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

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

NEW CONCEPT IN EMI SHIELDING USING NON-METALLIC CONDUITS

The EMI/EMP shielding requirements of today's airborne and ground support equipment (GSE) applications make the simple metal-braid-over-wire-bundle hard harness approach outmoded in its need to meet *all* of the design objectives of a modern weapons system. A wire harnessing approach has been developed so that the design engineer can protect his wiring to meet the requirements of both an EMI/EMP and physical-mechanical environment. This harnessing concept is modular, consisting of four basic building blocks which can be selected on a properties basis and assembled to suit the various and varying configurational needs of the installation.

Hellically convoluted high temperature plastic tubing provides the wire bundles with strain relief protection, protection from the corrosive action of aircraft and swamp area fluids, and a thermal barrier, while acting as a highly flexible structural platform for the EMC wire. The braid wire is selected and processed from metals with special electrical properties specific to the EMI/EMP environment to be shielded. An integrated system of breakouts, and EMI secure termination hardware complete the building block modules.

Selected on the basis of properties requirements and worked in concert, these modules can be assembled with any of a variety of configurational and physical-electrical synergisms. The overall effect is to provide the EMI and design engineer with a harnessing system which is at once hard electrically and structurally, while at the same time structurally flexible, schematically variable, and physically maintainable.

Materials and Design Selection

A wire harnessing system such as that provided by ICore is a simplified approach to solving the sophisticated problems confronting engineers who must contend with the effects of modern outside RF fluences. The spectrum of these RF fluences has increased both in range and amplitude over the past decade to where conduit designs must now protect wire bundles from EMI low frequency H fields, mid frequency E fields, plane waves, and hostile environment high amplitude EMP resulting from nuclear explosions.

Utilizing the non-metallic plastic core approach, the designer has the following options:

1. Lightweight fabrication in thin-walled tubing constructions vs more rugged but heavier, thicker walled tubes.
2. Convolution design for medium or ultra high flexibility vs weight and flexual life.
3. Plastic materials selection based upon:
   1) Physical-Stress-Strain requirements.
   b) Operating temperature.
   c) Toughness and flexibility.
   d) Solvent resistance.
   e) Flamability.
   f) Weight per foot.
   g) Cost.

Once the designer has selected his non-metallic conduit system, the wire braid covering can be selected:

1. On the basis of fabrication desires, woven sock to be slipped onto the tube or direct braiding onto the structural convoluted tube.
2. On the basis of protection required.
   a) Physical requirement; small gage stainless steel or titanium.
   b) Electrical protection particularly outside RF fluences.

Three general materials categories are open to the engineer from which wire braid materials may be selected for the specific EMI application:

1. Materials which are nonferrous and highly conductive and thus specific for mid frequency E field attenuation.
2. Materials that are drawn from high nickel and ferrous alloys by controlled processes designed to provide a high magnetic permeability and H field protection. Specially processed and annealed metals can be selected by the engineer which will give him a unique non-metallic braided conduit property, EMP protection at minimum cost.
3. Materials which provide a compromised E and H field protection resulting from a composite structure of highly conductive metal clad over a core of high permeability ferrous wire.

Configuration into an operating system is then a matter of selecting the proper designs from a wide variety of breakout and termination hardware:

1. Transition pieces provide multi size and directional breakout of wire bundles. Split transitions provide easy bread boarding and ready access to the wire bundles while solid transitions without seams are more EMI secure.
2. EMI secure and hermetically sealed junction boxes and panel adaptors terminate the harness system while the BAT (Braid Application Termination) provides the important link between the braided EMC conduit and these end points.

To the wire installation designer, the BAT is a simplified method of terminating braid and tubing simultaneously with a minimum number of parts, securely but in a repairable maintainable manner. To the EMI engineer, the unique double thread design of the BAT finishes a lightweight system with 360° metal-to-metal attachment of the braid between surfaces having a wedge lock which allows maximum pressure to be exerted on the braid independent from coupling nut-to-connector torque.

Points to Remember

When synthesized into a completed assembly, all of the modules combine synergistically. Thus, many properties such as flexibility, thermal stability and flexual life are greater than the averaged addition of the modular contributions. Of most importance, a system for solving many of todays complex EMI harnessing problems simply and with a multitude of options should be provided. The designer has choices at each stage of his development of the harness scheme. He has the ability to go back and change his approach or indeed a whole segment of his design at minimum materials and rework cost. As such, the EMCore approach provides an advancement in the state of the art in EMI wire harnessing, keeping pace with demands placed upon modern aircraft and weapons design.

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° 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.

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.

1971 IEEE EMC SYMPOSIUM RECORD

22. "Measuring Connector Shielding Effectiveness During Vibration"–Knowles & Brossier
23. "Cable Shield Effectiveness Testing"–Knowles & Olson
24. "Shielding of Cylindrical Tubes at Low Frequencies"–Johnson & Shenfeld
25. "The Measurement of Coaxial Cable Immunity to an Electromagnetic Field in the VHF Range"–E. Nano