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OPTICAL FIBERS, INTEGRATED OPTICS AND THEIR MILITARY APPLICATIONS LONDON, ENGLAND, 16-20 MAY 1977

DR. VERN N. SMILEY

29 SEPTEMBER 1977

UNITED STATES OF AMERICA

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REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: ONRL-C-12-77	2. GOVT ACCESSION NO.
	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): OPTICAL FIBERS, INTEGRATED OPTICS AND THEIR MILITARY APPLICATIONS, LONDON, ENGLAND, 16-20 MAY 1977.	5. TYPE OF REPORT & PERIOD COVERED: CONFERENCE 16-20 May 1977 rept.
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): DR. VERN N. SMILEY	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Office of Naval Research, Branch Office London, Box 39, FPO New York, New York	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS	12. REPORT DATE: 29 August 1977
	13. NUMBER OF PAGES: 11
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): UNCLASSIFIED
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

DISTRIBUTION UNLIMITED: APPROVED FOR PUBLIC RELEASE

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

OPTICAL FIBERS	GRADED INDEX
INTEGRATED OPTICS	STEP INDEX
SINGLE MODE	OPTICAL COMMUNICATION
MULTI-MODE	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A review is given of some of the papers presented at a Conference which was held in London, 16-20 May 1977. Emphasis is placed on past, present, and future devices for military applications. The review is organized in the same manner as the Conference format under the subtitles: systems, integrated optics, propagation, sources and detectors, and couplers.

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CONTENTS

OPTICAL FIBERS, INTEGRATED OPTICS AND THEIR MILITARY APPLICATIONS
LONDON, ENGLAND, 16-20 MAY 1977

I. INTRODUCTION

The Optical Fibres, Integrated Optics, and their Military Applications, Meeting in London, England, 16-20 May 1977, was a joint symposium of the Electromagnetic Wave Propagation Panel and the Avionics Panel of the NATO Advisory Group for Aerospace Research and Development (AGARD).

In one respect the choice of meeting place seemed apropos for a conference on optical applications for the military in view of an inscription encircling the dome above the Assembly Hall in Church House that reads, "*Holy is the true light and passing wonderful lending radiance to them that endured in the heat of conflict* ...."

The more than 50 papers presented were grouped into 6 sessions: overview, systems, integrated optics, propagation, sources and detectors, and couplers. Authors were from military laboratories, industrial establishments working on military contracts, and some institutions having no military connection. Papers were presented and translated in both French and English. The French-to-English translations were usually understandable, with a few exceptions. The majority of the papers have been published as an AGARD report, AGARD-CPP-219, and I have included a list of papers and authors as an appendix. In this report I will first discuss some papers of interest to me and then summarize the important results at the end.

II. OVERVIEW

The first session was an overview of military applications of optical fibers. The lead-off speaker was H.F. Taylor Naval Ocean Systems Center (NOSC San Diego), who gave a comprehensive theoretical review of optical fibers, discussing the state-of-the-art in fiber characteristics and the development of components for optical-fiber communications systems. Taylor then summarized US Army, Navy, and Air Force applications of fiber optics. The Air Force and Navy have both demonstrated the feasibility of replacing wire-pair and coaxial cables on aircraft for transmission of signals. A six-station telephone system was operated successfully on the USS LITTLE ROCK in 1974. More sophisticated systems for transferring high-speed digital and analog video data on ships are in development.

H. Kogelnik (Bell Telephone Laboratories, Murray Hill, NJ) reviewed the field of integrated optics, sometimes referred to as OICs (optical integrated circuits). The simplest of these devices is a single-mode dielectric waveguide in the form of a film or a strip having cross-sectional dimensions approximately a wavelength of the radiation being transmitted and with higher refractive index than its surroundings. Other devices which have worked in the laboratory are: directional couplers, modulators, switching networks, filters, and waveguide sources. A significant part of the effort has centered on new materials and new methods of fabricating components. An example of a recent waveguide is an embedded strip of Ti-diffused $LiNbO_3$ produced in a sequence of five relatively simple steps involving the use of photoresist and metallic layers, and etching and diffusion techniques. Phase modulators and switched directional couplers and networks have been made in a similar way.

Aircraft, underwater, and space applications were also discussed in this session. P. Lecat (Service Technique des Télécommunications de l'Air Paris, France) described how the use of fiber optics in place of conventional coax or wires improves the resistance of signal transmission systems to damage from electric fields generated by nuclear explosions and currents induced by lightning.

G. Wilkens (NOSC, Hawaii Laboratory) described undersea communications cables in which long undersea cables containing fiber optics are being developed for transmitting signals over distances up to 10 km. Some completed tests of these cables show that further development is needed. If attenuation losses less than 5 dB/km are to be routinely achieved, higher minimum strain-to-break values in long fibers are required. In addition, care must be exercised in jacketing so as not to produce microbends, and internal voids must be avoided during cable production.

A. Johnston (Jet Propulsion Laboratory, Pasadena, CA) gave the details of NASA's program to use fiber-optic links on the Space Shuttle.

B. Ellis [Royal Aircraft Establishment (RAE), Farnborough, Hants.] described fiber-optics work in the UK. He pointed out that Plessey Ltd. has recently developed a light-emitting diode (LED) that can be modulated up to 1 GHz. Since this is larger than required, even for future systems, and since the bandwidth is generally limited to values lower than this by the fiber-optic transmission line itself, all further development of LEDs has been stopped in the UK. Ellis also stated that a fiber-optic transmission link was installed on HMS TIGER on 26 July 1976 and is working satisfactorily. A data link for a diver's life-support system was also successfully tested.

An important problem of loss and pulse distortion from microbends in the single-mode operation of single and multimode fibers was discussed in a paper by H.G. Unger (Institut für Hochfrequenztechnik, Technische Universität Braunschweig, FRG). He showed in a theoretical treatment that losses due to random bends in the cabling process are negligible if the fundamental-mode spot size is small compared with the core diameter. In addition, Unger stated that pulse-distortion effects arising from microbends can be kept small by using mode filters.

III. SYSTEMS

The session on systems featured a description of various military experimental fiber-communication applications that have been tested. These included a 31-channel experimental optical-fiber link for the command and control of destroyer escorts that was described by E. Hara and H. Frayn (Communications Research Centre, Department of Communications, Ottawa, Canada). In this system digital signals were transmitted between two consoles by using single optical fibers for each channel.

A description of the performance characteristics of a 2-km optical-fiber, 20-Mbit/sec digital transmission system was given by T. Eppes and J. Goell (ITT Electro-Optical Products Division, Roanoke, VA) and R. Gallenberger (NOSC). They used an LED source, avalanche photodiode receiver and multifiber graded-index cable with six channels per cable. Test results demonstrated the feasibility of wideband communication over several kilometers.

Two papers emphasized economic considerations in military applications of fibers. One paper authored by R. Greenwell and G. Holma (NOSC) discussed the economics of the A-7 aircraft application mentioned earlier. Results of comparison with costs of systems using coaxial cable and twisted-shielded pair cable clearly showed that the fiber optic system is economically beneficial.

T. Alper (SHAPE Technical Centre, The Hague, Netherlands) developed a cost model for an optical-fiber communications link and determined normalized cost curves for a short, pulse-position modulation (PPM) system with a signal-to-noise ratio (SNR) of 70 dB and a long system using pulse-code modulation (PCM) with a bit-error rate (BER) of 10^{-9}. Sources were LED's and fibers with parabolic profile, graded-index cables. The cost of the short system using 1-MHz bandwidth, 40-dB/km fibers is $100 per channel per km. The cost for the long system is determined almost entirely by the cable cost for transmission rates less than 1 Mb/sec, while at higher rates the cost depends somewhat on the number of repeaters. The cost for a 32-channel system with a pulse rate of 2 Mb/sec, a repeater spacing of 2 km and 20-dB/km cable is $8,000 per km or $250/km/ch. The cost for a 10-dB/km cable is $12,000 km or about $400/km/cm.

IV. INTEGRATED OPTICS

Integrated optics has been an interesting research area for the past eight or nine years. Significant advances have been made recently, and efforts are being directed towards incorporating miniature waveguides, modulators, switches, and filters into practical devices. High-capacity data-transfer systems will eventually use single-mode optical-fiber transmission lines, as they offer higher bandwidths and faster switching capability than multimode fibers. A paper by T.G. Giallorenzi and A.F. Milton (Naval Research Laboratory, Washington, DC), read by L.F. Drummeter, pointed out that integrated optical circuits have been developed that can switch or modulate light from single-mode transmission lines. They stated that coupling a single-mode fiber to another fiber and to a thin-film waveguide has been achieved with losses less than 0.5 dB and 4 dB, respectively. Polarization becomes important in single-mode circuits; therefore, polarization-insensitive switches are required and are in development. Several single-mode data-bus designs were described.

G.D. Mitchell (Univ. of Washington, Seattle) succinctly and amusingly pointed out the problem of matching rectangular diode lasers to circular single-mode fibers by showing a picture of a child attempting to pound a square peg into a round hole. He further emphasized that a good single-mode coupler has not been achieved yet; a transition structure is required. Mitchell has tested some glass transition elements which have 14-dB loss.

G.B. Brandt *et al* (Westinghouse Research Laboratories, Pittsburg, PA) have made and demonstrated phase modulation with bulk acoustic modulators on optical waveguides at frequencies up to 1.7 GHz. They project that a modulation frequency of 10 GHz is possible before fundamental limitations set in.

V. PROPAGATION

An important military consideration with fiber-optic signal transmission is security. A paper presented by A. Johnston (Electrical Sciences and Engineering Department, UCLA) described three nondestructive methods for "tapping" optical fibers. The first method is particularly suited for use with plastic-clad glass fibers. A portion of the plastic cladding is stripped off and the core immersed in a fluid whose index of refraction nearly matches that of the core. This results in a small amount of leakage. The second method consists of lowering the temperature of the fiber. Since the index of the core and cladding vary differently with temperature, the numerical aperture (NA) changes and leakage develops as the temperature is lowered. The third method, applicable to both glass-clad and plastic-clad fibers, involves bending the fiber which results in leakage. Continuously monitoring the power level seems to be the only way to detect the tapping of fibers.

Four papers were given concerning the transmission characteristics of graded-index fibers. These fibers contain a radial gradient in the index of refraction in order to reduce intermode dispersion from that of step-index fibers. Small departures from the nominal profile in graded-index fibers can reduce the bandwidth and cause pulse distortion. A simple method referred to as the "near-field profiling method" consists of measuring the transmitted intensity through a fiber as a function of position when illuminated by a Lambertian source. Another methods uses a focused spot and measures the transmitted intensity as a function of launching position. Both of these methods require correction for "leaky modes" although, according to J.A. Arnaud (BTL), good results can be obtained by using the latter method for short fibers if the correction is carefully made, or if the fiber is sufficiently long, the correction can be ignored. Other participants felt that the method Arnaud described does not give satisfactory results. W.J. Stewart (Allen Clark Research Centre, The Plessey Company Ltd. Towcester, UK) described an experimental method in which corrections for leaky modes are not required.

VI. SOURCES AND DETECTORS

Six papers on Sources and Detectors treated the subject of injection-laser diodes as transmitters for fiber-optic communications. In particular, the use of stripe geometry in double-heterojunction GaInAsP/InP was discussed. This laser, described by J. Hsieh (Lincoln Lab., MIT), operates cw over a wavelength range from 1.1 to 1.25 μm, which is optimal for propagation through single-mode glass fibers.

Degradation of laser diodes has been a subject of concern for many years. Recent test results from several laboratories show that a 20,000-hour lifetime can now be reached with little degradation.

Two papers discussed the importance of mechanical stress on diode reliability. Stress develops during welding operations or results from thermal effects caused by high operating temperature.

G. Zaeschmar (NOSC) gave a theoretical analysis of the problem and presented experimental measurements of degradation in terms of light output vs applied mechanical stress. Experimental results and theoretical behavior are in good agreement.

An interest in modular approach was apparent in several papers throughout the Conference. One example was the paper by A. Jaques and L. D'Auria (Thomson-CSF, Orsay, France) in which they discussed a transmitter module consisting of the laser, laser-to-fiber coupler and the driving control circuits.

An interesting paper was presented by G. Ripoche (Laboratoires de Marcoussis, Centre de Recherches de la Compagnie Générale d'Electricité, CGE) on very fast silicon avalanche photodiodes. [illegible] discussed a diode with a five-layer structure and compared [illegible] performance characteristics with those of conventional four-layer avalanche diodes. This system had a rise time of 0.5 nsec and a gain of 80.

VII. COUPLERS

Several requirements for various kinds of couplers must be met for fiber communications systems from the simple situation of the branching of one fiber to two fibers, to more complex systems like multiterminal data buses. C. Stewart and W.J. Stewart (Allen Clark Research Centre, The Plessey Company Ltd.) described a directional coupler for a multimode waveguide that is a separate component applied to an existing fiber without changing it. The fiber is pressed against the edge of a thin glass plate that has a sinusoidal grating. The fiber assumes the shape of the grating, causing strong mode coupling and subsequent loss of radiation from the fiber which gets trapped in the glass. The light is then focused into another fiber or a detector. The output coupling efficiency is 20%. The device can also serve as a variable attenuator.

L. D'Auria and A. Jaques have developed several kinds of coupling modules including a prototype seven-port central coupler. The central bundle has 259 fibers and each branch 27 fibers.

J.F. Farrington and M. Chown (Standard Telecommunication Laboratories Ltd. Harlow, UK) described a multi-terminal data system in the form of a time-division multiplex system for avionics applications. They are breadboarding a system which will have 10 terminals and 100-kbit/sec transmission data-rate per terminal.

The kind of bonding used in cable terminations for fiber optic bundles is important for military applications, especially in the field. R. Quarmby (Hellerman Deutsch, East Grinstead, Sussex, UK) described a dry hot-forming technique that, with a few minutes training, can be applied with a portable tool.

Several single-fiber demountable connectors were described by J. Archer (ITT Standard Telephones and Cables Ltd., Leeds, UK). A key factor in the acceptance of single fibers as opposed to bundles of fibers for military applications has been the development of reliable coupling devices for fiber-to-terminal interfaces. One technique developed by ITT consists of mounting the two fiber ends to be mated in concentric ferrules in such a way that the two polished fiber ends come into proper register. A high degree of accuracy is maintained by using cheap watch-jewel inserts drilled to accommodate fibers of different diameters.

VIII. SUMMARY

The Conference was, in the author's opinion, successful in reviewing and presenting the latest developments in fiber and integrated optics with emphasis on military applications. Omitted from the presentations, however, was any work on improving the strength of long single fibers. This is important for fibers many kilometers long. Moreover, nothing was said about radiation damage to fibers.

Some important points brought out during this Meeting are:

(1) There is a growing interest in the modular approach.
(2) GHz modulation of LEDs is now possible.
(3) Recent work indicates that diode lasers will be available in the optimum wavelength region near 1.1 μm.
(4) Laser-diode reliability has improved greatly during the last few years.
(5) Advances have been made recently in modulators, switches, and multiterminal data-bus devices.
(6) Several new connectors and couplers are now available.

APPENDIX I

LIST OF PAPERS PRESENTED

SESSION I-OVERVIEW

REVIEW AND ASSESSMENT OF FIBER OPTICS FOR MILITARY APPLICATIONS
by H.F. Taylor

REVIEW OF INTEGRATED OPTICS
by H. Kogelnik

L'AVENIR DES FIBRES OPTIQUES POUR LES APPLICATIONS AERONAUTIQUES MILITAIRES
par P. Lecat

RECENT PROGRESS IN OPTICAL FIBER CABLES FOR USE IN THE OCEAN
by G.A. Wilkins and R.A. Eastley

FIBER OPTIC SYSTEMS FOR DEFENSE APPLICIATIONS IN THE UK
by B. Ellis

A REVIEW OF NASA FIBER OPTIC TASKS (Abstract Only)
by A.R. Johnston

FUNDAMENTAL MODE SIGNAL TRANSMISSION IN SINGLE—AND MULTIMODE FIBRES
by K. Petermann and H.G. Unger

BEAM EVOLUTION ALONG A MULTIMODE OPTICAL FIBER
by S.U. Shin and L.B. Felsen

TESTING OF TENSILE STRENGTH OF OPTICAL FIBER WAVEGUIDE
by C.K. Kao, M. Maklad and J.E. Geoll

COLOUR MULTIPLEXING TECHNIQUES AND APPLICATIONS IN OPTICAL WAVEGUIDE LINKS
by D.A. Kahn

SESSION II-SYSTEMS

FEASIBILITY DEMONSTRATION OF OPTICAL FIBER PAYOUT COMMUNICATION SYSTEMS FOR MISSILE GUIDANCE
by W.H. Culver

AN EXPERIMENTAL OPTICAL-FIBER LINK FOR THE COMMAND AND CONTROL SYSTEM 280
by E.H. Hara and H.C. Frayn

SESSION IV-PROPAGATION

HOW DOES ONE INDUCE LEAKAGE IN AN OPTICAL FIBER LINK?
by C. Yeh and A. Johnston

ETUDE ET RESULTATS DE LA FONCTION DE TRANSFERT DES FIBRES OPTIQUES
par R. Bouillie, J.C. Bizeul et M. Guibert

DETAIL RESOLUTION IN OPTICAL FIBRE INDEX PROFILING METHODS (Abstract Only)
by W.J. Stewart

NOVEL TECHNIQUE FOR MEASURING THE INDEX PROFILE OF OPTICAL FIBERS
by J.A. Arnaud and R.M. Derosier

INFLUENCE OF THE REFRACTIVE INDEX PROFILE ON THE TRANSMISSION QUALITY OF GRADIENT INDEX OPTICAL FIBRES (Abstract Only)
by G. Gliemeroth, K. Krause, N. Neuroth, and F. Reitmayer

TRANSMISSION CHARACTERISTICS OF GRADED INDEX FIBRES
by P.J.B. Clarricoats, J.M. Arnold and G. Crone

DISPERSION EVALUATION IN MULTIMODE FIBERS BY NUMERICAL TECHNIQUE APPLICATIONS TO RING SHAPED AND GRADED INDEX WITH A CENTRAL DIP
by A.M. Scheggi, P.F. Checcacci and R. Falciai

FINITE-BANDWIDTH PROPAGATION IN MULTIMODE OPTICAL FIBERS
by B. Crosignani, P. Di Porto and C.H. Papas

SESSION V-SOURCES AND DETECTORS

INJECTION LASER TRANSMITTER FOR LONG DISTANCE OPTICS COMMUNICATION
by E. Schiel, G. Talbot and H. Kressel

GaInAsP/InP DOUBLE-HETEROSTRUCTURE LASERS FOR FIBER OPTIC COMUNICATION
by J.J. Hsieh

REPRODUCTIBILITE DE FABRICATION DES DIODES LASERS
par E. Duda, J.C. Carballès et J. Apruzzese

PHYSICS AND TECHNOLOGY OF DEGRADATION IN GaAs LIGHT EMITTING DIODES
by G. Zaeschmar

RELIABLE SEMICONDUCTOR LASERS FOR WIDE-BAND OPTICAL COMMUNICATION SYSTEMS
by A.R. Goodwin, P.R. Selway, M. Pion and W.O. Bourne

SESSION VI-COUPLERS