CABLE ASSEMBLY TESTING FOR EMI

Whether we are interested in near, far, or mid-near field effects, each shielding effectiveness test method for cable assemblies has its advantages.

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INTRODUCTION

Each type of cable assembly test for EMI/RFI compliance is designed to detect a specific EMI/RFI problem and each type of test will produce different results. The tester must be familiar with each test and select the one which will give him the desired results. Transfer impedance tests show gross overall shielding with the internal conductors acting as a single conductor (e.g., coaxial cable). Antenna tests measure the response of a cable to medium and far field effects (far field being defined as greater than one wavelength of the incident radiation). Reference wire tests made with a wire running along the outer shell of a cable assembly detect the cable assembly response to near field effects.

SPECIFICATION/TEST DEVELOPMENT

This section analyzes the various test type specifications and how they are related to the use of the cable assembly and the internal (and shield) design of the cable. Also transfer impedance, antenna and reference wire testing are examined.

TRANSFER IMPEDANCE TESTING

Transfer impedance testing was developed as a means to predict the shielding effectiveness of coaxial cables with a single inner conductor and one or more cable shields. This testing technique calls for an overall shield (or two) to be placed over the cable and for measurements to be taken. It is designed to measure near field effects.

First described by Schelkunoff in 1931[1] the technique of shield transfer impedance measurement has found extensive applications in many areas. In Schelkunoff's work he defined the surface transfer impedance of a shield as follows: "If a current is caused to flow along the conductor of a cable, with its return path on the surface of the shield, then the longitudinal voltage along an incremental length which results on the inside surface of the shield is related to that current by the surface transfer impedance, and has units of impedance per unit length." This thought can be expressed mathematically as:

$$Z_t = (V_{shield} / I_{shield})$$

Measurement techniques for determining shield transfer impedance are many and varied; however, each places other shield(s) around the cable under test. As one adds additional shields, the accuracy of the transfer impedance determination increases; however, for all practical purposes, one additional shield will provide all of the accuracy necessary to produce useful results.

A simple method described by Martin and Mendenhall[2] called the "short-short" method gives acceptable results in frequency ranges where the cable under test is electrically short when compared to the wavelength of the radiation being measured. When the cable approaches the wavelength of the radiation, resonances are measured which will mask the attempt to determine the transfer impedance.

The method described by Martin and Mendenhall relies on a closely woven braid pulled over the cable to be measured and a triaxial transfer impedance test fixture formed between the braid and the cable under test. A tracking generator provides a suitable current source and a spectrum analyzer measures the voltage (Figure 1).

Since transfer impedance is only one of five variables in the formula for shielding effectiveness, special care must be taken to eliminate or at least minimize the other four variables in order to have the measured transfer impedance accurately describe the shield and its effectiveness.

An explanation of the total shielding effectiveness calculation leads to a prediction of those terms that must

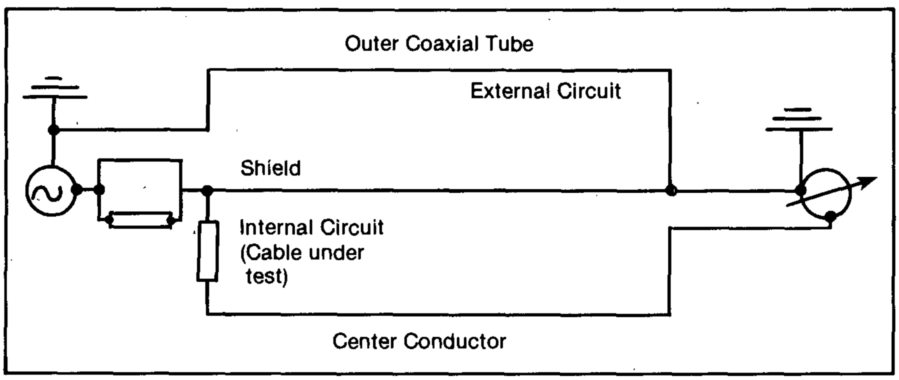

Figure 1. Transfer Impedance Test Fixture.

be minimized in order for transfer impedance to describe the shield. The transfer impedance Z_t, can be related to shielding effectiveness as follows:

Let shielding effectiveness be

$SE = (P_{out} / P_L)$

where

$P_{out} = I^2$

P_L = Power to end of line = (V_L^2 / Z_o)

and

$$F = \frac{[4(1 - \epsilon_{12}\epsilon_{22})(1 - \epsilon_{21}\epsilon_{11})}{(1 + \epsilon_{11})(1 + \epsilon_{22})(1 - \epsilon_{12})(1 - \epsilon_{21})]}$$

where

ϵ_{11} = Reflection coefficient of the drive line at the source

ϵ_{21} = Reflection coefficient of the drive line at the termination.

ϵ_{12} = Reflection coefficient of the pickup line at the termination.

ϵ_{22} = Reflection coefficient of the pickup line at the detector.

The following equation for transfer impedance can be derived from known results:

$$Z_T = \sqrt{Z_{01} Z_{02}} \sqrt{(1 / SE)(F / L)}$$

where

Z_{01} = Characteristic impedance of the drive line.

Z_{02} = Characteristic impedance of the pickup line.

If we now solve for shielding effectiveness, then:

$$SE = \frac{Z_{01} Z_{02}}{Z_T} \left(\frac{F}{L}\right)^2$$

which when rewritten in logarithmic form to express the results in dB gives:

$SE = 10 \log_{10}(Z_{01}) + 10 \log_{10}(Z_{02}) + 20 \log_{10}(F) - 20 \log_{10}(L) - 20 \log_{10}(Z_T)$ dB

The various terms of this formula are related to cable construction. The first term $[10 \log_{10}(Z_{01})]$ characterizes the relationship of the cable shield to all other conductors in the vicinity including the shield itself. The second $[10 \log_{10}(Z_{02})]$ characterizes the dependence of the shield's effectiveness on the internal construction of the cable. The third term $[20 \log_{10}(F)]$ characterizes the dependence of the shielding effectiveness of the way in which the conductors and the cable shield are terminated. The fourth term $[20 \log_{10}(L)]$ indicates that the shielding effectiveness for short cables (less than one-quarter of a wavelength) goes down as the square of the cable length decreases. The final term $[20 \log_{10}(Z_T)]$ shows that shielding effectiveness increases as surface transfer impedance decreases.

Of the five terms characterizing shielding effectiveness, only the final term describes the shield leakage, so only that term is affected by the actual design of the shield. If it were possible to completely control all of the other terms, the surface transfer impedance would be sufficient to totally specify shielding.

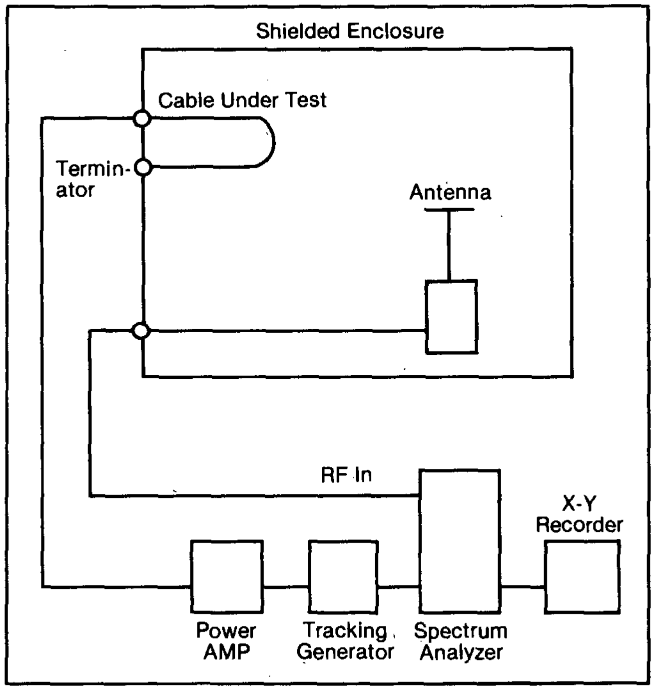

Figure 2. Antenna Measurement System.

ANTENNA MEASUREMENTS

Antenna measurements offer an alternative that is not as dependent upon the total design of the cable and its shield. Measurements of an equivalent system without a shield are made; then measurements of the same system with a shield are made. The system of Figure 2 shows a typical configuration used to make antenna measurements.

Antenna measurements by their very nature provide a direct result of shielding effectiveness. The technique calls for one set of measurements to be made with an unshielded cable of exactly the same construction as the shielded cable. The shielded cable then replaces the unshielded cable in exactly the same location relative to the antenna. The measurements are then made with the shielded cable in place.

The shielding effectiveness of the shielded cable is the represented by;

SE = voltage (dB) unshielded cable
– voltage (dB) shielded cable

Since this technique relies on an empirical solution and is only as good as the repeatability of the measurements, the following possible sources of error must be considered:

- Differences between the shielded cable core and the unshielded cable.
- Variances in the positioning of the two cables.

- Variation in the output power level of the power amplifier during the two runs.

This method is typically of greatest value when used in determining absolute power levels emitted by a system in a test to some standard such as FCC Part 15, Subpart J. Even in this measurement, extreme care is taken to ascertain that the test site is calibrated and all reflections are accounted for before proceeding.

REFERENCE WIRE TESTS

Reference wire tests have been developed in order to measure shielding effectiveness in the mid-near field. One such test is described in Missile Command Specification, Cable Assembly, Special Purpose, Electrical, General Specification for MIS-20097. This specification was developed to control cable assemblies used in and around the radar of missile systems. These cable assemblies are exposed to the transmitting fields of the radar system and must be tested in order to determine if they can perform their design function within those fields.

Since we are in a strong radar field, the test attempts to duplicate those fields to some extent and to determine if the cable assembly shields will protect the wires from the radiation. The cable assembly to be tested must be maintained in a consistent configuration during each test and between tests. A non-metallic material, such as plywood, acrylic, etc., should be used to support the cable assembly under test and the reference conductor. In this test, sufficient isolation must be maintained between the signal source and the receiver to achieve the dynamic range required for the tests. A reference conductor is placed in near proximity to the cable assembly as shown in Figure 3.

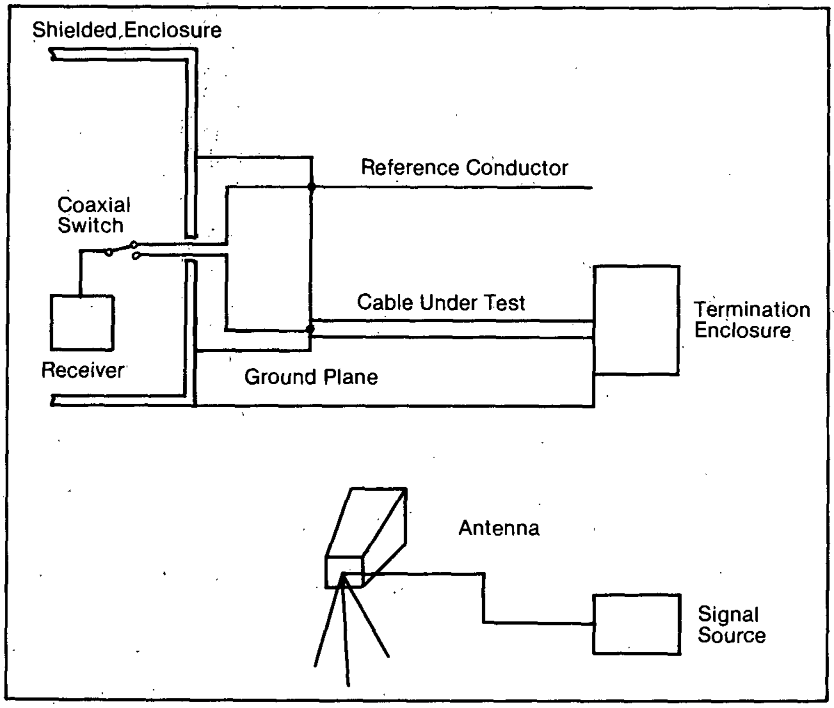

Figure 3. Reference Conductor Shielding Effectiveness Test.

The open circuit voltage is measured on the center conductor of the cable assembly under test and compared to the open circuit voltage of the reference conductor. For multiconductor cables, voltage measurements are made on at least one conductor of each lay of the cable, in addition to the center conductor.

As in the antenna measurements described above, the shielding effectiveness of the cable assembly is calculated by subtracting the voltage in dB on the reference conductor from the voltage in dB on the cable assembly.

This test by its design has been able to provide reasonable assurance that any assembly passing the test is able to withstand the environment of the radar systems in operation.

COMPARISON OF TECHNIQUES

Each test technique has its place and its function. Attempts to characterize the shielding effectiveness of a cable assembly can result in confusion. Whether we are interested in near, far or mid-near field effects, each technique has its strengths. The prediction of the performance of cables in a different field or configuration from that in which it was tested is not reliable. When one makes antenna measurements or reference wire tests, it is obvious that different cable dress or a slightly different positioning of the cable can make vast differences in the results obtained. When one treats a cable as a single conductor as is done in transfer impedance measurements, errors are found when multiple signals flow at the same time within the cable.

It is therefore clear that one must consider how the cable assembly is to be used when selecting the type of test to be performed. In fact, it is often necessary to perform several tests in order to classify the shielding effectiveness of the cable assembly. A cable assembly which will perform well in a near field at high frequency may not perform well in a far field at lower frequency. Tests and calculations have proven that only in the frequency range of approximately 20 to 30 MHz is there any reasonable correlation between the various measurement methods.

The reason that this correlation exists in this frequency range is that the differences between near field and far field effects for cable assem-

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blies are not so pronounced between those frequencies. A full rigid mathematical proof will not be shown here, but the physical size (nominally the diameter) of the cable assembly in that frequency range helps to mask the differences that would otherwise be obvious.

CONCLUSIONS AND RECOMMENDATIONS

As we have previously shown, it is vital that the end use of the cable assembly be known before the choice of test method is made. If, however, the cable assembly is to perform only in EMI fields in the range of 20 to 30 MHz, the choice of test method is not as important since the methods are generally equivalent in that frequency range.

It is recommended that if multiple signals are expected within a cable assembly (i.e., not a coaxial cable), then either the reference wire or the antenna test should be used. This is especially true if the usage will be at frequencies in the range of 50 to 500 MHz. For higher frequencies, either the antenna test or the reference wire test may be used since the wavelength of the radiation will be shorter than the average cable assembly and the fringing effects of the end of the assembly will have very little or no effect on the final result. ■

REFERENCES

1. S. A. Schelkunoff, "The Electromagnetic Theory of Coaxial Transmission lines and Cylindrical Shield." Bell Systems Technical Publication, Monograph B-816, 1939.
2. Albert B. Martin and Mark Mendenhall, "A Fast, Accurate, and Sensitive Method for Measuring Surface Transfer Impedance." IEEE Transactions on EMC, Vol. EMC-26, No. 2, May 1984.
3. MIS-20097D, Missile Command Specification, Cable Assembly, Special Purpose, Electrical, General Specification For. U.S. Army Missile Command, Redstone Arsenal, Alabama.

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a Certificate of Conformance (C of C) placed in the shipping carton. In the latter two instances, it is vital that the receiving inspection department preserve this data with the Inspection Report for future traceability.

COMPONENT PLACEMENT

The routing of wire cables near heat generating components should be monitored carefully during the manufacturing process. The Quality Inspector should be aware that the routing of cables away from electrical components is required by the agencies and that this routing is part of their inspection procedures. The manufacturing drawings may not define the wire routing clearly, and the routing could be found unacceptable by the agency inspector.

CONCLUSION

The cautionary reminders listed above are based on extensive experience with both the planning of agency reviews and with the actual factory inspection following the agency review. Implementation of these suggestions will ensure an easy and efficient transition from the review process often planned by the engineering group to the factory inspection performed by the quality group. ■