A 5.1 km REPEATER LESS FIBER OPTIC SYSTEM FOR MULTICHANNEL OPERATIONS

Robert C. Tenten

Manhattan Cable TV
New York, New York

The present state of the art in fiber optic cable loss is about 4 to 5 dB/km. Operational bandwidths of 300 MHz can be achieved over that distance when using fiber with bandwidths in the 900 MHz to 1 GHz/km range.

In order to provide high quality multichannel signal transmission over extended distances, it is advisable to use FM transmission to overcome the intermodulation products of presently available laser transmitters and improve signal-to-noise performance.

This paper describes a practical 5.1 km fiber optic system using no repeaters. Wide deviation FM video transmission is used to obtain a signal-to-noise ratio of over 52 dB per channel. Up to eight channels can be carried on each fiber.

Because of the increase in the number of channels originated at the Manhattan Cable TV origination facility, a new transportation trunk with higher capacity became a necessity (Figure 1). Thirteen channels to the Head-End and a minimum of four monitor channels back to the origination center were required.

In the process of looking at the alternatives available for this transportation trunk which covers a distance of 5.1 km, the following criteria were considered most important:

1) Quality Transmission
2) Maximum Channel Capacity
3) Minimum Number of Repeaters
4) High Reliability
5) Low Cost

When comparing a coaxial cable trunk to a fiber optic system in the underground duct system of Manhattan, it turns out that the fiber optic system has greater advantages and lower cost.

1) <u>Quality Transmission</u> - Since this trunk is used to carry signals from our originating center to the Head-End for distribution to subscribers, a signal-to-noise (S/N) ratio of at least 52 dB is required. This is comparable to the S/N ratio that is obtained from a satellite receive-only earth station. Also, since

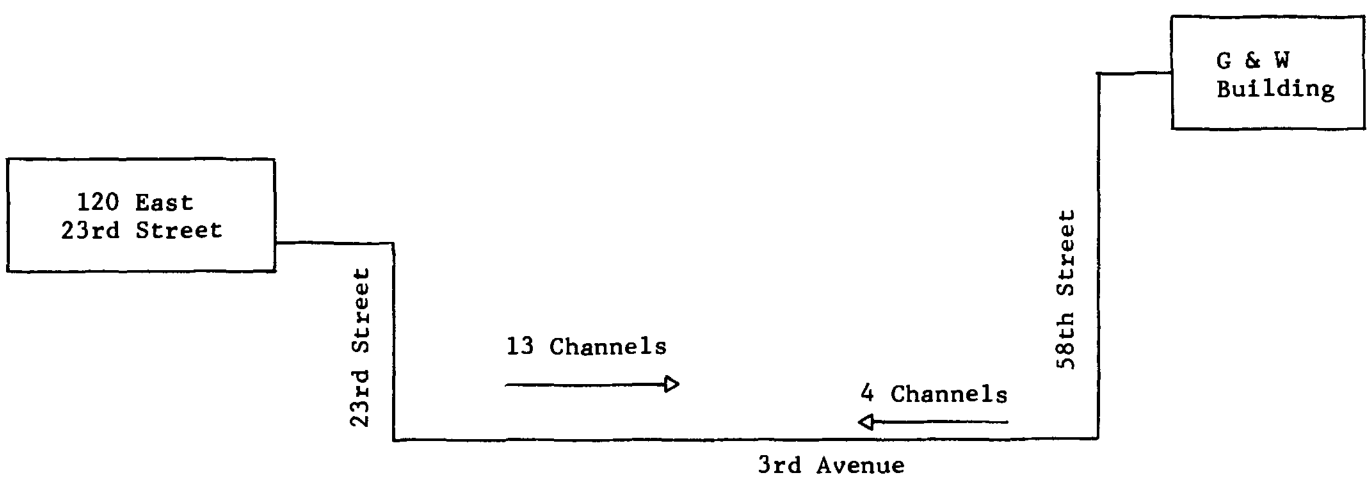


FIGURE 1 5.1 km Fiber Optic Program Trunk the S/N ratio of the video cassette is in the 45 dB range, there only will be about 1.0 dB degradation in performance. This translates to about 0.5 dB difference in degradation at the end of the system. In order to achieve this S/N ratio, an FM Transmission System should be used. Nonlinearity of the laser in optical transmitters produce harmonic and intermodulation distortion. In order to determine an acceptable level of interference, tests were run with 6 to 8 FM signals. Results show that the carrier to interference (C/I) ratio must be at least 30 dB for quality signals.

2) Maximum Channel Capacity - Optical fiber is presently available in a wide variety of bandwidths. The specification is usually given as MHz per km. These bandwidths range from 10 MHz per km up to 1 GHz per km. When more than one kilometer of fiber is cascaded, the bandwidth is reduced according to the following formula:

$$f_t = \frac{f_1}{1 + \sqrt{N - 1}}$$

f_t = Total system bandwidth

f_1 = Bandwidth of 1 km of fiber

N = System length

In order to achieve a 300 MHz bandwidth with no repeaters over 5.1 km distance, fibers with approximately 900 MHz to 1 GHz bandwidth must be used:

for f_t = 300 MHz N = 5.1 km

$$f_1 = f_t \left[1 + \sqrt{5.1 - 1}\right]$$

$$f_t = 906 \text{ MHz}$$

Greater bandwidth could be achieved in the system by using one or more repeaters, but this was not in the best interest of system design or cost.

3) Minimum Number of Repeaters - The ideal design for the 5.1 km system would have no repeaters. As mentioned above, the penalty that is paid when repeaters are not used is a reduction of system bandwidth. However, it was judged that approximately 300 MHz bandwidth would be sufficient for the system requirements.

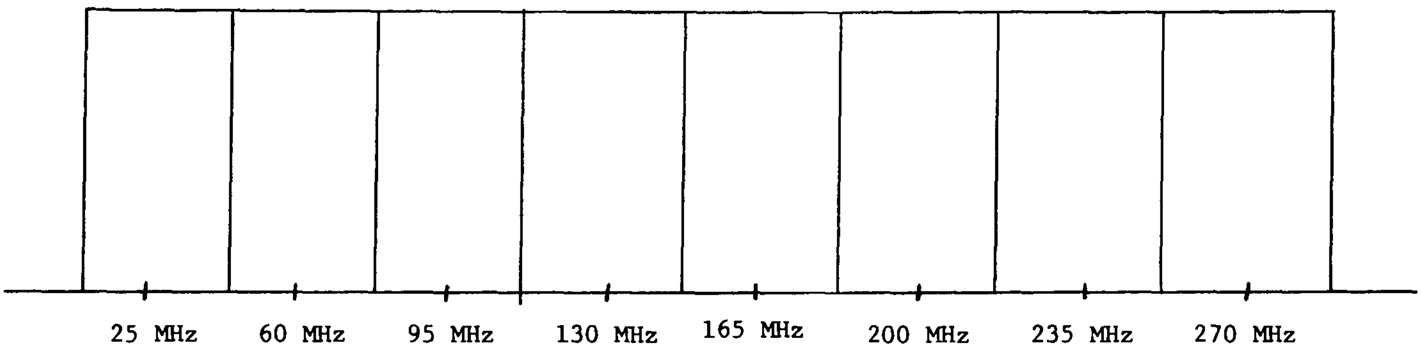
In order to transmit 13 channels, it would be desirable to put 7 or 8 channels on a fiber. Two fibers could be used for transmit and one fiber could be used for receive. This would allow channels to be added easily in the reverse direction, since four slots would be available on that fiber. The forward direction could accommodate one to three additional channels before an additional fiber is needed.

The system loss to obtain the required S/N ratio is about 26 dB. If a connector and splicing loss of 3 dB is allowed, then a fiber loss of 23 dB is required over the 5.1 km. This equates to 4.5 dB/km of cabled fiber loss, a value that is not too difficult to achieve with fiber that is presently available.

Adequate S/N ratio can only be achieved by using wide deviation FM equipment. A deviation of 8 MHz was used to obtain an FM improvement factor of about 26 dB. Channel spacing is 35 MHz and can be accommodated on a 300 MHz system. The channel center frequencies are 25 MHz, 60 MHz, 96 MHz, 130 MHz, 165 MHz, 200 MHz, 235 MHz, and 270 MHz (Figure 2).

4) High Reliability - The trunk is designed to be very reliable. a great deal of protection is designed into the cable to ensure protection from the conduit and manhole environment found under the streets of Manhattan. Among the many possible hazards that which most severely attacks conventional aluminum sheath cable is the continuous presence of moisture in either liquid or vapor form. To combat this condition, five multi-mode graded index glass fibers were stranded around a non-metallic central strength member and secured with core binders. This core was then filled with a water impervious filling compound to prevent the penetration of liquid moisture into the core. Because of this, exposure to moisture is limited and the potential for moisture - induced microcracking in the fiber is minimize.

Mechanical protection for the fiber core is achieved by a three layered construction composed of an inner core jacket of polyethylene, a serving of Kevlar, and a second polyethylene jacket overall. As a result of the heat of extruding the second jacket, the Kevlar strands become imbeded in the second jacket resulting in a reinforced composite section providing the tensil strength and crush resistance



FM Channel Assignments FIGURE 2

required by the core during the installation process.

As additional protection against moisture, a flat aluminum tape, protected on both side with a fused and chemically bound polyethylene film, was formed around the second jacket. A final jacket of polyethylene completed the construction. During the extrusion of the final jacket, the polyethylene film on the aluminum is fused to the jacket creating a moisture resistant metallic sheath overall.

The installation of the cable presented an entirely new set of problems. The biggest of these was the congestion in the manhole and on the cable racks. The fiber optic cable was to be placed along with a bundle of conventional coaxial cable in a common duct. Due to the bulk of the cable bundle, and the congestion and misalignment of ducts, the longest feasible length that could be pulled was about 600 feet. Pulling 600 foot lengths of the optical cable is out of the question be- it would result in 30 splices and the potential for 15 dB of loss due to the extra splices.

To overcome this problem, a welded aluminum conduit with a thermoplastic, anti-corrosion flooding compound and a polyethylene jacket was pulled in as an additional component of the coaxial bundle. When the bundle had all been placed, a pulling line was pneumatically blown thru the conduit section. This line was later used to pull the fiber cable into that conduit. The result of using this approach was that fiber cable length of 1 km could be pulled. This mini-duct conduit also provide capabilities to replace any given length of the optical cable should it ever become necessary. When the entire 5.1 km was pulled, Sealtight tubing, placed over the mini-duct was pulled over the fiber cable and dressed against the cable rack. This Sealtight tubing was mechanically coupled to the mini-duct in each case producing a continuous protection of the optic cable from beginning to end of the run.

The five cable splices required were performed with the fusing technique due to its's inhert low loss (less than 0.5 dB per splice) and its's superior mechanical properties. To facilitate splicing, General Cable developed and obtained approval for a explosion proof welding enclosure which could be used to splice in the manhole despite a possibly gaseous environment.

Overall System Design - The number of channels that can be placed on a fiber is determined by the overall fiber bandwidth, the total fiber loss, the desired signal-to-noise (S/N) ratio, and the amount of intermodulation distortion at a given laser power output (Figure 3).

Given that an improvement factor of 26 dB is available using an 8 MHz deviation FM system, then the carrier-to-noise (C/N) ratio required for a 56 dB S/N ratio is 30 dB. A 56 dB S/N ratio is chosen to allow some margin in the system for aging and additional splices required to repair any breaks.

Using an avalanche photodiode detector, a C/N ratio of 30 dB can be achieved for 8 channels at a receive power level of

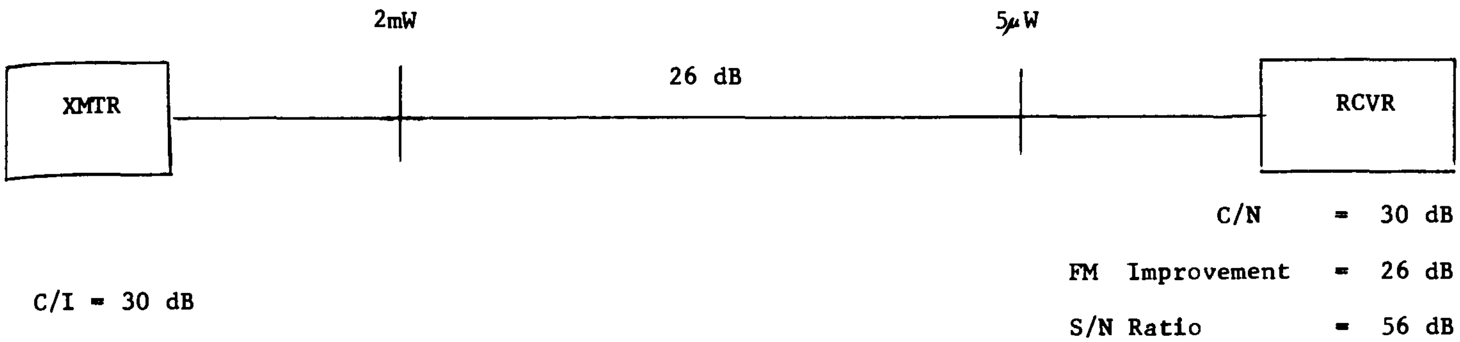


FIGURE 3

5μWatts. The required output power from the fiber pigtail of the laser transmitter must be about 2mW with a system loss of 26 dB.

At the 2mW pigtail output, the laser is operating at a point where the intermods are down at least 30 dB.

5) Low Cost - If a coaxial system is used from Manhattan, installation of expensive sidewalk boxes with a costly street cut between the manhole and box would be required. It turns out that a fiber system without repeaters costs less than a coaxial system under these conditions. In addition, the fiber has more channel capacity than a coaxial cable in this application. Since we could put up to 8 channels per fiber on a 6 fiber cable for a total of 48 channels.

Summary - It is quite possible to install a high-capacity fiber optic trunk having high quality transmission parameters and reasonable cost. Up to eight channels can be accommodated on each fiber and no repeaters are used over the 5.1 km distance. Low loss wide bandwidth fiber and wide deviation FM transmission are combined to provide a system that has pushed forward the state of the art.