THE SHIELDED CABLE TESTER (SCT): AN IN-SITU HARDENED CABLE TEST SYSTEM

The SCT detects cable shield faults that evade visual inspections, milliohm-meter checks, and quadraxial transfer impedance tests.

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INTRODUCTION

Shielded cables play an essential role in the design of complex electronic systems; they enable each system to operate in severe electromagnetic environments. Thus, it is imperative that the integrity of shielded cables be verified so that commercial systems continue to function during and after exposure to lightning, electromagnetic interference (EMI), and other forms of electromagnetic radiation. It is, of course, even more critical that weapon systems be able to endure these forms of interference as well as more severe radiation, such as electromagnetic pulse (EMP).

Unfortunately, cables are routinely subjected to a great deal of day-in, day-out abuse, such as vibration, corrosion, and rough handling, which can cause the shielding to break down. In fact, shielded cable testing has consistently shown that threaded connector/backshell joints degrade in the operational environments; so far, every system tested has had these degradations. Further, degradation has occurred regardless of the specific design features or fabrication processes (including various connector accessory manufacturers, connector materials, etc.). Even those connector backshells treated by Loktite™ or retaining wire showed no improvement under operational conditions.

Because of the prevalence of hardened (shielded) cables on military systems, it is of paramount importance that the integrity of these shields be verified by Hardness Surveillance (HS). These cables must provide the RF shielding vital for high-altitude electromagnetic pulse (HEMP) and electromagnetic compatibility/electromagnetic interference (EMC/EMI) hardness. The quality of this shielding determines the amount of energy coupled to sensitive interface electronics through the cable core wires -- the stronger the shielding, the higher the protection against failure or degradation. However, until recently, the complex cabling requirements of today's sophisticated systems have made traditional verification methods extremely difficult, if not impossible.

Measuring the hardness of shielded cable in complex electronic systems is facilitated with a specialized tool, the Shielded Cable Tester (SCT). The SCT can measure the transfer impedance of a shielded cable without removing the cable from its host system, thus saving the costly dismantling and reassembling tasks necessary for in-lab testing.

BACKGROUND

The SCT was developed to fill a specific Air Force need -- to perform in-situ HS testing on electromagnetic pulse (EMP) hardened cable shields. Its development was begun in 1985 under the Weapons Laboratory (WL) EMP Test Aircraft (EMPTAC) Program. Laboratory experiments performed to define principal SCT characteristics included direct comparisons to data acquired in a quadraxial test fixture to establish SCT accuracy. This work led to a functional proof-of-concept SCT.

Beginning in early 1986, various experiments on the EMPTAC and on operational military aircraft resulted in a refinement of the proof-of-concept SCT. SCT data was demonstrated to be analytically related to the free-field, time-domain HEMP response of a cable. This proved the SCT's direct relationship to the actual free-field HEMP transfer function, and confirmed its usefulness as a valid HS tool.

In 1987, an SCT prototype and procedures were developed and validated for use by the Oklahoma City Air Force Logistics Center (OC-ALC). The SCT has since been used to collect data on various system cables on the B-52, B-1B, E-3A, EC-135, Minuteman and GWEN.

Also in 1987, the SCT concept was implemented on the Common Strategic Rotary Launcher (CSRL) Program. The CSRL SCT is used for hardness assurance (HA) testing of cables on the production line. The CSRL SCT automatically gives a pass/fail indication based on predefined criteria.

In exploring the utility and adequacy of the SCT concept, this article addresses both its capabilities and limitations as an HS and hardness assurance tool. It contains a brief description of the SCT, an overview of its hardware/software configurations, samples of several test data interpretations, and a summary of SCT performance.

DESCRIPTION OF SCT

The Shielded Cable Tester is a relatively simple test technique. It quantifies the performance of a cable shield from 10 kHz to 100 MHz. Thus, it is useful as a HEMP HA/HS tool or as an EMI/lightning protection verification tool.

The SCT induces a known current on the shield of the cable under test (CUT), and measures the induced core-to-shield voltage on a single core wire, giving

$$Z_t = \frac{V_{core}}{I_{shield}} \text{ (ohms)}$$

after automatic correction for probe and instrumentation factors. A simplified sketch of the SCT concept is shown in Figure 1.

As a HEMP HS tool, the SCT is highly automated so that depot technicians can operate it efficiently and accurately. Because it can measure cables in-situ, there is no need to remove the cable under test from the host system. Instead, one connector

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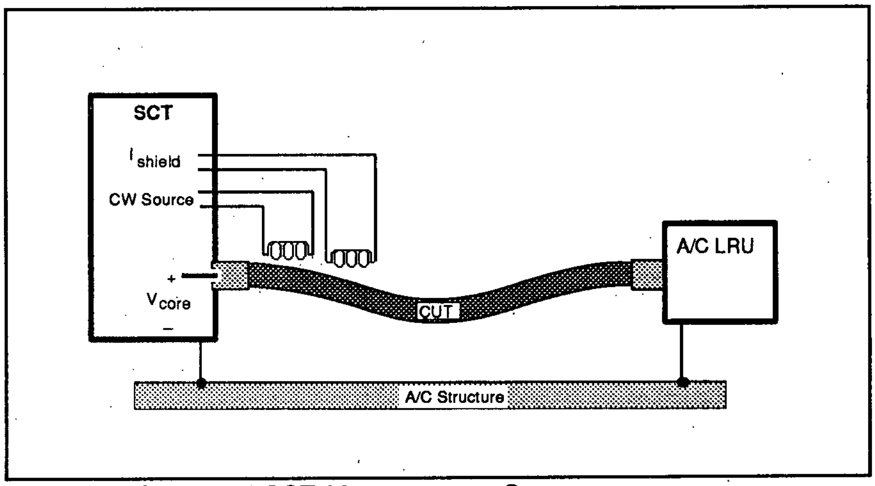

Figure 1. Sketch of SCT Measurement Concept.

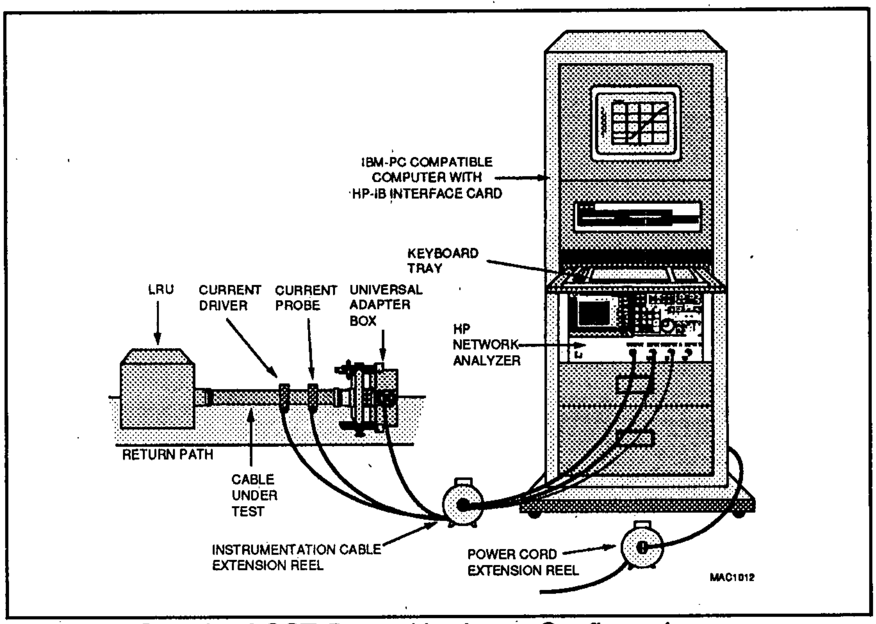

Figure 2. Sketch of SCT Depot Hardware Configuration.

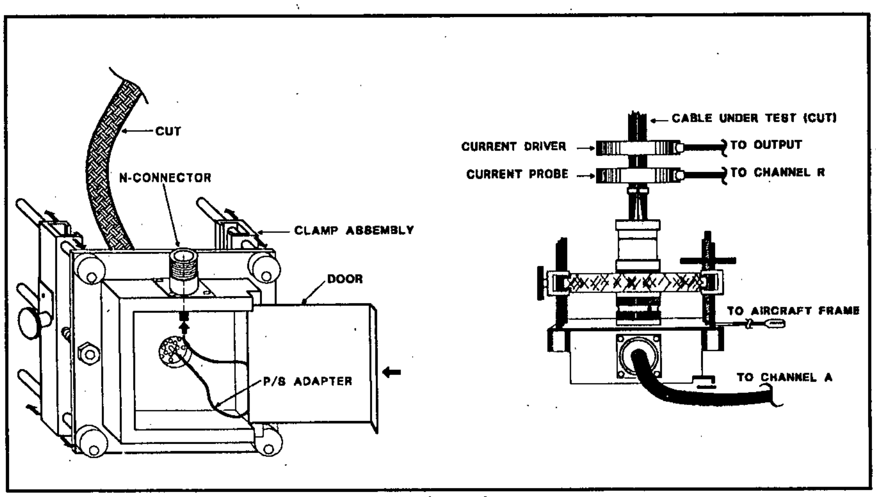

Figure 3. Universal Adaptor Box (UAB).

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of the cable is disconnected and hooked to the SCT. No special mating connectors are required to connect to any MIL-STD-38999 connector since the SCT uses a single universal adapter box to make this connection. Also, since most of the cable, including the opposite end of the cable under test remains untouched, little preparation is needed to conduct the testing.

Once testing begins, the operator simply follows prompts on the SCT computer screen. If pass/fail criteria are available for the cable under test, the SCT will make an automatic pass/fail determination. All data are archived for later review on any IBM PC compatible computer.

The SCT measures the total transfer impedance of a cable shield. The total transfer impedance (Z_t) is the underlying physical property which describes the shielding provided by a cable shield:

$$\mathbf{V}_{core}(\omega) = \mathbf{i}_{shield}(\omega) \cdot \mathbf{Z}_t(\omega)$$

and

$$\mathbf{Z}_t(\omega) \approx \mathbf{R}_{dc} + j\omega\mathbf{M}_{12}$$

where the components R_{dc} and M_{12} are useful to summarize the transfer impedance in two scalar numbers.

Since SCT data summarize transfer impedance, they can be (and have been) used to accurately predict the actual HEMP response of a cable under test. As a result, these data are more meaningful than simple "shielding effectiveness" data. In fact, SCT data can be combined with HEMP free-field test results to derive high confidence pass/fail criteria.

SCT HARDWARE/ SOFTWARE

The SCT mainly uses off-the-shelf hardware. Figure 2 shows a depot hardware configuration.

The "universal adaptor box," or UAB shown in Figure 3, is an essential non-standard part of the SCT. The UAB connects to any MIL-C-38999 series 1-3 connector; no special mating connectors are required.

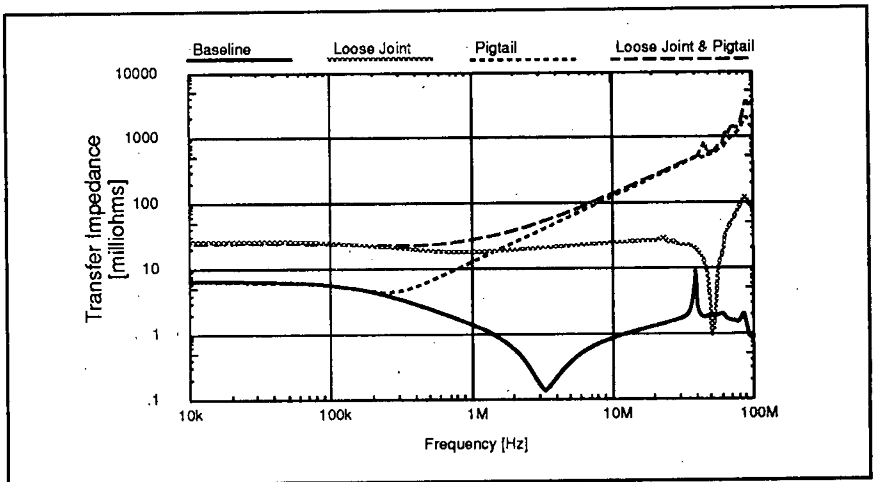

Figure 4. SCT Data Contains Unique Fault Signatures.

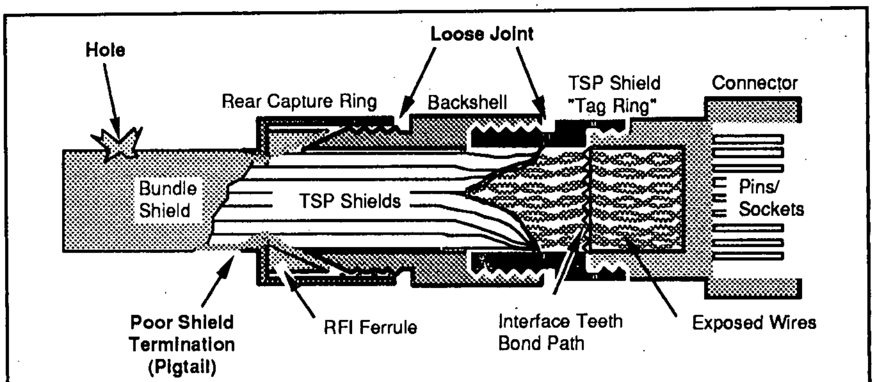

Figure 5. Cable Shield Faults are Usually at Connectors.

Thus, the SCT rapidly measures almost all military HEMP hardened cables without using any special connectors or adaptors.

The SCT software, named SAMDAS, contains more than 10,000 lines of code. SAMDAS exercises complete control over all SCT equipment. It automates all test, analysis, and logging tasks so that the SCT can be used by technicians without special skills or extensive training. Via a simple nested-menu format, SAMDAS performs the following functions:

- Initialization of the network analyzer;
- Verification of SCT calibration;
- Data acquisition and storage with informative headers;
- Data analysis (decompose Z_t and R_{dc} and M_{12} components, determine pass/fail based on specific criteria); and
- Data retrieval and plotting/printing of overlays and headers.

SCT DATA INTERPRETATION

The SCT can do more than simply detect the presence of a shield degradation. By comparing HS data with baseline data and/or pass/fail criteria, the SCT can determine the type, location, and severity of the degradation.

Every cable has a unique transfer

impedance signature that is readily discernable using the SCT. Further, each type of cable shield fault also has a unique signature. Thus, by comparing a baseline signature with the SCT signature of a cable with a faulted shield, one can immediately identify, categorize, and determine the severity of the fault. The SCT data overlays shown in Figure 4 illustrate that several types of shield degradations (faults) are apparent.

Each fault type is linked to a failure at a specific location in a cable assembly, as shown in Figure 5.

The "loose joint" fault signature is indicative of degradations that occur at connector and backshell joints. This signature is simply a frequency-dependent increase in the baseline shield signature. It is called a "loose joint" fault because it is most often caused by a loose threaded joint in the connector assembly. However, corrosion in a tight joint will result in the same signature.

A "pigtail" fault is caused by a non-circumferential termination of the shield braid at the connector backshell attachment point. Its signature is an increase in the baseline signature that is directly proportional to frequency. This type of fault is less common than the "loose joint" type fault. In the case where both a "loose joint" and a "pigtail" are evident in the same cable, the result is additive, as shown in Figure 4. Therefore, both faults can still be detected.

The least important type of fault is a "hole" in the shield braid. This type of fault is rarely observed in an operational cable. Furthermore, it is not severe in terms of its signature. Figure 6 shows the SCT signature of a large "hole" (same diameter as CUT) compared to previous signatures. Note that the "hole" signature is well below the other signatures.

Another aspect of SCT data interpretation involves the high frequency resonances apparent in the data. Note that all data shown in Figures 4 and 6 have distinct resonant peaks and notches in the 50-100 MHz region. The cause of this structure is standing waves on the interior transmission line (core wire to shield) and exterior transmission line (shield to surrounding structure). These standing waves are unavoidable in the in-situ environment. The interior and exterior lines are simply not good transmission lines; they do not have a uniform impedance and they are badly mismatched. However, the SCT can detect and characterize all important cable shield faults in the presence of this structure.

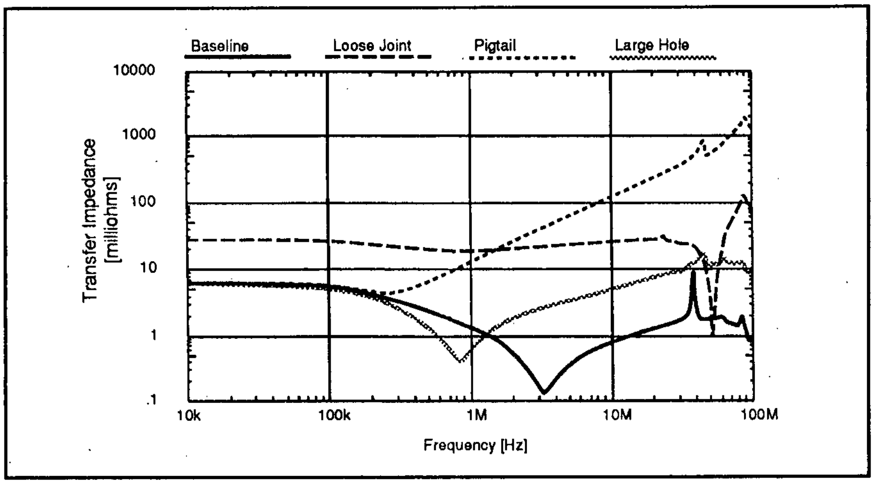

Figure 6. A "Hole" in a Shield is Relatively Unimportant.

CONCLUSION

In a variety of tests, the SCT has detected cable shield faults that have evaded visual inspections, milliohmmeter checks, and even quadraxial transfer impedance tests. Further, it detects faults well below the level at which repairs must be initiated, so adequate warning of an impending hardness problem can be obtained. In addition, the SCT is simple to operate, testing and data interpretation are highly automated, and the data are repeatable. ■

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