What Are You Smoking? Automating Short Circuit Testing for Automotive Systems and Harness Design

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Overview

Protecting vehicle wire harnesses from overloads that could be catastrophic is a critical design criterion. The designer must ensure that the fusing strategy protects the wiring. This process typically involves calculating the maximum load on each wire manually and then comparing the result to a spreadsheet that may have been created many years ago.

This process is very error prone due to its manual nature. You might find that alarming — and it is — but cars and planes are driving and flying just fine. There are several reasons that is so:

1. **Circuits are over protected.** Due to the manual nature of most design processes designers tend to err on the side of caution; this means wires that are larger than needed for the actual load. Over protection adds both cost and weight to the harness.
2. **Physical testing.** Very expensive physical prototypes are built and test engineers physically test the design to ensure the circuits are protected. This is costly both in time and money, and is often so late in the design process that changes resulting from this testing are very expensive to make.
3. **Engineers and designers are smart.** Many designs are simply carried over from year to year. History tells them what works and what doesn't – but we must ask the question: is this the most efficient way to design?

Analysis and Simulation

We often hear the words simulation and analysis when we are discussing circuit protection. While simulation has often been heralded as the savior of wire harness design it is rarely implemented, and if it is, it creates a huge bottleneck in the process. First a highly trained skilled simulation expert must create complex models, run their simulations and then analyze the results. The results are then fed back to the harness engineering team who then in turn must make decisions based on the often complex and difficult to understand graphs and results.

An important input that is always missing in doing simulation this way is the actual configuration of the vehicle. Not all loads are present in all vehicles. An example is a car where navigation is optional. Which simulation will be done – with navigation or without? Let's add an optional moon roof into the mix: now you have $2^2 = 4$ vehicle models to simulate. As you add in more optional content you can see the number of simulation combinations climbs to 2^n where n= the number of options.

For a simulation and modelling expert who has expertise in the creation of motor models and wire models, the complexity of potentially billions of vehicle combinations is outside the scope of any simulation. Even if you could run that many simulations, there would be insufficient time to interpret all of the resulting simulation charts and graphs to make a meaningful design change prior to building vehicles in production. Design-to-manufacturing times are shrinking every year; there is no time to do simulation this way, which forces designers to choose wire and fuse sizes based on historical lookup tables in a spreadsheet or on paper. Assuming no manual mistakes are made, the designer usually ends up with an over protected design that increases cost and weight.

What is to be done?

The solution to this dilemma is to harness the expertise these simulation experts have and empower every engineer to analyze their designs and provide fast and meaningful feedback. By capturing the criteria for wire and fuse sizing – your engineering intellectual property – we believe that your design tools should inform your engineers whether a problem exists or not. Analysis tools should analyze the vehicle and point the engineers directly to specific problems, and moreover, suggest solutions to those problems based on your engineering know-how. Staring at graphs and curves of detailed simulation runs for a handful of optional content is a long process and still subject to the interpretation of the data.

It's easy to get started, with the right tools

There is a cheaper and more accurate way to design. A step in the right direction is to capture the design data in an electronic format that can be analyzed with software. With the right set of design tools, engineers and designers can implement rules to implement correct-by-construction design methodologies. Problems can be found early in the process, well before physical prototypes are built — perhaps eliminating the need for prototypes altogether.

This correct-by-construction methodology, where software tools analyze the design *as it is being done,* requires several parameters:

1. Accurate load information for devices that draw current, e.g.:

Motor Size (hp)	*115 Volts*	*208 Volts*	*230 Volts*
1/7	5 Amps	3 Amps	2.9 Amps

2. Current flow through electronic control units (ECU's):
    a. We often hear that the inside of ECU's is proprietary and the task to model them is very daunting. When you focus on the task at hand – determine if your fuses protect your wires – modelling of the internal ECU connectivity is trivial with the right engineering tools. An example of all that might be needed is shown in figure 1 (hypothetical example).

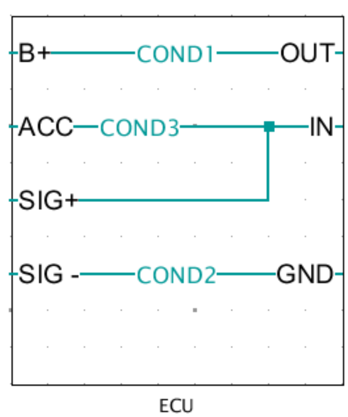

Figure 1: For fusing, a simple model can be used for the ECUs.

3. A model of the architecture of the vehicle describing the location of the components and the relative temperatures of each area of the vehicle and the harness interconnect points, as shown in figure 2.

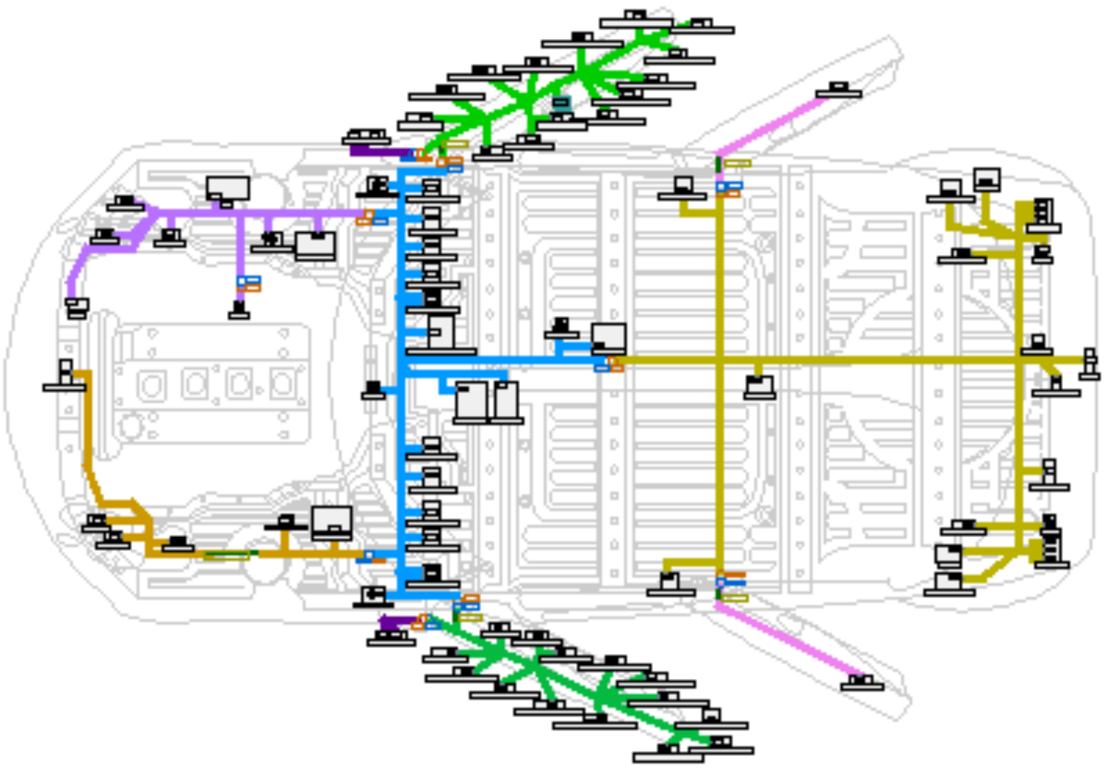

Figure 2: The location and temperature extremes for harness interconnect points must be modeled.

4. Accurate models for the battery, fuses, wires, and the basic discrete devices found in your vehicle (lamps, motors, switches, grounds, relays, etc.)

You can do this

Figure 3 shows an example of what is possible with the right set of tools. The engineer can take the recommended wire size (in the column Wire $CSA_{(max)}$) and actually apply that to the design, driving part number selection from this information.

Results | Concerns | Rules

Name	Applied Voltage	Applied Current	Applied Power	Wire CSA (max) ▼
PWR-IGN-RUN-2	0.13905	13.10975	1.822911	1.75
PWR-IGN-RUN-1	0.07492	13.1097	0.982179	1.75
PWR-BATT-4	0.01066	13.1098	0.13975	1.75
PWR-BATT-2	0.13905	13.1098	1.822918	1.75
PWR-BATT-1	0.01259	13.10995	0.165054	1.75
GND-BATT-1	0.045154	13.1097	0.591959	1.75
9N-GND-AIRBAG_EC...	0.074595	6.00026	0.44759	1.0
PWR-IGN-ACC-2	0.05592	4.19363	0.234508	0.75
PWR-IGN-ACC-1	0.10379	4.193635	0.435257	0.75
2N-POWER-5-2	0.13289	5.16635	0.686556	0.75

Figure 3: With the right toolset, engineers can easily apply standardized wire sizes directly to the design.

With this information, design decisions can be made early in the process, prior to any physical parts being built. By embedding the years of experience your engineers have, you can offer this level of analysis and decision making to a much broader audience as well.

Finding problems early saves money

The graphic in figure 4 depicts the relative cost of making changes to designs during the design cycle of a vehicle. The later the problem is found the more costly it is. Warranty and recalls cost vehicle manufacturers billions of dollars a year — which significantly impacts the bottom line of companies that don't discover problems until the vehicles are already in customer hands. Where you want to find problems is as early in the design process as possible.

Enabling your design engineers to continuously analyze their designs prior to manufacturing a prototype saves time, money and can improve reliability of your products. Most testing for electrical design starts in the prototype phase where the cost is highest represented by the faded curves following along the red line in figure 4. If you spend more time and energy up front in the IDEA to LOGICAL DESIGN phases, you will spend much less time, money and effort during Integration and have less Warranty and Recall's.

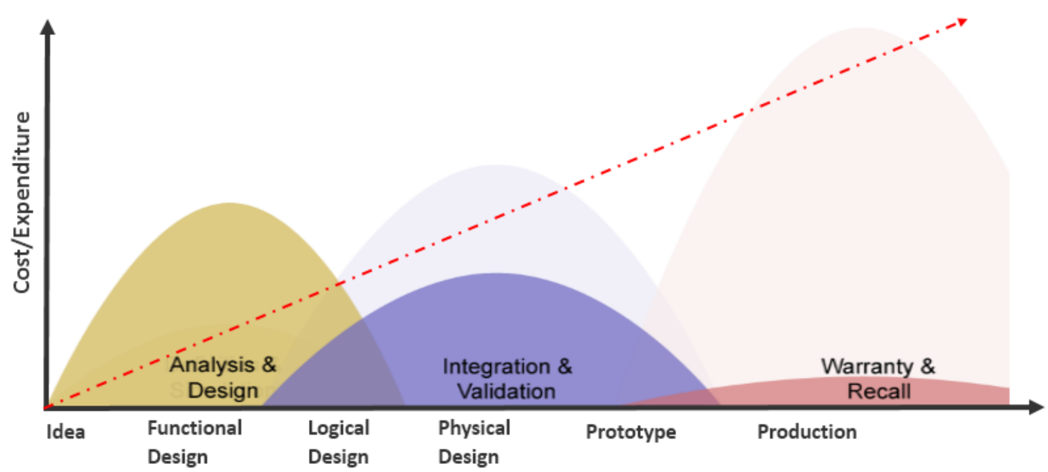

Figure 4: The further into a design (or production) a fault is found, the more costly it is to rectify.

Removing the need for prototypes

A type of wire and fuse sizing analysis that is becoming more popular is short circuit testing. There are three types of short circuit testing, as depicted in figure 5.

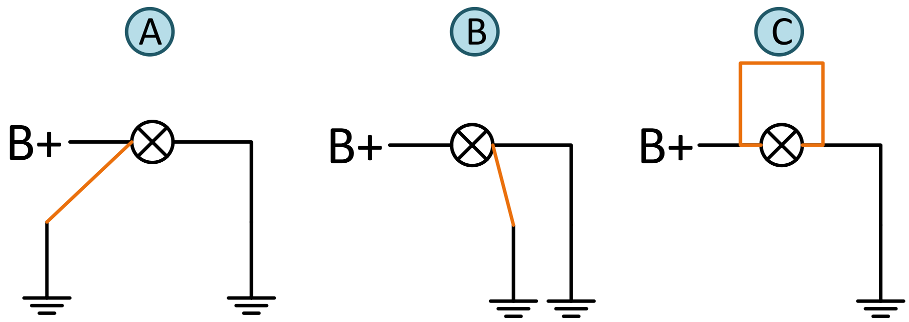

Figure 5: Three types of short-circuit testing: A - High Side short testing, B- Low Side short testing, and C - Short over the load testing.

Typically this type of analysis happens with physical testing. This entails building a very expensive prototype vehicle after the design is complete, which can cost upwards of $1,000,000 or more. These prototype vehicles are built not only for electrical testing but also physical testing. Short testing of this nature runs the risk of damaging the wiring which would require an expensive repair in order to make the vehicle ready for the next test the vehicle is scheduled for. This type of testing should be accomplished in a virtual environment prior to design completion, prior to the building of expensive prototypes, and should be available to every harness engineer in your organization not in the hands of a select few simulation experts.

Fuse blow time vs. wire fume characteristics

An analysis that is starting to catch on in Japan is to size the fuses such that under short circuit testing the fuse will blow prior to the wire covering material beginning to fume, or smoke. Wire manufacturers in Japan are starting to publish the fume characteristics of wires so vehicle manufacturers and harness manufacturers can do this type of fuse sizing and wire sizing.

The main driver behind this type of testing is durability. As the wire heats up under stressful load conditions and the covering of the wire begins to fume the durability of wire is compromised. This can lead to any number of durability issues. As the insulation weakens in a wire deteriorates it can become brittle and potentially lead to exposing the bare wire underneath and potentially causing a dangerous short. Imagine an airbag circuit shorting unexpected and deploying while driving. The cost of warranty and recall costs are staggering. The more testing you can do up front, the more design engineers you can have doing the testing, the easier the testing is and the better the products will be.

This type of testing, sometimes referred to as “Wire Smoke Testing” is being done with physical vehicle prototypes and is costly and time consuming. This principal of this type of testing is outlined below – briefly, the load is shorted (either on the High side, Low side or across the load) and the circuit is observed. If the covering material of the wire begins to fume prior to the fuse blowing then a solution is investigated. This could involve changing the fuse to a larger size, a fuse with a shorter blow time, a larger wire, a wire with a different material, etc. Figure 6 illustrates the concept.

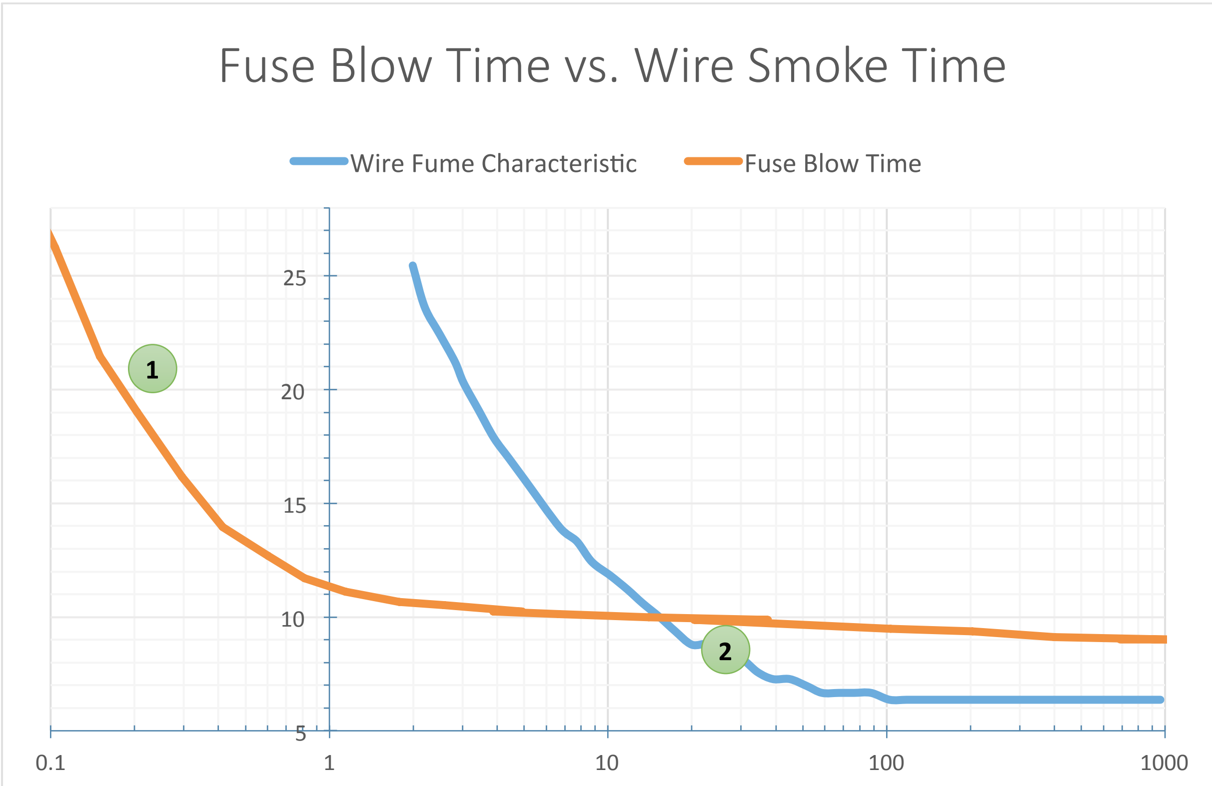

Figure 6: Fuse blow time and wire smoke time.

In the graph in figure 6, we have taken a hypothetical FUSE and WIRE and have plotted the Fuse Blow Time and Wire Smoke Time (both in seconds) vs. Current (Amps). Let's take a look at two points on the graph:

1. At about 20 Amps we see for this WIRE and FUSE combination the Fuse will Blow (orange line) prior to the Wire Smoking (blue line). This is the desired condition.
2. At about 8 amps, we see the wire will smoke prior to the fuse blowing. This is NOT the desired condition as this could lead to deteriorating of the wire material and overall cause a durability issue

There are tools available and on the market today that can help you do this. Ask yourself if automating any of these types of analysis in a virtual environment early in the design process by any engineer in your company is important:

- Full vehicle load testing
- Automated testing of multiple vehicle configurations
- Automatic Fuse sizing and part number selection
- Automatic wire sizing and part number selection
- Automated short circuit testing – High side, low side, over the load or rotating through all three

- Testing for fuse blow time vs. wire material fume time to increase the durability of your wiring

Summary

Testing physical prototypes presents two expensive problems: (1) the prototype is very expensive to build and maintain and (2) faults found as late as the prototype are very expensive to fix. The solution is to employ virtual prototypes and simulation for systems that can be properly simulated. Wiring harnesses are readily simulated and virtual prototypes can readily detect faults, such as short circuits or time for the fuse to blow vs. time for the wire to smoke. Employing these tools can not only save a great deal in costs, but can remove significant time from the development cycle as well.