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IPC-TM-650 TEST METHODS MANUAL

Number **2.5.15**	
Subject **Guidelines and Test Methods for RFI-EMI Shielding of Flat Cable**	
Date **10/86**	Revision **A**
Originating Task Group **N/A**	

1 Scope It is the intent of these guidelines to describe the material properties and test procedures required to ensure effective RFI and EMI shielding of flat cable.

1.2 Definitions

1.2.1 Relative Shielding Effectiveness The attenuation difference in the electromagnetic field strength between an unprotected cable and a shielded cable system, which is expressed, $S = R_x + A + B$, where:

R_x = the losses caused by reflection in db
A = the losses caused by absorption in db
B = the secondary reflection losses of the shields in db.

The reflection losses are a function of the material, frequency, and type of field. Generally, the field within one wave length from a generating source will either be predominantly electric or magnetic, and at greater distance will propagate as a plane wave made up equally of electric and magnetic components. Thus, the reflection losses for each of these fields may be designated by:

R_E = electric or ''E'' field
R_H = magnetic or ''H'' field
R_p = plane wave field

The absorption losses are a function of the material and frequency but are independent of field type. If these losses (A) are greater than 10 db, the secondary reflection losses are negligible, and the expression for shielding effectiveness reduces to S = R + A.

The following are standard equations that may be used to obtain a rough approximation of a shield's effectiveness.

Absorption Losses:
$A = 3.38 \times 10^{-3} t\,(uGf)^{1/2}$

Reflection losses:
1. Plane wave

$$R_p = 108.2 + 10 \log \frac{G \times 10^6}{uf}$$

2. Magnetic fields

$$RH = 20 \log \frac{0.462}{r} \left(\frac{U}{Gf}\right)^{1/2} + 0.136\, r \left(\frac{Gf}{u}\right)^{1/2} + 0.354 \quad (r < \lambda)$$

3. Electric fields

$$R_E = 353.6 + 10 \log \frac{G}{ur^2f^3}$$

$$(r < \lambda)$$

where:

G = conductivity relative to copper
u = magnetic permeability relative to free space
f = frequency in Hertz
r = distance from source to shield in 2.5 cm
t = thickness of metal shield in 0.0025 mm
λ = wavelength

A field surrounds every source of electric energy. The simple situation of an electric current flowing through a wire causes a field to exist around the wire, whose magnitude and direction follow well-known principles. Part of the energy in any field is propagated through space and eventually dampens to zero. The remaining part of the energy of a field either returns to its origin or is absorbed by some receiving source. A dipole antenna behaves in this manner; part of its energy becomes a radiation field, while another portion (that periodically returns to the antenna) becomes the induction field. The general mathematical expression that describes an electromagnetic field is rather complex and is usually discussed in texts on field theory. It is easier to discuss this expression in terms of its electric vector E and its magnetic vector B, where E has the dimension of V/1 and units of volt/meter and B has the dimensions of $VT/1^2$ and units of volt-second/meter^2. E and B can then be written as the sum of two components:

$$E = E_i + E_R$$

$$B = B_i + B_R$$

The components of the induction field are E_i and B_i, while the components of the radiation field are given as E_R and B_R, E_R, and B_R are proportional to B_o/R ($B_o = w/v_oR$, where w is the angular frequency of the field in radians and v_o is the velocity of propagation in meters per second.) E_i and B_i are proportional to $1/R^2$, where R is the distance from the source in meters. The ratio of the two is B_oR or wR/v_o. It can be concluded from this that for very small values of R and any given values for w and v_o, the induction field will be so much greater than the radiation field, that the latter may be neglected. However, if R is very large, the radiation field is important and the induction field can be discarded.

Induction fields are either high- or low-impedance fields. A high-impedance field is defined as a field whose impedance is higher than the impedance of the dielectric in which it exists. A low-impedance field has an impedance lower than the impedance of the dielectric. High-impedance fields are associated with a voltage source and most of their energy is contained in their electric component, while low-impedance fields are associated with a current source and most of their energy is contained in the magnetic component.

1.2.2 Shield Impedance An important parameter associated with these radiating fields is the characteristic impedance, which is the ratio of the electric to magnetic field components. For a plane wave in free space, the characteristic impedance is 377 ohms, and correspondingly for intense electric or high impedance fields, it is greater than 377 ohms, and for strong magnetic or low impedance fields, it is less than 377 ohms. The difference in characteristic impedance between an incident field and a shield is directly proportional to the reflection losses. The characteristic impedance of a shield varies with the material's permeability, conductivity, and frequency. Shield impedances are generally low at low frequencies and increase directly with frequency. Since at all frequencies, electric (E) fields are high impedance and magnetic (H) fields are low impedance, the corresponding reflection losses are high for electric fields at low test frequency and low or poor for magnetic fields at the same test frequency. As test frequencies increase, the impedance mismatches decrease for electric fields (decrease in R_E) and increase for magnetic fields (increase in R_H). The absorption losses for both electric and magnetic fields increase with frequency. It can be concluded from this that good shielding effectiveness against predominantly electric fields can be obtained with most high conductivity shielding materials. At low frequencies, R_E losses are so high that small absorption losses may be neglected and, at high frequencies, even though most of the transmitted energy is coupled to the shield, absorption losses are high enough for adequate shielding if all nonconductive openings in the shield are eliminated. Shielding against magnetic fields presents a different situation at low frequencies, where absorption and reflection (R_H) losses are small. Here, uniform 100% shielding is essential and in most cases ferromagnetic, highly permeable materials are employed to increase absorption losses. At high frequencies, both reflection and absorption losses are high, and shielding effectiveness is good for magnetic fields.

Table 1 shows properties of various metals at 150 KHz and 400 MHz and the corresponding absorption loss in db. The significance of this table is to show the necessity for highly permeable materials to shield against low frequency magnetic fields.

3 Test Specimen None

4 Equipment/Apparatus None

5 Procedure None

6 *Notes*

6.1 Shielding effectiveness is usually determined more precisely by measurement than by calculation, especially when 100% shielding is impractical. To obtain the attenuation capability of a shielding material about a flat cable, it is more practical to test a cable system for its susceptibility to radiated energy.

Figure 1 shows a test setup designed to measure shielding effectiveness in a flat cable for electric and magnetic radiating fields. Two 1.5 m cable specimens, one shielded and one unshielded, are terminated in their characteristic impedance at the generator source end and attached through a coaxial switch to a field intensity meter (or similar device) at the other end. These two cable samples are mounted and suspended 2.5 cm above a conducting ground plane and 7.5 cm to either side of a bare unshielded copper wire (see Figure 2). This radiating copper wire is connected at one end to a RF signal generator and is terminated at the opposite end in either a short or non-radiating open circuit.

6.2 When the bare wire is open circuited, the majority of the radiated field is electric, and when it is short circuited, magnetic fields dominate. Since the cables are only 7.5 cm away from the radiating source, electric and magnetic shielding effectiveness can be measured separately at frequencies up to approximately 4 GHz. It is assumed that if a shield is effective under these conditions, it will be equally effective against plane wave radiation.

6.3 Four readings must be taken at each test frequency. First the voltage pick-up in the unshielded specimen is observed and is used as the reference level for the voltage measurement on the shielded line. The shielding effectiveness in decibels is given by:

$$S = 20 \log V_u/V_s$$

where:

V_u = voltage induced into unshielded cable
V_s = voltage induced into shielded cable

Table 1

Metal	Relative Conductivity G	Relative Permeability u	Properties of Various Metals at 150 KHz			Properties of Various Metals at 400 MHz		
			Absorption Loss in db A	Magnetic Reflection Loss in db R_H	Electric Reflection Loss in db R_E	Absorption Loss in db A	Magnetic Reflection Loss in db R_H	Electric Reflection Loss in db R_E
Silver	1.05	1	1.34	34.7	198.5	6.92	48.9	155.7
Copper	1.00	1	1.31	34.5	198.3	6.76	48.7	155.5
Gold	0.70	1	1.09	32.9	196.7	5.65	47.1	154.0
Aluminum	0.61	1	1.02	32.4	196.1	5.28	46.6	153.4
Magnesium	0.38	1	0.80	30.3	194.1	4.17	44.5	151.3
Cadmium	0.23	1	0.63	28.1	191.9	3.24	42.3	149.1
Nickel	0.20	1	0.58	27.5	191.3	3.02	41.7	148.5
Iron	0.17	1,000	17.06	1.07	160.6	88.14	11.8	117.8
Tin	0.15	1	0.50	26.3	190.0	2.62	40.5	147.3
Steel, 1045	0.10	1,000	13.10	0.0001	158.3	67.6	9.8	115.5
Lead	0.08	1	0.37	23.6	187.3	1.91	37.7	144.5
Mu-Metal	0.03	80,000	64.13*	7.3	134.0	331.17	0.93	91.2
Permalloy	0.03	80,000	64.13*	7.3	134.0	331.17	0.93	91.2
Stainless Steel	0.02	1,000	5.85	-1.3	151.3	30.23	4.2	108.5

*Valid only if incident field does not saturate metal.
Calculations are for a 0.0025 mm thick shield 2.5 cm away from the radiating source.

These readings are taken with both open and short circuits on the radiating bare wire.

6.4 It should be noted that although a shield may be quite effective in protecting a cable system, tests should be made to determine the affect the shielding materials have on the internal electrical cable properties.

In a cable system handling high-speed digital pulses, the choice of shielding materials can greatly affect important transmission characteristics. If a shield is applied to suppress strong magnetic fields and a ferromagnetic material is used, which has a low conductivity, it will create a direct capacitance coupling between adjacent signal carrying conductors. This coupling will cause an increase in the crosstalk between signals and will also distort the output rise time of the pulse.

If shielding is necessary on a sophisticated transmission line system, a few tradeoffs might be necessary to obtain the optimum operating conditions.

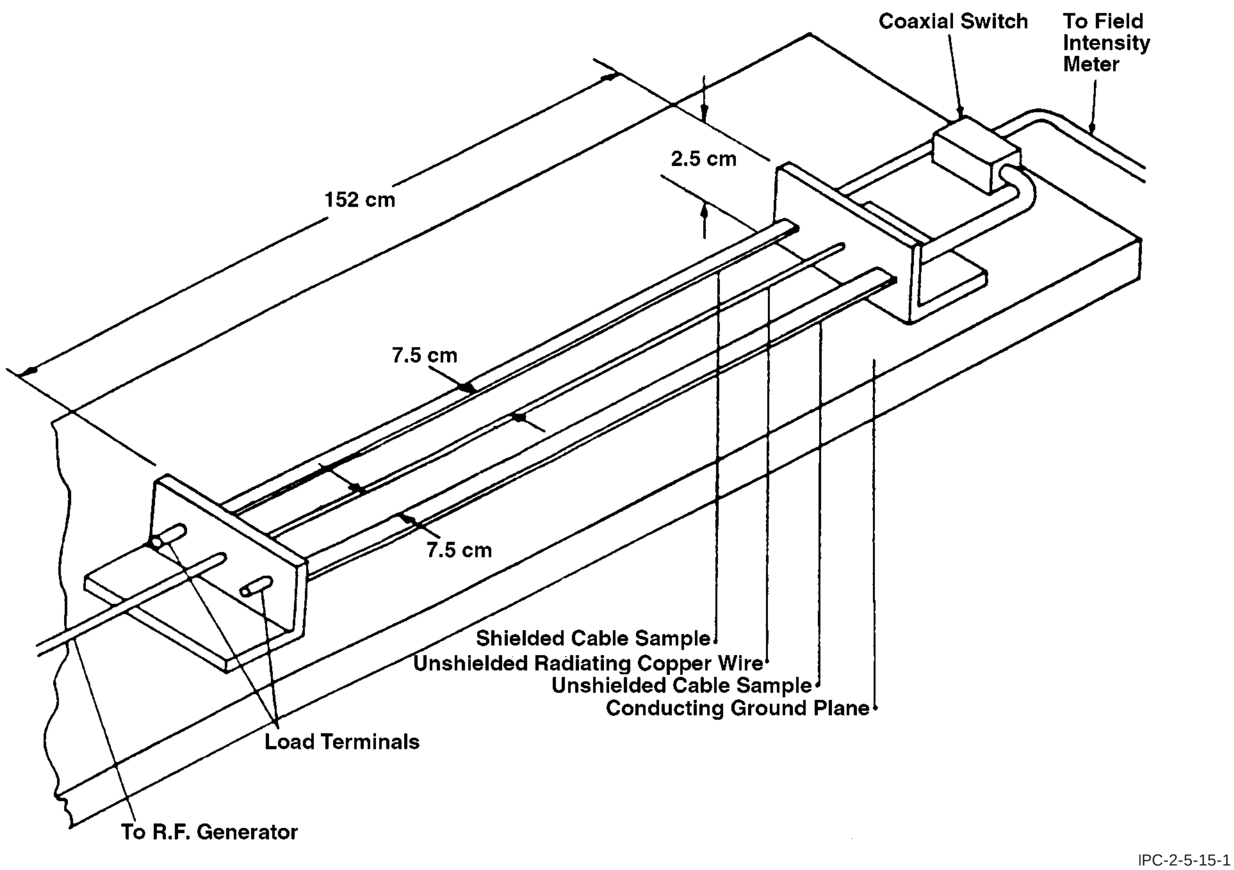
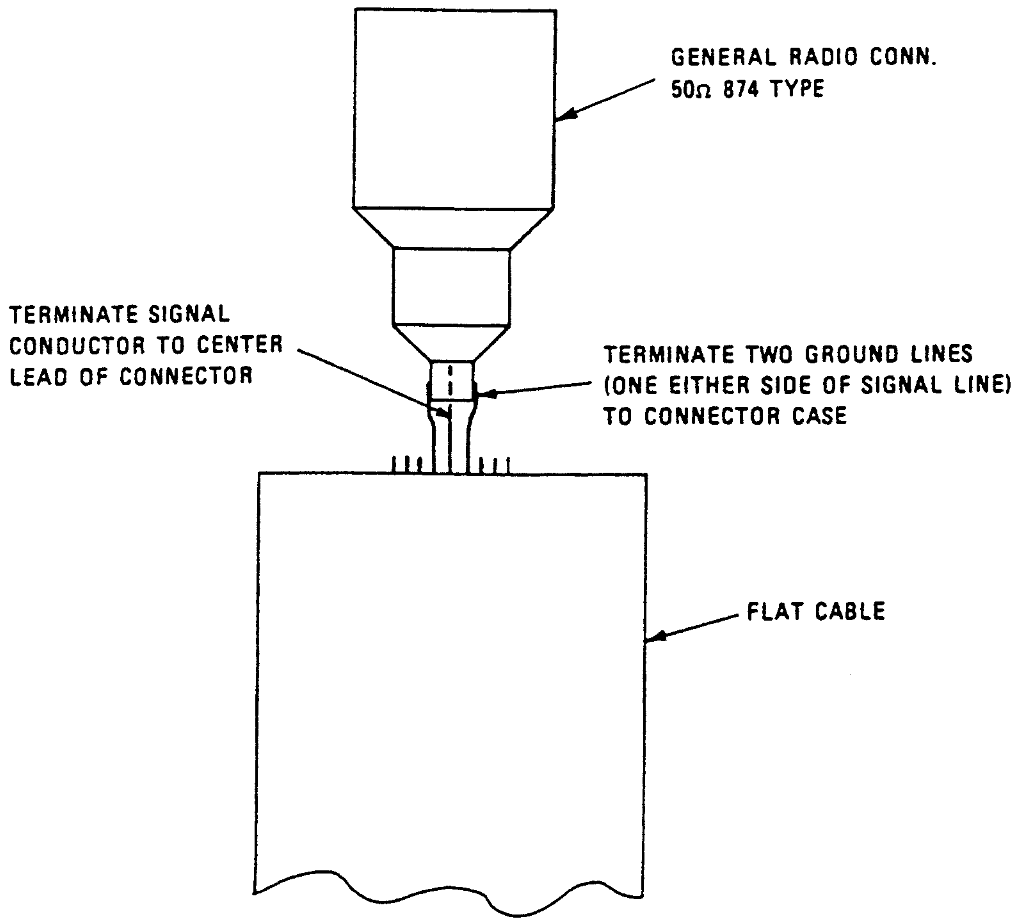


Figure 1 Shielding Effectiveness Test Setup



NOTE: ALL TERMINATIONS SHOULD BE MADE AS SHORT AS POSSIBLE AND TOTAL AREA SHOULD BE SHIELDED WITH WIRE MESH OR COPPER FOIL

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Figure 2 Connection of Copper Wire