

EDS Ground Topologies for Composite-Bodied Motor Vehicles

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ABSTRACT

The presence of composite-bodied vehicles in the non-specialist marketplace is challenging the original equipment manufacturers (OEMs) and their tier-one suppliers (T1s) in terms of how best to replace a metal body structure as a means of completing electrical circuits. Alternative wiring topologies are considered, their key electrical and mechanical characteristics are compared and an optimum solution is proposed. Its performance is quantified by calculation and modelling and then compared with actual measurements taken from a vehicle simulator. These are benchmarked against typical values which are found in welded-steel body structures.

INTRODUCTION

In conventional vehicles, the body structure is generally used to complete the electrical circuits – specifically the “ground” return from the consumers back to the battery. (There are some intrinsically safe vehicles intended for use in hazardous environments which use completely isolated circuits, but these are not considered here). The replacement of welded metal with a composite alternative prevents this from being practical. Whilst carbon-fibre bodies are conductive, their high resistance makes the completion of circuits impractical, and they bring associated challenges for the electrical distribution system (EDS) designer (ref. 1.).

Glass reinforced plastic (GRP) structures are essentially non-conductive in the context of the currents usually found in motor vehicles.

Several options are available to replace this “lost” conductivity, for example, the embedding of metallic planes within the composite material or the provision of additional cables to complete the circuits. In an extreme example of the latter, each individual ground cable might be routed directly back to the battery negative terminal.

This paper examines three options using cables and quantifies their parameters by modelling and measurement, so enabling an optimum solution to be recommended.

METALLIC PLANES OR CABLES?

In practice this is more an issue of “and” rather than “or”. The embedding of metallic copper or aluminium laminae within the composite material or on its surface provides potentially excellent conductivity and screening but at a cost of the complexity of the body moulding processes. An alternative is to metallise the stranded reinforcement material to achieve an equivalent effect, and although this has found applications on military vehicles and in aircraft, its cost is prohibitive in an automotive context. In fact surface or embedded metal planes are used locally where screening is necessary, but otherwise, cables offer a solution which can be equally effective, at conventional costs.

TOPOLOGY CHOICES FOR CABLES

As mentioned in the introduction, the provision of cables connecting each load back to the battery is a simple solution to the problem. If the power feed and ground return cables are routed together within the EDS, an implementation with excellent electromagnetic compatibility (EMC) can be realised. However, the resulting wiring harness will be bulky due to the additional cables, and this may be exacerbated by the need to increase cable cross sectional areas (XSAs) to meet the desired resistance and volt-drop specifications for the complete circuit.

An alternative solution, which more closely mimics conventional vehicles by providing a number of ground “studs” to which clusters of ground circuits can be connected, is therefore seen as desirable.

There are 3 potential topology options: star, bus, and ring and these are described below:-

STAR – In this concept, a number of cables radiate from the battery negative connection and are terminated with a ground stud to which conventional harnesses may be connected. (See figure 1 below).

RING – A single cable connects to every ground stud, and both ends of the cable are connected to the battery negative. (See figure 3 below).

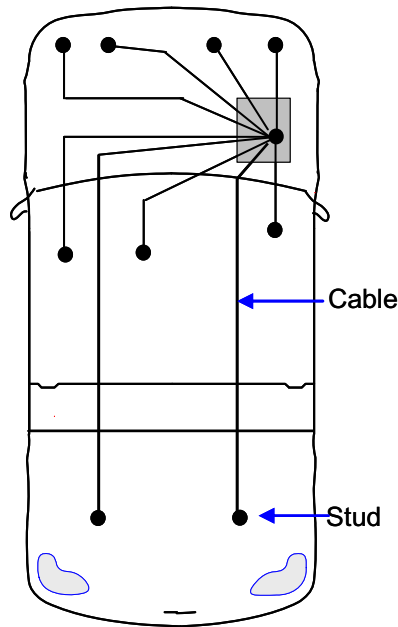


Figure 1: Star Topology

BUS – A single cable connects to a number of individual ground points and the battery negative. Several of these assemblies support distinct geographic areas of the vehicle. (See figure 2 below).

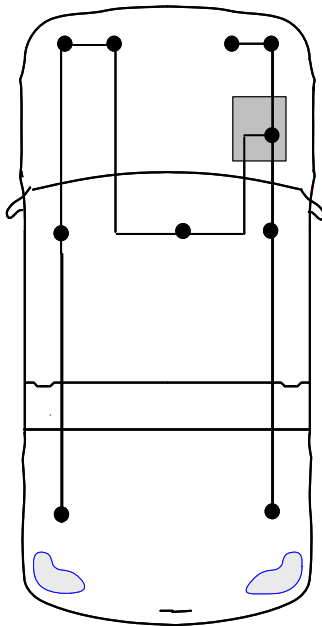


Figure 2: Bus Topology

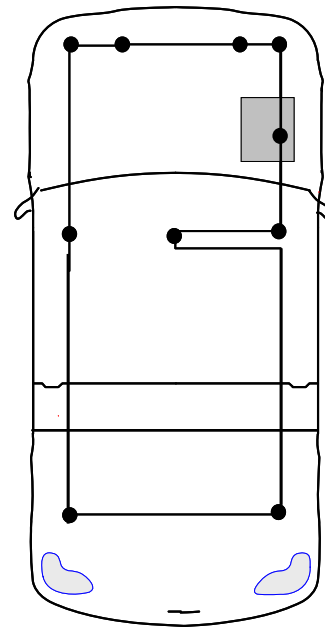


Figure 3: Ring Topology

In practice, combinations of these topologies might be appropriate for specific vehicle applications, but for the purposes of analysis, the basic structures summarised in the above figures will be assumed.

COMPARISON PROCESS

The three topologies which have been defined above have been assessed against the following criteria:-

- DC Performance
- Electromagnetic Compatibility (EMC)
- Failure Mode Effects Analysis (FMEA)
- Physical Aspects
- Vehicle Build Constraints
- Cost

For each category, the relevant strengths and weaknesses of the 3 topologies are considered and explained, following which a rating is applied. Score 3 indicates the best option, 2 neither best nor worst and 1 the worst performance in the particular category. In arriving at the score, the calculated performance is compared with LEONI's in-house ground circuit benchmark criteria which are to achieve a maximum circuit resistance of 1 mΩ or a maximum ground circuit volt drop of 250mV, whichever is more appropriate to the application.

DC PERFORMANCE – There are two significant areas of interest: the maximum volt drop which occurs between the ground stud and the battery negative, and the degree of interaction / offset which might occur between the voltages existing at every stud under all vehicle operating conditions. For the volt-drop condition, this is simply a matter of selecting an appropriate cable size for the duty. In terms of interaction, this is minimised by the star topology, localised by the bus, but not constrained in the ring where a change in the current sunk by any specific node will affect the volt drop at every other one. On this basis, the assessment is: - Star 3, Bus 2, Ring 1.

ELECTROMAGNETIC COMPATIBILITY

Transient Performance - Here the resistive and reactive elements of the ground network impedance are considered.

The influences of these parameters are:-

1. The response to current changes, related primarily to the slew rate of the power switching device.
2. Any ringing / resonance, related to the Q factor of the circuit.

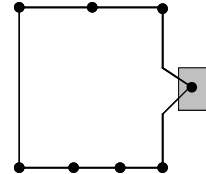
The transient performance was evaluated using the equivalent circuit shown in Appendix 1. This demonstrates that for the cable lengths and XSAs expected from typical vehicle dimensions, the predominant effect is the result of the power feed network rather than the ground circuit. The fact that the ring effectively parallels two circuit impedances, thus reducing its value compared with the bus and star, results in it achieving the maximum score, giving Ring 3, Bus 2, Star 2.

Radio Frequency Interference (RFI) – The radiation and susceptibility to interference of the 3 topologies are determined primarily by their dimensions. In particular, resonance in the broadest frequency bands (70-150 MHz) should be avoided where possible, due to the potential impact of high powered transmitters. The ring is effectively a large loop antenna and may be disadvantaged. However, a bus may similarly be considered to be a dipole and the star topology an array.

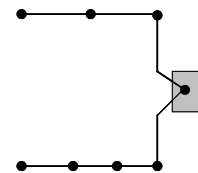
Using typical vehicle dimensions, the ring and bus options are resonant at around 70MHz, and so are just within the critical frequency range. The star, with its range of lengths can be resonant over the frequency range of 60 – 300 MHz. To quantify the practical impact of this risk, a full RF modelling assessment was performed (see appendix 2). This indicated that when the ground and associated power distribution network were considered together, the star was indeed most susceptible to resonance whereas the ring performed slightly better than the bus. The scores are therefore:- Ring 3, Bus 2, Star 1.

FMEA INTEGRITY – This aspect considers how each of the topologies connects to the battery negative post. On the assumption that, whichever topology is employed, there are equal numbers of connections to the vehicle wiring harnesses, it is the interface to the battery which is the influencing factor. The three topologies are compared conceptually:

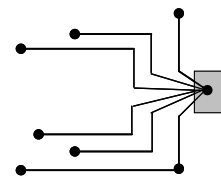
Ring – The ring would connect to the battery as shown below. This has only two connections, and in the event of one of these failing, that remaining would still provide connectivity, albeit with a reduced system performance.



Bus – Again, there are only two connections, but if either were to fail, the functionality of a significant element of the total vehicle would be lost.



Star – For the star, there is potentially one connection for each limb of the structure. However, any failure would have a much more localised effect than in the case of the bus topology above.



Taking the relevant factors into account, the scores assigned were: Ring 3, Star 2, Bus 1.

PHYSICAL ASPECTS – This considers the number and variety of parts required to realise each of the three topologies. To achieve the FMEA benefits outlined above, the ring would comprise one continuous length of cable. Bus and star alternatives would have increasing numbers of cables and connections, but with their XSAs optimized for the specific function. A typical application which was studied using all 3 topologies, gave the following result: