MESAF – A Framework for EMC Analysis

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1. Introduction

The development of computational electromagnetics (CEM) over the last thirty years has made modelling of EMC problems possible. Simulation offers cost advantages over measurements; delays due to availability of the test object or facility are avoided and different configurations can be evaluated before constructing the best design. However, many real systems are very complex and application of CEM can itself be a long and costly exercise, requiring experienced staff and extensive computing resources, especially at high frequencies. In particular, modelling the level of detail experienced in modern products in the Defence and Avionics industries can be prohibitive. These constraints have lead to the requirement for an intermediate level code for EMC type problems; software less complex than CEM but more accurate than simple ‘back of the envelope’ calculations. This idea provided the impetus for the development of MESAF.

MESAF (Multilevel EMC System Analysis Framework) has been designed for use by EMC engineers on a PC. The software uses the concept of electromagnetic topology which enables the routes by which energy couples through complex structures to be defined quickly and simply. A database of transfer functions is then used to quantify the coupling and the code can then indicate the parts of the product where EMC compliance is likely to be problematic. The engineer can make modifications to the system design and determine their effect. MESAF provides a support tool for engineers during the product design phase, so different configurations can be assessed. The software is not intended to replace the final EMC compliance test, but to reduce the likelihood of test failure. MESAF can also be used to assess the impact of post design modifications on compliance. The software operates in the frequency domain and is a general code that can be applied to any product or system. It can be used for assessing both susceptibility and emissions.

2. Design of MESAF

MESAF was developed with the EMC engineer in mind, and is based on the work of LoVetri et al (references [1],[2]). The software is user friendly, GUI driven and adaptable to data owned by the user. There are five essential components in the software, as shown in figure 1, and each opens in a separate window:-

1. The **EM Topology Window**, where the user defines the system.
2. The **ISD** (Interaction Sequence Diagram), which shows the system connectivity and where the user quantifies the system coupling.
3. The **Database**, where transfer functions, specifications and threats are stored.
4. The **Solver Window**. Here the program is run and the worst case path through the ISD (the path with minimum attenuation) displayed. Pass/failure at given sub-units in the system is also indicated.
5. The **Results Window**, which facilitates display of signal levels at all sub-units and frequencies modelled in both tabular and graphical form.

2.1 The Electromagnetic Topology Window

MESAF uses the concept of electromagnetic topology (references [3], [4]). It is necessary to understand this idea fully to use the code properly. EM topology is a way of defining the *electromagnetic* configuration of a system. The structure is split up into a collection of *electromagnetic volumes* separated by *screening surfaces.* Coupling between the

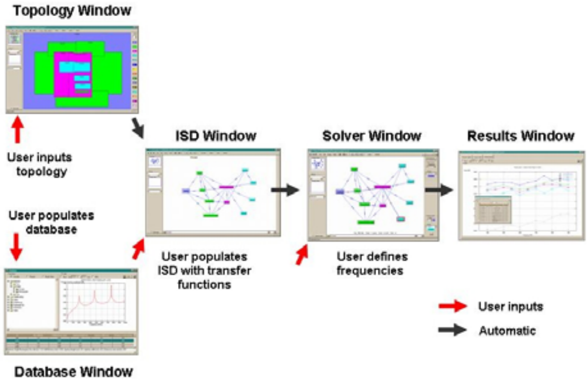

Figure 1 Components of MESAF Software

volumes occurs through the screening surfaces, and via any cables in the system. The electromagnetic volumes are placed at different topological levels, starting with the space exterior to the system at level 1. The connectivity of the system is defined by the interaction paths between the electromagnetic volumes. Coupling can occur between level n and levels $n-1$ and $n+1$, but no other levels, and is quantified by the transfer functions. The topological decomposition of the system is dependent only on its connectivity, and not on geometrical details. This makes the EM topology quick and easy to define.

Consider the example shown in figure 2. It shows a piece of equipment consisting of a ventilated case (A) containing a power supply (located inside a second screened, ventilated case B) connected by a cable to a subunit X which has a printed circuit board located inside a screened case C. The topological decomposition of this system is effected as follows and shown in figure 3:-

1. Define the space exterior to the equipment as electromagnetic volume 1, at level 1.
2. The case A separates volume 1 from the interior cavity of the equipment which is defined as electromagnetic volume 2 at level 2.
3. Energy couples from electromagnetic volume 1 to volume 2 via the ventilation aperture in case A. The coupling can be quantified by the transfer function of this aperture.

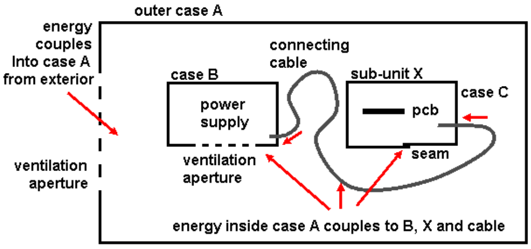

Figure 2 Model Illustrating Definition of Electromagnetic Topology

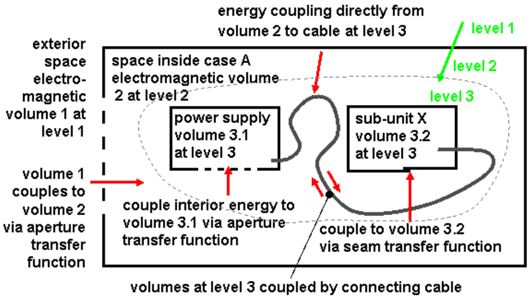

Figure 3 Electromagnetic Volumes and Topology for Model in Figure 2

4. Energy inside the case, in electromagnetic volume 2, can couple to both the power supply via the aperture in case B and the pcb in subunit X via the seam in case C.
5. Define two electromagnetic volumes at level 3 – the interior of the power supply, electromagnetic volume 3.1, and the pcb, volume 3.2.
6. Energy couples from the equipment interior, electromagnetic volume 2, to volume 3.1 via the screened case B and from volume 2 to volume 3.2 via the screened case C.
7. The power supply is connected to subunit X by a cable. This can also pick up energy from electromagnetic volume 2 and so is defined as electromagnetic volume 3.3.
8. The cable couples electromagnetic volume 3.1 to 3.2.

The user creates the electromagnetic topology for their system in the EM Topology window. Information on the system connectivity only is required, and this can be specified by drawing boxes to represent each electromagnetic volume. These are colour coded to define the different levels and can be labelled. The

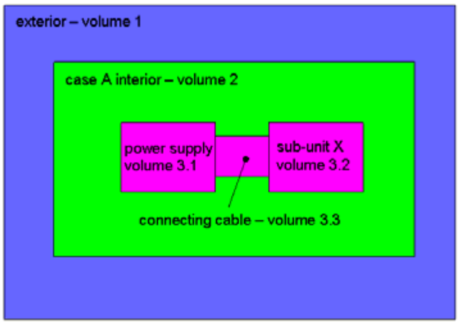

Figure 4 Electromagnetic Topology for Model of Figure 2

topology diagram appropriate to the model of figure 2 is shown in figure 4. From the topology MESAF automatically generates a connectivity diagram for the system, called the Interaction Sequence Diagram (ISD). The user can view the ISD by clicking on the appropriate icon on the screen.

2.2 The ISD Window

The ISD is used to quantify the coupling between the topological entities in the system. Each electromagnetic volume is defined as a node on the ISD. The coupling paths between the electromagnetic volumes appear as lines joining the nodes. The ISD is essentially a network showing the system interconnection. The ISD for the example system in figure 2 is shown in figure 5. The transfer function for the ventilation aperture in case A couples nodes 1 and 2. The transfer functions for the aperture in case B and the seam in case C define the coupling between nodes 2, 3.1 and 2, 3.2 respectively.

The MESAF user defines the coupling in their model by applying transfer functions to the paths between the nodes. This is done by a simple point and click mouse operation. The user opens the database window and selects the transfer functions appropriate to the model. These appear as a list in the ISD window. The user clicks on the transfer function name, then the ‘load’ button, then the path on the ISD where the transfer function is required. To make population of the ISD easier for complex models, the path changes colour when the transfer function is added, and hovering the mouse over paths and nodes generates a pop-up identifying label. Tables are provided so users can check that the ISD is populated correctly.

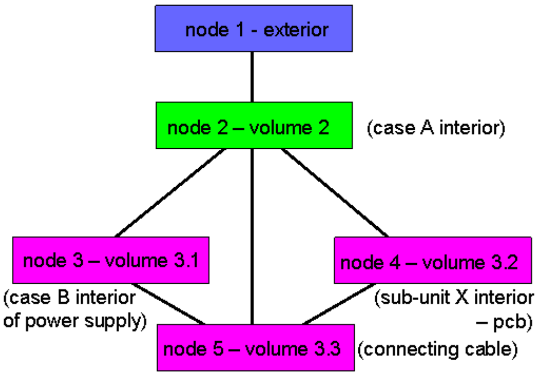

Figure 5 ISD for Model of Figure 2

2.3 The MESAF Database

The database is at the core of the MESAF software and is essential to the code operation. It facilitates storage of different types of transfer function in an organised and accessible way, so also performs a useful independent function. The database in the code consists of two components; the MESAF Database which contains a collection of general transfer functions, and the User Database where the user stores transfer functions specific to their project(s). The format of both databases is the same, and they can be browsed to select the appropriate transfer function. Once a transfer function is chosen a graph showing the frequency dependence of the function is displayed in the database window. This enables the user to check that the right one has been selected.

2.4 The Solver Window

The ISD is essentially a directed graph with the edges between the nodes weighted by the transfer function values. A standard *k*-paths algorithm can be applied to find the minimum path through such a network. The minimum path has the least attenuation and hence the highest signal level at the target node. The algorithm used in MESAF enables minimum paths between all pairs of nodes in the model to be calculated. MESAF is a frequency domain code and the user specifies the frequency range and number of points within that range where calculations are required. The solver is then run and the minimum path between any pair of nodes at any frequency can be displayed on the ISD in the solver window. The MESAF database stores threats and specifications which can be added to specific nodes on the ISD in either the ISD or solver windows. The code then computes the signal at the target node for the applied threat and compares it with any specification level at the node. If the signal exceeds the specified level the node is highlighted in red, indicating failure. The user can then modify the design to ensure compliance.

2.5 The Results Window

The MESAF solver enables a results matrix to be generated, containing the field strength at each node on the ISD at all frequencies modelled. This data is available in tabular form in the results window. It is presented in two forms; signal level at a single node for all frequencies modelled and signal level at all nodes at a single frequency. The results tables also define the path to each node in the problem, by identifying the node numbers and labels, and state any threat and specification levels applied to the nodes. This makes it easy to check the model. The tables can be exported easily to other documents. The signal at a chosen node is also plotted as a function of frequency. In addition to the minimum path, the search algorithm also enables the next four paths closest to the minimum path to be displayed on the ISD in the solver window. Data for these paths is shown in the results tables. They can also be plotted on the results graph. This is useful as any paths in the model with attenuation very close to the minimum path can be identified. If the system needs improvement, these paths may need attention in addition to the minimum path, and it is useful to do all the modifications together.

3. An Example MESAF Model

This section demonstrates the application of MESAF to a problem involving current pick-up on the cable looms in an aircraft. Figure 6 is a schematic view of the aircraft showing the main sub-units and associated cabling. There are two management computers, M1 and M2, two further system computers W1 and W2, and a data computer. There are four electronic engine controllers. Three computers D1, D2 and D3 control the cockpit displays. Other sub-systems include the autopilot, speed controller, IFF, two GPS systems and a ground proximity detector. This is located towards the tail of the aircraft. The engine controllers are in the wings and the displays in the cockpit. The cable looms extend over the whole aircraft with considerable scope for pick-up if the screening is not adequate.

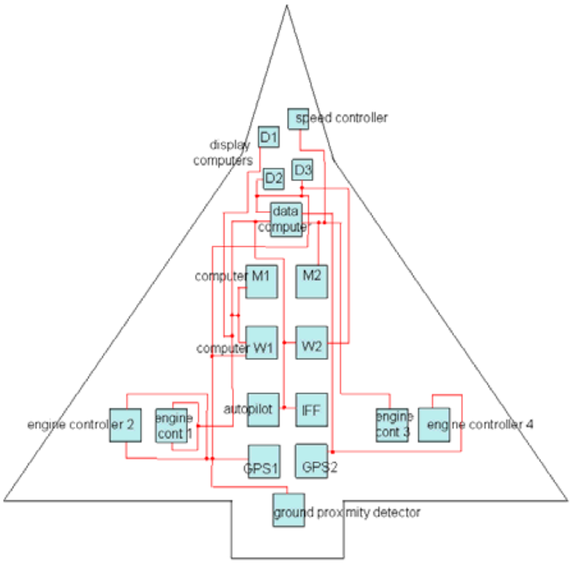

Figure 6 Example Aircraft System

For engineers with experience of EMC on aircraft, the electromagnetic topology for input to MESAF can be defined fairly easily by referring to figure 6. First the topology at level 1 (the exterior) and level 2 (the units that couple directly to the exterior) is defined as shown in figure 7. There are three units at level 2 – the fuselage and two wings. The other sub-units are located internal to the aircraft and so are placed at level 3 in the topology. These units are shown in figure 8. At this point there are no interconnecting cables in the model, although the internal sub-units are located in the topology window in positions suitable for interconnection. At this stage the modeller needs to be flexible in positioning sub-units to facilitate connections, and some trial and error is required. Finally the external screens of the cables are added,

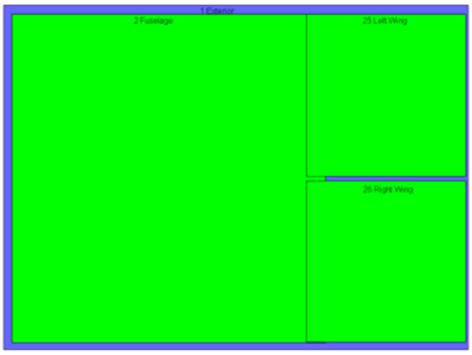

Figure 7 Electromagnetic Topology at Levels 1 and 2 for Example Aircraft System

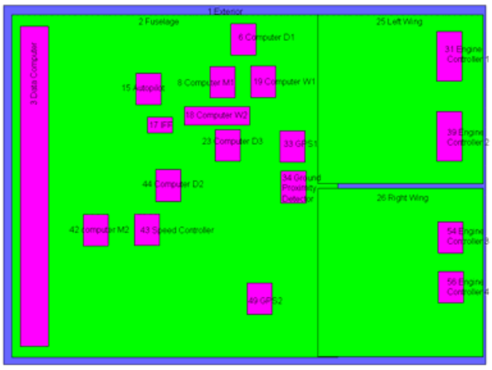

Figure 8 Electromagnetic Topology at Level 3 for Sub-units in Example Aircraft System

also at level 3, as shown in figure 9. The cables are shown in a slightly lighter shade in figure 9 for easy identification. If desired coupling down to cable cores at level 4 could be modelled, provided cable data and time were available.

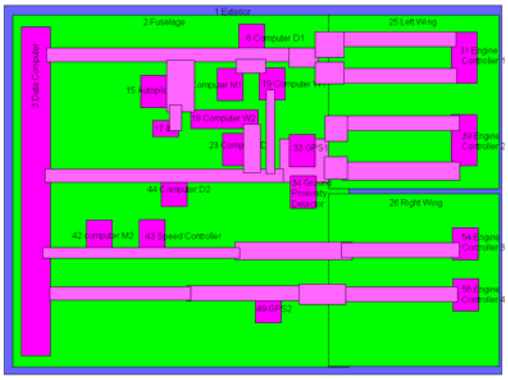

Figure 9 Electromagnetic Topology at Level 3 Including Cables in Example Aircraft System

Once the electromagnetic topology is defined, MESAF automatically generates the ISD for the model. This is shown in figure 10. The user populates the ISD with the right transfer functions. The shielding effectiveness data for the aircraft fuselage and wings was used for the paths between these components and the exterior. Cable transfer functions over the frequency range 50MHz-1GHz were computed using the BAE SYSTEMS boundary element code EMMA_F:BE3D. The aircraft contained cables of twenty different lengths which were all modelled. Where the cables run close to the aircraft walls a ground plane was included in the model. Each cable was illuminated from ten different angles of incidence with different polarisations and the resulting currents averaged in order to attempt to simulate the random nature of the internal illumination in the aircraft. Finally these transfer functions were loaded into the user database and applied to the correct paths on the ISD.

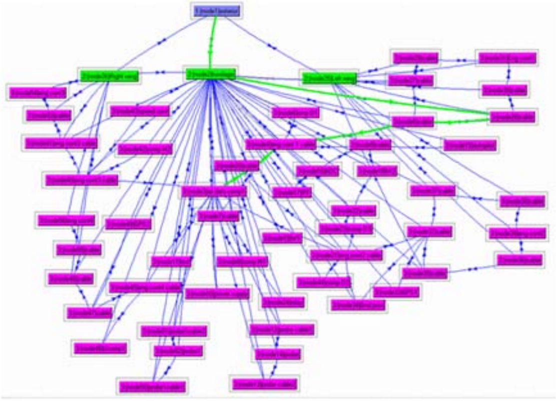

Figure 10 ISD for Example Aircraft System

The MESAF solver was run at 50MHz intervals over the frequency range 50MHz-1GHz. The model contained 56 nodes and each frequency step took 2-3secs on an HP Compaq PC with a 3GHz Pentium IV processor and 500Mb RAM running Windows XP. Output can be obtained at any node in the model but in this case the current pickup on the data computer (node 3 in the model) was calculated. The results are shown in figure 11 and are compared with measurements to 400MHz (the maximum available) in figure 12. The agreement was encouraging given the assumptions inherent in the model and the use of calculated, rather than measured transfer functions. The sensitivity of the model to

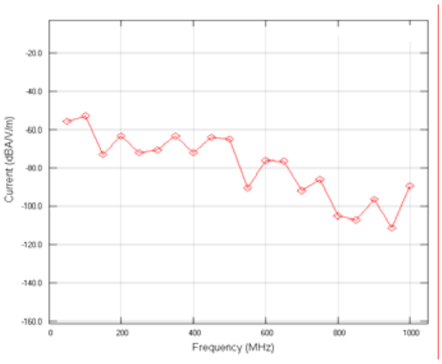

Figure 11 Current Pick-up for Data Computer Cables (Node 3) in Example Aircraft System

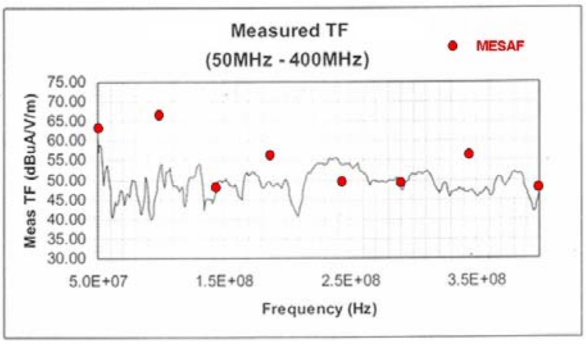

Figure 12 Comparison of Measurements and MESAF Model for Current at Data Computer

variations in cable length was also assessed and this gave differences of up to 5dB in the signal levels predicted. Agreement may well be poorer at lower frequencies because MESAF relies on the assumption that both events along a single path in the model, and adjacent paths in the model, are not closely coupled. This becomes less true as the frequency is reduced. The worst case path to node 3 is shown as the green line on the ISD in figure 10. It involves coupling of the external field into the main fuselage (node 2), and thence onto the cable loom from engine controller 1 (nodes 28, 5 and 4) to the data computer at node 3.

4. Conclusions

This paper has summarised the principles behind MESAF and outlined the components of the software. Code development has progressed to the stage where robust software is available for design engineers to use. The program has been demonstrated with an aircraft model, showing how it can be used to assess field ingress to complex systems.

MESAF provides a simple and cost effective method of assessing EMC problems in complex systems. It is easy for engineers to use on a PC and does not require specialised mathematical knowledge. It offers the advantage of building models using existing transfer function data owned by the EMC engineer, and uses their expertise in understanding how system components are linked in an electromagnetic sense. It also enables the essential components of any system and its transfer functions (both computed and measured) to be recorded systematically, in one place. The code shows the engineer where the electromagnetically weak parts of the design are located. It can be used iteratively to assess the effect of improvements to the system to achieve compliance, and also to facilitate more cost effective design for EMC.

5. References

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6. Acknowledgements

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