



PRTTUBING

WRAP AROUND HEAT SHRINKABLE TUBING

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ABSTRACT

PRT tubing is a side entry, wrap-a-round, heat shrinkable tubing that provides the high performance characteristics of solid heat shrinkable tubing and the installation ease and time savings associated with an electrical tape wrap. It eliminates 99% of the electrical harness disassembly problems classically associated with a shrink tubing repair by eliminating the need to slide the tubing over the end of the wire. A PRT repaired cable provides performance and longevity comparable to standard shrink tubing while minimizing installation and down time.

Heat shrinkable tubing has been used for years in both commercial and military applications to bundle and jacket electrical wiring. The tubing's unique ability to change dimensions when heated provides an excellent means of creating a high performance secondary jacket that provides additional chemical, electrical, mechanical and thermal protection in addition to circuit identification. However, classic heat shrink tubing has several installation-related limitations. The tubing requires the installer to fish the items to be covered through the tubing prior to heat recovery. The issue is of minor consequence at the wire board fabrication level where wire end access is easy. However, the "fishing through" process becomes time consuming and labor intensive when in-service wires or cables require repair. Typical wire harnesses have large electrical connectors and mounting clamp hardware that also limit repair access. A wire bundle requiring repair between cable breakout branches presents an even bigger repair challenge. All these issues hamper installation of conventional shrink tubing as a repair medium.

Use of standard shrink tubing for these repairs requires extensive cable disassembly. Electrical connectors and cable end hardware must be removed and then re-installed and re-tested to insure correct re-wiring. This process is time consuming and requires skilled personnel with the specialized connector disassembly and assembly tooling. This procedure raises the risk of potential damage to high cost electrical connectors that may not be readily available as spares. In many cases, removal of the connector may not be possible at all (i.e. a potted back shell). Historically, these repair problems have been addressed with the use of special high expansion ratio shrink tubing which is typically four to six times the diameter of the cable in its expanded state. The problem is that high ratio tubing's may not be readily available, have a limited size range, yield a stiff cable repair and still may not be large enough to accommodate the connector size. Furthermore, it rarely solves repair problems that occur between cable branch breakouts cables that passes through a bulkhead and cannot be removed.

As a result, cable repair problems have typically followed more installation friendly methods. Solutions such as using adhesive backed or self-vulcanizing tape wraps, loose fitting side entry jackets, liquid sealants, bulky pre-molded splice kits, spiral cut tubing and combinations of the above. Although these methods minimize disassembly and labor time, they do so at the expense of cable reliability, longevity and performance.

PRT tubing was developed to provide easy and economical solutions to these problems!

PRT TUBING

Wrap Around Heat Shrinkable Tubing

Background

Heat shrinkable tubing has been used for close to fifty years in both commercial and military applications to bundle and jacket electrical wiring. The tubing's unique ability to shrink when heated provides an excellent method of creating a tough and reliable secondary jacket for interconnect wire and cables. It can also add a variety of additional performance characteristics including chemical, electrical, mechanical and thermal protection. In addition, it can be used to provide alphanumeric circuit identification in a large complex harness or to color identify critical systems circuitry. However, classic heat shrink tubing has several installation-related limitations. The classic tubing requires the installer to fish the items to be covered through the tubing prior to heat recovery. This issue is of little consequence when a harness is being fabricated at the board level, since the fabricator has easy access to the wire ends. Although, the "fishing through" process can become time consuming and labor intensive when cable lengths are long. In-service wire and cable present additional problems when they require repair or modification. Typical wire harnesses have electrical connectors installed at the ends which are quite large relative to the cable diameter. These connectors can preclude or hamper installation of standard heat shrink tubing. In addition, a wire bundle that requires repair between cable breakout branches can require extensive disassembly and down time to repair using classic heat shrink tubing.

The use of standard heat shrink tubing as a repair material requires the cable assembly to be disassembled to the point where the cable can be slid through a new piece of tubing. The electrical connectors, connector end hardware and harness clamps would all have to be removed, then replaced and then re-tested to insure correct re-wiring. This process is not only time consuming but it requires skilled personnel with the appropriate connector disassembly and assembly tooling. It also risks potential damage to high cost connectors and secondary parts that may not be readily available as spares. In many cases, removal of the connector is not possible at all (i.e. potted backshell). Historically, the only heat shrink tubing solution to these types of repair problems have been the use of special high shrink ratio tubing that is typically four times the diameter of the cable it is intended to cover. In some cases this material can be slid over the connector and still be shrunk down to the cable diameter that needs repaired. Some problems with high shrink ratio tubing are that it may not be readily available, it has a limited number of sizes, is quite expensive, yields a very thick and stiff jacket, requires a connector disconnect and re-connect and ultimately, it still may not be large enough to accommodate the connector size. Quite often the cable is damaged between cable breakouts branches or the cable passes

through a cabinet wall or bulkhead and cannot be removed at all. In these instances, the high shrink ratio tubing does not provide a solution. Only complete removal of the cable assembly will allow wire access for a standard heat shrink tubing installation.

As a result, cable repair has typically followed more installation friendly methods. These repair methods tend to be very craft sensitive and the resulting cable performance may vary widely from installer to installer. Some of the solutions that have been utilized include; adhesive and self-vulcanizing tape wraps, loose fitting zip-on jackets, liquid sealant, pre-molded splice kits and spiral cut extruded tubing among others. All of these methods typically minimize the labor time involved to make a repair but they do so at the expense of cable longevity and performance. What has been needed is a material with the performance attributes similar to the original cable jacket or heat shrinkable tubing, but with the installation convenience of a wrap around jacket.

Classic Problem

Wire and cable damage tends to fall into two categories, minor and severe. Minor cable damage is typically limited to the outer cable insulation material being pinched or scraped which degrades the dielectric and environmental performance of the wire. The damage may or may not expose the primary conductor or EMI shield below the outer jacket. However, if not repaired, the jacket insulation may split or crack in service leading to corrosion, system failure or possibly an electrical arcing condition. Severe damage typically consists of broken wire strands or cables where the primary conductor strands have been cut or nicked severely. This type of damage is actually easier to address than the minor type because the decision becomes rather clear. Either replace the entire wire or install a splice kit. Splice kits, although undesirable, are relatively easy to install since the wires are already cut in half or close to it. System tear down is limited and numerous types of splice kits exist to make this type of repair. The minor damage type can be very frustrating because in many cases the primary conductor has only superficial damage and cutting a good conductor in half to facilitate installation of a splice is generally seen as undesirable. Yet, historically there has been no easy way to make these minor insulation repairs and provide decent reliability without tearing a large part of the system apart to access the damage area (Photos 1 & 2).

The PRT family of products was developed specifically to fill this need. PRT is not a splice kit and it should never be used as such. If the primary conductor is cut or the EMI shield has been damaged so severely such that more than one half the shield circumference is missing then PRT should not be considered as a repair option. If the damage level falls within the definition of minor, then there is no need to destroy a good conductor simply to make an insulation repair. In minor repair situations the use of PRT can result in a repair that takes only minutes instead of hours. It can reduce the vehicles down time and in turn reduce

the overall repair cost. The PRT solution eliminates secondary component damage since very few other components are affected. The material reliability is generally much higher than other quick fix solutions and depending on the installed environmental conditions the product can be expected to have a lifespan between two to twenty years.

What is PRT

The PRT product can best be defined as an application modified heat shrink tubing. PRT is made from standard cross-linked polyolefin heat shrinkable tubing, conforming to the requirements of Mil-I-23053/5, Class 1. PRT is created by longitudinally splitting the tubing and laminating a transfer adhesive along one of the split edges. A special acrylic pressure sensitive adhesive designed for adhesion to low surface energy plastics and oil-contaminated surfaces is used. The adhesive provides an outstanding bond over a service temperature of -40°C to 150°C, exhibits good fluid resistance properties and is flame retardant allowing the PRT product to pass UL224, VW-1 flammability requirements. The tubing material has also been re-sized to accommodate the circumference change associated with the material overlap inherent to a wrap around tubing. The wrap around design allows other materials to be added such as EMI shielding and hot melt adhesive layers resulting in a very versatile repair product. Currently PRT is available in four variations including the original standard split tubing (PRT), an EMI shielded version (PRT-S), an environmentally sealed tubing (PRT-ES) and an environmentally sealed shielded cable repair kit (PRT-1553). The product provides wrap around repair capability to wire and cable diameters as small as .040 inch to over 5.0 inches (Photo 3 & 4).

Unlike standard heat shrink tubing, it is not necessary to be concerned with the expanded tubing size or the material shrink ratio when using PRT. The material is purposely sized using a simple numerical designation. Each size fits a specific cable diameter range. One simply measures the cable outside diameter and selects the correct material size from the PRT sizing chart. PRT looks very different from conventional tubing when viewed in cross-section. The material also appears extremely oversized for the wire or cable diameter it is intended to cover. This illusion occurs because conventional heat shrink tubing is rarely viewed laid out flat, where the actual amount of material required to cover a given diameter can be seen (diameter vs. circumference). Another reason that PRT looks too large is that it actually is! For the PRT tubing design to work, there must be enough material present to cover the circumference of the intended cable when fully shrunk plus provide enough material to give an appropriate sized closure overlap. It should be kept in mind that the PRT closure overlap area also shrinks when heat is applied. The amount of extra tubing required for the overlap, in the expanded state can represent two or three times the finished overlap width. On a large size PRT part this could represent as much as 1.5 inches of extra tubing material when laid out flat versus the material required for tubing without an overlap. Installation personnel should not to be concerned by the large

size appearance of PRT. As long as the correct size material is selected from the sizing chart the PRT will create the proper fit when fully recovered.

PRT also offers the user several side benefits other than installation ease that are not immediately obvious. Since PRT tubing is split, the inherent hoop stress present in standard shrink tubing has been relieved. This means that PRT is not “notch sensitive” during heat recovery like conventional tubing. As a result, tubing nicks, cuts or ragged edges do not cause PRT to split like conventional tubing when heated. This feature allows installers to cut holes, wedges or other unusual shapes in the PRT material without fear of destroying the tubing when it’s heated. It is even possible to cut tapered shapes from the PRT material to create tapered transitions.

There is only one critical rule to follow when using PRT tubing; *always select the correct size*. When sized correctly, the PRT tubing will shrink down snugly against the cable about the same time the tubing stops shrinking. The result is a fully recovered jacket with minimal residual stress and a fully developed wall thickness. If installed on too large a cable diameter the tubing’s adhesive joint might tear open or the resulting tubing’s wall thickness will be thin. This condition is no different than conventional shrink tubing. Conventional shrink tubing is designed to be sized in the same way PRT is sized (close to the fully recovered diameter). If conventional shrink tubing is sized incorrectly, the tubing does not tear itself open like PRT might but will retain a large amount of “unresolved recovery” and in turn retain a high level of stress. In this condition the tubing wall thickness is less than the designer’s intention when compared with a fully recovered tube. The resulting thin wall thickness yields poor abrasion resistance and reduced dielectric strength. Since the tubing is under a great deal of stress, a small nick or scrape may cause the material to split open in service. Many installation personnel have unknowingly fabricated cable assemblies that were doomed to fail in service because of the miss-guided belief that one size fits all!

Lastly, it’s important to keep in mind that since PRT tubing was originally extruded in a round shape by the tubing manufacture, the PRT product inherently wants to return to that original extruded shape. Thus, PRT exhibits no tendency to open up at the adhesive joint once installation is complete. Even if the adhesive were to be dissolved completely, the tubing would still retain its round, closed shape.

PRT Testing

The PRT product was originally developed as a field repair for the commercial electronics industry and released as such in late 1990’s. This was followed by a slow growing interest within the commercial and military aerospace communities for use as a cable repair on in-service aircraft. As a result, the product has evolved beyond the original design to include an environmentally sealed version (PRT-ES) and an EMI shielded cable repair kit version (PRT-1553). The PRT-

1553 kit was developed to repair minor EMI shield damage in addition to creating the environmentally sealed cable jacket repair.

The testing of PRT has also had a two phase history. The original testing was performed by the Zippertubing Company to determine the commercial validity and limitations of the adhesively closed wrap around heat shrink tubing concept. In 2002, this was followed by some limited field evaluations by the US Coast Guard to determine the materials practicality as an airborne repair product. These initial field evaluations led to an evolution of the product into several variations aimed at fulfilling the severe requirements associated with aircraft. These modified variants were placed in field service for two years and then were examined and tested at the Air Force Research Laboratories, Wright-Patterson AFB at the request of the Coast Guard.

The following is a synopsis of the test data developed on PRT to date from both sources. It is intended to provide the reader with an idea of the integrity of the PRT product under a variety of environmental conditions. The test conditions were selected based on the limitations of the Mil-I-23053/5 tubing material as well as those seen in typical wire harness installations. Prior to use of this product the user should always independently test any environmental conditions that exceed those described herein. Performance data for the basic tubing material is well documented and can be found in Military Specification MIL-I-23053/5 as well as from most tubing supplier's specification sheets.

A. Closure Adhesive Manufactures' Performance Data

- 1) Excellent adhesion to lightly oil contaminated surfaces and low surface energy plastic substrates (i.e. polyethylene, polypropylene, polystyrene),
- 2) Adhesion strength: 136 oz/inch to polypropylene plastic after 72 hr @ R.T.,
- 3) Bond strength increases as a function of time and temperature,
- 4) Bond strength not adversely affected after 7 days at 32°C and 90% R.H.,
- 5) Bond strength not adversely affected by edge exposure to UV light,
- 6) Bond strength unaffected after 100 hrs immersion in water,
- 7) Bond strength maintained after temperature cycling: four cycles of 4 hrs @ +70°C, followed by 4 hrs @ -29°C, followed by 4 hrs @ +22°C,
- 8) Bond unaffected by exposure to most oils, mild acids and alkalis;
- 9) Suggested service temperature -40 to +150°C

B. Zippertubing Development Data

1) Overlap Adhesive Joint (Lap Shear):

- 1.0" x 1/2" specimens, pull speed 4.0"/min., 10 samples per data point
- Data shown is mean values (lbs) plus one standard deviation

Test Condition	Tubing #1 (121°C Shrink)	Tubing Mfg. # 2 (90°C Shrink)	Tubing Mfg. #3 (90°C Shrink)
R.T. for 24 hrs. (no heat recovery)	26.65 lbs 2.43 S.D.	21.55 lbs 3.08 S.D.	22.75 lbs 1.60 S.D.
Heat Shrunk (+24hrs @ R.T.)	41.66 lbs 1.34 S.D.	29.61 lbs 3.35 S.D.	29.28 lbs 3.07 S.D.
Heat Shrunk (+24 hrs @ -20°C)	41.87 lbs 1.89 S.D.	29.97 lbs 3.01 S.D.	29.44 lbs 2.79 S.D.
Heat Shrunk (+24 hrs @ 135°C)	43.67 lbs 1.15 S.D.	31.45 lbs 1.15 S.D.	30.64 lbs 2.17 S.D.
Heat Shrunk (+336 hrs @ 135°C)	43.14 lbs 1.57 S.D.	30.70 lbs 1.06 S.D.	31.43 lbs 1.82 S.D.

Results:

Bond strength varies with polymer formulation. Strength increases with heat exposure and dwell time. Strength not degraded by exposure to high or low temperature extremes or long term exposures to 135°C. Follow-on tests show the adhesive is not degraded by temperatures of 150°C for 336 hours. Strength degradation begins above 175°C and adhesive crystallizes at 200°C.

Conclusion:

The adhesive material appears more than adequate as a tubing closure material since it develops a strong shear strength bond to the MIL-I-23053/5 Polyolefin material. The application of heat to the adhesive system increases the bond strength by 35 to 65 percent. This improvement once heated makes the adhesive system more desirable as a closure material. Long term heat exposure indicates that the adhesive system is acceptable for continuous service at the 135°C operating temperature limit of MIL-I-23053/5 tubing. Test facility limitations restricted low temperature evaluations below -20°C. However, based on the cold-soak test results it seems reasonable to accept the -40°C temperature rating claimed by the manufacturer.

2) Fluid Resistance

Test Type: Bond joint condition; visual and fingernail lift of adhesive joint
Conditions: Immersion: 10 specimens, total immersion in test fluid @ R.T.
Dip/Drain: 30 sec. immersion / 3 hours drain, 3 cycles / day @ R.T.
Test Criteria: -New samples exposed to 24 or 336 hours total immersion @ R.T
-New samples exposed to fluids that caused any failures in the 24 & 336 hr. exposed to Dip & Drain test (splash environment)

TEST FLUID	IMMERSION		DIP & DRAIN 168 hrs
	24 hrs	336 hrs	
Tap Water	No effect	No effect	N/A
Salt Water (5% NaCl)	No effect	No effect	N/A
Coolant (50:50 Ethylene Glycol)	No effect	No effect	N/A
IPA (Isopropyl Alcohol)	No effect	No effect	N/A
MEK (Methyl Ethyl Ketone)	Disbond	N/A	No effect
Brake fluid (DOT 3)	No effect	No effect	N/A
Motor Oil (10W30)	No effect	No effect	N/A
ATF (type FA)	No effect	Disbond	No effect
Hydraulic Oil (ASTM-2882)	No effect	No effect	N/A
Washer Fluid	No effect	No effect	N/A
Gasoline	Disbond	N/A	No effect
Diesel Fuel (#2)	Disbond	N/A	Disbond *

Results:

The PRT adhesive shows good overall fluid resistant when exposed to commercially available oils, solvents and cleaning solutions. Only three fluids negatively affected the adhesive joint during the 24-hour exposure test. Of the three failures, two (MEK & Gasoline) did not produce failures when exposed to the Dip & Drain test. The Dip & Drain test was intended to represent a real world splash exposure that would be expected to occur from time to time. Continued total immersion in either of these two fluids presents a much larger safety issue than any concern about the adhesive. Diesel fuel caused adhesive bond joint failures in the 24 hour immersion test and the Dip & Drain test.* It should be noted however, that the Dip & Drain failure appeared five days into the seven day test cycle and the bond joint failure was limited to the bottom edge of all test specimens. The oily nature of diesel fuel caused a drip to cling to the bottom of the specimens creating a localized immersion situation. The ATF fluid caused adhesive failure in the 336 hr immersion test but not in the 24 hr test or Dip & Drain test.

Conclusion:

The data suggests that solvents that are highly volatile and evaporate quickly will not negatively affect the adhesive joint due to the short dwell time at the adhesive's exposed edge. Splash exposure followed by cleanup of oily solvent fluids like diesel fuel and ATF will probably not degrade the adhesive joint. However, long term exposure to these two materials in swamp-like conditions should be avoided since localized failure can be expected. PRT users should evaluate any fluids unique to their specific application where continuous exposure is likely.

3) Adhesive Joint Flexure

Test Type: Joint separation of PRT jacketed cable bending around mandrel.

Quantity: Each data point represents 5 test specimens.

Conditions: Finished cables of 0.448" OD bent around a 4-1/2" diameter mandrel (10x cable diameter per Mil-Std-454). Specimens were bent so the adhesive joint was positioned at 90 and 180 degrees from the mandrel surface. Each specimen cycled 3 times at 30 minute intervals (specimens returned to test temperature between cycles)

Criteria: Visual examination for bond separation

Test Condition	Seam @ 90 Degrees	Seam @ 180 Degrees	Comments
24 hrs @ 25 C (3 cycles)	No Disbonds	No Disbonds	No overlap kinks, Cable slightly stiff
24 hrs @ 135 C (3 cycles)	No Disbonds	No Disbonds	No overlap kinks, Cable very flexible
24 hrs @ -20 C (3 cycles)	No Disbonds	No Disbonds	No overlap kinks, Cable very stiff

Results:

No bond separations or overlap kinks in any of the exposure test conditions.

Conclusion:

The jacket overlap area should be positioned on the outside of cable bend radii whenever possible. Cable bend ratios of 10:1 or greater will not cause bond joint separations. PRT users with bend radii requirements less than the recommended 10:1 ratio may want to consider using one of the following installation options as a means of maintaining overlap integrity with tighter cable bends. Some process technique variations may be required to achieve acceptable results.

- 1) Install PRT material on a pre-bent cable configuration so stress is relieved.
- 2) Bend the PRT jacketed cable into position while the PRT material is still warm.
- 3) Select a PRT jacket size that is slightly larger than required (loose fit).

4) Flammability

Test: -Suspend 1/2" x 12.0" samples vertically above flame source
 -Flame impinges on material edge (5 specimens each test)

Conditions: -Shrink all specimens around an undersize mandrel & remove
 -Condition specimens 48 hours at 25°C and 70% R.H.
 -Expose specimen edge to 2.0" natural gas flame (15 sec) remove
 -Reapply flame for 15 seconds

Criteria: -Visual examination, measure burn length, note any dripping

Test	Mil-I-23053/5 Tubing (control)	Transfer Adhesive (on metal tube)	PRT Tubing (flame on overlap)
Smoke & Flame	Flames slightly while in flame	Very little in flame	Flames slightly while in flame
Self-Extinguish	2-3 seconds after flame removed	Immediate after flame removed	Immediate after flame removed
Char length	1/4 to 3/8 inches	1/8 inch	1/8 inch
Dripping Material	None, material curls up in char area	None	None, material curl up in char area

Results:

The pressure sensitive adhesive used to seal PRT does not support flame and does not flame up when exposed directly to flame. The adhesive does not drip and produces very little smoke when exposed to flame. The PRT construction overlap region burns less than the basic Mil-I-23053/5 tubing itself. This may be due to the fire retardant nature of the adhesive and the thicker tubing section at the overlap. The adhesive joint does not open up when exposed to flame.

Conclusion:

PRT is a highly flame retardant product that meets or exceeds the flammability requirements of the basic M23053/5 Class 1 tubing.

<u>Note:</u>
PRT has passed Underwriters Laboratories flammability testing to the requirements of UL224, VW-1. Material is recognized under file #E72210, Volume 1, Section 6.

5) Weathering

Test Type: Outdoor exposure
(Sun, UV, Rain, Dirt, Heat/Cold, fresh and salt water immersion)
Test Site: Laguna Hills, California, USA
Quantity: 1 specimen, 1/2" x 6 foot
Condition: Boat trailer wiring harness was jacketed using PRT-#5. The wire harness was positioned on top of the frame rail to provide maximum UV exposure.
Data: Visual examination for adhesive separation, deterioration and cracking
Duration: 09-15-1999 to 10-17-2005

Results:

Test terminated after six years and one month when the test fixture was sold. No visible evidence of bond joint separations anywhere along the jacket length. No evidence of tubing cracks or splits. The tubing was slightly stiffer than when originally installed but could be flexed using thumb pressure. The tubing was clamped to the trailer two inches back from the PRT tubing ends. This was done to keep the tubing ends free and allow them to open up if that was the materials nature. It also allowed the tubing ends to be subjected to snagging and flexure. No separations were seen at either end. At three years of field exposure, half of the test jacket was accidentally over-sprayed with black enamel paint. This had no negative effects on the PRT tubing or adhesive joint. At test termination the tubing's adhesive overlap joint was pried apart using a slot screwdriver and the joint was found to still be tacky and bonding to the tubing very aggressively.

Conclusion:

PRT is not adversely affected when exposed normal outdoor weather conditions. The high adhesive strength combined with the tubing's inherent nature to remain round and closed indicates that PRT should perform very well under long term field conditions. It is recommended that PRT users design their installations so that the PRT jacket ends are retained by a cable clamp, cable tie or string tie to minimize any potential snag damage.

6) Out Gassing (Spacecraft)

Test Type: Percent Total Mass Loss per ASTM E595-77/84
Test Site: Raytheon Corporation, El Segundo, California (09/2000)
Program: Classified Space Program

Results:	Mil-I-23053/5 Polyolefin Tubing:	= 0.95 %
	PRT Tubing Construction:	= 1.10 %
	NASA 1124 Publication (desired limit)	= 1.00%

Conclusion:

The adhesive used in PRT adds a small amount to the total mass loss in a vacuum environment versus standard tubing. Although PRT exceeded the NASA limit by 0.10% the customer determined that the repair benefits definitely outweighed the small increase in out gassing and considered it irrelevant.

PRT Application Recommendation

Based on internal test data and customer feedback from actual field applications the Zippertubing Company believes that the PRT family of products will perform well under most environmental conditions and provide years of service when the following conditions are met;

- 1) Follow the Zippertubing installation instructions closely.
- 2) Operational Temperatures: -55 to 135°C for PRT and PRT-S
-55 to 110°C for PRT-ES & PRT-1553 Kits
- 3) Avoid immersion or swamp-like conditions when exposed to highly volatile solvents, fuels and oils. Total avoidance is best. However, brief splash exposure followed by cleanup will generally not degrade the material. Long term or repeated exposure may reduce service life. (Consult Zippertubing Engineering for recommendations in severe applications)
- 4) Avoid exceeding a 10x cable diameter bend radius. Tighter radii are possible when the PRT is installed on a pre-bent cable (1st choice) or if the cable is bent into the final position while the PRT tubing is still warm and elastic (2nd choice).
- 5) Avoid use on cables where the PRT tubing will be in constant flex motion unless bend radius is very large or tubing has been purposely oversized.
- 6) If installed as an abrasion protective layer, orientate the overlap seam area towards the suspected abrasion source prior to shrinking. The PRT material is twice the normal wall thickness in this localized area.

Note:

All statements and technical information contained herein are based on tests we believe to be reliable, but the accuracy or completeness is not guaranteed under all circumstances. Before using Zippertubing products, the user shall determine suitability for the intended use, and user assumes all responsibility for improper selection. Published attenuation values of Zippertubing shielding have been verified by laboratory testing of the respective shielding materials. Actual installed attenuation values may differ due to installation techniques and final assembly operation parameters, which are beyond the control of the Zippertubing Company. Actual attenuation values can only be determined by the end user testing the completed assembly. U.S. and international patents and patents pending. Copyright 2008 The Zippertubing Company, Los Angeles, California.

6) Aircraft Field Test

In 2003 the U.S. Coast Guard challenged the Zippertubing Company to come up with an environmentally sealed version of the PRT product for use in airborne applications. Zippertubing added a hot melt adhesive layer to the existing PRT product design to create an environmentally sealed cable repair product known

as PRT-ES. The hot melt material utilized is a commercially available polyamide hot melt adhesive in tape form designed specifically for use with polyolefin heat shrink tubing. As the PRT-ES shrinks, the tape melts and flows to create an environmental seal between the wire jacket and the PRT tubing. A follow-on request was made to provide an EMI shielded cable repair version that could also repair damaged EMI shield braid strands on Mil-Std-1553 data bus cable and typical non rigid coax cable. Zippertubing added a 6 inch strip of Z-3250-CN, nickel over copper plated polyester fabric EMI shielding tape to the PRT-ES product and created the PRT-1553 repair kit. These pre-packaged kits are designed to repair damaged shielded cable with diameters up through 1/4 inch. Larger diameter shielded cables can also be repaired using these same materials when procured individually in bulk form. The Zippertubing installation procedure *ZT04-98-001: PRT Shielded Cable Repair* describes the procedure to create both the small and large diameter shielded cable repairs.

The US Coast Guard made several prototype installations and ultimately installed the PRT-ES product on a 6570 helicopter which had a Mil-W-22759/34 wire with insulation damage (Photo 5 & 6). This vehicle logged over two years and 1,407.1 flight hours with the PRT-ES repaired wire in place. The installation was made per the Zippertubing installation instructions and was located in an area within the operational temperature range of the PRT-ES product. Unfortunately, the installation was also exposed to a variety of fluids that Zippertubing recommended be avoided. The wire harness and repair sleeve were soaked with hydraulic oil, possibly jet fuel and an anti-corrosion compound known as Fluid Film (Eureka Chemical Co). None of these fluids had ever been tested by Zippertubing, but the jet fuel and hydraulic oil were suspected to be detrimental to the overall lifespan and performance of the PRT-ES repair product.

At the end of the 2 year (1,407.1 hour) operational period the PRT-ES repair was examined and found to be soft, swollen and sticky. At that time the repair was still functioning and had exhibited no evidence of a service failure (Photo 7). The US Coast Guard removed the repair and submitted it along with a request for a materials evaluation to the Air Force Research Laboratory/Materials Integrity Branch, Dayton, Ohio. The AFRL/MLSA undertook a detailed examination of this sample and reported it's finding back to the US Coast Guard in June 2007¹. The following is a synopsis of the results from the AFRL/MLSA report. The author encourages the reader to obtain a copy of this report to understand all aspects of this evaluation. The AFRL/MLS evaluation report stated the following;

- A 500 VDC Electrical Resistance test resulted in a value of $5 \times 10^{13} \Omega$ indicating the insulating value of the repair tubing had not failed.

¹ White, Edward L. and Hierholzer, James
Assessment of Wraparound Shrinkable Tubing Repaired Wire and Cable,
14 June 2007, Evaluation Report No. AFRL/MLS 07-043, The University of Dayton
Research Institute Materials Integrity Branch (AFRL/MLSA), Wright-Patterson
Air Force Base, Ohio 45433-7718

- A two minute 2,500 VAC Wet Dielectric test indicated that no breakdown of the insulation in the repaired area of the wire sample occurred.
- The environmentally sealed wraparound heat shrinkable tubing used to repair damaged insulation protected the wire electrically over a two-year period. However, materials degradation was noted in the sealing materials, which could lead to eventual failure.
- Aliphatic hydrocarbons and esters identified in the chemical analyses caused the environmental hot melt seal material and the edge seal adhesive to become semi-solid at the end fillets and along the length of the seam edge overlap. The environmental seal, however, was not compromised and the hot melt seal beneath the black tubing remained solid and provided protection and insulation in the damaged area of the wire (Photo 8).
- The hot melt seal beneath the black tubing provided good adhesion for the overlap seam and the tubing could not be pulled apart.
- The chemical data suggest that Fluid Film, while possibly present on the surface of the black tubing, was not observed in the decomposed hot melt and not responsible for the barium observed on the environmentally sealed wraparound heat shrinkable tubing.
- Previous fluid immersion testing reported in report AFRL/MLS 06-014 concluded aliphatic hydrocarbons like those found in JP-5 and JP-8 fuel will soften the butyl acrylate and hot melt adhesives. The presence of barium and esters, however, could be an indicator of hydraulic fluid exposure. The same fluid immersion testing included exposure to typical hydraulic fluids, namely MIL-PRF-83282, MIL-PRF-87257A and MIL-PRF-5606, without any deleterious effects to the environmentally sealed wraparound heat shrinkable tubing. From a chemical standpoint, aliphatic hydrocarbon esters typically are compatible with butyl acrylate and polyamide type materials.
- The source of the environmentally sealed wire repair seal degradation could not be determined. The empirical data suggest the aliphatic hydrocarbons, which soften the butyl acrylate and the polyamide hot melt adhesives, were either from jet fuel exposure or from materials that contain identical aliphatic hydrocarbons as jet fuel. It is highly possible the esters could have come from the butyl acrylate. Softening of hot melt at the fillets and edge seal adhesive at the overlapping edge of the tubing could be an indication the environmental seal is beginning to fail.
- The CPC product Fluid Film did not degrade environmentally sealed wire repair materials in a 48-hour exposure.

Based on the AFRL/MSL report details listed above it would appear that the negative effects seen on the US Coast Guard sample were likely the result of JP-5 or JP-8 jet fuel exposure. As stated, previous AFRL/MSL testing had shown that common aerospace hydraulic oils typically did not cause the damage witnessed in the Coast Guard sample. These results support Zippertubing's own internal test data showing that most oils do not harm PRT, but volatile fuels will

reduce the service life of the PRT products and can soften and eventually destroy the closure seam and hot melt adhesives. It also reaffirms Zippertubing's warning to avoid installations in areas likely to see fuel exposure.

In spite of the products condition it's important to remember that the sample tested did not fail! Post service testing showed that after the two year service cycle the material was still intact. It withstood both electrical resistance and wet dielectric testing and ultimately did not allow corrosion of the protected wire conductor. Based on these results, it seems realistic to assume that when exposed to severe conditions like those seen in the U.S. Coast Guard sample, the PRT-ES and PRT-1553 products should be viewed as an interim repair method. The PRT product will definitely keep a vehicle in operation until such time that the repair can either be replaced to continue extending the vehicle operation period or until the vehicle can be torn down completely to replace the damaged wire. The data also indicates that less severe installations could be expected to have a very long service life. It is suspected that a similar repair in a less abusive environment (no fuels and minimal oils), such as a radio rack or electronics bay would yield a lifespan that might exceed a decade or even the service life of the vehicle. It is impossible to place an absolute service life on the PRT products due to the extreme number of environmental variables. Zippertubing suggests that users follow the installation recommendations closely. When a repair must be made in an area where the environmental exposure is outside of the manufacture's recommendations, a periodic inspection cycle should be instituted to continually evaluate the condition of the repair and determine if the repair should be replaced. Because a PRT repair is relatively fast and inexpensive, it may be desirable to perform several repair cycles prior to pulling the vehicle from service to replace the damaged wire.

7) EMI Testing of PRT-1553

In addition to the request from the U.S. Coast Guard for an environmentally sealed style of PRT came the request for an environmentally sealed kit that could repair superficial EMI shield damage. Zippertubing developed the PRT-1553 repair kits by adding a strip of EMI shielding cloth tape to the basic PRT-ES product. The design intent of this product was to allow the installer to repair minor damage to the EMI shield braid on Mil-Std-1553 data bus cable and non rigid coax cables. Minor damage is defined as no damage to the primary conductor insulation beneath the shield. And the shield braid damage cannot extend more than one half the cables circumference. Any combination of primary conductor insulation damage and/or braid separation that exceeds these requirements is beyond the capability of the PRT-1553 kit. When the damage is beyond the limits described herein only an approved shielded cable splice kit should be used or the wire should be replaced.

In March 2007, the Zippertubing Company contracted with the Integrated Demonstrations and Applications Laboratory (IDAL), Electromagnetic

Interference Lab (AFRL/SNRA), Wright-Patterson AFB, Ohio, to perform EMI shielding tests on RG-180 coax and Mil-Std-1553 data bus cables that had been repaired using the PRT-1553 kits. The results were reported in a test report dated 9 April 2007². Two sets of test cables were fabricated from Mil-Std-1553 data bus cable and RG-180 coax cable. One of each cable type was purposely damaged with a defect falling within the PRT-1553 damage parameters. The cables were repaired using the appropriate sized Zippertubing PRT-1553 kits (Photos 2, 9 & 10 illustrate the RG-180 damage and repair). The repaired cables were sent to the IDAL laboratory for testing. This testing was performed as a comparison to the same type of testing that had been performed in February 2007 for the US Navy located at Patuxent River, MD³. Testing performed in February had shown that the technique did not yield good results, *“when a large section of the cable shield (approximately 2 inches) was removed and repaired with the Zippertubing product.”* The new test effort evaluated cables with damage levels within the prescribed Zippertubing product limitations. The test cables used for this test were the same “control cables” used in the February testing. Figures 1 thru 8 show the shielding performance for Transfer Impedance and Induced Voltage from 100 KHz through 18 GHz for the April 2007 tests. The data illustrates that there is essentially no difference between the original undamaged cable data and the PRT-1553 repaired cable data! The two sets of data follow each other so closely that in many instances it is hard to distinguish the control and the repair curves.

The IDAL report concluded that, *“the transfer impedance and radiated field results for the repaired cables were similar to the baseline cables. It is not clear how the cables may have performed if an evaluation had been performed on the cables with the damage present prior to repair due to the small amount of damage.”* This laboratory report’s conclusion infers that perhaps a damaged cable with no repair at all would have performed with similar results. Such a point is sheer conjecture and it’s hard to imagine repair personnel ignoring even minor shield damage when evaluating the best repair method for a damaged shielded cable. Allowing any piece of electronic equipment, let alone a commercial or military aircraft, to operate with a shielded cable containing known shield damage is asking for trouble.

² Zentner, John C. and Coffman, Steven C.
Shielding Effectiveness Comparison: RG180 Repaired Cable with Original Cable; MIL-STD-1553 Repaired Cable with Original Cable, 9 April 2007,
Prepared for V. Shrader, The Zippertubing Co, 13000 S. Broadway, Los Angeles, CA
Integrated Demonstrations & Applications Laboratory (IDAL), Electromagnetic Interference Lab
AFRL/SNRA, WPAFB, OH

³ Zentner, John C. and Coffman, Steven C.
Shielding Effectiveness Comparison: RG180 Repaired Cable with Original Cable; MIL-STD-1553 Repaired Cable with Original Cable, 15 February 2007,
Prepared for Oliviu Muja, NAWCAD AIR 6.7.1.6 22347 Cedar Point Rd Patuxent River, MD
Integrated Demonstrations & Applications Laboratory (IDAL), Electromagnetic Interference Lab
AFRL/SNRA, WPAFB, OH

It is important for the reader to remember that the PRT-1553 shield repair kits were conceived as a fast and simple repair method for “minor” shielded cable damage. The PRT-1553 kit is not a splice kit and it should never be thought of as such. It is intended solely for cables where the damage is superficial and does not justify cutting a basically good cable in half and installing a large bulky splice.

PRT Installation

Caution:

The following is a brief synopsis of the PRT installation procedure. It is not intended to be a substitute for the detailed step by step procedures defined in the specific Zippertubing PRT Installation documents!

- 1) Determine the outside diameter of the cable to be covered.
- 2) Select the correct size PRT material from the material sizing chart.
- 3) Open the PRT material along the split line (so the adhesive release liner is on the outside) and place the wires or cables inside (Photo 11)
- 4) Peel back the adhesive liner a short distance and align the non-adhesive edge over the exposed adhesive so all the adhesive is covered (Photo 12)
- 5) Seal the entire tubing length in this fashion (Photo 13).
- 6) Use a hot air type of heat gun with a reducer nozzle to shrink the tubing. Do not use a classic tubing heat reflector! The tubing requires a minimum temperature of +194°F (+90°C) to begin shrinking, but a temperature setting of approximately 250-275°F (121- 135°C) is best.
- 7) Apply heat to the adhesive overlap area only! Fully shrink the overlap area over the entire tubing length first. This process heat-sets the adhesive system and minimizes any tendency for the tubing to tear open during heating. Don't be alarmed when this area curls up, continued heating will cause it to eventually lay down flat. The adhesive overlap area requires extra heat soak time due to its thickness and to insure complete recovery of the inner layer (Photo 14 & 15).
- 8) After the overlap length has been shrunk, allow the PRT to cool briefly and then apply heat to the remaining tubing circumference as necessary.
- 9) When the tubing is cool enough to touch, rub your thumb along the warm overlap edge to insure that the tubing edge is not lifted. The rubbing action will also cause any exposed adhesive to ball up ahead of your thumb and be removed. With PRT-ES tubing do not rub the seam until the hot melt material has cooled and solidified (Photo 16).

Synopsis

The PRT family of products offer both commercial and military interconnect users a fast, easy and reliable means of repairing electrical wires and cables. Repair of superficial jacket and shield braid damage has never been easier! In addition, when utilized within the recommended application limits, PRT will provide years of reliable service. Whether PRT is thought of as an intermediate repair or a long

term solution is totally dependant on the application environment. Users should always be aware of the product limitations and not fall into the trap of believing that PRT is the solution for all problems or applications. The PRT product offers field repair personnel a new tool for their ongoing battle of maintaining complex wiring system problems.

Acknowledgements

The author would like to acknowledge the following and sincerely thank them for their countless hours of testing, coordination and consultation expended during the development of the environmentally sealed PRT-ES and PRT-1553 products. There is no doubt that these products are better as a result of their tireless effort.

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Photographs

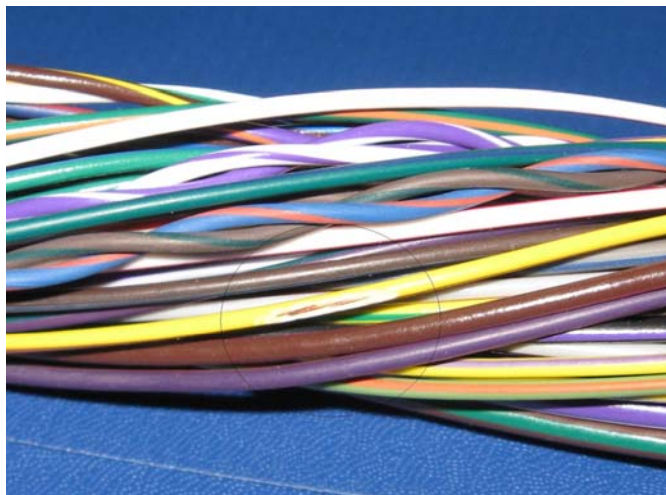


Photo 1: Minor primary wire damage



Photo 2: Minor shielded cable damage

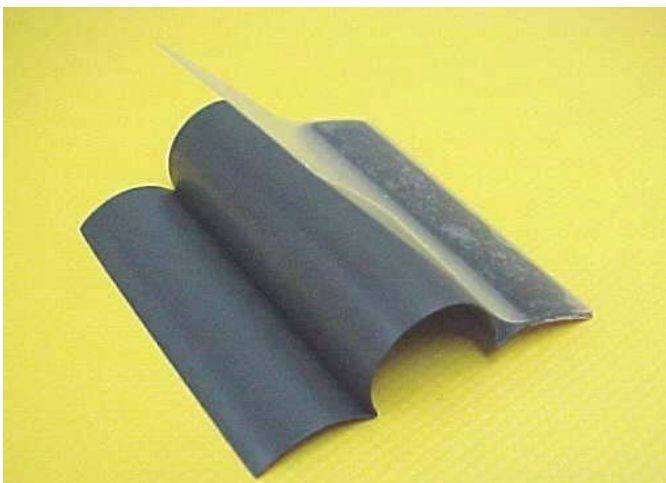


Photo 3: PRT-ES wrap around tubing



Photo 4: Finished PRT-ES repaired wire



Photo 5: US Coast Guard test vehicle

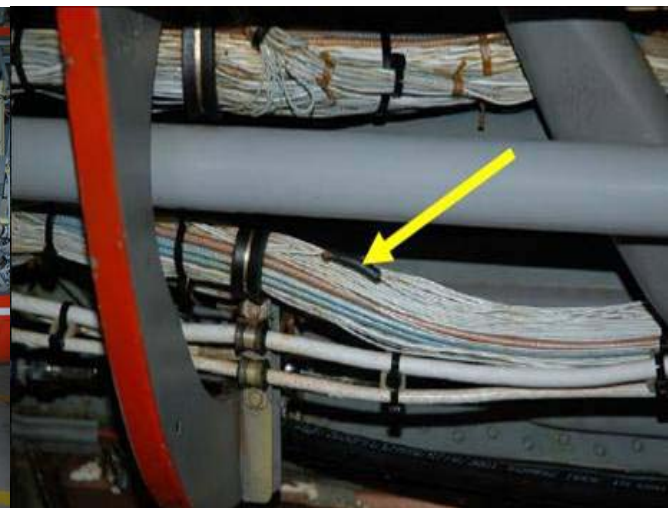


Photo 6: PRT-ES Installed repair

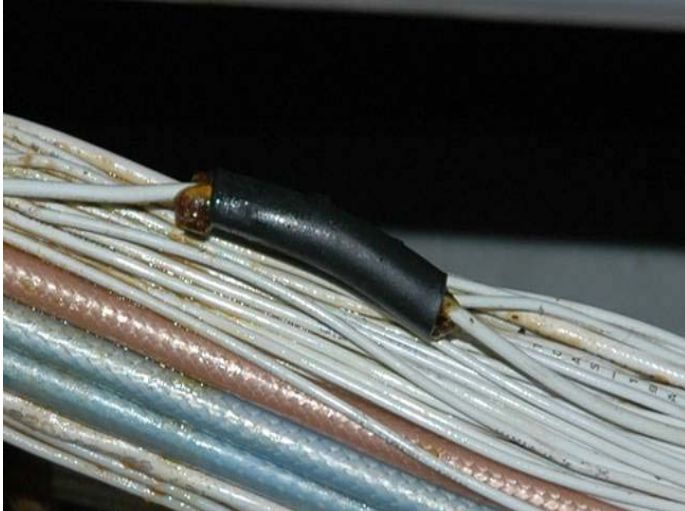


Photo 7: PRT-ES as removed after 1,407.1 hours

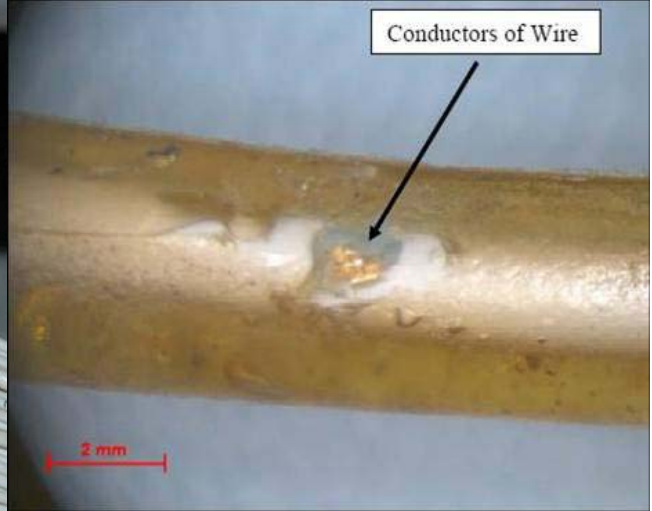


Photo 8: No wire conductor corrosion

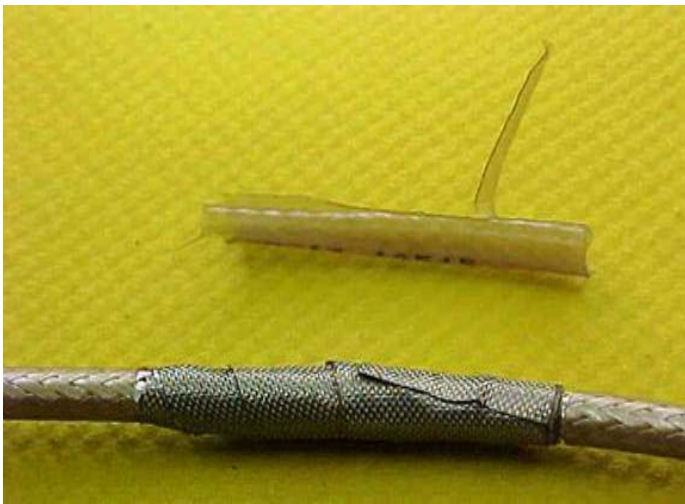


Photo 9: RG-180 shield repair with EMI tape



Photo 10: Finished RG-180 repair test cable

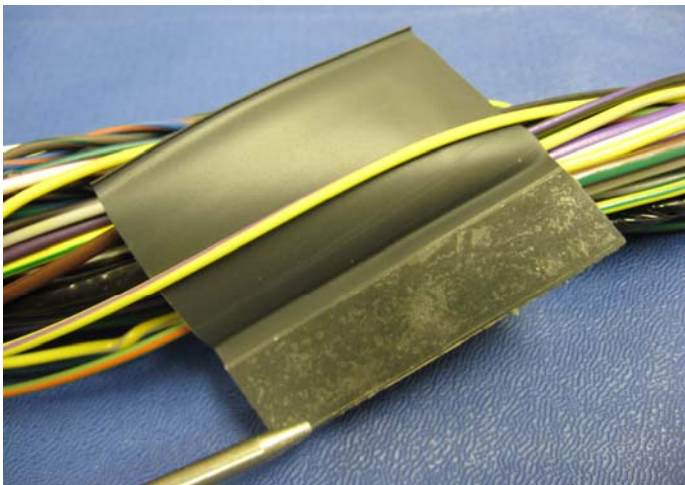


Photo 11: PRT-ES tubing slipped under wire

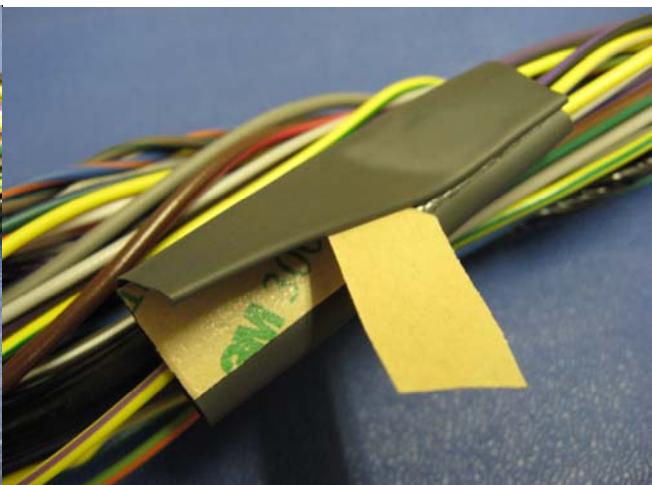


Photo 12: PRT-ES adhesive fully covered

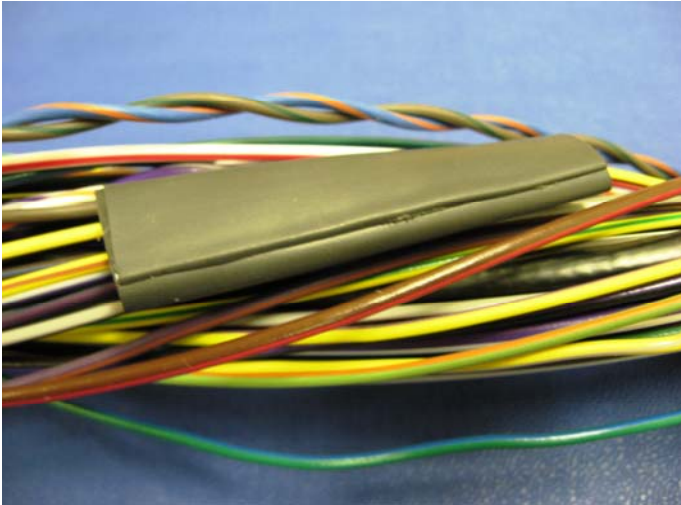


Photo 13: PRT-ES completely closed around wire

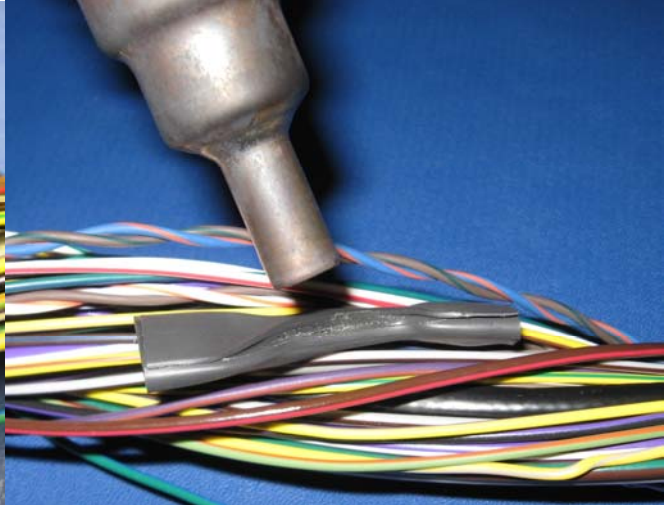


Photo 14: Reducer nozzle shrinking overlap area



Photo 15: Overlap area curled up upon heating

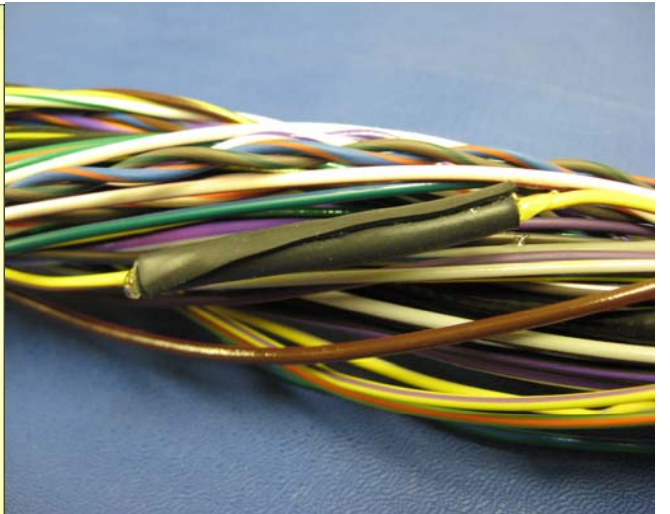


Photo 16: Finished PRT-ES repair

Figures 1 to 8: Repaired Cable EMI Performance

(Source: IDAL Electromagnetic Interference Lab, Test Report 9 April 2007, AFRL/SNRA, WPAFB, OH)

Transfer Impedance RG-180

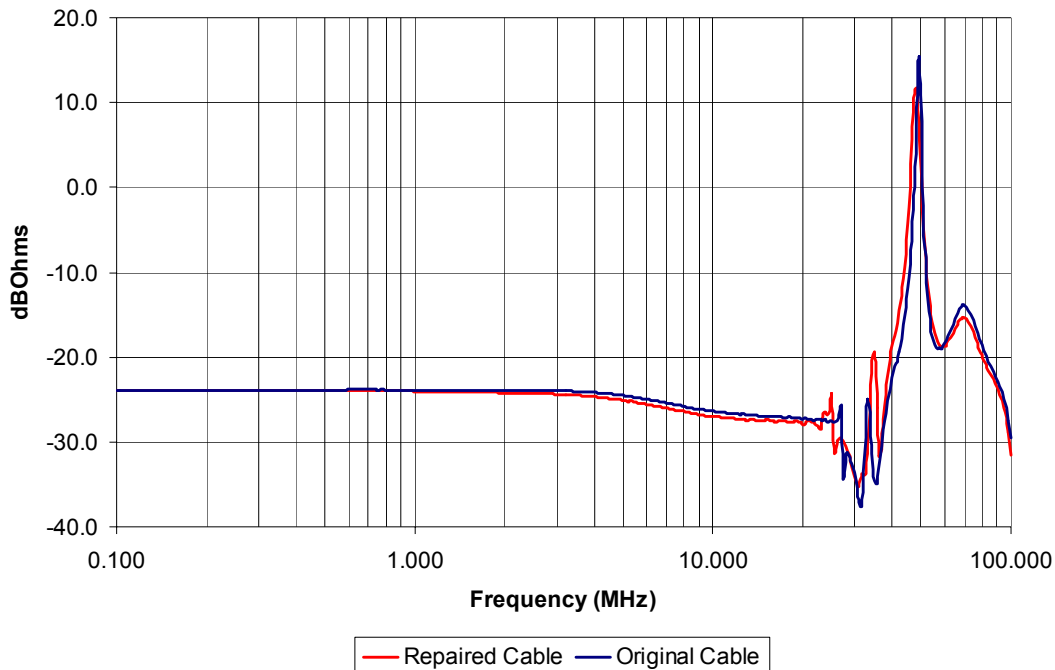


Figure 1: RG-180 performance @ 100 KHz to 100 MHz

Induced Voltage for 100 V/m Field

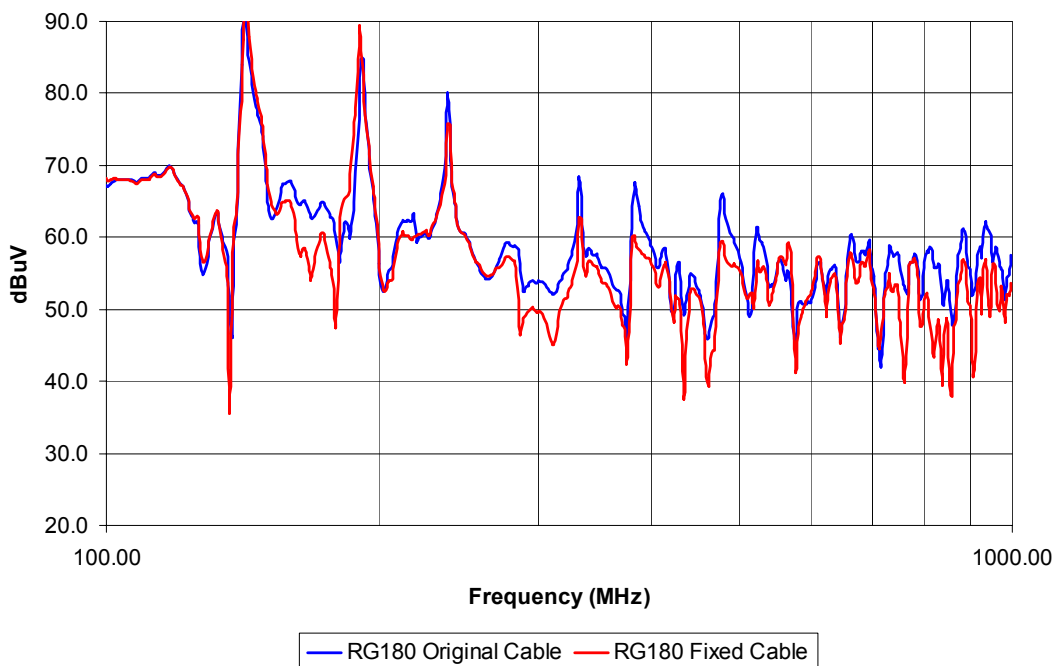


Figure 2: RG-180 performance @ 100 MHz to 1 GHz

Induced Voltage, 100 V/m Field

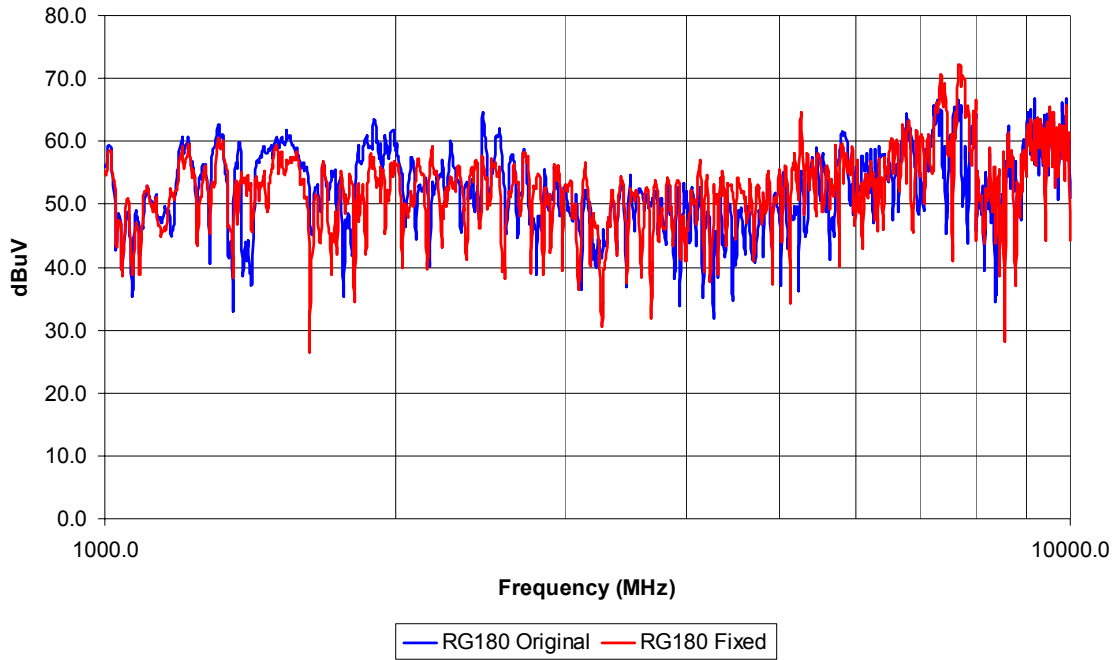


Figure 3: RG-180 performance @ 1 GHz to 10 GHz

Induced Voltage, 100 V/m Field

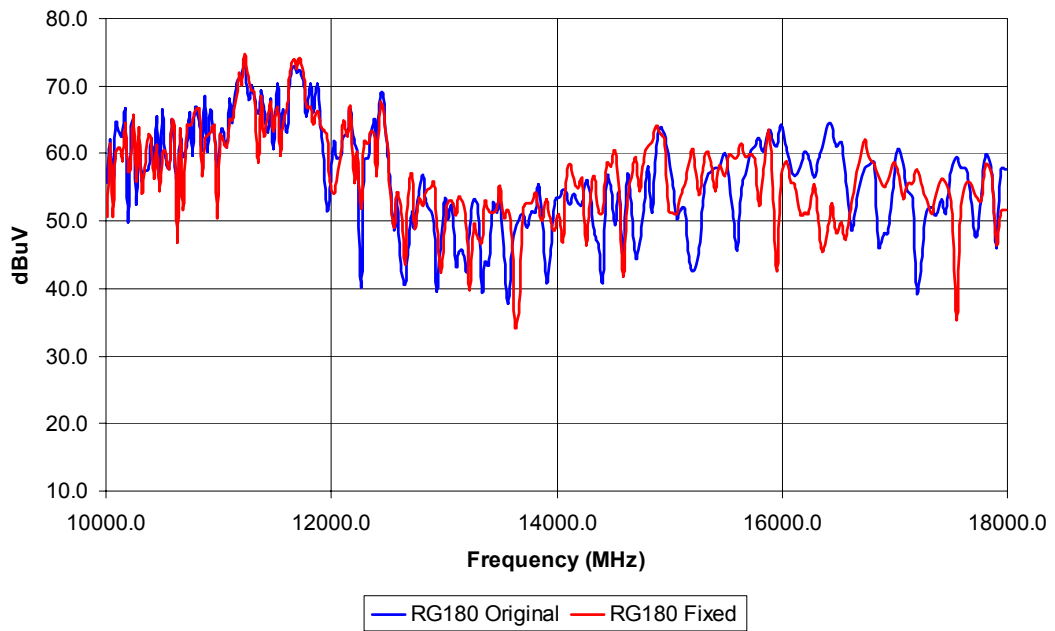


Figure 4: RG-180 performance @ 10 GHz to 18 GHz

Transfer Impedance MIL-STD-1553

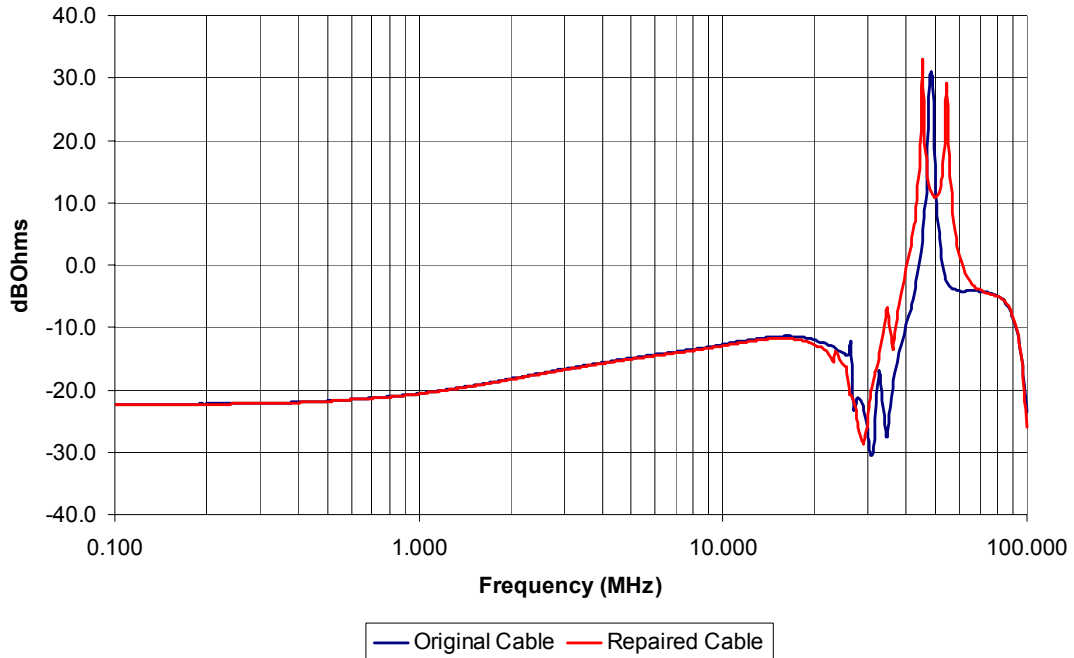


Figure 5: Mil-Std-1553 performance @ 100 KHZ to 100 MHZ

Induced Voltage, 100 V/m Field

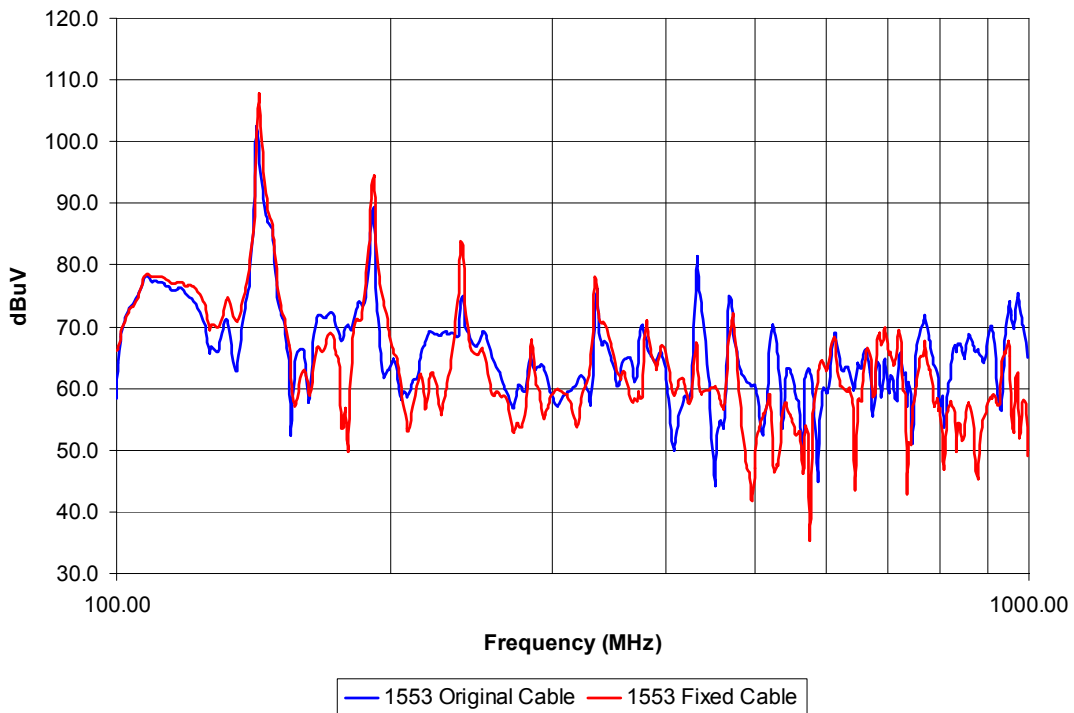


Figure 6: Mil-Std-1553 performance @ 100 MHz to 1 GHz

Induced Voltage, 100 V/m Field

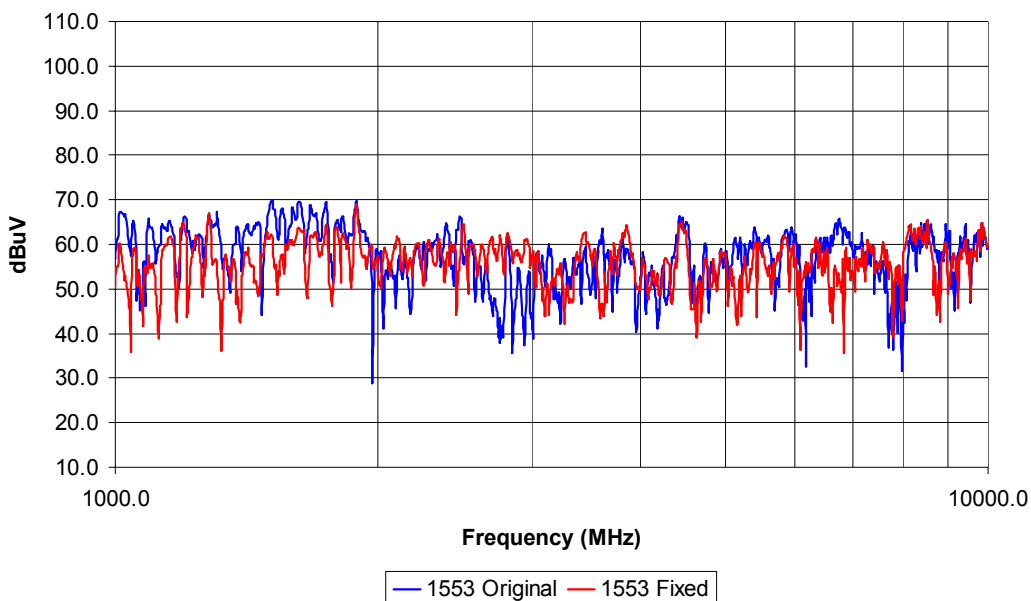


Figure 7: Mil-Std-1553 performance @ 1 GHz to 10 GHz

Induced Voltage, 100 V/m Field

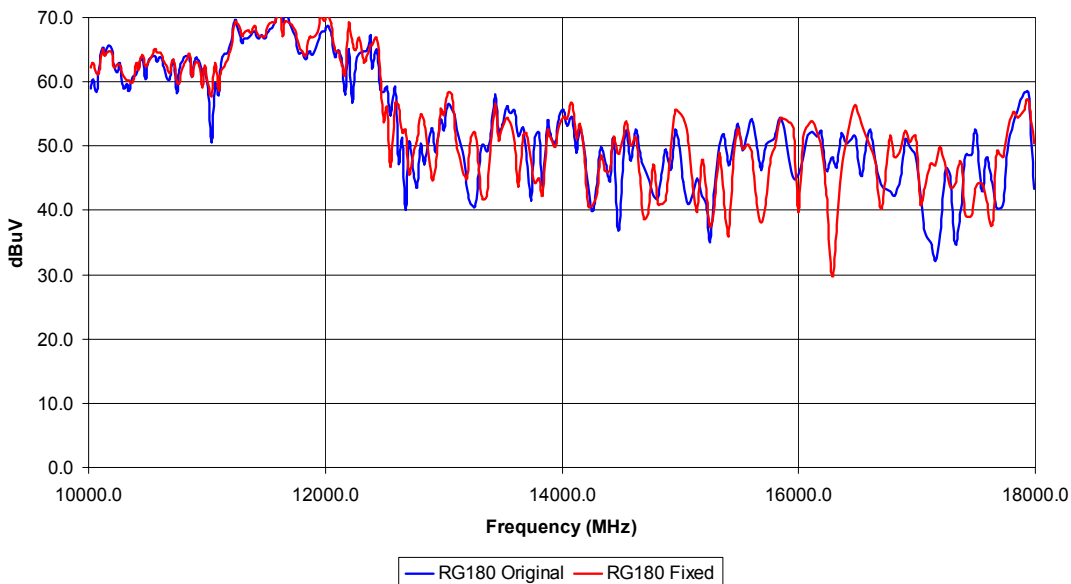


Figure 8: Mil-Std-1553 performance @ 10 GHz to 18 GHz

Note:
Figure 8 graph from the Integrated Demonstrations & Applications Laboratory (IDAL), Electromagnetic Interference Lab, AFRL/SNRA, WPAFB, OH is misidentified as RG-180 instead of Mil-Std-1553 cable.