THE ARCHITECTURE AND ANALYSIS OF THE XK8 ELECTRICAL SYSTEM

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1. Introduction

The Electrical Distribution System (EDS) is the network of wire, connectors, fuses and relays which carry the electrical power, signals and information around the car. It is the "backbone" and "nervous system" of the XK8.

The primary objectives in designing the new distribution system for the project were to reduce wiring, weight, packaging space, and complexity; improve ease of manufacture; reduce build time of vehicle; lower development costs; improve quality. Additionally produce production intent design and process significantly earlier during the development of the vehicle. This was achieved via system integration, increased system robustness and in just 36 months from programme approval.

We shall firstly describe the overall design approach, and then some of the details of the actual harness design.

2. The Design Approach

2.1. The Multiplex Option

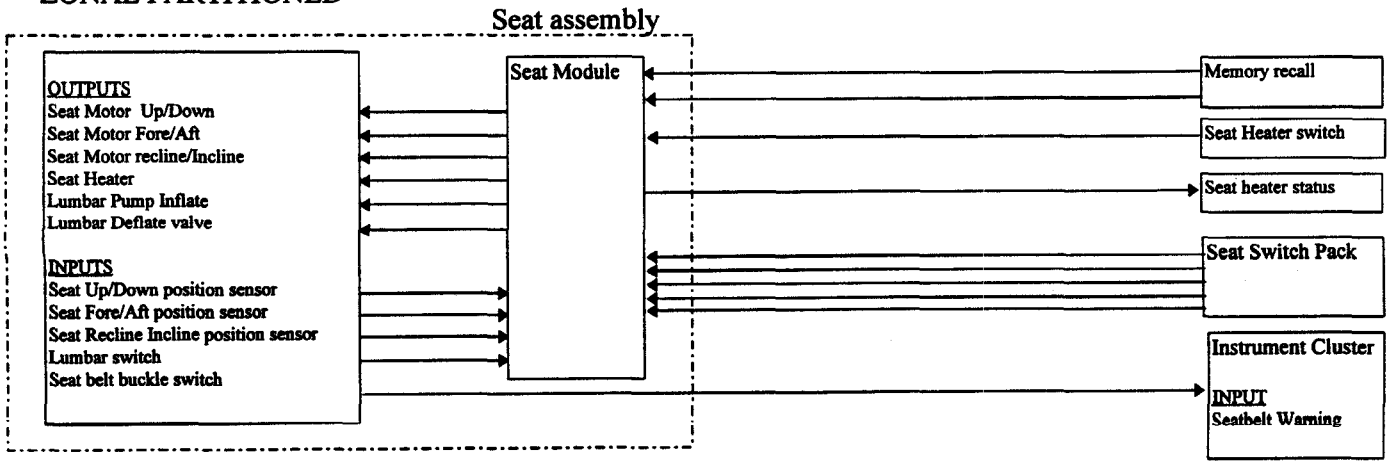
A primary decision involved using either traditional 'point-to-point' wiring, or a multiplex approach. Initial investigations showed that wiring and connector reduction using a multiplex system would offer advantages to manufacturing in terms of ease and speed of assembly, and the possibility of enhanced diagnostic capability. With this decision taken, attention could then be directed to the actual hardware architecture.

2.2. The Architecture

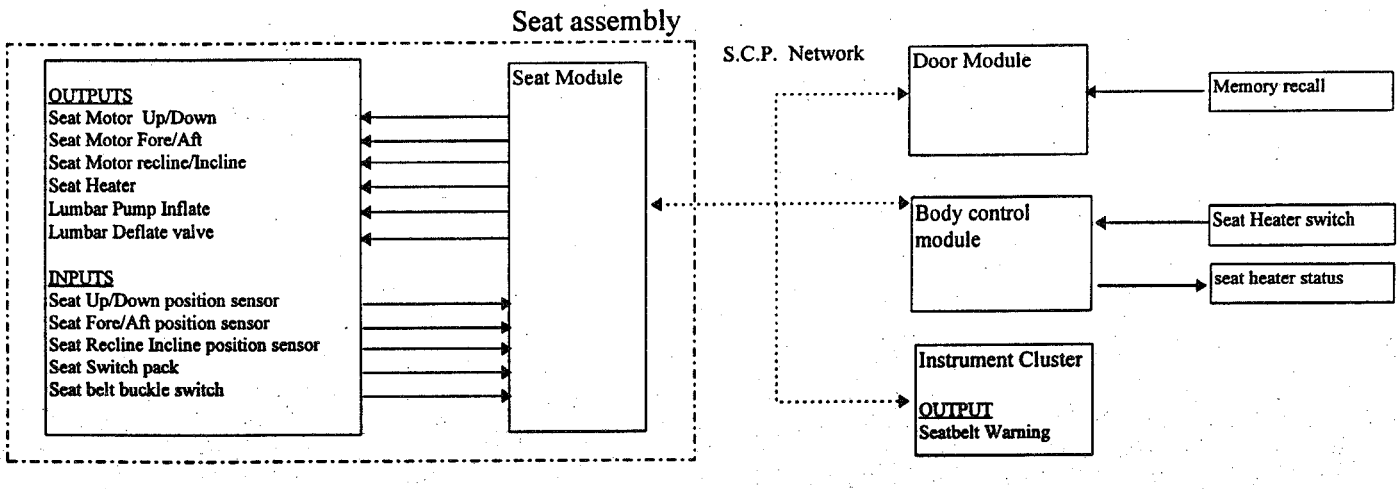
In this regard Jaguar has followed an evolutionary approach. The Jaguar distribution architecture used on the 1995 model XJ6 was quite advanced, in that much of the system integration had already been 'Zonally Partitioned' making it suitable for a communication network, where by functional partitioning of inputs and outputs could be applied. Some examples of functional partitioning are:

a) Control module located in seat assembly:

ZONAL PARTITIONED



FUNCTIONALLY PARTITIONED



Some other Applications of Functional Partitioning are:

- Separate door modules controlling door functionality.
- Separate boot module controlling rear functionality and security, plus convertible hood control.
- Separate Body module located in 'facia' for wipers, interior lighting, driver controls, and lighting

However some of the system functionality is shared across all modules via the S.C.P. Network , based upon location of input and output requirements..

Power Distribution

A major consideration is the treatment of the power cable. This is substantially influenced by the position of the battery, which is fitted in the rear of the vehicle. The reasons for this choice of position were:

- Protection to the battery in the event of a crash. Growth of battery physical size compounded this issue due to Key-off loads / stand time and increased electrical feature/ accessories. This required the battery to be located in the boot since packaging in the underbonnet area was likely to compromise the distinct Jaguar style.
- Increase in vehicle underbonnet temperatures, combined with improvements in charging performance, required the battery to be located in a lower ambient temperature to prevent the battery 'boiling'. The increase in underbonnet temperature is a result of increased engine performance, and the use of close-coupled catalytic converters mounted directly to the exhaust manifold. Again an increase in cooling performance of the underbonnet area was likely to compromise the distinct Jaguar style of the XK8.

The disadvantages of this choice of position is that the alternator becomes a sizeable noise source to many of vehicle electrical systems, both through the circuitry (AC-ripple) and through radiation. To assist in reducing the noise generated by the charging system, a dedicated cable has been used to combine both charging and starting.

More generally, the wiring was designed to give maximum separation between noisy circuits 'sources', and potential sensitive circuits 'receptors'. This was achieved by locating sensitive signals and low current signals in a separate harness. The noise signals were located in another harness and routed to provide separation of the harnesses in the vehicle. The wiring has also been routed to avoid in potential sensitive areas e.g. near the In-Car Entertainment components. This has improved the immunity of the vehicle to electromagnetic coupling.

2.3. Systems Approach

The traditional approach to electrical design has tended to concentrate on individual components, and to try to infer overall system performance on the basis of correctly performing individual components. While the approach is not without its merits, it ignores the fact that the whole system has to perform correctly, i.e. the interactive effects between components and modules. The approach which Jaguar has adopted is referred to in-house as a 'Circuit-Led' approach. In this approach the desired functionality is traced to the electrical circuit that is required to deliver it. This circuit defines the 'system', i.e. the collection of components in a given circuit. The approach therefore naturally focuses on critical issues such as required component input/output conditions, interface criteria, noise creation and immunity, and in general environmental requirements.

The design of the system / circuit consists of two parts, design rules and circuit analysis..

a) The Design Rules are mainly codified experience, e.g.

> The steady state load current through a standard automotive fuse should not exceed 70% of the fuse rating. $I_L \leq I_N * 0.7$
>
> Where:
>
> I_L = Total Load current.
> I_N = Fuse Rating.

This rule has been based on a number of factors that could influence the fuse under continuos running conditions: ambient temperature, fuse interface, area of connecting cable, temperature rise of connector and cable, due to ohmic dissipation.

b) Circuit analysis is traditional, i.e. essentially an Ohm's law analysis, though to this has been added signal analysis, such as:

- Short Circuit Analysis - for fuse blow time
- Voltage Survey - full interaction via ground and fuse trees
- Load Survey - determines current through each fuse.
- Sneak Analysis - uncovers potential unwanted current paths (logical).
- Signal Analysis - electrical sensitivity and characterisation.
- Branch Analysis - fuse and ground trees connectivity (logical).

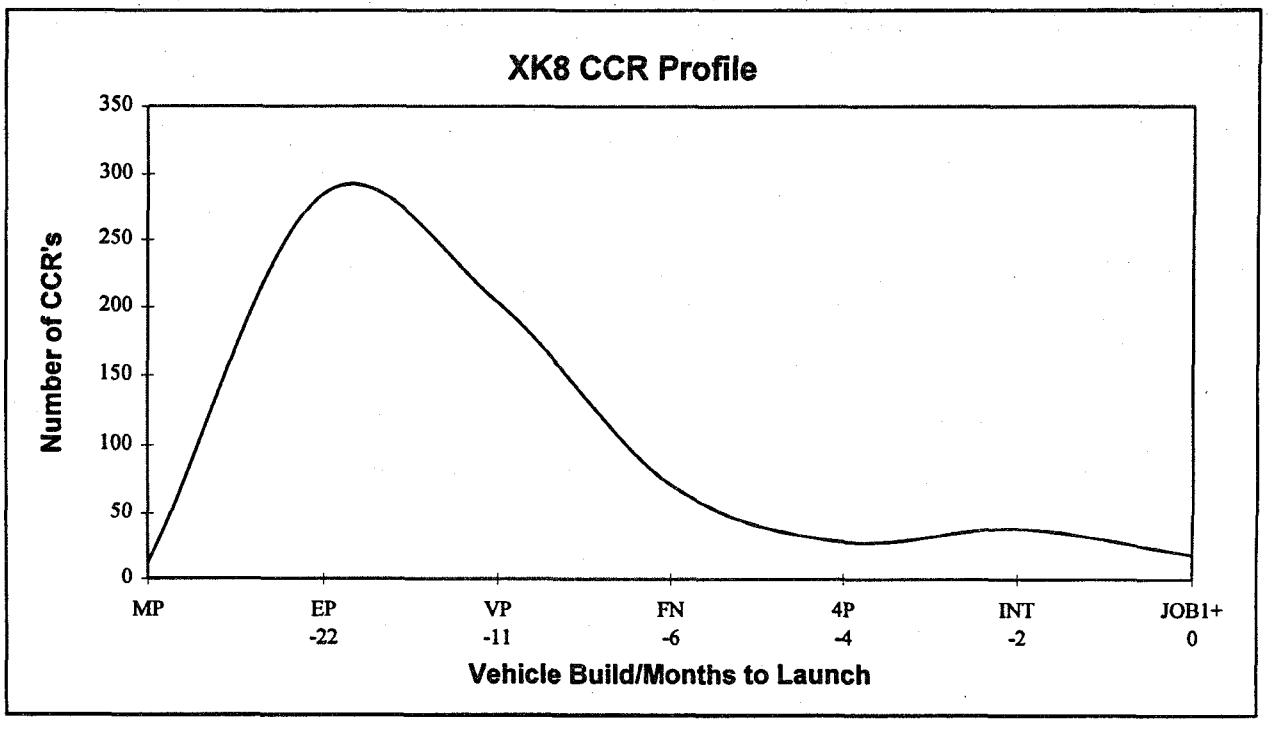
The circuit analysis activity has been greatly assisted by linking the CAD harness design and the analysis environment. This process has been under development in Jaguar for about ten years. A number of process simplifications of component behaviour are used in the development of a circuit model. This procedure is well-justified in terms of resource and time. Accurate / detailed component modelling is labour intensive and it is often the case that the component design will change significantly during the course of development, and sometimes it may even be deleted. In addition to these simulation techniques, there a number of cases where more sophisticated tools are used, e.g.

- Transient Analysis - Real time signal response.
- Sensitivity Analysis - measure of design performance, in relation to variables/ system parameters.
- Stress Analysis - measured value of a component considering de-rating and specified rating.
- Characterisation - Simplified component model for design rule checking..

The point we wish to bring out here, is that traditional circuit modelling allows the design of harness elements such as fuses, relays and of course the harness cable itself, to be incorporated into the system performance assessment. Overall, the combination of design rules and circuit analysis has had a substantially beneficial effect upon the development of the total electrical system. With the system circuits well understood, provided components are to specification and assembly in the vehicle is correct, then development testing is more effective. Fewer cars are needed to test vehicle variants, and the traditional problem of test data appearing from one build phase simultaneously with the need to specify the 'new improved' components for the next phase is substantially overcome. Indeed, the typical traditional situation of many late changes arising from a belated understanding of component tolerances, and susceptibility to sneak circuits is greatly improved. Additionally with a stable wiring design base, the validation of the complex software driving the multiplex system can concentrate on function rather than having to cope simultaneously with the physical circuitry.

Did the approach work ?

A good measure of success or otherwise, is the time-profile of the 'Circuit Change Requests' (CCR's) in the months prior to the Job 1. The accompanying figure shows very clearly that the majority of changes occurred in early prototype phases and thereafter declined rapidly. There was however a slight increase in a late build phase due to an accumulation of actual driving experience with a larger number of pre-production cars, cost reduction activity and the experience of building cars in increasing volume.



Note: CCR freeze date was approximately 4 months prior to Build date. Build dates are shown. For example: start of FN Build date is -6 months, CCR cut off date would be -10 months.

3. The Distribution Design

3.1. The Power Cable Architecture

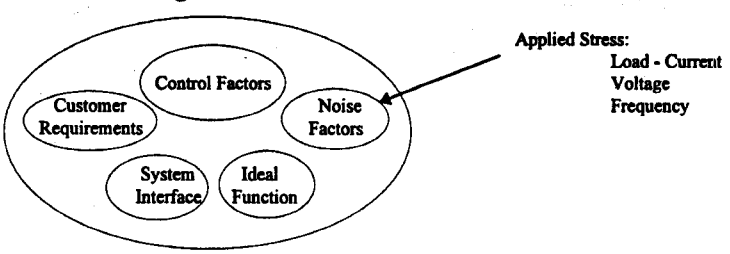
The XK8 benefited from the use of the power cable architecture as previously applied to the Jaguar XJ6 saloon model introduced in 1994. Since relocation of the battery into the rear of the vehicle the electrical noise generated by the alternator has become a considerable electrical noise source to many of the vehicles electrical systems, and in particular the audio circuit, previously identified as a customer concern.

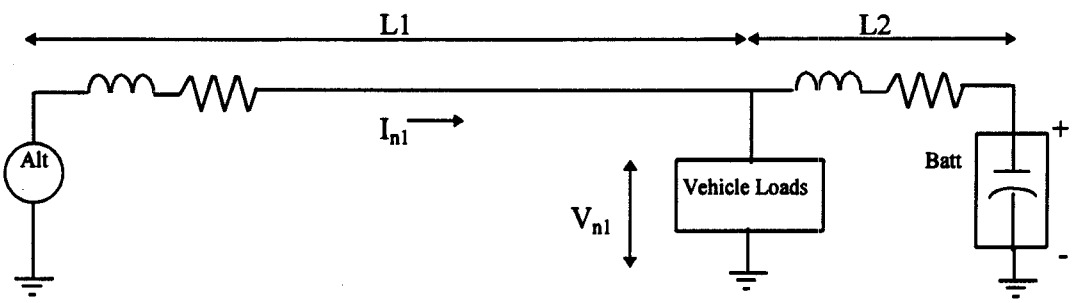
In reducing the electrical noise and stress generated by the charging system a dedicated cable has been used for charging and starting. All electrical systems are supplied directly from the battery, which provides suppression of the electrical noise.

Ensuring all loads come from the battery source considerably reduces the voltage range at the components and minimises the high voltages (typ. 14 - 15v) generated by the charging system of the vehicle.

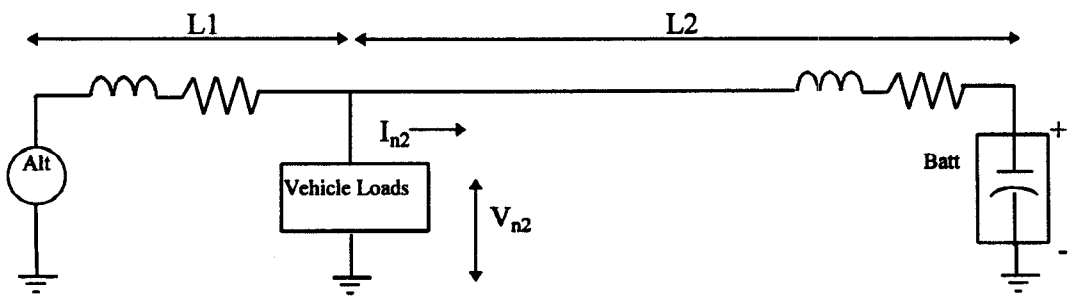
The charging cable was also partitioned away from the vehicle wiring system and components giving increased immunity from Electromagnetic coupling (see fig 1. on page 6).

Robustness Thinking:





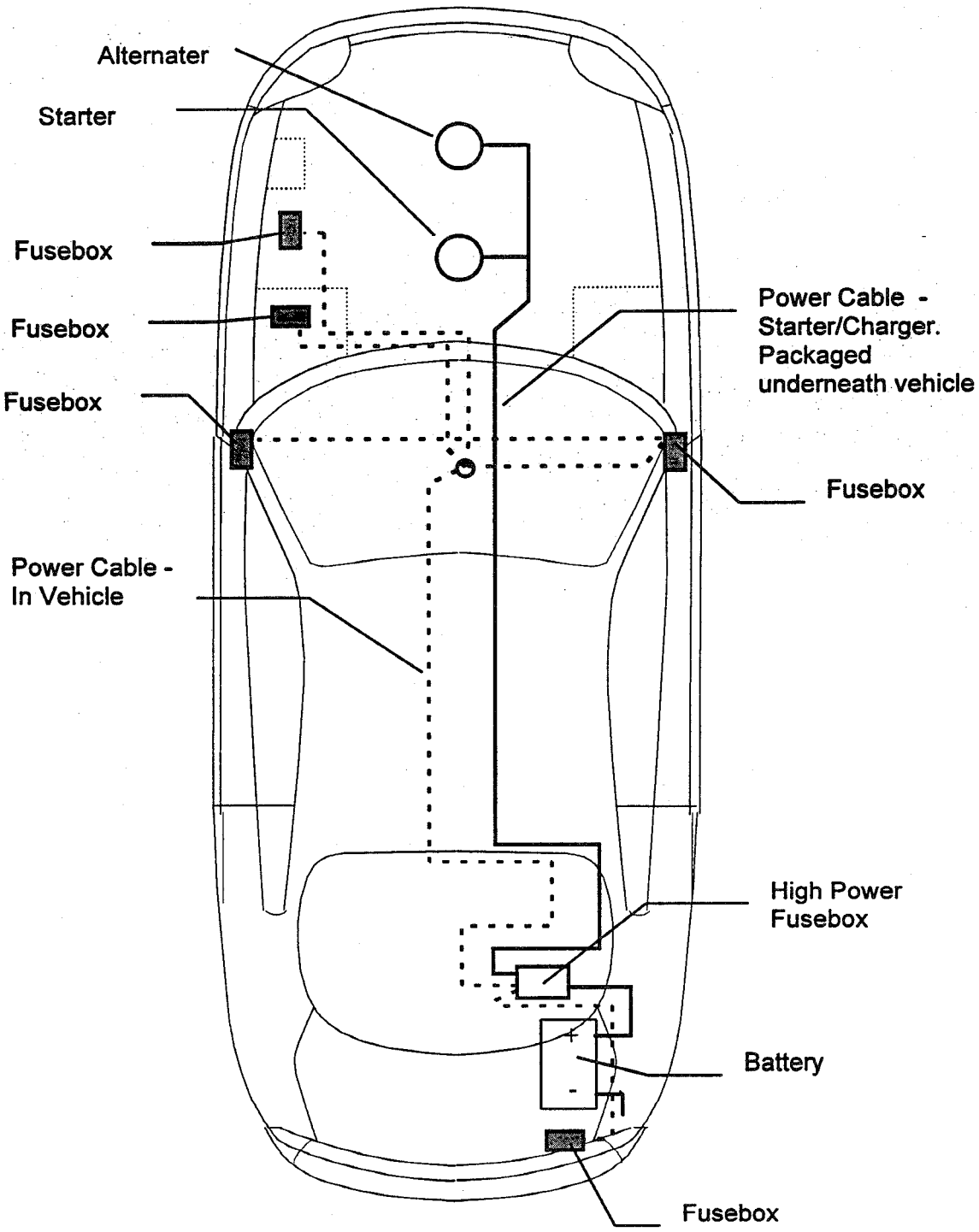
(Front Battery Application)



(Rear Battery Application) $V_{n2} > V_{n1}$

V_n = Voltage Noise (AC Ripple, DC volts)

Fig 1. Fusebox and Power Cable location



3.2. Some Wiring Information

The XK8 has approximately 1.6 km of cable.

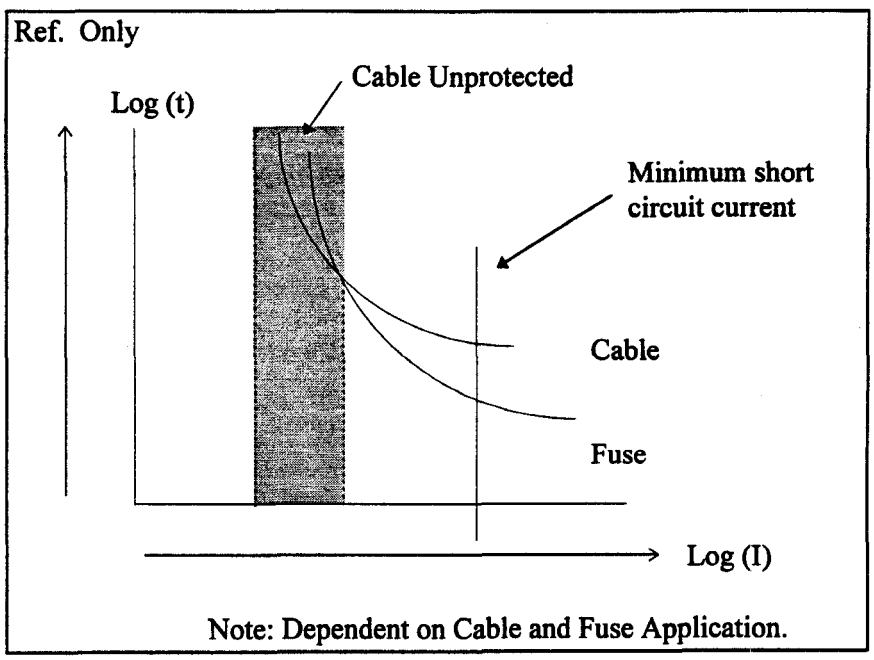
Signal Cables	Power Cables
approx. 1.26 km	approx. 3.4 km
79% of Total Cable	21% of Total cable

3.3. Fusing

The XK8 uses 79 Standard fuses (ATO®) and 3 MEGA® fuses. The vehicle adopts a zone based fusing architecture consisting of 5 fuseboxes (See Fig 1. on page 6). Zone based fusing indicates that vehicle loads are supplied from a local fusebox, the simplest zoning of a vehicle is to divide the car in to four corners.

The boxes have been supplied via a large diameter cable giving very little common mode resistance back to the battery. This architecture provides the following benefits:

- Increased Resistance to EMC.
- Increase in fault current ensuring very fast fuse blow times, this avoids operating the cable and fuse in undesired time/current areas (I/t). (Lower resistance between fuse and load)



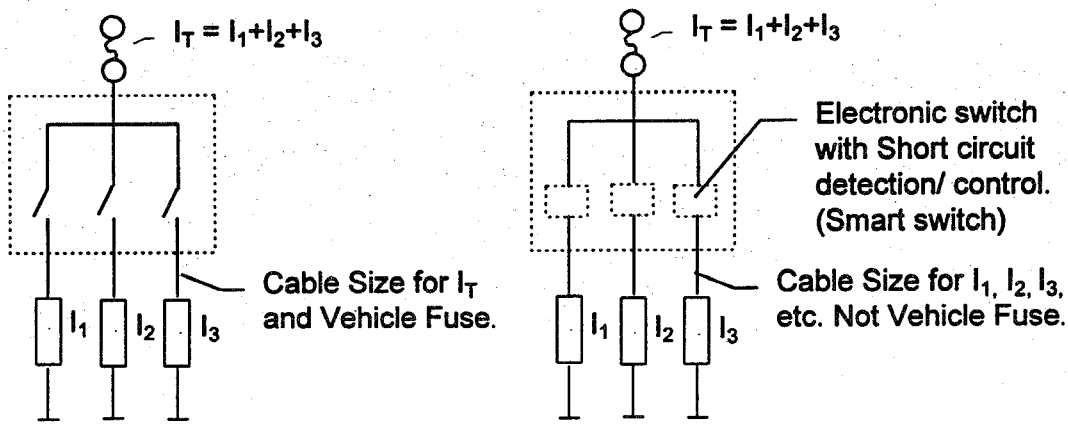
- Allows smaller Gauge cable to be used.
- Shorter Cable length.
- Reduction in number of circuits sharing a fuse.
- Reduced number of interconnects.
- Increased resistance to Electrical disturbance.
- Allows Relays to be packaged in fusebox - remote switching (No waterproof relays required, brackets, etc).

The XK8 has full circuit protection. The battery cable fusing has been achieved by the use of MEGA® Fuse. A combined 500A fuse consisting of two 250A devices has been used for starter circuit/Battery protection.

3.4. Circuit Protection Integration

The fuse count has been kept to a reasonable level despite minimising the use of common fuses on multiple circuits. This has been achieved in a number of ways on the XK8 vehicle:

- The Body Processor Module has 18 switched outputs supplied via 4 fuses, each output has Short circuit and overcurrent protection. This strategy provides fault isolation, avoiding vehicle fuse blow. This feature has also allowed smaller gauge cable to be used on the output wires since the Body Processor module provides isolation of the fault removing the need for the vehicle fuse to provide protection to these cables.



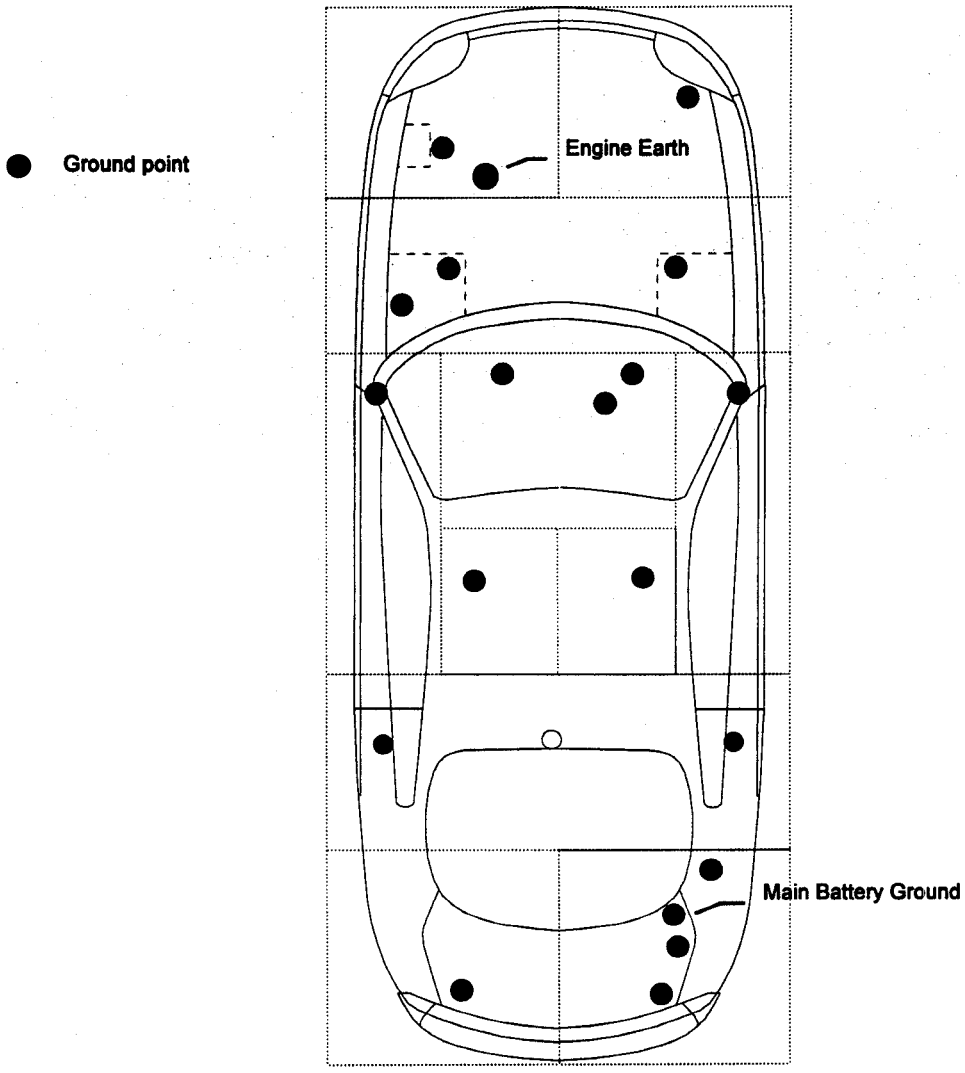
- The Security Locking Module has 5 switched outputs with Short circuit and Overcurrent protection.

- The use of software to control functions that have traditionally required thermal circuit protection devices or slow blow fuses. The following systems have had this feature since launch of the XJ6 Saloon introduced at 1993 model year.

  Wiper Motor - Software stall protection.
  Window lift - Software stall protection on Global close/Open.
  Door locking - Software stall/door lock cycling protection.
  Seat Movement - Software Load management/stall protection.

3.5. Grounding

The XK8 uses 21 ground points. The vehicle grounding has been partitioned into a zone based architecture. The grounding has also been classified into categories to reduce electrical disturbances on the grounding implementation. In general noisy 'Source' circuits have been separated from signal 'Receptor' circuits. The use of zone based grounding increases the vehicle resistance to EMC/electrical disturbances.



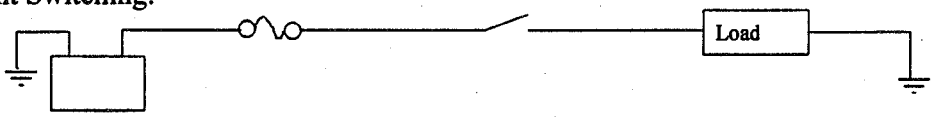
Benefits:

- Allows smaller gauge cable to be used.
- Shorter cable length.
- Reduction in number of circuits sharing a ground points.
- Reduced number of interconnects.
- Increased resistance to electrical disturbance.

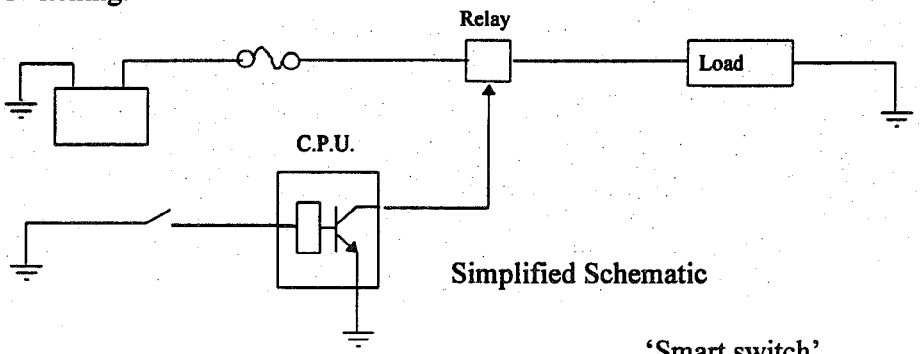
3.6. Remote Switching

Jaguar has utilised remote switching since the introduction of the XJ6 saloon introduced at 1985. This was possible with the introduction of low current switching technology and the use of a Central Processor Unit to control the vehicles Body System electronics, these can be loosely defined as non driver functions operated by the driver or passenger.

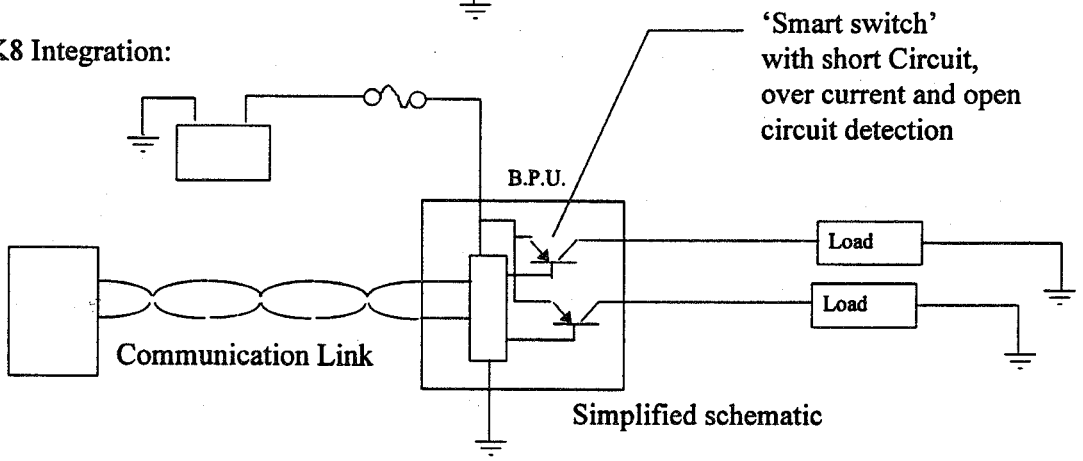
High current Switching:



Low current switching:



XK8 Integration:



The XK8 however has had a higher level of integration of remote and Smart switching into the following modules. This is a result of the location of the six control modules (Functional partitioning).

2 off Door module (Mixed Technology)
2 off Seat Module (Mixed Technology)
Security Locking Module (Mixed Technology)
Body Processor Module (Mixed Technology)

This leaves a total relay count of around 30..

- 16 Packaged in fuseboxes.
- Up to 12 Standard Relays located in harness.
- 5 Micro Relays located in harness.
- No Waterproof relays required.

Reducing Harness weight, Wiring size, cable length, packaging space and reduction in relay noise.

3.7. Signal Analysis

All modules were designed to ensure that all signals have an active threshold of 10 mA. This greatly increases the resistance to EMC, electrical disturbance and leakage currents arising with age of the vehicle. Sensitivity analysis was used to consider what impact the wiring, connectors and switch gear may have on the Active and In-Active margins of each modules input circuitry, considering: ageing, wear, Battery voltage, Ambient temperature, tolerance, component interaction on fuse and ground networks, etc.

Emphasis has then been placed on signals/signal types that do not comply with the minimum current rule requirement, allowing greater attention to be given to those circuits, e.g. twisted pair, shielding, cross coupling, filtering, special attention to terminal plating and connector application, etc.

4. Summary and Conclusion

Jaguar has demonstrated, by the innovative use of its design rules and circuit analysis methods, that real benefits can be achieved. This is mainly evident through the significant reduction of late changes to the electrical distribution system of XK8 over previous vehicles. Undoubtedly this approach, coupled with systems engineering disciplines, has kept the development costs manageable, maintained the quality attributes, and supported effective validation of the complex vehicle systems that depend on the EDS. XK8 is the most advanced vehicle Jaguar has ever produced, and despite this, it is the most successful engineered, electrical distribution system ever undertaken. We expect that this confidence is further vindicated by customer satisfaction measures and reduction of warranty costs during full volume production.