Which Distribution Communications Environments are Best Served by Fiberoptics?

Robert J. Landman, President
H&L Instruments
1440 Rollins Road
Burlingame, CA 94010USA
Telephone (415) 342-7850
Fax (415) 347-1065

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Introduction

Before considering the question directly, let's look at fiberoptics from a historical perspective and gain a basic understanding of the technology. Communications fibers are dielectric rod wave guides which are members of a broad class of structures called surface wave guides or surface wave antennas. In 1870, Tyndall demonstrated that light, by the phenomenon of total internal reflection, could be guided within a water jet. Serious engineering studies of the broader class of structures called traveling wave antennas began shortly before World War II, just after high frequency microwave sources were developed. The first dielectric wave guide to be studied at optical frequencies was the glass-coated, glass fiber developed for fiberoptics imaging applications. The basic design is the same, regardless of the use, namely there is a central core glass which conducts the light and an outer clad glass which minimizes light leakage out of the core material. The effect is due to index of refraction differences in the two materials. The details are quite complicated and do not have to be understood for one to be able to effectively utilize the technology.

By the late 1950's, several laboratories had developed the technology required to produce close-packed assemblies of glass fibers, each a few microns in diameter, with adjacent fibers less than one micron apart. These fiberoptic bundles were used to construct infrared image converter plates and fiberoptic bore scopes. Early experimenters studied what were observed to be wave guide-mode patterns with a view to substantially eliminate them as they deteriorated the images transmitted. The understanding that grew out of the developing body of knowledge led Dr. Charles Kao of ITT, in 1966, to postulate that optical fibers could be used for communications provided the then gross attenuation of the fibers (200 dB/km) could be reduced to a satisfactory level.

Fiber Technology

There are two materials used to make modern fibers, plastic and glass. Plastic fibers are not suitable for distribution applications as their high loss (1000 dB/km), limited operational temperature range, low strength and low bandwidth limits their use to distances of 50-200 meters. Glass fibers transmit most efficiently in the near and far infra-red portion of the spectrum (800-1550 nanometers (nm)) so light emitting diodes (LEDs) and semiconductor lasers are used as electro-optic transmitters and silicon, germanium and indium-gallium-arsenide photodiodes are used as electro-optic receivers. The working range of fiberoptic devices is from +5 dBm (singlemode semiconductor laser) to -50 dBm (indium-gallium-arsenide avalanche photodetector detection limit for a bit error rate of 1 part in10-9). Information is encoded into light pulses by amplitude (AM), frequency (FM), frequency shift keyed (FSK), pulse shift keyed (PSK) or pulse code modulation (PCM) techniques. Each has its advantages and disadvantages.

There are three types of glass fiber which are described according to their central core glass construction as step index, graded index and singlemode. The step and graded index fibers are multimode fibers. All glass fibers have an outer glass covering called the clad. Step index fiber is useful for short distances (less than 2 km) as it suffers from the highest loss and has the poorest bandwidth. Hard clad silica (HCS) with a 200 micron core and 230 micron clad (200/230) has a 20 MHz/km bandwidth and is used in office LANS, industrial control applications and in some aircraft LANS.

An older but still used step index fiber is 100/140 which requires connectors which are non-standard as the clad diameter is larger than the more commonly used 50/125 and 62.5/125 fibers. While 100/140 has a useful 100 MHz/km bandwidth, it is still somewhat lossy and has, for the most part, been replaced by less costly, higher bandwidth and lower loss graded index 50/125 and 62.5/125 fibers.

Unlike 100/140 which can only be used at 850 nm, modern dual window graded index fibers can be used at either 850 or 1300 nm; the attenuation at 1300 nm is typically one third of what it is at 850 nm so by using slightly more expensive transmitters and receivers, the range of the system is tripled. 50 micron fiber has a slightly lower loss and higher bandwidth and is presently somewhat less costly but when spliced or joined by connectors, the smaller core size causes joint losses to be somewhat higher. Less light can be coupled (launched) into 50 micron fiber than 62.5 although the lower overall loss on long distances makes up for the launch deficiency. 62.5 micron fiber is gaining in popularity due to extensive use by AT&T and others; it has become the industry standard.

Singlemode fiber has an extremely small core 8-9 microns in diameter while the clad is the same as multimode fibers, 125 microns, so similar connectors can be used. A higher precision is required as misalignment of cores when mating or fusion splicing fibers is more critical. Transmitters cannot launch much light into such a small core, but the internal losses of singlemode fiber are minimal as only one waveguide mode is supported, i.e. the attenuation is extremely low (.35 dB/km). For longer distances, singlemode fiber is advantageous since at the far end of a fiber, the photodetector is the same. The bandwidth is much higher for singlemode fiber (20 GHz) because higher order modes which would cause the light pulses to propagate slower and which would distort the light pulses are not supported. The transmitter characteristics are the only limit to achieving virtually infinite bandwidth.

Two new developments hold great promise, solitons and semiconductor optical amplifiers. Solitons are a phenomenon discovered by Linn Mollenauer of AT&T Bell Laboratories. The soliton is a light "packet" that once launched into a singlemode fiber does not see its pulse shape degrade whatsoever with distance. Semiconductor optical amplifiers consist of an optical gain medium pumped by a semiconductor laser. The device offers bi-directional direct amplification of the optical signal. There is no need to convert to the electrical domain. At present there are commercial devices with 10 dB gain available but they are still very expensive.

The Exponential Growth of Fiber

In April of 1977, General Telephone installed the first link carrying regular telephone service in Long Beach, California at 1.544 Mb/s over a graded index fiber with a 6.2 dB/km loss. Today, 4 GHz signals are capable of being sent 100km over singlemode fiber without a repeater. From its first use in 1977, the use of fiberoptics for telephone communications has so expanded that only fiberoptics is being used for new transatlantic and transpacific submarine cables and AT&T's major transcontinental microwave is idle, replaced by fiber cable. Sprint has abandoned most of the microwave system it inherited from Southern Pacific. Boeing's newest airplane, the 777, will be the first commercial airplane to be wired exclusively with fiberoptic communications. Most industrial computer local area networks are fiberoptic. The NASA space station Freedom will have a fiberoptic communications system aboard which interconnects all computers and power systems. In just fifteen years, the use of fiber has increased exponentially.

Electric Utility Utilization of Fiber

How is fiber being used in electric utilities? A 1990 survey conducted by the Utilities Telecommunications Council reported on 99 municipal, rural and independent investor owned electric utilities usage of fiberoptic communications. Of the 99 respondents, 66 of them commented on why they switched from Telco, microwave, powerline carrier, radio and other communications means to (or increased their use of) fiber:

1990 UTILITIES TELECOMMUNICATIONS COUNCIL SURVEY - Reason for Use of Fiber

30	Increased bandwidth (capacity)
18	Cost savings
12	Non-conductive benefits
12	Improved reliability (low maintenance)
13	Improved signal quality (low noise) EMI proof
7	Control of our own facilities
7	Microwave in rough terrain too difficult & costly
2	Stability of system (no weather fades)
4	Improved technology
4	To gain experience with fiber
4	No licensing required
3	Underground ducts available
3	Long term growth
3	Sell/lease excess fiber capacity
2	Poor Telco security
2	Redundancy
1	Microwave multipath problems downtown
1	Lack of available frequencies
1	Telco will not allow metallic connect
1	Backup to microwave
1	Radio spectrum scarce
1	Hostile power plant environment
1	Avoid obstruction from new downtown construction

Certainly, regardless of bandwidth requirements, we have shown in the Pacific Gas & Electric system installed in 1987 (described at the DA/DSM '91 conference in Palm Springs and at the IEEE T&D conference in Dallas this year) that underground systems are a prime candidate because existing energized feeder ducts can be used to carry fiber cables. Overhead systems will continue to be replaced by underground systems due to esthetic, weather and EMF concerns. The main concern is cost. Mistakenly, fiber is assumed to be too expensive yet as the UTC study shows, the prime reason for choosing fiber is to save money not to spend it.

Is Fiber Too Expensive?

Every product has a price volume curve; we would all agree that electromechanical watt hour meters are at the flat portion of the curve. The costs of fiberoptic electronics components (transmitters, receivers and connectors) is still declining somewhat while the cost of fiber has already flattened out due to the extensive deployment by telephone companies. What makes fiber appear costly is the way systems are specified. To make the point, I would like to tell you about a project that was on track then suddenly died and was quickly rejuvenated.

I called the client who told me that the project (to link 30 pad mounted S&C feeder switches) was going radio because a fiber approach was far too costly. The utility telecommunications department has a standard that requires 12 multimode and 12 singlemode loose tube gel filled fibers in all fiberoptic cables. The plan also required splice cases, a lot of fusion splicing (24 fibers at each switch), patch panels at the SCADA Master and at each switch location and pre-terminated connector pigtails fusion spliced to the loose tube fibers. This is a plan that allows for a considerable amount of future growth (recall that one of the items most mentioned in the UTC study was capacity for future growth). This plan has an enormous labor and materials budget.

Our system (and others) requires just two multimode fibers. The distances between switches is short so it really doesn't make a lot of sense to put in excess fibers as they most likely will not ever be used. The ducts remain roomy so that if a need for additional fibers occurs later on, one should pull in another cable.

Service spares are worthless as what typically causes cable failures is a dig-in or feeder cable blowout which cuts all fibers or so damages the cable that it has to be replaced anyway. Besides, fiber loop systems are redundant so the failed fiber cable does not cause any node to fail. We have found that it is quicker, easier and less expensive to pull out the damaged cable and replace it. There are tight buffered outside plant breakout cable designs which are long enough so that no fusion splicing is required between switches and these types of cables can be directly terminated with Siecor crimp connectors that do not require epoxy nor polishing as they contain a pre-polished fiber and matching gel (the connectors can be put on by a lineman strapped to a wooden utility pole in the rain). I explained to the client that a radio system has zero excess capacity, no redundancy and no fibers so if telecom wanted spare fibers for other uses they should find the budget money themselves! He agreed, the project is back on schedule as our fiber approach turned out to be less costly than the 900 MHz radio system.

Above ground the issue requires that one look to the future and at the same time consider the past and try to estimate what the needs will be ten or fifteen years from today. Radio based systems are going to be limited to perhaps 4800 baud due to bandwidth constraints. Today, 1200 baud seems to be the norm for SCADA systems but the density of RTUs is very small. What happens to the scan rate when all overhead switches, reclosers, tap changers and circuit breakers are monitored? What about harmonics monitoring and other power quality issues? Will radio systems saturate; will they ultimately have the capacity required for a high speed automated power distribution system? Over the long haul are powerline carrier or radio-based systems cost-effective? You must be the judge.

Fiber could be the winner in the battle for space on the electromagnetic spectrum. The growth of wireless communications technologies has been astounding. According to the Cellular Telephone Industry Association, cellular phone service has gone from just over 90,000 subscribers in late 1984 to more than 6 million in mid 1991. According to Motorola, it could be that in the year 2000 as many as 150 million wireless devices will be in active use in the US. People move about so wireless is required to allow people to communicate. Electric utility distribution equipment does not (the recloser on the pole outside my window hasn't moved in 8 years).

Optical fiber is, and will remain, a transmission medium par excellence. A great body of literature supports that conclusion and indeed, at IEEE and other electric industry meetings authors, regardless of choice of communications medium, are often heard to confirm this conclusion. Its primary advantages of low loss, wide bandwidth, small size, strength, flexibility, and low cost coupled with its special advantages of immunity to electromagnetic noise and to electromagnetic eavesdropping, are unique and meet the demanding requirements for transmission of information for distribution automation.