OPTICAL WAVEGUIDES - FUTURE CABLE FOR CATV

W. Bart Bielawski
Corning Glass Works
Corning, New York

Abstract

Low-loss waveguides are solid fibers of glass only 5 thousandths of an inch in diameter. Information is transferred over optical waveguides by appropriately modulating near infrared source such as an LED or laser and detecting the change in the output flux with a compatible solid-state detector such as PIN or avalanche photodiode. Measurements of such fiber waveguides in lengths over 3000 feet show total attenuation as low as 2 dB/km and bandwidth capability as high as 500 MHz in one Km length.

Transmission characteristics of optical waveguides are independent of operating frequency and temperature, promising relatively simple and reliable systems.

Corning expects to develop waveguide cables which will be cost competitive with coax on a per foot basis.

Availability of practical light sources and detectors limits current capability to construct useful systems. From the input/output devices' point of view, digital rather than analog operation would be preferred in most cases.

Introduction

The technology of optical waveguides presents major new possibilities. Optical waveguide conductors are applicable to all kinds of CATV systems. They will be especially useful in interactive CATV. Conventional system configurations such as the "Party Line" or "Rediffusion" can be constructed using optical waveguides to offer considerably greater system capability and improved performance. Optical waveguides make it also appropriate to consider entirely new system configurations seeking effective use of waveguides unique properties for improved system/cost performance. One such novel configuration, the radially extended star, can be used as a system model commensurate with the key requirements of interactive CATV.

Unique Capabilities

Great Bandwidth. Optical waveguides are capable of multigigabit bandwidth in less than one thousandth of an inch of conductor cross-sectional area. The initial systems will clearly be limited by the available input/output devices rather than conductors. The transmission plant will be capable of taking advantage of continuing technological progress in sources and detectors resulting in system upgradability. Space and wavelength division multiplexing represent additional means of further upgrading the system. Thus, a transmission plant installed today can be expected to meet the growing requirements literally decades ahead.

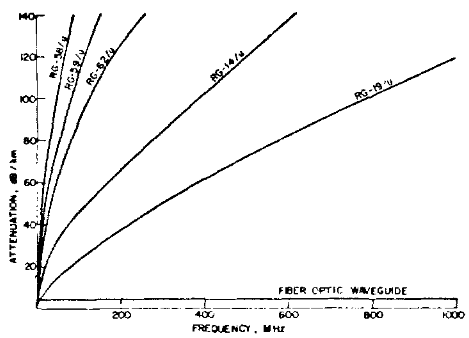

FIGURE 1. Relative dependence of attenuation on operating frequency, Optical Waveguide vs. Coax.

Low Attenuation. Optical waveguides characterized by total attenuation of only 2 dB/km have been achieved recently. Attenuation in optical waveguides is not only much lower than that of any available coax cable but it is virtually independent of the signal frequency. This allows repeater spacing of several miles instead of a fraction of a mile in conventional systems, resulting in correspondingly increased permissible trunk lengths or for a fixed distance, in savings of amplifier costs. The performance of existing systems is limited by the accumulated distortion, noise and phase and amplitude nonlinearities. The degree of degradation tends to be proportioned to the number of amplifiers in a trunk. System based on optical waveguides will require fewer amplifiers resulting in an immediate improvement in performance. Further, the waveguide system probably will not require frequency and delay compensation, again saving costs and improving the system's performance.

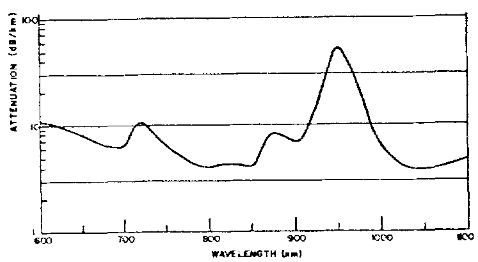

FIGURE 2. Typical spectral attenuation of recent multimode waveguides.

Dielectric Conductor. Waveguide cables will be immune to electromagnetic interference and high temperature, as well as free of ground loop problems. This should result in high performance, reliable systems, as well as yielding immediate savings by system simplification such as elimination of the need for temperature compensation which is required in conventional systems.

Small Size, Low Weight. Waveguide cables will be much smaller and lighter than conventional conductors. This should decrease installation costs and make it possible to construct systems in areas where existing duct space cannot accommodate conventional systems.

State of Development

Corning has achieved total attenuation in long samples of waveguides as low as 2 dB/km in the near infrared. Multikilometer individual low-loss fibers have been made. Such fibers have been packaged into long jacketed bundles suitable for use with LED's. Low-loss bundles (1,000 ft. long) have been delivered to Federal Government laboratories starting in March, 1972. Preliminary experiments with individual fiber coating and high-temperature jacketing have produced successful results. Experiments with armored cables consisting of several metal conductors and one fiber optic bundle strongly suggest compatibility of fiber optics with cable-making processes and equipment. On the basis of successful experience with modified standard connectors such as BNC, UHF and OSM, extensive use of developed connector hardware is expected. Engineering prototypes of splicers for bundle joining or repair and passive couplers for use in data bus environment have also been constructed.

Corning is developing techniques and processes for packaging these waveguides in cable form with terminations suitable for optical, electrical and mechanical coupling. We expect these cables to be competitive with coax on a per foot basis, which combined with waveguides low-loss and large bandwidth will provide a remarkably low cost-per-channel-mile technology.

Input/Output Limitations

Semiconductor sources and detectors are generally assumed in considering communication links based on waveguides. At this time, they severely limit the practical usefulness of optical waveguides.

Sources

Since low-loss waveguides have small cross-sectional area and low numerical aperture, it is important to reduce the angular and spacial spread of the source power, thus the key parameter of the source is its radiance ($W/sr\text{-}m^2$). The ideal source would be a CW, room temperature, solid-state injection laser. This device, although reported on a laboratory basis, is not available at this time. The alternatives are to operate the available lasers at cryogenic temperatures or on a low duty cycle basis - neither of them seems satisfactory. Other lasers, either "mode-locked" or externally modulated, are regarded as inherently costly and probably inadequate in respect to life expectancy and reliability and thus inappropriate in most CATV applications.

Light emitting diodes (LED's) are readily available and relatively inexpensive but are deficient in several major respects. From the device point of view, LED's are slow - generally operable only at well below 100 MHz, highly non-linear and limited in respect to power output - typically low milliwatts. In respect to waveguides, the available LED's require use of many fibers - typically 50 to 100 in a bundle to keep input losses to a tolerable level. This is so because LED's are much larger than waveguide fibers and emit light in a broad angular distribution. Use of many fibers in a bundle increases its cost without any benefit in respect to its bandwidth or attenuation.

Detectors

Avalanche photodiodes and PIN diodes are proposed as the corresponding solid-state detectors. Quoted in the literature, gain bandwidth products of 80 GHz appear adequate for most CATV purposes. However, the avalanche photodiodes are highly non-linear. Coupling detector to optical waveguide is a minor problem. Its noise characteristics are of prime importance.

It is informative to view the source/waveguide/detector system in terms of the minimum discernible signal (SNR = 1), or the minimum light flux which produces an output current just equal to the noise current.

From published data, typical MDS values for PIN and avalanche photodiodes at 100 MHz are 10^{-6} W and 10^{-8} W, respectively. Assuming SNR of 40 dB, the incident optical power at the detectors must be 10^{-4} W and 10^{-6} W, respectively. (Note these are square law devices.) Allowing for input coupling losses, at this time only a marginal link could be constructed using these devices in conjunction with available LED's. Power levels associated with lasers would clearly solve the problem.

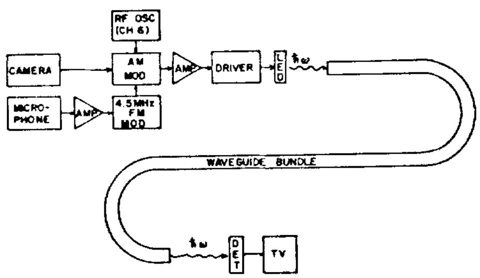

FIGURE 3. Video link demonstrating transmission at channel 6 over 1000 ft. low-loss waveguide bundle using commercially available source and detector.