be done with the use of dedicated microcontrollers. This controller can directly take care of unwanted effects and can also perform a feasibility check of the command it was given the command itself is far more likely to be accurate as it is protected by the various error mechanisms of the protocol. Additionally a dedicated motor controller can react immediately when implementing safety critical functions. Take for example a window winder, which has to be switched off when something blocks the windows path, e.g. a child's head or the hand of an unconcentrated driver.



Legend:

- N1 - Dashboard / Steering wheel (control)
- N2 - Driver Power seat
- N3 - Passenger Door (mirror, window-winder)
- N4 - Sunroof
- N5 - Drivers Door (mirror, window-winder, control)
- N6 - Headlight control left
- N7 - Headlight control right

Figure 1.: DC-motors in automobiles

Also in industrial applications sensors and actuators are increasingly controlled by fault tolerant multiplex bus systems producing the need for integrated applications optimized controllers.

DC motor control system

A basic DC motor control system is shown in Figure 2. The regulator reads in the DEMAND value, sets the CONTROL value and compares the actual speed FEEDBACK value.

Currently there are two main implementations of a DC motor control systems: an electromechanical solution where the motor is switched on and off by relays where only the speed of the motor is monitored, and secondly, a fully electrical solution with a discrete or integrated H-Bridge. In the latter the motor's speed can be adjusted much more precisely than in the former. The SENSOR block consists of either a slotted disk to scan the movement of the motor optoelectronically or of an converter measuring the current flowing through the motor.

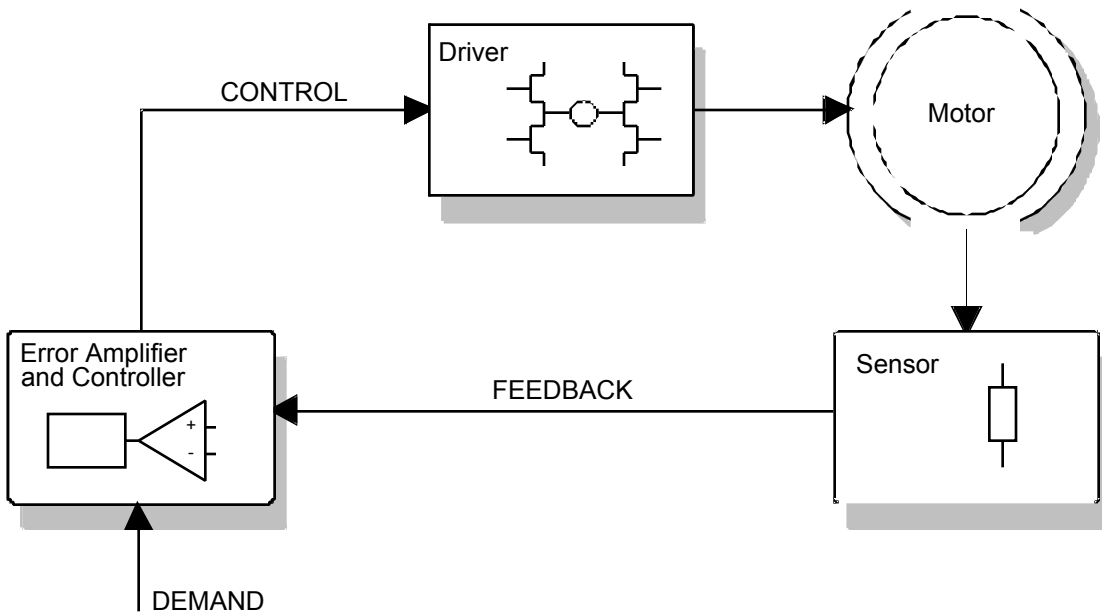


Figure 2.: Basic DC motor control system

Integrating a DC motor control system using National's COP884BC

National Semiconductor's COP884BC microcontroller addresses both implementations. The functional block found on this controller includes a high speed constant resolution PWM timer which can be used to control the H-Bridge with a minimum of external parts. However this PWM timer also has the option of monitoring the speed of the motor by high resolution frequency measurement if it runs in capture mode. Additionally two on-chip comparators allow sensing of the current through the motor. One of them has an input which can be switched to two pins. The integrated CAN interface addresses the need for highly reliable multiplexed data communication. Figure 2 shows a block diagram of the implementation and the following paragraphs describe the functional blocks in more detail.

H-Bridge:

The typical control means for DC motors is the H-bridge. It consists of four transistors A1, A2, B1 and B2 connected like an H with the motor in the middle. This scheme allows current to flow into the motor from either side. In Figure 3 if A1 and B2 conduct, current flows from left to right and vice versa if A2 and B1 are conducting. The other transistor pair is switched off. Care must be taken that both transistors of one side (A1 and B1 or A2 and B2) do not conduct at the same time, else a short circuit - called shoot-through - would result. The transistors are typically MOSFET type. To control the speed of the motor a PWM signal is applied to the gates A1 or B1. The voltage across the motor is dependent on the duty cycle of the PWM signal. If both transistors of one direction conduct, i.e. a duty cycle of 100% at the high side driver, the motor runs at full speed.

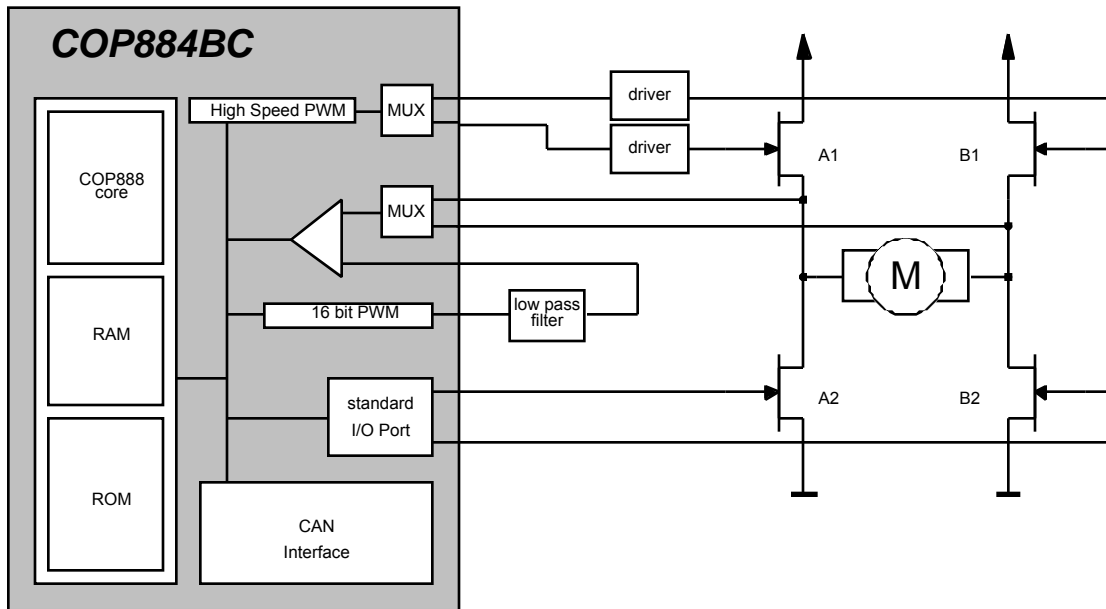


Figure 3: Motor control with COP884BC block diagram

Two additional points have to be taken into consideration when operating a DC motor with a MOSFET H-bridge. Firstly, as the high side drivers typically are n-channel MOSFET devices, the voltage on the gate needs to be higher than the voltage on the drain. This can be done with a simple bootstrap circuit which charges up a capacitor during the PWM low cycle and generates a voltage of approximately $V_{bat} \cdot 2$ as soon as the MOSFET starts conducting. The higher the overall frequency of the PWM signal, the lower the required capacitor value. Secondly a motor consists of a coil and a magnetic core which resonates at the PWM frequency. The PWM signal permanently starts and stops the motor. If the PWM signal is below 20 kHz (audible range) someone next to motor will hear the PWM induced resonance of the core. Therefore the PWM frequency should be chosen above the audible range. Nationals COP884BC microcontroller offers a unique high speed constant resolution PWM timer which is capable of generating PWM frequencies up to 39 kHz completely processor independently and which covers the full PWM range from static high to static low with only one register. The PWM signal can be routed to two output pins of the microcontroller to directly connect to a bootstrap circuit for each of the two high side drivers saving external components. Both low side drivers can be directly connected to ports of the microcontroller.

Current Feedback

To measure the load of the motor and to be able to switch it off in the case that the rotor is jammed a comparator can be used with a current to voltage converter. Usually one wants to set a specific current limit which should not be exceeded to prevent motor failure. There are two solutions for voltage to current conversion: a resistor in the ground line of both low side drivers or to use the R_{ds-on} resistance of each low side MOSFET. The latter has the advantage that no additional resistor is introduced to the system as an additional resistor would result in an additional voltage drop thus reducing the efficiency of the system. The COP884BC with its two comparators mapped to I/O ports supports both set-ups. Also the analog multiplexer on comparator 2 allows the measurement of two independent currents. A reference voltage, i.e. maximum voltage, is connected to the other terminal of the comparator. A simple way to generate this reference voltage is to use a PWM signal and a low pass RC-type filter. The PWM frequency is applied to the low pass filter. At the output of the filter a voltage directly proportional to the duty cycle will result. This circuit causes in the comparator output to toggle as soon as the voltage indicating the current through the motor exceeds the voltage set by the reference. Figure 4 shows the block diagram of this comparator and the mapped I/O pins together with the PWM timer generating the reference value. The R_{ds-on} resistances are also indicated in the figure.

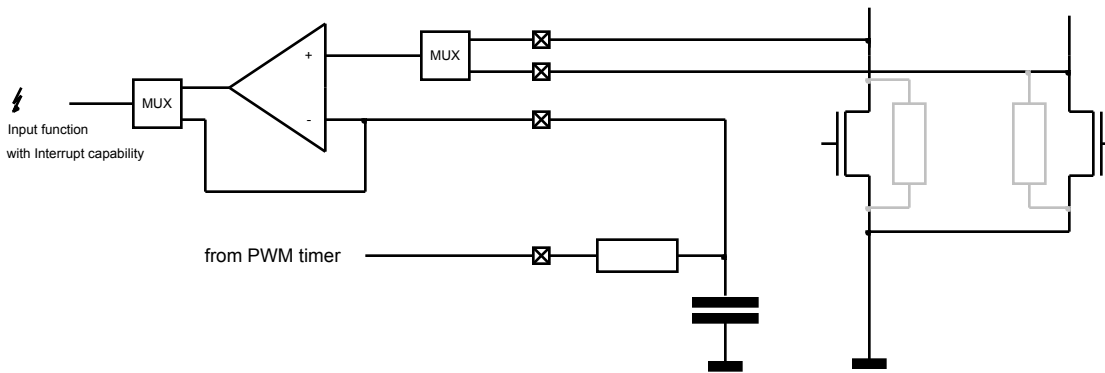


Figure 4.: Comparator and PWM

Multiplex Interface

The highly reliable, state of the art CAN protocol was chosen. CAN operates in either single or dual wire configuration with minimal amount of external components (ISO low speed interface). The CAN interface implemented on the COP884BC addresses the need for a highly sophisticated - but low cost communication. The interface is fully compatible to the CAN specification 2.0 B (passive). To address the cost efficiency National reduced the number of registers down to four for each message resulting in fully automatic processing of two byte messages by the interface and the need for software interaction for longer messages. This scheme can be used as the part works as a motor controller and CAN is only used for set-up purposes. Also the acceptance filter is reduced to seven bits as fine filtering of the messages can be done by software as well. Typical bus speeds of a distributed controller are 125 kBit/s which gives 128 us for two bit times which is sufficient for the controller to store away the data if the message is longer than two data bytes.

Glue processor

The processor controlling the motor has to set the PWM frequency, read in the current and gets commands through the CAN interface. Additionally it may perform other tasks like doing diagnosis, reading in switches and setting status bits to the output world. For this functionality the 2 kbyte of ROM and 64 bytes of RAM are sufficient. The application optimized COP8 uC family provided by NSC offers a highly efficient code set and dedicated functional blocks for various applications. The feature family COP888 core supports a vectored interrupt scheme allowing the easy implementations of interrupt routines for the different on-chip peripherals. These include three interrupt sources for the CAN interface, one high prioritized external interrupt, one for the comparators and an additional multi-sourced external interrupt and a total of four for the various on-chip timers. To reduce the current consumption of the controller two power saving modes HALT and IDLE are implemented. The former completely freezes the processor and all on-chip peripheral blocks. However, the device will wake-up if a CAN message is received or by seven other input signals which are user programmable. IDLE mode freezes the core and all peripheral blocks except for the IDLE timer and the clock circuit allowing faster wake-up times or periodic wake-ups. All I/O ports of the chip have Schmitt trigger input and weak pull-up capability allowing the designer to reduce the external component count. Additionally specific blocks to reduce electromagnetic emissions of the part have been implemented.

With the configurable controller methodology (CCM) and the newly installed European microcontroller design center, National Semiconductor addresses the need for system solutions and application optimized microcontrollers.

Conclusion

National's COP884BC, COPCAN-1, uC integrates most of the required blocks for highly sophisticated DC-motor control, allowing a designer to develop a cost effective network- controlled actuator with a few external components in a space saving 28 pin SO package. It integrates the PWM timer perfectly suited for H-bridge control and thereby removes an expensive integrated pure analog controller. Additionally COPCAN-1 shows that an application optimized CAN interface does not necessarily have to have the high cost associated with various CAN implementations.