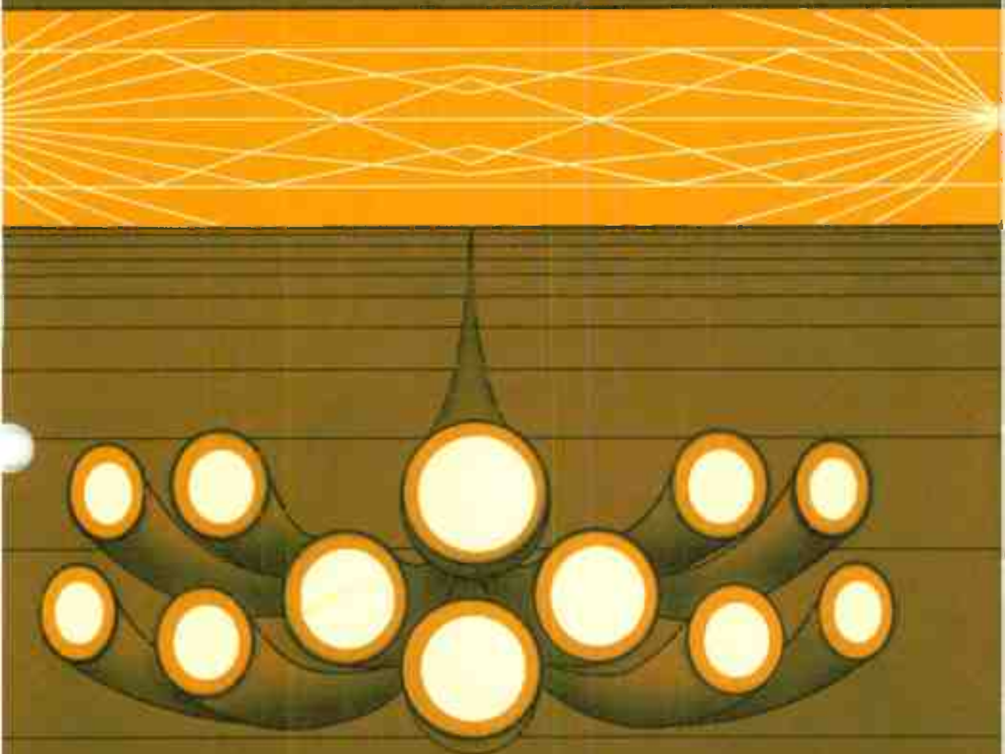
GTE LENKURT

# DEMODULATOR

NOVEMBER/DECEMBER 1978



# FIBER OPTICS IN TELECOMMUNICATIONS

**As recently as late 1975, many experts were predicting that operational fiber optic communications systems would not be in service before the mid-1980's. However, increasing demands for telecommunications services and growing costs of copper-wire have combined to accelerate development of fiber optic systems. Systems have been installed and field tested in the United States, Japan, Canada, Great Britain and other European countries. Some of these systems are now fully operational. Today, it is apparent that fiber optical systems will be an important part of the telephone network by the mid-1980's.**

For some applications, fiber optical systems have distinct economic and technical advantages compared to copper-cable systems. Fiber optical cable also has some unique problems which are not encountered in conventional cable. Both the advantages and the problems are pointed out in the following discussion.

Figure 1 is a block diagram of a system using fiber optics as an interoffice trunk. As shown in the figure, analog telephone signals enter the terminal and are converted to digital signals by a conventional PCM channel bank. The advantages of digital transmission are easily realized by optical systems because of their wide bandwidths and negligible crosstalk. However, amplitude modulation is also used for low capacity systems. Several low capacity, AM systems are available or being developed for the industrial market.

Returning to Figure 1, the encoded digital signals are amplified and used to intensity modulate a light source, such as an injection laser diode (ILD) or light emitting diode (LED). Both of these devices are relatively inexpensive and compatible with the optical fiber cable presently being manufactured.

The light pulses output of the light source are carried over optical fiber cable to the repeater. At the repeater, the pulses are detected by an optical-detector, photo diode. These detectors convert light input to an electrical output. The two most commonly used are the pin (PIN) diode and the avalanche photo diode (APD).

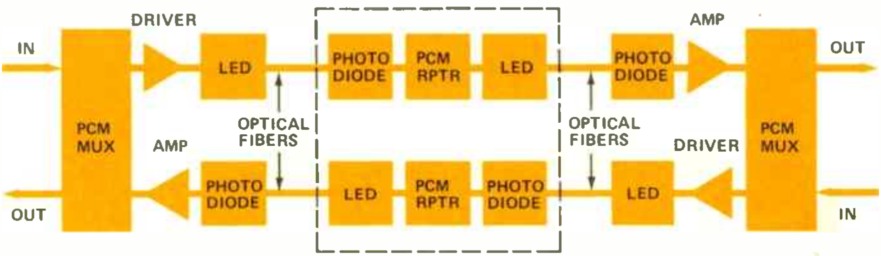



*Figure 1. A simple, hypothetical optical communications system using currently available PCM equipment.*

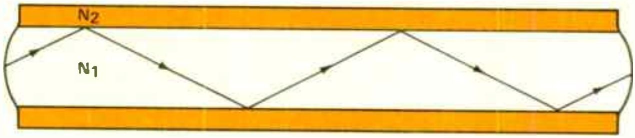



*Figure 2. Typical ray traveling a length of optical fiber.*

The electrical output pulses are detected, amplified, retimed, and regenerated by the PCM repeater, then used to drive a light source which converts them back to light pulses for transmission to the distant terminal. At the terminal the light pulses are again converted to electrical pulses and processed as conventional PCM received signals. Signals to be transmitted in the opposite direction are processed the same as described above.

From the foregoing discussion and examination of Figure 1, it is apparent that the optical portion of the system is composed of three parts, the light source, the optical fiber cable and the photo-detector. The following paragraphs describe each part. The cable is discussed first, since it represents the newest technology and its characteristics affect the operation of the other two.

## Fiber Optical Cable

A simplified optical fiber is diagrammed in Figure 2. It has a cylindrical glass fiber core with a diameter d and a uniform index of refraction $N_1$. The core is surrounded by a concentric layer called the cladding, which has a lower index of refraction $N_2$. A light ray entering the core of this cable at one end will traverse its length and exit at the other end, conforming to the reflection principle of physical optics which states: When a light ray passes from one optical transmission medium to a boundary of another medium with a lower index of refraction, it will be reflected back into the original medium. This process is repeated over and over as the light passes down the core. Each time reflection occurs a slight amount of light intensity is lost. Largely due to impurities in the fiber, some additional losses are incurred as the light travels down the fiber. These two factors are the principal components of attenuation per unit length of cable. Attenuation is discussed in detail later in this article.

Another cable characteristic affecting light transmission is the input light acceptance. Figure 3 shows three light rays, A, B and C. Ray A enters the fiber coaxially with the longitudinal axis of the fiber and propagates through the cable as shown. Ray B enters the cable at an angle $\theta$. and propagates along the fiber by a reflective process. Ray C enters the fiber at an angle greater than $\theta$, and escapes through the side as shown. Light rays entering the fiber within the cone shown by dotted lines in Figure 3, will propagate along the cable. Rays at greater angles will not.

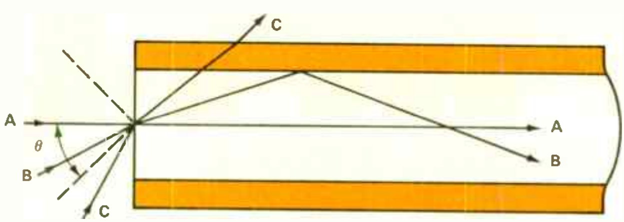



*Figure 3. Input light-acceptance.*

The maximum propagation angle, $\theta$, is mathematically related to the difference in the refractive indices of the fiber $N_1$ and cladding $N_2$ so the light gathering ability of a cable can be expressed numerically. This ability is known as the numerical aperture, NA, and can be derived from the following equation:

$$NA = \sqrt{N_1{}^2 - N_2{}^2} = \text{Sin } \theta$$

where $N_1$ and $N_2$ are the peak values of the reflective indices.

Just as in electro-magnetic waveguide propagation, only certain modes can propagate along an optical fiber cable. The number of modes (M) is determined by the core diameter (d) the numerical aperture NA and the light wavelength ($\lambda$). The relationship is shown in the equation:

$$M = 0.5 \left(\frac{\pi d \, NA}{\lambda}\right)^2$$

From this equation, it can be seen that; For a given wavelength, the number of modes can be decreased by reducing the diameter of the core. When the diameter approaches the wavelength only a single mode will propagate. Such a single-mode cable eliminates modal dispersion, which is a limiting factor on the bit rate capacity (bandwidth) of fiber optical systems.

The cause of modal dispersion is shown in figure 4 which depicts the paths of two rays traveling through an optical fiber. As shown by the figure, ray A is not reflected as often as ray B, so A travels a shorter path and will exit the cable sooner than B. As a result, pulses composed of rays which are coincident in time when they enter the fiber will be dispersed in time (broadened) as they travel down the cable.

As previously stated, single-mode cable eliminates modal dispersion. However, the core diameter of such a cable is so small that efficient coupling between it and the light source is extremely difficult to achieve and maintain in the field. Single mode cable is primarily used for laboratory applications.

Much more efficient coupling is obtained by multimode fibers. There are two types of multimode fibers; step index and graded index. The term step-index derives from the fact that this cable has an abrupt change of refractive index between the cladding and the core. The difference between the refractive indices gives a larger value to $\theta$, and the diameter of the core is much greater than in the single-mode cable, therefore the light gathering ability and hence the coupling efficiency of step-index cable is much greater than single-mode cable. The penalty paid is the greater dispersion effects resulting from the larger differences in path lengths between the extreme modes.

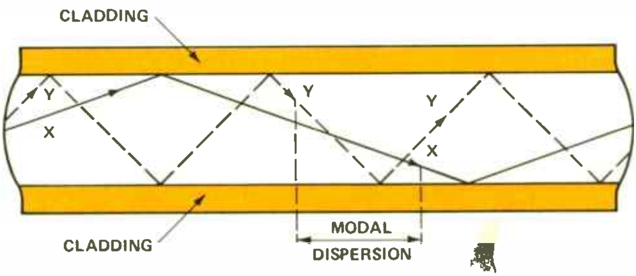



*Figure 4. Modal dispersion.*

Graded-index, multimode fiber represents a compromise which provides good coupling efficiency and reduces the effects of modal dispersion.

This is accomplished by providing a graded index of refraction profile across the fiber cross section, instead of the uniform profile of the step-index fiber core.

The graded-index fiber profile provides an index of refraction which is maximum at the center of the fiber cross-section and decreases with increasing radial distance from the fiber core. Because of the relationship between propagation velocity and refractive index, rays traveling along the centerline will have a lower velocity than rays traveling off the centerline. The center line rays travel a shorter distance at a lower speed. The off-center rays travel a longer distance at a higher speed so, both rays exit the fiber more nearly coincident in time than is the case for step-index cable. The ability of the fiber to "capture" rays for longitudinal travel is also enhanced by the graded index profile because it effectively increases the fiber's numerical aperture. Figure 5 compares the modal dispersions of the 3 fiber types.

In addition to modal dispersion, there is another dispersion effect called material dispersion. Material dispersion results from the fact that different wavelengths of light propagate at different velocities through a given medium. Since practical light sources are not monochromatic, they radiate light rays with different wavelengths. The light radiated by a LED may have a wavelength spread as great as 50 nanometers. Lasers are substantially better in this respect, with spreads in the 4 nanometer range.

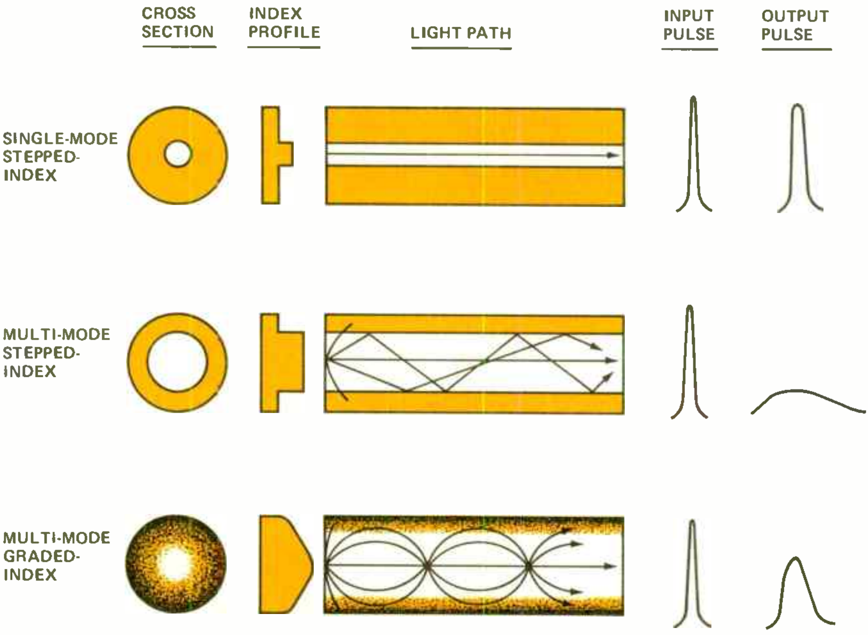



*Figure 5. Propagation through optical fibers.*

Dispersion effects, both mode and material, are the principal factors limiting the bit rate capacity of fiber optical systems. Modal effects can be greatly reduced by graded index cable but material dispersion effects are present in all types of cable. They can only be reduced by a truly monochromatic light source.

## Transmission Losses

Transmission loss (attenuation) is another important characteristic of fiber optical cable. Attenuation in an optical fiber is measured in dB just as are wire cable losses. The optical equivalent to wire-cable resistance is called absorption. Absorption means the conversion of light into heat.

One of the important causes of absorption is impurities in the fiber material, primarily metal ions and OH ions in the glass core. Impurity absorption can be reduced by carefully controlling the core material to avoid impurities.

Another important cause of absorption loss is the scattering effect. Scattering losses result from fundamental fluctuations in glass density and composition and from imperfections in the core/cladding boundary. The latter can be reduced by careful fabrication of the core.

Also, scattering loss is inversely proportional to the fourth power of the light wavelength. Present fiber optical systems are operating on wavelengths in the vicinity of 0.8 to 1.0 $\mu$m which is not the optimum range for reducing scattering loss. Intensive research and developments efforts are underway to perfect light sources and detectors which operate at longer wavelengths.

Radiation losses are also present in any real fiber optical system. Microbends in the fiber can cause radiation losses. These bends are sometimes incurred during cable fabrication. They can be largely avoided by minimizing all contact between the fibers and other bodies. Radiation losses can also result from abrasions or dirt on the outer surface of the fiber.

The total cable losses vary widely with cable type and light wavelength but generally fall within the range of 4 to 20 dB per kilometer.

Any real optical fiber system will use connectors and splices to join the fibers. Optical losses incurred in connectors and splices result from discontinuities and misalignment at the junction. The amount of loss is dependent upon the fiber alignment and optical characteristics. Splice losses are lower than connector losses because splices are carefully aligned with precision fixtures and the joint is permanently bonded with a refractive index matching agent that reduces reflection discontinuities. Connectors are detachable by definition – so their alignment is less precise. Typical splice losses range from 0.3 to 0.7 dB. Typical connectors losses range from 1.0 to 2.0 dB.

## Mechanical Properties

The dielectric glass used to make typical optical fibers has great intrinsic strength. However, the small diameter of the fibers make them too fragile for field use. Microscopic fractures and flaws greatly reduce the fiber strength and further serve as a focal point for additional weakening resulting from minute bending or flexing. Also glass is brittle and cannot be stretched like copper cable.

To overcome these problems, the fibers are made into cables. Cables are built in different configurations for various reasons but practically all of them have, in addition to the fibers, one or more strength members, some kind of buffering material and an overall sheath.

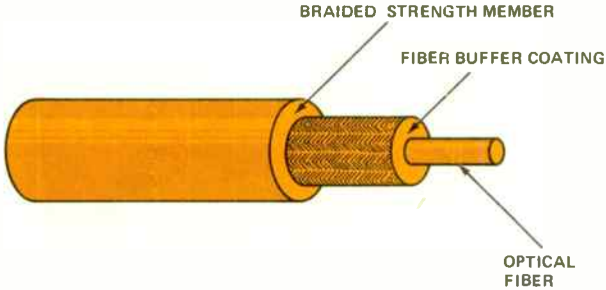



*Figure 6. Single fiber cable.*

## Single Fiber Cable

Figure 6 depicts a single fiber cable. The optical fiber is located in the center and surrounded by the buffering material. This material has good chemical resistance in itself and is also impermeable to most chemicals. It is usually in the form of a coating on the fiber. It also provides mechanical buffering against abrasion. A strength member forms the next layer surrounding the buffered fiber. It provides protection against impact, crushing and longitudinal stretch forces. The outer jacket of the cable is a tubular sheath. It minimizes microbending losses and establishes a limit of cable-bending radius. The jacket also shields the fiber from the environment.

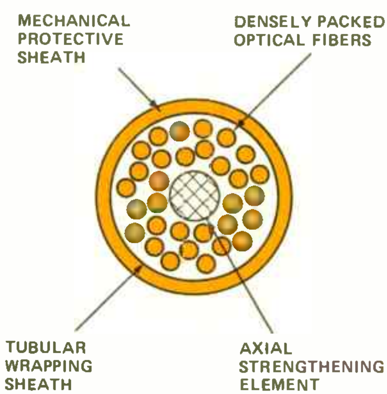



*Figure 7. Axially strengthened optical fiber cable.*

## Multiple Fiber Cable

One form of multiple fiber cable is bundled cable. As the name implies, this cable encloses many optical fibers bundled together. Originally, bundled cables enclosed several hundred fibers. They were fabricated to provide reliability through redundancy and to provide good light collection without focusing the source. This type cable has high losses so it is only suitable for applications using short cable runs.

A simple design configuration for bundled cable is shown in figure 7. This design has the disadvantage that the strengthening element occupies the center of the face – so the light gathering efficiency is reduced. Also, the individual fibers are not buffered from each other. Therefore, they are vulnerable to abrasion and microbending. The principal advantage of this construction is its simplicity.

Another cable configuration contains individual fibers which are isolated from each other by a filler. Each fiber has a buffer coating and a jacket. The fibers are bound together by a tubular wrapping. All of these elements are encased in a woven strengthening sheath which also controls cable bending. An outer jacket protects against mechanical stress and prevents environmental damage.

The foregoing discussion describes fabrication techniques which are used by one or more cable manufacturers.

Figure 8 is a picture of an actual commercially available cable, General Cable Corporation's type AT, designed for pressurization and burial.

The cable contains six graded index fibers in a laminated plastic tape carrier, seven insulated copper wire pairs and an axial strength member. The wire pairs are used to power repeaters, aid in fault location and provide order-wire facilities. The optical 3 dB bandwidth is 400 MHz per kilometer. The average loss in the fibers is less than 6.5 dB per kilometer. Figures 9 and 10 show cables manufactured by Siecor, for installation in ducts.

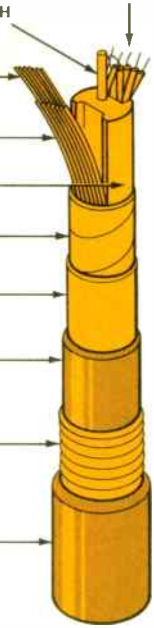



*Figure 8. Fiber optic cable, type AT.*

## Light Sources

Light emitting diodes and injection laser diodes are the two most common light sources used in fiber optic communications systems. LED's have a light power out to driving current input characteristic which is approximately linear over a large driving current range. Therefore, they can be amplitude modulated by varying the drive current.

LED light emission are lambertian. The light rays emanate over an entire hemisphere. Therefore, efficient coupling into multimode cable is difficult. Typical power coupled into the cable is around 50 microwatts. Their emission spectral width (range of wavelengths of radiated light) ranges from about 40 to 50 nanometers, which translates to an upper limit on bit rate capacity of about 200 Mbps. Rates of about 50 Mbps are about the highest used in actual practice.

The laser is a threshold device. It "turns on" when the drive current reaches threshold and provides a large increase in output power. The light power output versus drive current input characteristic is linear over a limited region, so lasers are best used in digital applications.

Laser spectral widths are about 4 nanometers which is much better than LED's. Therefore, material dispersion is not a problem and lasers can be modulated at Gbps rates. Laser radiation is relatively directional (15° by 40°), so coupling to the cable is more efficient. Typical coupling losses are about 5 dB in contrast to 15 dB typical loss for an LED. Laser power into the cable is a few milliwatts.

The most serious drawbacks to lasers are their relatively short lifetimes and variations in threshold with temperature and age. Typical lifetimes are about 10,000 hours. To gain wide acceptance by the telephone industry, mean time before failure (MTBF) must approach 100,000 hours. LED's have a somewhat better MTBF than lasers but

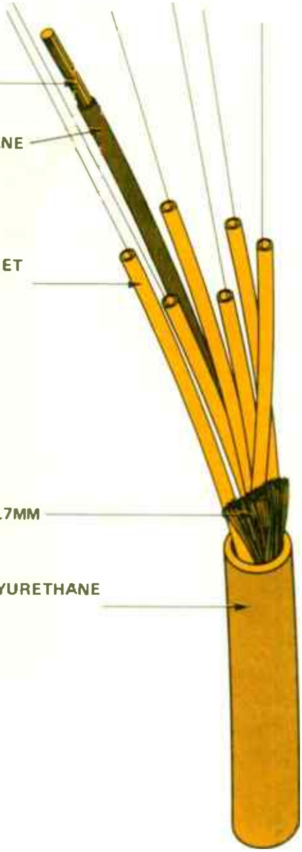



*Figure 9. 6-fiber cable for duct installation.*

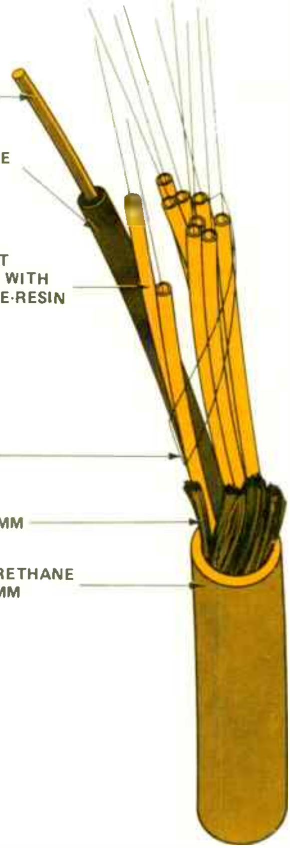



*Figure 10. All dielectric 10 fiber cable for duct installation.*

are typically below the 100,000 MTBF point.

The commonly used LED's and lasers both use Gallium Arsenide doped with aluminum as the active semiconductor element. Gallium Arsenide radiation has a wavelength of 905 nanometers. The aluminum doping shifts the wavelength to a range between about 800 and 850 nanometers, which reduces the attenuation presented by the more generally used optical fibers.

## Optical Detectors

Two optical detectors are quite satisfactory for fiber optical communications systems. They are the pin (PIN) diode and avalanche photo diode (APD). Both of these devices have excellent conversion efficiency (ability to convert light power input into electric current output). They also have fast response times and are low noise devices.

The PIN diodes are simple, easily used devices. However, they have relatively poor sensitivity. The sensitivity of an optical detector is defined as the minimum light input required to provide a given performance level (signal to noise ratio for analog systems; bit error rate for digital systems).

APD's have better sensitivity than PIN diodes because of the gain provided by the avalanche process. Typical APD gain is about 100. Signal to noise ratios can be improved by a factor of 10 by using an APD in place of a PIN. However, APD's have the disadvantage of high bias voltage requirements and performance degradation with temperature increases.

## Summary and Future Probabilities

Economics is the principal motivating force behind the increasing use of fiber optic systems by telephone companies. For example, General Telephone Company of Indiana is currently installing a fiber optic system at an initial cost of $300,000 and will have invested a total of approximately $2.8 million when the system reaches full capacity in about five years. This is in contrast to an estimated $4.3 million cost for a conventional system, of the same capacity, over the same route.

Fiber optics also provide certain technical advantages over copper cable in terms of bandwidth, immunity to noise and repeater spacing requirements. Probably the greatest single deterrent to widespread acceptance of fiber optics for telephone applications is the absence of a reliable, long-lived light-source, capable of operating in the telephone environment.

Intensive efforts are underway to develop such devices. In fact some of the newer devices have exhibited MTBF rates approaching a million hours, based on the results of accelerated life tests. The laboratory experts are expressing a reasonable confidence level in their tests. However, telephone company engineers prefer empirical information gathered in their own operating environments. Never-the-less, it is reasonable to assume that these devices will exceed the 100,000 hours requirement in the field. Therefore, the light source reliability and life problems will be solved in the near future.

BIBLIOGRAPHY


1. YEH, Leang P., *Fibre-Optic Communications Systems*, Telecommunications, September 1978, Horizon House Inc., Dedham, Ma.

2. Kleekamp, Charles and Metcalf, Bruce, *Designers Guide to Fiber Optics*, A four part series, Electronics Design News, January 5, 20, February 20, March 5, 1978, Cahners Publishing Inc., Boston, Mass.

3. Uradnisheck, Jay, *Estimating When Fiber Optics Will Offer Greater Value in Use*, Electronics, November 1978, McGraw Hill, N.Y., N.Y.

4. GTE Lenkurt Demodulator, Optical Comnunications, November 1975.

# DEMODULATOR TITLE LISTING

**The date and title of every Demodulator, from the first issue, March 1952 to December 1978 is listed below. The list is in reverse chronological order. We hope it will provide a handy reference for our readers.**

## 1978

| | |
|---|---|
| JANUARY | Determining Site Coordinates |
| FEBRUARY | The Volume Unit |
| MARCH | Antenna Decoupling |
| APRIL | Loop Pulsing |
| MAY | Operational Amplifiers |
| JUNE | Operational Amplifiers |
| JULY | Microwave Receiver Interference |
| AUGUST | Microwave Receiver Interference |
| SEPTEMBER | Microprocessors in Telecommunications |
| OCTOBER | Microprocessors in Telecommunications |
| NOVEMBER | Fiber Optic Systems |
| DECEMBER | Fiber Optic Systems |

## 1977

| | |
|---|---|
| JANUARY | Digital Data System |
| FEBRUARY | Introduction to Microprocessors |
| MARCH | Thick Film Hybrids/*GTE Lenkurt Demodulator* Enters 26th Year |
| APRIL | Solar Power for Telecommunications |
| MAY | Testing of Microwave Radio Systems, Part 1 |
| JUNE | Testing of Microwave Radio Systems, Part 2 |
| JULY | Worldwide E&M Signaling, Part 1 |
| AUGUST | Worldwide E&M Signaling, Part 2 |
| SEPTEMBER | Advances in 2-GHz Radio Technology |
| OCTOBER | Differential Absolute Delay Equalization |
| NOVEMBER | Digital Radio |
| DECEMBER | Data Set Interfaces |

## 1976

| | |
|---|---|
| JANUARY | Data Modem Developments |
| FEBRUARY | Energy Conservation in the Telecommunications Industry |
| MARCH | Bucket Curves, Part 1 |
| APRIL | Bucket Curves, Part 2 |
| MAY | Increasing PCM Span-Line Capacity |
| JUNE | RF Repeaters |
| JULY | Switching and PCM System Interfaces, Part 1 |

| | |
|---|---|
| AUGUST | Switching and PCM System Interfaces, Part 2 |
| SEPTEMBER | Update on Waveguide Technology |
| OCTOBER | Logarithmic Units of Measure |
| NOVEMBER | Microwave Mixers |
| DECEMBER | International System Metrics |

## 1975

| | |
|---|---|
| JANUARY | PCM Update, Part 1 |
| FEBRUARY | PCM Update, Part 2 |
| MARCH | Light-Route Radio Systems |
| APRIL | Filter Design Techniques, Part 1 |
| MAY | Filter Design Techniques, Part 2 |
| JUNE | Resonant Transfer |
| JULY | Anomalous Propagation, Part 1 |
| AUGUST | Anomalous Propagation, Part 2 |
| SEPTEMBER | Basic Semiconductor Memories, Part 1 |
| OCTOBER | Basic Semiconductor Memories, Part 2 |
| NOVEMBER | Optical Communications |
| DECEMBER | Lasers |

## 1974

| | |
|---|---|
| JANUARY | Computer-Aided Drafting and Documentation Systems |
| FEBRUARY | Extended Length PCM Systems |
| MARCH | PCM Field Study |
| APRIL | A Glossary of Signaling Terms |
| MAY | Telephone Transmitters and Receivers |
| JUNE | Basics of Telephone Relays |
| JULY | Some Fundamentals of Telephone Signaling |
| AUGUST | Data Transmission: Principles and Problems |
| SEPTEMBER | PCM Over Microwave, Part 1 |
| OCTOBER | PCM Over Microwave, Part 2 |
| NOVEMBER | PCM Over Microwave, Part 3 |
| DECEMBER | Special Services . . . An Introduction |

## 1973

| | |
|---|---|
| JANUARY | Innovations in Microwave Transmission |
| FEBRUARY | PCM Repeatered Line |
| MARCH | Packaging Techniques |
| APRIL | Common Channel Signaling Systems |
| MAY | Space Diversity |
| JUNE | PCM Cable Considerations |
| JULY | Connectorization |
| AUGUST | Concentrators & Multiplexers |
| SEPTEMBER | FDM Modulation Plans and Polylithic Crystal Filters |
| OCTOBER | Digital or Analog Transmission |
| NOVEMBER | Third Generation Supervisory Control Systems |
| DECEMBER | Computers and Supervisory Control |

## 1972

| | |
|---|---|
| JANUARY | Toll-Quality PCM |
| FEBRUARY | Optical Transmission |
| MARCH | Twentieth Anniversary: Yesterday and Today |
| APRIL | New Maintenance and Testing Trends |
| MAY | Microwave Applications |
| JUNE | Multiline Protection Switching |
| JULY | Microwave Transmission Engineering (Part One) |
| AUGUST | Microwave Transmission Engineering (Part Two) |
| SEPTEMBER | Strip Transmission Lines |
| OCTOBER | Carrier in Customer Distribution Networks |
| NOVEMBER | Microstrip Technology |
| DECEMBER | Phase Jitter |

## 1971

| | |
|---|---|
| JANUARY | Communications and the Environment |
| FEBRUARY | The CATV Video Microwave Link |
| MARCH | PCM Signaling and Timing |
| APRIL | The Computer in Industry |
| MAY | Coaxial Communications |
| JUNE | 12-GHz: A New Look by Industrials |
| JULY | PCM-FDM Compatibility (Part One) |
| AUGUST | PCM-FDM Compatibility (Part Two) |
| SEPTEMBER | PCM-FDM Compatibility (Part Three) |
| OCTOBER | Data Modems |
| NOVEMBER | Line Equalization for Data Transmission |
| DECEMBER | Cable Tests and Measurements for PCM |

## 1970

| | |
|---|---|
| JANUARY | Lasers for Communication |
| FEBRUARY | Holography |
| MARCH | Subscriber Carrier |
| APRIL | Progress in Solid-State Radio |
| MAY | Cables |
| JUNE | Cable Developments |
| JULY | Domestic Satellites |
| AUGUST | Some Aspects of Microwave System Reliability |
| SEPTEMBER | High Speed Data Transmission |
| OCTOBER | Communications Yardsticks |
| NOVEMBER | Crystal Filters (Part One) |
| DECEMBER | Crystal Filters (Part Two) |

## 1969

| | |
|---|---|
| JANUARY | Circuit Conditioning (Part One) |
| FEBRUARY | Circuit Conditioning (Part Two) |
| MARCH | Protective Relaying |
| APRIL | Reflectors & Repeaters |

| | |
|---|---|
| **MAY** | Overloaded Microwave Systems (Part One) |
| **JUNE** | Overloaded Microwave Systems (Part Two) |
| **JULY** | Microwave Sources |
| **AUGUST** | Developments in Satellite Communications |
| **SEPTEMBER** | Facsimile |
| **OCTOBER** | The Reach for Higher Frequencies (Part One) |
| **NOVEMBER** | The Reach for Higher Frequencies (Part Two) |
| **DECEMBER** | Binary Logic and PCM |

## 1968

| | |
|---|---|
| **JANUARY** | Undersea Cable |
| **FEBRUARY** | Supervisory Control |
| **MARCH** | PCM (Part One) |
| **APRIL** | PCM (Part Two) |
| **MAY** | Computer Time-Sharing |
| **JUNE** | Ringing |
| **JULY** | Data Loading for Military Communications |
| **AUGUST** | ACI: Automatic Car Identification |
| **SEPTEMBER** | Negative Resistance Devices |
| **OCTOBER** | Hybrid Microcircuitry (Part One) |
| **NOVEMBER** | Hybrid Microcircuitry (Part Two) |
| **DECEMBER** | Solid State Review |

## 1967

| | |
|---|---|
| **JANUARY** | Ground Stations for Satellite Communications |
| **FEBRUARY** | Protection Systems for Microwave Radio |
| **MARCH** | Fifteenth Anniversary |
| **APRIL** | Trends in Microwave |
| **MAY** | Missile Range Communications |
| **JUNE** | Coaxial Cable Communications |
| **JULY** | Remote Power from Fuel Cells |
| **AUGUST** | Uses of Low Speed Data |
| **SEPTEMBER** | Station Carrier |
| **OCTOBER** | Millimeter Transmission |
| **NOVEMBER** | Multipath Fading |
| **DECEMBER** | Integrated Circuits |

## 1966

| | |
|---|---|
| **JANUARY** | Worldwide Defense Communications. . .AUTOVON/AUTODIN |
| **FEBRUARY** | Telegraph Transmission Over VF Multiplex Systems |
| **MARCH** | Community Antenna TV |
| **APRIL** | dB and Other Logarithmic Units |
| **MAY** | Operating Standards for Frequency Division Multiplex Systems |
| **JUNE** | The Computer and the Engineer |
| **JULY** | Signaling Over Telephone Trunks |
| **AUGUST** | Echo Suppression |
| **SEPTEMBER** | Data Communications (Part One) |
| **OCTOBER** | Data Communications (Part Two) |

| | |
|---|---|
| **NOVEMBER** | Pulse Code Modulation |
| **DECEMBER** | Satellite Communications |

## 1965

| | |
|---|---|
| **JANUARY** | Microwave for TV Transmission |
| **FEBRUARY** | DC Power Plants for Communications Systems |
| **MARCH** | Load Capacity of High-Density Multiplex Systems |
| **APRIL** | Information Theory and Coding – Part 1 |
| **MAY** | Information Theory and Coding – Part 2 |
| **JUNE** | Delay Distortion |
| **JULY** | Transmission System Planning |
| **AUGUST** | Introduction to the Traveling Wave Tube |
| **SEPTEMBER** | Requirements of a Human Communications Channel |
| **OCTOBER** | Characteristics of Waveguides |
| **NOVEMBER** | A Review of the Laser – A Prospect for Communications |
| **DECEMBER** | Development of Multiplex Telephony |

## 1964

| | |
|---|---|
| **JANUARY** | Hybrids |
| **FEBRUARY** | Data Timing for HF Radio Transmission |
| **MARCH** | The Universal Voice Channel |
| **APRIL** | Microelectronics |
| **MAY** | Noise Performance in Industrial Microwave Systems – Part I |
| **JUNE** | Noise Performance in Industrial Microwave Systems – Part II |
| **JULY** | The Properties and Uses of Piezoelectric, Quartz Crystals |
| **AUGUST** | Heterodyne Repeaters for Microwave |
| **SEPTEMBER** | Basic Concepts of Engineering Reliability |
| **OCTOBER** | The Theory and Use of Compandors in Voice Transmission Systems |
| **NOVEMBER** | Characteristics of Transmission Lines |
| **DECEMBER** | Noise |

## 1963

| | |
|---|---|
| **JANUARY** | The Transmission of PCM Over Cable |
| **FEBRUARY** | Major Breakthrough in Data Transmission – "Duobinary Coding" |
| **MARCH** | Signaling in Carrier Channels |
| **APRIL** | The Varactor Diode |
| **MAY** | Antenna Systems for Microwave – Part I |
| **JUNE** | Protective Relaying, Vital Communications for Power Transmission |
| **JULY** | Antenna Systems for Microwave – Part II |
| **AUGUST** | HF Radio Transmission |
| **SEPTEMBER** | A Discussion of "Levels" and "Powers" in a Carrier System |
| **OCTOBER** | Performance Testing of Television Channels – Part I |
| **NOVEMBER** | Performance Testing of Television Channels – Part II |
| **DECEMBER** | Filter Flanking, What and Why? |

## 1962

| | |
|---|---|
| JANUARY | Precise Frequency Control |
| FEBRUARY | The Transmission of Color Television Over Microwave |
| MARCH | Surge Protection of Transistorized Circuits |
| APRIL | Rapid Microwave Switching |
| MAY | Earth Satellite Communications |
| JUNE | Maintenance of Transistorized Communications Equipment |
| JULY | Take the Mystery Out of Microwave Literature |
| AUGUST | More About Logic |
| SEPTEMBER | Co-ordination Between Carrier Systems |
| OCTOBER | Shielding and Grounding |
| NOVEMBER | Time-Division Multiplex — New Promise for Old Technique? |
| DECEMBER | The Versatile Oscilloscope |

## 1961

| | |
|---|---|
| JANUARY | New Techniques in Power Conversion |
| FEBRUARY | The Hall Effect |
| MARCH | Microwave Diversity — How it Improves Reliability |
| APRIL | Military Versus Commercial Carrier System Design |
| MAY | How to Evaluate Radio and Carrier Noise Performance |
| JUNE | Special Code Techniques for Improved Data Transmission |
| JULY | Masers, Lasers, and Atomic Resonance |
| AUGUST | Novel Uses of Datatel |
| SEPTEMBER | The New Microwave — Part I |
| OCTOBER | The New Microwave — Part II |
| NOVEMBER | dBa and Other Logarithmic Units |
| DECEMBER | New Knowledge About Transistor Reliability |

## 1960

| | |
|---|---|
| JANUARY | The Importance of Controlling Levels |
| FEBRUARY | The Push for Faster Data Transmission |
| MARCH | Methods for Transmitting Data Faster |
| APRIL | Noise |
| MAY | The Tunnel Diode |
| JUNE | The Changing "Look" of Communications Equipment |
| JULY | Delay Distortion — Cause and Cure |
| AUGUST | Time Sharing, Growing Trend in Communications |
| SEPTEMBER | Logic Circuits in Modern Communications |
| OCTOBER | The Difficult Problem of Exchange Trunk Carrier |
| NOVEMBER | Crosstalk |
| DECEMBER | Microwave Intermodulation Distortion — and How It Is Measured |

## 1959

| | |
|---|---|
| JANUARY | Multiplexing and Modulating in Carrier Telephone Systems — Part II |
| FEBRUARY | Some Requirements of a Human Communications Channel |

| | |
|---|---|
| MARCH | Mobile Telephony |
| APRIL | The Use of Filters in Carrier Telephone Systems |
| MAY | Amplifiers for Carrier Applications |
| JUNE | Information Theory and Modern Communications |
| JULY | A Review of Telephone Signaling |
| AUGUST | Speech Loading of Carrier Systems |
| SEPTEMBER | How to Increase Microwave Reliability |
| OCTOBER | Basic Measurements in Communications |
| NOVEMBER | Why So Much Data Transmission? |
| DECEMBER | The Very Important Klystron |

## 1958

| | |
|---|---|
| JANUARY | Measuring Voltage and Power at Carrier Frequencies |
| FEBRUARY | AM Versus FM for Digital Data Transmission |
| MARCH | Measuring Power and Frequency at 6000 Mc |
| APRIL | Power Supplies for Carrier and Radio Equipment |
| MAY | Carrier — Past, Present, Future |
| JUNE | The Transmission of Information by Means of Carrier |
| JULY | The Behavior of Open-Wire Lines and Cables at Frequencies Above 150 Kc |
| AUGUST | The Use of Vestigial Sideband in High-Speed Data Transmission |
| SEPTEMBER | The Use of Vestigial Sideband in High-Speed Data Transmission |
| OCTOBER | Carrier Channels for Telegraph and Data — A Review of Fundamentals — Part I |
| NOVEMBER | Carrier Channels for Telegraph and Data — A Review of Fundamentals — Part II |
| DECEMBER | Multiplexing and Modulation in Carrier Telephone Systems — Part I |

## 1957

| | |
|---|---|
| JANUARY | Carrier System Co-ordination |
| FEBRUARY | Transformers for Carrier Systems |
| MARCH | Detection of FM Signals |
| APRIL | Waveguides for Microwave Systems |
| MAY | The Effect of Transistors on Carrier Maintenance |
| JUNE | The Klystron |
| JULY | Microtel, A New 6000 Megacycle Microwave System |
| AUGUST | Some Aspects of Interconnecting Different Carrier Systems |
| SEPTEMBER | Some Practical Aspects of Digital Data Transmission Over Telephone Facilities |
| OCTOBER | Ferrite Devices for Microwave |
| NOVEMBER | Protecting Communication Circuits from High Voltages |
| DECEMBER | 6,000 Mc Radio Systems — Some Equipment and Operating Considerations |

## 1956

| | |
|---|---|
| JANUARY | The Use of Radio Frequency Spectrum by Common Carriers |
| FEBRUARY | Oscillators for Carrier Systems |
| MARCH | Choice of Open Wire Facilities for Carrier Operation |

| | |
|---|---|
| **APRIL** | Telephone Channels for Data Transmission |
| **MAY** | Frequency Measurements in Communications Systems |
| **JUNE** | Capacitors for Carrier Systems |
| **JULY** | Repeaters for Open-Wire Carrier Systems |
| **AUGUST** | Importance of Carrier in Nationwide Toll-Dialing |
| **SEPTEMBER** | Transpositions for Open-Wire Lines |
| **OCTOBER** | Estimating the Noise Performance of FM Microwave Systems |
| **NOVEMBER** | A Program for Carrier Equipment Maintenance |
| **DECEMBER** | Selection of Towers and Antennas for Microwave System Use |

## 1955

| | |
|---|---|
| **JANUARY** | Alarm Circuits for 45-Class Carrier |
| **FEBRUARY** | Cable Transmission Characteristics in the Carrier Frequency Range |
| **MARCH** | Carbonyl Iron Cores for Miniaturized Carrier Components |
| **APRIL** | Distortion in Carrier Circuits |
| **MAY** | 45-Class Carrier Networks |
| **JUNE** | Some Engineering Features of the New Type 45BN Cable Carrier Systems |
| **JULY** | Some Types and Applications of Relays Used in Carrier Equipment |
| **AUGUST** | A Brief Description of the Transistor and Some of Its Potentialities |
| **SEPTEMBER** | Remote Control and Supervision of Industrial Operations |
| **OCTOBER** | Introducing Type 45CB, A New 4-Channel Carrier System for Open-Wire Lines |
| **NOVEMBER** | Amplitude Modulation in Carrier Communication |
| **DECEMBER** | The Theory and Applications of Piezoelectric Crystals |

## 1954

| | |
|---|---|
| **JANUARY** | An Explanation of DBA and Other Logarithmic Units |
| **FEBRUARY** | Transmission of FDM Channels by FM Point-to-Point Radio |
| **MARCH** | Techniques for Measuring Open-Wire Lines for Carrier Applications — Part I |
| **APRIL** | Techniques for Measuring Open-Wire Lines for Carrier Applications — Part II |
| **MAY** | A Progress Report on 45-Class Carrier Equipment |
| **JUNE** | Some Factors Affecting the Propagation of Microwave Over Point-to-Point Radio Systems |
| **JULY** | Vacuum Tube Reliability in Carrier Telephone Systems |
| **AUGUST** | Transmission of Dial and Teletypewriter Signals Over Carrier Telephone Channels |
| **SEPTEMBER** | Problems in Hybrid Balance |
| **OCTOBER** | Some Types and Sources of Noise in Communication Circuits |
| **NOVEMBER** | Line Filters for Carrier Telephone Installations |
| **DECEMBER** | Some Factors Affecting Open Wire and Cable Extensions for Radio Carrier Systems |

## 1953

| | |
|---|---|
| JANUARY | How to Prepare and Use Profile Charts of Radio Link Routes |
| FEBRUARY | An Elementary Explanation of the Effects of Parallel Connection of Filters |
| MARCH | Basic Principles of Compandors and Their Application to Carrier Systems |
| APRIL | Automatic Transfer Circuit for Point-to-Point Radio Systems |
| MAY | Some Factors Affecting Levels in a Carrier Terminal |
| JUNE | Some Factors Involved in Design of Carrier System Filters |
| JULY | Germanium Diodes in Carrier Systems – Why They Are Used – How They Work |
| AUGUST | Basic Principles of Carrier System Regulation and Equalization |
| SEPTEMBER | Operation and Application of Hybrid Junctions |
| OCTOBER | Transmission Line Characteristics and How They Affect Carrier Operation |
| NOVEMBER | D-C Terminal Circuits for Carrier Telegraph Systems |
| DECEMBER | The Effect of Impedance Mismatch on Carrier Circuits |

## 1952

| | |
|---|---|
| MARCH | Introducing A New Publication for Carrier Communications |
| APRIL | Copper: No. 1 Problem |
| MAY | How to Determine Transmission Losses in Radio Links |
| JUNE | Transmission of Signals Over Carrier System Channels |
| JULY | Some Engineering Features of the New Type 33C Carrier Telephone System for Channelizing Radio Links |
| AUGUST | A Brief Discussion of Frequency Division Multiplexing |
| SEPTEMBER | Supervisory, Control, and Alarm Facilities for Point-to-Point Radio Systems |
| OCTOBER | Limiters in Carrier Systems, What They Are – And How They Work |
| NOVEMBER | Some Engineering Features of the New Type 24C Carrier Telegraph System |
| DECEMBER | A Discussion of "Levels" and "Powers" in a Carrier System |

GTE LENKURT
1105 COUNTY ROAD
SAN CARLOS, CALIFORNIA 94070

ADDRESS CORRECTION REQUESTED

Bulk Rate
U. S. Postage
PAID
San Carlos, CA
Permit No. 37

PIC00319C015 1
B J PICOU

319 CRAWFORD ST
LAFAYETTE LA 70501

# Announcement

Effective April 1, 1979 the price of the GTE Lenkurt Demodulator loose leaf binder will be $2.50. The new price defrays our cost for the binder, including shipping charges.

The binders may be obtained by writing to:

GTE Lenkurt Demodulator
M/S C134
1105 County Road
San Carlos, CA 94070.

We request prepayment.

GTE LENKURT

VIDEO, VOICE & DATA
TRANSMISSION SYSTEMS

**The GTE Lenkurt Demodulator** is circulated bimonthly to selected technicians, engineers and managers employed by companies or government agencies who use and operate communications systems, and to educational institutions. Permission to reprint granted on request.