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Interaction Notes

Note 415

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TOPOLOGICAL ANOMALIES IN TEST METHODS

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ILLUSTRATIONS

I INTRODUCTION AND BACKGROUND

A. Interference Control Philosophy

If connection with the analysis of system response to incident EMP,[1*] the concept of system topology has proved a powerful tool. It permits the decompositon of very complicated systems into simple elements such as transmission lines, antennas, cavities, apertures, etc. that are amenable to analysis, [2,3]. Work on the mathematical formalism for describing the shield topology and penetration paths in terms of transmission and scattering theory is continuing.[4]

The consideration of shield topology is also very useful in designing system immunity to interference.[5,6] Susceptibility analysis uses topology to separate a system into tractable pieces, but the system designer must reverse the process to synthesize a shield topology that will restrict penetration of interference to a tolerable level. This must be done without unduly compromising the performance of the primary functions of the system and without radically increasing its cost.

Interference control, in general, is concerned with separating undesirable sources from susceptible circuits. For example, the perfectly conducting closed shield in Figure 1 completely isolates the volume enclosed by the shield from electromagnetic sources outside the shield. Therefore, if a system could be enclosed in such a shield, it would be completely immune to lightning, EMP, and other external sources of interference.

Unfortunately, a serious practical limitation on the use of perfect shields is the fact that such a closed system does not allow electromagnetic signals to enter or leave the system. Since a system with which one cannot communicate generally is not useful, the shield must usually be compromised to allow information to flow into and out of the system. Further compromises are usually necessary to supply power to the system and to

*References are given at the end of this report.

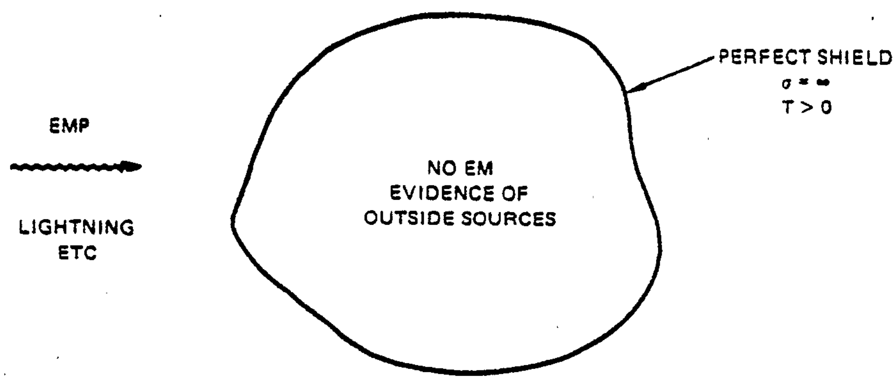


FIGURE 1 ELECTROMAGNETIC ISOLATION WITH A PERFECT SHIELD

dispose of waste heat. Doors and access hatches are necessary to allow the equipment to be installed and serviced. Many more accommodations must be made if the system requires human operators. Finally, perfect conductors for large scale shielding are not yet practical.

These deviations from the perfect shield mean that two or more levels of shielding may be required to protect small-signal circuits from the EMP. A two-level shield system is illustrated in Figure 2. Some variation of this system is rather common; the first shield might be the building or room shield and the second shield would then be the equipment cabinets. If no building shield is provided, the first level of shielding will be the equipment cabinets and cable trays and the second level will be shielded compartments within the cabinets. For aircraft, the first level would be

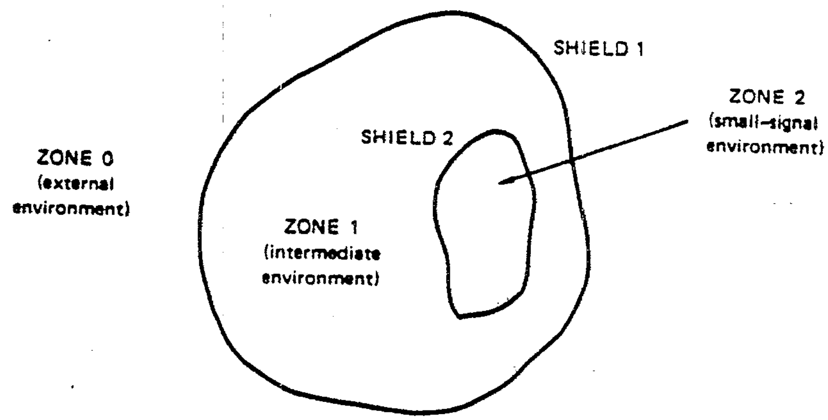


FIGURE 2 TOPOLOGY OF A TWO-LEVEL SHIELD SYSTEM

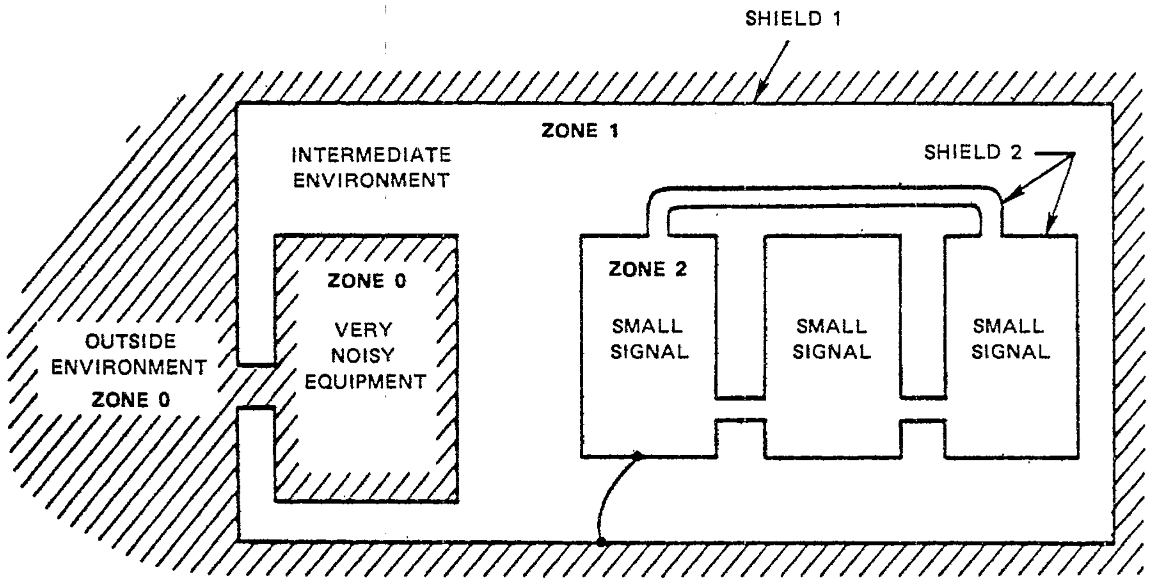
the metal skin and the second shield would be the avionics cases or housings. For ships the hull, decks, bulkheads, and equipment cases serve as shields. Such multilayer shields occur naturally as a part of the structural design in many systems; with a modest interference-control design based on topological concepts, an effective shield system can be developed.

B. Allocation of Shielding

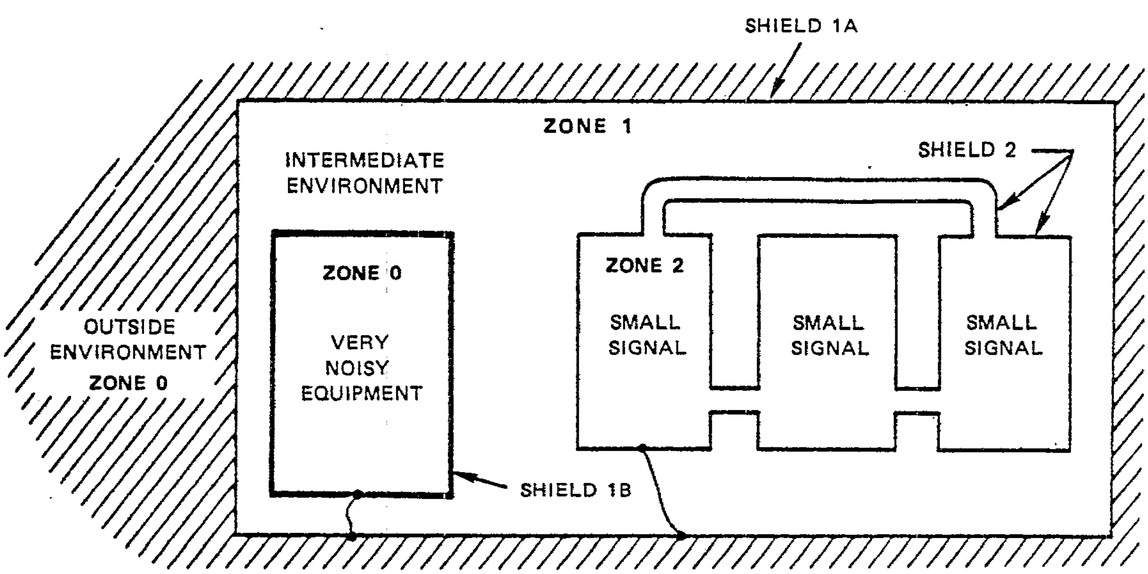
To control external interference in a system having two levels of shielding (e.g., missile skin and equipment case), it will be necessry to develop some basis for allocating the shielding between the two surfaces. If the quality of both shields can be controlled, a rational allocation is to require the outer shield to reduce the signals induced in internal circuits by external sources of interference (EMP, lightning) to a level small compared with the response of these circuits to internal sources (switching transients, etc.). Similarly, the second-level shield, the equipment cases and interconnecting cable shields, would be required to provide enough additional interference reduction that interference penetrating the second-level shield is comparable to or less than that produced by normal circuit operation.

If this allocation of shielding can be applied, the requirements applicable to packaged, interconnected subsystems are that (1) they be able to tolerate the ambient environment, and that (2) internal interference smaller than the signal level not degrade the performance of the circuit. That is, the only requirement unique to the external source is that the outer shield be capable of reducing the externally induced interference to the level of internally generated system interference.

Exceptionally noisy intermediate environments may be produced by high power transmitters, large rectifiers, dc to dc convertors etc., inside the first shield. It is often desirable to reduce the interference produced by these devices to avoid procuring special high-tolerance equipment for a system. Two topologically different approaches to controlling such sources are depicted in Figure 3. In the first approach, the first shield is distorted to exclude the offending source, thus preserving the moderate intermediate environment with one shield. In the second approach, (Figure 3b), a separate shield is provided to confine the offending source. The same principles are used to design the confining shield (shield 1B) that are used to design the facility shield (shield 1A), except that the source is inside shield 1B, while it is outside shield 1A.



(a) NOISE SOURCE EXCLUDED BY FIRST SHIELD



(b) NOISE SOURCE CONFINED BY SEPARATE SHIELD

FIGURE 3 METHODS OF TREATING VERY NOISY EQUIPMENT WITHIN A SHIELDED SYSTEM

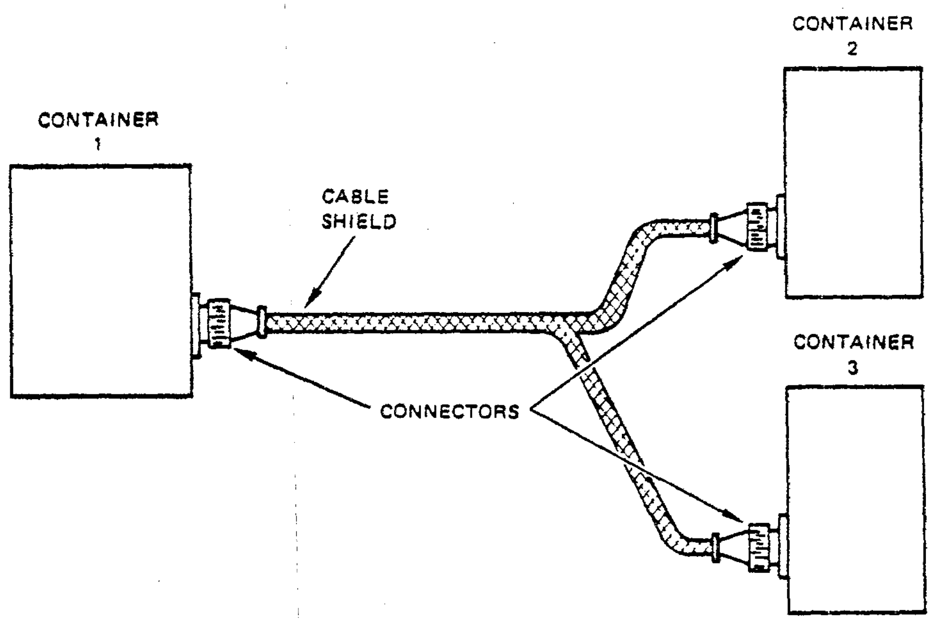
C. Elements of the Second Shield

Figure 4(a) is an example of a shield system including a shielded cable and connectors. In this example, the equipment cases, the cable shield, and the connectors form a continuous shield system analogous to those labeled shield 2 in Figures 2 and 3. This shield system completely encloses the electronic circuits in the containers and the interconnecting wiring in the cables. Thus, as illustrated in Figure 4(b), interference sources outside the shield can affect the circuits inside the shield only if the interference penetrates the container's walls, penetrates the cable shield, or penetrates the connector. Evidently, if the connector shell is not a good shield, the entire shield system will be compromised.

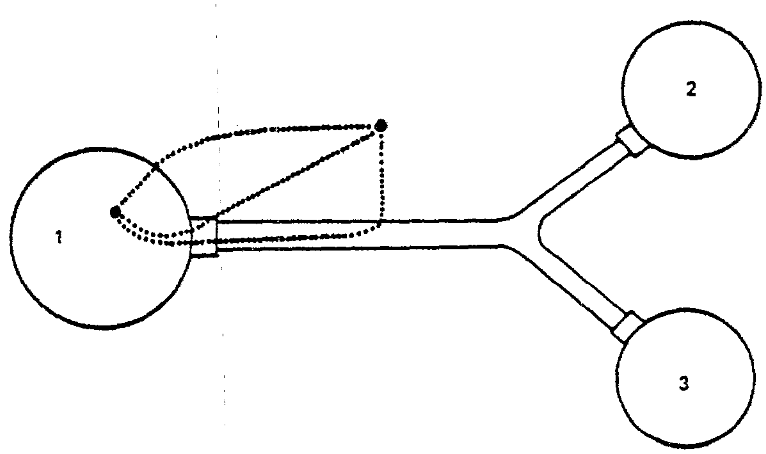
In an operational installation of equipment such as that illustrated in Figure 4(a), the principal excitation of the shield is almost always the current flowing along the cable shields and connectors to the containers, and hence to structural ground through the container mounting hardware or ground strap. Below 100 MHz, these currents are more likely to be induced on the cable shield by adjacent cables or by gradients in the ground system than by an incident wave (such as that required by the MIL-STD-461/462 tests).

A more detailed picture of this excitation is given in Figure 5, in which the current path over the connector and the junctions between the connector and the cable shield and container are illustrated. Note that the cable shield is a segment of transmission line that is short-circuited at its ends through the connector and container. Thus, a connector such as that shown is Figure 5 is usually subjected to maximum transmission line current, and any constriction in or interruption of the current by the connector allows the shield current to interact with the internal conductors.

The emission tests defined by MIL-STD-461/462 conducted and radiated emission tests are intended to determine the amount of interference produced by the equipment, both inside the shield (conducted emissions) and outside the shield (radiated emissions). The susceptibility tests illustrated in Figure 6 are intended to establish a minimum tolerance of the



(a) INTERCONNECTED SUBSYSTEMS



(b) SHIELD TOPOLOGY AND INTERACTION PATHS

FIGURE 4 INTERIOR SHIELD SYSTEM AND SHIELD TOPOLOGY

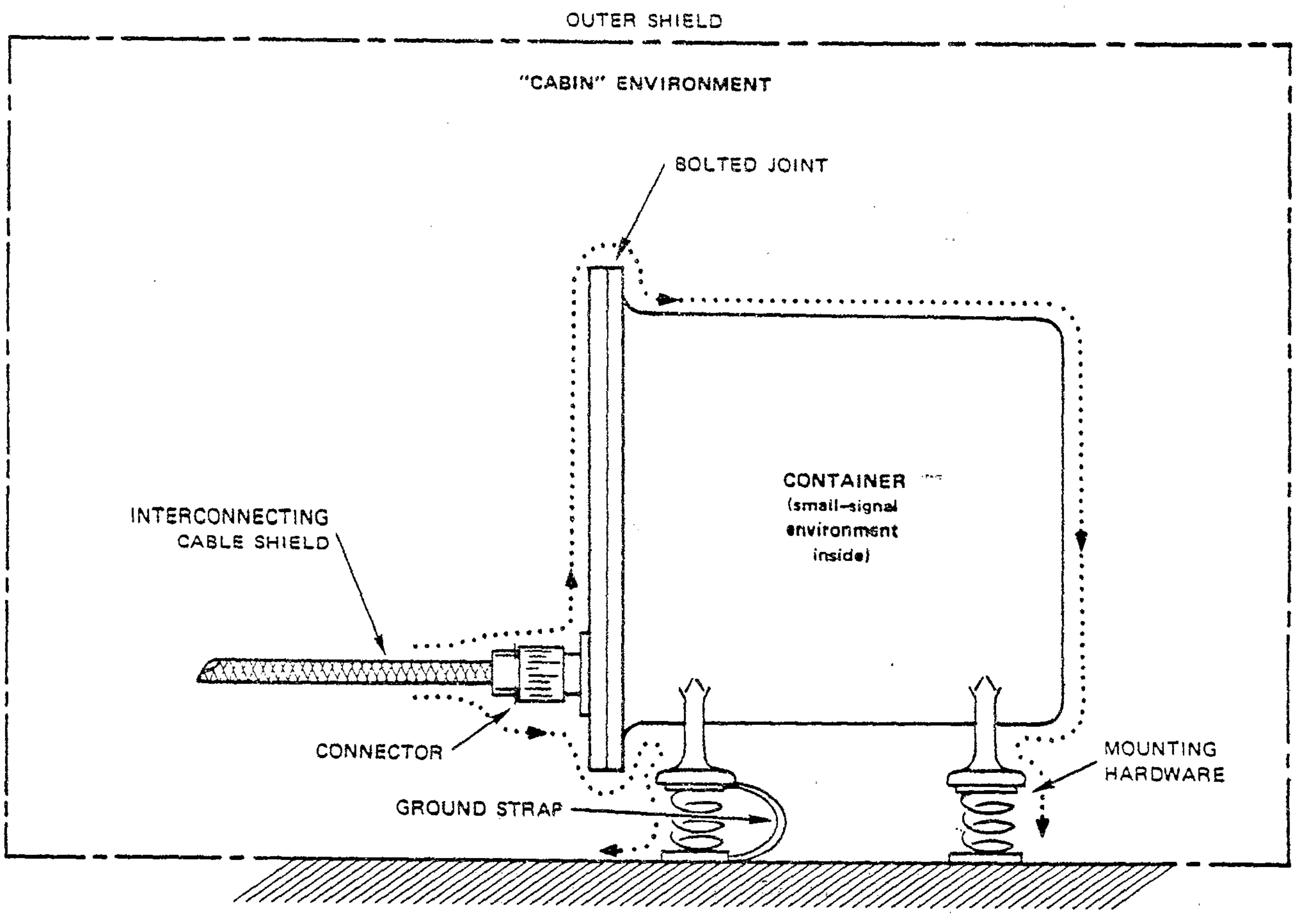


FIGURE 5 EXCITATION OF SHIELD SYSTEM CONTAINING CONNECTOR

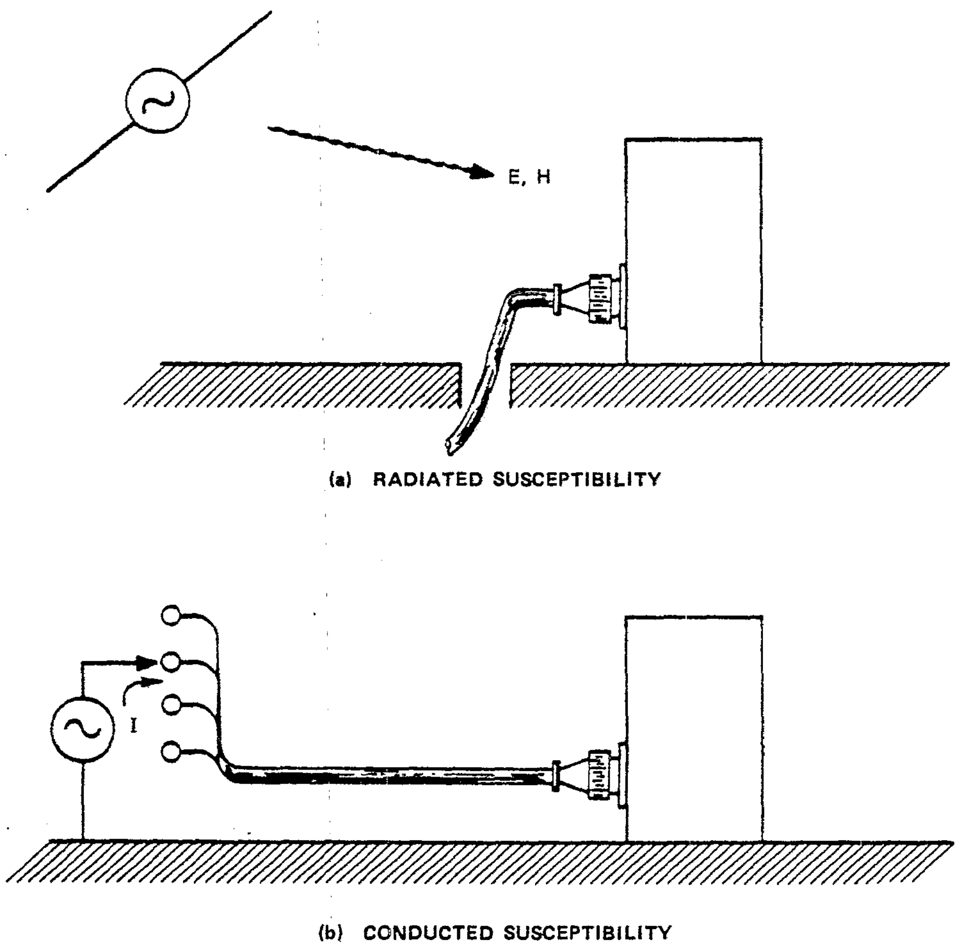


FIGURE 6 TESTS UNDER MIL-STD-460-SERIES STANDARDS

equipment to interference propagated on internal conductors (conducted susceptibility) and penetrating the shield (radiated susceptibility). Unfortunately, the nature of the radiated emission and susceptibility tests is such that the intended goals may not be realized at frequencies below 100 MHz because the cable shield and connector are not usually properly excited in the radiation tests. At microwave frequencies, where the attenuation of transmission line currents is sufficient to limit the buildup of large propagating cable shield currents, the MIL-STD-461/462 tests may be more representative of operational conditions.

II SUBSYSTEMS TESTS UNDER MIL-STD-461/462

The individual subsystems comprising the overall system are subjected to a number of different tests to define their electromagnetic properties. For a number of reasons, it is appropriate that tests at this level be carried out. Since the subsystems generally comprise the Zone 2 units indicated in Figure 3, it is important that their properties be defined as early as possible in the development program. In particular, it is important to know whether a subsystem is indeed to be treated as a Zone 2 victim, or as a source and excluded as a Zone 0 region (as illustrated at the left of Figure 3).

A practical consideration for requiring subsystem level tests is that their implementation fits naturally into procurement practices. The subsystem manufacturer can be charged with their performance and documentation as deliverable items on his contract. If a particular subsystem does not meet specifications, this fact is detected early in the program and suitable adjustments can be made on the unit in question or on the system as a whole. Also, the designer/manufacturer is most familiar with the design details of his subsystem, and is most suited to devise and implement the modifications necessary to assure ultimate compliance with the specifications.

In general, standards such as MIL-STD-461A outline a large number of measurements and test levels. However, the tests actually carried out on a specific system generally comprise only a small subset of the tests listed. Furthermore, the test levels and frequencies of interest are generally tailored to include any special features of the sytem such as the presence of high-power radars associated with the system or its location.

A. Emission Tests

These tests, performed in two general modes--conducted emission and radiated emission--measure the interference emanating from a subsystem either on cabling associated with the subsystem or as radiation from imperfections in the cabinet shield. The tests are intended to determine whether the box in question is benign electromagnetically or whether it generates unacceptable levels of interference. From the topological zoning point of view, the internally generated interference sets the lower level at which subsystems (Zone 2 systems) must be able to operate. As indicated earlier, it is not beneficial to reduce externally generated interference to levels substantially below the internally generated noise levels. Thus, the acceptable level established for internally generated interference should be compatible with system operating levels, but the levels presently specified in MIL-STD-461 are somewhat arbitrary.

Conducted emission measurements are intended to determine the type and level of interference leaving the subsystem cabinet on the electrical conductors interconnecting subsystem cabinets. These measurements are performed by coupling a receiver such as an oscilloscope or a spectrum analyzer to the subsystem under test using a suitable device such as a broadband current transformer. Topologically, this measurement defines the interference (1) conducted out of the interior of the second shield by the penetrating conductors or (2) conducted out of the cabinet (but still inside the shield) on shielded interconnecting conductors. In the second case the level of the conducted emission may be reduced by identifying and modifying the source (e.g., slowing down the switching rates in an offending power supply, etc.). In the first case it may be reduced by decreasing coupling to the source by improving the Zone 1/ Zone 2 shield as well as by controlling sources.

Topologically, radiated emission tests are intended to measure the internally generated interference escaping the second shield. They are performed by operating the subsystem under test and measuring the electromagnetic signals outside the subsystem shield using a broadband receiving antenna feeding a suitable swept receiver or spectrum analyzer. Thus, this test detects interference escaping through imperfections in the equipment shield itself and provides data on the system-generated interference outside the equipment cabinets.

B. Susceptibility Tests

These tests, intended to determine that the subsystem can tolerate a prescribed level of interference, are generally conducted in two modes: conducted susceptibility and radiated susceptibility. As indicated earlier, in Figure 6 the conducted susceptibility test is performed by injecting currents on the cables leading to the subsystem under test. Topologically, the conducted susceptibility test is intended to determine the susceptibility of the subsystem to interference carried into the cabinet by conductors penetrating the Zone 1/Zone 2 shield or by interconnecting cable conductors. Conducted susceptibility of the subsystem may be controlled by the addition of limiters or other filters at the Zone 1/Zone 2 shield (at the subsystem cabinet).

Topologically, the radiated susceptibility test is intended to ascertain that the quality and integrity of the shielding provided by the subsystem cabinet and the cable shields are adequate to protect the enclosed circuits from sources outside the shield.

To evaluate the adequacy of the subsystem shield, the susceptibility tests must be conducted in such a way as to assure that the system is properly excited. For example, when the susceptibility to external sources is tested, it is important that the cable currents be allowed to flow onto the cabinet and excite apertures and other imperfections in the cabinet shield just as they would on the installed equipment. Thus, a test setup similar to that in Figure 7 should be used. Here the test cabinet is grounded as it would be in an operational situation so that the cable currents flow through the "entry panel" and excite the cabinet itself.

Figure 7 shows a capacitive or inductive coupling system used to induce common-mode currents on the unshielded interconnecting cable conductors. Generally, interference induced on cables is generated as a predominantly common-mode signal. Thus, the test illustrated yields information on the common-mode susceptibility of the system. Unbalances in the cabling or in the system can transform common-mode currents into differential-mode signals. Also, it is possible that another subsystem (at the other end of the cable) can generate differential-mode signals on interconnecting cables.

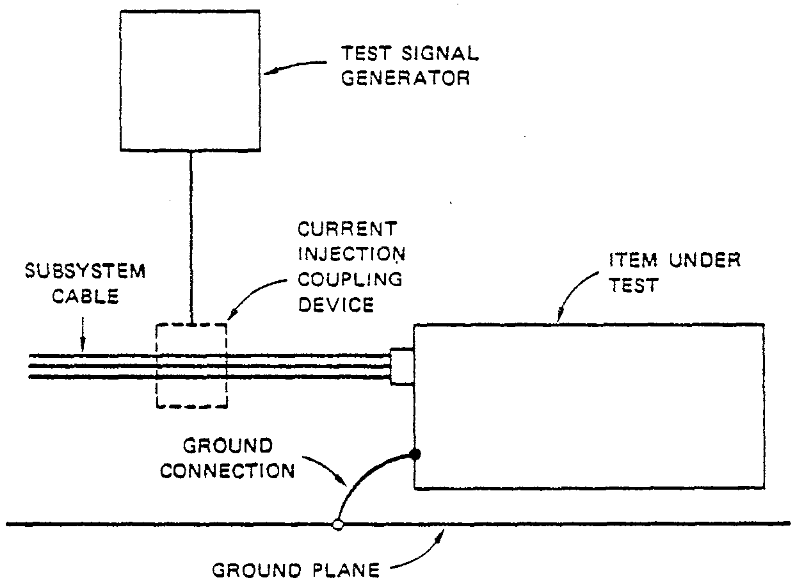


FIGURE 7 ARRANGEMENT FOR CONDUCTED SUSCEPTIBILITY TESTS

When the radiated susceptibility tests are performed, it is important that full excitation of the subsystem cabinet be permitted. In general it is found that below UHF the main currents on the box are delivered by the cables. Thus, a test arrangement such as that shown in Figure 8 should be used. Here, a signal generator and coupling device are arranged to induce currents on the cable shield. The ground strap is installed at the intended location on the cabinet of the test item. In this way, the currents contributed by the cabling will excite currents on the cabinet as they would in the actual installation.

At microwave frequencies, the radiated susceptibility tests can be carried out by illuminating the box alone, since the currents contributed by system cabling are of far less importance.

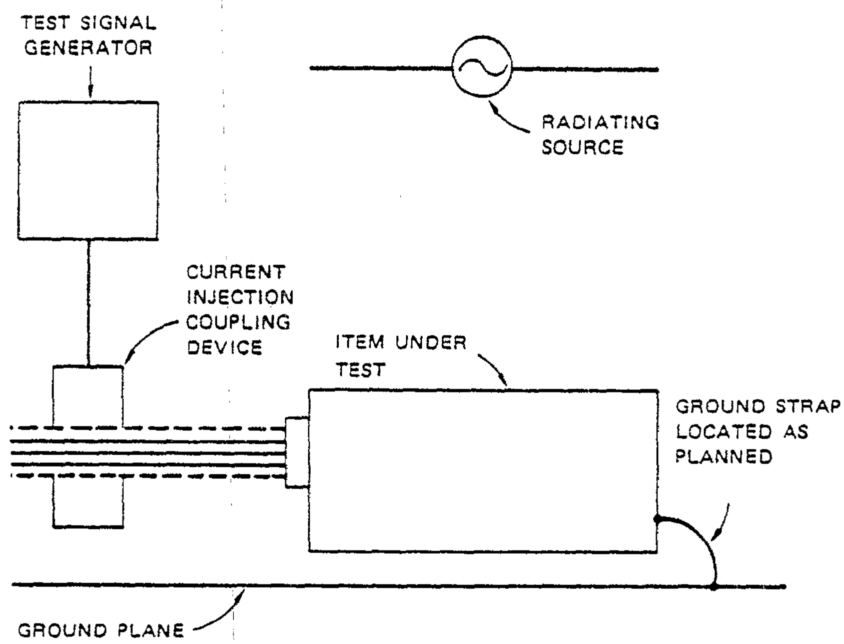


FIGURE 8 ARRANGEMENT FOR RADIATED SUSCEPTIBILITY TESTS

III CONCLUSIONS

In their present form, MIL-STD-461/462 appear to have the following shortcomings or inconsistencies when their requirements are examined in light of rational interference control topology:

(1) The level of interference emission permitted does not appear to be related to any interference control allocation system

(2) The method of exciting the equipment shield in the susceptibility tests is not relatable to the excitation of the shield in the installed configuration

(3) The method of measuring the "radiated" emission is not relatable to the environment produced by the equipment in the configuration in which it is installed.

Correction of these inconsistencies would not only make the standards compatible with EMP requirements, but would undoubtedly produce qualified equipment that performed better and more predictably in other interference environments.

REFERENCES

1. C. E. Baum, "How to Think About EMP Interaction," Proceedings of the 1974 FULMEN Meeting, Air Force Weapons Laboratory, Kirtland AFB, New Mexico (April 1974).

2. F. M. Teshe, et al., "Internal Interaction Analysis: Topological Concepts and Needed Model Improvements," Interaction Note 248, Air Force Weapons Laboratory, Kirtland AFB, New Mexico (July 1975).

3. F. M. Teshe, "Topological Concepts for Internal EMP Interaction," IEEE Transaction on Antenna and Propagation, AP-26, pp. 60-64 (January 1978).

4. C. E. Baum, "The Role of Scattering Theory in Electromagnetic Interference Problems," P. L. E. Uslenghi, (Ed.) Electromagnetic Scattering, Academic Press (1978).

5. E. F. Vance, "Shielding and Grounding Topology for Interference Control," Interaction Note 306, Air Force Weapons Laboratory, Kirtland AFB, New Mexico (April 1977).

6. E. F. Vance, J. E. Nanevicz, and G. A. August, "Technical Inputs and EMP Design Practices for Intrasite Cabling of Telecommunication Facilities," Final Report, Contract DAAG 39-76-C-0021, SRI Project 4587, SRI International, Menlo Park, CA (June 1977).