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Implementation of e-fuse software functionality for automotive

Bachelor's Thesis

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Bachelor's Degree in Industrial Electronics and Automation Engineering

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Fdo. José Luis Ramírez.

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I want to thank my supervisor, Xavi Mateu for giving me opportunity to allocate part of my dedication in my workplace to completing this thesis, while working in customers projects. This has given me the opportunity to learn about vehicle electronic systems, and I have been able to apply it in the development of this project.

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Finally, I want to thank my family and friends that have supported me during the development of this project. Their patience and their motivation has pushed me forward to the completion of this thesis.

Resum

Aquest projecte es motivat per l'interès de desenvolupar un fusible electrònic implementat per software, sense lligams a una peça de hardware determinada, que s'utilitzi en els sistemes electrònics dels vehicles.

Aquest projecte inclou l'estudi de la funció d'un fusible i un fusible electrònic per vehicles. Seguidament tracta el desenvolupament de l'algoritme de funcionament del fusible electrònic i la implementació en software per us en vehicles. Per validar el funcionament del software s'ha creat un prototip que simula les condicions d'operació del fusible electrònic.

En aquest projecte he tingut la oportunitat de treballar en el desenvolupament de tecnologies d'avantguarda per l'electrònica de vehicles. Els fabricants de vehicles estan interessats en implementar els fusibles electrònics als seus productes.

Paraules clau: software, fusible electrònic, automoció.

Resumen

Este proyecto está motivado por el interés de desarrollar un fusible electrónico implementado por software, sin ataduras a una pieza de hardware determinada, que se utilice en los sistemas electrónicos de los vehículos.

Este proyecto incluye el estudio de la función de un fusible y un fusible electrónico para vehículos. Seguidamente trata el desarrollo del algoritmo de funcionamiento del fusible electrónico y la implementación en software para uso en vehículos. Para validar el funcionamiento del software, se ha creado un prototipo que simula las condiciones de operación del fusible electrónico.

En este proyecto he tenido la oportunidad de trabajar en el desarrollo de tecnologías de vanguardia por la electrónica de vehículos. Los fabricantes de vehículos están interesados en implementar los fusibles electrónicos en sus productos.

Palabras clave: software, fusible electrónico, automoción.

Abstract

This project is motivated by the interest to develop a software-implemented electronic fuse, untethered to a particular piece of hardware, for use in vehicle electronic systems.

This project includes the study of the function of a fuse and an electronic fuse for vehicles. Next, it deals with the development of the electronic fuse operation algorithm and its implementation in software for use in vehicles. To validate the operation of the software, a prototype has been created that simulates the operating conditions of the electronic fuse.

In this project I have had the opportunity to work on the development of cutting-edge technologies for vehicle electronics. Vehicle manufacturers are interested in implementing electronic fuses in their products.

Keywords: software, electronic fuse, automotive.

Prelude

This thesis has been developed within the framework of a Work Contract at Lear Corporation in Valls, Spain. The department in which this project has developed is the Advanced Department. It is part of an ongoing larger project to internally develop several conceptual technologies to implement in future client's projects.

In the Advanced department different technologies are being developed, this thesis is focused on electronic fuses and its software development. The electronic fuse design is prepared for wire harness protection. The software development is framed on automotive use of electronic fuses.

Given that the development of the thesis has been carried out entirely in Lear Corporation Valls facilities, all the information that supports the realization of itself, both technical and theoretical, as well as the technological solutions and results, are owned by Lear Corporation and remain under the protection of the relevant confidentiality agreement. That is why there will coexist a public version and another confidential part of this document.

So that this fact does not condition the comprehensibility of the public version of the present, it has been decided to keep the theoretical bases of the software development in both versions. The software development and implementation, as well as the results, are subject to confidentiality.

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1. Project description and reasoning

With the coming of modern technologies to the automotive ecosystem, like driver assistance technologies or new propulsion methods, there is an increasing demand for a more environmentally sustainable transport. In this matter, the electronic automotive industry, Tier 1 and Tier 2 suppliers, need to find ways to improve the electronic systems in several areas like efficiency, weight and reliability.

One of the key factors for improving electronics systems performance in the vehicle is weight reduction. As the quantity of electronic systems increase in the car, to have lighter electronic system is key to reduce the environmental impact of the vehicle, its manufacturing cost and improve the options of integrating more hardware options in a vehicle.

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Figure 1. Evolution of vehicle electronic architecture

Another factor that is extremely relevant in the need for improved electronic systems is the introduction of driver assistance technologies. These technologies require that the systems powering them have an increased degree of redundancy and control. The protection systems in these areas need to be able to actively act on the possible failures that may occur to avoid them and ensure a higher degree of security of these systems.

These situation leads to the development of new and better methods to protect the electronic hardware in the system. The component that focusses the scope of this project is the wire harness and how to protect the cables in a way that adapts to the new requirements of the automotive environment. These requirements mandate to avoid the use of typical fuses and require the implementation of electronic fuses or e-fuses.

An e-fuse is a combination of hardware and software that performs a functionality comparable to a fuse with added benefits, like increased precision and better adaptability to different operating conditions. These devices are currently getting to the market as commercial solutions are being presented by the electronic suppliers. The goal is to make a software that implements the e-fuse functionality into a SmartFET device that does not have it implemented from its manufacturer.

1.1 Project scope and overview

This project aims to develop a functional prototype demonstrating the implementation of the software functionality to create an e-fuse using a traditional SmartFET device that lacks the e-fuse functionality. The end product of the project is the code that implements the designed protection algorithm in a prototype system for evaluation of the performance of the software in various scenarios.

The software developed will be flashed in a protype system to test the functionality. The prototype is made of a switching device and a microcontroller unit that runs the software written to implement the e-fuse in the hardware.

Further details about the prototype are in chapter 3.2.

1.2 Objectives

Based on the scope of this project, three main objectives are defined:

- Develop a software for automotive use that implements the e-fuse functionality.
- Evaluate the functionality and performance of the e-fuse software using a prototype system.
- Verify the use of an e-fuse to substitute a traditional fuse for the protection of wires.

2. Theoretical basis

The flow of electrical current increases the temperature of the devices through which it is flowing. This is because of the electrical resistance that electrical devices have. The increase in temperature of an electrical device is related to its electrical resistance and the amount of electrical current flowing through it. These two parameters determine the temperature that an electronic component reaches during operation. The operating temperature determines for how long any electronic component can be conducting a determined amount of current. The nominal current stated for a component is the amount of current that the electronic component can conduct for an infinite amount of time, without surpassing its maximum operating temperature.

Having the component temperature as the determining factor for nominal current operation, the ambient temperature where the electronic component is operating is relevant to state the nominal current that any component can stand.

The flow of electrical current through an electrical conductor connecting a power source and an electrical load is defined by two parameters. The first one is the electric power being transported to the load. The second one is the voltage at which is being supplied this power. These two parameters are related to the electrical current by Ohm’s law. This law defines how to calculate the current flow, in Amperes(A), related to the power being delivered, in Watts(W), and the voltage, in Volts(V), that is receiving the load.

$$Voltage(V) = Resistance(\Omega) * Intensity(A)$$

$$Power(W) = Voltage(V) * Intensity(A)$$

Being the case that the temperature will increase in the electrical and electronic devices when there is current flow, all these devices need to be protected against overheating to avoid damaging any component.

In the automotive environment all electronic systems need to be designed and implemented considering measures to avoid equipment failures and possible failures that can occur during operation.

The relevant component for this project is the transmission device connecting the power source and the load, the cable. The cable needs to be protected against overheating to avoid damage to the insulating material that covers it. Overheating of the cable can also cause damage to the connections to the power source and to the load. This situation can lead to a significant failure, like a short-circuit.

The protection method used for avoiding overheating of cables is the installation of fuses between the power source and the cable and the load. These devices disconnect the circuit in case the temperature or the current flow in the cable are excessive. These devices have many drawbacks that impose limitations in its use cases. These limitations are also a determinant factor for the design choices in the electronic systems that must integrate them. From a mechanical point of view, the use of conventional fuses increases weight in the system because imposes the need for oversizing to a certain degree the cables that is protecting.

The next step in cable protection is the electronic fuse or e-fuse. This functionality is used to electronically protect the cable from overheating and over currents. This kind of protection is more flexible, as it does not need to be implemented with a unique component.

As will be seen, the e-fuse differs from the conventional fuse in the fact that the e-fuse is a functionality that can be implemented by software or by hardware, in difference to the fuse that is specifically an electronic device with a single function.

The use of e-fuses also includes some features, as reconnectable systems after failure or the capacity to isolate parts of electronic systems without the existence of a failure.

2.1 Fuse

“A fuse is a small safety part in an electrical device or piece of machinery that causes it to stop working if the electric current is too high, and so prevents fires or other dangers.” [1]

As can be extracted from the definition, a fuse is an electrical device that is used to protect electrical or electronic systems from excessive flow of electrical current. This device actuates by melting itself in case of excessive temperature produced by the excessive electrical current. The electrical connection between both ends of the fuse is broken once it melts and the electrical circuit is opened.

This device has been used extensively since the introduction of electrical and electronic systems into vehicles. It has been used to protect the wire harness of the vehicles from being damaged due to over current.

This kind of protective device is very suitable for the automotive application because it does not require any external input, like a power source, to work. It also provides security in its use, as the operating principal is based on physics law.

Despite of the benefits of this device, it also has many drawbacks. The main drawback being the fact that once the device actuates to protect the electrical components, it is destroyed and must be replaced to reconnect the electrical circuit. This characteristic imposes many limitations in the placement of these devices inside a vehicle, as they need to be easily reachable to be replaced in case of circuit protection.

Another drawback that needs to be accounted when using a fuse is its protection curve. This defines the amount of current that will trigger the actuation of the device in relation to the ambient temperature in which it is operating. The variability of this key parameter forces to oversize the section of the cables being protected to account for the possible ambient temperature variations.

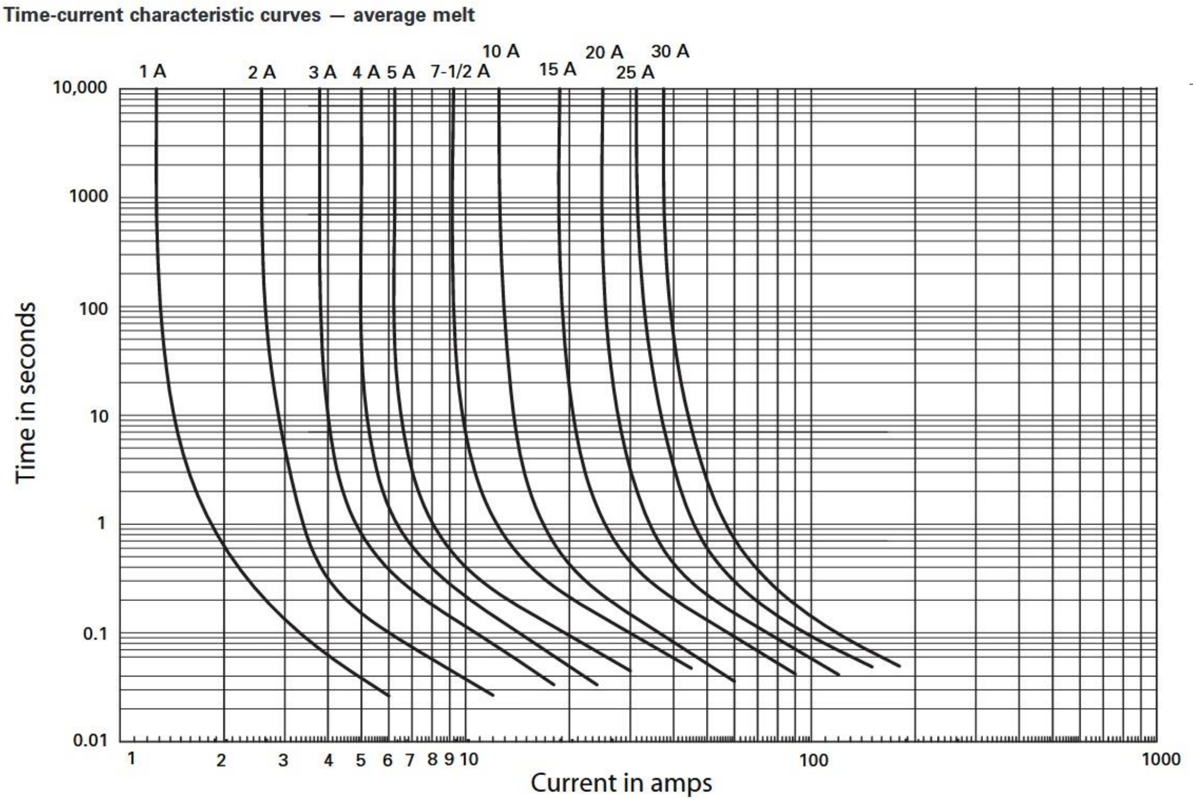

Figure 2. Fuse response characteristic curve [4]

These limitations in the fuse make it not suitable for use in the protection of forthcoming electronic systems in vehicles. The current use of traditional fuses in vehicles imposes limitations in the design of the wire harness in the automotive industry due to wide safety margins that need to be applied to cover all protection cases.

With the objective of reducing the weight of the wire harness of the vehicles and with the vision to implement new and more complex electronic systems, the need for electronic fuses is greatly increasing.

2.2 e-fuse

An electronic fuse or e-fuse is an electronic device that implements the functionality of a fuse using electronic hardware and software. Its operating principle is not based in the destruction of any physical device to open the circuit, like in a traditional fuse. On the contrary, an algorithm processes the measured current flowing through the cable and calculates when it is necessary to disconnect the circuit due to excessive current flow or temperature. The disconnection of the circuit is done by opening an electronic switch. This action can be reversed without the need of replacing any physical components.

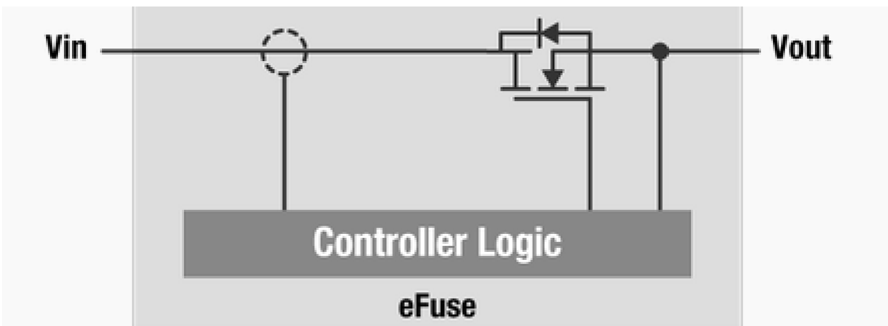

Figure 3. e-fuse schematic design [2]

The e-fuse device can be divided in two parts: hardware and software. The hardware needed for an e-fuse is an electronic switch and a measuring device to know the flow of current. In electronic systems for vehicles, these two hardware components are integrated in a single component called SmartFET. This component usually integrates complementary functions like open circuit detection, to detect if there is no load connected to it, and fault detection, to detect if there is a power source connected where the load is supposed to be, or there is a short-circuit after the switch. A use case for these functions is detecting if a light bulb in a vehicle has blown.

The software for an e-fuse device contains the algorithm that is used to trigger the protection in the circuit. This algorithm is developed into a software strategy that controls when the circuit is protected. Several strategies for the wire protection can be implanted.

For this project, the strategy developed to protect the circuit is a time-based strategy. This strategy uses the maximum current conduction performance of the protected cable and the time factor to ensure the current flowing through the wire is within the operating limits of the cable. In case the current flow is over the current limit, the circuit is disconnected. The strategy implements thresholds for adjusting the sensibility of the protection and the behavior of the system in case of the actuation of the fuse.

The software is responsible for the operation of the SmartFET, so all the commands for connection and disconnection of the switch are supervised by the protection algorithm. The software is divided in different software components that allow to implement the algorithm in different hardware devices with minimal modifications and adapt the protection thresholds to each different case.

The use of e-fuses in an electronic system has many benefits over the use of conventional fuses. The first one being the no destruction of the physical component in case the protection is triggered. This allows to place the components in a less reachable but more optimal place in the vehicle. The second benefit is the possibility to reconnect the isolated part of the circuit automatically or remotely using only software commands. This permits to bring back to function parts of the systems that have been isolated because there was a temporary fault or malfunction. Another benefit of an e-fuse is the reduced reaction time when a failure occurs in the circuit. This reduces the strain on components when a fault occurs.

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Figure 4. Time response comparison between fuse and e-fuse

One positive effect of the use of e-fuses in a vehicle is the reduction in weight in the wire harness in it. This is because the protection threshold in an e-fuse can be adjusted more accurately to the expected currents and is not dependent on ambient factors like temperature. This situation allows to reduce the cable section, as there is no need to consider variability in the protection limits for the cable.

These devices have some drawbacks that must be considered. The first one is the need of an external electronic system to power the SmartFET device and the microprocessor that is running the protection algorithm. In case this system fails, the e-fuse cannot function. The second limitation is the need of a device that executes and runs the WPA algorithm, that can be inside or outside the hardware used for the switching and measurement function.

2.2.1SmartFET

A SmartFET is an electronic switching device that has implemented complementary functionalities to the switching function. These added functionalities are basically the measurement of current flowing through it and overtemperature and overcurrent protection. It can also implement complementary capabilities, such us serial communication.

The SmartFET device has a Metal-Oxide-Semiconductor Field-Effect Transistor (MOSFET) in its core. This is the part that takes care of opening and closing the electrical circuit. Around the MOSFET there are the complementary electronic elements to control the transistor. These elements include mainly the power supply for the transistor and the elements around it and the microcontroller to implement the internal operating logic of the SmartFET.

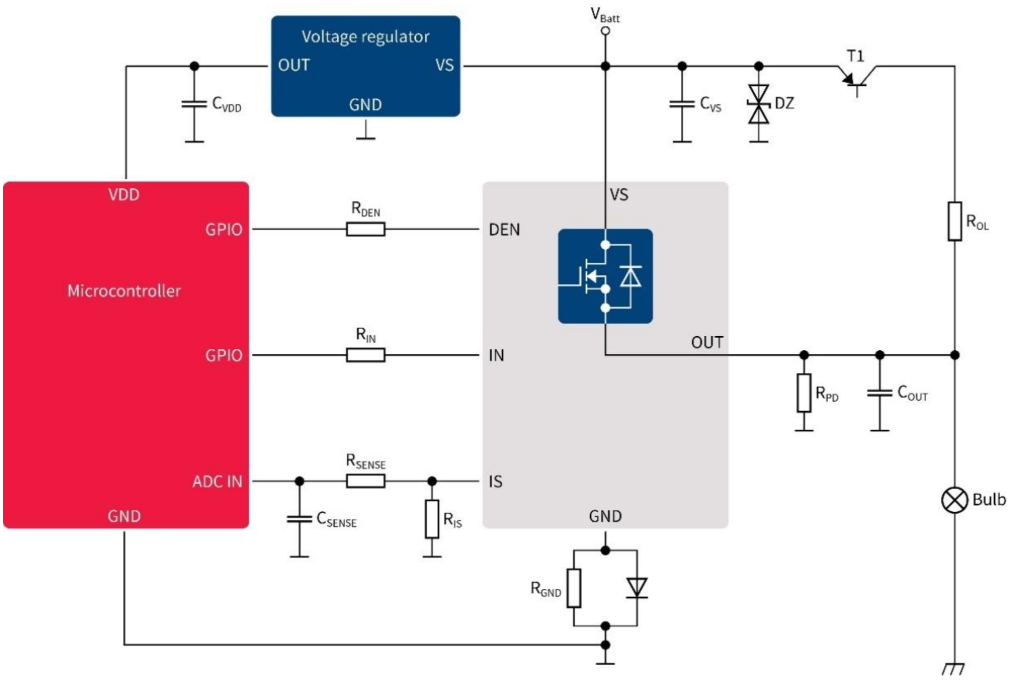

Figure 5. SmartFET schematic design [9]

In the SmartFETs currently used in the automotive industry, all the elements listed above are integrated into a single electronic component. This component has connection pins or pads that are used to operate de device and read the information being provided by the SmartFET. The SmartFETs are mounted in a printed circuit board that has the needed connections to link the pads with the main microprocessor and the outputs of the system.

2.3 Market situation

In the last two years, OEMs have been looking into improving the electronic systems in their vehicles. Their demands towards electronic systems suppliers have gone towards requiring the use of e-fuses. This need has pushed to the creation of commercial solutions.

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Figure 6. STMicroelectronics vehicle architecture roadmap

3. Practical part

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4. Conclusions

This thesis project initiated with the goal to design a software that would implement the e-fuse functionality into a SmartFET that does not have that functionality implemented.

4.1 Results assessment

4.2 Objectives completed in relation to results

4.3

4.4 Future evolution

4.5 Personal conclusions

On a personal level, developing my Bachelor's Thesis in conjunction with Lear Corporation has been a magnificent experience.

It has been a great opportunity to develop a technological solution for the current automotive market. And doing so involved in currently developing projects, it has allowed me to enlarge my knowledge regarding automotive electronics and cutting-edge technology in this sector.

I am satisfied with the result of the project and I expect to continue with the development of it in Lear Corporation.

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6. Annex

6.1 Code

6.2 Software Low Level Design