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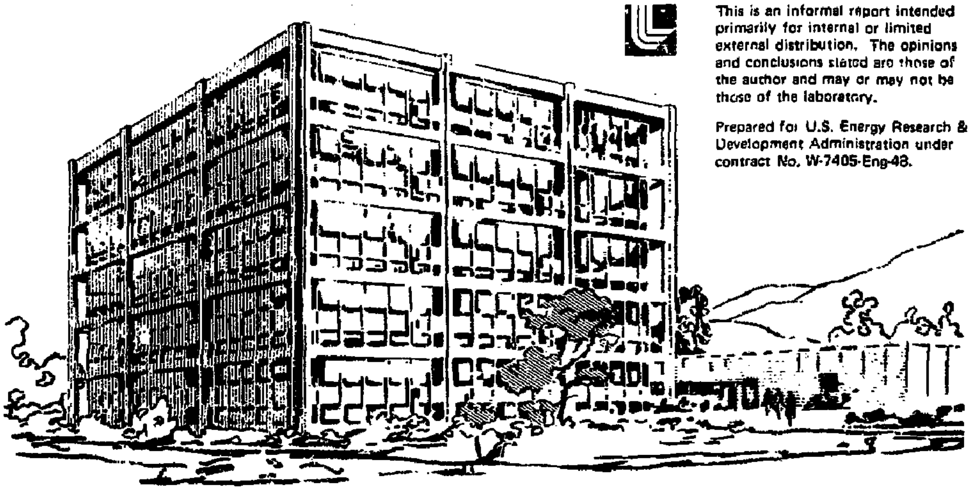

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AN EMP PROTECTION PROCEDURE FOR ELECTRICAL/ELECTRONIC SYSTEMS* **

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Abstract

This paper presents a procedure for the protection engineer to follow in assessing a system with respect to its susceptibility to an electromagnetic pulse (EMP), and in determining whether the system requires protection. If the system is determined to be vulnerable to EMP, the procedure also indicates how to decide upon the most suitable protection scheme. The discussion centers on two flow charts, which illustrate the step-by-step procedure which utilizes the necessary ingredients of EMP protection engineering discussed in a previous paper. The description of the protection procedure is divided into two parts: the first dealing with issues on the macroscopic or lage-scale system level, while the second is concerned with operations on the subsystem level or lower.

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1.0 INTRODUCTION

In a previous paper[1], we identified and discussed the ingredients needed by the protection engineer to access a system from the standpoint of its susceptibility to EMP, and to determine if and what kind of protection might be required. An example was presented to clarify the fundamental methodology upon which a protection procedure is based, as well as to explain the use of the various terms pertinent to EMP protection engineering. In this paper, we provide a procedure to follow which utilizes the ingredients discussed previously. The key to the procedure is represented by two flow charts, Figures 1 and 2. The following discussion will parallel the steps indicated on the charts, and will also include references to other sections of the Protection Engineering Guidelines[2] (PEG) pertaining to the various steps in the procedure.

The first portion of the procedure illustrated by Figure 1 is concerned with overall system level issues. It should be apparent that the majority of protection problems will not be concerned with this level of discussion. Indeed, most of the protection engineers will use the Guidelines to perform operations at the subsystem level (Figure 2), while the overall system problem is generally of concern to System Project Officers and major system contractors. The description of the protection procedure, then, will be divided into those two portions: the first dealing with the macroscopic or large-scale system level, while the second is concerned with operations on the subsystem level or lower.

2.0 PROTECTION PROCEDURE - MACROSCOPICS SYSTEM LEVEL

Figure 1 depicts the manner in which overall system parameters are used to reduce a complex system problem down to clearly stated subsystem performance specifications. It is assumed that the system mission, threat, scenario, employment and the deployment of the system are known, as well as the overall system description. From these inputs, the description of the system's environment, configuration, modes of operation, and the constraints are obtained.

The system's environment refers to the electromagnetic environment in which the system must operate. As indicated in Figure 2, this environment is determined by considering the overall systems inputs - mission, threat, scenario, employment, and deployment. For problems at the macroscopic level, the determination of the system's electromagnetic environment constitutes the desired output, and becomes a necessary input for the determination of the (electromagnetic) environmental parameters required at the subsystem level, and will be discussed in more detail in the next section of this paper.

The other three outputs mentioned above; system configuration, modes of operations, and the constraints, are used with the system description and operational hardness criteria to determine the mission critical subsystems. The identification of the mission critical subsystems constitutes one portion of the system decomposition problem, in which the entire system is reduced (decomposed) into subsystems which are amenable to both subsystem susceptibility and interaction and coupling analyses. As a general rule, system decomposition will usually be accomplished at metallic interfaces, i.e., racks, chasses, etc.

Once the mission critical subsystems have been identified, suitable performance descriptors must be determined. It is necessary that these performance descriptors adequately measure the performance of each of the subsystems. This involves the identification of performance descriptors of the system elements, and the determination of the ranges that these descriptors are permitted to assume based on the overall system specification. If the overall system specification is not provided, the system analyst must first identify how the system should perform in its environment (the operational hardness criteria), then establish system performance descriptors, and finally determine system specifications.

Subsystem performance descriptors are identified by selecting candidate descriptors and then conducting sensitivity tests to determine their influence on system performance. If a candidate produces an appreciable degradation in system performance for plausible variations due to the EMP environment, it is selected as a subsystem performance descriptor. Using either the specification for the system or for a portion thereof,

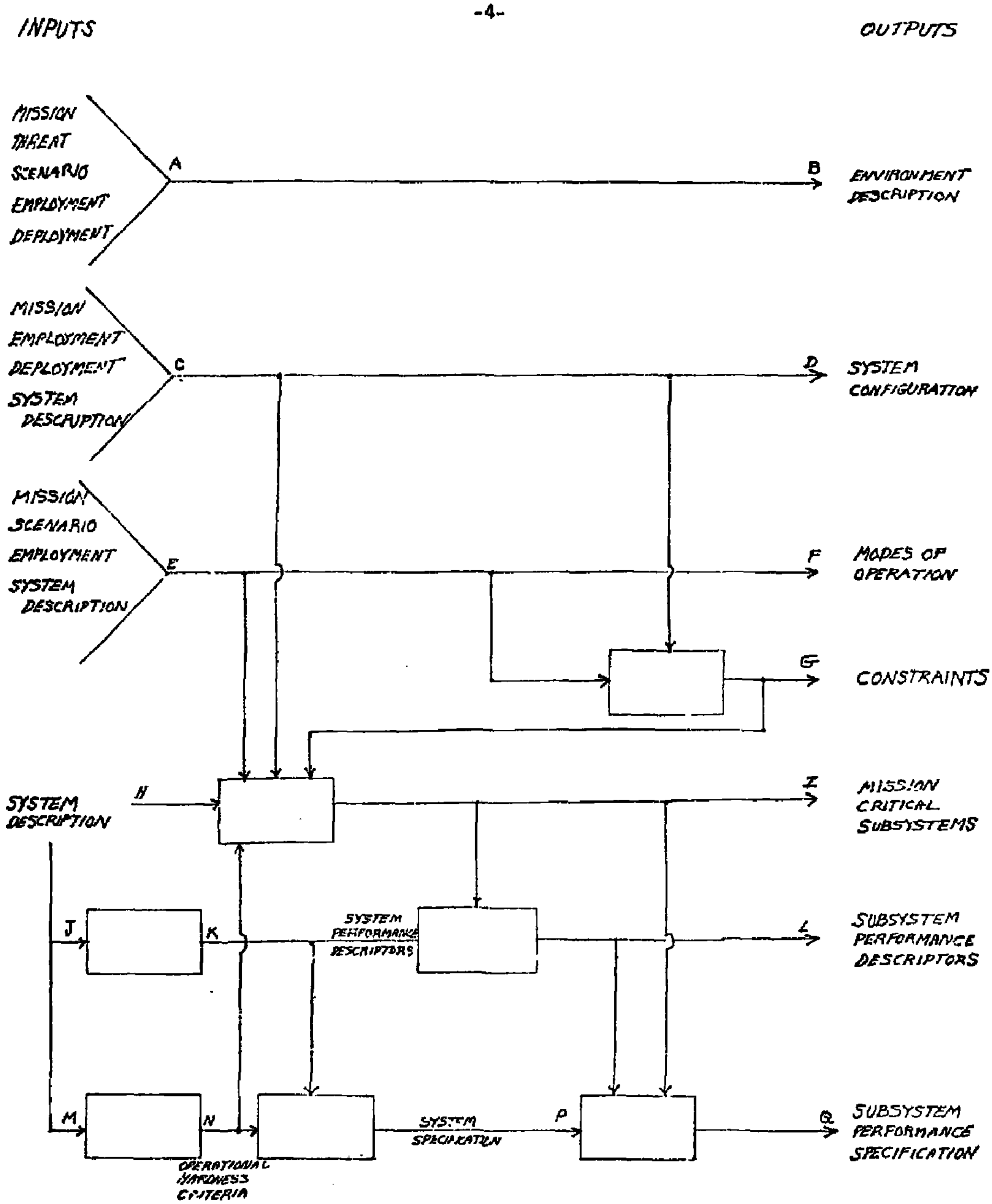
INPUTS
OUTPUTS
MISSION
THREAT
SCENARIO
EMPLOYMENT
DEPLOYMENT
A
B
ENVIRONMENT DESCRIPTION
MISSION
EMPLOYMENT
DEPLOYMENT
SYSTEM DESCRIPTION
C
D
SYSTEM CONFIGURATION
MISSION
SCENARIO
EMPLOYMENT
SYSTEM DESCRIPTION
E
F
MODES OF OPERATION
G
CONSTRAINTS
SYSTEM DESCRIPTION
H
I
MISSION CRITICAL SUBSYSTEMS
J
K
SYSTEM PERFORMANCE DESCRIPTORS
L
SUBSYSTEM PERFORMANCE DESCRIPTORS
M
N
OPERATIONAL HARDNESS CRITERIA
SYSTEM SPECIFICATION
P
Q
SUBSYSTEM PERFORMANCE SPECIFICATION

Figure 1

subsystem performance descriptors are varied and ranges which produce tolerable performance degradation are then identified as subsystem performance specification, the final output of Figure 1. Note that a trade-off among specifications must occur since the total degradation in performance is the composite result of all descriptors. This trade-off relies on the judgment of the engineer and is made effectively with knowledge of both the interaction and coupling problems and the subsystem susceptibilities. Additionally, the engineer, in selecting specifications, must also consider the ease of protecting the subsystem if protection is required. All other aspects being equal, the subsystem offering the easiest or least costly protection scheme should receive the "tightest" specifications.

This concludes the discussion of that portion of the protection procedure illustrated in Figure 1. As mentioned previously, these operations are conducted at the macroscopic system level; that is, large scale system considerations are of concern. The majority of the protection engineering problems involve analyses and tests at the subsystem level, and are the subject of the next section.

3.0 PROTECTION PROCEDURE - SUBSYSTEM LEVEL

At the subsystem level, the protection engineer usually knows the subsystem performance specifications. If not, he follows the procedure leading from the "no" answer to the question "Do you have subsystem specifications?" shown in the first block of Figure 2. This procedure is essentially the same as that presented in Section 2 in that the mission critical subsystems have been identified, and we know the subsystem performance descriptors (if not, we determine them in the same way as we did in the last section). This entire process is elaborated upon in considerable detail in a previous paper[1]; particularly in the example.

The next two steps are rather obvious, and will not be discussed in any detail. The first of these is to order the subsystems to be studied. This ordering may be based on criticality, ease of analysis, or whether the engineer has some prior knowledge of their relative susceptibilities. At any rate, he next selects a subsystem and asks the question, "Do I

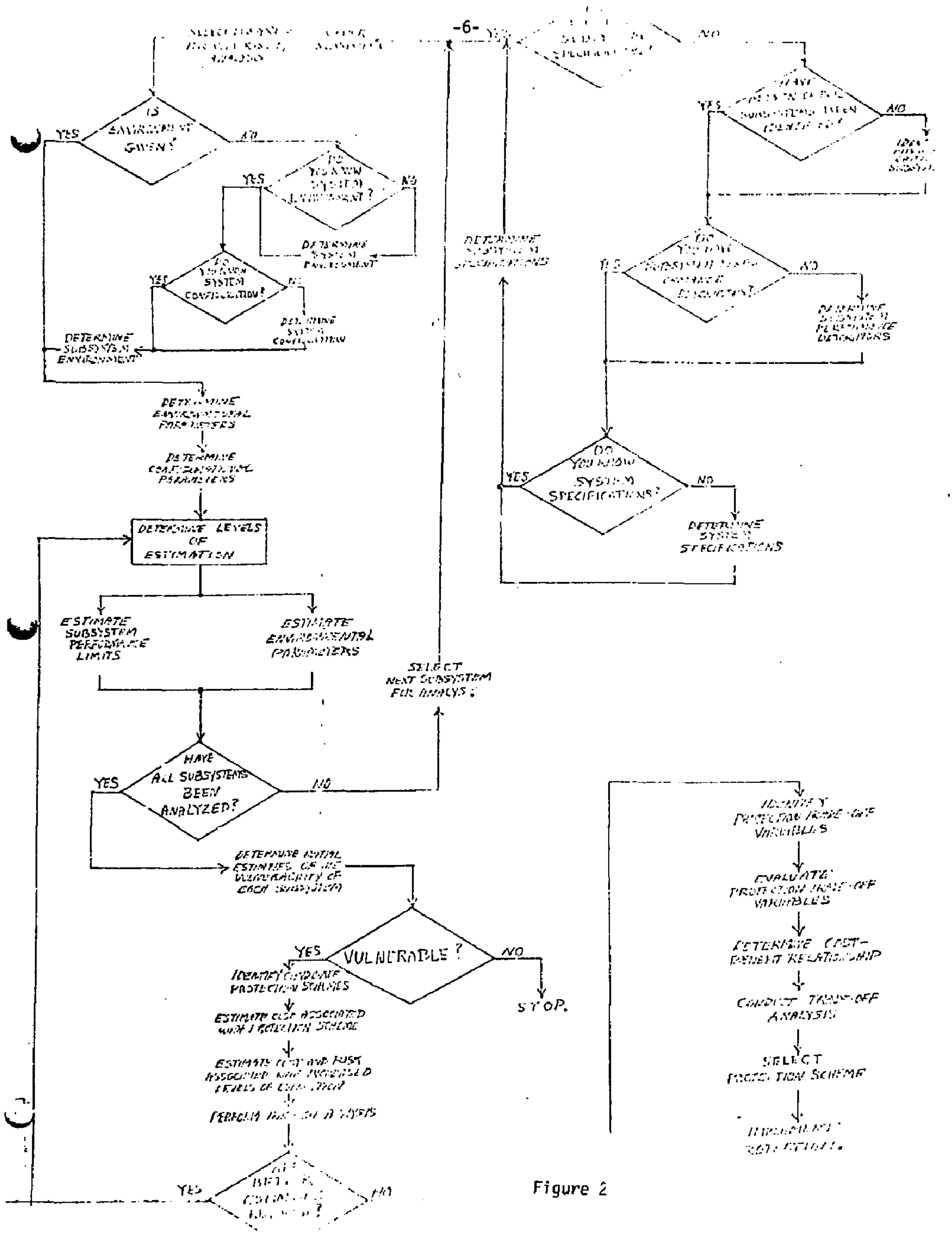
YES
NO
DETERMINE SUBSYSTEM ENVIRONMENT
DETERMINE LEVELS OF ESTIMATION
ESTIMATE SUBSYSTEM PERFORMANCE LIMITS
ESTIMATE ENVIRONMENTAL PARAMETERS
HAVE ALL SUBSYSTEMS BEEN ANALYZED?
SELECT NEXT SUBSYSTEM
VULNERABLE ?
STOP.
DO YOU KNOW SYSTEM SPECIFICATIONS?
DETERMINE SYSTEM SPECIFICATIONS
SELECT PROTECTION SCHEME

Figure 2

know the electromagnetic environment of the subsystem?". A "yes" answer leads directly to his determining the appropriate environmental parameters and the pertinent environmental configuration. A "no" answer presents a different situation.

If the environment of the subsystem is not known, the initial step is to ascertain the electromagnetic environment of the system as a whole. This will usually be given; if not, it is determined following the procedure outlined in Section 2.0. With the environment of the system known, we then ask if we know the system configuration. If we do, then we proceed on to the determination of the subsystem's electromagnetic environment. Determining the subsystem environment may entail a considerable amount of work; we will defer our discussion of this point until the next paragraph. If we do not know the system configuration, we now determine it by methods discussed in Section 2.0, and proceed on to the next step - determination of the subsystem environment.

By knowing the configuration of the system as a whole, we can now determine where the subsystem under consideration lies, electrically and physically. Although this may appear to be a relatively simple task, it may well be compounded by the fact that the subsystem lies buried deep within the system, and the coupling paths to energy collectors are not obvious. It is, nevertheless, necessary to determine the fields in the vicinity of the subsystem and the currents induced on penetrators into the subsystem. This determination should be in the form of a worse-case estimate. For example, in the B-1 program, it was assumed that all penetrators into subsystems would carry 10 amperes; a result of illumination of the aircraft and subsequent attenuation by the aircraft skin. At any rate, once the electromagnetic environment of the subsystem has been estimated, we then are ready to proceed to the next step, which is the specification of the appropriate environmental parameters and the environmental configuration.

As far as the environmental parameters are concerned, they are determined by the engineer involved with the actual damage or upset mechanisms of the components within the subsystem or of the subsystem itself. These mechanisms may be directly related to peak current, rise time, energy or similar quantities. Once these quantities have been identified, we continue the analysis by specifying the appropriate environmental configuration, which specifies the layout of the subsystem and its associated penetrators. For example, coupling between parallel leads results in a considerably different estimate than for leads which are not parallel. Thus, we can see that spatial factors are certainly important in specifying the environmental configuration of the subsystem.

Having identified the appropriate environmental parameters and armed with the knowledge of the environmental configuration, we now decide on what level of worse-case estimation is required at this stage in the analysis. You will notice another input to Level of Estimation block in Figure 2. This input clearly indicates that determining the appropriate level of estimation is an iterative procedure; however, at this point in the discussion, let us assume that we will work with simple first level estimates of both the environmental parameters and the subsystem performance limits. These estimates are determined by methods discussed in detail in Volumes II and III of the Protection Engineering Guidelines[2], which also present considerable data for use in obtaining the appropriate estimates. The estimates are now compared and, if the values of the environmental parameters do not exceed the values of the subsystem performance limits, the subsystem is not vulnerable to EMP, and we proceed to the next subsystem and follow the same procedure for it. If the estimates of the environmental parameters exceed those of the subsystem performance limits, however, we must continue our analysis.

If we have estimated that our subsystem is vulnerable, our first inclination would be to immediately implement measures to protect it. This might be a mistake since we are dealing with worse-case estimates and, in reality, the subsystem may well be invulnerable. Thus we must continue with our analysis of that subsystem by returning to our flow chart. What we must do at this point is to determine whether we should implement protection now or refine our subsystem susceptibility estimates, our environmental parameter estimates or both.

The first step is to identify candidate protection schemes such as filtering, shielding, spark gaps, or other methods described in detail in Volume IV of the PEG. This volume discusses protection procedures, the merits of the various procedures, and also contains data and references to sources which provide information necessary for use in the next step, which is to estimate the costs associated with each candidate protection scheme. The costs referred to in this context involve money, performance (introduction of possible undesirable effects such as transients from spark gaps, slower data rates, etc.), and other factors which bear on the overall operation and maintenance of the system.

We next estimate the cost and risk associated with making more refined estimates (increasing the level of estimation). In our context, risks refers to making an a priori judgment concerning the probability that our efforts to improve the accuracies of our estimates will indeed be worthwhile. Risk, then, must be considered in the next step, in which we perform a trade-off between the costs associated with protection and those involved with obtaining better estimates. At this point, we are now prepared to answer the question posed in the next decision block: "Are better estimates required?" A "yes" answer leads us back to the determination of the estimation levels for subsystem performance limits, environmental parameters, or both, and we follow the same procedure until we determine the subsystem to be invulnerable to EMP, or we decide to go ahead and protect it.

If we have decided that better estimates are not required and that our subsystem is indeed vulnerable, we must now decide how to protect it. We first identify the pertinent protection trade-off variables and then evaluate them, from which the cost-benefit relationship can be developed. Factors that must be considered include knowledge of protection methods and devices available, and the associated cost data. The process is similar to that used in deciding whether to continue with the vulnerability estimation procedure or to protect the subsystem, except that here we are trying to determine the best protection scheme based on the knowledge that the subsystem does require protection. Once we have decided upon a protection scheme, the obvious and concluding step is to implement it.

In this paper, we have presented a protection procedure to follow which results in a system which is hard with respect to EMP. The emphasis has been on the development of an orderly method founded on worse-case estimates, and the comparison of these estimates; a trade-off. Bear in mind that we have not explicitly discussed testing a system or subsystems for hardness; that and related issues are considered elsewhere (see "Protection Engineering Guidelines"). It is also important to realize that, regardless of the level of the protection problem under consideration, this procedure will provide the engineer with paths to follow in approaching and ultimately solving his protection problem since the accompanying flow charts can be entered at the point commensurate with the level of the problem, and followed from there to the desired conclusion.

REFERENCES

1. V. R. Latorre and L. R. Spogen, "The Ingredients of An EMP Protection Engineering Methodology," UCRL-

2. Latorre, V. R., et al., Protection Engineering Guidelines, in preparation for Defense Nuclear Agency under Subtask R99QAXEC091.

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