Shielded Wires and Wiring
Chapter 14

Advantages of Shielding

Shielded conductors permit the transmission of low level signals, at high impedance levels, through areas where excessive interference voltages would be induced into low impedance conductors by low frequency magnetic fields, or in areas where sensitive information must be sent. Shields on wires act the same as shields on rooms, the continuous enclosure acting as a Faraday cage barrier to radiated fields. Magnetic fields near the surface will set up currents in the conductor which tend to cancel the incident fields. However, the shield is only as good as its ground reference, since shield currents radiate like any other wire. For best results, both the internal wire and the outer cable must be individually shielded.

Applying the term shielding effectiveness to a cable/connector assemble is really a misnomer. Shielding effectiveness for a cable assembly is a measure of the quality of its shielding[1], and is determined by measuring the Surface Transfer Impedance of the cable assembly. Surface transfer Impedance is the ratio of the magnitude of the longitudinal voltage drop on the outer surface of the shield to the current on the inside of the shield. This subject will be covered again in detail later in this chapter.

The magnetic shielding effectiveness of ordinary non-ferrous shielding materials is considerably lower than that of ferrous materials below approximately 100 KHz. Even ferrous materials have a relatively low magnetic shielding effectiveness at 60 Hz and 400 Hz when applied in reasonable thickness. Twisted wiring, even without a shield, provides the most effective isolation from low frequency magnetic fields.

The choice between shielding, using coaxial cable, or wire twisting, and the decision as to shield and twist or not is a perennial source of confusion. Hardware limitations, level of security, and amount of hardening required frequently determine the approach which will provide the best system performance. Examples of various shielded cable configurations are provided in Figure 14-1 from Belden[2]**.** Table 1 compares several cable types relative to shielding effectiveness, percent coverage, etc. The conductive cotton shield shown in the figure is typical of conductive textiles compared in the table. Similarly, Aluminum Mylar is typical of the aluminum foil type shielded wire shown in the figure. A discussion of hardware and wiring isolation system limitations that will influence the selection of an optimum wiring configuration follows.

Twisted Shielded Pairs Verses Coaxial

Balanced, shielded twisted pair cables and coaxial cables are complementary rather then competitive. Each has strong and weak points. Twisted conductors are the only effective means of preventing power frequency and audio frequency magnetic fields from introducing an interference voltage at the functional circuit end of interconnection wiring

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[1] MIL-STD-1377 (NAVY), Effectiveness of Cable, Connector, and Weapon Enclosure Shielding and Filters in Precluding Hazards of Electromagnetic Radiation to Ordnance; Measurement of, 20 August 1971.

[2] Design Guide for Electronic Wire and Cable, Belden Corporation, 1972.

in situations where conductors are balanced to ground, and the shield is not a current-carrying member of the system. Conventional non-ferrous shielding braids are not effective magnetic shields at low frequencies. Specialized magnetic shielding foils are also relatively ineffective magnetic shields at low frequencies when used in practical thickness.

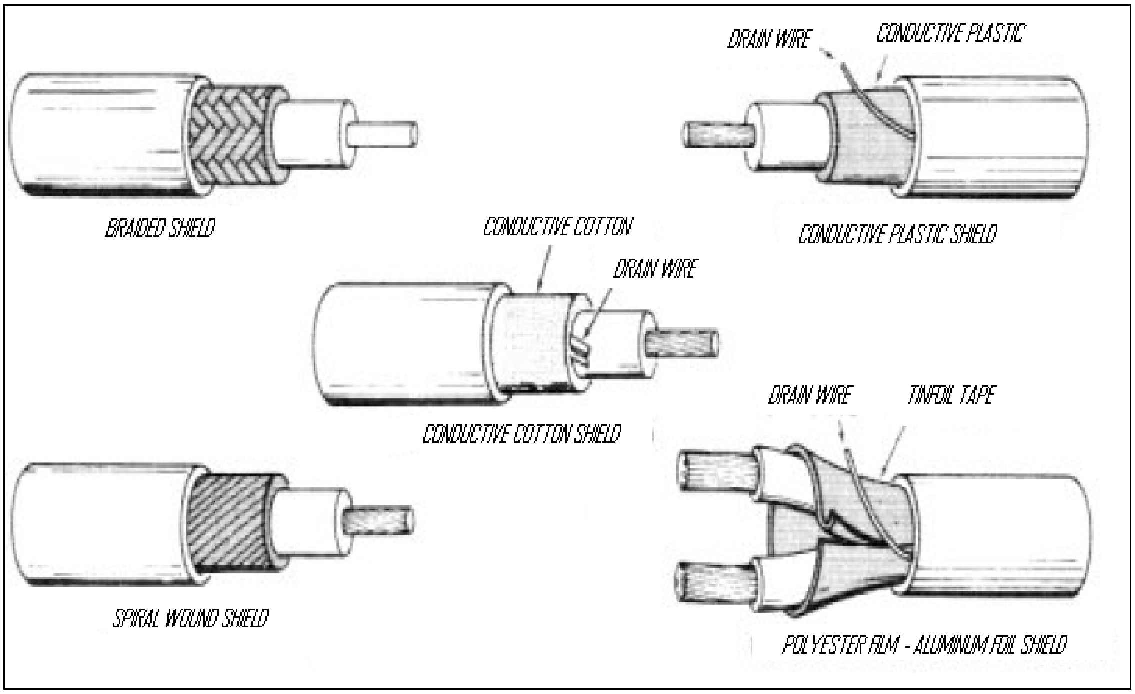

Figure 14-1 Various Cable Configurations

Coaxial cables are most suitable for unbalanced circuits with the shield grounded and serving as one conductor. Coaxial cables are more nearly broadband frequency devices than are twisted pairs. The shield on a coaxial cable is not as effective as shielded pairs since signals picked up by the shield can be conducted and coupled directly into the functional circuit. The only way to avoid this problem is to use a triaxial constructed cable, which is both expensive and difficult to terminate. Coaxial cables are primarily used at both audio and radio frequencies, and have lower capacitance per foot and lower attenuation than twisted cables.

Shielded Wiring

When a high impedance conductor is in close proximity to a second conductor and a structural ground plane, it becomes part of a voltage divider circuit due to the mutual capacity of the three objects. The voltage divider consists of the capacity between conductors in series, with the capacity between the conductor and the structural ground plane.

Substituting a shielded conductor for an unshielded conductor decreases the conductor-to-conductor capacity and increases the conductor-to-ground plane capacity, thus producing a voltage divider with greater attenuation. Two adjacent unshielded conductors in the center of a cable bundle 50 feet long have a mutual capacity of approximately 500 picofarads, forming a voltage divider with negligible attenuation if the terminating impedances are high. When the shields are grounded to the ground plane, the center conductor-to-ground plane capacity will be approximately 6000 picofarads, forming a voltage divider with an attenuation of 1200 to 1 if the terminating impedances are high.

Advantages to Using Twisted or Shielded Wire

Wires act the same as transducers. As mentioned previously, an electric field will induce a voltage between conductors passing through it. A magnetic field induces current flow in conductors passing through it. A voltage differential between conductors produces an electric field between the conductors. Finally, current flowing through a conductor produces a magnetic field around the conductor with flux lines following the right hand rule.

A twisted wire is capable of reducing the conversion efficiency of the conductors, as a transducer, by a factor of 10,000 to 1 when the wire is properly selected and installed. Twisted wire is normally used in low frequency low impedance circuits that are located in areas associated with high magnetic field problems. Shielded wire is normally used in high frequency high impedance circuits associated with electric field problems.

If wires having a tight twist and tight shield braid weave are selected for use, the achievable limits of improvement are controlled by the installation configuration. Breaks in the cable at connectors and other terminations violate the integrity of both the conductor twist and the shield braid continuity.

Since twisted or shielded conductors can have a theoretical improvement factor of 1000 to 1 over untwisted unshielded conductors, then the achievable improvement factor is controlled primarily by the total length of perturbations in the twist, or shield, unless the total cable length exceeds 1000 times the total length of the perturbations. The achievable improvement factor is the reciprocal of the perturbation length as a fraction of the total cable length. A cable with a total length of five feet, and perturbations having a total length of one-half foot would have an achievable improvement factor of five divided by one-half or 10 to 1, even though the theoretical improvement factor of the cable was 1000 to 1, or 10,000 to 1 under ideal conditions.

For any cable of reasonable length, the only practical way to increase the achievable improvement factor is to decrease the total length of cable termination perturbations. Reactive cable terminations may have a significant effect on the actual achievable improvement factor, but are a function of circuit design rather than cable design. If shielded wire is substituted for the two center conductors, they will have a negligible mutual capacity except for the areas near each connector where the center conductors are exposed. If the unshielded portions of each center conductor at both ends of the cable have a total length of six inches, the capacity between just these two center conductors will be about 5 picofarads.

The principle types of flexible shielded cables commercially available include shielded single wire, shielded twisted pairs, and coaxial wires. The shield itself can be made of braid, semi-flexible conduit, or foil.

Shields are either formed as an integral part of the wire, or can be added such as in the case of "Zippertube" as shown in Figure 14-2.

Braided Shields

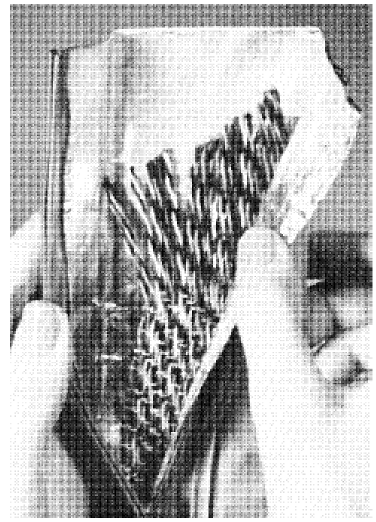
Figure 14-2 Zuppertubing

Braided shields are not perfect conducting cylinders since they have many small holes which permit leakage of electric and magnetic fields. The weaving of the braided wire shield is described in terms of the number of bands of wires (carriers) that make up the shield, the number of wires in each carrier (ends), and the number of carrier crossings per unit length (picks). These characteristics, along with the radius of the shield, define the volume of metal in the shield, the optical coverage and the weave angle. A large volume of metal not only implies low resistance and good shielding, but it also represents a larger weight problem for aircraft.

Shielding is usually dependent on the percentage of cable coverage provided by the shield braid, and/or the thickness of the shield material. The optical coverage of a shield is a measure of the number of holes in the shield. The higher the optical coverage in a shield, the smaller the open area of the holes, and the better the cable shielding capabilities. The holes between the individual bundles of wire forming the shield can be approximated as a group of diamonds, the size and orientation of which depend upon the weave angle. There will be more leakage into or out of holes with their long axes oriented circumferentially to the end of the shield than there will be if the long axes of the holes are oriented along the shield. Other things being equal, a shield with a small weave angle provides better shielding performance than one with a large weave angle.

The shield braid angle and percent braid coverage are determined in accordance with MIL-C-7078C, with a minimum coverage of 94% indicated for GSE flight deck applications. Figure 14-3 shows a braided shield cable with about 85% coverage under flexing conditions.

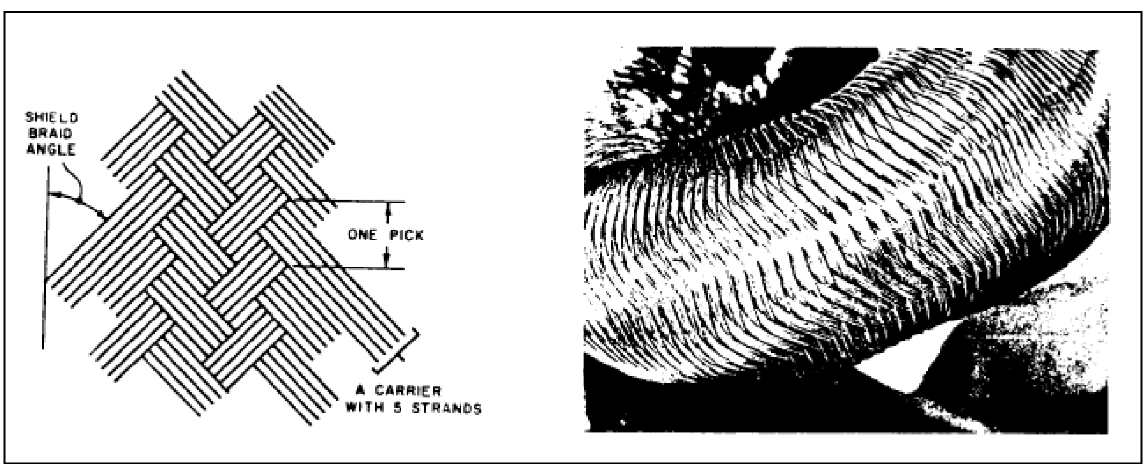

Figure 14 - 3 Typical Braid Weave Angles

Flexibility vs. Weave Angle

Shielding effectiveness can be improved by making the shield more dense, but that reduces the flexibility of the shield. Small diameter shields can be made with a small weave angle, but on large diameter cables the weave angle must be large to maintain flexibility. An alternative construction involves two overlapping layers of braid. Using two similar layers of braid will reduce the resistance of a single braid by a factor of two (and double the weight of the shield), and can reduce the transfer inductance by a much greater factor. Transfer inductance is the dominant impedance for frequencies above about 1 MHz and will be further discussed below.

Electric field leakage is another source of coupling via capacitive leakage through the holes in the shield. If the shielded cable is subjected to a changing electric field, dielectric flux will pass through the holes in the cable from the internal signal conductor (or from an external signal source). If coupling is from an external source, the flow of these dielectric, or displacement, currents through the external load impedances produces a voltage between the signal conductor and the shield. Noise currents flowing through the external impedance of the shield may, if the shield is not perfectly grounded, produce a voltage between the shield and any external ground structure.

Transfer Impedance of Cable Shields

As was previously mentioned, cable shielding is sometimes specified in terms of a figure of merit known as Transfer Impedance. The most informative measure of shielding effectiveness is Surface Transfer Impedance (STI) as described in MIL-STD 1377[3]. Transfer Impedance (Z_T) is useful in assuring the isolation provided by the cable's shield primarily because of its repeatability and because it relates the voltage induced on the inside of a cable shield to a current flowing on the outside of the shield. Since the voltage drop along the cable is proportional to length, Z_T is normalized to a unit length.

Most shielding effectiveness measurement methods use radiated fields to measure the combination of reflection and absorption of field strength. Two difficulties exist with this technique when applied to cables. The first relates to the inconsistencies encountered when trying to measure field strength propagated through holes in walls. The fringing effects associated with the edge of the shield's wall hole, plus the waveguide characteristics of the hole itself, can drastically effect the viability of this technique for realistic measurements.

For the cable shield case under consideration, where coupled currents over a wide frequency range can exist on the shield surface, primarily the penetration loss of the shield is the most effective. At high frequencies, the skin effect separates the differential-mode return current flowing on the inner surface of the cable shield from the coupled current flowing on the outer surface. Skin effect relates to how well high-frequency currents can penetrate conductors. Skin depth, ξ, represents the distance below a conductor's surface where the current density due to surface current flow falls to 1/e. Skin depth can be determined by:

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[3] MIL-STD-1377 (Navy), Effectiveness of Cable, Connector, and Weapon Enclosure Shielding and Filters in Precluding Hazards of Electromagnetic Radiation to Ordnance, Measurement of, 20 August 1971.

$$\xi = \sqrt{\frac{2}{\omega\mu\sigma}}$$

where

ω = the frequency of the coupled current
μ = the permeability the conductor
σ = the conductivity of the wire conductor

The standard equivalent circuit for a single cable and shield is one which depicts, through the use of transformers, the self inductance of both the conductor and the shield and the mutual inductance between the two. These self and mutual inductance's must be known with great precision if shielding effectiveness for the cable is to be calculated accurately without using Transfer Impedance methods. Another advantage to using Z_T is that it can be easily tested in a production environment.

The Transfer Impedance of a rigid or semi-rigid cable that uses a solid, tubular shield has the characteristic that it decreases with frequency as the skin depth becomes shallower. Transfer Impedance for this cable type is determined from:

$$Z_T = R_o \frac{(1+j)\frac{t}{\delta}}{\sinh[(1+j)\frac{t}{\delta}]}$$

where t = shield thickness

$$R_o = \frac{1}{2\pi a\sigma t}$$

R_o = DC resistance of the cable shield
where a = the outer radius of the cable shield

When flexible shields are used, magnetic field coupling dominates, and the Transfer Impedance can be expressed as:

$Z_T = Z^d + j\omega M_{12}$

where M_{12} = the mutual inductance between the outside of the shield and inner conductor

Z_d = the diffusion impedance

Diffusion impedance is proportional to the DC resistance of the woven shield and diminishes with frequency.

The term transfer inductance (L_{12}) should not be confused with the mutual inductance (M_{12}) between the shield and the conductor. M_{12} depends on the physical parameters of the cable shield. For the two conductor system, mutual inductance is the shared inductance between conductors while transfer inductance refers to a conductor and its associated shielded cabling. If the resistance of the shield were zero, and if the mutual inductance between the shield and the signal conductor were equal to the self-inductance, that is, unity coupling, the flow of current on the shield of the cable would not cause any voltage to be developed between the shield and the signal conductor.

Transfer impedance is commonly used in EMP and lightning analysis work. The process and values are referenced from a TEMPEST perspective only as a means of determining with consistency the shielding effectiveness of cable/connector combinations. A number of sources are available for additional information on Transfer Impedance, the primary source considered by this author is by Vance[4][5].

Non-permeable Cable Magnetic Shielding Properties

The only way a non-permeable metal cable shield can prevent penetration of an external H-field into the shielded volume is by generating an opposing magnetic field of the same strength but opposite in direction. This situation exists when the shield forms part of a closed loop, as shown in Figure 14-4, allowing the induced current to flow.

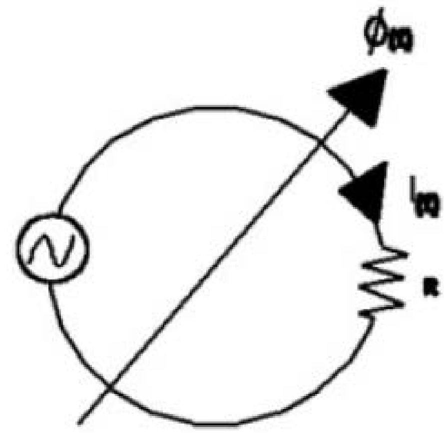


Figure 14-4 Flow in Loop

The induced current created its own magnetic field, which opposes the incident field and creates a null inside the cable. Lenz's Law states that the field produced the loop will oppose any change in the external field. The issue here is nulling a sine wave with another sine wave 90 degrees out of phase, which is impossible. The solution is to shift the phase of the second sine wave until cancellation occurs.

Phase shifting can be done by making the loop resistance very low. If loop resistance is high, the induced current is small (equal to induced EMF divided by R) and also proportional to the rate of change of the incident magnetic field (from Faraday's Law of Induction). That would produce a null. If resistance is low, the loop current is larger, and the induced magnetic field may be nearly proportional to the incident magnetic field so that nulling can occur.

The response of a closed inductive loop to an external sinusoidal flux passing through the loop results in the EMF due to the external field being diminished by the amount of EMF caused by the loop current, to arrive at a resultant EMF which would drive current around the loop. The resultant equation is:

$$\frac{d\phi}{dt} - L\frac{di}{dt} = iR$$

The first term is induced EMF from the external field (Faraday's Law of Induction). The second term is the EMF due to loop self inductance. The iR quantity is the resultant voltage developed across the loop resistance. Loop resistance could be distributed around the loop, or it could be a discrete, localized resistor for ease of measurement. For the purpose of this analysis, knowledge of flux direction is unimportant, so other combinations of algebraic signs would also work.

Now let R go to zero and assume that the excitation is sinusoidal. For this condition, the equation simplifies to:

$i'(t)=\varphi'/L$

[4] Jerse, Thomas, Application of Shielded Cables, RF Design, January, 1991.

[5] Vance, E.R., Coupling to Shielded Cables, Chapter 3, John Wiley and Sons, New York, 1978.

The equation above can be rearranged and written as Φ' = i'(t) L. Loop current is in phase with the impinging magnetic flux. The flux produced by the loop current also happens to be Φ' = iL and the two equal fluxes are in opposite directions, so that the total flux passing through the loop is zero. The cancellation of fluxes through a hypothetical closed loop goes a long way toward reducing fields very near the loop, and explains the shielding process of magnetic fields in cables.

Now suppose resistance R is non-zero, and that Φ(t) and i(t) are sinusoidal functions with frequency $\omega = 2\pi f$ (f is in hertz). It can be shown that the amount of flux cancellation will depend on both R and L.

If $R \ll \omega L$, then induced EMF is drastically reduced. If $R \gg \omega L$, then induced EMF is not significantly reduced. In terms of shielding effectiveness, as the frequency of the impinging noise field is increased through the RF range, the requirement for a low R is gradually relaxed and magnetic shielding becomes easier. As frequency is decreased into the audio range, R may have to be so low as to be unattainable and shielding effectiveness disappears.

This analysis is applied to the loop formed by a cable braid and a ground plane. EMF on the coax inner conductor will track the braid EMF. As the EMF on both is reduced, the desired shielding is achieved.

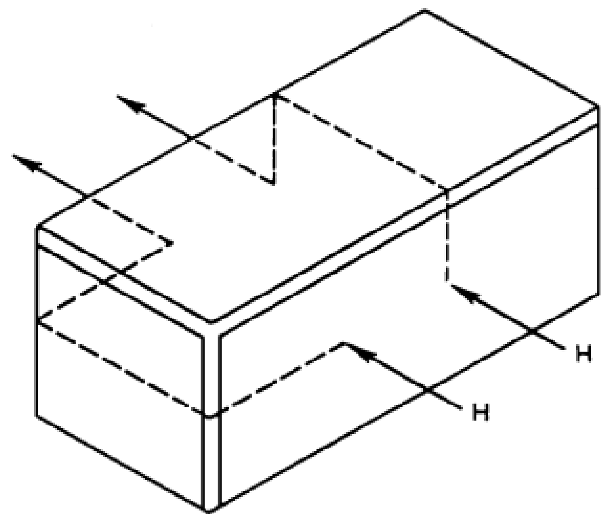
For the real world case of non-uniform magnetic fields near a cable shield, the non-zero fields integrate out to a total of zero over segments of a coax, so that the total EMF can be zero. The whole shielding concept works only if all loop inductance is coincident with the portion of the loop where the total EMF is to be zero. (the shielded cable from end to end). Any other inductance, such as the inductance of a pigtail termination at the end of the cable braid, will degrade shielding effectiveness.

Figure 14-5 shows the case of flux diversion through μ- metal. In this case, the lines of flux are channeled through the metal until the metal saturates.

where,
μ_0 = permeability of air ($4\pi 10^{-7}$)
H_0 = H-field exterior of enclosure (oersted)
A_e = effective flux capture area ($A_e = 2A$)
a_T = total cross-sectional area of four panels
Δ = material thickness
h = enclosure height
l = enclosure length
B = flux density (gauss)
A = physical flux intercept cross-section area of enclosure perpendicular to magnetic flux lines (four side panels)

Limitations of Shielding Conductors

For low frequency isolation, shields must be connected to the structural ground plane at only one end to prevent the flow of current through the shield as a result of small differences in the voltage potential of the ground plane at each end of the shield. The shield and center conductor form a one-turn coaxial transformer. Interference or problem causing currents flowing through the shield induce an interference voltage in the center conductor. The one end shield grounding philosophy is only satisfactory for solving low frequency interference problems, and conflicts with the requirements for high frequency shielding. Note that most direct TEMPEST radiated problems result from high frequency signal leakage, while ground loop TEMPEST coupling problems occur when shields are connected at both ends.



$$B = \frac{\mu_o H_o A_e}{a_T} = \frac{\mu_o H_o A_e}{4\Delta(h + l)}$$

Figure 14-5 Flux Paths Available

The shield must be connected to the structural ground plane through extremely short jumpers at many points along its length in order to prevent the existence of an ungrounded length of shield greater than one-tenth wavelength long at the highest frequency of interest. An ungrounded shield or shield grounding conductor greater than one-tenth wavelength long has considerable impedance to the structural ground plane. Any potential appearing on the shield as a result of capacitive coupling from other conductors or as a result of voltage drops due to interference ground currents flowing through the shield will be both radiated and capacitive coupled into the cable’s center conductor. This subject is further examined in the chapters on interactive grounding.

High currents flowing through the shields due to wiring resonances will induce an interference voltage in the center conductor through the mutual inductance. This shield grounding philosophy is only satisfactory for isolating high frequency interference problems, and conflicts with the requirements for low frequency shielding.

The conflicting requirements of high and low frequency shield grounding techniques prevent the application of a simple panacea to solve all grounding problems. Each circuit must be individually analyzed. In cases where satisfactory operation requires optimum shield grounding throughout the frequency spectrum, isolated multiple shields may be used, with the outside shield grounded through extremely short jumpers at frequent intervals, and the inside shield grounded at one point only.

Conventional non-ferrous shielding braids are not effective magnetic shields, but work well as electrostatic shields at low frequencies. Most metallic materials are satisfactory shields against both electric and magnetic fields at the higher frequencies.

Minimum Practical Cable Lengths

It’s impossible to achieve worthwhile signal radiation improvement factors unless the twisted or shielded portion of the cable is at least an order of magnitude longer than the total untwisted or unshielded cable length. System interconnection cables must be considered in conjunction with the related internal cables of the assemblies. Most wiring wholly internal to an assembly does not involve long enough conductors to provide a useful improvement factor.

Shielded Wire or Cable Design Guidelines

Regardless of how cable shielding is determined, certain basic techniques or guidelines should be followed. The guidelines below are simple rules to follow when designing and specifying shielded wires or cables.

1. For good E field shielding it is necessary to:
    A. Minimize the length of a center conductor that extends beyond the shield
    B. Provide a good ground on the shield.
2. A shield placed around a conductor and grounded at one end has no effect on the magnetically induced voltage in that conductor.
3. To prevent H field radiation from a conductor forming a ground return loop between both ends, the conductor should be shielded and the shield should be grounded at both ends.
4. For maximum noise protection at low frequencies, the shield should not be one of the signal conductors. Also, one end of the circuit must be isolated from ground. At low frequencies, large noise currents are induced in ground loops.
5. Braided shields should be terminated uniformly (circumferentially) around the braid at the connector for best isolation.

Return Lead Filter Requirements

Electronic hardware leads are usually grounded to the structural ground plane through various techniques. High frequency circuit returns are generally connected directly to an assembly structure which is in turn bonded to the main structural ground plane. Returns connected to a well designed high frequency assembly structure rarely exceed a length of one inch, and normally have a negligible inductive reactance below one hundred megahertz. Conventional circuit returns are generally isolated within the component, carried through an interface connector, and grounded through some other length of conductor to the main structural ground plane.

The inductive reactance of the short jumpers used to connect high frequency circuitry to a structural return path is negligible at the TEMPEST problem frequencies generated by most pulse, square wave, and transient generation components. Since the return path impedance is so low, and the voltage developed across this path is therefore negligible, a true single ended circuit is created throughout the compromising frequency spectrum. In this case, a return path filter is not required for differential mode signal reduction.

Balanced and Floating Circuits

The return conductors of balanced circuits and floating circuits have the same lengths and inductive reactance as the "hot" conductors. If filters are required in the "hot" conductors, filters are also required in the return conductors. Balanced line-to-line filters require a structural ground plane reference through a capacitive (or inductive) center-tap to eliminate common mode interference. An ungrounded filter capable of eliminating line-to-line interference is not capable of eliminating line-to-ground plane interference due to the lack of radio frequency continuity between each line and the ground plane.

Single Point Ground Circuits

The return conductors of circuits referenced to a single point are essentially floating circuits throughout the interference frequency spectrum. The return circuit conductors, measured between the component connector and the appropriate ground studs, have varying lengths as previously stated. These lengths have appreciable reactance, producing significant voltage drops throughout the frequency spectrum generated by most pulse, square wave, and transient signals.

Again for this reason, if filters are required in the "hot" conductors, filters are also required in the return conductors. The "hot" conductor and the return conductor which is returned to a single

point ground, must be treated as a floating circuit that requires a balanced filter with a center-tap referenced to the structural ground plane.

Crosstalk Controls

A common problem in the TEMPEST design of cables and wiring is crosstalk. By crosstalk we mean the coupling of a signal from one conductor to another due to its close physical proximity. When coupling occurs in the secondary conductor, it may again couple or re-radiate to other conductors, and/or it may cause the secondary conductor's signals to indicate erroneous messages.

There are a number of recent articles in the literature that treat the phenomenon of crosstalk in general, and for specific cable types. Since crosstalk is primarily a problem of proximity, its reduction involves improving the coupling between a signal and its reference.

Some of the worst crosstalk offenders include cable connectors, printed circuit board connectors, and chip carrier or Dip package pins, primarily due to the close association of individual parallel wires within the packages. The following methods are commonly used to reduce crosstalk problems.

1. Use shielded twisted pair cables.
2. If a flat cable is used, run reference lines between signal lines. This approach can be improved if the reference lines are larger then the signal lines.
3. Minimize printed circuit line and cable lengths.
4. Route switching lines away from quiet lines. It is often acceptable to route all data lines involved in parallel bus structures together. Control, clock, and other "quiet" lines should be physically isolated from the noisy switching lines. As is also sometimes the case, noisy switching lines must be isolated from each other since crosstalk between such lines may create a longer settling time for the bus.
5. Use as many reference pins as possible in printed circuit board and cable assembly connectors.

6. Assign and isolate connector pins to take advantage of maximum isolation and separation of noisy and quiet lines. This condition is shown in Figure 14-6.

If attention to crosstalk is provided early in a design, its effects can be greatly reduced. However, if crosstalk is ignored until late in the design, the required fixes can become very costly.

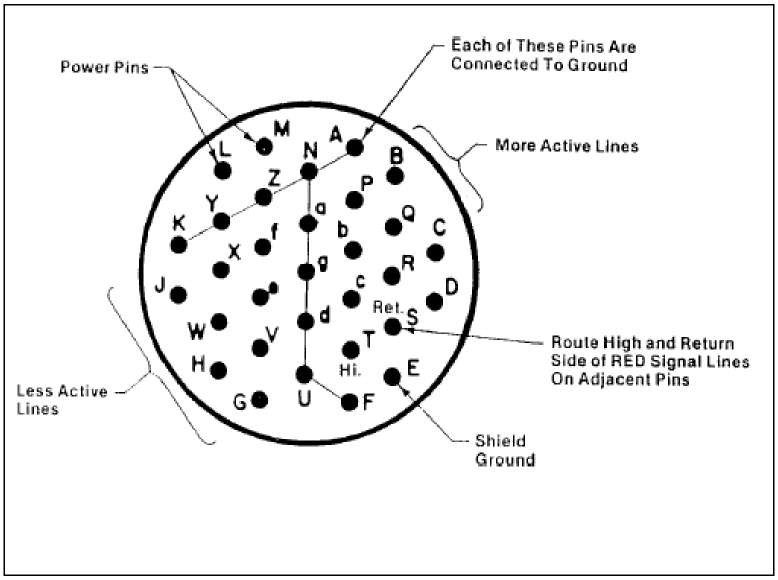


Figure 14-6 Connector Pin Isolation

Ribbon Cables

While ribbon cables are becoming the standard rather than the exception in most data processing equipment, ribbon cable manufacturers and the engineers that specify their use are also becoming knowledgeable in their proper application. Ribbon cables are now available with shields, multiple internal ground traces, and various shielded conductor types as shown in Figure 14-7. In addition, installable shields and split ferrite cores are available to place over the internal ribbon cable. Like many cable types, the ferrite sleeve chokes off the common mode signal flowing in the cable while allowing the differential signal to pass through unaffected. Typical ribbon cable designs are shown in Figure 14-8.

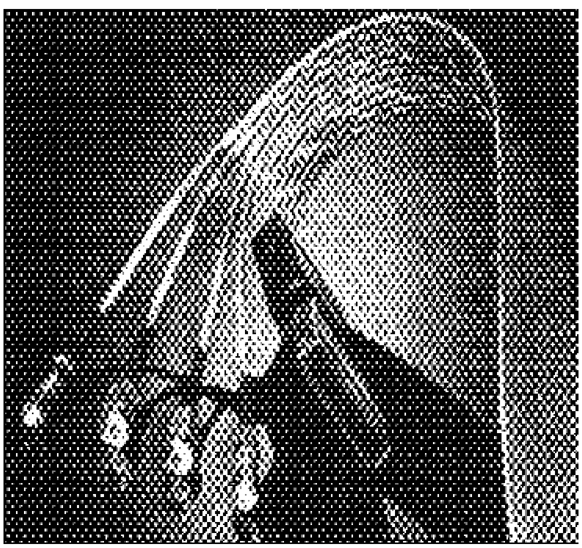


Figure 14- 7 Ribbon Cable with Coax and Shielded Connectors

Ribbon Cable Crosstalk and Radiation

In TEMPEST applications, the two major problems with ribbon cables are crosstalk and radiated emissions. Since each wire in a simple ribbon cable is exactly parallel with every other wire, distributed capacitance and mutual inductance create considerable opportunity for crosstalk.

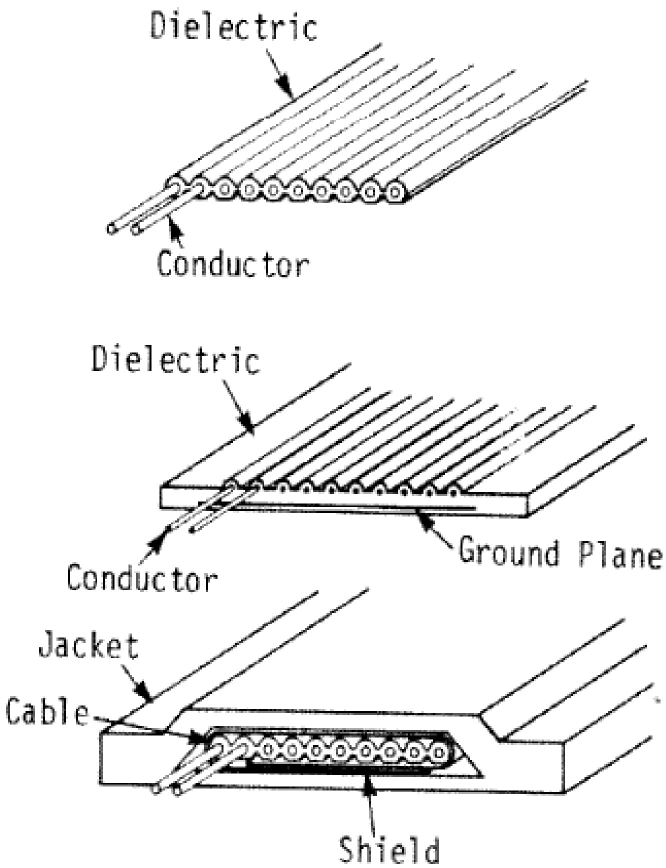


Figure 14-8 Typical Ribbon Flat Cable Design

Not only is direct crosstalk in ribbon cable experienced, but, as previously explained, sometimes the sensitive signal couples to a less controlled signal or control line and is again re-radiated at some other circuit connection point, causing even further contamination of the overall circuitry. While this problem is often controllable inside an individual shielded box, the use of ribbon cables in place of heavy shielded harnesses in composite aircraft applications represents a severe protection for not only TEMPEST, but also for EMP and Lightning protection.

Several mechanical and layout techniques are available that will reduce the radiated problems associated with ribbon cables. Some techniques also increase the internal crosstalk isolation.

For the simple wire, radiation is affected by proximity to grounded wires. In general, a 20 to 30 dB reduction in emission level is achieved by grounding the odd numbered wires in a ribbon cable.

The following mathematical relationship describes the twist rejection resulting from twisting parallel wires within a ribbon cable. Obviously, emission characteristics are further changed when a ground plane or an outer shield are incorporated.

$$R_{dB} = -20\log_{10} < (\frac{1}{2nL+1})[1+2nL\sin(\frac{\pi}{2n\lambda})] > \quad dB$$

where n is the number of twists per meter
L is the cable length (m)
λ is the wavelength (m)

Since twisting, adding a ground plane, or jacket shielding affect cost and signal transmission performance[6], engineering tradeoffs are necessary when selecting one method over another. Summarizing the techniques[7] to reduce radiated emissions are:

1. Reduce the spacing between individual wires by increasing the AWG wire size and reducing insulation thickness. Only a small (6 dB max) reduction in radiation is possible with this approach while crosstalk between wires is increased.
2. Join alternate signal returns together at the connector at each cable end. Multiple grounds between conductors can be created in this way, especially if signal returns are individually floated, which will reduce both emissions and crosstalk. The condition is shown in Figure 14-9.

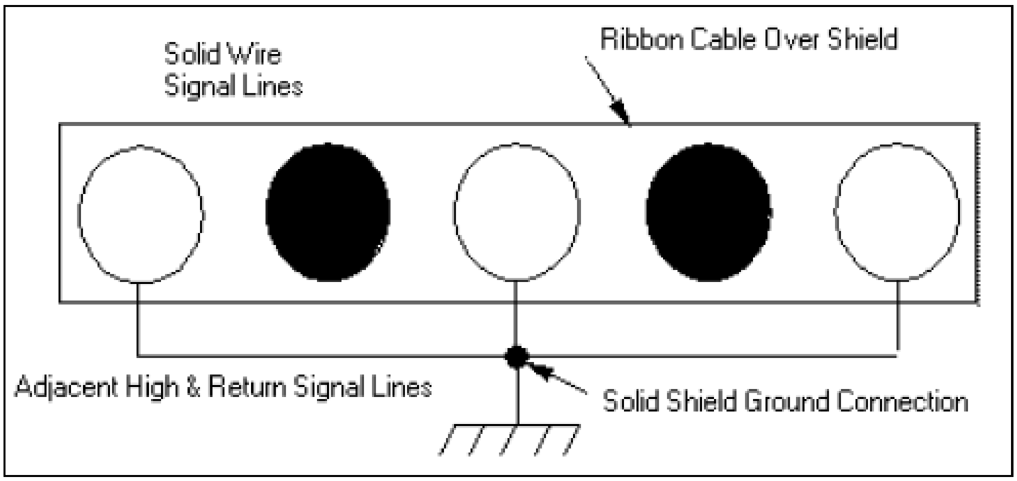


Figure 14-9 Alternate Grounding of Ribbon Cable Wires

3. Ribbon cables are available with twisted pair wires. If balanced signals are being used, twisted pairs will reduce considerably crosstalk and radiation problems.
4. Replace unshielded ribbon cables with shielded cables, or employ an envelope type shield over the existing cable.
5. Replace discrete ribbon cable with stripline flexprint cable. Methods available to reduce both crosstalk and shielding are shown in Figure 14-10.

Connectors

Various cable-to-board connectors are used to terminate multi-pin ribbon cables. This cable connector type comes in various configurations. However, regardless of connector type, the design thrust in new hard wire cable and connector systems is to provide the capability for increased signal speed while at the same time decrease cable and connector size and packaging costs. Digital pulses with subnanosecond rise times have considerable high frequency content, which in turn demands careful control of impedance discontinuities within the transmission line system.

[6] 1 Palmgren, Charlotte M., Shielded Flat Cables For EMI and ESD Reduction, EMC Technology, Vol. 1, No. 3, July 1982.

[7] White, Don, The Role of Cables & Connectors in Control of EMI, EMC Technology, Vol. 1, No. 3, July, 1982.

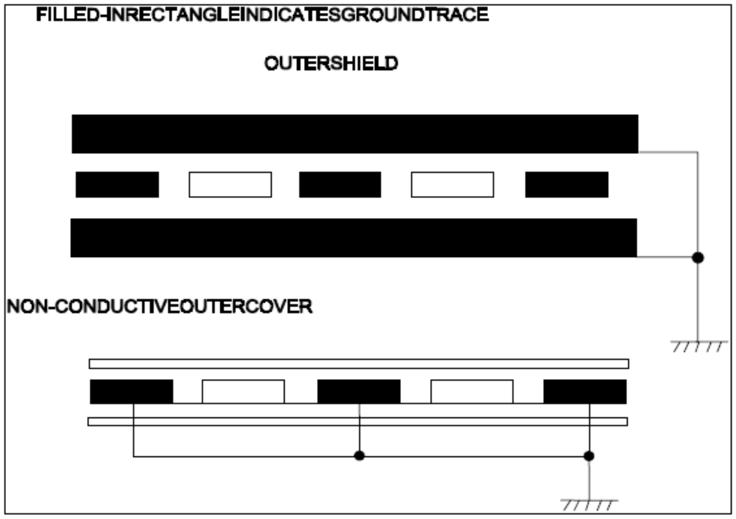


Figure 14-10 Stripline Flexprint Methods

In order to maintain the needed control, while also increasing signal throughput, designers have often adapted their conventional connectors by committing a large number of signal pins to function as ground connections. Another approach to maintain control has been to carefully control the dimension, spacing, and dielectric properties of the connector/pin assembly. While each of these techniques enhance the ability of a cable and connector combination for signal transmission, the same approaches also work to reduce the escape secure emissions from the assembly. However, since the design thrust is on cross channel coupling reduction, even the best crosstalk noise reduction techniques can be compromised if outside signals can couple into the cable system.

General Cable Termination and Connector Guidelines

The following design considerations are relevant in the application of shielded cables and connectors to aircraft platforms.

1) Cabling penetrating the case should be shielded and the shield terminated in a peripheral bond to the case at the point of entry.

2) Cable shield grounds should be maintained separate from any signal grounds or circuitry grounds.

3) Cable shields should be bonded peripherally to adapter and connector shells; cable shields should not be "pig-tailed off" and run through on connector pins.

4) Connectors should be of the type which make peripheral shield (shell) ground before the pins mate during the process of connection. The pins should disconnect before the shield (shell) separates.

5) Pins of connectors leading to electronic circuitry should be, wherever possible, female. Otherwise, they should be recessed male pins so as to exclude contact with any portion of the shell of the mating connector or with operator fingers.

6) Connector backshells should be selected such that they do not degrade the shielding effectiveness of the entire cable harness assembly.

References

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