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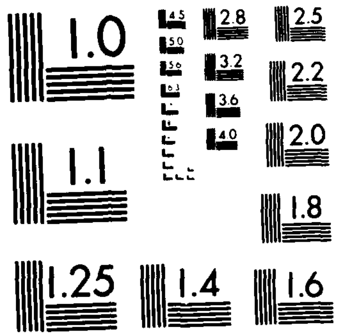

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Report 2430

THE ROLE OF FIBER OPTICS IN PHYSICAL SECURITY SYSTEMS

Prepared by the
DIRECTORATE FOR COMBAT ENGINEERING
PHYSICAL SECURITY EQUIPMENT DIVISION
BELVOIR RD&E CENTER

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23 July 1986

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In this report, we discuss the application of fiber optics communication technology to physical security systems, and how this differs from secure communications. Emphasis is on work being conducted by the US Army Belvoir RD&E Center. Also, the application of fiber optic sensor technology to physical security (investigated in conjunction with the US Naval Research Laboratory) is discussed.

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ILLUSTRATIONS

THE ROLE OF FIBER OPTICS IN PHYSICAL SECURITY SYSTEMS

I. INTRODUCTION

The US Army Belvoir Research, Development and Engineering Center is currently investigating development of a communication link for a tri-service Facility Intrusion Detection System (FIDS), using fiber optics as the transmission medium.

The FIDS is a highly secure, microprocessor-controlled system that provides physical security for high priority DOD installations. The basic system is designed to monitor and display the security status of areas to be protected. Each secure area is protected by a control unit which monitors the alarm/non-alarm status of sensors within that area. Fiber optic links will be used to enhance system operation for protection of high priority assets.

Advances in fiber optics in the last few years demonstrate that optical fibers can serve as sensor transducers by using a variety of techniques. The use of such devices as intrusion detection sensors also has several advantages. Some of these are increased sensitivity, directivity, and geometrical flexibility of configuration. The prospect of lower-priced sensors in the near future may be an advantage as well. A detailed discussion of fiber optic data transmission links and optical transducer sensors as applied to physical security needs is presented.

Basic to the use of fiber optics in this application is an understanding of the fundamental phenomenology of fiber optics data communications and the threat facing physical security data links. It is essential to realize that having "secure" communications for intrusion detection systems does not necessarily mean privacy but, rather, authentication. If a tapper succeeds and is able to eavesdrop, useful information need not be gained. Instead the prime objective can be to deceptively inject data or "spoof" the system.

The objective of any communications system is to transfer information from one point to another. This information transfer most often is accomplished by superimposing (modulating) the information onto an electromagnetic wave (carrier). The modulated carrier is then transmitted to the destination where the electo-magnetic wave is received and the information recovered (demodulated).[1]

A military requirement to develop a communication link for the FIDS, using fiber optics as the transmission medium, is being investigated. The FIDS is based around a Command, Control, and Display Subsystem (CCDS) console. Each modem located within the CCDS is currently capable of communicating with up to 16 zones. Each zone is separately polled over twisted wire pairs. Because of security requirements, the electrical modems will be selectively replaced with fiber optic modems and will be capable of performing all of the inherent functions of the original modems.

The FIDS is a manned security system that monitors the status of a large array of intrusion sensors such as door switches, ultrasonic motion detectors, vibration, and surveillance cameras (Figure 1). In the protected areas, the sensors are divided into geographically adjacent groups and are connected to local microprocessor-based Control Units (CUs). The CUs periodically poll their sensors to establish security status, and the CUs are similarly polled by the CCDS. If an alarm is activated in a protected area, the affected sensor communicates this fact at the next CU interrogation. The CU then transfers this information to the FIDS console at the next CCDS interrogation.

Communication between the CU and its sensors is carried over the Internal Data Link (IDL) which can be up to 500 feet long. The communication link between the CCDS and CU, known as the External Data Link (EDL), can be up to 16 km long. Both are bidirectional with control, deterrent, and operational status information being transmitted in addition to alarm status. Because the sensors of the IDL provide the link with its own security, its

[1]Gagliardi, R. M., and Karp, S., "Optical Communications," John Wiley and Sons, Inc., 1976.

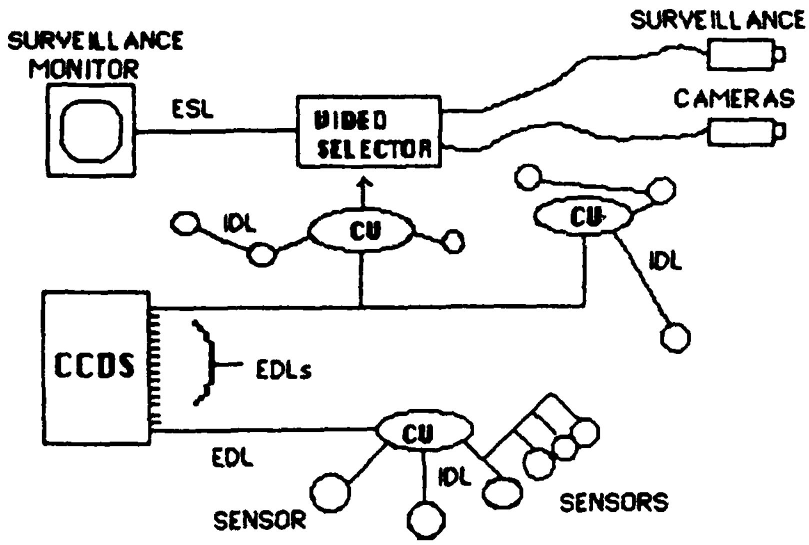

FIGURE 1: Overview of the Facility Intrusion Detection System (FIDS).

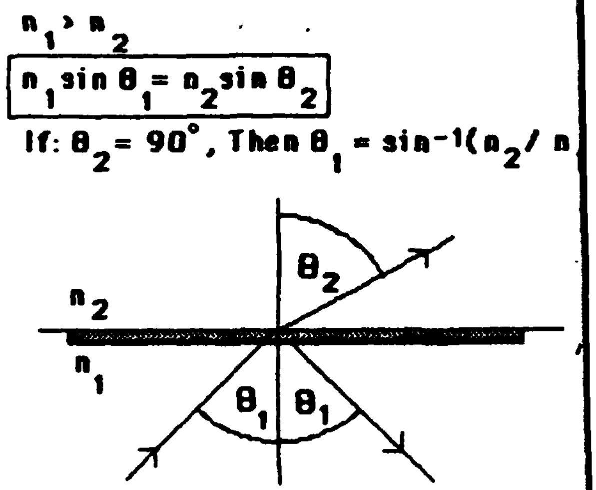

FIGURE 2: Snell's Law.

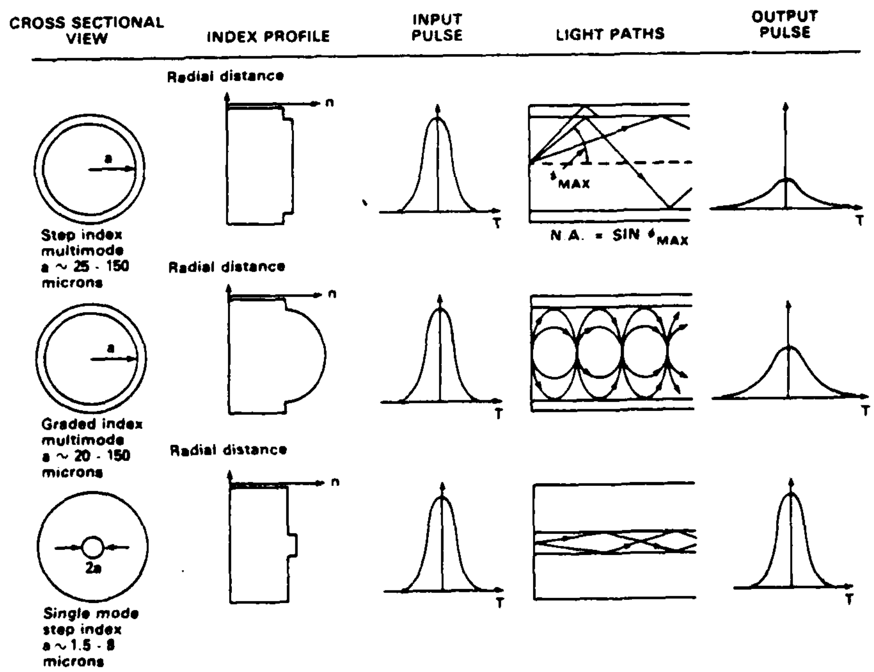

FIGURE 3: Optical fiber profiles and propagation patterns. (US Naval Research Laboratory, report under contract N00173-79-C-0138,©IEEE 1978).

data is in clear text and requires only a communication chip at each sensor to interface with the CU. The EDL uses encryption to protect its transmission lines. The surveillance video links are in addition to the IDL and EDL. The CU may control camera selection, but the signal transmission is independent of both the IDL and EDL links and is in unencrypted text.

II. THE PHENOMENOLOGY OF FIBER OPTICS

An optical fiber used today is more correctly called a dielectric waveguide because the propagation of electromagnetic radiation through an optical fiber is a guided wave phenomenon.[2] Several good review articles exist on the mathematical description of optical waveguides.[3,4] The ground work for understanding these waveguides was laid by James Clerk Maxwell in 1865. While we shall approach the workings of an optical fiber from a less mathematical level, it is important to remember that the propagation of the wave governed by Maxwell's equation is a more correct description than that given by geometrical optics.

An optical fiber, simply, is a fiber of very pure silica-glass with an outer layer or "cladding" of glass applied to it, thus forming the light guide. Light is contained within the fiber by means of a phenomenon known as total internal reflection. Total internal reflection is described by a simple equation known as Snell's Law: light moving across an interface from a region of higher refractive index to one of lower refractive index will be bent away from a line perpendicular to the surface of the interface where the light strikes. In mathematics, this is stated--

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

where n_1 and n_2 are the indexes of refraction for the two regions, and θ_1 and θ_2 are the angles made by the incident and transmitted rays with the perpendicular (sometimes called a "normal"). This is shown clearly in the Snell's Law diagram (Figure 2). As θ_1 increases, θ_2 does also until θ_2 equals 90°. At this point, all the light of the transmitted ray just skims the interface and, at any higher angle of θ, is totally confined to region one, which is the core in the case of a fiber.

There are three basic types of fibers in use today. These are shown in Figure 3. In cross section they are a step-index, graded-index, or single-mode fiber. In the step-index, the index of refraction is constant throughout the core. The result of this is a conceptually simple fiber in which light entering at one end travels different paths through the fiber, depending on the angle at which it entered. Those entering at sharp angles are propagated at what are called high-order modes, and those which stay close to the axis are called low-order modes. In a step-index fiber, high-order modes travel a longer distance (due to their reflection back and forth) than low-order modes, which travel straight down the axis to the other end. Therefore, we observe the phenomenon of "pulse spreading" or dispersion. This limits the amount of information we can send down a fiber because for very high data rates, pulses (as in a digital system) smear out into one another and become indistinguishable. In the "graded-index" fiber, this is compensated to a certain extent. The index of refraction of the core is controlled in the manufacturing process to give it a gradient. The value of the index of the core varies from a maximum at the center of the fiber to that of the cladding at the edge (usually by the inverse square of the core radius).

[2] Unless otherwise stated, the wavelength region of fibers and components in this report is .80μm to .9μm.

[3] Barnoski, Michael K., Editor, "Fundamentals of Optical Fiber Communications," Academic Press, Inc., New York, 1976.

[4] Olshansky, R., "Propagation in Glass Optical Waveguides," *Reviews of Modern Physics*, Vol. 51, No. 2, p. 341ff, 1979.

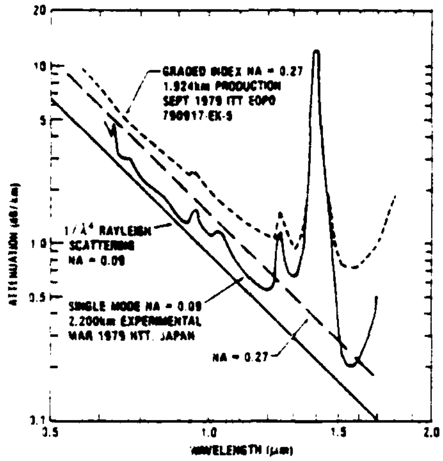

FIGURE 4: Attenuation of some optical fibers as a function of wavelength (λ). (Courtesy Robert J. Hess, ITT Electro-Optic Products; GWU Continuing Engineering Education Course #541, October 1980.)

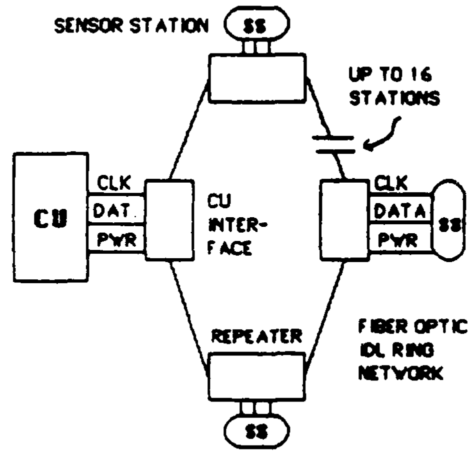

FIGURE 5: Fiber optic Internal Data Link (IDL) ring network.

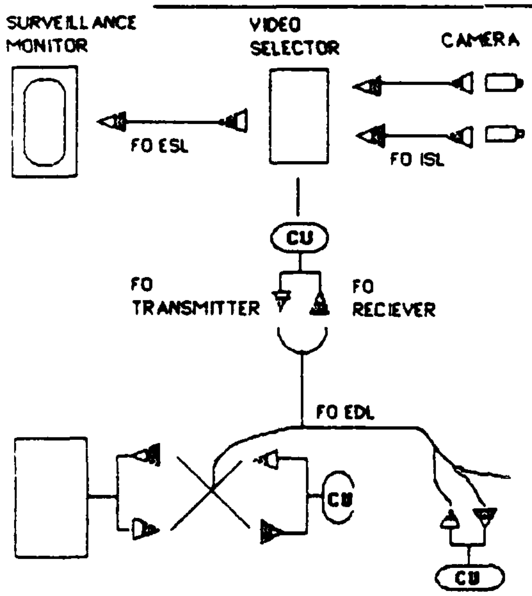

FIGURE 6: FIDS incorporating the Fiber Optic External Data Link (EDL).

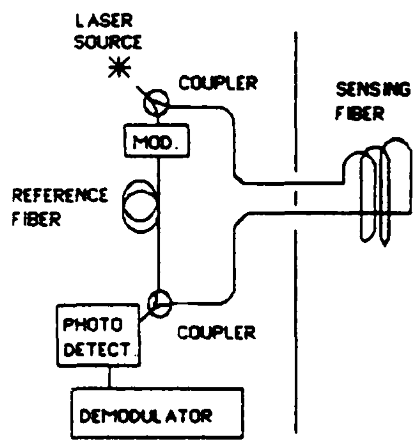

FIGURE 7: Schematic diagram of the interferometric air acoustic sensor.

When light in the high-order modes travels in a graded-index fiber, the light is refracted smoothly back to the core, rather than abruptly reflecting at the cladding. Since light travels slower in mediums of higher refractive index, the further from the axis the ray travels, the faster it moves. Therefore, higher and lower modes arrive at nearly the same time at any given point along the axis, reducing dispersion greatly. In a single-mode fiber, like a step-index, the core is of uniform index, but the diameter of the core is so small that only the lowest-order modes can propagate (the first TM_{00} and TE_{00}). The "single" mode has the least dispersion and, therefore, can carry great amounts of information without modal distortion.

Another major consideration for an optical fiber is absorption. The lower limit for the absorption of a glass or fluid material is the molecular or "Rayleigh" scattering limit.

> "[The] scattering of the light can be caused by the random arrangements of the molecules of the core material, which makes the material look slightly granular at light wavelengths. It is this [phenomenon]...that sets a lower bound to the loss of light in glassy or fluid materials."[5]

The attenuation decreases as the inverse fourth power of the wavelength.[5] Other absorption is caused principally by impurities in the glass.

> "If as little as one part per billion of certain metals (or even water) is included in the glass...the fiber will absorb a significant amount of light."[5]

Some recent examples of this are given in Figure 4, showing the absorption spectra for two fibers with the Rayleigh scattering limit for each. This limit is not only a function of the material. It also varies with the Numerical Aperture (NA) of the fiber. The NA for a given fiber is the sine of the highest angle which can enter the end of the fiber and still be propagated down the waveguide. Thus, it is a measure of the coupling efficiency of the fiber to a light source.

III. SYSTEM CONSIDERATIONS

The unique advantages of optical fiber transmission over electrical transmission, for a host of applications, make its use attractive with regards to performance and cost. For many applications, optical fiber transmission offers wider bandwidth, larger repeater spacing, and smaller cable cross sections than were previously possible. In addition, since cables employing optical transmission neither pick up nor emit electromagnetic radiation and offer total electrical isolation, the problems of RFI, EMI, EMP, ground loops, and sparking, associated with electrical cables, are eliminated.

Thus, with reference to the FIDS operational needs, the advantages associated with fiber optics can be exploited to enhance FIDS performance in several areas:

a. Being a dielectric, fiber optics provide complete isolation from EMI and the effects of EMP.

b. Compared to fiber optic capabilities, FIDS has relatively low digital data rates, permitting longer link length than is practical with wire.

c. Optical fibers are typically less prone to harassment by an intruder, and while not secure in and of themselves, they make compromise by tapping or "spoofing" (deceptive substitution of data) more difficult. Unlike wire links, any intruder wishing to defeat or interact with the fiber optic link must damage the fiber optic cable in order to gain access to the data flow.

d. Once an intruder commits to gaining access to the fiber optic data link, the act of eavesdropping is a difficult and delicate process requiring skills and equipment.

[5] Cook, J.S., "Communication by Optical Fiber," *Scientific American*, Vol, 229, No. 5, p. 29, November 1973.

e. By adding the simplest line-security supervisors to the fiber optic link, the task of successfully penetrating a fiber optic cable, undetected, becomes much more difficult.

IV. THE INTERNAL DATA LINK (IDL)

The IDL functions as a link connecting the CU to as many as sixteen sensor/deterrent stations. Presently, the electrical IDL consists of two twisted wire pairs. One pair forms a time-division, multiplexed, bidirectional data bus which connects electrically in parallel the input/output of the CU with those of the stations. The other pair provides the CU clock as a timing reference to each of the stations.

To permit two-way communications between the CU and stations, a series-ring fiber optic network is used (Figure 5). The CU transmits its interrogation/command signal to the first station in line, which receives and then repeats the signal to the next station, and so on, until the last station receives and repeats the signal to the CU. As each station receives and repeats the CU interrogation, it decides whether it is the one being addressed by the CU. If it is, its subsequent response is transmitted to the next station in line and repeated until finally reaching the CU.

To connect the surveillance camera to either a guard monitor station or a CU-actuated switching subsystem, the fiber optic Internal Surveillance Link (ISL) is used. The fiber optic ISL is a developmental model composed of two parts: the fiber optic video link and the fiber optic line security supervisor.

The fiber optic video link is a compact, lightweight system for transmitting video signals, using an optical waveguide over distances of one-half kilometer or greater. This system consists of three major components (Figure 6): an intensity-modulated optical transmitter module, fiber optic cable, and optical receiver module with Amplitude Gain Control (AGC). The transmitter converts the electrical video signal into a light of varying intensity. The receiver reconverts the varying light intensity transmitted over the fiber optic cable into electrical video. Input and output of the system is a 1Vp-p (sync tips to video peak) signal terminated and driven into 75 ohms via standard BNC connectors. Both the transmitter and receiver are small enough to be mounted to an existing video source without additional design to incorporate them into an overall video distribution system.

V. LINE SUPERVISION

Authentication techniques which are use with standard electrical communications, and which rely on format, procedure, or protocols, may be used as easily with fiber optics (e.g. encryption, parity checks, interrogation/response schemes). The use of optical waveguides opens other possibilities which may complement these techniques. Some of the more obvious are optical power monitoring, "whispering" (minimum power transmission to defeat eavesdropping), "shouting" (maximum power transmission to defeat injection), and Optical Time Domain Reflectometry (OTDR) to detect discontinuities in the fiber by measuring Rayleigh or molecular backscattering/reflection. All of these techniques have advantages and disadvantages, merits, proponents, problems, and detractors. Some, like power monitoring, are environmentally sensitive and others, like OTDR, are cumbersome, time consuming, and/or expensive (a good OTD Reflectometer may cost upwards of $10,000). The decision to use one or more of these techniques largely depends upon the threat expected, system configuration, and budget (both cost and optical power). With proper design, an intruder's task can be made arbitrarily difficult. To "spoof," the intruder must first tap, read the signal without disrupting the data communications, and then inject without disruption, which requires the removal of the authentic data. Aside from any steps deliberately taken to hinder, Murphy's Law works against the intruder and for the security system in almost all aspects of the attack.

It should be emphasized, however, that if privacy is desired, do not depend on fiber optics alone. Tapping is possible. Much of the effort which has gone into commerical cable design has been intended to prevent the production of radiation modes in the fiber of communications cables.[6]

[6] Horgan, John, Assc. Ed., "Thwarting the Information Thieves," *IEEE Spectrum*, Vol. 22, No. 7, p. 36, July 1985.

VI. FIBER OPTIC SENSORS

Under Belvoir Research, Development and Engineering Center sponsorship and funded by the Defense Nuclear Agency, the Naval Research Laboratory (NRL) has been developing fiber optic sensors for incorporation into intrusion systems. Currently, the transduction mechanisms for two fiber optic intrusion sensors have been investigated. The first sensor fabricated is a fiber optic floor mat pressure sensor used to detect the weight of an intruder. In the development of this sensor, which operates on the principle of microbend fiber loss, several commerical fibers and sensor configurations were tested. A threshold detection device was fabricated and tested after it was determined that the simplicity of such a device was attractive, because of both the cost and the geometrical flexibility associated with such sensors.

The second device is a passive air acoustic interferometric fiber optic receiver designed for incorporation within an ultrasonic intrusion detection sensor. Yet to be proven are the potential advantages of such a sensor to reduce false alarms and countermeasures due to the inherent EMI immunity of fiber optics. The transduction mechanisms of fiber sensors in the 20 kHz to 30 kHz ranges were studied extensively. Ultimately, a planar fiber optic device which uses various radii of fiber winding as part of the transducer was constructed (Figure 7). This geometry was selected to give a narrow detection pattern and, thus, reduce nuisance alarms. Laboratory measurements indicate that such a device will meet or exceed the detection thresholds of current ultrasonic devices. If lower false alarm rates are achieved, the user will have the advantage of using higher sensitivities, increasing detection probabilities.

VII. A LOOK TO THE FUTURE

Fiber optics will become more attractive as physical security and control systems expand to handle larger facilities and as a need grows for expanded communications; sensing capability; and EMI, TEMPEST, and Lightning/EMP protection.

To show the current state-of-the-art, here are some numbers:

- Longest repeaterless link (laboratory result) -- 445 Mbits/s @$\lambda = 1.55$ μm, 170 km.[7]
- Highest (data rate) x (distance) product (laboratory) -- 1 Gbit/s over 120 km.[8]

Systems such as these are pushing back the state-of-the-art but are demonstrating that current physical security systems with relatively low data rates and maximum runs on the order of tens of km may be able to upgrade their capabilities without replacing contemporary fiber optic components, when upgrading becomes a major system issue. The possibility exists for situations involving hazardous/explosive atmosphere where integrated optical sensor/datalink systems may be devised to address the issue of spark or hazardous environment, physical security, and sensing systems.

VIII. CONCLUSIONS

Extensive work has been done on the potential benefits that fiber optics technology can offer FIDS. In most cases, early advanced developmental equipment was fabricated to demonstrate these benefits. The experience and information gained with fiber sensors will be used to improve existing sensors. The investigation will continue on other fiber optic sensing phenomena for magnetic, acoustic, infrared, and electric field sensors. The feasibility of using optical fibers as a transmission medium, a sensor transducer, and for other applications has been demonstrated. As long as the fiber optic sensor phenomenon continues to show benefits for magnetic, acoustic, infrared, and electric field sensors, the efforts will continue.

[7] Toba, H., et al., "Electronics Letters 20," pp. 370 and 371, April 1984.

[8] Link, R.A., et al., "A 1 Gb/s Lightwave Transmission Experiment Over 120 km Using a Heterojunction APD Receiver," *OFC '84*, Post Deadline Paper WJ7, January 1984.

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