

Cabling Guidelines for Electromagnetic Compatibility

FOREWORD

Changes in this revision are format/editorial only.

1. SCOPE:

These cable practice recommendations tend toward design guidance rather than standardization. EMC achievement tests can be standardized, but the means for achievement should not be constrained. The material can best be described as an essay on cabling, and the theme is that a cable is just a part of a complete circuit, the interconnect circuit. Cable EMC performance is thus determined largely by circuit design; it is unrealistic to expect cabling techniques to compensate for improper impedance, symmetry or waveform in the circuit.

2. REFERENCES:

There are no referenced publications specified herein.

3. BACKGROUND:

Cables are system elements containing interconnect circuits, and these cause more interference than do circuits contained inside boxes. Circuits in general exhibit a class of EMI problems related to conduction which includes crosswalk, ground loops, common impedance coupling and sneak circuits. All result from a unique characteristic of electric conduction; the current delivering energy from source to load must flow in a closed path, a circuit. As illustration, consider the functional flow diagram for any system and compare with the wiring schematic; function lines usually will not be found to correspond to wires in any consistent, simple manner. Perhaps 20% of the functional flow lines do correspond one for one with nominally "complete" transmission lines; e.g., pairs or triples, coaxes or triaxes. The rest of the function lines are implemented with single wires sharing a common return or, frequently, finding a return elsewhere. Even the nominally "complete" transmission lines are seldom truly complete; typical lines lose several percent of the fundamental return and most of the harmonic return in other cables and in structure. The functional flow lines which represent one-way energy flow are, in other words, implemented with circuit flow, that is, loop flow. This results in large apertures and shared impedances, both of which cause interference. Conduction and induction interference is more

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3. (Continued):

of a chronic problem in cable circuits than in single chassis circuits, or even in long distance transmission circuits. Chassis circuits and long distance lines are unified designs, the latter having matched drivers and receivers. Cable circuits in contrast are not really designed. Typically, the driving and receiving end circuits are given to the cable designer as constraints, and he then must make the best of them. For these two reasons; i.e., circuitous flow and fragmented design, cables require careful attention early in any program. This AIR, therefore, stresses integrated design of the entire interconnect circuit.

4. DEFINITION OF INTERCONNECT CIRCUIT:

The term "interconnect" refers to wiring which connects circuitry inside one box to circuitry inside another box some distance away. Noting that there are "boxes" within, and upon, other "boxes" in complicated units, the essential feature of an interconnect is that it traverses system structure. A "box circuit" in contrast stays within, or on the (metal) surface of one unified chassis.

An interconnect circuit consists of cable wires plus their terminating circuitry in the boxes at each end and at any intermediate junction box. These latter driving and receiving elements will be called end-circuits; they are, nevertheless, incomplete circuits, being part of the complete interconnect circuit.

Circuitry which is complete within one chassis may be called box circuitry. Multi-rack circuits like computer circuits are "box circuits" if the racks are bonded into a continuous bay, but should be thought of as "interconnect circuits" if the racks are electrically distinct from each other. Figure 1 illustrates these definitions.

5. COUPLING AND CONTAINMENT:

The first and most obvious prerequisite for interference is transfer of energy, that is, coupling. At great distance, coupling consists of emission, path and reception. At close range; e.g., between two circuits in a cable, coupling consists of induction and conduction. Coupling is controlled by the "geometric" measures, twisting, balancing, and shielding in contrast to the "modulation" measures of Section 6. Coupling results from poor containment of energy within physical envelope and so the term "containment" can be used to describe both the goals of bottling up and excluding energy. The second section of the guide, "Interconnect Circuit Design" deals entirely with prevention of coupling between a circuit of interest and some environment.

The degree of containment that should be designed into a circuit for compatible operation in the system (e.g., whether or not to twist, shield or balance) depends upon many factors. The least understood, yet most important factor, is the one generally called "influence factor", and this is taken up next.

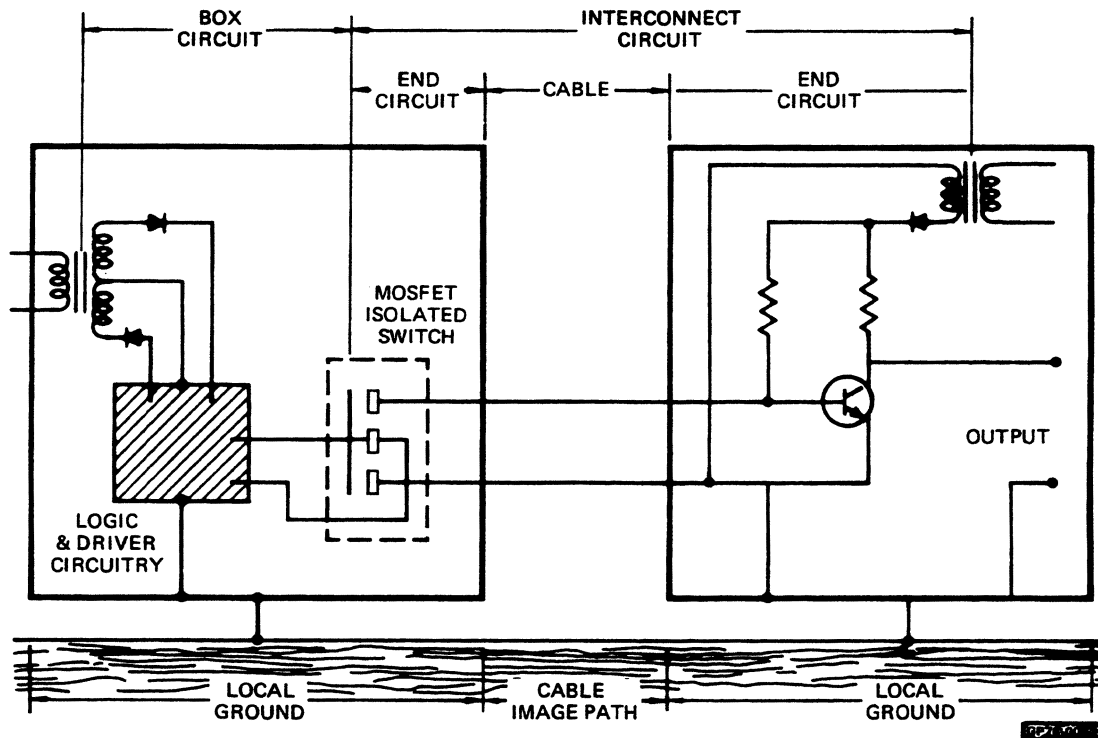


FIGURE 1 - Interconnect Circuit

6. INFLUENCE FACTOR:

In order for one interconnect circuit to interfere with another, the coupled signal of Section 5 must be of certain frequency, have certain modulation, and occur at certain times, and these specifics depend on the frequency, modulation and timing of the receptor. The need for twisting, shielding, balancing and so forth, therefore depends on this mutual "time-frequency" relationship, as well as on the "space-amplitude" relationship; i.e., energy transfer. The modifying effect of time-frequency coincidence upon the situation has been called "Influence Factor":¹

$$\text{Effective interference signal} = (\text{Coupled signal}) \times (\text{Influence Factor})$$

In the example of the reference, the influence factor for powerlines versus telephone lines describes the harmonic power falling within the speech bandwidth. Influence Factor is decreased by time and frequency control measures, such as gating, coding, frequency translation and rise time control. The modifying effect of Influence Factor upon containment design is difficult to foresee. Nevertheless, the protection afforded by time-frequency measures must be considered in order to avoid shielding overdesign.

1. From telephone practice; e.g., Telephone Influence Factor for Power lines near telephone lines.

6. (Continued):

An extremely large interfering signal can cause a category of response different from that just discussed. Demodulation, overloading or damage can occur when the signal exceeds normal limits. The Influence Factor concept does not apply to such conditions.

7. GROUND:

In electrical usage "ground" means a current sink of infinite capacity. An ideal ground must, therefore, be large enough to return a sink current to its source wherever that might be. An ideal ground must also be highly conductive and accessible. Not all regions have a ground; if a continuous conductor extends and is accessible throughout a region then that conductor forms "ground" for that region. This intuitive concept of ground is analogous to the frame of a mechanical system.

If a system cable pattern is made up of many small loops (dense population of boxes highly interconnected) and if a ground is desired, then it should be a plane. If two such regions situated some distance apart are joined into one system by long cables, then a criterion for the ground link is needed. To require that both ends of the link be at the same potential could be unrealistic. The general criterion is that the ground link be wide enough and close enough (to the link cables) to enable formation of a good image of the link cables. This requires that the ground link carry the full net distributed charge on the link cables. This is the criterion for an elongated ground.

Usage has blurred the meaning of the term "ground". In common usage "ground" can mean either a true ground as described here, or just a wire that eventually connects to power common. It is recommended that the term "ground" be specifically modified if other than true ground is meant. To this end, the classic upside down "tree" symbol should be discarded; it no longer has meaning. The chassis connection symbol

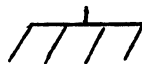


FIGURE 2

is definitive and useful: Whether or not chassis is a good ground, there is no doubt about the meaning of this symbol. In most aircraft and spacecraft the structure is the only true ground available, so the chassis connection symbol becomes synonymous with a ground connection. All other connections to ground-like conductors should be identified with modified symbols, for example



FIGURE 3

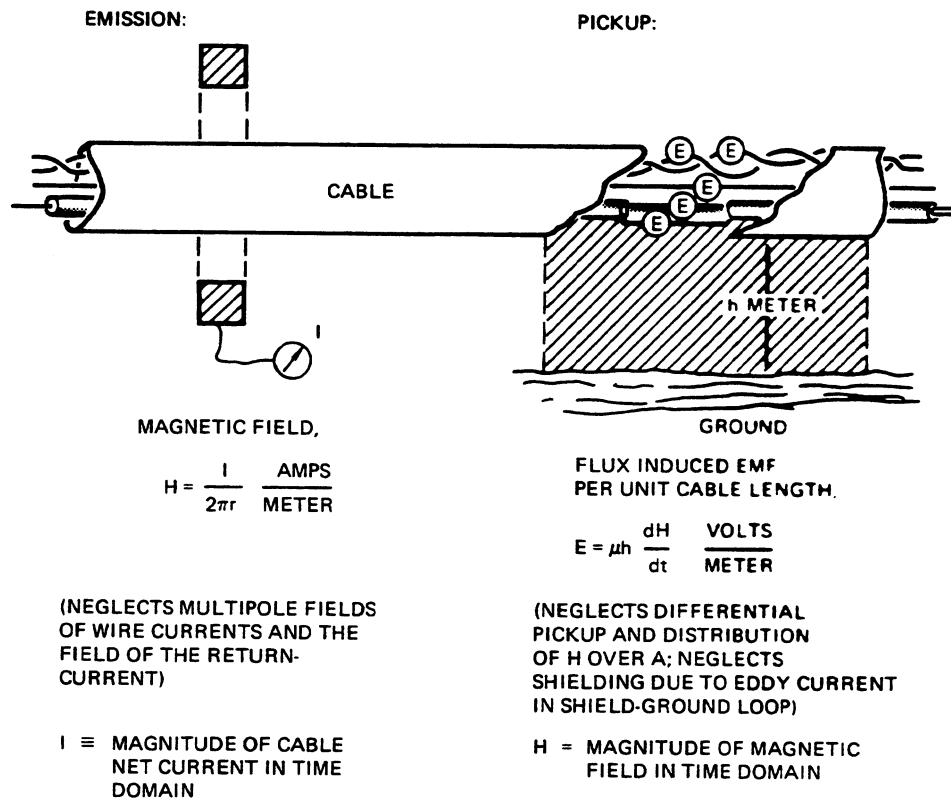
for which a complete description is provided.

8. MODELS FOR ENVIRONMENTAL COUPLING:

When two circuits are being designed to work together with no third party, then the problem variables are mutual ones: mutual inductance, mutual capacitance, relative power and relative timing. In the more usual case, an individual interconnect circuit is designed, tested, and qualified for an anticipated environment and specified level of emission. Constraints for this problem are based on some kind of assessment of Influence Factors (see Section 6) between the circuit and the eventual system. The problem variables in this artificial half-situation are environmental ones. Recommended models for use in the important low frequency range up to 1 MHz are described below.

Emission from the circuit to the environment is best measured in terms of net monopole source current and charge. The net current in the interconnect wire bundle can be defined to be the reading of a clamp-on ammeter. This variable corresponds to the dominant mutual inductance of the complete two-circuit situation. The net charge per unit length of the bundle is not readily measured because a suitable probe is not readily available. The rod antenna of MIL-STD-461 provides an indirect measurement. Net charge is, nevertheless, the variable which determines the radial (monopole) electric field of the bundle. Net charge corresponds to the dominant mutual capacitance in the complete two-circuit situation. Dipole and higher order source variables exist and can be significant. However, it is seldom necessary to consider multipole sources during circuit design; twisting and light shielding will always control the higher order fields, should control be needed.

The effect of environmental magnetic field on the circuit under design can be represented by voltage generators of equal value put in series with each wire of the circuit bundle. The common value of voltage equals the derivative of the expected magnetic flux threading the loop between bundle and ground, plus any IR drop in ground. This value for the equivalent generator can be called the "reference shift" to which the circuit is subjected. This reference shift corresponds to the effect of mutual inductance and resistance in the complete two-circuit situation. The effect of environmental electric field on the circuit can be represented by current generators in shunt with each wire. Diagrams of the four models just described appear in Figures 4 and 5.



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FIGURE 4 - Environmental Coupling Models - Magnetic