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System Threshold Bounds Inferred From Normal Operation (U)

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(U) Systems generate a significant amount of transient interference directly during normal operation as a.c. power is switched, rectified, and used to operate relays, solenoids, and other devices. These sources are inside the system and frequently are tightly coupled to sensitive circuits. Furthermore, the system has to contend with these transients throughout its life, and their rates of rise and peak amplitudes can be significant. (Peak transient voltages of a few hundred volts are not uncommon in systems using 120-volt a.c. power.) Thus, if a system-level electromagnetic pulse (EMP) barrier reduces the EMP-induced transient to below the level of this system-generated transient activity, the system will be immune to the EMP (providing, of course, that it functions properly when the EMP is not present). This paper discusses some of the properties of system-generated transients and the implications of their use as a threshold.

(U) The system-generated stress of interest here is that generated inside the electromagnetic pulse (EMP) barrier but outside the equipment cases or housings, as illustrated in Fig. 1. The transients are generated by the switching, control, and processing of electric power, and they are distributed to the internal equipment on the power and ground conductors and by mutual coupling to signal input and output leads. The transients may be produced periodically in equipment such as rectifiers and converters or they may be produced occasionally by thermostatically controlled heaters and air conditioners, sump pumps, solenoids in time clocks, valves, vending machines, and so forth. A common feature of these sources is that each launches a transient wave on the power-and-ground system. Since all internal equipment is served by the power and ground networks, the switching transient is distributed to all internal equipment.

(U) If there is enough EMP protection to reduce the EMP-induced stress until it is weaker than the stresses the system itself produces during normal operation, then the system will not benefit from further improvement in the EMP protection. Furthermore, if we know that the EMP-induced stress is weaker than the normal system-produced stress, we do not need to understand the EMP responses in detail to know that the system is immune to the EMP. This makes the system-generated stress particularly interesting—it is the upper bound on effective EMP protection, and it is a threshold that virtually eliminates dependence on knowledge of EMP interaction with the most complex parts of the system.

(U) In spite of the fact that the equipment must tolerate this transient environment to operate in peacetime, little is known about the system-generated environment. One can, however, estimate from switching characteristics and operating voltages the magnitude of the transient voltages produced near the switch.[1,2] Figure 2 illustrates the generation of a transient by a switch closing a 120-volt, 60-Hz circuit at the peak of the voltage wave. When the switch is closed (Fig. 2a), a charging wave propagates toward the load and a discharging wave propagates toward the power source. Figures 2c and 2d illustrate the voltage and current waves on the power wires a few nanoseconds after the switch is closed. Note that the 120-volt a.c. power switched at the voltage peak produces two 85-volt waves propagating away from the switch. Either of

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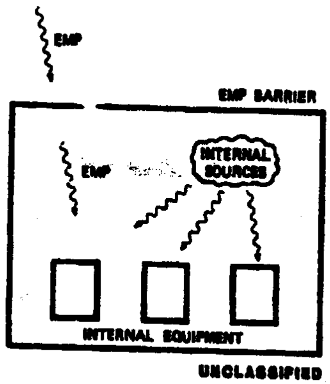

Figure 1. (U) System topology with EMP and internal sources.

these could double at an open circuit or high-impedance termination to produce a 170-volt transient. Solenoids, relay coils, and similar inductive devices can induce transients that are several times the peak line voltage when they are switched off (unless they are provided with diode suppressors). The rise times of switching transients are very short (nanoseconds) close to the source, but they may be stretched by dispersion in propagating through the system.

(U) In most systems, the transient waveform caused by switching the operating power is very complicated because of the reflections and losses in the system. In Fig. 3, the voltage waveform across an inductor at the end of a switched line is shown to illustrate how even a simple transmission line circuit can generate a very complicated waveform.(U) Waveforms more complicated than the one in Fig. 3 are typically encountered in practical systems, because the circuits are much

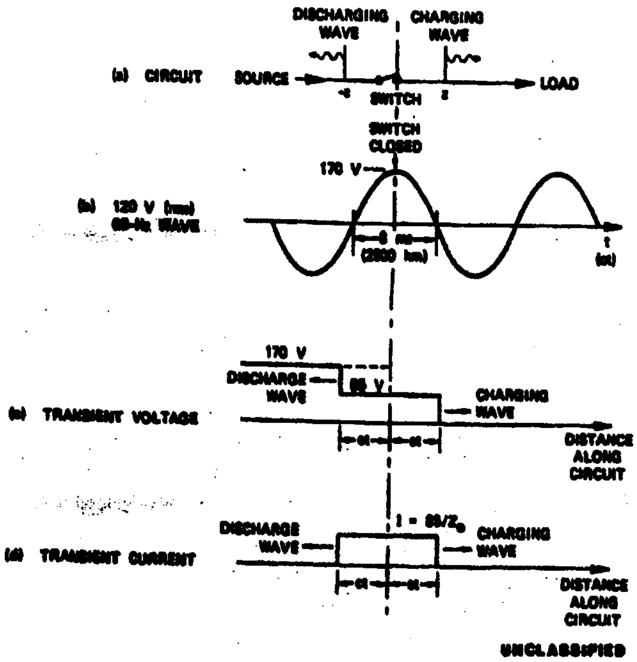

Figure 2. (U) Generation of a power-switching transient.

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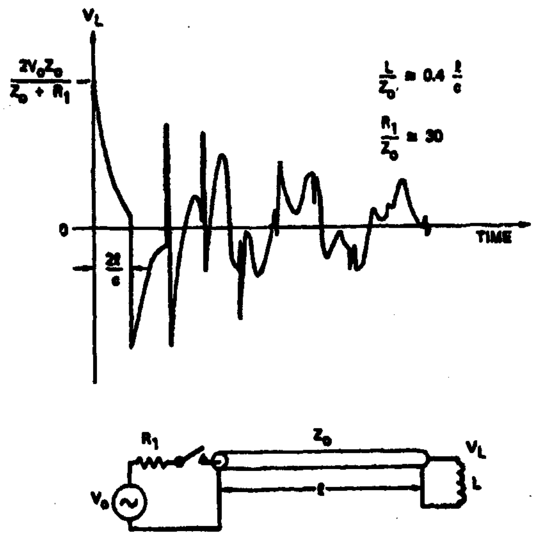

Figure 3. (U) Transient on switched inductive power circuit.

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more complicated and often involve several lines of different lengths with different loads.

(U) The extreme complexity of the internal responses is, in fact, one reason for interest in the system-generated transient and for concern about having to understand the EMP response of this part of the system. (The EMP response is yet more complicated, since we must first understand how it interacts with the system exterior and penetrates the EMP barrier before we can predict the responses of these internal circuits.) Since we know that all equipment and internal cabling must tolerate this system-generated environment in the absence of the EMP, we can assume that the equipment will tolerate the EMP if we can be assured that the EMP stresses the circuits less than these switching transients. Furthermore, if we make the comparison just inside the EMP barrier (that is, at the inside terminals of filters, surge arresters, or other barrier elements), we can be assured of the system transient's dominance without knowing either the system transient or the EMP response deep inside the system or inside the equipment.

(U) Finally, use of the system-generated transient stress as the EMP threshold takes advantage of the equipment's inherent immunity to transients, since the EMP requirement on internal equipment is that it tolerate the peacetime system environment. But because this EMP requirement does not impose any new or EMP-peculiar requirements on the internal equipment, no special inventory of "EMP boxes" is required to support systems protected in this manner, and the maintenance problems that accrue from having an EMP box that is functionally interchangeable with a regular box are avoided.

(C) Although no operational systems in the United States are known to have used the system-generated transient stress as a threshold for EMP hardening design purposes, this effect has been achieved, coincidentally. Thus when electronic component damage is used as the threshold, the large margin used to account for uncertainty in coupling and threshold usually makes the EMP-induced stress less than the system-generated stress deep in the system. Similarly, since system-generated transients often exceed circuit operating levels, when the protection is designed to make the EMP-induced transient smaller than the operating level, it is also smaller than the system-generated transient level. Test crews have observed that making measurements of EMP-induced transients inside aircraft and missile systems is difficult when the

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system is energized and operating because the system-generated noise masks the EMP-induced transient and causes frequent false triggers; hence most testing is done with the system dormant (power off).

(U) The use of the system-generated stress as the threshold for EMP protection purposes also implies that this stress is known and can be controlled—at least at the inside surface of the system-level EMP barrier. At present, the control of the system interference environment is specified, albeit rather loosely, in MIL-E-6051 for electromagnetic compatibility purposes. There is thus a precedent for determining and controlling system-generated interference, but past interest has been in the narrow-band interference rather than the transient stress of concern in EMP protection. However, widespread use of digital circuits in military systems is expected eventually to inspire a greater interest in transient interference in these systems, with or without the EMP. It is also entertaining to speculate on the effect that better control of the transient environment inside the system might have on the mean time before failure of electronic systems used to monitor and control weapon systems.

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