Next Generation I&C Systems
Integrating Optical Technology to Meet I&C Challenges

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ABSTRACT

The concepts of fiber optics have been in existence since the late 1890's when the Total Internal Reflection theory was first proposed. Since that time, great accomplishments have been achieved, most of which have occurred in the last three decades. Optical technology has served the telecommunications industry quite well in providing a means of transmitting vast amounts of information over extended distances with low power requirements. Additionally, the small packaging of optical components and cabling, as well as interference-free signal transmission capabilities, make it an ideal and necessary upgrade to conventional technology in advancing Instrumentation and Control systems.

Consider now, that in order for fiber optics to take a serious foothold in the nuclear I&C world, some key events must occur. One such event, the new Qualification Standard for Fiber Optics in Class 1E Systems is rapidly nearing completion in the IEEE writing committee. Following the release of the new Optical Qualification Standard is the requirement for an industry wide implementation plan that can be effectively applied to both existing and new reactor technologies. To achieve state-of-the-art optics in nuclear I&C systems is not as complicated or far-fetched as one might believe, as fiber optics are highly adaptive to any existing instrumentation through a very simple and easily to qualify signal conversion process.

Keywords: I&C Optics, Instrumentation Optics, Fiber Optics

1 INTRODUCTION

This presentation focuses on the use and qualification of fiber optics in Nuclear Power. Although fiber optics have been available for longer than the computer itself and has experienced most of its growth through the telecommunications industry, a full scale debut into nuclear use has been relatively slow in developing.

Recent revisions to IEEE Standards have helped to pave the way for application growth in non-Class 1E systems and this is just the beginning. A new Draft Trial use Standard is in writing committee for qualifying fiber optic cable, field splices and connectors for Class 1E applications. It is expected that this new Trial Standard will spark an enormous surge in nuclear optical technology.

The amazing properties of fiber optics lend a great deal of solutions to the complex mission of Instrumentation and Control, in that optical fiber is immune to electromagnetic interferences, are capable of carrying multiple redundant channels simultaneously and require far less space than current carrying cables. In addition, most analog or digital based signals today, including current, voltage or simple contact closure, can easily be converted and transmitted on fiber optic cables.

It is important to note however, that fiber optics and optical installation practices used in telecommunications and other industries are significantly different and may be far less tolerant than that which is required for Nuclear Power. In light of this, the Nuclear Engineer and plant maintenance personnel must be quickly brought up to speed on how the nuclear version of fiber optics can and will be used in their plant facility, as well as in the new generation reactors. This includes numerous forms of emerging optical electronic devices, interfacing with legacy instruments, cable design architectures, connectivity components, preventive maintenance procedures, and system testing requirements.

Today, the widespread use of fiber optics in other industries has led to development, standardization and refinement of network and link architectures that are capable of carrying multiple bi-directional signals of variable information on a single fiber, the size of a human hair. The optical signal can be transported on everything from a simple point to point link to a complicated ring-mesh redundant system cabling that is virtually fault free.

Applications in nuclear power already include security and surveillance systems, plant administration, engineering computer systems, non-Class 1E Instrumentation and Controls, monitoring functions, modernized fire protection systems and biometrics, to name a few.

More recently, analog to digital and digital to digital optical converters have been ruggedized to meet nuclear qualifications for harsh environment applications. They have also been miniaturized to the point where they can fit into less than one inch of instrument housing or DIN rail mounting space with the capability of delivering noise-free and instantaneous signals for thousands of feet, even when routed in direct contact with high voltage circuits.

Understanding where we are and where we will soon be regarding fiber optics in nuclear power plants.

In addition to the introduction of fiber optics to Class 1E systems in the very near future, Nuclear Power Plant Instrumentation and Control circuits can also expect to undergo major overhauls with a new cabling system that is truly capable of supporting 21st Century Next Generation advancements.

For years the nuclear power industry has deployed fiber optic cable for satisfying a number of functions. Using IEEE 383 as the parent Standard, as well as IEEE 323 equipment qualification guidelines, Nuclear Systems and Computer Engineers have successfully implemented optical based solutions in numerous plant situations. Today however, fiber systems, cable and components have changed significantly from that of past years. What was once a simple process to upgrade data channels from 10 Mb/sec to 100 Mb/sec, has become significantly more difficult with multiplexing and higher data rates.

This is primarily due to the fact that as bandwidth increases, quality of components, enhanced component installation practices and reduced transmission distances play important roles in system upgrades. Today, the Nuclear I&C Engineer is faced with transmission quality issues that at times seem unmanageable. Couple this with the fact that aging copper circuits in nuclear power must be upgraded for plant life extension and it quickly becomes apparent that there is a dire need for a true Fiber Optic Nuclear Standard.

If you are looking for that new Standard, it's just around the corner. The new Draft Trial use Standard for Qualifying Fiber Optic Cable and Components for Class 1E Nuclear applications was first assigned to the Writing Committee P1682 in the spring of 2006. Its accelerated release date, although not yet firm is expected to be sometime in the very near future. During the interim, IEEE 383 has undergone revision as well in order to fill in some of the voids and to give some basic principles and guidelines in fiber optics for Nuclear Engineers. It should be noted however, that IEEE 383 is still a Standard that was originally based on qualification of copper cable and no matter how you sum it up, IEEE 383 does not address all the important issues of qualifying fiber optic cable and components for use in Class 1E applications.

In order for Nuclear Engineers to effectively integrate optical technology to meet I&C challenges, they will first need to be trained and qualified themselves in the qualification methods, applications, engineering and component selection of fault tolerant optical based systems. Since optical circuits have the capacity to offer significantly more solutions than shielded twisted pair and other low voltage circuitry, it is important that the Engineer's knowledge base regarding fiber optics is expansive. From this point, the Engineer will be able to select the right optical components and apply the new Qualification Standard in order to create cost effective and logical solutions toward modernizing both Class and non-class I&C systems.

Next Generation reactor designs rely heavily on fiber optic I&C circuits, as will impending plant upgrades. It is for this reason that regulatory bodies have already commenced extensive fiber optic training of their inspectors in regard to 1) component selection, 2) system designs and 3) installation qualification criteria. These three basic knowledge principles form the basis for successful integration of optical technologies to meet I&C challenges of the future.

An overview of the new IEEE Draft Trial Use Standard P-1682/D1, for Qualification of Fiber Optic Cable and Components in Nuclear Power.

The proposed Draft Trial use Standard provides general requirements, directions and methods for qualifying Class 1E fiber optic cables, terminations, field splices, connectors and interfaces for service in nuclear power generating stations. Categories of cables and components included are those used for control and instrumentation services, as well as signal and communication cables.

It includes provisions and direction for:

Fiber Optic Cable Qualification for manufacturers
Field Qualification of Cable Assemblies
Field Qualification of Fiber Optic Connection Components
Field Qualification of Fiber Optic Splicing and Splice Components

Parent documents include IEEE 323-2003, Standard for Qualifying Class 1E Equipment for Nuclear Power Generating Stations and IEEE 383 Type Test of Class 1E Electric cables, Field Splices, and Connections for Nuclear Power Generating Stations.

It should be noted here that IEEE 323 may be used in conjunction with the newly approved Draft Trial Use Standard for the purpose of Qualifying fiber optic components, or cable assemblies that interface with or within devices covered by IEEE 323, such as existing I&C components.

Fiber Optic Principles Qualification Criteria

The principle of qualification section of the new Draft Trial use Standard will address the role of qualification as it relates to fiber optic cables and installation support components. As is common with any qualification standard, demonstration of performance in regard to specifications and proving that no mechanical or design failures will lead to common cause failures under postulated service conditions exist is required. In addition, the Qualification Guidelines will include provisions for testing and analyzing signal waveform and throughput during Type testing, as this too may be affected by postulated service conditions. This is the first time that an IEEE Standard will specifically address fiber optics alone for Class 1E Qualification purposes.

Additionally, degradation or aging followed by exposure to environmental extremes such as radiation, uncommon pressures, temperatures, mechanical stresses, submergence and chemical sprays or a combination of these resulting from Design Basis Events DBEs, which can result in failure must also be considered.

Because fiber optic cables and components are comprised of numerous subcomponents with different mechanical properties and materials of construction to consider, it is necessary in most instances to evaluate the effects of each and every component and subcomponent of the entire assembly, as well as the transmission signal in order to establish the legitimate Qualification of the entire circuit.

Achieving balance and parity in design begins with an understanding of all optical components and their capabilities.

In order to design and effectively deploy a Qualified Class 1E optical I&C circuit or system, the Engineer must first have a thorough understanding of optical medium variances and their capabilities, cabling connectivity, support components and cabling options. Also, a base knowledge of analog and digital interface components, additional power and heat load calculations and advanced cabling architectures is necessary. The following represents only a small portion of the information needed for qualification and design of an optical based I&C infrastructure.

Transfer Medium (Fiber Optic Cable and Cable Assemblies)

A typical fiber optic cable is made of doped silica glass, which propagates light by internal refraction and reflection principles. The fiber optic cable is classified by type (Single Mode Step Index and Multimode Graded Index) as well as core/cladding diameter (i.e. 8.3/125 or 62.5/125).

Single-mode Step Index fiber with its extremely small core, is the most expensive of all cables to install even though the fiber itself is less expensive than other types. Single-mode fiber only propagates one mode or path of light making it highly efficient over longer distances and high data rates. This type of cable requires a precision alignment to a highly defined beam of light in order to propagate effectively. In addition, singlemode fiber is less tolerant to contamination than other fiber types resulting in the need for a more aggressive preventive maintenance schedule.

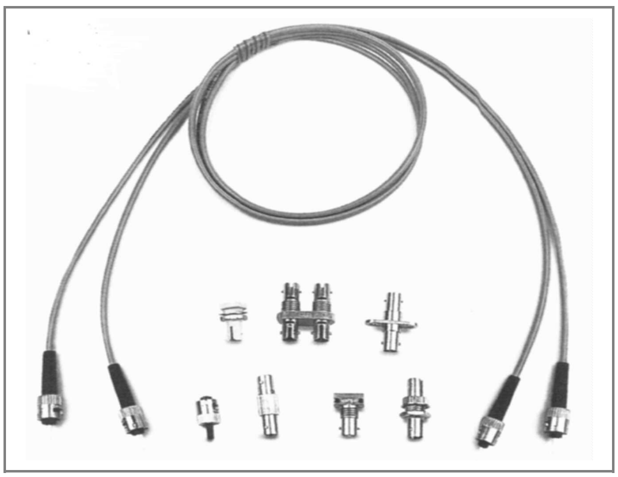


Figure 1.

Above is a fiber optic cable assembly and installation support components prepared for qualification. The glass transfer medium may consist of a specified sample cable length with connectors affixed to each end with coupler devices representing interlink or end equipment connections.

The most logical cable selection for Instrumentation and Control functions in nuclear power is Multi-mode Graded Index, 50/125 micron or 62.5/125 micron fiber.

Multimode Graded Index fiber exhibits a variable core density cross-section, with the highest density or preferred Mode Order found near the center of the core. This cable design reduces inter-modal dispersion and acts to focus and guide broader wavelengths of light into the fiber's near center core where it propagates effectively. Precision alignment of splices and connections, although still important, is far less critical than single mode fiber requirements. In addition, preventive maintenance schedules are more relaxed than that required for singlemode circuits.

Application Distance Guide:

50/125 MMGI 3 kilometers for data transfer rates up to 100 Mb/sec
62.5/125 MMGI 2 kilometers for data transfer rates up to 100 Mb/sec

Table I – Example of a design table, showing fiber types applicable wavelengths, anticipated bandwidth and maximum transmission distance capabilities.

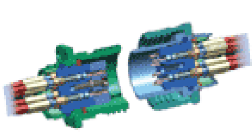
Fiber Type	Source Wavelength	Bandwidth (data rates)	Maximum Transmission Distance at Specified Data Rate	Maximum Transmission Distance on bandwidth upgrade to (times ten current bandwidth)
MMGI 50/125	850nm LED (1300nm)	10 Mb/sec	3,000 meters	2,000 meters
MMGI 50/125	850/1300nm VCSEL	1,000 Mb/sec (Gbic)	550 meters	350 meters
MMGI 62.5/125	850nm LED (1300nm)	10 Mb/sec	2,000 meters	2,000 meters
MMGI 62.5/125	850/1300 VCSEL	1,000 Mb/sec	350 meters	350 meters
SMSI 8.3/125	1310nm	1,000 Mb/sec	3,000 meters	3,000 meters
SMSI 6.0/125	1310/1550nm	10,000 Mb/sec (plus)	Unlimited	Unlimited

Nuclear Engineering and Qualification Guide to Connector Selection

There are a multitude of fiber optic connectors on the market today ranging from top of the line high quality metal body versions to lower cost plastic body styles. For each type and selection of body style there are also multiple methods for bonding or fusing the glass fiber to the end connection. Selection of the appropriate type of fiber optic connector for Nuclear Instrumentation and Control applications is largely dependent upon the function and ambient conditions that the connector will be subjected to, as well as Qualification requirements for Class 1E applications. Following is a condensed version of an engineering table showing common connector styles that may be suitable for Qualification.

Note that the body style is a very important consideration as some connector styles and body types are not well suited for harsh environments, high vibration areas, thermal expansion and contraction, thermal shock, humidity, chemical spray, radiation and high density applications.

Table II Fiber Optic Connector Styles

Connector Style	Materials of Construction	Glass Bonding Style	Common Use	Suitability for Mild or Harsh Environments	Adaptability to fiber or cable jacket diameters	Identifying Characteristics
 MULTIMODE ST	Available in plastic or metal body configurations, with ceramic, zirconia or polymer ferrules	Mixed epoxy, anaerobic epoxy, soft adhesive, high temp adhesive, crimp and polish, crimp with no polish	Inter-network or equipment connections in high vibration areas as very little movement or shifting will occur	Metal body and ceramic or zirconia ferrule is well suited for harsh environments when using an epoxy or adhesive bonding agent	Easily adapted to 900 micron and 3.0 mm simplex or breakout fiber types. Not suitable for direct connection to 250 micron buffered fiber and requires heat shrink buildup for adapting to 1.6 to 2.8 mm single or breakout jackets	White, black or gray boot denotes Multimode applications only
 MULTIMODE SC	Available in plastic body configuration with ceramic, zirconia or polymer ferrules	Mixed epoxy, anaerobic epoxy, soft adhesive, high temp adhesive, crimp and polish, crimp with no polish	Commonly referred to as the subscriber connector, used for work-place quick disconnect and medium density patch panels and Light Interface Units	Plastic body with ceramic or zirconia ferrule is suitable for controlled or “mild environment” applications	Easily adapted to 900 micron and 3.0 mm simplex or breakout fiber types. Not suitable for direct connection to 250 micron buffered fiber and requires heat shrink buildup for adapting to 1.6 to 2.8 mm single or breakout jackets	White, black or gray boot with gray body generally denotes Multimode applications only
 FC SINGLEMODE STEEL BODY	Metal body configuration with ceramic, zirconia ferrules	Mixed epoxy, anaerobic epoxy	Connection to data transmitting equipment in high vibration areas, Use is primarily dictated by an equipment specific application	Total stainless steel body makes this connector well suited for harsh environment applications.	Primarily designed for 3.0 mm simplex or breakout fiber types. Not well suited for direct connection to 250 or 900 micron buffered fiber. Requires heat shrink buildup for adapting to 1.6 to 2.8 mm single fiber or breakout	Blue boot indicates “for Singlemode PC, UPC, SPC use only”. SC is a keyed-screwed female thread connection.
 LC DUPLEX	Plastic body configuration with ceramic or zirconia ferrule. Plastic snap together dual encapsulating housing	Mixed epoxy, anaerobic epoxy, soft adhesive, crimp with no polish	Low loss data connection used for high density and equipment specific applications.	Plastic body with ceramic or zirconia ferrule is suitable for controlled or “mild environment” applications	Easily adapted to 900 micron and 3.0 mm simplex or breakout fiber types. Not suitable for direct connection to 250 micron buffered fiber. Requires heat shrink buildup to adapt to 1.6 to 2.8 mm jackets.	Gray or white boot and body for multimode, blue or yellow boot with blue body for singlemode
 (Ruggedized, harsh environment or) tactical multi-channel pin and socket	Metal body, butyl rubber bushings, ceramic or zirconia ferrules.	Mixed epoxy, anaerobic epoxy	High density inline or ruggedized equipment connections	Suitable for extreme harsh environments. Water, dust and chemical spray resistant.	Easily adapted to both 900 micron and 3.0mm breakout cable. Can be used with other cable styles with heat shrink build-out kit.	Typically OD green body, configured as pin on one side and socket on the opposite. Fiber type is stamped on the body.

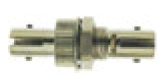
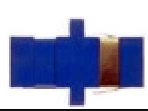
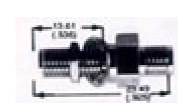
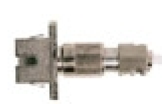
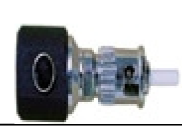
Choosing a connector style becomes much more complicated when Qualification standards are applied. Some key issues to consider include mild or harsh environment applications, vibration sensitivity, and whether the selected connector style is compatible with the type of fiber optic cable and equipment on which it is to be used. In light of these key issues, there are thousands of fiber optic connector variations and variables to consider.

When it comes to Type Testing connectors for Class 1E Qualification, the Nuclear I&C Engineer or assembly provider will need to assemble test samples to their completed (as to be installed) configuration prior to performing the specified tests. At this time it is proposed that the new IEEE Draft Trial Use Standard will adopt Type Testing for connector assemblies in two distinct categories; one for harsh environment Qualifications and one for mild environment Qualifications. Common tests, depending on the environmental classifications are expected to include temperature, humidity, vibration, number of insertions/extractions, radiation exposure, tensile strength and signal throughput. Because there is no difference between a bulkhead coupler and an equivalent connector style equipment connection, it is expected the Type Test will be able to be completed with the connector affixed to a simple bulkhead connection coupler.

Connector Coupling Interface Devices

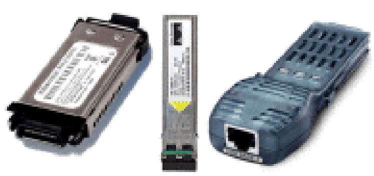
Couplers are those devices that join two fiber optic connectors together or join a single fiber optic connector to a piece of equipment such as an optical sensor, media converter or other interface device. The coupler enables quick connect/disconnect of mated connector pairs. Internal to the coupler body are precision alignment sleeves that precisely join the fiber ferrules. The most common alignment sleeves are ceramic, zirconia and phosphorous bronze. Although most sleeve inserts are favorable upon initial installation, the ceramic or zirconia sleeves are less susceptible to wear, variables in thermal expansion and chemical spray. If Qualification issues are involved, you may be wise to stay with ceramic or zirconia sleeve inserts. Below are many of the common couplers used in today's fiber optic systems and links.

Table III Fiber Optic Couplers

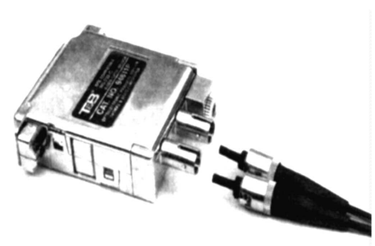
ST ST couplers are typically stainless steel or chrome dipped steel alloy with locking nut for bulkhead mounting.		**MTRJ** MTRJ couplers are plastic body and come in the dual fiber configuration only. They utilize metal snap lock tabs for bulkhead mounting.	
SC SC couplers are plastic body with metallic snap band for bulkhead mounting.		**SMA** SMA couplers are typically stainless steel or chrome dipped steel alloy with male threads on either side and a threaded locking for bulkhead mounting.	
FC FC couplers are usually stainless steel or chrome dipped steel alloy with screw mounts for bulkhead mounting.		**Hybrid** Hybrid Couplers are used to join dissimilar connector styles together such as ST to SC. They can come in either plastic or metal body styles and are bulkhead mountable.	
LC LC couplers are plastic body in the singular or dual connector style with metal snap lock tabs for bulkhead mounting.		**BFA** BFAs or bare fiber adapters are used to temporarily terminate fiber for testing purposes and usually come in the most common connector styles.	

Optical Transmitters and Transceivers

The transmitter converts the variable incoming analog or digital electrical signal to a digital modulated light pulse equivalent. Common transmission light sources in use today are Light Emitting Diodes LED's, Lasers and Vertical Cavity Surface Emitting Lasers VCSELs. It is important to note that a fiber optic transmitter or transceiver is simply a device that converts electrical analog or digital pulses to equivalent light pulses at a specific wavelength and frequency. This technology is not restricted to just Ethernet or computer connectivity, but can also be used for process control, instrumentation, motor control, measurement equipment, protective relay controls and much more. In fact, just about anything that is electrically monitored or controlled can be interfaced to and is compatible with optical connectivity. Transmitters and transceivers come in a variety of mild and harsh environment configurations. They can be configured to support virtually any installation requirement including free standing, explosion proof housings, cabinet rack nest and DIN rail mounting channels.



Plug and play signal router transceiver modules



RS 232 and 422 to fiber transceiver module

DIN rail 4 to 20 mA to 850 nm optical ST

Figure 2. Transceivers

The laser source driver is generally used for long distance or highly multiplexed applications. When coupled to single-mode fiber, the laser source is capable of transmitting vast amounts of information over several miles without the aid of repeaters or signal amplification. The laser however, is extremely expensive and more sensitive to thermal variances when compared to an LED.

The LED has gained popularity for shorter distance transmissions and in-plant I&C applications where electromagnetic and radio frequency disturbances are prominent. Under such conditions the LED is capable of transmitting virtually any converted analog or digital signal to distances in excess of 3,000 meters with no induction affects. Because an LED is simply a semi-conductive PN junction with no moving parts, its life expectancy is well into millions of hours of continuous operation. In fact, the LED is so simple to manipulate that any type of analog signal can be configured to directly modulate the optical output power just by adding sufficient bias to operate in its linear signal range.

The LED source is inexpensive, operates under a wide temperature range, requires very little operational power and exhibits excellent reliability and stability with aging. LED devices used in monitoring applications only require a single optical strand whereas, control loops incorporating feed forward and feedback features use two strands.

Requiring only 100 to 200 milliwatts of electrical power to generate a -14 deciBel milliwatt low heat optical power output, the LED is ideally suited for remote sensors and control devices. In existing plant applications, simple logic should dictate that removing the thousands of analog and digital electric based sensors from service in order to replace them with optical output sensors is not feasible. This is not to say however, that the new era of optical based digital instrumentation and control is a far fetched idea with little promise. To the contrary, achieving a plant wide optical based digital instrumentation and control network can be an easy accomplishment and result in a highly effective process control system if we were to consider a valuable lesson learned from the Broadband Industry.

One plan to bring it all together based on lessons learned from another highly successful industry.

In the case scenario of updating the national network from analog to optical digital, the Broadband Industry faced many of the same obstacles as we will, only on a much larger scale. They began their massive refit by first concentrating on a rapidly deteriorating analog cabling system. It took nearly a decade from the late 1980's through the late 1990's to pull a cross-mesh of extremely high count optical cable from state to state and city to city in order to form a reliable and redundant digital optics communication system. This was all accomplished without disruption to the existing cabling plant. Next, they revamped their central offices and routing/switching stations in order to handle the much higher communication capacity available through the new optical circuits. Their final challenge, commonly referred to as "the last mile", was to push the increased bandwidth through newly deployed metropolitan fiber optic circuits toward the tens of millions of end user points. Unfortunately, many of these end users were already wired to accommodate analog.

This dilemma was short lived as it spurred some advanced research and design innovations, where engineers learned that although the existing user's aging analog line could not support the new digital signals over a long distance, they could easily handle the required digital capacity over shorter distances. The solution came in deployment of neighborhood concentrators called User Interface NODES or DSLAMS.

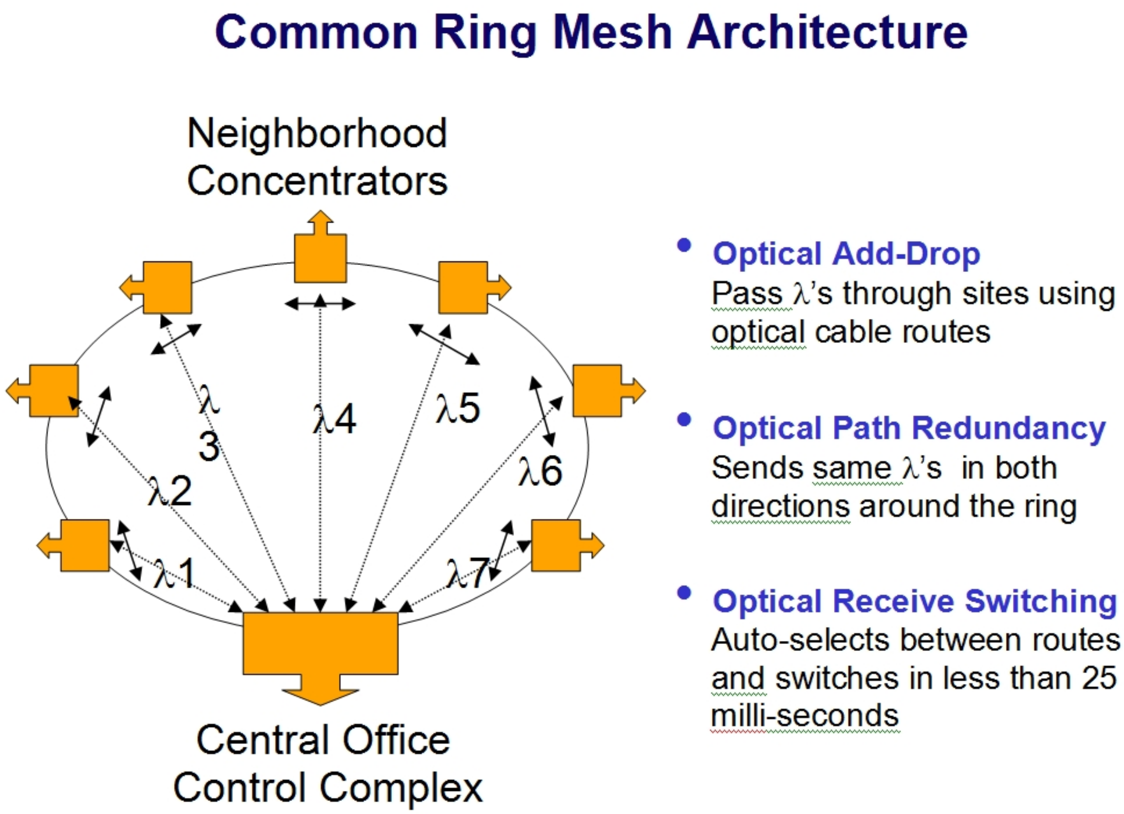
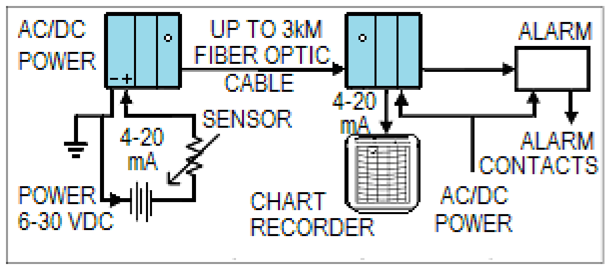


Figure 3.

The concept applied by the Broadband Industry has proven to be a logical and easily achievable goal using a small part of the existing cabling system coupled close to the user interface with a high capacity optical circuit through analog to optical converters. To handle the extreme ambient conditions of the outdoor cabinet, where thermal and moisture fluctuations could be overwhelming to conventional electronics, engineers developed very rugged coated circuit boards and harsh environment converters.

Consider now the issues that a twenty-five year old nuclear power plant faces in regard to instrumentation and controls. Although some upgrades have been made along the way in order to accommodate new instrumentation, the basic nuclear instruments and sensors are still in tact, fully functional and as robust as they ever were. The issue of more concern is that of aging instrumentation cabling. Comprised of a number of polyvinyl insulated conductors surrounded by an aluminized-mylar shield, a drain wire and a polyvinyl jacket, standard instrumentation cabling of years back does not have an unlimited life expectancy and is certainly not immune to failure. When this cable begins to deteriorate the signal that it carries becomes more susceptible to Electromagnetic Interference EMI and Radio Frequency Interference RFI causing a loop signal gain error. The greater the transmission distance and proximity to induction or radio frequency sources, the more susceptible this cable becomes to failure. Even newly installed shielded twisted pair cable can be affected if separation requirements are not met.

The answer to effectively integrating optical technology into existing plant I&C systems may be as simple as following the lessons learned principle. By strategically placing instrumentation and control concentrator cabinets throughout the plant in highly populated sensor and control equipment zones, the existing instrumentation cable can be shortened to a reasonable length, thereby increasing its operational effectiveness with little, if any induction interference.



ANALOG SENSOR TO DIGITAL OPTICS LINK

Figure 4.

Within the concentrator cabinet, sensor and control function device links can be collected from nearby input/outputs without replacing the inline process control instruments. Those signals can then be converted to equivalent optical outputs for an EMI and RFI free transmission up to three thousand meters (nearly ten thousand feet) on a single fiber pair along with numerous other sensor or controllers signals using time division multiplexed 850 nanometer to 1300 nanometer wavelengths.

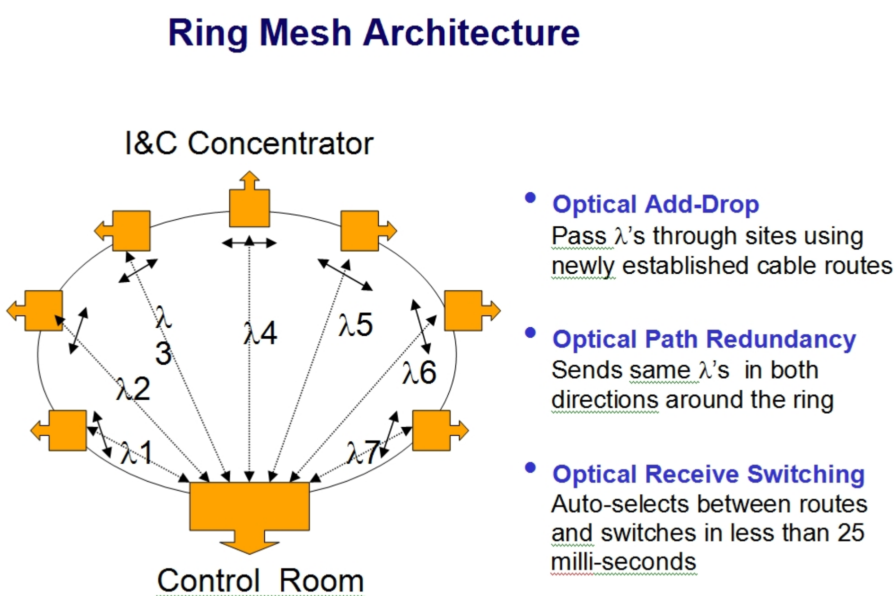


Figure 5.

Figure 5 shows a WDM ring similar to that used by the Broadband Industry. Using this concept on a smaller scale, a Nuclear I&C Engineer could establish a redundant optical path for monitoring and control signals. In a local access optical system, it is likely that the traffic channel will transmit through the most direct path available. However, it could also be routed through interconnected add/drop concentrator cabinets before reaching its destination. Since optical signals travel at a modified light speed of approximately 146,000 miles per second in multimode fiber, the time that it takes for a signal to pass through the longest route is still only measured in nanoseconds.

With an efficient design and use of integrated analog to digital optic converters coupled with WDM components, a highly cost effective deployment of multiple redundant signal paths could easily be accomplished without replacing existing in-line sensors and control devices.

WDM systems can either use different wavelengths for different channels or simply assign independent channels (signals) to a dedicated time slot, commonly referred to as Time Division Multiplexing TDM. Each channel may transport homogeneous or heterogeneous traffic, such as 0 to 5 volts or 4 to 20 mA from pressure, flow, temperature, level and other instruments in a synchronous or asynchronous mode.

WDM functions are accomplished by a Multiplexer "MUX" at the transmitter end and a De-multiplexer "DMUX" at the receiver end. In order to facilitate end to end communication through multiple paths, the MUX and DMUX units are positioned at all the add/drop concentrators, as well as at the control room location.

At the concentrators, the multitude of existing user interface cables are collected and routed into independent digital electric to digital optical media converters that are coupled with optical multiplexers.

Figure 6. Analog 4-20 mA to Optical Converters Coupled To Multiplexer Module

The optical side of each multiplexed grouping is then connected to a fiber optic based signal router via a fiber optic patch cable where up to two hundred and fifty independent bi-directional signals can be coupled onto a single fiber pair for transmitting back and forth to the control room.

The benefit of multiplexing numerous signals on the same fiber pair is that they become very easy to route between host I&C concentrators that are linked together using a mesh topology. This layout would establish numerous redundant paths for the information to travel to and from the control room, motor control centers or other monitoring locations. Mesh topology and the vast number of redundant channels that it creates is a proven technology that is already in use for computer systems at the nation's largest commercial nuclear power plant.

2 CONCLUSIONS

In addition to the benefits of zero EMI induction and Radio Frequency Interference, the use of fiber optic cable in lieu of copper would lighten the load on raceway supports and hangers, reduce raceway and penetration fill and is capable of multiple redundancy without excessive cable deployment.

One thing is for certain, there are many ways to design a fiber optic based I&C system, but when it comes to the strict requirements of Class 1E Qualification, the plant environment is no place for trial and error. Knowledge is power when it comes to understanding and maximizing the true capabilities of fiber optics and this kind of power can only be obtained in the classroom, where nuclear based fiber optics is the subject.

Once the Nuclear I&C Engineer understands how fiber optics work and the critical aspects of cable and component selection in regard to specific applications or Qualification Standards, the process of creating a logical and reliable topology or logical path layout becomes more of a simple choice than a design challenge.

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IEEE, P1682 Draft Trial Use Writing Committee

4 REFERENCES

IEEE 323 Standard for Qualifying Class 1E Equipment for Nuclear Power Generating Stations
IEEE 383 Type Test of Class 1E Electric Cables, Field Splices, and Connections for Nuclear Power Generating Stations
ANSI American National Standards Institute
NEMA NEMA TS-1, NEMA TS-2 Environmental standards
TIA/EIA Telecommunications Industry Association / Electronic Industries Association
FNT Fiber Network Training and Consulting Services, Nuclear Training Divison Course, FNT-450-NUC, Rev. 0 "Engineering and Qualification of Fiber Optics for Nuclear Power"
EPRI, 1993 case study for EPRI-TR-101950 Project 2487-02 Fiber Optic Temperature Sensor