EM Effects Control Using Topological Concepts

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Statement of the Problem

- The goal is the protection of complex electrical systems

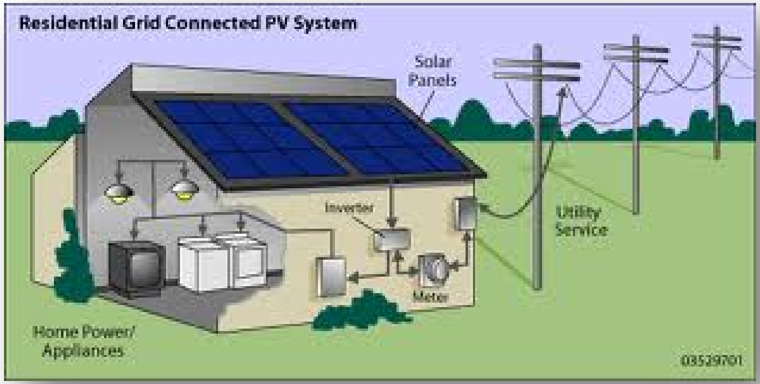
Defense Systems

Examples of Airborne Systems

Examples of Communication Systems

Examples of Transportation Systems

Electrical Power Systems



Statement of the Problem

- The issue is the protection of complex electrical systems

- against various types of electromagnetic (EM) threats

  – Lightning and electrostatic discharge (ESD)
  – Nuclear electromagnetic pulse (NEMP)
  – Microwave environments
  – Fast, short duration EM pulses

HPEM Threat Examples

NEMP

Natural Lightning

Microwave Environments

Fast and Short Pulses

Various Approaches are Possible

- Remain unaware of potential problems,
- Recognize the problem, but do nothing about it, or
- Study the problem and develop a solution

In this presentation, we will take the third approach

The Question – How to Protect Complex Systems?

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  - And frequently, attempts are made to organize this mess.
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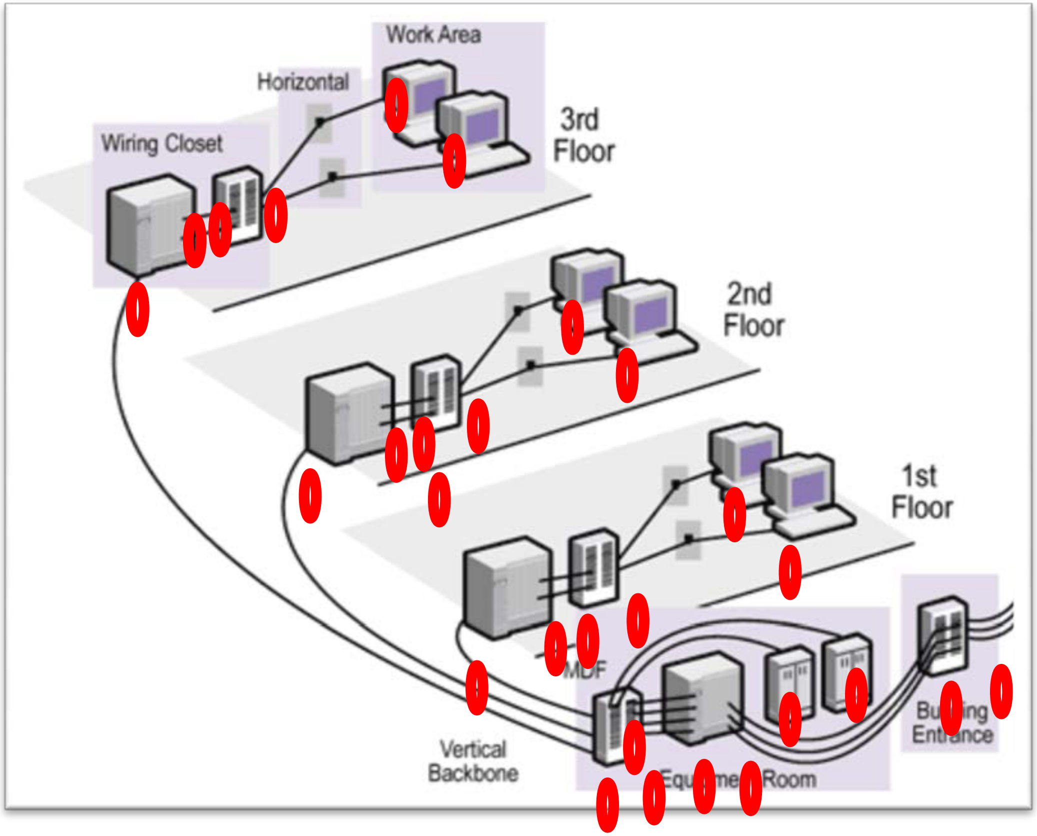
Pin-Hardening: A Possible Solution ?

- In pin-hardening, each conductor leading to a potentially susceptible piece of equipment is protected.
  - using a filter, surge protector, nonlinear device, etc.

· **EXAMPLE OF A MULTI-FLOOR COMPUTER INSTALLATION**



Pin-Hardening: A Possible Solution ?

Pin Hardening approach is unfeasible for many systems due to:

- ❑ initial cost of hardening elements
- ❑ high installation cost
- ❑ added weight to the overall system
- ❑ too many hardness critical items (HCI) that require periodic surveillance
- ❑ serious hardness maintenance issues

No, not for complicated systems.

What is the Alternative ?

- Electromagnetic Shielding
  - First described by Benjamin Franklin in 1755 in a shielding experiment which showed that a probe inside a charged enclosure was not affected by an external charge.
  - Later investigated by Michael Faraday in 1836, whose name is now associated with the “Faraday cage”
  - Used by J. C. Maxwell in 1876 for the protection of munitions

Electromagnetic Topology

- The application of global shielding to complex electrical systems assisted by the concept of *Electromagnetic Topology.*
- EM Topology is the description of the shielding enclosure(s) surrounding potentially vulnerable equipment for the purpose of providing EM protection.
  - It involves a description of the size, shape and other properties of the enclosing shields,
  - the locations and properties of imperfections (both deliberate and unintentional) in the shield, and
  - a description of the signal propagation paths in and through the shields.

Electromagnetic Topology (con't.)

- To understand EM effects on a complex, shielded system, we can think of the system as having of several layers of conducting surfaces which shield the interior.
  - this is known as the "onion" concept of shielding (Ricketts, L. W., J. E. Bridges and J. Miletta, **EMP Radiation and Protective Techniques**, John Wiley and Sons, New York, 1976.)
- This idea was Defined by Baum , and later formalized BY Tesche and others in the literature:
  - C. E. Baum, "How to Think About EMP Interaction", *Proceedings of the 1974 Spring FULMEN Meeting*, Kirtland AFB, April 1974.
  - F. M. Tesche, et. al., "Internal Interaction Analysis: Topological Concepts and Needed Model Improvements", *Interaction Note Series*, IN-248, October 1975.
  - F. .M. Tesche, "Topological Concepts for Internal EMP Interaction", *IEEE Trans. AP*, Vol. AP-26, No. 1, January 1978.
  - C. E. Baum, "Electromagnetic Topology for the Analysis and Design of Complex Electromagnetic Systems", pp. 467-547 in **Fast Electrical and Optical Measurements**, Vol I, eds. I.E. Thompson and L.H. Luessen, Martinus Nijhoff, Dordrecht, 1986.

Use of EM Topological Concepts for Response Estimation

- The system is examined for the principal shields or EM "barriers",
- Imperfections (openings) in these barriers are noted and categorized,
- An EM signal flow diagram is constructed,
- Models are developed for the most important aspects of the EM signal paths, and
- An estimation of the equipment responses to the EM excitation are determined using a variety of methods.

Other Uses of EM Topology

- Assists in the design of new systems with EM hardening requirements,
- Provides guidance for EM hardness verification testing,
- Aids in the determination of hardness critical items (HCI),
- Provides a starting point for hardness surveillance and maintenance (HM/HS) programs, and
- Helps in configuration control of a system.

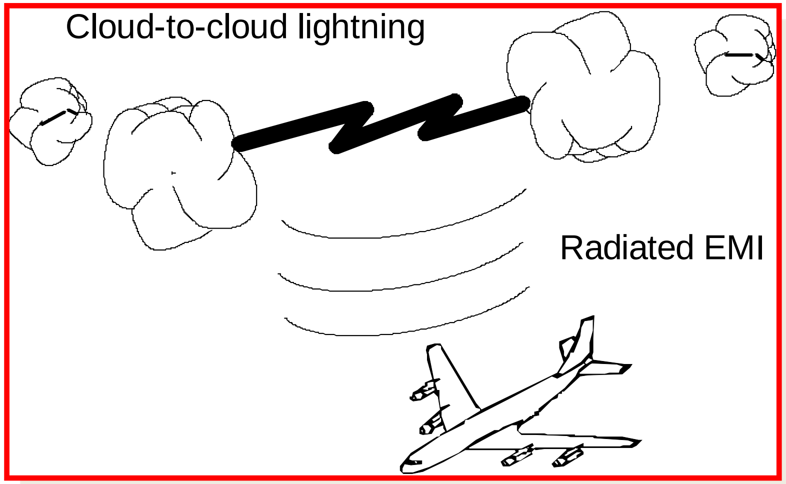
The First Step in Model Development Is to Determine the Topological Diagram

- This is a description of the principal shielding surfaces in the system and their interrelations to each other.
- Real shields are not perfect, and the external EM energy can enter by one or more of the following mechanisms: Acronym CAD
  - Conductive penetrations, formed by wires, cables or other conductors,
  - Aperture penetrations through holes in the shield, and
  - Diffusion through the barrier material.

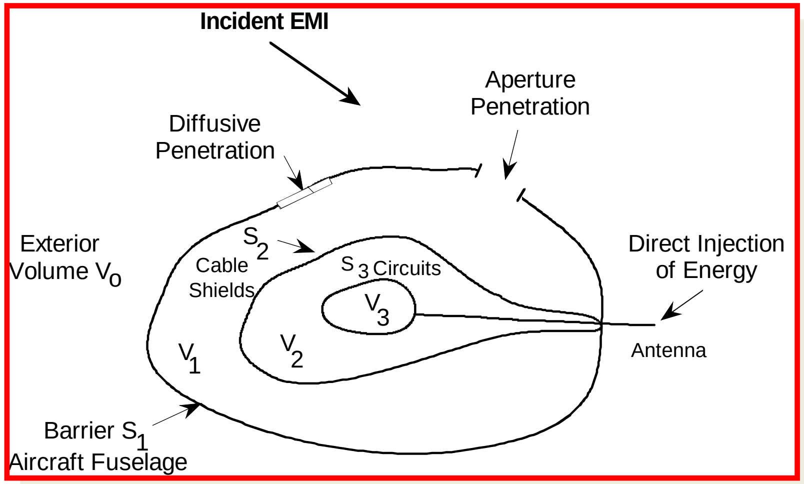
The Shielding Topology is Based on Conducting Surfaces

- Consider an aircraft excited by a distant cloud-to-cloud lightning discharge

<u>Physical configuration</u>



<u>System topology</u>



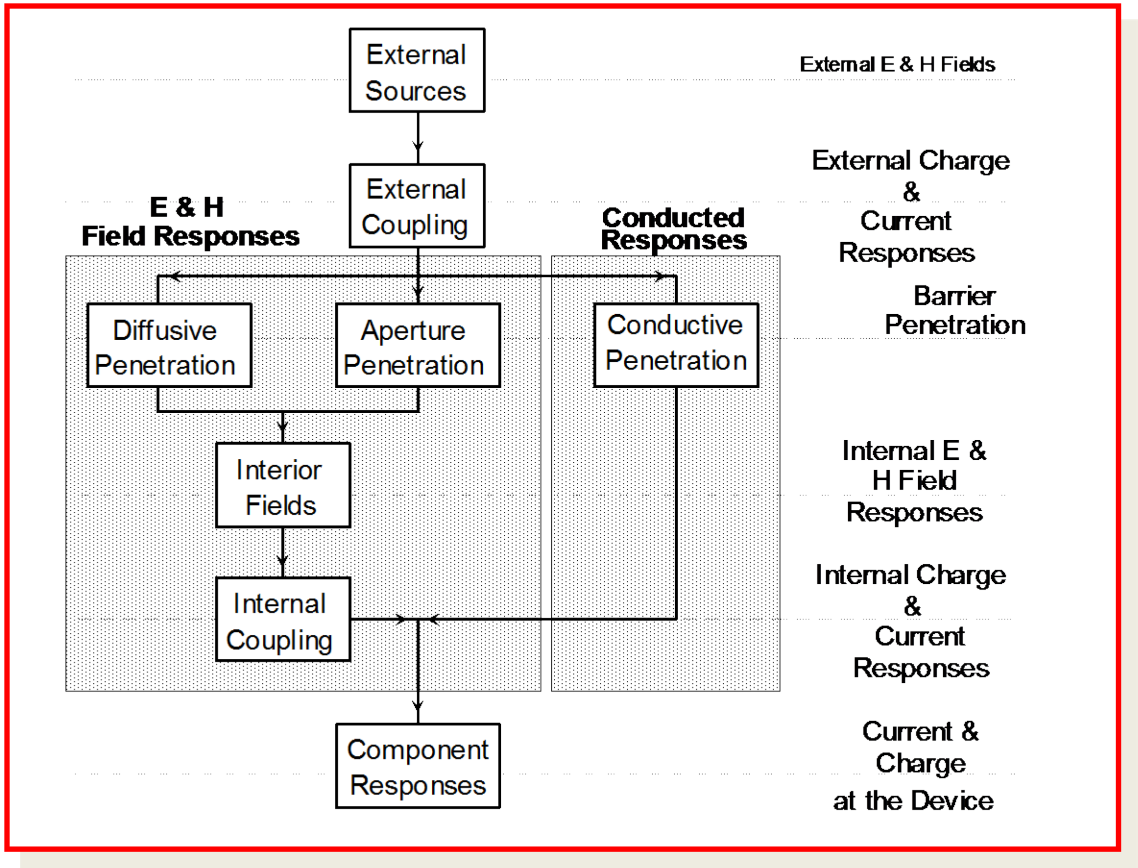
The shielding surfaces do appear like the layers of an onion.

The Interaction Sequence Diagram (ISD) Is Based on the Shielding Topology

- It represents the paths that the external EM energy can take from the outside to the inside of the system.
- Basically, this is a *signal flow diagram* developed from knowledge of the topological diagram and the shield penetrations.

Overview of the Interaction Sequence Diagram (ISD)

- For an external EM source, the following interaction sequence diagram results for the example aircraft:



From the ISD, a System EM Model Can Be Developed

- This results from the removal of all of the unimportant “clutter” in the system.
- This step in the analysis can require considerable judgment on the part of the analyst.
- Such models frequently use transmission line theory, but other simple EM models are also found: antenna theory, aperture models, etc.

A Circuit Model is Then Developed

- Once the system model is developed, it can be cast into an equivalent Thévenin or Norton circuit
  - Acting on a component or sub-system of interest that may be prone to upset or failure.
- In this manner, entire system interaction model is put into the form of a single equivalent circuit acting on a “victim”.
- The elements of this circuit usually are not known analytically:
  - they must be calculated using one or more approaches which provide numerical representations of the circuits

Summary of EM Interaction with Systems

Described as a process involving *Propagation*, *Coupling*, and *Penetration*

- Propagation:
  - EM energy moving from the external source to the system
  - EM energy moving within the system
- Coupling:
  - The induction of currents and charges on conductors by the EM fields
- Penetration:
  - Passage of EM energy through shielding enclosures
  - Leakage of apertures and seams
  - Unwanted signals passing through filters and/or surge limiters

Past Uses of EM Topology

- Study of HPM effects on an office building
- EMP hardening of a ground-based communication facility
- Design of EMP protection in a missile system
- Development of measurement program for EMP hardness surveillance in a C-130 aircraft
- EMP hardening study of the B-52 aircraft
- Study of EM effects on an automobile

Office Building

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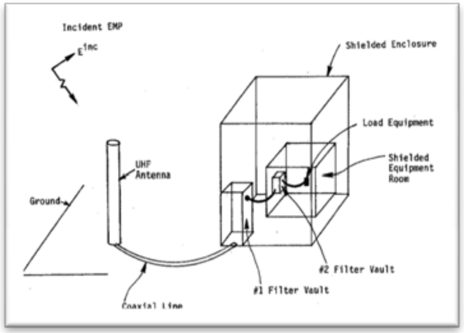
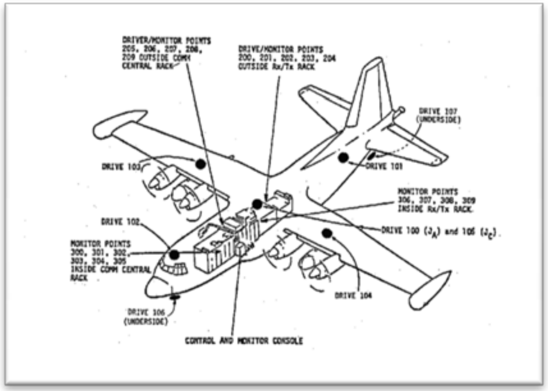


Ground based Communication Facility



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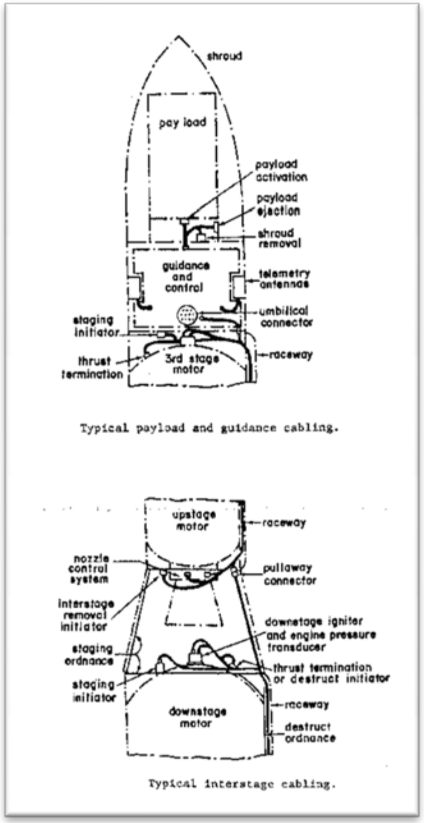


Missile system

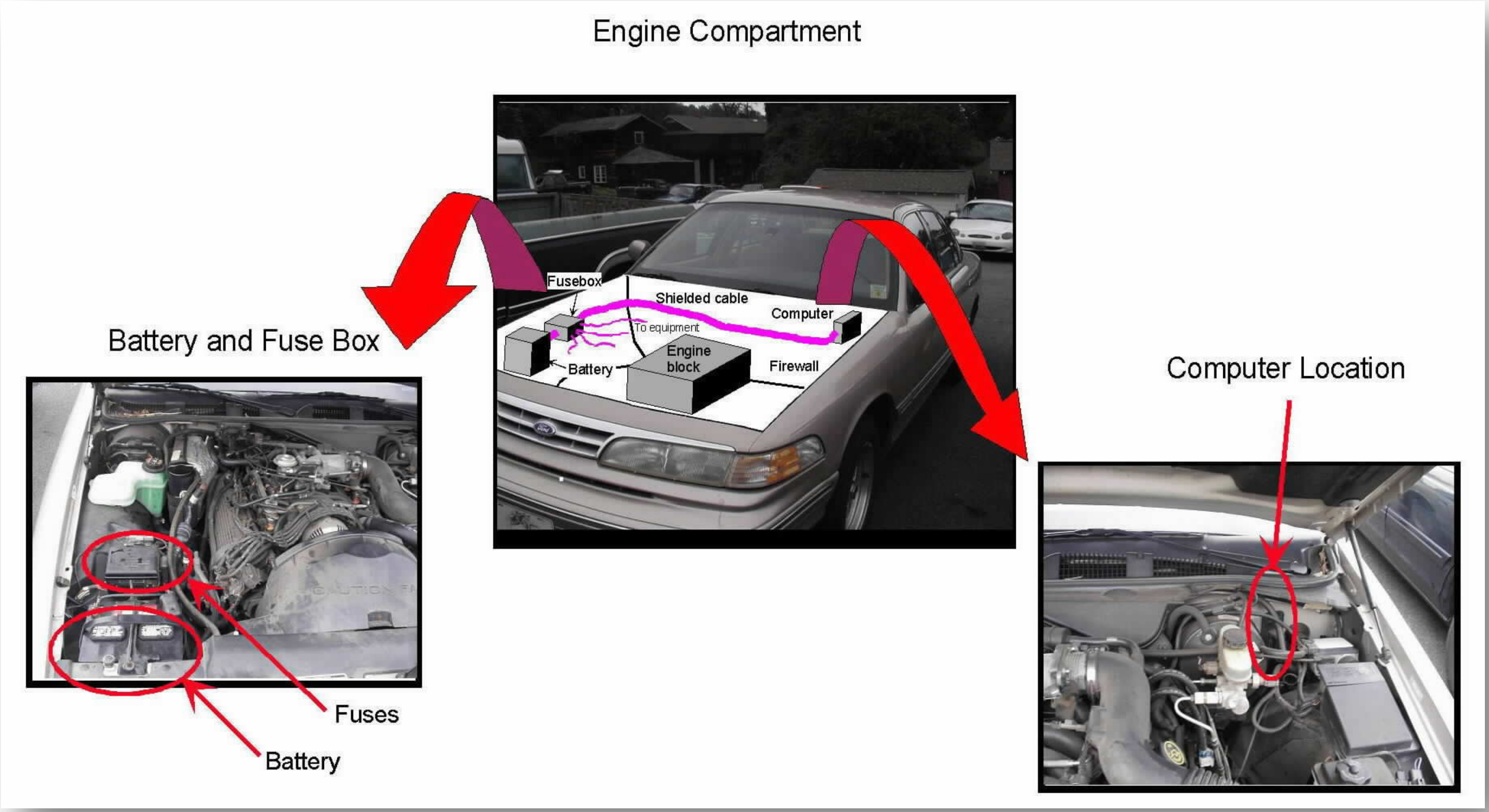
Illustration of a Topological Model for a Car

- Ford Crown Victoria sedan.

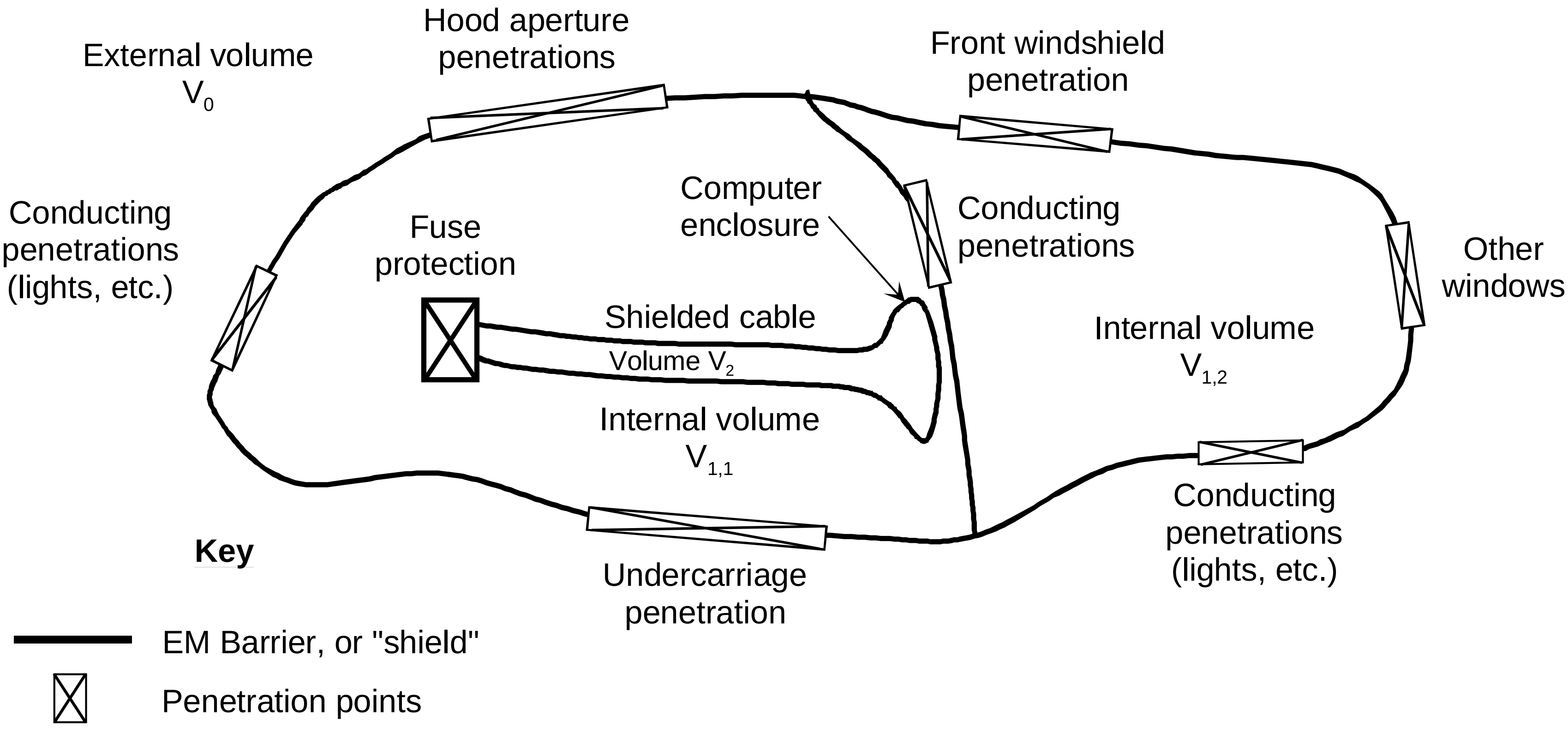
Major Entry Points for EM Energy

Physical Details of the System

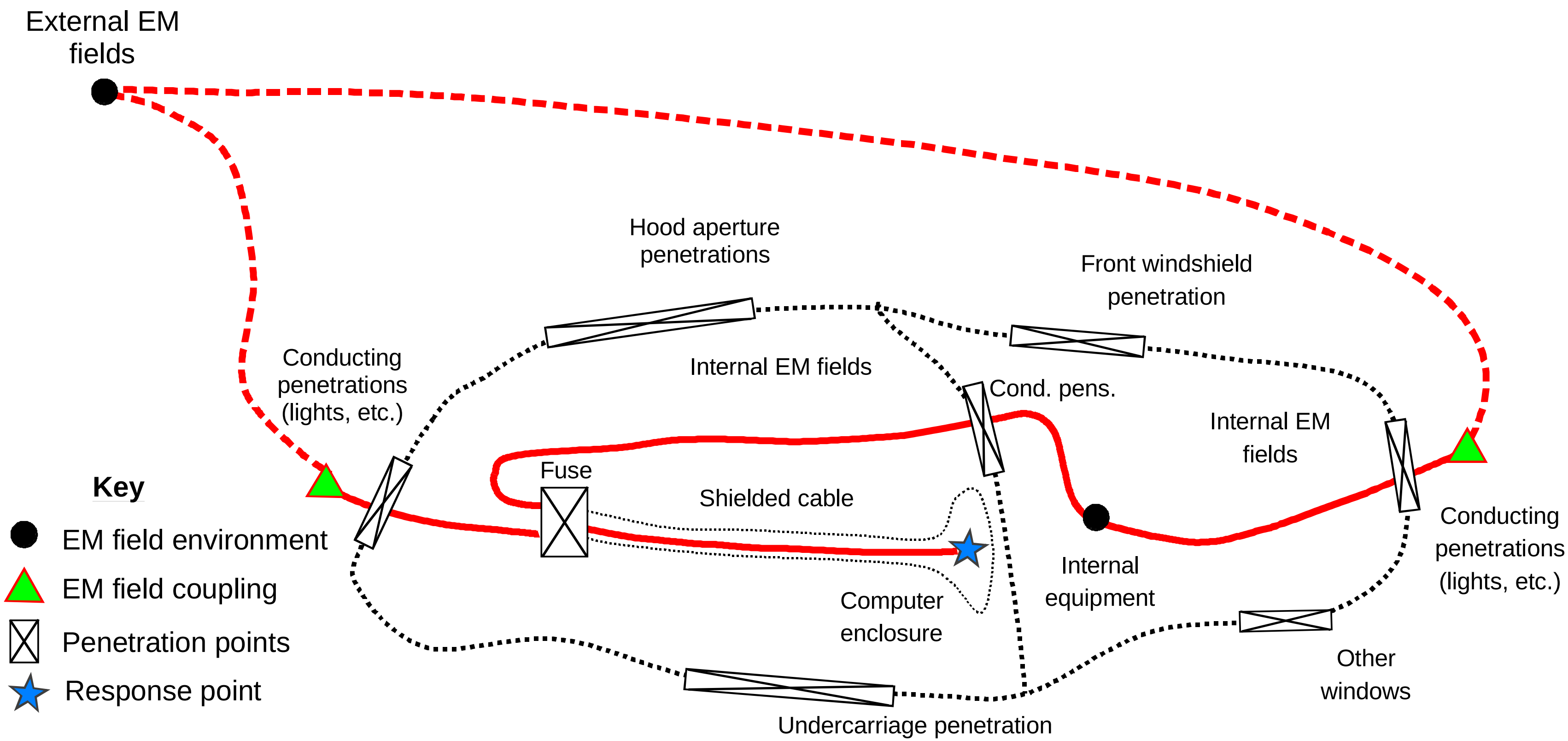
- Photos of the engine compartment, showing the locations of the computer, shielded cable, fuse box and other equipment.



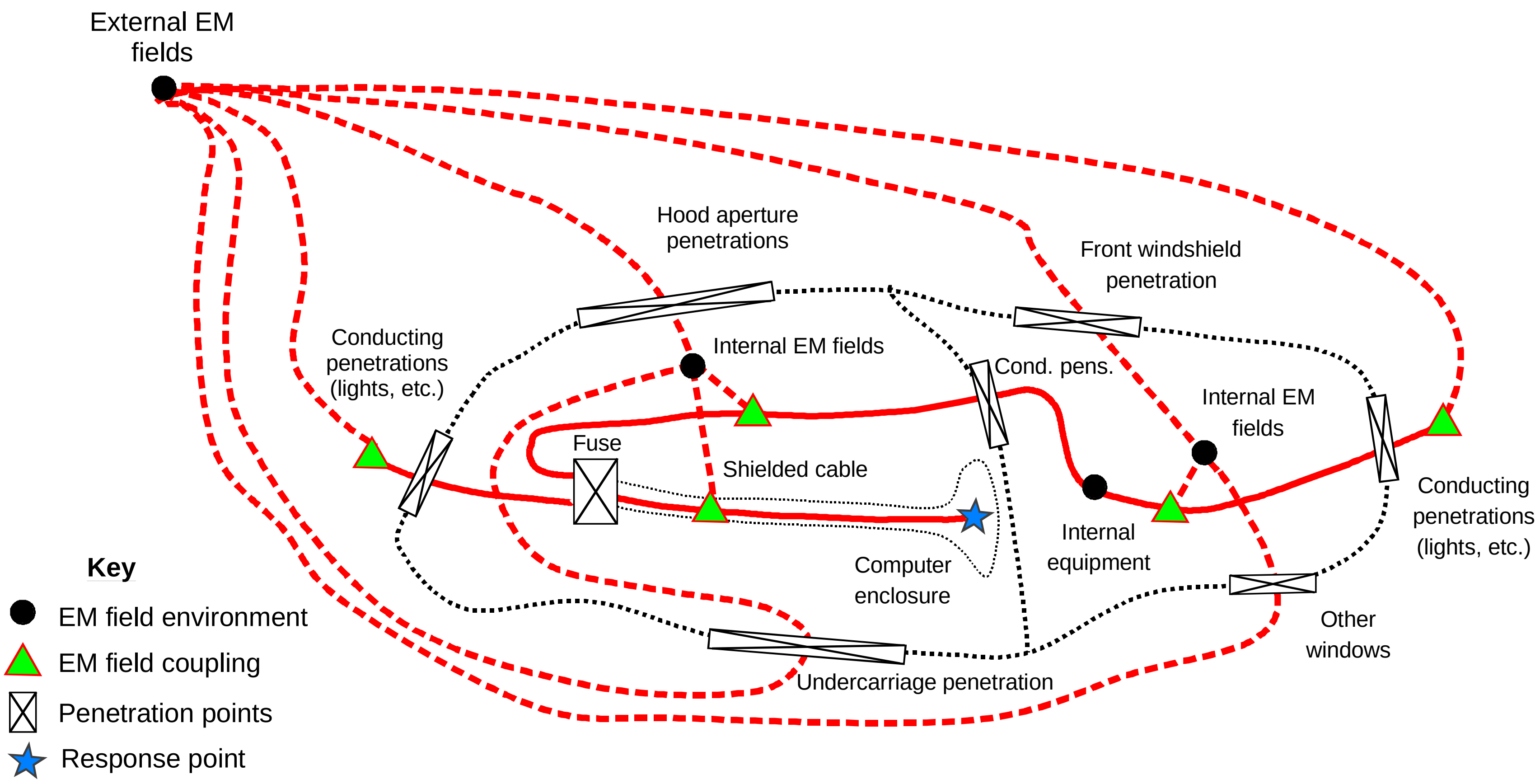
HPEM Shielding Topology for the Vehicle



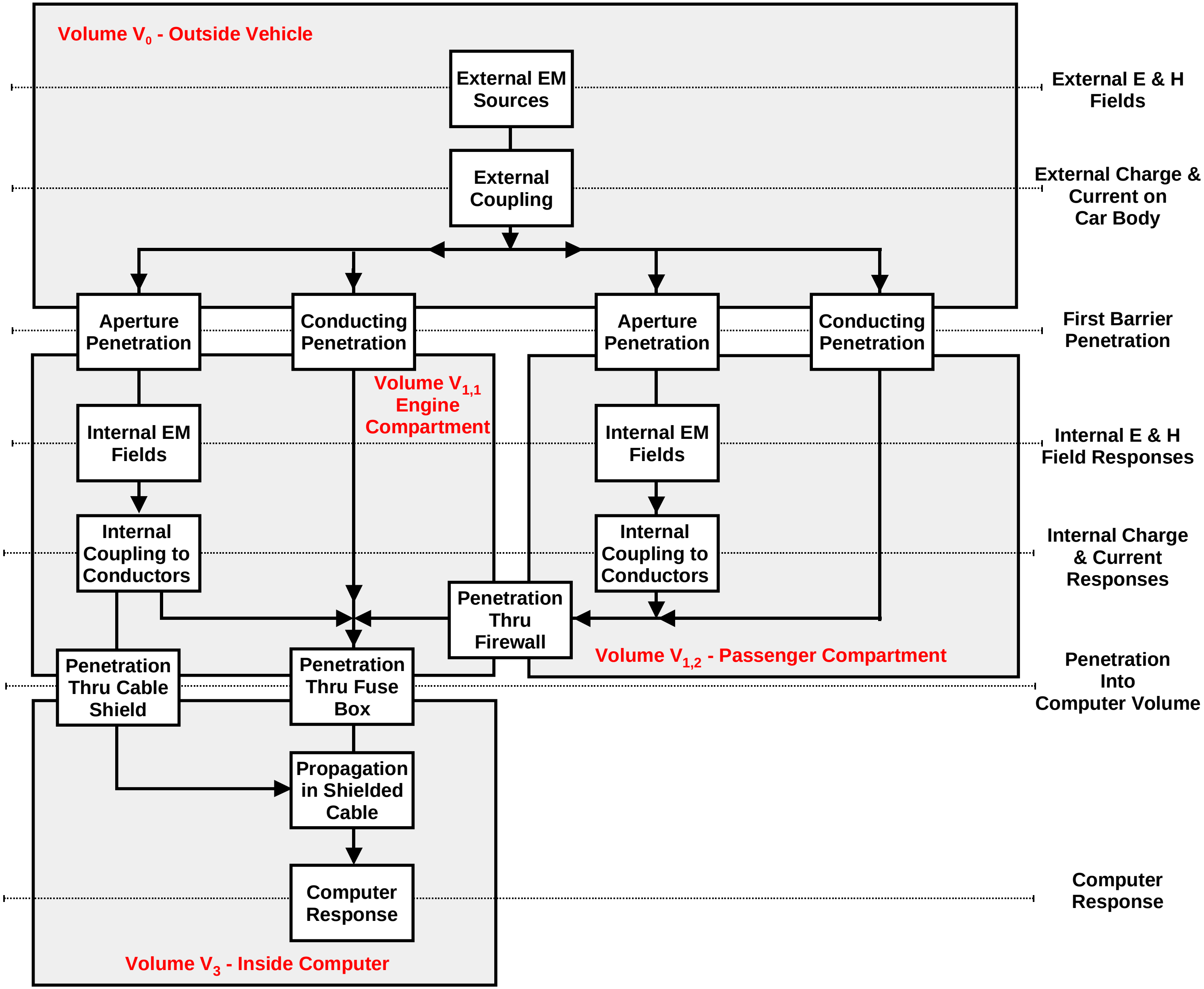
The ISD for the Hard-wired (Conductive) Signal Paths



The ISD for the Conductive and Aperture Signal Paths



Detailed ISD, Based of the Previous



EM Hardening Based on Topology

- The *fundamental principal* of EM hardening is to insist on a closed shield topology.
  - This is **not** a grounding, bonding, filtering, common-mode rejection or surge protection concept.
  - These latter techniques are **means** to control (or close) the shield topology.
- The basic topological hardening guideline is as follows:

> Completely enclose the potentially susceptible equipment in an EM barrier, and provide suitable EM protection for all penetration points in the barrier.

Summary

- EM Topology provides a structured way of understanding the EM field interaction with complex systems.
- It is useful for
  - initial system design,
  - performing analysis of system responses,
  - developing an EM hardening philosophy and plan,
  - assisting in developing system test concepts, and
  - maintaining a configuration control plan, and
  - developing a hardness maintenance and surveillance plan.