INSTALLATION AND FIELD OPERATION OF AN 8 KM FIBER-OPTIC CATV SUPERTRUNK SYSTEM

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NCTA Convention
May 20-24, 1979
Las Vegas, Nevada.

ABSTRACT

The BCN Fibre Optic experiment in London, Ontario is the first major fibre optic CATV supertrunk installation in North America.

The link transmits 12 NSTC color television channels and 12 FM stereo channels over an eight fibre cable 7.8 km in length. Audio, video and FM signals are digitized and multiplexed into a single 322 Mb/s bit stream modulating an injection laser diode transmitter.

This presentation describes the installation and field operation of the link, outlining construction problems and their solutions and describes the field maintenance procedures employed. Information is also presented on the reliability and performance quality of the system obtained to date.

Videotape highlights illustrating cable installation practices, splicing, connectorization and electro-optics installation and maintenance will be shown.

1.0 INTRODUCTION

Field trials of fibre optic technology are appearing through the communications industry and around the world. Major telephone companies have installed interoffice trunking and subscriber services using fibre optics. Power utilities have installed fibre optic data transmission systems in their high EMI environments.

The Canadian cable television industry has sponsored a major fibre optic supertrunk system in conjunction with a major Canadian cable manufacturer and with the Canadian Federal Department of Communications. The purpose of the field trial is to assess the potential impact of fibre optic technology when specifically applied to the needs of the CATV industry.

This paper describes the actual experiences as the system has been designed, manufactured, installed and commissioned then outlines the experiments that will be conducted during one year of operation by an operating CATV company.

2.0 PROJECT DESCRIPTION

2.1 The Consortium

BCN Fibre Optic Inc., formed from a group of companies, in co-operation with the Canadian Federal Government, is performing field tests on the first major CATV fibre optic trunk in North America.

The consortium is formed by Canadian Cablesystems, Rogers Telecommunications, National Cablevision, Cable TV, Premier Cablevision, and Western Cablevision in conjunction with Canstar Communications a division of Canada Wire and Cable Company Limited.

2.2 Project Status

7.8 km of fibre optic cable has been installed in London, Ontario, from the local TV station to the hub of London Cable TV.

The Electro-optic terminal equipment and two repeaters have also been installed in preparation for the start of the commissioning tests in March.

2.3 System Description

The fibre optic trunk uses graded-index optical fibres having a bandwidth-distance product in excess of 600MHz-km and attenuation less than 8dB/km. Eight small optical fibres (0.005-inch diameter) are formed into a single multifibre cable providing transmission capacity for a full 15 TV channel supertrunk in a cable less than 1/2-inch in diameter.

Of the eight fibres, six are actively used, allowing the two spare fibres to be used for expansion to 18 channels. The six fibres are allocated as follows:

Fibre No.	Function
1, 2	Each fibre carries three high quality digital baseband TV channels, three digital FM stereo channels plus parity and housekeeping data.
3, 4, 5	Each fibre carries two high quality digital VSB TV channels, two digital FM stereo channels, plus housekeeping data.

6 Fibre carries three channels of high quality digital baseband in the opposite direction (i.e. from distribution hub to head end).

Thus the system provides for full duplex (two-way) video communication.

All signals are converted into PCM digital form before going on the cable. To add to the information from the trial, two different approaches are used for the video encoding. "Baseband encoding" (BBE) transmits a signal through the fibre representing the baseband picture alone. "Vestigial sideband encoding" (VSB) transmits a signal representing the whole video composite, including the picture, the audio, and the color subcarriers. The BBE signal is simpler; but the terminal equipment for VSB is simpler and cheaper since it lacks modulation and demodulation equipment. The trunk will allow side by side comparison of the two systems.

Six of the video signals are BBE. Each one is sampled at 10.74MHz, three times the color subcarrier frequency. The encoding uses a 10 bit format. Eight bits are for the picture, the ninth for program audio and sync information, and the tenth for parity bits, one or two data channels.

Three BBE signals are multiplexed into one 322.2 megabit per second stream, along with the data, FM stereo, etc. Each of fibres one and two carries this signal to account for six video channels, six FM stereo channels, plus data, etc.

The VSB signals need a higher sampling rate to accommodate the 7MHz bandwidth of the composite signal. The PCM encoding produces a 161.1 megabit per second bit stream from each VSB signal, which again includes "housekeeping" bits data, and FM stereo. Two of these are multiplexed into the single 322.2 megabit per second bit stream; and each of fibres three, four, and five carries this signal, accounting for the other six video channels, six FM stereo channels, etc. Fibre six carries the three upstream video channels, in BBE form.

3.0 OBJECTIVES OF THE FIELD TRIAL

The field trials set out to determine the practicality of aerial fibre optic installation, using standard techniques to construct the fibre optic supertrunk. Two repeaters in the 7.8km length of the fibre optic cable, result in a comparable signal to that achieved using nine conventional co-axial trunk amplifiers.

The fibre optic cable is one half inch in diameter as compared to the standard one inch, co-axial type. The abundance of raw material for the glass fibre and its resistance to outside interference, makes fibre optic transmission an important part of future CATV installations.

This test link will determine the performance of fibre optic hardware under standard cable TV use:

1) Buried and aerial cable.
2) Fibre connectors.
3) Cable splices.
4) Headend and hub equipment.
5) Electro-optic repeaters.

A series of tests lasting one year will gather information about performance and reliability as well as the serviceability of the link.

4.0 ELECTRO-OPTIC SYSTEM: MODULE DESCRIPTION

The head-end and hub electro-optic equipment consists of combinations of seven modules. These modules are:

(1) Baseband video encoder
(2) Baseband video decoder
(3) VSB encoder
(4) VSB decoder
(5) FM stereo encoder
(6) FM stereo decoder
(7) Link test and maintenance unit

The various modules can be interchanged between the head-end and the hub to configure the fibres in the link for either upstream, downstream and loop through transmission.

4.1 Baseband Video Encoder/Decoder

The baseband video encoder and decoder are designed to transmit three baseband video, 3 digital FM stereo, and two asynchronous digital signals over a single optical fibre. The video data is digitized, multiplexed with digital data and transmitted as a 322 m/bits digital optical signal.

The baseband video system is composed of two independent rack mountable assemblies. The encoder drawer digitizes 3 baseband video inputs, and three audio inputs and combines them into a single data stream along with 3 digitized FM inputs and 2 asynchronous digital data inputs. The decoder drawer reverses this procedure, demultiplexing the various digital data stream and, in the case of the video and audio, converts the signals to their audio forms.

4.2 VSB Encoder/Decoder

The VSB encoder and decoder are designed to transmit 2 VSB video, 2 digital FM stereo and 2 asynchronous digital signals over a single optical fibre. The video data is digitized, multiplexed with the digitized FM stereo and asynchronous digital data and transmitted as a 322 mbps digital optical signal.

The VSB system is composed of two independent rack mountable assemblies. The encoder drawer digitizes 2 VSB video inputs and combines them in to a single data stream along with 2 digitized FM inputs and 2 asynchronous digital data inputs. The decoder drawer reverses this procedure, demultiplexing the various digital data streams and, in the case of the video, converts the signals to their analog forms.

4.3 FM Stereo Encoder/Decoder

Each drawer is capable of encoding (decoding) up to six FM stereo IF signals. The 10.7 MHz signal applied to the encoder is downshifted and digitally encoded into a serial bit stream of 9 bits per sample. This serial bit stream is multiplexed with others and sent to one of Baseband video or VSB encoders. The de-multiplexed bit stream recovered by the Baseband video or VSB decoders is applied to the input of a decoder where the signal is de-multiplexed, reconverted to analog form and upconverted to a 10.7MHz IF output.

4.4 Link Test and Maintenance Unit

The LTMU continuously monitors the bit error rate of the digital bit stream at the hub terminal. An automatic audible alarm sounds if the system BER exceeds a preset threshold.

A transponder module located in every repeater unit enables the LTMU and repeater subassemblies replies qualitatively as to the condition of the laser transmitter or the photodiode receiver. These data are visually displayed along with BER performance on the LTMU's digital panel readout.

5.0 FIBRE OPTIC CABLE DESIGN AND FABRICATION

Little was known of the requirements for fibre optic cable design at the start of the project. The final design has evolved as the result of actual production and test of various cable types.

5.1 Optical Fibre

The prime considerations in selection of optical fibre for the project were:

1) optical characteristics: attenuation, bandwidth or pulse dispersion
2) strength: able to withstand cabling, installation, operational environment
3) availability: required quantity, tested to required specification in time for the project
4) cost.

5.1.1 Optical Characteristics

The fibre selected was the Corning Glass Works product 6060 which is a graded index, outside vapour phase deposition (OVPD) type, with 6dB/km attenuation and 600MHz-km bandwidth. The industry has not yet established standards for measuring these parameters although Corning is attempting to lead the way. When comparing measurements it is important that the measurement technique be understood. Using different techniques, the same fibre will give a wide range of attenuation results. With 6dB/km attenuation and 600MHz/km bandwidth, each fibre is capable of carrying 2 or 3 complete CATV signals.

5.1.2 Strength

The strength of fibre is given as a probability of breakage if a known force is applied. The strength characteristic curve is generated empirically and is given as a guide for cable design. Each fibre is subjected to a 100% screen test of 25,000 psi. That is, each fibre is known to have had 25,000 psi applied continuously during the manufacturing process. Should a break occur, the fibre would be scrapped. With 25,000 psi as the known ultimate limit, 10,000 psi should be a safe design load for cable manufacture. The cable manufacturing industry expect that the proof test will be raised to 50,000 psi or 100,000 psi in the future.

5.1.3 Availability

At the time that the project was formed, Corning had the only proven capability to supply fibre of the required quality in the required quantities. Fibre at 6dB/600MHz falls into the "premium" portion of their manufacturing yield.

5.2 Cable Design

Various designs were considered, that would enable fibre optic cable to be manufactured, and installed with a maximum load of 10,000 psi on the fibres themselves. The loose buffer tube approach was settled on at an early stage. The fibre lies loose in a protective buffer tube so that minimal stresses are applied to the fibre. The buffer tubes are then stranded around a central strength of anti-buckling member. From this point, there are several possibilities which relate to basic cable construction rather than fibre optic cable construction.

1) Figure Eight Self Supporting Cable: This structure was not attempted, primarily because of the unpredictable wind and ice loading effect of the web joining the member of the cable core.
2) Concentric Self Supporting Cable: Test lengths of this type of cable were made where the support strength comes from spring steel members stranded around the fibre optic cable core. The strength characteristics were adequate but the handling and installation difficulties were extreme.
3) Lashable Cable: The final design selected for the project consists of the basic cable core protected with an Alpeth Sheath (aluminum bonded to a polyethelene outer jacket) for strength and as a moisture barrier. This cable is lashed using a conventional lashing machine to a conventional messenger wire.

5.3 Aerial Cable Specification

Performance specifications were developed over a period of months to reflect the operating environment in London, Ontario. The specifications were given to a number of cable manufacturers as a guide for cable design.

5.4 Cable Characterization and Test

The tasks of measuring the characteristics of cabled fibre and testing over the operating temperature range were greather than originally planned. The time consuming aspect of testing is the temperature cycling where it takes up to 24 hours for the ambient temperature in a cold chamber to penetrate to the core of a coiled cable. The designs tested were found to be adequate over the extreme temperature ranges.

6.0 CABLE INSTALLATION

The cable installation consists of 6.8km of aerial construction and a one kilometer section of buried cable making up to total 7.8km length. The installation parallels London Cable TV's existing 1" air dielectric co-axial supertrunk.

6.1 Buried Section

The buried section extends from the head-end location through a new sub-division and under a major street to the first pole span of the aerial construction. The cable used for the buried portion contains heavy steel armouring making the cable very rugged (over 1,000 lbs safe pulling tension) at the expense of adding to its weight. No special precautions were taken to provide a moisture barrier for this section of cable. This will enable investigation of the effects of moisture ingress in the cable. The cable has suffered no ill effects after 10 months of weathering.

The cable installation technique employed was direct burial in a trench roughly one meter in depth. A chart recorder was used to monitor attenuation of the fibre during burial and for a period of one month after installation. There were only very minor variations in attenuation noted during installation, which were directly related to handling of the cable. Attenuation changes were unnoticeable after the cable was installed.

6.2 Duct Installation

There were several short duct pulls required in the installation under roadways, railway tracks and into the head-end and hub locations. All duct pulls were less than 100 meters and were completed without damage to the cable. Pulling tension never exceeded 200 lbs. even where two ninety degree bends were pulled around one location.

6.3 Aerial Installation

The aerial portion of the supertrunk was installed using aerial cable pulling (with ropes and rollers) and direct lashing techniques (lashed directly from cable reel trailer to strand on streetside construction).

Equipment used to install each section of the cable was standard. In fact, the installation crew was not specially chosen; they were installers with years of co-axial cable experience.

The majority of the aerial installation was overlashed to existing strand. One kilometer was lashed to separate strand for comparison. Roughly three kilometers of aerial cable were installed with expansion loops at every pole while the remaining length of aerial construction contain no loops. In this way, the effects of expansion (thermal and mechanical) on the cable can more effectively be analyzed.

The installation crew reported no difficulty in lashing the cable. On the average roughly 0.6 km of cable were installed daily. Somewhat more handling of the fibre optic cable was required than for co-axial cable. This resulted from the requirement to minimize the number of splices in the link.

6.4 Repeaters

Two repeaters were mounted aerially (strand mounted) in the link. Spacings were as follows:

1) Head-end to repeater #1 : 2.7km
2) Repeater #1 repeater #2 : 2.7km
3) Repeater #2 to hub : 2.4km

6.5 Cable Installation Conditions

The installation of the entire supertrunk took place under both summer and winter conditions. The problems encountered were no more complex than standard co-axial installations. Intersections were crossed, repeaters hung, lashing accomplished, all without damage caused to the fibre optic cable.

7.0 SPLICING AND CONNECTORIZATION

One of the more challenging aspects of fibre optics is providing suitable splicing and connectorization. Experience obtained during the BCN installation indicates that considerable work is required to develop and refine hardware and techniques to the point where splicing and connectorization of fibre optic cable can begin to compete with co-axial cable.

7.1 Splicing

There are a total of 10 fibre optic cable splices in the BCN link. Specifically there are 3 splices in the span from the head-end to repeater #1, 2 splices in the span from repeater #1 to repeater #2, and 5 splices in the span from repeater # 2 to the hub.

The process of performing a fibre to fibre splice has evolved quite rapidly over the past year. A year ago, splicing was achieved primarily by epoxying two fibre ends together in a hollow tube or v grove. The time required for the glue to set varied from one hour to several hours and, during this curing time, extreme care was required not to move the fibres. Typical attenuations of a splice performed using this technique varied substantially over a range of 1 to 3dB. Splicing losses were also fairly temperature dependent.

Recently, however, the development of a fusion splicer has lessened the problems associated with fibre to fibre splicing. Fusion splicing can guarantee repeatable splices with losses well under o.5dB, and are relatively insensitive to temperature changes. Fusion splicing equipment is however relatively sophisticated. A typical fusion splicer consists of an electric spark gap and electrodes, a mechanism for aligning fibres and a microscope for visual alignment. This type of equipment does not lend itself readily to field usage.

The major stumbling block in performing field splices of optical cable, however, does not stem from the fibre splicing, but rather from the preparation of the cable ends to expose the bare fibres. Exposing fibres requires the removal of the outer jacketing and moisture barrier, the removal of an inner polyethylene jacket, the replacement of buffer tubes and the fibre preparation. These processes require the talents of a skilled technician with considerable experience working in a reasonably protected environment. To date, field splicing has been accomplished in a plywood hut mounted on a scissor platform. Splicing from a ladder, tent, or bucket truck requires refinement of the techniques and equipment presently in use.

The time required per cable splice was two days for the first splice in the BCN installation and was streamlined to three hours for the last splice as the technicians became more familiar with the techniques.

7.2 Connectorization

The process of installing a fibre optic connector involves epoxying the fibre to a steel ferrule and then mounting this assembly in the body of the connector. The epoxying process requires a 12 - 24 hour curing time which has not been attempted in the field. Where field connectorization is desired, connectors have been pre-installed in the factory or fibre pigtails with pre-installed connectors have been spliced to cables

Connectorized cables have been installed to mate with input and output ports of repeater modules and terminal electro-optic modules.

Air gaps, if greater than 5 thousandth of an inch, can create transmission difficulties because of effects on bandwidth/pulse dispersion. This requires very close attention to tolerances during the connectorization process. Connector developments in the near future will reduce this problem by providing self alignment and self positioning of the fibre ends.

8.0 TESTS TO BE CONDUCTED DURING THE ONE YEAR TRIAL

Of major importance to the successful fruition of the fibre optic field trial is the documentation and analysis of results of the many technical and non-technical tests to be conducted during the one year of operation. The tests to be conducted are categorized into two main types: tests which measure the technical and economic aspects of the system and surveys which give a measure of how technical staff cope with the technology changeover and their reactions to the new technology.

8.1 System Tests

Following is a partial list of the system tests to be conducted:

1) Tests are being established to give technical comparisons between conventional co-axial trunks and fibre links for:
   a) Mean time before failure (MTBF).
   b) Mean time to repair (MTTR).
   c) Service and maintenance on a routine basis.
   d) System performance as a function of aging.
   e) System performance as a function of temperature.
   f) System performance as a function of other environmental aspects (rain, snow, ice, wind, lightning).
2) Test and documentation procedures are being devised to draw operating cost comparisons between conventional co-axial trunks and fibre links for the above categories.
3) Test procedures for the simulation of trunk links in excess of 7.8 km are being established. The tests give comparisons of technical performance of the optical fibre link for distances up to 48 km with and without digital retiming at every third repeater and with and without the effects of cascaded digital modems. (Loop through tests.)
4) Tests are being performed to evaluate all link specifications including:
   a) Signal to noise ratio.
   b) Intermodulation distortion.
   c) Bit error rate.
   d) Differential phase.
   e) Differential gain.

   These tests provide comparative technical performance data on both baseband and VSB modulation approaches.
5) Tests are being performed to evaluate optical hardware performance specifications such as:
   a) Received optical power.
   b) Optical fibre attenuation.
   c) Optical fibre dispersion.
6) Specific techniques are being investigated in the following areas:
   a) Field splicing.
   b) Connector attachment.
   c) Location of a broken fibre.

d) Signal identification on a fibre.

e) Repeater module replacement.

f) Light source/receiver service and replacement.

g) Status monitoring.

h) Cable lashing.

i) Powering, regulation and surge protection.

j) Bi-directional signal transmission.

8.2 Personnel Acceptance and Adaptation Tests

Surveys are being designed to maximize information retrieval in the area of personnel acceptance and adaptation to the technology changeover. The surveys are intended to cover all aspects of optical fibre, CATV design, and operation. Specifically, the areas of interest are:

1) System design for the CATV Engineer.
2) System implementation for the Engineer/technologist.
3) System installation for the field technician.
4) System operation (maintenance and service) for the service technician.

9.0 CONCLUSION

The BCN installation is the result of a concerted co-operative effort of the Canadian Department of Communications, the Cable industry and a Canadian manufacturing company. It marks the beginning of a new era in telecommunications. The degree to which Fibre Optics will find its way into the cable network is in part established by the creativity and commitment demonstrated by government and industry. The BCN link may appear to represent a modest step forward in the technology of fibre optics when compared to more "blue sky", revolutionary installations which capture the attention of many advocates of the 'wired city' concept. However, the BCN installation represents a sound engineering systems approach to realizing a graceful evolution of fibre optic and digital technology into the CATV plant. The BCN project marks the beginning of the quiet revolution.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the valuable technical discussions by their colleagues at Harris ESD. Whitworth W. Cotten, Paul Casper and Dr. Richard Patisaul; at Canstar Communications, George Reesor and Tom Fan; and at Cablesystems Engineering, Ed Jarmain and Nick Hamilton-Piercy; and to the Canadian Cable industry consortium of BCN Fibre Optic Inc. Membership of the BCN consortium consists of Canadian Cablesystems Limited; Rogers Cable TV Ltd.; Premier Cablevision Ltd.; Western Cablevision; National Cablevision Limitee; Cable TV Ltd.; and Canada Wire and Cable Co. Ltd.

We would further like to acknowledge the technical and financial support given to this project by the Canadian Federal Department of Communications in Ottawa.

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APPENDIX I

SPECIFICATION: FIBRE OPTIC CABLE FOR ON-POLE INSTALLATION

Number of channels (fibres)	8
All channels of equal length per unit cable length	
Intentional torsion on fibres in cable not acceptable	
Cable attenuation (at least 7 of 8 channels)	6dB/km*
Cable bandwidth (dispersion)	600MHz km**
Pre-cabled fibre pull strength	0.25kg***
Recommended fibre tensile loading in cable	0.10kg
Fibre available in lengths of 1100 meters	
Fibre outside diameter	0.125mm
Fibre outside diameter with lacquer coating	0.132mm***
Pull strength of cable (self supporting)	2900kg
(supported)	230kg
Strength member preferably non-metallic (e.g. KEVLAR)	

Temperature Effects: Change in attenuation to be less than ±1dB over the following range:

Maximum temperature (with direct solar radiation)	50°C
Minimum temperature (no solar radiation)	-40°C

Driving rain with 80km/hr wind	30mm/hr
Freezing rain at 80km/hr wind	30mm radial ice
Maximum wind at 10m above ground	150km/hr

Outer jacket material: PE, PU or neoprene
Cable configuration, other than above, optional
Cable outside diameter (minor axis) should be less than 20mm

* Attenuation: measurements are normalized to one kilometer lengths and are specified at a wavelength of 820 nanometers. Measurements are carried out with a standard input radiation launch numerical aperture of 0.1. Measurements are made at room temperature.

** Bandwidth: The bandwidth of optical waveguides is derived from pulse-broadening measurements normalized to one kilometer lengths. A sub-nanosecond pulse of light (at 900nm) from a solid state LOC injection laser is launched into the waveguide. The laser spectral width is approximately 3.8nm (FWHM). Input launch conditions excite all propagating modes. The output pulse is monitored and represented in the frequency domain using Fourier transform methods. Bandwidth is specified at the optical power -3dB point.

*** As supplied by fibre manufacturers.

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Donald G. Monteith was born in Montreal, Canada, on April 29th, 1952. He received his Bachelor of Engineering honours degree in electrical engineering from McGill University, Montreal in 1973.

While in Montreal, he also undertook post-graduate work at McGill University in the area of video image enhancement and specialized colour graphics hardware design. He received his Master of Engineering degree in 1975.

In 1976 he accepted a position with Cablesystems Engineering, a division of Canadian Cablesystems Limited, where his primary functions were in the area of the research and development of broadband telecommunications for CATV applications.

In 1977, he was appointed Senior Project Engineer, Fibre Optic Systems, for Cablesystems Engineering.

Don is a Registered Professional Engineer and a member of the Association of Professional Engineers of Ontario. He is also the current chairman of the Fibre Optics Technical Sub-Committee of the Canadian Cable Television Association and in this capacity has authored and coauthored several papers on Fibre Optics for the CCTA. Don is also a member of the IEEE and a working member of a Canadian Sub-Committee of the International Electrotechnical Commission.

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Prior to joining Canada Wire, Joe spent six years with Woods Gordon & Co. as consultant in project management. He worked on major projects for the Canadian Post Office and the Iranian Telephone Company.

Joe was previously with CAE Electronics as an engineering and project manager responsible for projects related to flight simulation.

Joe received his Bachelor of Applied Science in Electrical Engineering from the University of Toronto in 1958 and his Master of Business Administration from the University of Toronto in 1978. He is a member of the Association of Professional Engineers of Ontario, Institute of Electrical, Electronic Engineers, the Engineering Institute of Canada and the Project Management Institute.