Abstract: In the course of developing a Shield Ground Adapter (SGA), two deficiencies were found: existing technology ground adapters require shipyards to stock large numbers of ground adapters of different sizes and style, and the frequency range of the test fixture is limited. NUSC have developed a new concept ground adapter that works equally well with different cables, conduits and stuffing tubes, in a wide range of different size combinations. In conjunction with this development we have combined the modified MIL-C-38999 triaxial test fixture with a network analyzer S-parameter test set, to extend the usable frequency range and sensitivity of the test method to one giga-Hertz.

I. INTRODUCTION

EXISTING shield ground adapters and conduit ground adapters, used for EMP protection aboard Navy ships, require a different ground adapter for every possible combination of cable/conduit and stuffing tube size. Therefore, a shipyard that commonly uses ten different cable, five different conduits and five stuffing tubes may have to stock as many as fifty cable-to-conduit adapters, fifty cable-to-stuffing tube adapters, and twenty-five conduit-to-stuffing tube adapters. This assumes that each size of cable, conduit, or stuffing tube is supplied to the shipyard by the same manufacturer. Some existing technology ground adapters require different adapters for variations in a cable, conduit, or stuffing tube size, even within the tolerances of a single nominal size, e.g. a one inch stuffing tube may have an outer diameter of 1.250 inch from one source and 1.300 inch from a different manufacturer, these could each require a different ground adapter.

NUSC has developed a Universal Ground Adapter (UGA) that eliminates the need for shipyards to stock large numbers of different sized ground adapters. By using an adapter that is tolerant of large dimensional changes, and combining it with a standardized end to end mating pipe thread, the number of different parts the shipyard must keep in stock is kept to a minimum. The “iris spring” technology used has been shown to have good long term transfer impedance performance, and avoids known degradation problems with electrical connections using standard “straight” thread. Pipe threads do not have this same degradation problem. With this scheme the most the shipyard would have to stock is fifteen female adapter sizes, one for each cable or conduit size, and five male adapter size for the stuffing tubes.

II. GROUNDING DEVICE PROBLEMS

The creation of a low impedance bond to ground of shipboard conduits and shields is not a problem that can be solved using standard plumbing supplies. To protect the below-decks areas of a Navy vessel from the high frequency, and high level cable currents caused by an Electromagnetic Pulse (EMP), a low impedance shunt to ground is needed. This wideband low impedance ground must be maintained in a hostile saltwater environment by sailors unfamiliar with the purpose of the device they are maintaining.

A. Thread Degradation

The typical method of grounding a cable to the hull at a penetration is to use an adapter that makes electrical contact with the cable shield or conduit using some variety of pressure contact, then threading the adapter into the stuffing tubes welded to the deck of the ship. This method of grounding cables and conduits also needs to provide an environmental seal against the elements. These adapters, to-date, have been initially successful in creating the electrical contact to the shield or conduit. One area where these adapters fail is in the threaded connection to the stuffing tube. The threads quickly corrode, rendering the adapter virtually useless. The problem is inherent in the fact that the stuffing tubes are designed to provide a means to keep water out, and are not well suited to solving the problem of keeping currents from an EMP out. They are, however, what are currently installed on the ships, and at this time there are no practical alternatives.

B. Thread Geometry

The severity of corrosion as an impedance problem is largely dependant on the physical configuration of the adapter and stuffing tube. From an electrical standpoint, it is acceptable if an adapter has limited corrosion in areas other than the electrical contact area, as long as the integrity of the electrical contact is maintained. The geometry of the stuffing tube thread is such that corrosion is accelerated in the worst possible place. The threads are loosely fitting to conform with the MIL-SPEC for stuffing tubes which calls out a type B thread. Type B thread
provides for quite loose tolerances so that a threaded part is easy to assemble. This loose tolerance works against the effort of providing a low impedance electrical contact. The gaps between loosely fitting threads trap contaminants which promote corrosion. Figure (1) is a representation of a typical stuffing tube thread interface.

The typical configuration in the stuffing tube has the adapter threaded into the stuffing tube bottoming out on a “gland” which provides the environmental seal. Therefore, the pressure applied to the thread area is dependant on the resilience of the gland. If the adapter is torqued tightly into the stuffing tube the initial pressure will only be maintained if the gland does not deform any further over time. If the gland hardens or permanently deforms, the result could be a loss of pressure to the thread interface and a degradation to the electrical performance.

D. Conduits/Cables/Stuffing Tubes

Differences in manufacturing methods and materials make the dimensions of stuffing tubes and conduits vary. Conduits, of the same nominal size, manufactured at different times or by different companies often have different dimensions. An adapter that depends on a tight tolerance for dimensions to function properly may not be interchangeable between the similar conduits from various manufacturers.

To meet the needs of varying sizes of conduits and stuffing tubes, a wide selection of adapter size combinations are needed. A shipyard using many different conduits and stuffing tubes may be required to stock or order an enormous variety of adapters.

III. GROUNDING DEVICE SOLUTIONS

A. Iris Ring Technology

The Iris Ring technology has been proven to create a long-term, high performance, electrical connection between a cable, or conduit, and the adapter body. The Iris Ring is a coil spring bent into a circle with the ends joined. The diameter of this circle is constricted around a cable or conduit strung through the ring, by sliding down the interior surface of a cone. With sufficient force applied this provides an effective electrical contact between the cable or conduit and the cone. The amount of force required is dependant on the stiffness of the spring, the slope of the cone, and the diameter of the cable or conduit. A patent has been awarded for a very simple, cost effective ground adapter which can be used with coaxial cable.

B. Thread Solutions

An improvement of thread electromagnetic performance may also be achieved by a change in the thread geometry. As mentioned above type B threads are quite loose. Another standard thread style is the type A, the difference being tighter tolerances required during manufacturing. Because the type A thread is manufactured much closer to the nominal size, it will provide a much tighter fit between mated parts. The resultant electrical contact will be improved due to increased contact area and increased force applied to the contact area. While the stuffing tubes already installed may not be changed to type A threads the new ground adapters maybe manufactured with them. Type A and B threads are fully compatible with each other. Although this would not completely solve the thread degradation problem, it may help relieve it.

C. Pipe Threads

Pipe threads are a tapered thread developed to provide a water tight seal when connecting pipe. A result of the this is a tight joint with virtually no gaps to promote corrosion. A pipe thread makes complete contact with the mating thread on all joint surfaces of the thread. Furthermore, pipe threads tend to cut into each other,
thus exposing a bright new surface to make contact. These threads have good long term electrical performance. Unfortunately pipe threads are not fully compatible with the straight threads presently used, and their is no practical means to implement their use into the existing situation.

D. Conductive Grease

A solution that can be implemented into all existing adapters is the use of a conductive grease. A grease fills the gaps in the threads with conductive material and provides a seal against the environment. Unfortunately the existing greases are not galvanically compatible with aluminum. These greases contain graphite or zinc, each of which promote corrosion.

The addition of Tin to Zinc creates a mixture that is galvanically similar to aluminum and thus does not promote corrosion. Dr. J. Masi and NUSC has developed Zinc/Tin conductive anti-seize greases that are galvanically compatible with the 2024, 5086 and 6061 series aluminum presently used aboard Navy vessels. This provides a corrosion inhibiting environmental seal for the thread region, thus increasing its electrical performance life span.

IV. PREVIOUS SGA AND CGA EFFORTS

An early prototype SGA developed by NUSC, demonstrated good long term performance of the iris ring contact area. However, the overall performance of the device degraded due to thread degradation where the adapter threaded into the stuffing tube.

An effort was made to avoid the thread degradation problem when developing a CGA. This CGA contacted the outside of the stuffing tube, using a spring system similar to the Iris ring. Even after salt spray test this product successfully demonstrated a good long term high performance since electrical contact was not dependant on the threads. However, performance of this prototype CGA does depend on a close tolerance for the outer diameter of the stuffing tube which makes its use impractical on Navy Ships where the outer diameter tolerances for stuffing tubes are not presently specified.

V. UNIVERSAL GROUND ADAPTER

NUSC has applied for a patent for a Universal Ground Adapter (figure 2). This adapter will provide a long term, low impedance ground path to stuffing tube or other metallic tubes when configured as either a SGA or a CGA. It provides a device to the shipyards that can be

![NUSC Universal Ground Adapter Diagram](image-url)
configured to solve a variety of ground connection applications. A system of mated adapters with a standardized interface reduces the number of parts a shipyard is required to keep in stock.

A. Universality

Without some form of Universal ground adapter, a shipyard that commonly uses ten different sizes of cable or conduit and five different sized stuffing tubes may have to stock as many as fifty different sized ground adapters. Furthermore cables, conduits, and stuffing tubes that are nominally the same size, but manufactured by different companies, may have different dimensions. In order to cover these dimensional differences, the shipyard may have to stock a set of ground adapters for each manufacturer. The NUSC UGA incorporates a pipe-threaded mating section between the two halves of the UGA. This thread is of a standardized size such that the half that fits one size conduit or stuffing tube may be mated with another half of almost any size, to fit any combination of conduit or cable. By using a UGA the same shipyard may be able to stock as few as fifteen different parts.

B. Iris Rings

The contact between the stuffing tube, conduit or cable, and the adapter is an Iris ring system. This is a proven system commonly used by connector manufacturers for back shells as well as SGA's and CGA's. An Iris ring does not tend to permanently deform, therefore, it maintains a fairly constant force on the interface throughout the life time of the adapter. Vibration of the adapter tends, through motion of the spring, to make the interface self cleaning.

By using a constricting style iris ring to contact the outside of the stuffing tubes the problems associated with straight threads are avoided totally. Because the iris tolerates variations in diameter, one size adapter will fit all units of the same nominal size.

The constriction of the Iris ring provides a powerful pull resistance. In many cases no other means of securing a cable is needed. In situations more tension than the iris can hold is applied, an additional strain relief may be added to the connector nut.

C. Pipe Threads

The adapter is made “universal” by the addition of the threaded interface between the two halves of the adapter body. This is a critical interface, as all the current must pass through the connection. Using pipe threads in this interface should reduce or eliminate the degradation problems associated with the standard straight threads. Any remaining degradation may be eliminated by proper selection of corrosion resistant materials and coatings. The addition of a corrosion inhibiting conductive grease will further protect this interface.

VI. TESTING

In conjunction with the UGA R&D effort, NUSC has developed a new test method to determine the surface transfer impedance for SGA’s, CGA’s and conduits. This test method uses a modified MIL-C-38999 test fixture and an S-parameter test set which effectively extends the usable frequency range of the testing and also provides an increase in measurement sensitivity.

A. Previous Methods

Several methods presently exist for measuring the transfer impedance or shielding effectiveness of a device such as a conduit, SGA or CGA. These methods generally use a triaxial test fixture similar to that described in MIL-C-38999, combined with some method of measuring input and output levels of the device under test. One method uses a cylindrical resistive current probe to measure the current level at the desired sense point, while directly measuring the voltage at the output. The other method uses a power splitter to measure the input power level and the output power is measured directly.

B. Problems

There are several problems associated with these measurement techniques. The current probe method is susceptible to ground loops and the length of the triaxial fixture is \( \frac{1}{4} \) wavelength limited. Furthermore the cylindrical current probe must be specifically design for the diameter of the triaxial fixture.

The power splitter measurement technique solves the above problems, but requires the use of a 50Ω series load on the input. This load and power splitter reduces the available sensitivity by 6 dB as well as adding errors to the measurements due to the frequency characteristic of the load itself.

C. S-Parameter Testing

The test method developed by NUSC uses an S-parameter test set to eliminate the problems mentioned above. The test set works in a similar fashion to the power splitter but is able to compensate for the lack of the 50 Ω load. This method eliminates the need to design a special purpose current probe and the special purpose 50 Ω load used in the second, therefore this method is less expensive to configure. With a potential test frequency range of greater than 1 GHz, this technique provides the widest test band of any of the transfer impedance test methods for conduit or ground adapters presently available. Furthermore, the sensitivity is not degraded due to test configuration limitations.

The following equations relate the S-parameter Matrix to the Impedance Matrix:

\[
S = (Z - I)(Z + I)^{-1}
\]

where

- \( S \) = Scattering Parameter Matrix
- \( Z \) = Impedance Matrix
- \( I \) = Identity Matrix
Solving for the Impedance matrix:

\[ Z = I - 2S[S - I]^{-1} \]  \hspace{1cm} (2)

The test fixture is a two port device (figure 3), thus \( Z \) and \( S \) are both 2x2 matrices, where \( Z_{11} \) is defined as the input impedance, and \( Z_{12} = Z_{21} \) is equal to the surface transfer impedance. Expanding equation (3) into the individual components and solving for \( Z_{21} \) yields:

\[ Z_{21} = Z_T = \left[ \frac{2[(S_{11})(S_{12}) - (S_{12})(S_{11} - 1)]}{(S_{11} - 1)(S_{22} - 1) - (S_{12})^2} \right] Z_0 \]  \hspace{1cm} (3)

where \( Z_0 = \) characteristic impedance of the test setup (50 Ω)

\[ Z_T (\text{dB/} \Omega) = S_1 (\text{dB}) + 28 \text{ dB} \]  \hspace{1cm} (5)

\[ Z_T = \left[ \frac{Z_0}{2} \right] \]

To simplify equation (3), it is assumed that the device has a good short to ground \( (S_{11} = S_{22} = -1 + j0) \), and the transfer impedance is very small \( (|S_{12}|^2 << 1) \), then:

\[ Z_T = \left[ \frac{Z_0}{2} \right] \]

or

\[ Z_T (\text{dB/} \Omega) = S_1 (\text{dB}) + 28 \text{ dB} \]

\[ Z_T = \left[ \frac{Z_0}{2} \right] \]

D. UGA Testing

At this time no prototype has been constructed that includes all the features documented in the patent. Figure (4) shows the transfer impedance of a sample UGA to be approximately 0.2 mΩ. The curve below is the transfer impedance of the CGA developed by NUSC that had difficulties with outer diameter ranges. Both curves show similar low frequency responses. The CGA curve, however, drops into the noise floor of the analyzer above 10 MHz. A number of factors that may account for the differences between the CGA and the UGA. The materials used for the Iris rings and plating, make a large difference in transfer impedance. The performance for different Iris ring/plating combinations range over 20 dB. The combination of olive drab cad coating over nickel plate on an adapter with a passivated 302 CRES iris ring had the highest impedance. The performance may improve by as much as 20 dB using a bright cad over nickel on the adapter with a bright cad on a Beryllium copper Iris ring. Material selection is an important part of any connector design, and the final performance of the NUSC UGA will be largely dependant on the materials selected. The improvement associated with the use of pipe-threads has yet to be verified by measurement.
VII. CONCLUSIONS

Shield ground adapters and conduit ground adapters used for EMP protection aboard Navy platforms are designed to provide a wideband low impedance connection to ground over long periods of time. However, their electrical performance degrades rapidly over time. Solutions to this degradation has been investigated by NUSC. One of the major contributor to the degradation is the corrosion problem at the threaded interface. The thread geometry needs to be changed to ensure a tighter fit in the thread by either using: type A, or pipe threads. A conductive grease can also be used to: reduce the corrosion, and provide an alternate path between the threads. A final alternative is to bypass the thread interface altogether by using the iris spring technology and connecting to the outside of the metallic tubes.

A UGA was developed by NUSC which incorporates these ideas. An added benefit of the UGA is the ability to connect various sizes of conduits from various vendors to ground using a minimum number of stocked parts. Further development of the UGA is needed to select the best combination of metals used in its design.

A new transfer impedance test method was also developed along with the UGA effort. This test method has a higher frequency range and increased sensitivity over previous test methods and it will be used to verify the EMP performance of Navy shipboard conduits and fittings.

ACKNOWLEDGEMENTS

Support for this project was provided by the Office of The Chief of Naval Research/Office of Naval Technology; Submarine Technology Program Element. Program Element Manager is Mr. Gene Remmers, Code 233. Technology Program Block Manager is Mr. Larry Becker, Code 0114 of the David Taylor Naval Ship Research & Development Center. Principal Investigator of the “Below-Deck EMC Program”, is Mr. David S. Dixon, Code 3431 of the Naval Underwater Systems Center, New London, CT.

Development of the UGA was partially funded by NAVSEA PM 423 (Mr. H. Smith & Mr. R. Jones) and NAVSEA 06D44 Mr. M. Berman.

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