

A Simple Method to Insure Bus-to-Bus Safety in Dual-Voltage Automotive Systems

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ABSTRACT

In some automotive electrical systems, it is advantageous to use power supplies and loads at two or more voltages. Often it is desirable to retain the single wire power architecture, with the car body providing the return circuit. A major difficulty in achieving this end is the matter of dealing with the possibility of a short circuit between feed wires at different voltages. It can be shown that source-side fuses cannot be relied upon to return the system to a safe state in all cases.

Substantial effort was applied to this problem in the early years of the 21st century, but the results were less than completely satisfactory. Using entirely separate cable harnesses for each voltage, with physically separated routing, minimizes the risk of such a short occurring in the harness. However, the use of more than one harness imposes a substantial cost penalty, and this solution does not provide an answer for the case where the short occurs at or within a load being serviced by more than one voltage.

Complicated sensing circuits with floating solid state switches (requiring expensive drivers) are also unattractive.

The authors offer a simple solution which can be implemented exclusively with ground-reference switches concentrated in the fuse block. This simple modification, coupled with the application of a very reasonable and easy-to-implement design rule for selecting wire gauges for the cable harness, can result in the system returning to a safe state following every fuse operation.

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INTRODUCTION

For a brief while, the auto industry gave serious thought to introducing 42 Volts as a standard dc distribution voltage on automobiles. Early implementations were anticipated to distribute power at two voltages, the new 42 Volts and the old standard 12 Volts (referenced herein as 14 Volts in accordance with the custom). With the exception of a few models, with very limited production, this proposal was not implemented. The reasons for this decision considered many factors. Principal among them was the additional cost associated with the proposed new system.

A significant contributor to the ongoing cost of producing such systems was the complexity introduced by the necessity to deal with the possibility of bus-to-bus short circuits.

The basic plan for early implementations of 42 Volts considered the 42-Volt system as an overlay over the 14-Volt system. There would be a common wire harness, and the system would be capable of providing both 14 Volts and 42Volts to a load, if that was desirable. It can be shown that if the fuse systems for the two different buses are not designed with the possibility of a bus-to-bus short in mind, such a short is not guaranteed to be restored to a safe situation by the action of fuses.

This paper presents a simple, elegant, solution to this problem.

THE PROBLEM

When a bus-to-bus short develops, the only safe end state occurs if the fuses feeding the affected circuits have both cleared. Some have argued that clearing of the high voltage fuse alone is sufficient; the remaining lower voltage may not

allow the high-voltage load to operate properly or at all, but it should not cause overheating or consequential damage. This reasoning neglects the probability that the short circuit itself is most probably not a zero-resistance connection. A substantial fraction of bus-to-bus shorts will produce dangerous overheating at the site of the short unless the current through the short is reduced to zero, which requires the clearing of both affected fuses.

When a bus-to-bus short occurs, it will be common for one of the fuses to open. This can be understood by referencing [Figure 1](#). The left half of [Figure 1](#) schematically presents two circuits, one fed by a 42-Volt source and the other by a 14-Volt source, each protected by a fuse F and feeding a load L , that have been connected by a short circuit on the fuse side of the load. In [Figure 1](#) and elsewhere in this paper, the subscript 1 is used to refer to quantities associated with the 42-Volt circuit; the subscript 2 refers to the 14-Volt circuit. The reader will understand that this work can apply to any circumstance where different voltages are applied in a ground-return system and where the possibility of shorts like the one being discussed is a concern.

The right half of [Figure 1](#) presents the circuit formed by a zero-resistance short, with the two voltage sources represented by Thévenin equivalents. It is more convenient in this analysis to use conductance rather than resistance to characterize impedance, thus the g symbols.

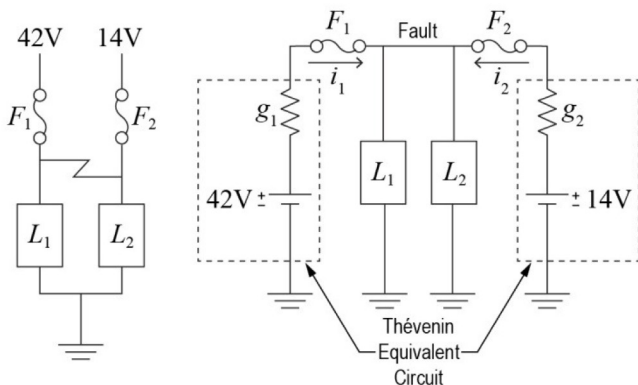


Figure 1. Schematic of a fault between two buses and an equivalent circuit.

The resistance of the parallel loads can be quite variable, but the maximum conductance for any reasonable combination of loads for a 42/14 Volt system is on the order of 1.5 mhos. A reasonable upper bound for each g_1 and g_2 is of the order of 20 mhos. It is apparent, therefore, that a large current will flow from source to source, for any normal pre-fault load, and one of the fuses, almost always the lower-rated one, will act quickly. Note that the clearing voltage required of the 14Volt fuses will be greater than 14Volts.

A problem can arise after the first fuse has cleared. While the upper bound of conductance for the parallel combination of loads is about 1.5 mhos, there is no practical lower bound. It is

common for automotive loads to present substantially variable equivalent impedances, depending on what the load is doing. So it is quite possible that the parallel load will draw a substantial current which is still below the rating of the remaining fuse. The second fuse cannot be counted on to act. This is a potentially dangerous condition, if the short circuit presents an impedance high enough to generate local heating but low enough not to substantially limit the current.

This result is presented with more formality in [1], upon which much of this paper is based.

The matter of the impedance of the short circuit deserves a bit more discussion. As a matter of formal logic, it is possible to postulate a short circuit of any impedance. It will therefore always be formally possible that a short circuit will draw a substantial fraction of the power capability of a source (approximately the product of the source voltage and the fusing current), without ever causing a fuse to blow.

This situation is not unique to dual-voltage systems. Every power circuit in every automobile poses this risk. As a practical matter, faults with this seemingly dangerous intermediate range of resistance (or conductance) do not pose an excessive risk. The vast majority of short circuits quickly cause fuses to blow. When a fault does occur with an intermediate impedance, substantial local heating frequently results. One of the early consequences is the melting of thermoplastic insulation, which frequently leads to a high-conductance short circuit and fuse blowing.

This paper does not offer a solution to the problem of the intermediate resistance short circuit. The risk is not substantially different for dual-voltage automobiles than for conventional vehicles, and no protection other than that described in the previous paragraph is provided in these conventional vehicles. The primary concern of this paper is to prevent a high-conductance short from evolving to a situation in which a section of wiring is fed by a circuit which is fused at a level too high to protect that section.

Other Solutions

When this problem first came to be recognized, enthusiasm for 42 Volts was high. Surely, it was felt, there must be a way to solve this problem.

One of the first solutions to be proposed, and one which was widely accepted as being adequate, is to incorporate a MOSFET in the junction box, in series with each line connecting the junction box to a circuit containing a load or loads. The MOSFET would occupy the place in the circuit formerly occupied by the fuse. (See, for example [2].) No need was seen for a series combination of MOSFET and fuse; anything the fuse could do the MOSFET can do at least as well.

On the other hand, replacing each fuse with a MOSFET is not a cost-neutral proposition. The cost is multiplied because each MOSFET requires a floating gate driver. Further, to do the fuse's work of interrupting a large overcurrent, each MOSFET must be large, and some sort of current sensor with appropriate logic to operate the MOSFET driver will be required for each circuit.

But this is what is required just to replace the fuses. We have already argued that merely tripping on overcurrent is not adequate for the task at hand.

A MOSFET in each circuit gives the junction box the capability to interrupt current to any circuit without that circuit first experiencing an overcurrent. However, the logic to decide when to do this is far from simple, as voltage in a fully functional automotive electrical system can vary over substantial ranges in response to many disturbances. So working from measurement of voltage alone, it will be difficult to detect the existence of a bus-to-bus short and perhaps impossible to detect it with certainty.

It will be shown later that it is possible to design a system in which it is guaranteed that at least one fuse will clear in response to a bus-to-bus short. Measurement of the voltage on the two ends of a fuse can provide evidence that a fuse has blown, and that the load side of the fuse is being back-fed from somewhere. By sequentially turning off all the other circuits (one at a time, and only briefly), it should be possible to identify the second circuit. This proposal includes a lot of measurement and a lot of fuss, but the measurement circuitry can all be included in the junction box.

Others have advocated avoiding bus-to-bus shorts by making them for practical purposes physically impossible [3]. Following this proposed plan, 42-Volt and 14-Volt wire harnesses would be entirely independent, and would be installed in locations far from each other in the automobile. Even in a collision the probability of a bus-to-bus short would remain effectively zero.

As a practical matter, for this to work, special requirements would be placed on dual-voltage loads. Absent special considerations, it makes great sense for most 42-Volt electrical loads to be dual-voltage loads. 42 Volts is attractive principally for loads whose peak power demands are higher than can conveniently be provided at 14 Volts. But any control commands would conveniently be sent to the load at a lower voltage; 14 Volts or in the case of a data bus, 5 Volts or lower. Any such dual-voltage load would require internal isolation between the different buses at least as robust as that achieved by the separation of the wire harnesses; otherwise the safety of the electrical system architecture would be compromised.

The separate wire harness strategy also relies on the absence of any post-initial-sale modification which would defeat the design intent. While such modifications may not be common,

those which do occur are arguably far more likely, per vehicle, to introduce a problematic short circuit at some point in the life of the vehicle.

By the time reference [1] appeared, 42 Volts was no longer of great interest. Recent activity in advanced automotive electrical systems suggests that this paper is once again timely.

A Simple Solution

The authors have performed an extensive study to evaluate alternative methods to achieve safety in the event of a bus-to-bus fault. Substantial time was applied evaluating purely passive modifications to the system, but all were found to be inadequate. A simpler solution using an active device has been identified. Its fundamental features are shown in Figure 2.

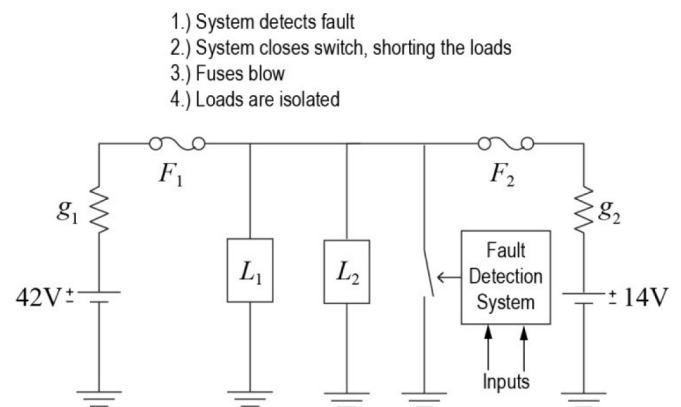


Figure 2. A Solution Using a Broadly-Defined Fault Detection System

In this system, a switch is controlled by a fault detection system. Each independent branch of the 14-Volt system has a similar switch and detector. The function of the switch is to short circuit load L_2 and anything else that might be connected to it through a fault, to ground. When a bus-to-bus fault is detected involving the particular 14-Volt circuit which is controlled by this switch, the switch is activated. The resulting short circuit clears both fuses, returning the system to the desired end state.

At this point in its presentation, the inputs to the fault detection system and the logical processes which are driven by those inputs are as ill defined as they were for the previous discussion of switches in series with each source.

The detection problem is essentially identical for the two different protection proposals. If the solution with series switches can be made to work, the solution in Figure 2 can be made to work.

A substantial cost benefit should accrue for this new proposal. The switch element is connected to ground. If a MOSFET is used, a ground-reference gate driver can be used. Further, the switch is not required to interrupt fault current. Both differences should lead to cost reductions. The proposed system does not retain all the fuses. This constitutes an additional cost element.