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Innovative Design of an Automotive High Side Smart Switch Based Upon Frugal Engineering Concepts

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Abstract

Automotive electronics is increasingly playing a vital role in all vehicle subsystems. Since an electronic control system needs to be interfaced with the outside world, an electronic smart switch forms a key output interface with various loads such as solenoids, lamps, motors, relays, fans etc. Although integrated circuit based smart-switch semiconductor solutions are provided by all global semiconductor vendors, they prove more often than not to be overdesigned for majority of situations relevant to low end vehicles. They are also generously loaded with standard high-end features like thermal and overload protection which may not always be required. In addition, external transient protection and on-chip diagnostic features lend further complexity to the entire solution.

This paper proposes a novel smart switch design which can be optimally tailored to given output load requirements such as current profile, thermal requirements, protection on one hand and provides optimal pin count by combining diagnostic and command functions into a common terminal pin. Transient protection requirement may be minimized by judicious choice of the active device.

The smart switch system design employs system engineering techniques which lists performance requirements and explores alternate system designs to meet the same. All the alternatives are rated on various performance counts to arrive at the rightmost choice fitting a given application. The paper ends with a subsystem design design example which covers both hardware philosophy and a state machine based low level command/diagnostic driver. Future directions and opportunities for these solutions are discussed at the end.

Introduction

Automotive engineering since its inception has focused upon delivering more value consuming minimum resources to all the stake holders. Automotive embedded systems are no exception [1, 2].

One of the driving factors behind rapid penetration of electronic smart systems in automotive engineering is driven by the enhanced value proposition. Sensors and actuators in particularly are benefited from smart electronic interfaces to the outside world. [3] discusses exhaust actuator behavior at low ambient temperatures and proposes a software strategy for the same, ensuring successful operation for the active exhaust valves. [4] dwells upon intelligent auxiliary battery management based on associated information obtained through sensors. It discusses an intelligent strategy to preserve the battery state of charge under all use cases, temporarily turning off auxiliary loads whenever necessary. [5] presents a unique example of electronic subsystem control consisting of gasoline particulate filter and active exhaust tuning valve. [6] discusses effects of differential pressure measurement characteristics on high pressure EGR estimation errors on Spark Ignition engines. It offers solutions to minimize the error. All these studies highlight various aspects of intelligent embedded control of various automotive systems.

An embedded system by its very definition is embedded within its end application. It is an integral subsystem of an end application system. Naturally, interface with the other neighboring subsystems play a critical role in governing application system behavior on one hand and role of the embedded system on the other. Input device interface is relatively less complex as regards protections against transients, guarding against accidental short circuits or reverse polarity compared to output device interface. This is so due to inherent high impedance nature of an input subsystem. However, for using smart power switches to control output devices transient handling and protection circuits play a major role making its architecture complex. The literature describes various techniques for achieving the same. [7] describes a pulse width modulation (PWM) based smart switch for automotive application. The solution is equipped with built-in protections including a thermal shut-down. [8] offers a hybrid solution for implementing a smart switch. It employs a mechanical switch to handle large continuous current, aided by an electronic switch which takes over for make and brake operations. A significant gap in above circuit. Short-circuit detection is retained as a strategy. However, since it is based on a simple digital input, the cost is minimized. The benefit in terms of reduction of repair time can be witnessed due retry strategy which auto-restores the switch operation after an accidental short-circuit. Row 5 again wins over the previous architecture featuring complex digital and analog micro-controller interface. Reuse of the output drive pin of the micro-controller is gain fully re-configured as a digital input pin for diagnostics. Hence zero increment of micro-controller pins for diagnostic interface earns five out of five rating.

Let us sum-up the insights employed to arrive at the proposed architecture for diagnostic:

***Pain-point*:** A complex mix of analog and digital signal processing and interfaces governed the diagnostic scheme for integrated switch architecture. This consumed multiple CPU pins, it also required enable pin to minimize current drain due to analog current signal.

Root-cause: Multiple protection mechanisms discussed in previous sections each required a diagnostic interface both analog or digital depending on the protection requirements.

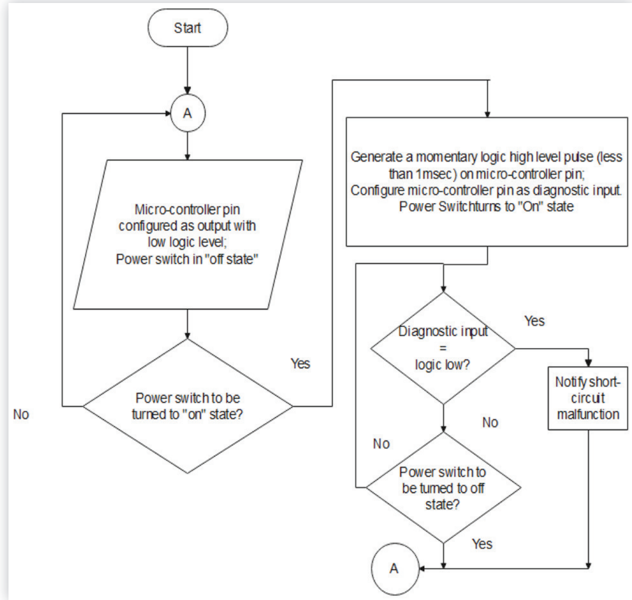
Proposed Solution: Since only short-circuit condition is to be diagnosed, A single CPU pin is reused for both command pulse as well as the diagnostics by alternately configuring the same as output and input. This leads to a frugal engineering solution driven by a common CPU pin and simple digital logic

Summary and Concluding Remarks

Figure 7 summarizes the overall implementation strategies for the revised architecture. The power-switch initialized into an “off” state. Micro-controller pin configured as “output low logic level” maintains the off state. Whenever an application command wishes to turn on the power switch, a logic high pulse is issued to the micro-controller output. This latches the power-switch into an “on” state. The micro-controller input can now safely be re-configured as diagnostic digital input since the latch no longer needs a base drive current from the same. During a short-circuit condition at the output, the latch is rest into an “off” state. This protects the power-switch on one hand and generates diagnostic message in the form of logic low input level read by the micro-controller on the interface pin. If and when the short-circuit condition disappears on its own, the micro-controller will be able to successfully turn the latch into “on” state again through an application dependent retry strategy. For turning the power-switch from “on” state to “off” state, the micro-controller interface pin needs to be configured as an output with a logic low level. This one pin interface for the micro-controller exploits the fact that after turning on the latch, the interface pin can be assigned a role of diagnostic input as a latch does not need a sustained drive input to maintain its “on” state.

The revised architecture consumes only a single CPU interface as against three pins (command, diagnostic and diagnostic enable) of the integrated architecture. It also replaces multiple component multiple protection/diagnostic subsystems of integrated architecture with a single transistor, four resistors and a single Zener diode.

FIGURE 7 Flow-chart indicating the driving and diagnostic/protection strategies for the revised architecture based on “on” and “off” states



This paper addresses a vital area of ECU interface to the outside world viz. output device interface. System design optimization in this area is multiplied manyfold since any single ECU needs to be interfaced with multiple output devices such as actuators, motors and illumination devices etc. Integrated circuit smart switches are popular choice with the ECU designer in line with the prevalent practice. However, these solutions are likely to consist of system blocks not relevant for a given application. This is particularly true for devices not featuring heavy inrush currents like lamp-loads. A simple discrete circuit switch is proposed which would improve cost to benefit ration particularly for low-cost vehicles such as two wheelers and low end four wheelers. The architecture may be further explored for packaging into a hybrid integrated circuit tailored around the PMOS switch.

Considering future course of research and development in this area, an SoC (System on Chip) solution for the high side switch can be considered. The novel solution also can be further evaluated by assembling the same on PCB and PCB level performance metrics could be evaluated on the same lines as performed in [13]

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Definitions/Abbreviations

ECU - Electronic Control Unit

PCB - Printed Circuit Board.

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