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Technical Findings from Sandia's Intrabuilding Recabling Project

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Technical Findings from Sandia's Intrabuilding Recabling Project

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Abstract

The United States and other leading nations are at the forefront of a global trend to implement both national and international enterprise networks via information highways. New or upgraded cabling infrastructures are essential to support these activities. As professionals in the telecommunications industry, we all are keenly aware of the challenges presented by such cabling upgrades.

Desktop connectivity must be established before we can expect quantum leaps in information flow, as suggested by new technologies and global concepts. Some businesses with campus-type facilities have undertaken this formidable challenge. Universities and other higher-level learning institutions, corporate research facilities, independent and government-funded laboratories, financial institutions, medical facilities, and unique suburban housing test sites have risen to this challenge. Sandia National Laboratories is one such organization (see Figure 1).

Figure 1. Sandia New Mexico campus (28.6 square miles).

Sandia National Laboratories wrestled with many important issues during a recent campus-wide intrabuilding recabling effort. These issues should be of great interest to telecommunication cabling designers, installers, and buyers.

Sandia's recabling project personnel reached these conclusions:

1. Manufacturers' published statistical data are incomplete.
2. Establishing acceptance criteria (beyond industry standards) is difficult.
3. Verifying acceptance criteria (beyond industry standards) is difficult.
4. Customary microscopic optical connector inspection is inadequate.
5. Interferometric optical connector inspection is necessary.
6. Both hand and machine field-polishing of optical connectors are acceptable.
7. Confined areas containing massive cable quantities are temporarily unhealthy.
8. High-performance quality is attainable at medium-performance cost.

Acknowledgments

The information contained in this report originated from the Intrabuilding Recabling Project at Sandia National Laboratories, 1993-1995. It was given via invitation as a professional presentation for the Building Industry Consulting Services, Inc. (BICSI) International Telecommunications Winter Conference in Orlando, Florida on January 16, 1996, and was subsequently published in the conference "Presentation Summaries" booklet.

Our thanks to BICSI for allowing us to present Sandia's communications cabling infrastructure findings to the international arena. We believe that the telecommunications industry as a whole, as well as users of such services, will benefit from these findings.

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Technical Findings from Sandia's Intrabuilding Recabling Project

Introduction

Sandia National Laboratories is a world-class scientific and engineering research and development (R&D) laboratory supporting Department of Energy (DOE) initiatives. It is composed of two major sites: headquarters and laboratories in Albuquerque, New Mexico, and other laboratory facilities in Livermore, California. Additional minor sites are located in Hawaii, Nevada, and Washington, D.C. The New Mexico site population is 8,000 people.

Sandia was originally created in the 1940s to support nuclear weapon design. Through the years, Sandia's broadening mission has expanded to include nuclear energy technology and waste management, alternate energy research, materials sciences, high-performance computing and information technology, microelectronics and photonics, advanced manufacturing methods, intelligent systems and robotics, and other leading edge technologies.

Today, Sandia's business is research and development in high-risk, high-payoff sciences and technologies. Partnerships for strategic alliances are earnestly sought after with other research facilities, industries, and universities. Sandia's technical staff is constantly challenged to discover and develop new ideas, materials, and applications. Success in these endeavors is increasingly dependent on information access/exchange and computing power. These requirements can only be satisfied by capable communication networks and their underlying cable systems. Customers' demands for unlimited capabilities within a cabling system are sometimes well justified, as is the case at Sandia National Laboratories.

Figure 2. Sandia New Mexico, 1951.

Sandia's business advancements brought heavy communication demands to aging (circa 1950) wiring systems. Sandia executive officers, participating in corporate level reengineering, chose to focus internal resources on creating a labs-wide information infrastructure. A Chief Information Officer (CIO) was appointed and a new and extensive support organization was formed. Laboratory staff dealing with any and all types of corporate information were, for the first time ever, consolidated under the CIO. Sandia's CIO recognized telecommunication cabling as a fundamental component of Sandia's corporate information infrastructure and diligently supported an ongoing campus-wide intrabuilding recabling project. In support of this project, Sandia-specific cabling standards were created. They were based on national and international cabling standards. The cabling system resulting from these standards can support all current and foreseeable future information movement demands.

The recabling project team's goal was simple – deliver a campus-wide cabling infrastructure that would enable Sandia's corporate information infrastructure and allow the Laboratories to maintain a position of superiority in the global research and development arena. Significant recabling efforts have recently been completed.

Sequence of Events

Fall '92	A campus-wide intrabuilding recabling project was conceived, socialized, and initiated at the Sandia New Mexico site.
Spring '93	Project leader and core team members were identified and commissioned.
Summer '93	Sandia-specific cabling standards were published defining components, testing procedures, and acceptance criteria.
Fall '93	Recabling construction started in three buildings.
Fall '94	The first recabled building was completed (September).
Fall '95	Nine recabled buildings were completed.

In addition to the recabled buildings, four new buildings were constructed with identical cable designs. This accomplishment exemplifies the success of the recabling team's ability to affect traditional engineering mentality.

To date, these efforts have provided approximately 60% of the Labs' New Mexico population with modern connectivity. This percentage will increase as recabling and new construction continues through 1996. Five additional buildings will be recabled and four new buildings will be occupied this year.

Massive quantities of intrabuilding copper and optical fiber cables have been installed and terminated at Sandia's New Mexico site. The following approximations are cumulative and include FY95 data.

1,125 miles of 4-pair Enhanced Unshielded Twisted Pair (EUTP) cable
700 miles of 4-fiber Optical Fiber (OF) cable
120,000 Optical Fiber ST-type Connectors

Sandia's cabling efforts since 1993 may appear unique. We believe they are only unique with respect to time. Within a few years, high quality cabling activities involving large quantities of cable and connectors will be commonplace. In that respect, Sandia's cabling can be thought of as an indicator of things to come.

Local and global market studies indicate constantly increasing growth rates of cabling activities (Ref. 1). These studies indicate particularly impressive surges in data cabling activities. Locally within the USA, data cabling annual growth rates are predicted to increase from 22% in 1995 to 26% in 2000. Globally, for the same time period, data cabling annual growth rates are predicted to increase from 27% to 31% (see Figures 3 and 4). These studies reflect increasing local and global desires to exchange information electronically. This is consistent with Sandia's early determination that cabling is a fundamental component of any information infrastructure. Information exchange capabilities are largely dependent on cabling capabilities.

Figure 3. USA Cabling Market Growth Chart.

Figure 4. World Cabling Market Growth Chart.

Sandia has experienced numerous unexpected and unprecedented performance-related cabling challenges since 1993. The following findings are supported by graphical and statistical data compiled at Sandia National Laboratories/New Mexico from 1993 through 1995. It is not our intent to criticize the performance of any company or its manufactured products. Rather, the intent is to share experiences among industry peers with a goal of wide-spread improvement. We believe that many others either have encountered or will soon encounter similar experiences. This paper is intended to heighten buyers' awareness of cabling project difficulties. We all are buyers at one time or another.

Findings

Finding 1. Establishing acceptance criteria that exceed industry standards (such as EIA/TIA 568A) can be very difficult.

Sandia's customer base demanded a cabling system with unlimited capabilities, while Sandia's management demanded cost containment, a very perplexing but common situation.

The decision to include Single Mode fiber in the horizontal distribution and establish stringent acceptance criteria was Sandia's approach to satisfy customer-demanded unlimited capabilities. Sandia management's cost containment mentality was addressed with detailed cost/performance analyses.

A search for knowledge and understanding evolved as part of Sandia's decision making process. This led to examining manufacturers' published component specifications which proved to be a very enlightening experience. Sandia found many manufacturers' published data to be incomplete.

Specific examples are μ (*mu*, population mean) and σ (*sigma*, population standard deviation). These refer to attenuation values commonly published by optical fiber connector manufacturers (see Figure 5).

<u>Manufacturer</u>	<u>Single Mode (dB)</u>		<u>Multimode (dB)</u>	
	<u>μ</u>	<u>σ</u>	<u>μ</u>	<u>σ</u>
AT&T	0.35	0.2	0.4	0.2
AMP	0.3	?	0.3	?
Siecor	0.4	?	0.3	?
3M	0.3	?	0.3	?
Fibertron	0.6	?	0.6	?

Figure 5. Statistical attenuation chart for BFOC/2.5 (ST-type) connectors.

These statistical values are frequently published to quantify assembled connector attenuation. Without knowing additional associated statistical information, such as *sigma* and distribution type, *mu* alone can be very confusing.

If an upper limit of acceptance were established at the statistical 1 *sigma* point and a normal distribution assumed, the statistical failure rate would be 16%, as seen in Figure 6 (Ref. 2). This failure rate was deemed unacceptable at Sandia, since it would have represented many thousands of dollars for wasted material and labor (connectors and their assembly). Extending the upper limit of acceptance to the 2 or 3 *sigma* point would reduce the failure rates. However, attenuation values at the manufacturers' 2 or 3 *sigma* points were totally unacceptable to Sandia.

Figure 6. Typical Standardized Normal Distribution.

To achieve outstanding attenuation values and lower failure rates, Sandia focused on reducing the mean and tightening the distribution. Tight distribution tends to indicate consistency in assembled products, such as optical connectors.

Sandia considered two approaches to accomplish this:

1. Convince manufacturers to:
 - a) improve connector sub-component tolerances (primarily ferrule tolerances) along with sub-assembly techniques such as ferrule positioning in the back housing;
 - b) improve fiber geometric parameters (primarily outside diameter variances and core concentricity), and;
 - c) improve coupler alignment sleeve tolerances.
2. Improve field termination techniques.

Sandia realized, through extensive involvement with connector, fiber, and coupler manufacturers, the extreme difficulties associated with manufacturing components with tolerances in the fractional micron range. Consequently, Sandia chose to conduct in-depth field termination process investigations.

The investigations resulted in termination process modifications involving cleaving, air-polishing, lubricants and papers, and polishing cycles and pressures. Sandia's modifications yielded significant reductions in mean attenuation and the standard deviation. These new values were well below manufacturer published values, as shown earlier in Figure 5. Sandia's improved values are shown in Figure 7 and Figure 8.

Figure 7. Sandia-improved BFOC/2.5 (ST) connector attenuation charts (Multimode).

Figure 8. Sandia-improved BFOC/2.5 (ST) connector attenuation charts (Single Mode).

At Sandia, Single Mode link performance is composed of two parameters, attenuation and reflectance. During Sandia's termination process investigation, Single Mode specific modifications yielded both attenuation and link return loss (reflectance) reductions. Figure 9 displays Single Mode link return loss at 1310 and 1550 nm wavelengths.

Figure 9. Sandia-improved link return loss charts (Single Mode).

Over 50,000 Single Mode BFOC/2.5 (ST-type) connectors were field-installed at Sandia with performance levels equivalent to factory-produced super PC ST connectors.

We believe similar field termination process improvements could be applied to all manufacturers' connectors, yielding similarly improved assembled performance beyond the manufacturers' published values.

Recommendation 1. Manufacturers should publish more comprehensive statistical data. This would allow buyers to better understand component performance and clarify cost/performance relationships in a highly competitive and saturated product market.

Recommendation 2. Buyers and installers should possess a fundamental knowledge of statistics. This would allow them to better understand component cost/performance potentials.

Finding 2. Verifying acceptance criteria that exceed industry standards can be very difficult.

During the course of Sandia's optical fiber field termination process investigation, much attention was focused on the connector ferrule. Geometric properties of a terminated ST-type connector can greatly affect transmission capabilities of mated connectors and, in the case of protruding fiber, can greatly increase liabilities with respect to connector longevity. To better understand ferrule geometry, Sandia employed interferometry (Ref. 3).

Early in Sandia's cabling effort, assembled connectors were inspected with several different microscopes and interferometers. These inspections were conducted primarily to discover the cause of wide variations in early link return loss measurements.

Sandia's microscopic inspections revealed limited two-dimensional information about ferrule tip geometry. Interferometric inspection revealed three-dimensional ferrule tip information. Sandia's interferometer inspections proved to be invaluable in improving link

performance and reliability. In addition, interferometers have become indispensable in the termination contractor education process.

When interferometers were used to inspect connectors in unacceptable Single Mode optical fiber links, severely undercut connectors were often found. Severely undercut connectors refer to connectors with the fiber polished well below the surface of the ferrule, as shown in Figure 10.

Figure 10. Severely undercut ST connector.

A severely undercut connector, when mated with a properly polished connector, will form an air gap between fiber ends. Any air gap will result in a theoretical reflection of -14 dB due to the glass/air interface.

Recent research within Bellcore has shown that connector ferrule tips are actually compressed when mated in a coupler (Ref. 4). The compression is slight, but, in many cases, enough to allow undercut connector fiber ends to contact. The amount of compression is dependent on ferrule tip radius, ferrule tip material, magnitude of fiber undercut, and connector spring loading force. This compression is graphically displayed in Figure 11.

Figure 11. Ferrule Tip Compression Graph (Ranging from 0.24 to 0.5 microns).

Belcore research has also revealed that permanent ferrule tip deformation occurs when connectors are mated. The extent of deformation is dependent on the amount of time mated and environmental conditions such as temperature and humidity (Ref. 5).

Several other ferrule tip problems were unintentionally discovered during interferometer inspections. One major problem was protruding fiber. Figure 12 shows a severely protruding fiber.

Figure 12. Severely Protruding Fiber.

A connector with a severely protruding fiber, when mated with a properly polished connector, will provide firm fiber-to-fiber contact. Fiber-to-fiber contact will yield excellent optical transmission performance. However, both the protruding fiber and the fiber in the properly polished connector will be subjected to higher pressures due to the reduced contact area. We believe long-term reliability and mating cycles are greatly reduced when connectors contain protruding fibers. At this time, fiber pushback and creep life that result from protruding fibers are under investigation. More understanding about how different adhesives respond to these pressures is needed.

Sandia's discovery of ferrule tip anomalies was not limited to Single Mode connectors. Multimode connectors, when inspected with interferometers, displayed the same types of variations (undercut and protruding fiber) as the Single Mode connectors. Sandia's modified Single Mode and Multimode field termination processes have produced connector ferrule tip geometry as shown in Figure 13.

Figure 13. Acceptable Connector Ferrule Tip.

Sandia's current optical link acceptance criteria includes attenuation and return loss limits. They will soon be modified to include connector undercut and fiber protrusion limits verified by interferometry. Inclusion of field interferometry testing (and the cost associated with it) was necessary for Sandia to meet demanding customer requirements.

Recommendation 3. Manufacturers should modify their recommended termination processes. This would help to minimize protrusion and undercut conditions.

Recommendation 4. Buyers should require interferometry inspection during the termination process. This would reduce the possibility of costly future rework to repair protruding and undercut connectors.

Recommendation 5. Installers should incorporate interferometry into their standard termination processes. Installers could then reduce warrantee liabilities associated with protruding and undercut connectors.

Recommendation 6. Optical fiber termination training should include interferometry. This would allow trainees to visually confirm their ability to produce high quality connectors.

Finding 3. Both hand polishing and machine polishing are capable of producing consistent high-quality connectors in the field.

Sandia investigated automated connector polishers to better understand their potential cost savings and termination consistencies. Sandia required stringent connector performance, whether hand polished or machine polished.

Sandia found that some multi-connector polishing machines are not capable of compensating for ferrule length variation. In these machines, some ferrules either crash or

over polish, while other ferrules under polish. These failures are due to variations in the connector's exposed ferrule length (C) as shown in Figure 14. This varying length (C) is the combined result of varying ferrule length (A) and varying insertion depth (B) of the ferrule into the connector housing. When connectors to be polished are locked into the connector holder plate, the varying length (C) causes ferrule tips to contact the polishing plate differently. Some ferrule tips will be subjected to high pressures as the polishing movements begin. Others ferrule tips may not contact at all at this point in the polishing process. When the polishing procedure is concluded, fractured, undercut, and protruding fibers result. These failures require time-consuming replacement or, in some cases, time- and material-consuming retermination.

Figure 14. Ferrule Length Variation Effects on Some Automated Polishers.

At Sandia, both hand polishing and machine polishing have been completed on thousands of ST type connectors. Both polishing techniques, when properly executed in the field, have proven to yield exceptional connector performance characteristics.

Some automated polishing machines offer an additional feature which Sandia found to be particularly useful. Some flat-tipped connectors were unintentionally installed on horizontal optical fiber cables. They could not meet Sandia's acceptance criteria. Rather than cutting off these connectors, polishing machines were used to dome the ferrule tips in the field. This requires an appropriate connector-specific doming process. At Sandia, hand-doming techniques did not yield consistency.

Recommendation 7. Automated field-polishing machine manufacturers should modify their polishers and include polishing procedures to produce 100% yield of high-quality connectors. This achievement would make automated field-polishing more attractive.

Recommendation 8. Buyers can consider both hand and automated field-polishing, but should demand high-quality connector performance. Allowing installers to choose hand or automated field-polishing methods should result in competitive pricing.

Recommendation 9. Installers should clearly understand automated polishing disadvantages and advantages. This knowledge could increase installers' overall competitiveness.

Recommendation 10. Optical fiber termination training should include both hand and automated polishing techniques. This would allow trainees to work for installers who polish with either technique.

Finding 4. Massive quantities of horizontal cables within confined areas (such as distribution rooms) can result in temporarily unhealthy concentrations of cable jacket vapors.

The air quality within telecommunication rooms can be negatively effected by the presence of large masses of telecommunication cable during installation as shown in Figure 15. This effect can have a direct impact on the productivity of the workers installing the cabling and result in project interruptions, schedule delays, and budget impacts.

Figure 15. Massive Quantities of Horizontal Cabling in a Typical Distribution Room.

Evidence suggests that cabling is capable of releasing (or out-gassing) vapors of chemical components present in the cable jacketing (Ref. 6). Phthalate plasticizers are commonly used in the manufacture of typical riser-rated telecommunication cable jacket. Approximately 40% of this jacket material is comprised of phthalate ester plasticizers of various types. The phthalate plasticizers were found to be classified as primary irritants.

There is little toxicological information relative to the effects of exposure, via inhalation, to phthalate plasticizers present in cable jacket material. Occupational Safety and Health Administration (OSHA) and National Institute for Occupational Safety and Health (NIOSH) publication research revealed that no air sample collection and analysis methods exist for the types of plasticizers of interest to Sandia. This research did reveal the existence of occupational exposure standards for two unrelated phthalates commonly used in the plastics industry. These standards are not always applicable to telecommunication cabling products or to work environments where telecommunication cable is being installed.

The available toxicological data and exposure standards for unrelated plastics industry phthalates, regardless of direct applicability, reinforce the need for ensuring that the indoor air quality within telecommunication closets or rooms is maintained to provide a work environment that is free of recognized or potential hazards. This was accomplished at Sandia by ensuring ventilation prior to cable placement and continuously thereafter until termination completion.

Ventilation can be provided by portable systems or by building heating, ventilation, and air conditioning (HVAC) systems. Portable ventilation systems can also be used in combination with building HVAC systems if the HVAC system is not effectively providing acceptable air quality.

The combination of no ventilation and large masses of riser-type cable in a room of relatively small volume can result in workers experiencing symptoms of exposure to irritating organic vapors. The symptoms include headaches, eye irritation, upper respiratory irritation, and combinations thereof.

Recommendation 11. Cable manufacturers should participate with OSHA in developing safety standards pertinent to installations of massive quantities of communication cables in confined spaces.

Recommendation 12. Buyers should ensure that some form of ventilation is provided to the distribution rooms prior to cable placement operations and operated continuously until all cable termination is complete.

Recommendation 13. Installers should inform their employees of symptoms and possible dangers associated with cable jacket out-gassing.

Recommendations 11, 12, and 13 will mitigate the health liability issue of cable jacket vapor exposure for all parties.

Summary

Sandia's extensive cabling efforts generated knowledge applicable to large-scale cabling projects. Sandia installed a high-performance cabling infrastructure at a medium-performance cost. Sandia's recent cabling efforts confirmed the trend shown in Figure 16. Other corporations with similar high-performance large-scale cabling needs should take advantage of this trend.

Figure 16. Sandia Cost/Performance chart.

As more corporations face the challenge to remain competitive in their businesses, cabling upgrades similar to Sandia's will become commonplace. Corporations choosing to invest in these types of cabling upgrades will enjoy immediate communication advantages and poise their corporations for future business expansions in ways yet unknown.

References

1. "WIT Inc., Report 11938 / 1, August 1995": World Market for Voice & Data Premises Cabling and Apparatus 1994-2000. World Information Technologies, Inc., Northport, New York.
2. *Understanding Statistics*. Robert R. Pagano. West Publishing Co., 1994.
3. *Basics of Interferometry*. P. Hariharan. Academic Press, Inc., San Diego, 1992.
4. "Effect of Ferrule-Endface Geometry on Connector Intermateability." *Conference Proceedings*, National Fiber Optic Engineers Conference (NFOEC), Volume 3. Boston, 1995.
5. , "Optical Connector Reliability During High Humidity Temperature Cycling." *Conference Proceedings*, National Fiber Optic Engineers Conference (NFOEC), Volume 3. Boston, 1995.
6. "Summary of Indoor Air Quality Concerns in Telecommunication Rooms and Synopsis of Work Stoppage Occurrence," Jeff Downs, Certified Industrial Hygienist. Sandia National Laboratories internal memo, August 1995.

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