CABLES, CONNECTORS AND RACEWAYS

INTRODUCTION

The electrical and mechanical designer spends much of his interference control efforts in the design of components without due regard to interconnecting cables and harnesses. The mechanical engineer designs the case or chassis seams with RF gasketing material, controls the machining and finishes of mating surfaces, covers holes with screening or honeycomb cells, and applies other mechanical controls. The electrical engineer specifies the power line filters, designs the grounding system, adds the transient noise suppressors and protectors, specifies the internal harnessing configuration, selects the connectors, and provides other electrical controls. However, unless the component is designed to operate independently from all other components or equipment, such as T.V., oscilloscope, radio, etc., the harness and cable configuration is delegated to subsystem and system engineers. Thus, the component design engineers only do half of the job.

Cable and harness configurations are critical in the component design to reduce the propagation of electrical noise (EMI) and its effects. The best electronic box, shielded enclosure or shielded room can always be compromised by poorly designed interconnecting cables. Cables provide a convenient path by which electrical noise is conducted out of the enclosure and then radiates or couples to adjacent wiring and equipment. The reverse process also occurs with external noise pick-up on cables being conducted into a well-shielded container. The filtering of the interconnecting lines does not always solve the problem. Lines which conduct clock pulses, digital signals, video signals, etc., cannot tolerate filters which affect the signals. These signals also appear as noise to other circuits when coupling to other lines occurs.

Systems engineers treat interconnecting harnessing very seriously in respect to noise control and electromagnetic compatibility. They realize that crosstalk is a real everyday problem, and intentional system radiation can have backdoor effects if it is allowed to get into system wiring. This problem is not limited to military applications or systems. It can occur in the home, industrial plant, in office buildings, scientific centers, hospitals, automobiles, aircraft, as well as electronic laboratories. A car radio can be jammed by electrical noise radiation from unsuppressed truck ignition systems. Noise from the fluorescent lights, razor, vacuum cleaner, etc., interferes with T.V. and radio reception. Computers are extremely vulnerable to the coupling of transients generated by air-conditioners or time-clocks. In the hospital, patient monitors are disturbed by the magnetic fields emitted by power lines, heating blankets and other electronic equipment. Electric typewriters and other office machines can make communications nearly impossible. Electronic fly killers have been known to affect aircraft navigational equipment. In all of these examples, the method of radiation and pick-up of the electrical noise is through cables. The primary means of protecting electro-explosive devices is through the design of its cables.

CABLE SEPARATION

The coupling of signals and noise between wires and cables is a function of the distance between cables. Thus, it is most advantageous to categorize the various types of cable signals and to provide maximum separation between them. This is not always easy to accomplish, especially on space vehicles, or in complex electronic facilities where there are numerous cables and harness restrained by limited cable troughs. It also becomes a problem when wires of different categories share the same cable connector. However, an attempt should be made to provide whatever separation is practical. The following categories are illustrative only, and are usually modified to match the partial line voltages, signal levels and frequencies:

a. **Category P, Power:**
   1. 115 volts and 240 volts single phase and three phase to motors, transformers, blowers, etc.
   2. Control wiring which includes relay logic, stepping switches, indicator light cricuits (incandescent), etc.
   3. RF power, primarily transmitter outputs.

b. **Category S, Sensitive Wiring:**
   This category includes moderately susceptible circuitry which is easily protected such as limited bandwidth audio amplifiers, input medium-level wide bandwidth video lines, properly designed digital computer input circuitry, clean dc power, etc.

c. **Category VS, Susceptible Wiring:**
   This includes very sensitive circuitry such as a servo null circuit working to a null level of less than 100 microvolts, electro-explosive devices, high-impedance, low-level high-accuracy sensor circuitry (such as 10 millivolt, 10,000 ohm, and 0.5 percent accuracy), and antenna input circuitry.

As an aid, these three categories of wires might have an identifying color for ease in wiring and identification. The three categories should be run separately via different routing and should cross at right angles.

COUPLING MECHANISM

Magnetic coupling is the phenomenon whereby a changing current in one circuit produces a changing magnetic field in the vicinity of another circuit and causes a voltage to be induced therein. A quantitative measure of the magentic coupling effectiveness is the mutual inductance M_{np}, which is defined as the magnetic flux linking the *p*th circuit per unit of current flowing in the *n*th circuit when no current flows in all other circuits. From reciprocity considerations, $M_{np} = M_{pn}$, i.e., the mutual inductance is also the flux linking the *n*th circuit per unit of current in circuit *p*.

Electric coupling is the phenomenon whereby a changing difference of potential between conductors of different circuits causes a displacement current to flow between them. The quantitative measure of electric coupling effectiveness is the mutual capacitance C_{np}, defined as the electric change induced on the ungrounded conductor of the *n*th circuit, when all other ungrounded conductors are at zero potential. Just as for the mutual inductance, reciprocity applies and $C_{np} = C_{pn}$.

In general, coupling between lines is due to a combination of electric and magnetic coupling. If either or both lines are shielded and their lengths are significantly shorter than a half wavelength, then the impedance from any point on the shield to the ground will be low and the electric coupling will be typically small compared with the magnetic coupling.

In the case of open wires (again, significantly short compared with a half wavelength), if the terminating resistances are significantly smaller than the characteristic impedances of the open wires, the net coupling will again be dominantly magnetic. An analysis based strictly on magnetic coupling should then have a wide range of applicability. In cases where the impedance restriction for open wires is violated, electric coupling should be considered.

When coupled interference is determined solely on the basis of magnetic coupling, the interference is dependent only on the character of the current in the source line, i.e., independent of voltages or impedances on the source line. The victim circuit may be replaced in all cases considered here by a series circuit consisting of the terminating resistors and inductance of the victim line and a voltage generator. The open-circuit voltage of the generator may be expressed in general for ac interference, as

$$e_2 = 2\pi f M i_1 \alpha$$

IMPORTANT FACTORS

Solving cable shielding problems must take into consideration all variables of any particular case. These variables include:

1. the impedance of the radiating device
2. the impedance of the susceptibility device or circuit
3. the frequency range of the interference signal relative to the desired signal
4. the levels of the interference relative to the desired signals
5. the length of the transmission line.

Proper shielding, or other cable treatment techniques, and proper grounding cannot be effective unless all these variables are carefully considered for the particular case under study.

Although the theory of shielding cables and that of cable coupling and radiation may be interesting, many engineers are just interested in shielding and protecting the cables sufficiently adequate to do the job. The following design notes are provided to help streamline the process:

1. Determine the type of fields which are to be attenuated.
   Electric Fields (electrostatic coupling)
   Magnetic Fields (inductive coupling)
   RF Fields (radiation)
2. Determine the type of shielding material that is required and the number of layers. (This relates directly to the amount of attenuation required.)
   Tin-coated Braid
   Hipernon (high permeability)
   Conduit
3. Identify special purpose applications.
   (FED-STD-222 and other FED/MIL/DCA Requirements)
4. Determine the type of shield termination desired. (360^{o} peripheral terminations are best for most applications.)
5. Select the connector and back shell adaptor which best suits your requirements and provides good electrical grounding.

Don't think that your problem is so unique that a suitable back shell adaptor, connector, or cable harness assembly is not commercially available. The back shell adaptors shown by GLENAIR (page 33), presents a proven concept of shield terminations that will satisfy shield termination requirements from the simple braid to flexible or rigid conduit. The split-case connector, as shown on page 32, is the newest of hundreds of adaptors and connectors offered by ELECTRO-ADAPTOR. ANIXTER BROTHERS, page 34, manufactures and assembles wiring systems, and makes cord sets, power connectors, and wire assemblies for automotive manufacturers. For secure communications and other applications, a flexible ferrous conduit or cable assembly such as that shown by the HALLETT MANUFACTURING COMPANY on page 37, may do the job. In recent years, the word Hipernon has found its way into the shielding terminology. Now AVICA offers Hipernon as a new high permeability flexible cable shield as shown on page 35.

Regardless of the nature of your problem, a simple phone call to any one or all of the above companies may save you days of engineering time resulting in the optimum solution.

REFERENCE MATERIAL

When you have cabling problems, your best bet is to call the technical representatives of the advertisers in *ITEM* or others listed in the Sales Office Directory. If you want depth in the subject, the IEEE Transactions on Electromagnetic Compatibility provides an excellent source of information. The following papers appear in these *Transactions*, as noted:

1. "Shielding Tests for Cables and Small Enclosures in the 1 to 10 GHz Range"–W. Jarva–February 1970.
2. "Magnetic Fields of Twisted-Wire Pairs"–S. Shenfeld–November 1969.
3. "Effects of Partial Shields on Transmission Lines at Low Frequencies"–N. Farhot, Y. Loh, & R. Showers–March 1968.
4. "Magnetic Field Pick-up by Flexible Braid Coaxial Cables" –J. Bridges and R. Zalewski–March 1968.
5. "Measurement of RF Leakage in Multipin Electrical Connectors"–F. Schor–March 1968.
6. "Coupling Between Open and Shielded Wire Lines Over a Ground Plane"–R. Mohr–September 1967.
7. "EMC of High Density Wiring Installations by Design or Retrofit"–W. D. McKerchar–March 1965.
8. "Coupling Between Lines at High Frequencies"–R. J. Mohr–December 1967.
9. "Analysis of Cable-Coupled Interference"–Greenstein & Tobin–March 1963.
10. "Leakage of EMI Along Stationary Conductors Passing Through Conducting Walls"–Lombardine & Goldhirsh–March 1963.
11. "Wiring of Data Systems for Minimum Noise"–J. V. White–March 1963.
12. "Predicting Magnetic Fields From a Twisted Pair Cable"–Moser & Spencer–September 1968.
13. "Anti-Interference Wires, Cables and Filters"–F. Mayer–September 1966.
14. "Shield Grounding Effectiveness in Interference Reduction in the 50 Hz to 15 KHz Frequency Region"–McDonald & Taylor–March 1966.

1968 IEEE EMC Symposium Record

15. "Internal Voltages and Currents in Solid Shielded Cables"–Vance & Nanevicz
16. "Common Mode Coupling Matrices"–T. H. Herring
17. "Coupling Between Open Wires Over a Ground Plane"–R. Mohr
18. "Penetration of Coaxial Cables by Transient Fields"–Miller and Torelios.

1967 IEEE EMC Symposium Record

19. "RFI Shielding with Conductive Pressure–Sensitive Adhesive Tapes"–Olyphant & Dahlen
20. "Resonance Properties of the Shield of a Coaxial Cable Over a Ground Plane"–DeMitt, Loh & Showers

1970 IEEE EMC Symposium Record

21. "Specifications for Flexible Conduit for EMI Shielding"–W. J. Prysner.