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Heresy or Breakthrough: Fibre Optic Cleaning Without Inspection and Call for an "Open Architecture" Fibre Optic Precision Cleaning Procedure

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Abstract: A new inspection device defines the three-dimensional nature of connector surface areas and potential debris in unseen and previously uncharacterized surfaces. Inspection and cleaning procedures emerged in 2006. There are limitations within these that are resolved with color digital photography of the three-dimensional surfaces rather than the limited two-dimensional perspectives of IEC 61300-3-35. The result is an update of cleaning processes that (only) consider 15-20% of a two-dimensional diameter of the area commonly termed an horizontal ‘end face’. Advanced inspection reveals not only the remaining ‘horizontal end face’, but also introduces and adds vertical surfaces to the ‘end face’ that result in a logical, obvious, and heretofore disregarded three-dimensional structure. (Figure 1) As well, the advanced inspection device reveals connector adapters which are commonly understood to be a source of cross-contamination of one connection to the other. Until this time, there has been no practical means to view connection adapters and alignment sleeve components. (Figure 2) All of these various surfaces may have debris that currently area not considered and are soil points that may induce cross-contamination. These surfaces, as to present an accurate definition of the connector, require redefinition from two dimensions to three. The results of this logical advance bring enhanced cleaning procedures, new tools, and more reliable transmissions for all fiber optic deployments. This means than instead of multiple recleaning, first time cleaning is more possible and successful deployments more probable. When existing standards were first written in 2006, there was less need for precision cleaning and inspection of these surfaces. As fibre optic capacities and transmission speeds have increased, awareness of the three-dimensional nature of connector surfaces leads network designers, installers, and researchers to adopt a higher standard of inspection and precision cleaning to meet the ever-advancing sciences of fibre optic transmission of all types. Each is equally mission critical and one open architecture cleaning procedure follows the crafts person and contractor and is written into specific network designs. In so doing, the network design itself becomes a training tool for subsequent deployments. A new inspection device defines the three-dimensional nature of connector areas and potential debris in unseen and previously uncharacterized surfaces. With IEC 61300-3-35, inspection and cleaning procedures emerged. There are limitations. One procedure is possible: adaptable to all cleaning products in a vendor neutral way.

Keywords: Fibre Optic Cleaning, Fibre Optic Inspection, IEC 61300-3-35, Auto-detect Fibre Optic Inspection

1. Introduction: The Need for One Precision Cleaning Procedure

For many, the topic of fiber optic cleaning is resolved. For others, it’s not necessary and unimportant. Still others clean with the latest tool, least expensive tool, or use the inside of a shirt collar because that is cleaner than the shirt front itself! As straight-forward is science of cleaning. For fiber optics the discussion is clouded by points-of-view that support specific products.

With all the cleaning product claims, even the latest rendition of a standard or training program leaves doubt and demonstrated reality that multiple cleaning procedures neither always clean the surface. As well, the limited field of view of ‘standardized’ fibre optic inspection instruments reveals that not all of the surfaces are actually 'seen' and therefore '100% inspection' is not being performed and cleaning procedures are limited to minor two-dimensional surface areas. The image in Figure 1 defines the three dimensional nature of a typical fibre optic connector 'end face'.

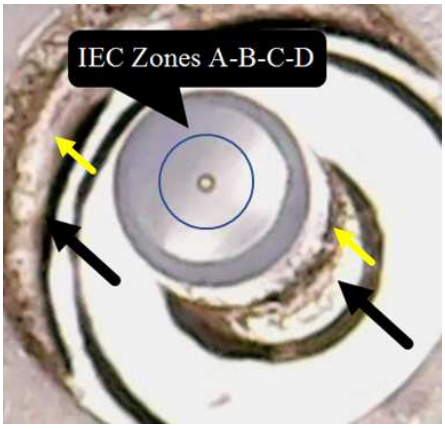

Figure 1. *Debris may be located outside existing characterization of connector surfaces.*

Noted within the black circle is a diameter of approximately 250-300 microns. This is the IEC 61300-3-35 characterization connector and defined as "Zones A-B-C-D". The remaining surfaces are not considered and contaminated leading to potential of cross-contamination in the time of post cleaning and post inspection.

As well, defined in Figure 2, adapters connection adapters and alignment sleeves are often not studied and the potential source of 'cross-contamination'. Unseen debris is present and 'pointed'.

Figure 2. *Alignment sleeves are source of potential cross contamination and are not characterized by existing standards.*

The thought of 1st Time Cleaning makes some smile and others brindle! However, beginning in 2005 with The Cisco Series® [1] first time cleaning was proven possible. A subsequent work in 2009 [2] that studied cleaning solvents and wiping materials was updated by a 2016 study [3] that demonstrated first time cleaning was attainable using popular cleaning tools that were modified by a process change. [4] A paper in 2008 encouraged an amalgamated cleaning and inspection standard for production lines and FTTx.

The first formal studies of solvent effectiveness were conducted in 2003 at Chemtronics®. [5] With the first publication of IEC 61300-3-35 a few years earlier, there was still reference to 99.9% Isopropanol (IPA) as a cleaning agent. The method at the time was "dry cleaning" and "wet cleaning". It would be with later updates to IEC 61300-3-35 that "wet-to-dry cleaning" was included, and subsequent inclusion of the phrase in other standards.

Telcordia GR-2023-Core noted three methods: 1). wet cleaning, 2). dry cleaning, and 3). combination-cleaning which is the clear definition of the term 'wet-to-dry' included in formal training sessions of the period. [6] "Wet-to-dry cleaning" is also noted in a series of product patents owned by Illinois Tool Works. [6]

2. The Foundations of the Science and Art of Precision Cleaning

The early years of The New Millennium witnessed a fiber optic Industry that rapidly evolved from near financial ruin to FTTx. Verizon® and Corning® lead with a new connector type that would establish fiber to the home. This quickly evolved to fiber to the desk and then throughout systems and networks as FTTx. For these early deployments that struggled with maintaining video, cleanliness of the connector surface was the primary concern. It was in this environment that my research began and continues to this day.

2003 Studies at Chemtronics® [5] studied cleaning efficacy of lubricating oil, animal fat and machine grease removal with: 99.9% reagent grade isopropanol, Novec® fluids, and a proprietary precision hydrocarbon. When research testing, "*worst case leads to best practices".*

In 2005, Cisco® reacted by advancing IEC 61300-3-35 from a 'simple test soils' (Arizona Road Dust©/Arizona Test Dust© and vegetable oil to emulate human body oil in a standard manner) to more complex dry and fluidic© debris. [1, 7]. The Cisco Series® introduced the concept of 'first time cleaning' by study of complex soils that, in order to 'pass', required a perfect 10-of-10. In 2009 a study of static field contamination by tribocharge was conducted [9]. In 2016 complex debris removal was characterized in an extensive study of popular cleaning tools used in a new procedure. The result was significant improvement of cleaning ability in a first-time result. [3]. 95% of these devices, including 'probe tools', reel cleaners, cleaning platforms and swab tools approached 1st Time Cleaning with the process change proposed as "Open Architecture" in this paper in the ability to remove "dry", "fluidic" and combinations of debris. This study was the first time 'combination debris', such as 'test dust and hand lotion' was recorded.

In 2010, Jason Kehren of 3M® outlined the cleaning efficacy of various solvents in his work "A Comparison of Hydrofluoroether and Other Alternative Solvent Cleaning Systems". [10]

The above studies were in response to requests from standards and approval groups who understood the installation environment, limitations of worker knowledge, and the need to baseline a cleaning procedure. As fiber optics continue to proliferate, work performed by skilled and semi-skilled crafts persons continues. Some have the proper equipment and others do not. All benefit from a concise, clear, and scientific procedure that is free from commercialism. As of now, there are not unified instructions: there is need establish one baseline method to future proof a best practice.

About 300 BCE Euclid established what would be termed 'geometry of straight lines'. By the Middle Ages desCartes formulated geometry in three-dimensions and Einstein's Theory of Relativity takes the concept of three dimensions to a higher plain. Fiber Optic Inspection is based on Euclid's two-dimensional thesis. Fiber optic connectors, adapters…and debris in the confines of these three-dimensional structure are critical to an Open Architecture Standard. Connector surfaces are not two-dimensional. Debris may 'reside' in unseen areas and 'awareness' of this possibility is essential to not only existing, but also future deployments as these may integrate.

3. The Procedure Is an "Open Architecture" Means of Cleaning

For some, the topic of cleaning a fiber optic connection is resolved by mandate: *only a fiber surface that is inspected is acceptable*. Others realize that 100% inspection is unlikely and seek a higher standard. More significantly, the popular range of inspection does not view beyond a limited horizontal surface area in a limited range of 'diameter'. *Therefore, existing inspection is not 100% of the total three-dimensional surface.* While cleaning these alternate surfaces may or may not be required, the most significant aspect is "awareness" debris may exist around and on these surfaces.

For example, the total horizontal surface of the 'end face' as shown in Figure 3 is 2500 microns. This surface 'passes' existing inspection standards as does the one in Figure 1. The area within the black circle is characterized by IEC 61300-3-35 (and associated standards) as "Zones A-B-C-D". As part of an 'open architecture' standard this surface area is redefined as "Primary".

However, in the instance of a 2.5mm connector, since only about 15% of the 'horizontal end face' and no portion of the 'vertical ferrule' is considered, the 'open architecture' standard enhances the 'primary surface' to include a 'secondary surface'. This is viable as debris from outside the field of view may cross contaminate and transfer in the time of post cleaning and inspection. [11, 12] The image below as to the left has "Secondary Contamination on the Zone-5 vertical ferrule. [22] The total "Zone-4" Horizontal end face is clean as shown also on Figure 1.

The 'open architecture' proposal redefines the 'primary surface' as Zones 1-2-3. The total horizontal surface becomes "Zone-4" and vertical surfaces are defined as "Zone-5".

Recharacterization into three dimensions is a critical awareness to assure all deployments are maximized to lowest loss and adherence to highest design parameters.

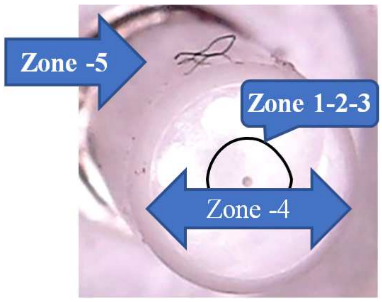

Figure 3. *"Primary Contamination" defined by IEC is as critical to precision cleaning as is "Secondary Contamination". Awareness is best practice.*

This deficiency is further exacerbated with review of The Cisco Series Soils as well as those in my 2010 and 2014 study where debris far beyond the simple soils of IEC 61300-3-35 is considered. [13] Dry debris may be attracted by tribocharged and moved during cleaning. A 'fluidic'© contamination may (quite naturally) flow about the surfaces. The reality is there are so many 'potentials of debris on myriad surface, often unseen, that there is a critical need to standardize to a higher common denominator. This is proposed as an "Open Architecture" means of precision cleaning of not only debris in standards such as IEC 61300-3-35, but also Telcordia GR-2023-Core in addition complex debris. [1, 3, 12] "Complex debris" is not unusual or improbable: a.) hand lotion and dust, b.) pulling lube and hand lotion, c.) perspiration and soil. The new proposed standard should detail *both* the advantages and disadvantages of specific products and procedures in a 'vendor-neutral' way. As such, each installation becomes applications specific and the responsibility of the individual craftsperson to decide which is best practice…in any specific environs. The Network Designer may specify cleaning procedures and Trainers called to a higher standard. OTDR Traces by EXFO® and AFL-Noyes® characterize insertion loss and reflectance: there is no doubt debris on surfaces impacts loss budgets and overall performance. Debris can also create misalignment; especially critical on multifiber connectors such as MT-Types or 38999 styles.

While 100% inspection is ideal, the reality is there are far too many incidents where this is not practical. An improved "open architecture" cleaning procedure does not obviate the need to 100% inspect, but rather acts as a critical Plan B for those, for many reasons that cannot inspected.

The unfortunate realities that work against an open architecture procedure are nearly two decades of training that require an update, significant investment in product cycles have been made, and change to an 'open architecture' method requires a complex series of agreements by vendors who subsidize the standards processes. It is for these reasons that those reading this paper may well decide to establish their own internal standard that is written in in applications specific means to a specific network design or installation.

The studied noted in this work, along with numerous others, clearly teach that an improved, low cost, easily understood, and universal 'open architecture' style fiber optic cleaning procedure is possible. Use of a solvent enhances cleaning performance of cleaning tools. [1-3] over a wide range of debris that exceed IEC 61300-3-35 and IEC TR 62627 which only consider relatively easy-to-remove debris such as test dust and light oil. The inclusion of 'combination debris' is an important consideration for not only IEC [3]. Proven First Time Cleaning Efficiency speaks to the potential of cleaning without inspection…critical for many who are managing fiber optic deployments on all levels. *To mandate inspection is less likely than to train an advanced cleaning technique.*

The critical factor is *awareness* that debris may be present in a wider area than previously understood. This challenge was presented to the author in 2008 by a RBOC FTTx deployment: concern that the Corning® OptiFit® dropped in mud would be sacrificed and lost. [14]

This 2008 requirement led to further and career-long study of the three-dimensional nature of debris. In this instance, not only did the 'end face' require cleaning, but also impacted mud required 'gross removal' from the recesses of the connector surfaces. These included: a.) there total horizontal surface, b.) vertical surfaces of the ferrule, and c.) the 'intersurfaces' of the connector to include adapters and alignment sleeves. While this cleaning procedure, surely uncommon, worked to prove that proper cleaning procedures are an invaluable option to jumper replacement or return of the circuit card for warranty, recycling or repair. Now the technician's awareness shifts to a higher plane: rather than clean the same limited area multiple times and frustration that 'I spent hours cleaning and still there was no positive test'. Technicians are dedicated.

Not all surfaces are cleaned each time the connector is opened: *only when cleaning as directed by IEC 61300-3-35 and IEC TR-62627 does not create a 'passed' transmission* (15) One of the concerns about standards is that participation and actual written standards are available only by paying a fee. Establishing an Open Architecture procedure benefits the industry.

4. Open Architecture and Existing Methods

For the last twenty years the actual fiber optic cleaning procedure has remained the same. The instructions and training reads: 'begin dry and if that does not work use the wet-to-dry technique'. The earliest version of IEC 61300-3-35/TR 62627 taught to 'begin dry and then use the 'wet technique'. [16] While, over the years, there has been referenced to drying the surface, there is no clear instruction how to actually perform the 'wet-to-dry' procedure. The first clear instruction appeared in USA Patent #6,865,770, US 833,6149B2, and foreign patents [17]. This instruction was then integrated into formal RBOC, CATV-MSO, and formal training sessions that continue to this day. [15] As well, Telcordia GR-2923-Core, published I the same time frame as IEC 61300-3-35, teaches three cleaning procedures and suggests using a solvent with all cleaning tools as a 'vendor-neutral' advance. [6]

At the time of my employment this technique was called "Combination Cleaning" for the ability to remove not only the IEC-Standard debris, but also the more complex types as presented by Cisco®. In 2016 [10] a vendor-neutral exhaustive study of commonly used cleaning tools and common debris was conducted. This was the first time that cleaning procedures were tested using "combinations of soil". This is a 'worst case to best practice' study of significance to existing and future installations; workers of all skill levels; trainers who need to update their curriculum to a new level.

Existing instructions are futile when unseen surfaces are not considered. "Dry Cleaning" has potential to be counterproductive: a.) debris may be moved and depending on the type of debris, may be speared, and easily not removed, [11] b.) dry cleaning can create a tribocharge that attracts additional debris [8, 9], and c.) Dry Cleaning is a 'mopping action' for fluids. The "wet-to-dry" technique improves on 'dry cleaning' as debris is attracted to moisture. [11]. However, the numerous and poorly defined means of 'moistening' can create 'flooding' not just in the time of cleaning, but also the time of post cleaning and inspection. "Wet-to-Dry Cleaning" presents a secondary advantage to dissipate static field contamination by tribocharge.

An "Open Architecture" cleaning procedure considers all debris types and establishes a 'worst case' procedure that removes all in as close to 1st time efficacy as the state of the art provides.

"Wet-to-Dry Cleaning" works best on dry debris. While 100% inspection is ideal, not only is this not probable, but more significantly, existing inspection only considers a small portion of connector surfaces. Existing inspection standards are not viewing the connector surface 100%. "Worst case leads to Best Practice": the 2016 study [3] forms the basis for "Open Architecture" cleaning that advances existing standards from minimum requirements to 'best practice'.

5. The Instructions Are Reversed

A 2009 White Paper written with my long-time development partner, Paul Blair [19] details the matrix of cleaning products and debris. This study was in response to the Cisco EDCS-519772 (18) that outlined various types of debris and results expectations dating to 2003. [16] This rigorous study resulted in clear realization that debris such as: 1.) graphite particles, and 2.) metal shavings, as well as 3.) simethicone, 4.) dry salt solution, and 5.) evaporated rubbing alcohol would not be removed using a "dry technique".

To break the 'surface bond' a low surface tension fluid was necessary. While excessive (wet cleaning) fluid might 'lift' metal shavings, excessive use could 'flood' the surfaces. Solvent selection is critical. [5] A common solvent is 'reagent grade 99.9% isopropanol with disadvantages that the solvency is limited to 'polar' soils and that in the instant the container is opened the hydroscopic nature of "IPA" is that degradation begins within 15-20 minutes. [25] Other fiber optic grade precision solvents are based on 'ultra-fast' evaporating carrier solvents that only partially remove (complex) debris leaving behind a residual contamination that is more difficult to remove than the original debris. [26]

The EDCS allowed use of a compressed gas duster, unspecified wiping materials, and unspecified swabs. There was a clear caveat of concern that Arizona Test Dust might scratch the fiber optic surface. To establish a universal 'open architecture' cleaning procedure we draw from eons of cleaning experience. Compressed gas dusters are not acceptable to clean fiber optic surfaces. [27]

While we enjoy the unique nature of fiber optic transmission sciences, we also benefit from established cleaning procedures. There are very few dry-cleaning procedures; the *dry process utilizing a wiping material is a mopping action for something that is "wet"*. However, numerous cleaning procedures use surfactants and solvents to complete the debris removal process. Whether the wiping material is pretreated with a fluidic medium, or the surface is cleaned with a soap or solvent, the majority of cleaning is done where some type of 'moisture' either breaks surface tension, emulsify debris, or, in the esoteric, dissipate static field leading to contamination. All of these are potential types of debris that can cause insertion loss, reflectance, or misalignment of fibers.

"Soaps" per se, is not acceptable. However, there are 'non-solvent' chemicals that require active drying. These may be 'aqueous' of 'semi-aqueous' solvents that have been used for decades with great success in electronics production. These chemical classes act as a 'surfactant': *a substance which tends to reduce the surface tension of a liquid in which it is dissolved*. [20]

The true science for fiber optic precision cleaning, leading to a common Open Architecture cleaning technique, lies in product selection to facilitate the process. In the late 1990's, at the time of the innovative CleTop® dry cleaning tool, precision solvent choice had undergone a total renewal. The 1989 "Montreal Protocol" either eliminated or created a phase out for cornerstone cleaning solvents that industrialized the planet, such as 1.1.1, Freon-113, Trike, and a series of CFCs and HCFCs. At that time, the fiber optic industry settled on 99.9% IPA. This solvent was acceptable for both end face cleaning and fusion splice prep. The HFE solvent selection noted in Mr. Kehren's paper were complemented by HFC types. Neither, as a 'neat solvent' had exceptional cleaning ability. Neither did 99.9% IPA. [21] Some precision hydrocarbons have exceptional performance at reasonable cost: not all are the same formulation.

As the decade progressed, so did solvent performance. This led to the need for an appropriate wiping material. Borrowing from Class-1 cleanroom expertise, certain hydroentangled polyester/cellulose wipers, and clean room grade microfiber materials. perform with distinction. Ubiquitous use of 100% paper wipers shall end. Certain pre-saturated wipers used for optical lens cleaning gained traction, even though some of those contained inappropriate amounts of a surfactant. Optical grade cleaners, lenses, microscopes and such are not acceptable for precision cleaning fiber optic surfaces. [28] What became clear is that excessive use of a solvent is as counterproductive as cleaning dry or without clearly defined procedures.

Recalibration from the last twenty years of product based marketing to process based success is the upcoming challenge for the Fiber Optic Industry. Re-training to a new vendor-neutral and open architecture procedure returns to the established dictum of "best practice".

Inspection studies performed using digital photography confirmed there is 'primary' debris as defined by IEC 61300-3-35, but also "secondary contamination" not considered as it is not viewable by existing microscopy and current understanding as fostered by standards that are 'minimum requirements' to assure best practice transmissions. [22].

Figure 4. *Debris is attracted to moisture. A measured amount of fiber optic grade cleaning fluid leads to enhanced cleaning of most popular tools.*

6. The Solvent Transfer Process©

The studies noted in this paper are, but a very few over the last twenty years that enable a bold and clear recommendation of an 'open architecture' cleaning technique. The commonality-of-the-procedure is the foundation that connects all who manage fiber optic connections, on any level, to an application's specific selection of solvents and actual tools to perform the task. For example: *none of the current 'probe tools' has the ability to clean an alignment sleeve*: this is the sole province of a swab tool. Cleaning Platforms have the distinct advantage of a larger cleaning surface which enables end face cleaning of direct contact connectors. Certain military and broadcast styles as well as expanded beam designs revert to precision swab tools. Some connectors have 'intersurfaces', spaces between fibers, that must be cleaned so there is no transfer contamination. [23] Product selection is applications specific to a task that may well be defined by the network designer rather than a procurement department with the vague request to 'buy fiber optic cleaning supplies'.

The choice of the proper wiping material and appropriate solvent is the foundation of open architecture cleaning. There is significant common ground. Nevertheless, one size does not fit all applications. A high-performance fiber optic grade solvent, used in minimal quantity in conjunction with an equally capable non-paper is the foundation of open architecture precision fiber optic cleaning. This usage is defined clearly as "The Solvent Transfer Process"© and is the author's refinement of the "wet-to-dry" phrase that can be misinterpreted. [11] This procedure was established between 2004 and 2016 and received formal approvals for field use. The technique is credited with hundreds of thousands of results with no complaints. [14]

7. Conclusions

"Dry Cleaning" is problematic: the process moves debris and *(depending on the wiping mechanism)* may displace but not actually remove it. Dry Cleaning can create a static field (tribocharge) that attracts more debris. *Dry Cleaning is a mopping action for fluids*. Although ideal, 100% inspection is not practical and, as it is, most existing inspection is only viewing far less than 100% of all sectors of fiber optic connectors. Therefore the title of the article is validated: there are significant numbers of fibre optic connection being cleaned without inspection of all surfaces. "Awareness" of this deficiency and recommendations of cleaning these surfaces become the a new 'best-practice/worst case' standard that easily is implemented in a cost-efficient way.

I established "wet-to-dry cleaning" as *"Wet-to-Dry 1-2-3"* in the early years: 2003-04. [4, 9, 17, 19, 22, 23, 27] *"Wet-to-Dry 1-2-3"* defined the amount of solvent, wiper, and technique that led to 1st time removal. As this paper documents, additional digital photographic inspection [24], defines debris, location and a vendor neutral, open architecture technique (12.22) which enhances performance of the majority of cleaning tools…likely one you are using now.

Dry Cleaning should be abandoned and eliminated from all standards and training. THE OPEN ARCHITECTURE PROCESS OF "SOLVENT TRANSFER" moistens the tool and defines the actual cleaning procedures in applications-specific terms that future proof all technicians at all levels.

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