A 4.5 KM OPERATIONAL FIBER OPTIC COMMUNICATIONS SYSTEM

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Abstract

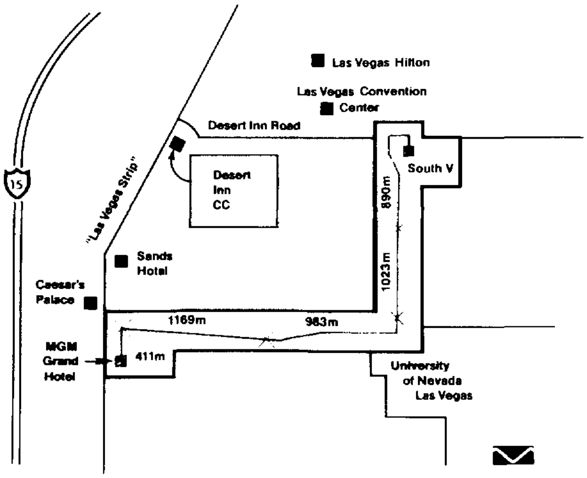
A 4.5 km (2.80 miles) operational fiber optic communications system has been installed and is currently being utilized for commercial telephone traffic. Aspects of fiber optic cable construction and manufacturing, cable placement, splicing, optical transmission equipment and field testing are presented.

Introduction

During the past several years, worldwide attention has been increasingly focused on developments in fiber optic technology and potential usage for telecommunications applications. Laboratory and development activity has advanced this technology at a rate faster than anticipated, resulting in field trial and operational systems installations.

The third such installation by an operating telephone company in the United States was recently completed by the Central Telephone and Utilities Corporation, Nevada division in Las Vegas, Nevada. The increased bandwidth and reduced repeater requirements, offered by optical communications techniques, were extremely attractive for an installation in an existing operational telecommunications system.

In December of 1977, the United States Independent Telephone Association held their annual national convention in Las Vegas and Centel, as host for the convention, decided to provide and demonstrate optical communications for the convention area in the MGM Grand Hotel. A non-repeatered T-1 PCM system was connected over a fiber optic communications link between the hotel and a central office location 4.5 km (2.80 miles) away, providing courtesy phones and a message center to serve the convention. Additionally, news services were displayed, slow scan TV was used for message posting and a remote computer was accessed for inter-active computer games over the optical link.



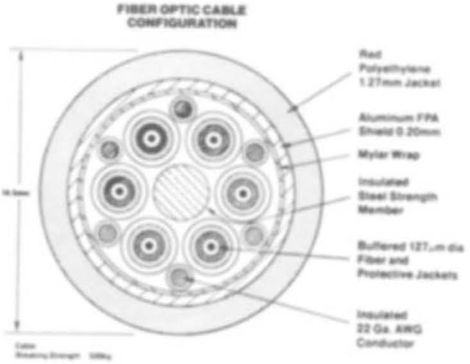
The entire system was developed and manufactured by the Valtec Corporation and its subsidiaries, Laser Diode Laboratories of Metuchen, New Jersey, and Comm/Scope Company of Catawba, North Carolina. The engineering staff, installation and splicing crews of Centel provided pre-construction make-ready, installation expertise, equipment, and personnel.

Cable Construction

Utilizing low-loss, graded index fiber manufactured by Valtec, a cable design was developed and tested which would allow direct placement in underground ducts with conventional installation techniques.

In the center of the cable is a strength member of stranded steel insulated with polyethylene. Stranded around the strength member are six fiber sub-units. Each sub-unit contains a single fiber, loosely contained in an extruded polypropylene tube. The polypropylene tubes are served with two layers of contra-helically wound Kevlar reinforcing fibers with an overall extruded polyurethane jacket to a diameter of 3.81 mm (0.150 inches). Each sub-unit was color coded for testing and installation identification. The fiber sub-unit so constructed proved to be capable of sustaining a 227 kg (500 pound) tensional force in a guage length of 50.8 cm (20 inches) around a 5.08 cm (2 inch) mandrel without breakage or damage to the glass fiber.

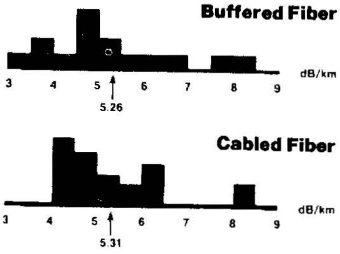
Stranded in the outer interstices of the six sub-units are six AWG 22 (0.64 mm) insulated copper wires. The entire stranded assembly is wrapped with a helically applied 0.05 mm (0.002 inch) polyester tape. A vapor barrier of 0.20 mm (0.008 inch) corrugated aluminum tape is applied longitudinally with an overlap. An ethylene acrylic acid coating on the outer surface of the aluminum tape bonds it tightly to an overall extruded outer jacket of bright red polyethylene. Overall diameter of the completed cable is 16.5 mm (0.650 inches). The cable was tested over a 100 meter (328 feet) length with a force of 500 kg (1,100 pounds) without sustaining cable damage or fiber breakage.



Factory Measurements

Spectral attenuation and pulse broadening measurements were made on each color-coded fiber sub-unit in each of the six cables manufactured. Final quality control attenuation measurements were made at seven wavelengths on the finished reeled cables. These measurements used a launch numerical aperture of 0.18 with a measurement accuracy of approximately ±0.1 dB/km. RMS pulse broadening was measured using a pulsed 900 nm injection laser diode with an input RMS pulse width of 0.30 ns. Accuracy of the RMS pulse broadening measurements has been determined to be ±0.2 ns.

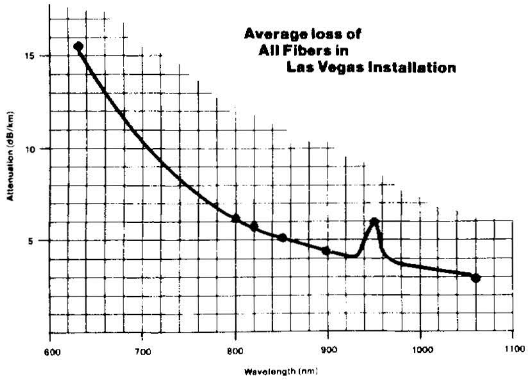
Histogram of Fiber Attenuation Measured Before and After Cabling Wavelength – 850nm.



As shown, there was a slight change in average attenuation before and after cabling. A greater change was observed in distribution; possibly due to cabling losses but also contributed to by induced micro-bending loss present in buffered fiber measurements.

AVERAGE FIBER CABLE PROPERTIES

Fiber Diameter	128.9 ± 3.3 mm
Core Diameter	68.2 ± 4.0 mm
Attenuation (850 nm)	5.11 dB/km
Attenuation (900 nm)	4.62 dB/km
Numerical Aperture	0.262 ± 0.005
Pulse Broadening (rms)	2.0 ± 0.6 ns/km



Installation

The fiber cable was placed in underground ducts connecting the South 5 Central Office to the MGM Grand Hotel. Prior to the actual cable installation, Centel personnel determined duct routing, cleared ducts to be used and installed pulling ropes between manhole locations where cable-end splicing would occur.

Conventional cable handling techniques and equipment were used throughout as cable reels were positioned on pay-off trailers over manhole locations. Attachment of the pulling rope to the cable was made with a "Chinese finger" grip with swivel. A heat shrinkable boot was placed over the cable end (under the grip) to prevent water from entering the cable since ducts were far from dry. The central steel strength member was wrapped around the end of the grip and clamped back on itself so that it could take much of the pulling force. The "Chinese finger" effect distributed the remaining forces to the strengthened fiber sub-units.

The cable was paid out downward into the manhole where it was well lubricated as it entered the ducts. At the pulling end, the cable passed around a 61 cm (24 inch) diameter sheave which translated the horizontal plane of the duct to the vertical pull, exiting the manhole onto a drum driven by a winch, whose clutch was set to slip at a predetermined 227 kg (500 pound) force. Throughout the installation, pulling speeds were held to 30.48 m (100 feet) per minute.

Pulling forces were measured several times during the installation by stopping the pull a few feet before the end and inserting a dynamometer between pulling rope and cable grip. Maximum tension was measured at 136 kg (300 pounds) in the first section [890 m (2,920 feet)] installed between the central office and first splice point. In this instance, the cable route made a large 90° turn followed by a sweeping dogleg. Measured tension on the longest pull [1,169 m (3,835 feet)] was 102 kg (225 pounds).

Field Measurements and Cable Splicing

Field measurements were made on each fiber of the installed cable. An LED operating at 880 nm was used for these measurements and since the fiber was butt-coupled to the LED emitting surface, full launch aperture was approximated. Due to the uncertainty in source and detector alignment in the field, and instabilities arising from time and temperature differences between the long length and short reference length measurements, field values are accurate to approximately ±0.5 dB. Coupled optical power was measured over an installed fiber length. The detector was then brought back to the source and a second measurement was made by breaking the fiber approximately 1 meter from the source. The dB difference in the two power levels was then calculated. No increases in average attenuation were observed when compared to factory measurements.

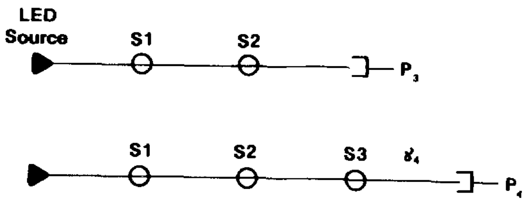
Fiber cable splicing was accomplished using a conventional telephone splice case(Smith 18" x 6 1/2") to provide a waterproof termination of the cable ends. The case was modified internally to contain a fiber splice mounting plate fixed to the center of the case. Approximately 1.5 meter lengths of fiber subunits were separated and coiled in the splice cases to provide for the possibility of future measurements and re-splicing.

Fiber splicing was done using simple splicing sleeves manufactured by Thomas and Betts of Elizabeth, New Jersey. These were tiny three alignment-rod splices with a viewing aperture in the center.

Fiber ends were prepared using a cleaving tool manufactured by Fujikura Cable of Japan to provide the clean cut, perpendicular fiber ends necessary. Prepared fiber ends to be spliced were inserted into the alignment rod splice and properly positioned by observation under a microscope. A 0.0005 to 0.001 inch gap was left between fiber ends. After the fibers were aligned, an index-matching epoxy was added through the viewing aperture. Then, heat shrinkable tubing was installed around the splice. After a brief training period, field splicing was accomplished by Centel splicing craftsmen who had no previous experience with optical fiber splicing.

Splice losses were calculated by comparing the power output from the first fiber to the splice to the output power of the far end of the fiber spliced to the first fiber. The total loss so calculated from these two power measurements represents the sum of the splice loss and the attenuation of the appended fiber. Therefore, the uncertainty in the measured splice calculations contains both the uncertainty of the field measurement and the uncertainty of the appended fiber attenuation.

Field Splice Measurement Method



$$L_{S3} = 10 \cdot \log \frac{P_3}{P_4} - \gamma_4$$

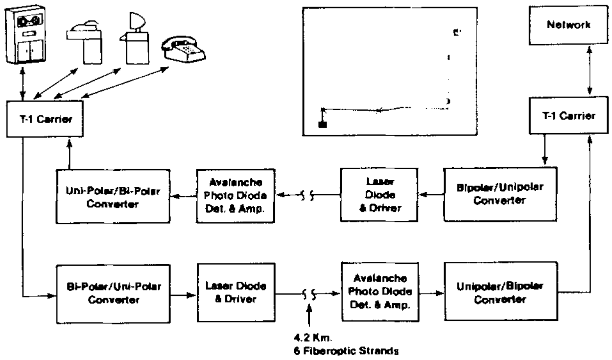
The average loss measured on 15 splices was 1.13 dB. Average cumulative loss was 0.90 dB, calculated after measuring system end-to-end loss and subtracting measured cable attenuation, giving good agreement with average measured loss and indicating approximately 1 dB as average individual splice loss.

Average end-to-end loss of the installed, spliced cable was 25.5 dB. Since the optical transmitter/receiver system was capable of accommodating approximately 48 dB end-to-end loss (for a BER of 10^{-6}), more than adequate margin was present in the system.

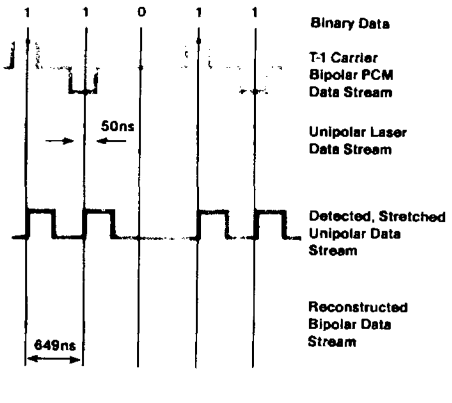
Optical Transmitter/Receiver System

The injection laser transmitter was designed and constructed by Laser Diode Laboratories of Metuchen, New Jersey, a division of Valtec Corporation. The transmitter utilizes an injection laser diode, with thermo-electric heater/cooler to maintain stud temperature at 25°C. (77°F.). A fiber pigtail is attached and protrudes from the rear of the transmitter where it is spliced to the cable fiber using the previously described fiber splicing technique. The splice is then housed in a small brass tube and attached firmly to the transmitter chassis.

The optical receiver was designed and constructed by Valtec and utilized a Texas Instruments avalanche photo detector module. Cable fiber was butted and clamped to the surface of the avalanche detector unit.



Use of an optical transmit and receive system required the conversion of bipolar PCM data at 1.544 Mb/s from the T-1 channel bank into a unipolar data stream. The normal 324 ns bipolar pulse was converted into a 50 ns unipolar pulse in order to reduce the laser duty cycle and increase its expected lifetime from 5,000 hours cw to 50,000 hours pulsed. Within the receiver, the pulses are stretched to the 324 ns width and re-converted to bipolar format, thus recreating the original bipolar data stream.



T-1 Carrier Pulse Conversions For Fiberoptic Transmission

Although a back-up optical transmit/receive system was installed concurrently with the primary system, the primary system operated flawlessly and the back-up was used only for demonstration purposes.

Conclusion

Immediately following the convention, the system was removed from the convention center and re-installed in the PBX room of the MGM Grand Hotel where it currently is in commercial usage, carrying 24 channels of voice communications to the central office. Testing has shown the optical link to be transparent by conventional T-1 PCM criteria. For the future, the fiber optic cable installation is capable of the higher PCM rates required for the DS-3 rates of 44.7 Mb/s.

A new technology has been successfully transferred from laboratory to field, and telephone company craftsmen have proven their ability to adapt to the new technology.

Acknowledgment

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