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[Gray shading indicates required elements; yellow shading]

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	___	**OTHER (Please describe)** ________________________________

ABSTRACT: The effect of pulling lubricant on high frequency data cables was studied. Several brands of Category 5E, 6 and 6A cables were used in the study. Cable performance and lubricant effect were determined through attenuation (insertion loss) measurements. This included air and closed-conduit aging studies. Tensile and elongation effects on jacket compounds were also determined. Coefficient of friction was measured for certain jacket / lubricant combinations. It was concluded that traditional cable pulling lubricants may not be appropriate for use on high frequency data cable. Alternatively, the new, thin-coat liquid lubricants were shown to effectively reduce friction with minimal effect on cable performance.

PATENT DISCLOSURE [OPTIONAL]

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The Effect of Lubricants on High Frequency Data Cable

Study Background

In some recent field installations, data cable that was pulled into conduit using common commercial pulling lubricants failed attenuation loss testing. Limited evaluation in the field indicated that the lubricants themselves could be affecting the cable. Since tension reduction (using lubricants) is often necessary in these installations, a study was fast-tracked to measure the effects of pulling lubricant on the signal properties of cable. Friction reduction and lubricant effect on the physical properties of the cable jacket were also studied.

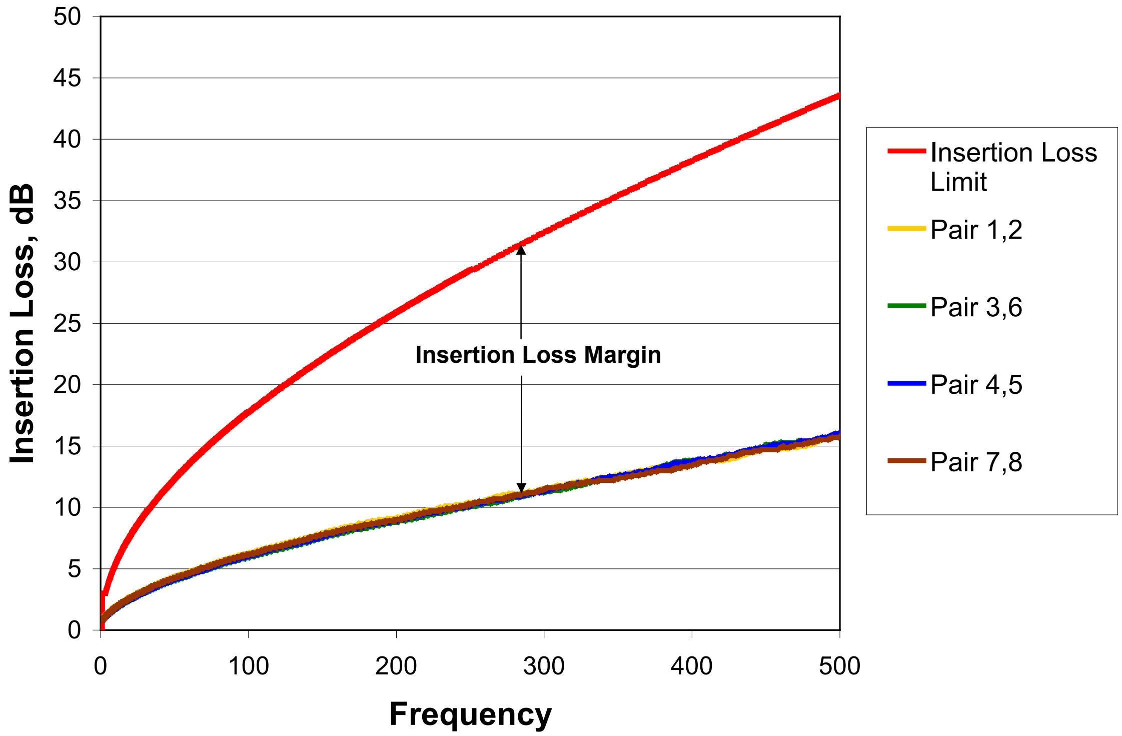
For this study, multiple cable manufacturers donated high-performance copper data cable. The cables were primarily Category 6, but included some 5E and 6A (augmented). Both shielded and non-shielded were represented. These cable brands were randomly assigned designations of A to F. Using this labeling, a valid cable description is “Brand A, Cat 6, unshielded”.

Fluke Networks loaned American Polywater a DTX 1800 CableAnalyzer™ Device. Fluke also provided technical training and assistance in making cable connections, testing the data cable, and interpreting the results for this study.

Analyzing the DTX 1800 Data

The Fluke tester sweeps a broad frequency range and automatically compares the attenuation to established TIA maximums for that cable type. Any single cable test produces extensive data, including a “pass/fail” to TIA standards as the typical printout in Appendix A shows.

Based on the initial testing, it was determined that insertion loss (or insertion loss margin) at 500 MHz could provide good comparison data. Any changes in cable performance were easily detectable at this high frequency.



Graph 1 Insertion Loss, Cable A Baseline, 100-foot Air Dry Test

Graph 1 clarifies the terms as used in this paper. The measured <u>insertion loss</u> (attenuation) in dB is shown for the four measured pairs. Also shown, via the red line, is the TIA limit for the allowable loss. This limit is 43.8 dB at 500 MHz. The <u>insertion loss margin</u> is the difference between the measured attenuation of the highest (worst) pair and test limit allowed.

The terms “insertion loss” and “insertion loss margin” are both used in this study. A majority of the graphs plot the insertion loss margin over time. This comparison to standard is convenient and can be read directly from the DTX-1800 printout. As the insertion loss goes up (attenuation increases), the insertion loss margin goes down. A cable “fails” the insertion loss test when the insertion loss exceeds the TIA limit (the lines cross) and the insertion loss margin turns negative for any of the cable pairs.

Insertion loss margin is seen to vary with cable brand, cable type, and length of run. However, since this study is to measure lubricant effect, the focus is on differences versus a non-lubricated control, and this control’s insertion loss and “pass/fail” status are not relevant to this comparison.

Testing Synopsis

The testing consisted of four protocols. The first two protocols exposed the cables to lubricants and studied attenuation effects. Parts 3 and 4 added physical jacket testing and coefficient of friction measurement. A summary of the test sections follows:

I. Cable Exposed to Various Lubricants and Allowed to Open-Air Dry

A. Nine 100-foot cable sections of a single cable type (Brand A, Cat 6, non-shielded) were wiped with different lubricants and allowed to air dry. A full system diagnostic test was run on the cable before the application of lubricant, immediately after the application of lubricant, and at regular time intervals until readings stabilized. When insertion loss changes were seen, they were immediate. Interestingly, any observed losses reversed and the cables recovered over time (as the lubricant dried).

pp. 5 - 6

B. The same nine cable sections were then soaked in the lubricants, removed, and again allowed to air dry. This increased the severity of lubricant exposure. Again, changes were observed and these changes reversed over time and the cable recovered.

pp 6 - 7

C. Cable length was increased to 300 feet and five cable brands were tested with two different lubricants. Both the control insertion loss and the effects of lubricants were clearly exaggerated at this length. Even so, the cable attenuation again returned to the control baseline as the lubricant evaporated. Differences between cable brands were observed during this test.

pp 7 - 9

II. Cable Exposed to Various Lubricants in a Closed Conduit System

A. One hundred foot sections of four different cable brands and types were bundled and coated with different lubricants (to excess) as they were pulled into three different conduits. The conduit ends were plugged with duct putty to eliminate the effects of air drying. Full diagnostic testing was done before the application of lubricant, immediately after the cable was pulled using the lubricant, and at weekly intervals. A water control with the four 100-foot cable sections was also monitored. This test showed insertion loss increase over time if the lubricant or water is not allowed to dry. This test included both Category 5E and 6, shielded and non-shielded data cables, and showed differences in performance between these cable types.

pp 9 - 12

B. Six 100-foot sections of different brands of Cat 5E, 6 and 6A (unshielded) were bundled and then coated with Polywater® FTTx Lubricant. The conduit ends were plugged with duct putty to eliminate the effects of air drying and evaporation. Full diagnostic testing was done before the application of lubricant, immediately after the cable was pulled using the lubricant, and at weekly intervals. A water control with the six 100-foot cable sections was also monitored. This test also showed insertion loss increase over time if the lubricant or water is not allowed to dry as in test IIA. This test showed variations in the control insertion loss dependent on cable design or other manufacturer particulars.

pp 12 – 14

III. Materials Testing After One-Week Soak with Various Lubricant Agents

Cable jacket compounds were immersed in various lubricants for one week at 50°C. Tensile and elongation properties of the cable jacket compound were measured and compared to non-aged jacket material. The results indicate that mineral oil and hydrocarbon-based lubricants can be detrimental to the cable jacket material.

pp 14 – 16

IV. Coefficient of Friction Testing

Six cables were pulled into an EMT conduit with two 90° bends. The pulling tension was used to calculate the coefficient of friction. A traditional cable lubricant, the new Polywater® FTTx, and dry clay-based lubricants were compared to the non-lubricated control. This testing showed significant friction reduction differences among lubricants.

pp 16 – 17

I. Lubricant Wipe on 100-foot Cable with Air Exposure

Part A: Nine Lubricants, 100 Feet Cable Wipe Test with Air Dry

In the first part of the test, 100-foot cable (Brand A, cat 6, unshielded) segments, all from the same reel, were coated with lubricant and hung in air. Diagnostic testing was done at regular time intervals until attenuation readings stabilized.

To allow the cable full air exposure, a hanging “cage” was constructed. This cage consists of four connecting poles to create an 8-foot by 10-foot by 10-foot rectangular box. Plastic knobs, inserted at three-inch vertical increments, kept the cable secure. These holders ensure that the cable does not cross itself and is fully exposed to the air without trapping variable amounts of lubricant between surfaces.

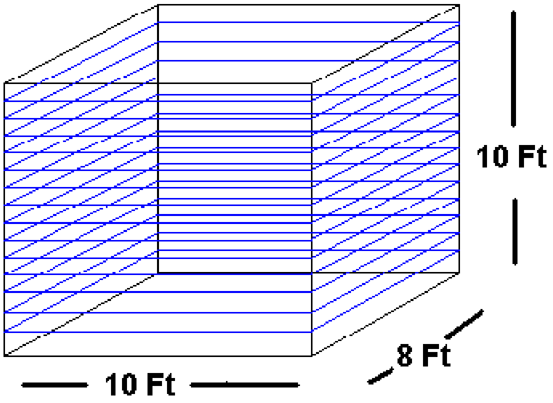
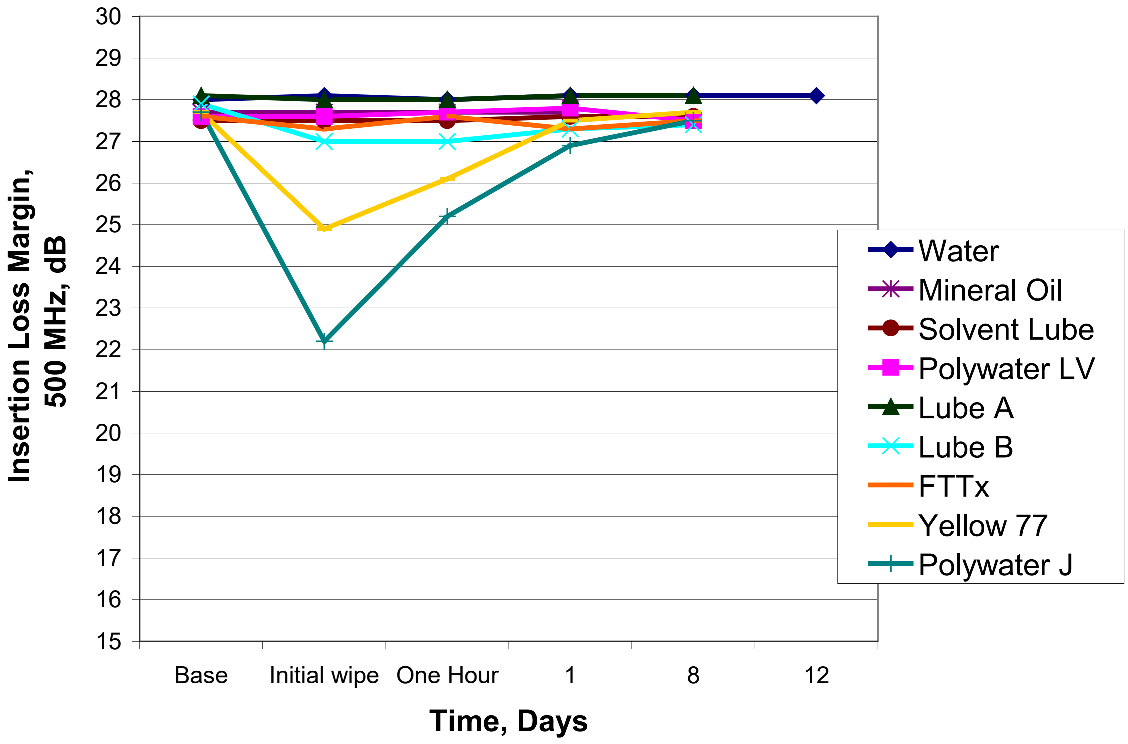


Diagram 1 Hanging Cage, photo left and rough diagram above.

A Leviton Extreme 6+ Connector was attached to each end of the cable, and the cable was carefully hung on the cage. A Fluke DTX 1800 was used to test the cable, and all margins are based on 500 MHz test limits. The DTX 1800 was calibrated to the cable type and length, and a baseline (control) diagnostic test was run.

In this testing, nine different lubricants were coated on the cable. The cable was thoroughly coated with a generous quantity of lubricant using a non-linting towel. The coating thickness was, therefore, somewhat proportional to the lubricant’s gel strength. An initial “lubricated” reading was taken shortly after the cable was coated with lubricant. Readings were then taken at regular intervals and the insertion loss margin (at 500 MHz) was recorded and graphed for analysis. See Graph 1.



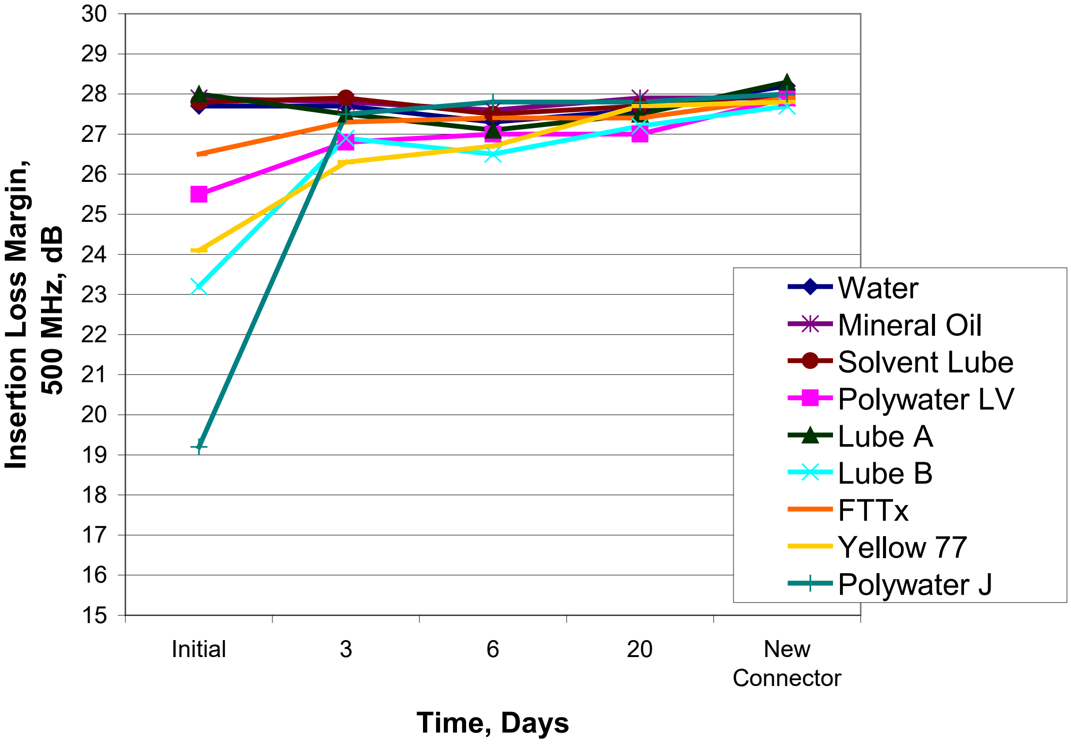
Graph 2 Insertion Loss After Lubricant Coating or Wipe, 100-foot Cable, Air Dry

For some of the water-based lubricants, the initial reading showed an immediate insertion loss increase. Other lubricants show no change. Over time, the readings return to the control value. The difference in insertion loss appears to be dependent on the coating thickness as well as the ionic content or polarity of the lubricant. Thicker lubricant coatings show more insertion loss.

Part B: Nine Lubricants, 100 Feet Cable Soak Test with Air Dry

After all the cables above returned to their baseline (control) readings, the cables were coiled and immersed in the (same) lubricant for one hour. The connectors and about one foot of each cable were not immersed. Cables were again hung back on the cage with air exposure. The connectors were wrapped during the hanging to keep them from being contaminated as the lubricant was literally dripping from the cables. An initial reading was taken shortly after the cable was hung. Testing was done at regular time intervals until attenuation readings stabilized.

Lubricant coating thickness, in this test, is again dependent on lubricant gel strength. The residual amount of lubricant is greater for the thicker gel and paste lubricants. All lubricants tested were volatile and eventually evaporated (dried).



Graph 3 Insertion Loss After One Hour Lubricant Soak, 100-foot Cable, Air Dry

After the one-hour soak, the insertion loss is somewhat higher than in the wipe procedure used in Part A (max of 9 dB versus 6 dB). Either the increased exposure time or quantity caused an increased impact on the cable attenuation. After just three days, most cables showed an insertion loss similar to their control reading (initial from Part A). After three weeks, all cables had recovered.

In this testing, NEXT and return loss test values showed some failures. Connector contamination was suspected. Although this did not appear to impact the insertion loss, all connectors were replaced after twenty-four days and the final values reflect the test with new connectors.

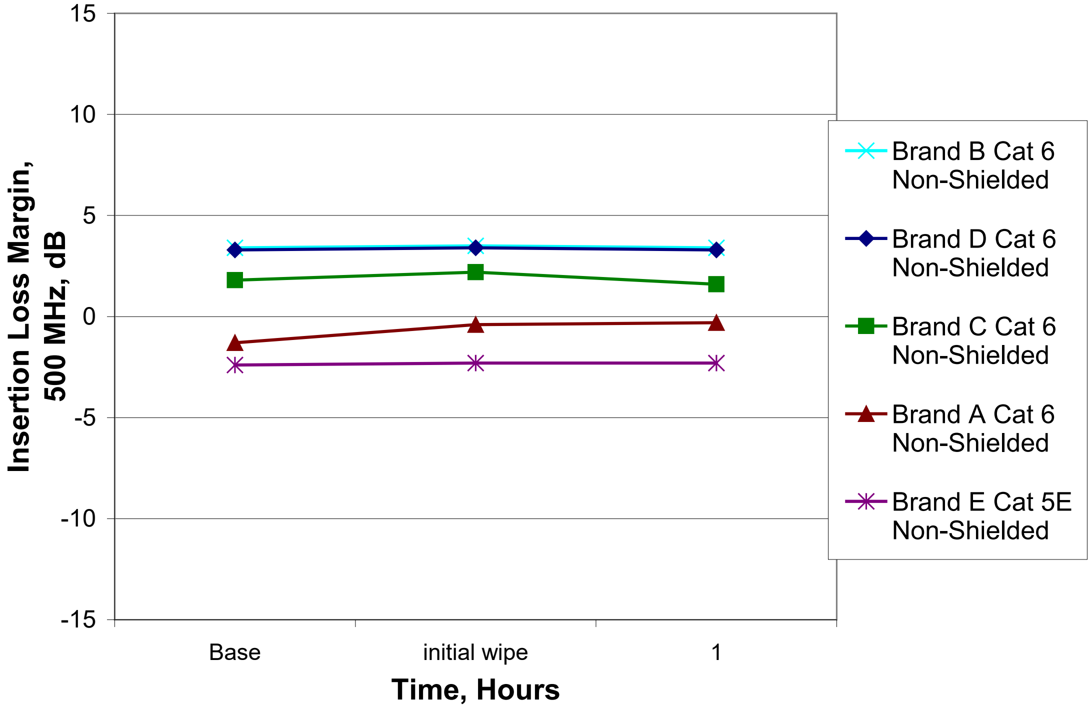
Part C: Two Lubricants, 300 Feet Cable, Wipe Test with Air Dry

In this test, the test length was increased to 300 feet. Testing was broadened to include five different brands, 4 Category 6 and 1 Category 5E cable. This testing was limited to Polywater® J and FTTx Wipe Lubricants.

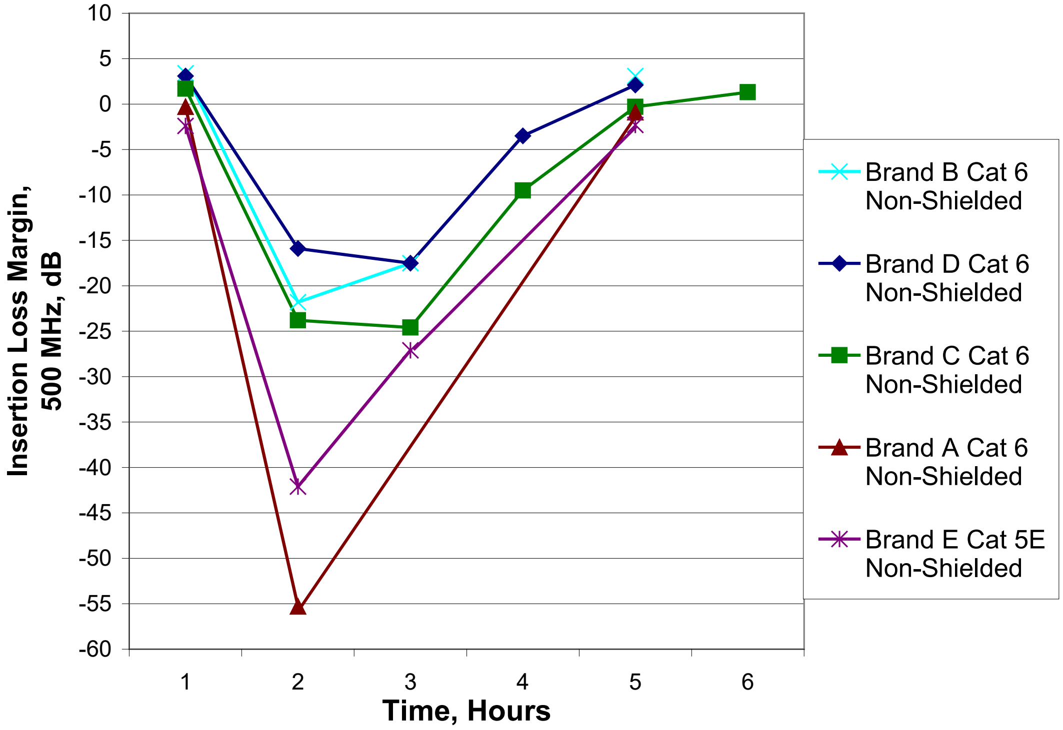
Each cable type was strung onto the holding cage described in Part A and a baseline test was run for each cable as a control comparison. The cable segments were generously coated with Polywater® FTTx Wipe Lubricant. A test was done immediately and after one hour. At one hour, any insertion loss returned to the baseline (control) value.

When the cable attenuation returned to the baseline, it was cleaned with isopropyl alcohol and allowed to dry. The cable segment was then coated generously with

Polywater® J Lubricant. Again, the diagnostic test was done immediately and then after one, four and twenty-four hours.



Graph 4 Polywater® FTTx Wipe Lubricant on 300-foot Cables, Various Brands



Graph 5 Polywater® J Lubricant Coated on 300-foot Cables, Various Brands

The longer test length combined with the high frequency comparisons result in near failure, even without lubricant coating. There are differences in performance between the cable brands. Cable brand A, used in the initial testing, is actually the most susceptible to the energy loss.

Graph 3 shows that the FTTx Lubricant has very little impact on the insertion loss. As expected, the Cat 5E cable, designed for a lower frequency than the other cable types, has the lowest baseline attenuation.

The testing with Polywater® J Lubricant (Graph 4) also shows that the insertion loss change is exaggerated for the longer lengths of cable. The scale of Graph 4 hides the differences in the baseline insertion loss. As with the 100-foot testing, the attenuation returns to normal after the cable has dried. Even with an insertion loss margin of negative 57 dB, at 500 MHz, the Brand A non-shielded Cat 6 recovered to its baseline measurement after one day. The lubricant effect is reversible and seems to absorb energy only when water is present.

II. Conduit Test

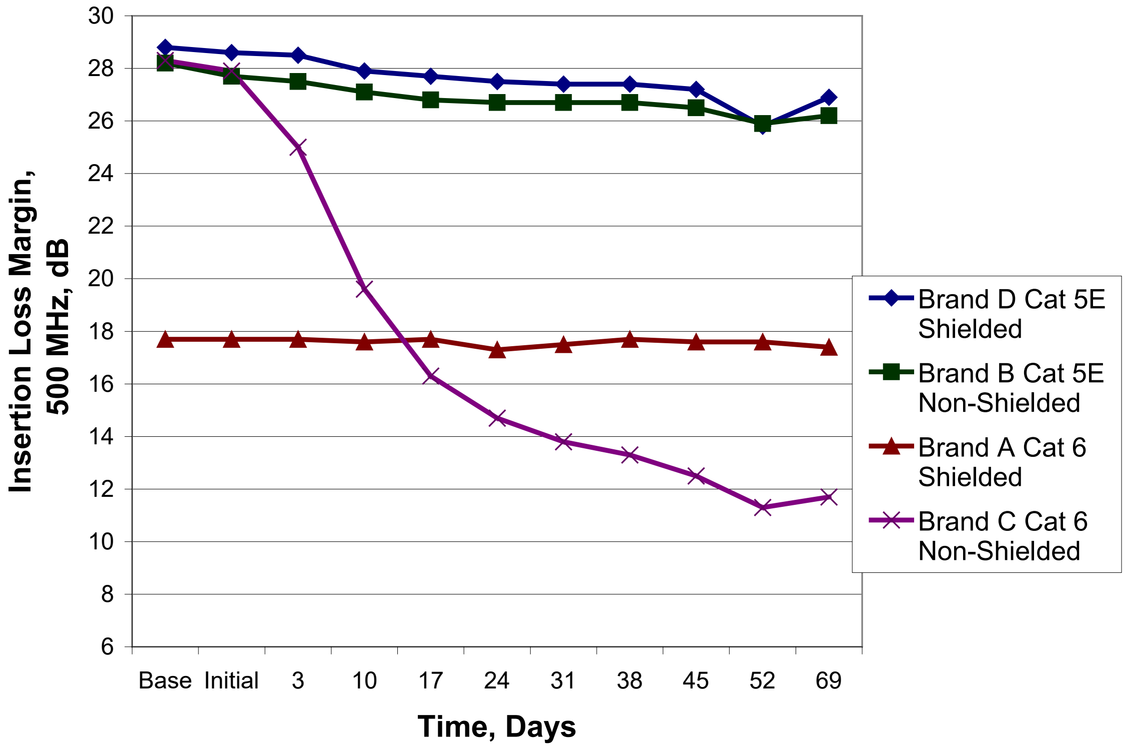
Part A: Four Different Lubricants in Separate, Closed Conduits with Four Cables Brands and Types

In the next part of the testing, four cables were coated with lubricant and pulled into conduit. The conduit was plugged to keep lubricant from drying. The cables (in conduit) were aged for an extended time period, and diagnostic testing was run at one week intervals.

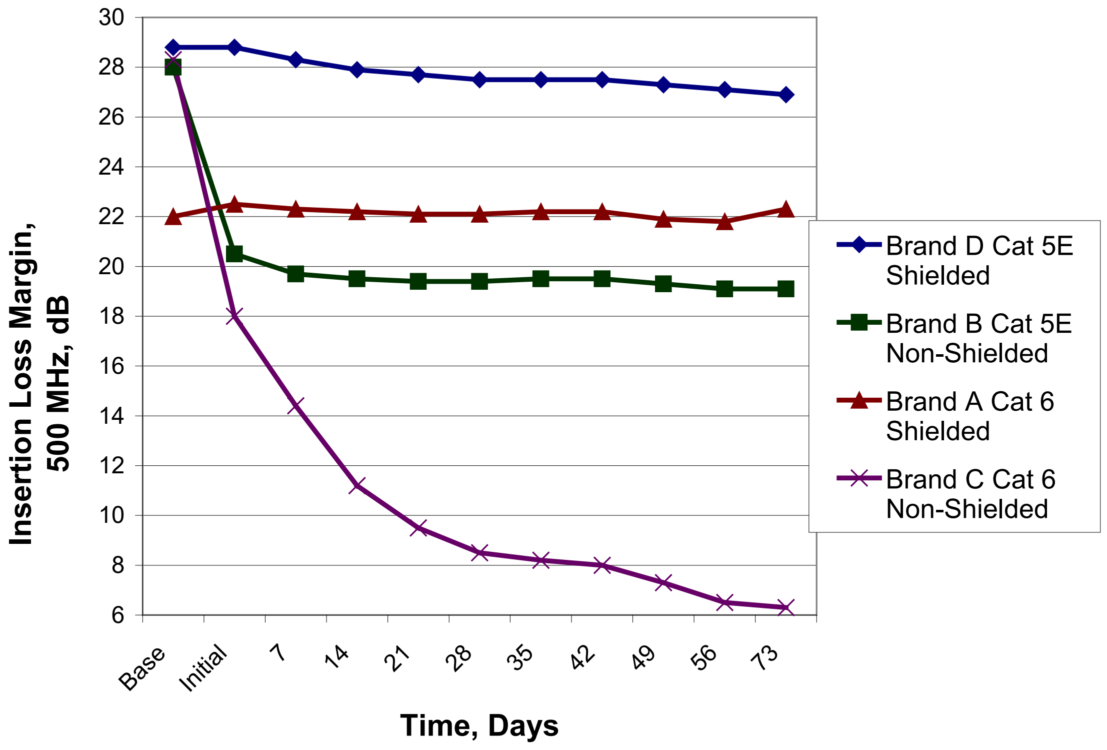
For this test, one-inch polyethylene duct was cut into 90-foot sections. Each cable in this section of the study was supplied by a different manufacturer. Shielded and non-shielded Category 5E and shielded and non-shielded Category 6 cables were tested. These cables were each cut into 100-foot sections and connectorized at both ends with an Extreme 6+ Leviton Connector. A baseline (control), diagnostic test was run on each cable. After the test was completed, one connector was removed to allow the cable(s) to be pulled into conduit.

The four cables were bundled and pulled into the conduit. For the Polywater® J and Yellow 77® Lubricants, one quart of lubricant was evenly coated on the cables as they were pulled. For the Polywater® FTTx Lubricant, the four cables were evenly wiped with four pre-saturated wipes. For the water test, one quart of water was added to the conduit and well dispersed after the four cables were inserted into the conduit. Based on typical field procedures, these are excessive quantities of lubricant/water and provide a worst-case scenario. Conduit was straight during installation, and great care was taken to limit pulling tension on the cables. A tension meter at the pulling end recorded pull tensions of less than 15 pounds force.

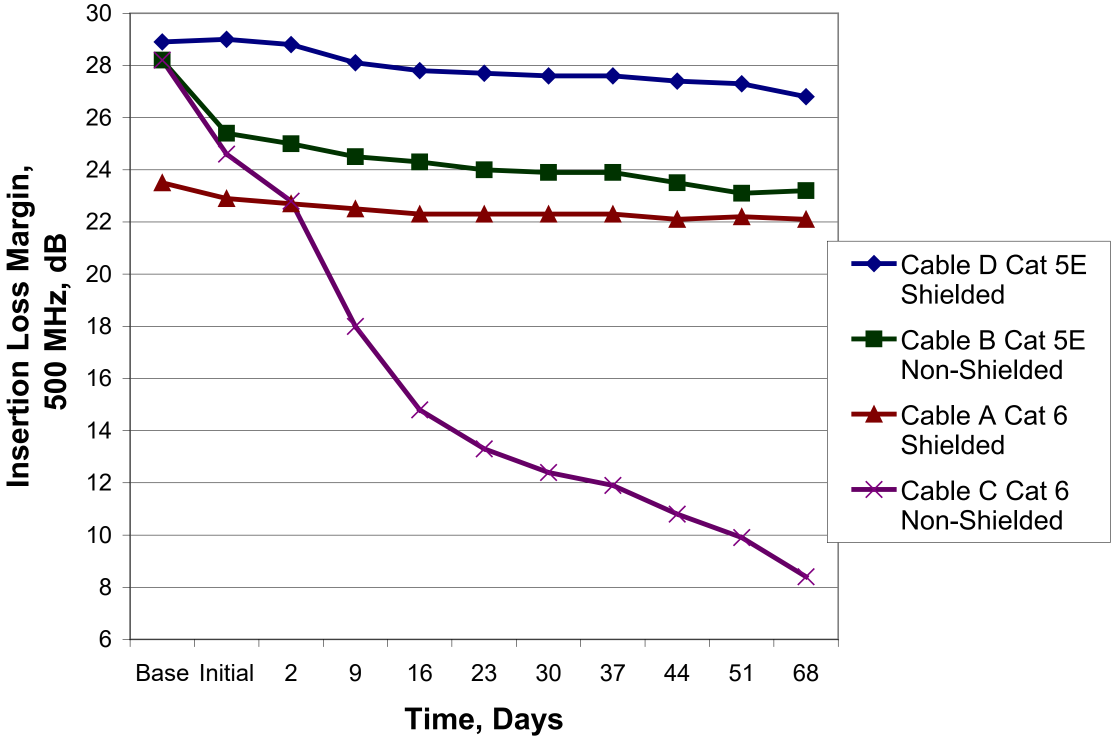
After the cables were installed in the conduit, the conduit ends were plugged with duct putty in an effort to completely block the conduit. The connectors were reattached, and an immediate diagnostic test was run. Conduits were then coiled and stored for long-term aging. Diagnostic testing was performed at seven-day intervals.



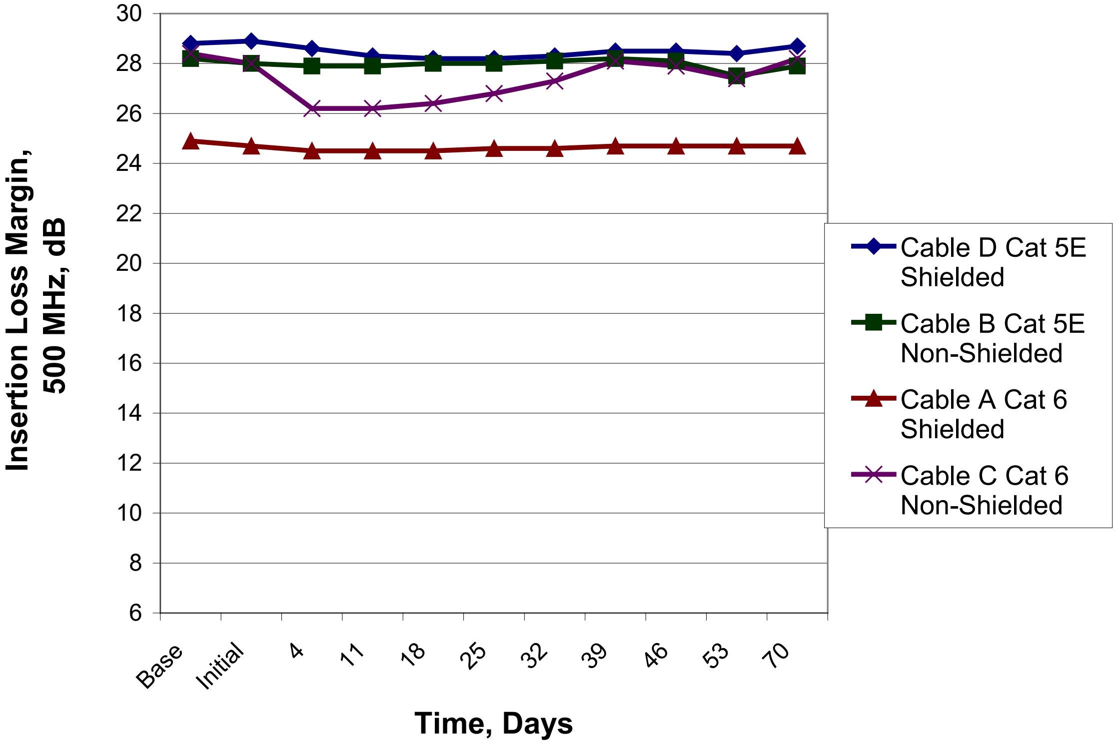
Graph 6 100-foot Cable Sections in Closed Conduit Filled with Water, Various Cable Types and Brands



Graph 7 100-foot Cable Sections, Coated with Polywater® J Lubricant, in Closed Conduit, Various Cable Types and Brands



Graph 8 100-foot Cable Sections, Coated with Ideal Yellow 77® Lubricant, in Closed Conduit, Various Cable Types and Brands



Graph 9 100-foot Cable Sections, Wiped with Polywater® FTTx Lubricant, in Closed Conduit, Various Cable Types and Brands

With each lubricant--as well as water--Brand A, shielded, Category 6 data cable shows little change in insertion loss. It does show a slightly lower insertion loss margin as a baseline. This value shows variability from cable section to cable section (graphs 5 – 8). These variations may be related to the quality of the connection and/or the cable design. Multiple attempts to change and improve the connection quality did not have any impact on these variances.

As with the shielded Category 6 cable, Brand D, shielded Category 5E data cable shows minimal attenuation change under exposure to the various lubricants and water.

In Graphs 5, 6, and 7, Brand C, a non-shielded Category 6 cable shows an increasing insertion loss over time. The two commercial cable lubricants, Yellow 77® and Polywater® J, show a similar insertion loss to that of the water exposure control.

In the same graphs, Brand B, non-shielded Category 5E cable shows an initial increase in insertion loss when exposed to Yellow 77® and Polywater® J, but no increase in plain water. The cable shows minimal insertion loss for the duration of the test.

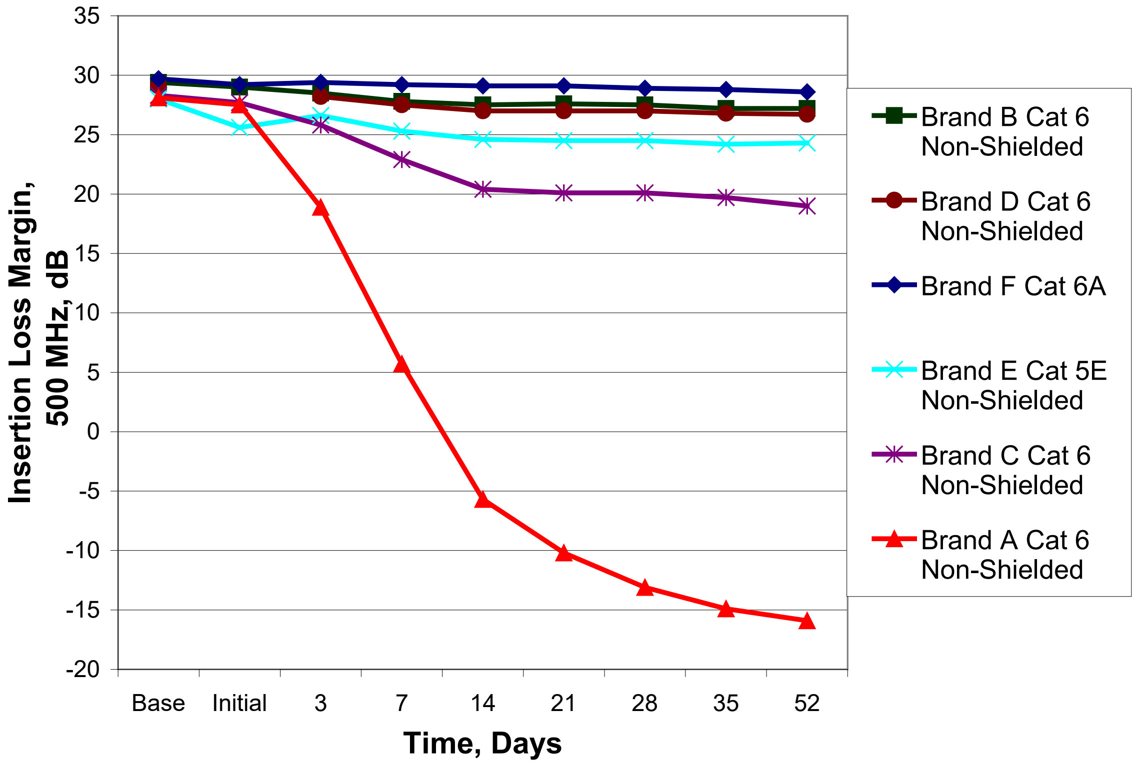
Graph 8 shows a minimal insertion loss variation from baseline insertion loss for all the cables exposed to the thin-coat, Polywater® FTTx Lubricant Wipe. *This testing confirms the hypothesis that a thin-coating of properly compounded lubricant has minimal impact on the signal properties of the high-frequency data cable.*

These data indicates that shielded cables are less affected by the lubricants and water. Surprisingly, it appears that insertion loss is greater in Category 6 than in Category 5E. However, these differences may also be attributed to differences between brands, as seen in the testing done in II.B.

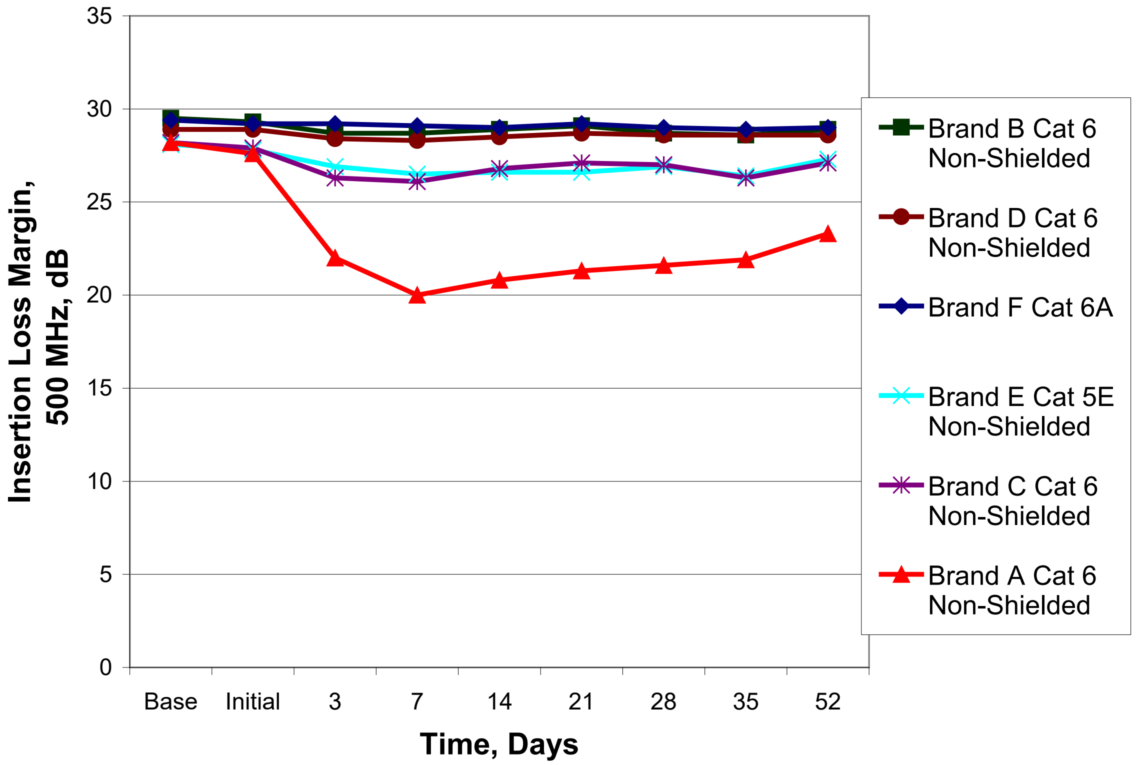
Part B: Polywater® FTTx and Water Control in Separate, Closed Conduits, Six Cable Brands

In the next part of the testing, six cables were bundled, coated with lubricant and pulled into the conduit. Four cables were non-shielded Category 6 cables from four different manufacturers. The other two cables included a Category 5E cable and an augmented, Category 6A cable. As before, the conduit was plugged to keep lubricant from drying. The cables (in conduit) were aged for an extended time period, and diagnostic testing was run at one-week intervals.

The preparation and test procedures mimicked Part A above. The cables were evenly wiped with four pre-saturated Polywater® FTTx Lubricant Wipes. For the water control, one quart of water was added to the conduit and well dispersed after the cables were inserted into the conduit.



Graph 10 100-foot Cable Sections in Closed Conduit Filled with Water, Multiple Cable Brands



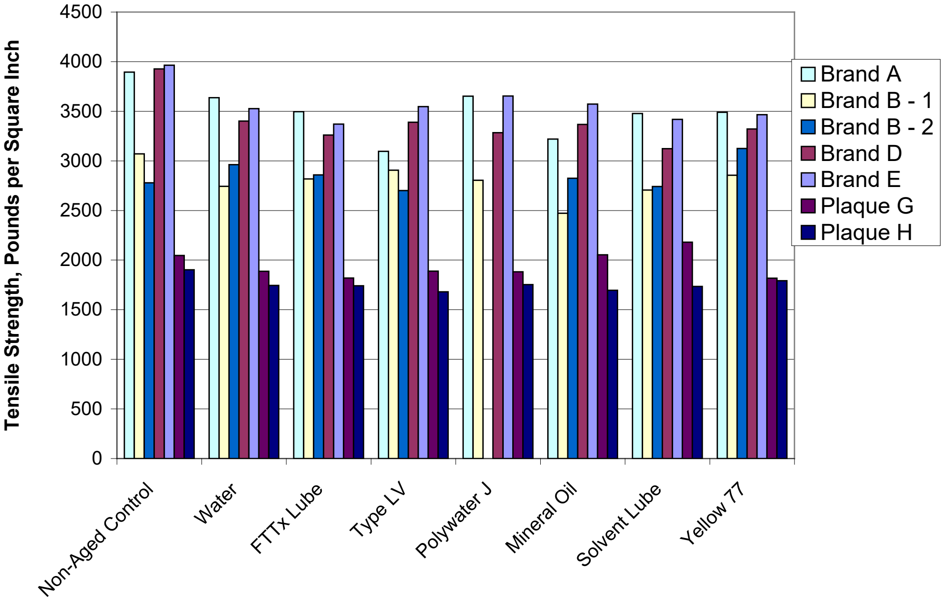
Graph 11 100-foot Cable Sections, Wiped with Polywater® FTTx Lubricant, in Closed Conduit, Multiple Cable Brands

The effect of water on the insertion loss in this testing varies with the cable brand. Brand A shows high insertion loss increase. Brand C shows a slightly lower increase in attenuation than when tested in Part A, although the change in graph scale exaggerates the difference. Brands E, B, D, and F show the least effect from water.

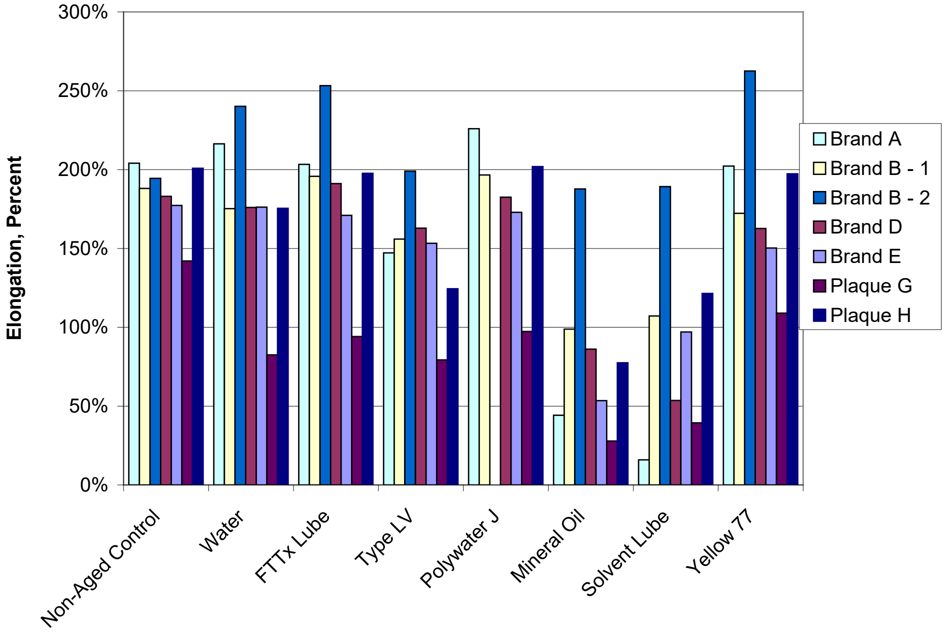
The thin coating of Polywater® FTTx Lubricant minimizes the effect of water-based materials on attenuation. Where the insertion loss with exposure to the FTTx Lubricant appears to peak after about a week (Graph 11), the cables exposed to water continue to show an increase in attenuation (Graph 10) over the duration of the test.

III. Materials Testing

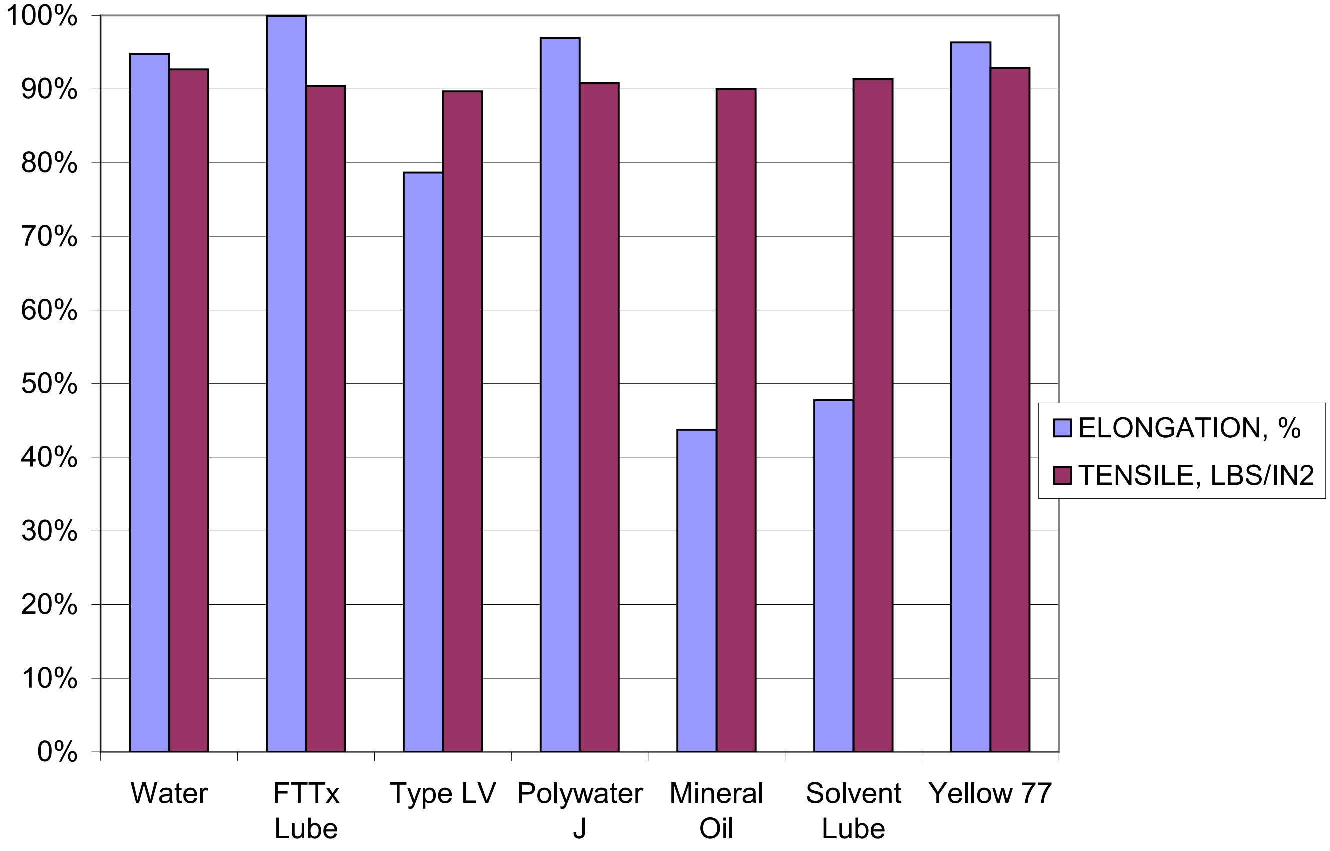
In this section of the test, plaques of the jacket material were obtained from the cable manufacturer. Cable jacket was also stripped from larger diameter, shielded cable. Test specimens are cut into "dog bone" shapes using ASTM Die C for the jacket material and Die D for the plaques. Tensile and elongation properties were tested using an Instron Tensile test device as described in ASTM D412. The test specimens were immersed and aged in the listed lubricants for seven days at 50° C. Specimens were removed from the lubricant, rinsed, and blotted dry. Specimens were allowed to rest for twenty-four hours before testing. No significant weight change was observed in any of the specimens.



**Graph 12 Tensile Testing,
Multiple Jacket Materials and Lubricants**



Graph 13 Elongation Testing, Multiple Jacket Materials and Lubricants



Graph 14 Average Tensile and Elongation Values Compared to Untreated Control

While the conventional pulling lubricants show minimal effect on the jackets' physical properties, the reduction in elongation properties is striking for the samples aged in mineral oil and a solvent-based lubricant. This is easy to see in the percent comparisons in Graph 13. The low-elongation samples were very brittle and would snap and break quite easily.

IV. Friction Testing

Each cable was tested for jacket "friction" without lubricant and with the coating of three different lubricants. A variation of one of American Polywater's common techniques was used. The cable was pulled into ¾-inch EMT duct with two 90° bends. A back weight was placed on the cable end, and the other end was attached to a winch with force measured by an in-line load cell. The cable was pulled at a steady rate, and pulling force measurements were taken at 0.5-second intervals. The coefficient of friction can be determined from the pulling force and the back tension. This was calculated using the Pull-Planner™ 2000 Cable Tension Calculation Software.

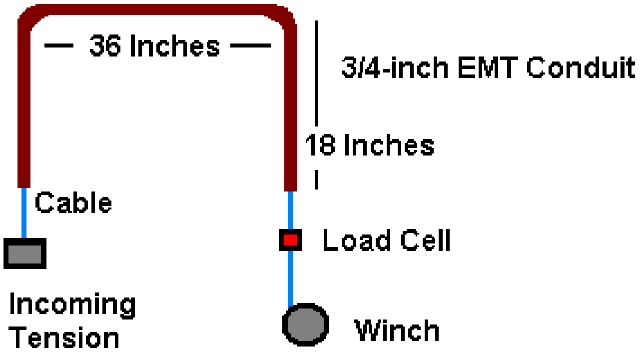
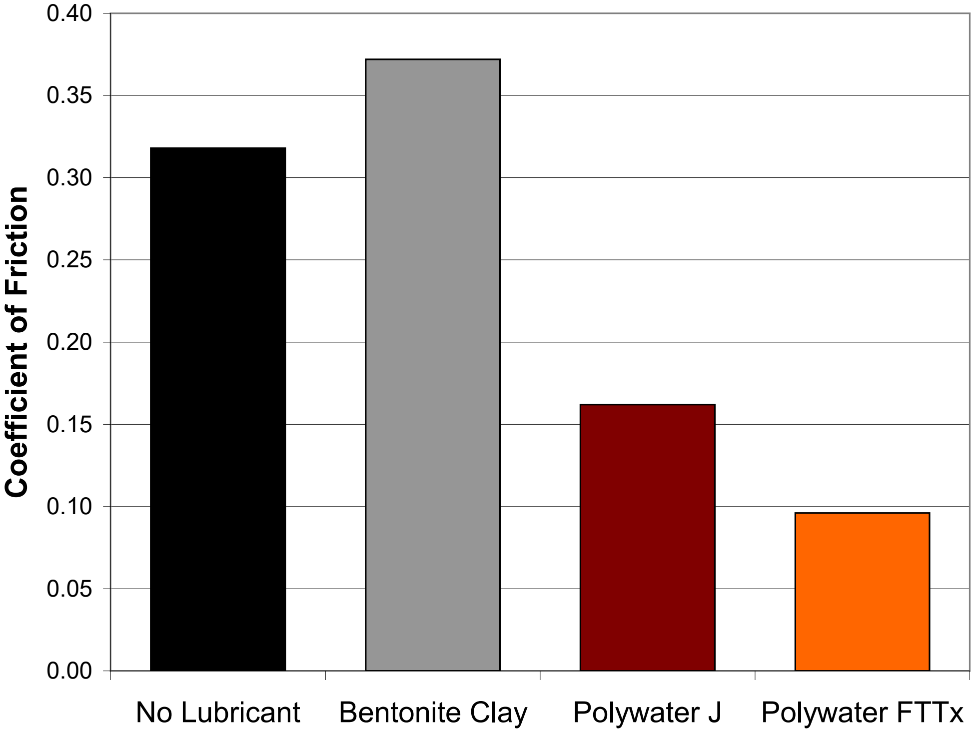


Diagram 2 Friction Testing Device



Graph 15 Average Friction Coefficient,
Six High Performance Data Cables, Different Lubricants

The dry lubricants do not act as lubricants for cable pulling. Both the Polywater® J Lubricant and the FTTx Lubricant have been formulated for optimum friction reduction. This testing confirms the friction-reducing properties of the FTTx Lubricant. Even with a very thin coating, this lubricant dramatically reduces tension.

The significance of fiction coefficient numbers is not intuitive. To provide field perspective, the table below shows projected tensions on a pull of 300 feet with the measured frictions above. Two scenarios are presented. The first is the TIA maximum of two 90-degree bends (equally placed) in the run. The second is the NEC maximum of four 90-degree bends (equally placed) in the run.

Lubricant	**Tension (TIA) 300 feet - 2 ea 90° bends**	**Tension (NEC) 300 feet - 4 ea 90° bends**
No Lubricant	27 lbf	76 lbf
Dry Clay	32 lbf	102 lbf
Polywater® J	17 lbf	28 lbf
Polywater® FTTx	14 lbf	18 lbf

Summary

Common commercial cable pulling lubricants are shown to affect data cable attenuation at high frequencies. The magnitude of the effect varies significantly by cable brand. Attenuation increase is also seen with plain water and other polar liquids and oils.
Commercially available pulling lubricants are made to carry through conduit on the cable, and are generally gels or pastes. They cover the cable with a thick coat. Such heavy lubricant coatings appear to increase the insertion loss. Specially formulated lubricants designed to be effective in ultra-thin coats show very little change in loss.

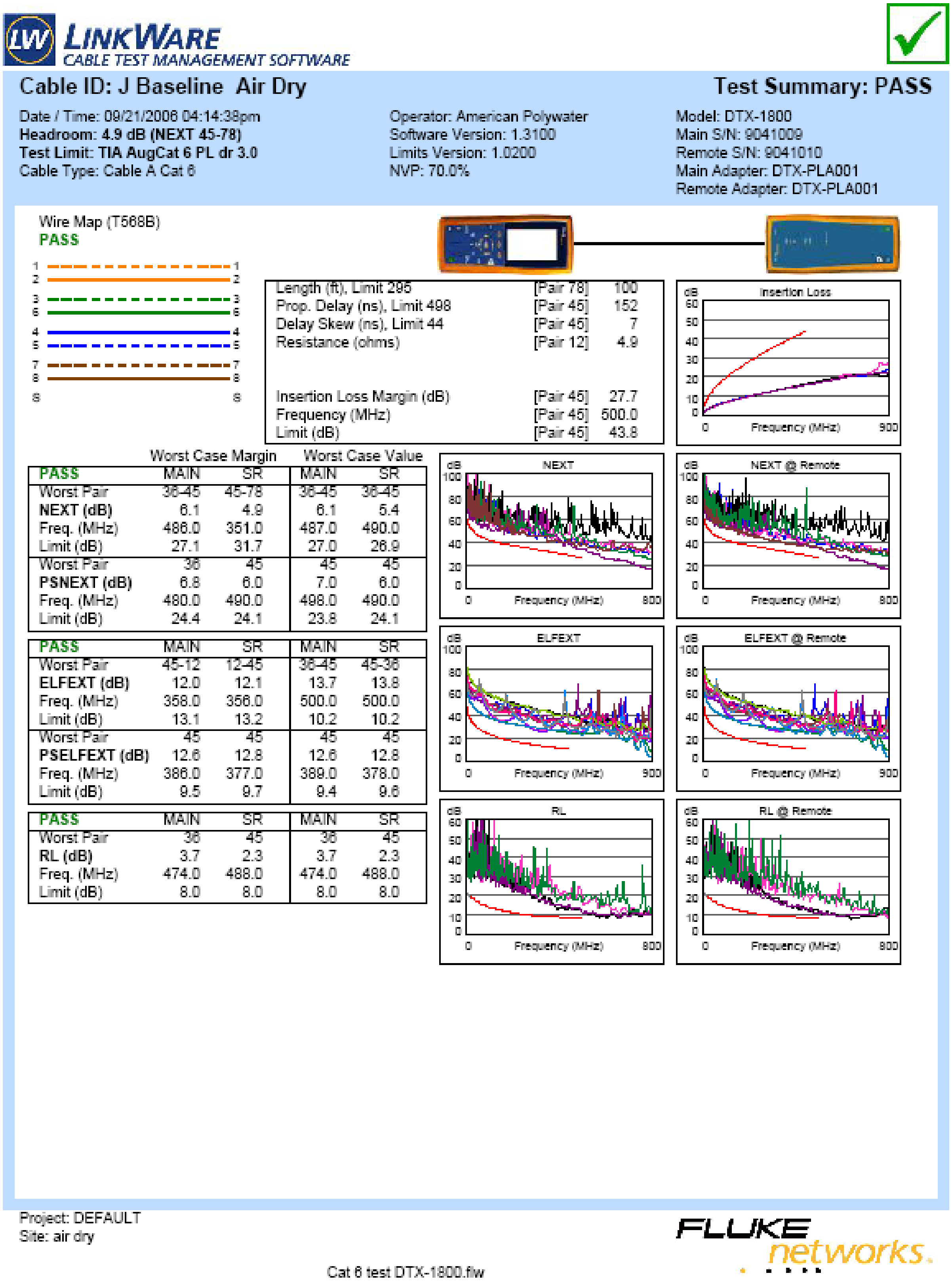
The use of non-polar oils or greases such as mineral oil or Vaseline® is shown to affect jacket physical properties, especially elongation. Such oils are not suitable as pulling lubricants for these cables.

The "dry" lubricants that were evaluated did not reduce friction compared to an unlubricated jacket in cable pulling tests. Since the primary function of a lubricant is to reduce friction, the use of a "dry" lubricant is unacceptable. For long and/or multi-bend conduit runs, high-performance lubricants that significantly reduce friction look like an absolute necessity.

Specially formulated, "thin-film" lubricants work well on the high-frequency data cables, reducing friction with only small quantities of lubricant. This type of lubricant is shown to have minimal impact on the data-carrying capacity of the high-performance cables, and it does not affect the physical properties of the cable jacket material. The viability of this solution needs to be confirmed with additional evaluation in real field installations.

Note: DTX Series CableAnalyzer™ is a trademark of Fluke Networks
Yellow 77® is a registered trademark of Ideal Industries, Inc.
Vaseline® is a registered trademark of Unilever

Appendix A – Output page from Fluke DXT-1800 Tester



LINKWARE
CABLE TEST MANAGEMENT SOFTWARE

Cable ID: J Baseline Air Dry

Test Summary: PASS

Date / Time: 09/21/2006 04:14:38pm
Headroom: 4.9 dB (NEXT 45-78)
Test Limit: TIA AugCat 6 PL dr 3.0
Cable Type: Cable A Cat 6

Operator: American Polywater
Software Version: 1.3100
Limits Version: 1.0200
NVP: 70.0%

Model: DTX-1800
Main S/N: 9041009
Remote S/N: 9041010
Main Adapter: DTX-PLA001
Remote Adapter: DTX-PLA001

Wire Map (T568B)
PASS

Length (ft), Limit 295	[Pair 78]	100
Prop. Delay (ns), Limit 498	[Pair 45]	152
Delay Skew (ns), Limit 44	[Pair 45]	7
Resistance (ohms)	[Pair 12]	4.9
Insertion Loss Margin (dB)	[Pair 45]	27.7
Frequency (MHz)	[Pair 45]	500.0
Limit (dB)	[Pair 45]	43.8

	Worst Case Margin		Worst Case Value	
PASS	MAIN	SR	MAIN	SR
Worst Pair	36-45	45-78	36-45	36-45
NEXT (dB)	6.1	4.9	6.1	5.4
Freq. (MHz)	486.0	351.0	487.0	490.0
Limit (dB)	27.1	31.7	27.0	26.9
Worst Pair	36	45	45	45
PSNEXT (dB)	6.8	6.0	7.0	6.0
Freq. (MHz)	480.0	490.0	498.0	490.0
Limit (dB)	24.4	24.1	23.8	24.1

PASS	MAIN	SR	MAIN	SR
Worst Pair	45-12	12-45	36-45	45-36
ELFEXT (dB)	12.0	12.1	13.7	13.8
Freq. (MHz)	358.0	356.0	500.0	500.0
Limit (dB)	13.1	13.2	10.2	10.2
Worst Pair	45	45	45	45
PSELFEXT (dB)	12.6	12.8	12.6	12.8
Freq. (MHz)	386.0	377.0	389.0	378.0
Limit (dB)	9.5	9.7	9.4	9.6

PASS	MAIN	SR	MAIN	SR
Worst Pair	36	45	36	45
RL (dB)	3.7	2.3	3.7	2.3
Freq. (MHz)	474.0	488.0	474.0	488.0
Limit (dB)	8.0	8.0	8.0	8.0

Project: DEFAULT
Site: air dry

FLUKE networks.

Cat 6 test DTX-1800.flw