1/2 7-24-75

25 NTIS

UCRL - 76568
PREPRINT
CONF-751021-1

LAWRENCE LIVERMORE LABORATORY
University of California/Livermore, California

COMPARATIVE EMP DESIGN PRACTICES

L. C. Martin

July 11, 1975

This paper was prepared for presentation at
1975 IEEE International Symposium on Electromagnetic Compatibility
San Antonio, Texas
October 7-9, 1975

MASTER

COMPARATIVE EMP DESIGN PRACTICES

L. C. Martin

Lawrence Livermore Laboratory
University of California
Livermore, California

Summary

A large amount of effort is devoted to the hardening of systems against various effects. The nuclear electromagnetic pulse (EMP) creates potentially severe protection problems *in hardening against* electromagnetic effects. Each hardening effort is usually supported through development or application of sets of rules, practices, constraints, etc., which aid in decision-making throughout the design process. Several excerpts from a few sets of EMP design rules and practices taken from relatively independent sources are presented for comparison of essential features and mode of expression. A general objective is to clarify some of the EMP practices present in general EMC work and to encourage further interchange of relevant information.

Introduction

A general awareness of certain of the electromagnetic nuclear effects which result in the electromagnetic pulse (EMP) is now widespread,[1] and protection or hardening measures have been and are still being implemented for a wide variety of systems. Representative nuclear hardening programs can exhibit several phases of analysis and testing before decisions are made as to the exact type and form of protection against the effects of an EMP. Irrespective of the difficulties in solving a specific EMP protection problem, there are certain practices and guidelines which are being advocated at present. This paper addresses the nature of many such practices and provides specific comparisons for a number of them taken from several relatively independent sources. The scope of this paper is limited, as many practices are also formulated as general electromagnetic compatibility (EMC) design rules, and no attempt is made for completeness of coverage. In fact, a general objective is to clarify some of the EMP practices present in EMC work and to encourage further interchange of relevant information.

Categorization

Design practices here refer loosely to that body of knowledge which includes techniques, procedures, guidelines, rules, and other such items which provide a basis for establishment of a design or some details for its implementation. As "practices," these may or may not be decidedly well-established and may or may not have an entirely rigorous foundation or extensive theoretical development. Nevertheless, in the absence of design formula which can be related to a specific EMP transient, practices will ordinarily follow from basic considerations or from previous *experience. They are seldom all-encompassing and* frequently are somewhat controversial. Special situations often require an amendment of an established procedure. Thus, it is essential to become aware of many practices, the way they are stated, what are *believed to be essential points, and differences in* requirements which lead to new specifications.

There are many possible ways to develop and discuss the subject of practices. It is desirable that design practices become closely tied in with the general requirements for hardening or protection of a system against the EMP. The general EMP hardening or protection problem can be broken into rather basic technological areas dealing with

methodology,
susceptibility,
interaction,
and protection engineering information.

These of course are interrelated, and the extent of knowledge or resource base in any one area will have a distinct effect on the degree of completeness of involvement in the other areas. EMP design practices should be to the forefront and central for reference in all of these major areas, since they do represent what is actually being accomplished or likely to be attainable, rather than merely to postulate idealism. Unfortunately, the very nature of practices makes many of them less well defined and relatable to these other areas. In examination of the various types of practices, one could look at the following somewhat familar categories:

System Engineering Aspects
System Layout and Grounding
Shielding and Bonding
Cabling and Connection
Protection Measures and Devices
Implementation, Fabrication, and
    Maintenance
Subsystems and Components
Hardness Assurance

Again, there is overlapping and interacting of content in many of the above areas. The scope of activity which bears on the EMP protection problem is thus really quite large and must be somehow assimilated with other requirements in the above areas.

In review of material for this discussion of practices, only a few practices from selected areas are presented. These are primarily in the categories of systems aspects, layout and grounding, cabling and connecting, and shielding.

Excerpts of Design Guidelines and Practices

Sources

Below are presented excerpts and summaries of selected sets of design practices and guides from a few diverse sources. The source material varies from general handbook reference to construction recommendations to interconnect system design rules. Although abbreviated in some cases and taken somewhat out of context, the following are intended to be sufficiently complete to indicate the dominant or controlling technical features.

Set A--Missiles and Aircraft

The following are excerpts from a section in a missiles and aircraft handbook.[2] They include general approaches as well as specific guidelines. Below are listed some general considerations.

Missile System Design

1. Use no more than one ground point for all electronic circuitry.

2. Separate and balance all power leads on long runs.

3. Use the shielded twisted pair concept on all other lines and ground all shields outside packages.

4. Shield the entire electrical/electronics system with a solid-metal enclosure.

5. Place all sensitive circuits in one compartment (place sources of noise in other compartments).

6. Filter all leads entering (leaving) the sensitive circuitry compartments.

Aircraft System Design

An alternate to a total shielding of an aircraft is to individually shield all the cables and packages; then the following guidelines apply:

1. Use a one-point circuitry ground.

2. Separate all power leads.

3. Balance power leads on long cable runs.

4. Use shielded twisted pair wiring concept on all lines except power lines.

5. Build all power leads in separate bulk shielded cables.

6. Build all other leads in bulk shielded cables.

7. Use metallic enclosures for all electrical and electronic packages.

8. Filter all leads entering or leaving high noise level packages. This includes motors, choppers, inverters, power relays, high power transistor switching circuits, etc.

9. Filter all leads entering or leaving a transmitter package except the transmitter output coax.

10. Use a filter/arc suppressor on all deliberate receiving antennes on low power transmitters using semiconductor output devices. Filtering will be limited by pass band requirements, but the combined filter/arc suppressor will, in general, handle the problem.

11. Design all fuel gages with a filter/arc suppressor in the probe line at the tank. The arc suppressor must be constructed to force the arc on the outside of the tank and must use a dielectric seal which ensures no vapors are at the arc point.

Set B--Designer's Checklist Related to Construction Practices

The following are taken from a guide for incorporation of EMP protection into Emergency Operating Centers. These represent a partial list of construction practices useful in reducing problems of EMP interference during nuclear tests.

1. Isolate power (motor-generator sources, lightning arrestors on lines).

2. Place wires in boxed, grounded conduits.

3. Use a grounded screen over air-conditioning outlets where they enter shielded areas and ground all ducts.

4. Connect steel reinforcing bars in concrete to the shielding and grounding system.

5. Use largest rated available lightning arresters on power station transformers. Use more sloping devices to lower arrester breakdown voltage.

6. Provide gas gaps on telephone lines with low impedance grounds.

7. Ground outer shields of cables and insure continuity.

8. Ensure that signal cable shields are well grounded at their point of entry.

9. Place power and signal cables in ferrous conduit and bury at least three feet deep.

10. Connect water pipes and other penetrations into the grounding system.

11. Equip both antennas and input leads which cannot be directly grounded with lightning arresters or protectors. (Baluns need to be self-healing.)

12. Educate all personnel in requirements for protection practices.

13. When a balanced pair lead is tied into a coaxial cable through a matching balun, do not interrupt the shielding provided by the outer coax conductor. A grounded copper plate mechanically crimped to the coax cable shield has been used effectively.

14. Ground and connect together electrically all seemingly nonessential conductors, such as elevator cables, metal airducts, and equipment cabinets.

15. Because existing grounds are often of high surge impedance, provide a counterpoise at each protective device location. (Note that counterpoise requirements will vary with geographic location since earth conductivity varies greatly.)

16. Ensure that the entire conduit system is well grounded.

17. Avoid use of nonconducting lubricants when fastening conduit pipes together.

18. Ensure that electrical contact exists between conduit and terminal box. (Frequently the conduit is pushed against the box but insulated from it by paint.)

19. Install a grounding strap from terminal box to door of box for hinged doors.

20. Either use adequate surge protection on oil-filled transformers and other thick voltage gear to prevent explosions or use dry rather than oil-filled transformers inside the shielded enclosure. (Oil-filled transformers can explode and spread burning oil; dry transformers only burn.)

21. Provide surge protection for emergency power equipment.

22. Use lightning protection techniques on all aboveground lines.

23. If power equipment supplies several sites, install lower values fuses at the equipment end rather than at the power end of a system.

24. Use circuit breakers rather than fuses, since breakers can be set more closely and reset more quickly. Check fuses, where provided, periodically for deterioration.

25. Do not use slow-blow or delay fuses or breakers.

26. Design breakers (where feasible) to take no more than the largest expected load.

27. Provide automatic closing doors in preference to mechanical closures and recessed fits for shielded room doors.

Set C--Ground System Complex

The following are excerpts from a set of EMP design guidelines[4] intended to minimize the interference effects from an EMP. The ones selected are taken from area referred to as grounding, circuit layout, shielding and cabling.

Grounding

A. Use a single point ground (a single structure point) system for an individual system complex (geographically compact).

1. The single point ground is connected to the system structure with impedance of less than 0.5 ohms.

2. Sub-assemblies use separate and isolated power and signal grounds.

3. Detachable equipments use single point grounds with common for power, signal, shield, and chassis grounds.

B. Use a multipoint ground system for a group of (closely located) system complexes which includes a grid counterpoise with driven earth grounds, ground buses, green wire circuits, conduits, lightning protection circuits, and other major (grounded) interconnecting elements.

Circuit Layout

1. Grounding circuits are separate single wires from remote units to their respective single point ground.

2. A chassis is grounded to its respective structure per MIL-B-5807.

3. DC power supply and signal return circuits are insulated and isolated from each other and other return circuts, and are grounded only at their respective single point grounds.

4. Shield grounds are terminated as follows:

a) Shields on coaxial leads shall be RF grounded at both ends per standard practice. Shields on leads carrying RF will be RF grounded at both ends and along the length of the shield, as necessary.

b) Shields on leads carrying frequencies of DC to 100 KHz will be grounded at one end only. If the shield is designed to retain a signal, it will be grounded at the source end. If the shield is intended to exclude signals, it will be grounded at the receiving end.

c) The shield will cover as much of the interior wire as possible consistent with construction techniques.

d) The shield grounding strap shall be routed to ground or its terminal over the shortest possible distance.

5. Other circuit considerations:

--design and layout to avoid loops in circuitry
--make only the one connection of grounding circuits to the reference point
--avoid routing signals over routes which are parallel
--isolate input from output leads on high devices such as filters and arc suppression devices
--do not use shields as low impedance paths or as conductors of current for functional circuitry

--provide wide, short bond straps and avoid "pigtails"

--avoid parallel grounding conductors which follow different routes and form ground loops

Cabling

1. Shield "critical" cables separately.

2. Install all interconnection cables in conduit and bury deeply when feasible.

3. Maintain continuity of cable shield layers which should be only connected as specified for grounding.

4. Provide for connection of system shields to corresponding cable shields, in proper order, without intercrossings between "electromagnetic zones."

5. Avoid ordinary braid shielding and use solid metal or specially woven multilayer braiding.

6. Do not interrupt outer cable shielding at "tap-in" junctions.

7. Provide terminations for each electromagnetic path in multilayer shielded cables (as well as for inner conductor) and terminate each identified propagation path or duct, resistively in its characteristic impedance.

8. Ensure good contact bonds between outer cable shields or conduits and individual structures. Paint or non-conductive finish is a serious problem. Do not use nonconducting lubricants when preparing and assembling conduit.

9. Use twisted shielded pairs for signal circuits to provide for common mode rejection.

Set D--Interconnect Design Ground Rules

This set of rules is taken from a paper dealing with an interconnect cable system[5] during the conceptual design phase.

1. An exterior cable shield which completely encloses all wiring shall be used.

2. Exterior cable shields shall be bonded to the periphery of the backshell of connectors with a continuous RF-tight conductive surface.

3. RF-tight connectors possessing peripheral RF bonding Conductive surfaces between the plug and the receptacle shall be used.

4. RF-tight conductive receptacle mounting shall be used on packages to provide low-impedance termination for cable shields.

5. Interior cable shields shall be bonded at each end to the electronic package connector.

6 Where single-wire circuits must be used, they shall be shielded.

7. Power or signal circuit wires shall be twisted with their returns to reduce magnetic coupling.

8. Twisted shielded conductors shall be used for all arming, firing, transient generating and sensitive signal circuits. Each system design area shall determine which of its circuits require additional protection through shielding, and the optimum type of shielding will be provided depending on circuit needs.

9. Where flat cable application precludes the use of shielded twisted conductors, use multipoint grounded adjacent trace "shields" in addition to top and bottom shield foils.

10. Use adjacent pins on cable connectors for signal or power circuits so that twisted conductors may remain in closest proximity to each other at the connector and in the lay of the cable. Connector pins will be selected so as to isolate sensitive circuits from potential interference sources.

11. Electrical wiring enclosures, such as cable trays or compartments intended to act as shielding enclosures, shall comply with the shielding requirements of an electrical/electronic package. Where connectors are not used, means shall be provided to bond with conductive surfaces the pendant cable shields to the wiring enclosures.

12. For 3-phase 4-wire circuits or 2-phase 3-wire, or single phase split-circuits, use twisted triads.

13. For 3-phase 4-wire circuits, use 4 wires twisted.

14. Where wiring in a cable bundle consists of both shielded and unshielded wires, enclose the entire cable within a shield.

15. All shields, within or on the outside of a cable, must be insulated from each other and any metallic supporting structure except at bonding points.

16. Power and signal circuits which place direct dc loads on any electronics battery sections shall have their singlepoint, low-resistance ground on the negative (return) line at a suitable power distribution point or package. Other connections to ground on either the positive or negative lines, as required for instrumentation or other system functions, shall not present a total resistance shunting a battery or its grounded return circuit of less than 1000 ohms.

17. Power sources isolated from electronics battery by dc/dc converters shall have the same grounding requirements as the electronics battery except that the system ground point shall be located at the dc/dc converter through conductive bonding surfaces to the system structure.

18. If grounding of balanced ac circuits is desired, single-point grounding at an electrical neutral point shall be used.

19. External power systems for the system shall be grounded at the systems power distribution point.

Comparisons

The preceding presentation of just a few of the many sets of rules, guidelines, and practices which are evolving continually in the EMP protection area has been limited to those which are less intricate in statement. Comparisons of expression indicate the following:

- -Precision of statement is found in yes/no rules of practices or in certain topological considerations.
- -Direction of choice is found in many rules of practice.
- -Some rules dictate or imply use of as hierarchial set of others.
- -Some rules use conventional (though possibly misleading) jargon.
- -Other rules use conventional, well-recognized terminology.
- -Most sets of guidelines include some glossary of terminology.
- -Some rules will resort to qualifiers as "as short as possible" or "as economically feasible," or other such extremes.

In the complete sets of guidelines there are, of course, many supporting statements and qualifications which clarify intent and offer some explanation of content.

Conclusions

After this brief look at several examples in technical expression which have been considered appropriate to place in the practices category, a few general conclusions and recommendations appear warranted.

Although many design practices are established for the designer in the manner of guidelines or constraints, the exact implementation may be difficult to ascertain and evaluate. Also, there are apparently no standardized circuit protection practices; there are also some popular approaches to overall system protection. In particular, apportionment of protection, as compared to a total shielding concept, is one such approach.

In many systems, also there appears to be almost no "new" design, rather an upgrading of existing hardware. Consequently, there appears to be consistently a state of combined retrofit or modification with the new design integrations.

There is need to develop methodology or rules to guide experience in setting forth a sufficient set of design practices for new systems encountered. There is need also to strive to state as explicitly and precisely as possible all practices which one encounters. Finally, one should encourage refinement of practices and, in particular, behavior both good and bad.

Acknowledgment

The author appreciates the general cooperation by several individuals and oranizations in discussion and providing information pertaining to EMP Protection Engineering. In particular, Martin Cooper and Jack Ashford of Martin Marietta Corporation, Donald Stevens of Rockwell International, Robert Parker of Sandia Corp., J. R. Burgoon of Lockheed Missiles and Space Co., Inc., Edward Mead of GTE Sylvania, John Dahnke of TRW Systems Group, and Dr. Joshi of Raytheon have been very helpful in this work. This area of work was supported by the Defense Nuclear Agency under Subtask EC-091 and was performed under the auspices of the U. S. Energy Research and Development Administration.

References

1. "DNA EMP Awareness Course Notes," Defense Nuclear Agency, DNA 2772T, August 1973, (AD 769781).

2. "Electromagnetic Pulse Handbook for Missiles and Aircraft in Flight," Sandia Laboratories, September 1972, Air Force Weapons Laboratory Publication, AFWL-TR-73-68 (AD 919395L), pp. 358-363.

3. "EMP Protection for Emergency Operation Centers," Defense Civil Preparedness Agency, TR-61A, July 1972, Appendix B.

4. Martin Marietta Corporation Publication ICM 01401000-001.

5. "Cable Design and Test Practices," J. R. Burgoon, Jr., Lockheed Missiles and Space Co., Inc., Lawrence Livermore Laboratory Protection Engineering and Management Note, PEM-18, pp. 2-4.

Printed in the United States of America
Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22151
Price: Printed Copy $____*; Microfiche $2.25

*Pages	NTIS Selling Price
1-50	$4.00
51-150	$5.45
151-325	$7.60
326-500	$10.60
501-1000	$13.60