The Start of Optical Fiber Communications as Seen from a U.K. Perspective

John E. Midwinter, *Fellow, IEEE*

Invited Paper

***Abstract*—The author joined the U.K. optical communications program in 1971, when it had already been running for at least six years and he then observed it during its most formative phases. This is a personal account of some of its triumphs and its disasters that may carry lessons for others in the future.**

***Index Terms*—Optical communications systems, optical fibers.**

I. The First Five Years (1965–1969)

MOST accounts of this topic start with the publication of the classic paper by Kao and Hockham in 1966 [1] but for the purposes of this article, I wish to draw attention to the fact that this paper was actually first received for publication in November 1965 and was thus an account of work already completed during 1965, 35 years ago! Rereading the paper with the benefit of hindsight, one cannot fail to be struck by several impressive details. The analysis of the single-mode dielectric waveguide for optical use would alone have been considered a good basis for a paper by many authors today, but these authors went much further and attempted to bound both the materials problems in fabricating one and the system implications if it was to be competitive as a telecommunications transmission medium. The target of 20 dB/km attenuation was derived and shown to be at least plausible from a materials viewpoint, even though optical fiber guides of the time were more typically of 1000–10 000 dB/km loss. Thus, this benchmark paper not only established a concept but set down some key targets that had to be achieved for a practical system based upon it to emerge. As a result, the work in the U.K. was focused from the outset on the achievement of low-attenuation glass waveguides and I have reason to believe that the same message was taken by others outside the U.K. But more of that later.

It is generally much less well known that having published the theory paper, Kao and co-workers went on to study the optical properties of the readily available glasses of the time [2], [3]. They developed a measurement technique whereby they could estimate the attenuation of a block of glass using an optical path of less than 10 cm length. By this means they were able to show that glasses existed in the late 1960s whose optical losses were well below the 20 dB/km target that they had already set. The major remaining problem was how to convert these glasses into low-loss waveguides. Once again, with the benefit of hindsight, it is intriguing to realize that Kao's work pointed in exactly the right direction, since the low-loss glasses he had identified were all fused silicas which form the basis of today's low-loss fibers. Sadly, however, these glasses had very high melting points, typically in the region of 1800 °C, and there was little experience in the U.K. of working at these temperatures among the fiber-optic community who relied upon multicomponent glasses with much lower melting temperatures.

The problem with these low-melting-point glasses was that they were formed by mixing powder starting materials and melting them together in platinum crucibles prior to extruding them through a platinum nozzle to form a fiber. This was a standard technique for fiber-optic light-guide manufacture where low loss was not required, but was a nightmare where very low loss was essential, since each stage in the process tended to add contamination. The most critical contaminants were the commonly occurring metallic impurities iron, copper, cobalt, etc., so well known as the source of glass colorations in decorative glasses. Contamination levels of sub-parts-per-million were needed and proved nearly impossible to attain. However, despite these difficulties, it should be recorded that Kao's target of sub-20 dB/km attenuation was achieved but only at a time when it had become clear that this was not the best route to follow [4]. Thus two bold steps forward had been marred by one step backward, one in which one may note Kao's own group had also participated as well as my own and others outside the U.K.

During the period 1962–1971, I was studying lasers and nonlinear optics under largely defense-funded programs. Much of the discussion around me centered on dreams of how this primary oscillator at a frequency of many 100 THz and the associated parametric mixer and oscillator technology would inevitably lead to super bandwidth communications and signal processing systems. Joining the U.K. optical communications program in 1971, I still recall the huge culture shock when I discovered that the work was targeted at transmission systems carrying a mere 140 Mbit/s rather than the multiple Terabits I had expected. Again, hindsight shows that this target was absolutely correct, since the very sharp focus it brought to the program led to deployed, revenue-earning systems in the shortest time. Charles Kao had set the right objective and F. F. Roberts, who led the BPO program at that time, championed it. History now

Manuscript received June 28, 2000.

The author is with the University College London, London WC1E 7JE, U.K. (e-mail: j.midwinter@ucl.ac.uk).

Publisher Item Identifier S 1077-260X(00)11497-2.

1077–260X/00$10.00 © 2000 IEEE

Authorized licensed use limited to: British Telecommunications via the BT Library. Downloaded on July 21,2025 at 16:18:17 UTC from IEEE Xplore. Restrictions apply.

shows that it was these "unambitious" systems that made possible the subsequent development of the Terabit technology we now observe today. Without the intermediate stages, I have little doubt that the whole project would have foundered. Speaking, as it were, from the other side of the fence, as leader of the R&D program in BT Laboratories during the critical period that service deployment was being seriously considered (1977–1984), I had many occasions to be thankful for that practical focus since in the late 1970s, even 140-Mbit/s transmission channels were considered large except for a very few routes in Europe and talk of vastly higher rates would have probably led to dismissal of any proposal as an irresponsible dream.

II. The Critical Five Years (1970–1974)

By 1970, the dream of an optical fiber communications system looked as far away as ever, since progress in driving down the fiber attenuation, while steady, was excruciatingly slow. Semiconductor lasers were also still frighteningly unreliable with operating lives measured in minutes or hours rather than the decades needed and the practical details of how to joint or splice cable and fiber had barely been considered. However, at the IEE Trunk Telecommunications Conference [5] in 1970 in London, a bombshell burst upon the scene with the claim by Corning Glass that they had produced a fiber with attenuation below the magic 20 dB/km attenuation target set by Kao. Shortly afterwards, their results were fully confirmed at the (British) Post Office Research Centre (PORC, later to become BT Labs) and at Standard Telecommunications Laboratories (STL, part of STC), Kao's home. More auspicious still, small samples of the breakthrough fiber that had accidentally been left behind were analyzed to show that the fibers were fabricated primarily of silica, the very material that Kao had identified some years earlier as the most likely candidate. The real starting gun had now been fired and the period up to about 1975 saw many of the key ingredients for success fall into place as well as the global program start to take off. Yet it is easy to forget how formidable some of the problems appeared at that time, just as I entered the program on my return from the U.S.

The early Corning fibers were fragile beyond belief, because to achieve their low attenuation, the fibers had to be annealed in an oxygen atmosphere at a very high temperature after pulling. This seriously damaged the surface of the pristine fiber as drawn from the molten state and massively weakened it, just as scratching its surface with a diamond would. Switching to a different core dopant, from titanium to germanium, avoided the need for annealing and thus removed the first-level problem. This, together with the development of polymeric coatings that were applied immediately after glass solidification during the drawing process ultimately led to the strong fiber we take for granted today and opened the way to studies of how to cable such fibers.

The prospect that low enough attenuation fibers were likely to become a reality switched additional attention on to other factors, such as launching, splicing, and dispersion, as well as intensifying the efforts to extend source reliability. The single-mode fiber seemed to present insuperable handling problems because of its extremely small core, and thus interest grew in fibers with larger cores, namely multimode fibers. As a result, a brief perusal of the literature of that time finds numerous papers on topics such as multimode propagation, propagation in graded-index media, and the effects of mode coupling in multimode fibers. The slow realization that to achieve low mode dispersion in a graded-index fiber required astonishingly tight control of the index profile spawned a huge program of studies in all the leading laboratories of techniques to measure the index profile and the pulse dispersion with precision, and the literature of the time is littered with results on both, many confusing. The final resolution of such apparently simple issues as how to specify the dispersion in a graded-index fiber was not resolved until many years later.

Studies of the loss mechanisms in the fiber slowly elucidated the critical importance of the OH ion contamination in the glass and the development of techniques to remove this opened the way to fibers with well below 10 dB/km attenuation at the GaAs-based sources wavelengths (850–900 nm). But another loss mechanism that was much studied and discussed is now almost never mentioned. This was microbending. Multimode fibers suffered from mode coupling between the guided modes and also between the high-order guided modes close to cut-off and the cladding or lossy modes. The result was that subjecting the fiber to small bends or lateral pressures such as are readily applied when winding on a drum or cabling led to unpredictable and time-varying increases in attenuation as well as to changes in the multimode dispersion on long lengths of fiber. This appeared to be a system designers nightmare in which neither the attenuation nor the dispersion could be predicted for a long installed and jointed length of fiber using data taken from the individual lengths. Of course this remains the case today, but we are more relaxed about it and simply allow large design margins, since for really demanding transmission problems we use single-mode fiber which largely avoids the problem.

III. Early Deployment (1975–1979)

It is frequently forgotten today that at the start of this period, the Millimetric Waveguide system was at an advanced stage of development and was widely seen as the next generation of wideband telecommunication transmission system and hence, posed death, or at least major delay, to optical fiber. The system had been designed to carry data rates up to about 20 Gbit/s and was fully developed for deployment at rates up to and well in excess of any traffic demand existing that time. In the U.K., a full field trial was in progress over a 14-km route from the PORC at Martlesham (now BT Laboratories). By comparison, optical fiber "systems" of the time largely consisted of drums of fiber spliced together on optical benches with lasers and detectors mounted on optical micropositioners, and as such were the subject of ridicule by "real engineers." There was no alternative but to move "out of the lab" as soon as possible.

Note also that 1975 saw the launch of two major technical meetings on Optical Communications. The forerunner of OFC was held at Williamsburg, VA, in January and the forerunner of the ECOC was held in London at the IEE in September. The European series first took the name ECOC a year later when the conference was held in France, and with it the Optical Waveguide Theory Workshop was launched, a small group who met annually thereafter for some 5–10 years to review the state of knowledge on fiber properties and to exchange best practice. The photo in Fig. 1 shows the group from the first meeting held

Authorized licensed use limited to: British Telecommunications via the BT Library. Downloaded on July 21,2025 at 16:18:17 UTC from IEEE Xplore. Restrictions apply.



Fig. 1. First optical waveguide theory workshop attendees. **Back Row:** LeMezec, CNET; Felsen, Brooklyn; Someda, Bologna; Jeunhomme, CNET; Gloge, Bell; Unger, Braunschweig; DiVita, CSELT; Olshansky, Corning; Stewart, Plessey. **Center Row:** Clarricoats, QMWC; Midwinter, PORC; unknown; Love, ANU Canberra; Adams, Southampton; unknown; Kawakami, Tohoku; Petermann, Braunschweig. **Front Row:** Kapron, Corning; Snyder, ANU Canberra; Cozannet, CNET; Vassalo, CNET.

at CNET in France in 1976 and features many of the personalities of the time.

At the 1975 IEE meeting, there was a report of a fiber system in operation with the Dorset (U.K.) Police service from STC but apart from raising interest, it fell far short of convincing the telecommunciations companies that fiber was for them. However, 1975 did see the decision at PORC to plan the first U.K. telecommunications system deployment, and this was matched by proposals from STL for a trial installation also. The PORC work went ahead during 1976 and in January 1977, a 13-km length of BICC/Corning fiber cable was laid from the PORC into Ipswich, the nearby town. Later that year, STL installed a better engineered link operating at 140 Mbit/s over a 9-km route but with two intermediate repeaters.

In retrospect, the PORC trial was an interesting experiment that had far greater impact than it probably deserved. Whereas the Millimetric Waveguide trial had required a hugely expensive special duct network laid with unparalleled precision, our fiber cable was pulled into ducts already crowded with other conventional copper cables. The jointing and installation was done by young B.Eng. and Ph.D. graduates who fortunately knew little of the reasons why the task was supposed to be impossible without using much more expensive and sophisticated test and handling equipment. And almost every corner that could be cut was, very much in the British experimental tradition of "pink string and sealing wax." By April 1977, the link had shown an ability to transmit 8 Mbit/s over an unrepeatered length of 13 km and 140 Mbit/s [6] over an unrepeatered length of 8 km. The cost had been minimal and, most importantly, it had shown that fiber cables could be installed virtually anywhere that cable ducts already existed.

The STC trial demonstrated a much more solidly engineered system, yet one that was probably still not economic, but taken together, the two trials undoubtedly had the required effect. Within the Post Office, I believe that it was our demonstration of the longer repeater spacing that attracted the greater interest since the STC 3-km spacing was deemed uneconomic. It also gave a vivid demonstration of how complex graded-index fiber dispersion could be, since one section of the overall link was formed, deliberately, of alternating sections of over and under compensated graded-index fiber, showing alternately multimode pulse spreading and recompression [6].

Once again with hindsight, it is interesting to read a senior engineer of the time saying of the Millimeter Waveguide at a meeting in London in March 1977 just as our fiber trial was heading for break-through, "The (MM Waveguide) technology

Authorized licensed use limited to: British Telecommunications via the BT Library. Downloaded on July 21,2025 at 16:18:17 UTC from IEEE Xplore. Restrictions apply.

now exists … and an operational system can therefore be available at the date required. Fiber-optic systems have been demonstrated … and are likely to become available within a decade" [8]. Just months later, the Millimetric Waveguide project was dead and substantial orders for the delivery of production fiber equipment followed about twelve months later after intensive discussions between the U.K. suppliers and the BPO. The first revolution had occurred but the seeds had already been sown for the second even before the first was complete.

The understanding of the role of water contamination in the fiber had made clear that lower losses were likely at longer wavelengths than 900 nm once it could be controlled. Then, in 1975, Gambling and Payne from Southampton [9] published a paper showing that material dispersion in silica-based fiber passed through zero in the region of 1300 nm. At the time, it attracted little interest since there was no expectation of working at that wavelength and pulse dispersion was dominated by the multimode effects in graded-index fibers. However, following the unexpected ease with which installation and jointing had occurred during the BPO 13-km cable-in-duct experiment and with growing evidence that OH contamination was rapidly being reduced, interest returned to Kao's original 1965 proposal for the single-mode fiber. By the end of this period, reports of extremely low-loss single-mode fibers were emerging from BT Labs [10] as well as many other labs, showing the rather disturbing truth that operation at 1300 nm was far more favorable from a loss viewpoint that at 850–900 nm and that conceivably, the 1550-nm window would be even better. Linking together the favorable loss data with the zero material dispersion data for 1300-nm operation pointed to a possibility of much superior fiber systems.

In the U.K., the repeater power supplies for the existing metallic cable routes were housed in buildings along the major duct routes spaced by about 30 km or less with the repeaters themselves dispersed in manholes between them. It suddenly became clear that if the deployment problems of monomode fiber could be solved and new active devices could be developed for 1300-nm operation, the U.K. cable network could be dramatically simplified with all powered equipment being housed in existing surface buildings. Thus, even before the first production 900-nm/graded-index systems were delivered, they appeared to be obsolete and an awful dilemma emerged.

IV. The Second and Third Revolutions (1980–1984)

The first equipment orders placed in 1979 for delivery during 1980–1981 were based upon specifications for 900-nm operation graded-index system, yet even before they were delivered, some contracts were renegotiated to allow delivery of 1300-nm graded-index technology and increasingly, this wavelength dominated deployment, completing a second revolution and apparently setting the scene for a degree of stability. Yet by 1981, my own research group at BT Labs had demonstrated 140-Mbit/s transmission through 39 km of single-mode fiber at 1300-nm wavelength and through 49 km of the same standard single-mode fiber operated at 1550 nm [11]. Linking this with the observation above concerning line plant led to the painful realization that Kao had been right from the outset. The vast amount of work involved in the development of graded-index technology had in many ways been a diversion, albeit a necessary one, en route to the holy grail. BT switched to single-mode technology for long-haul route procurement in 1983, having churned through three technology generations in just four years, a terrifying rate of change at the time.

Other work at BT Labs explored the use of coherent transmission and detection in the 1550-nm fiber window, primarily with the aim of exploiting the improved receiver sensitivity associated with homodyne and heterodyne detection [12]. Almost as a by-product, it produced a growing awareness that the optical spectrum could be accessed in a microwave-like manner, each megahertz by megahertz. The later development of the erbium doped fiber amplifier (EDFA) at Southampton [13] probably rendered the coherent technology redundant but the experience of working with optical spectrum in so detailed a manner laid valuable foundations for the later study and deployment of dense wavelength-division multiplexing (DWDM).

Early in this period (February 1980) also saw the first optical-fiber undersea cable laid in the U.K. by STC in the Loch Fyne trial in Scotland. It involved a cable length of 9.5 km which was used for 140-Mbit/s transmission studies as well as the later addition of an experimental underwater repeater. The target was the first transatlantic fiber cable, something that seemed impossibly ambitious at that time given the hugely long lead times for the earlier technologies used in undersea deployment, but it led to the target of a transatlantic cable in the late 1980s.

However, soon after this trial undersea cable deployment, very serious alarm bells started to ring when an inland fiber cable system in the U.K. failed as a result of a huge increase in fiber attenuation. A crash program at BT Labs and the cable manufacturers involved quickly established that hydrogen was penetrating the glass fiber and generating an absorption spectrum very similar to the OH water-contamination spectrum. Since it was well known that undersea coaxial-cable systems generated copius amounts of hydrogen by electrolysis, something close to blind panic could be observed in the community. Suffice it to say that changes to both cable and fiber design removed the problem and as a result, the first transatlantic cable system, TAT-8, went ahead in 1988 on schedule and amid much favorable publicity. It was the forerunner of a huge new underwater cable business.

In 1984, with fiber rolling out across the U.K. and Europe, I took the opportunity to change direction and move to a university chair at the University College London (UCL), initially funded by BT. It was a time when, in the U.K., great publicity was being given to "digital optical computing" and, sensing a growing interest in optical networks and perhaps optical switching, it looked interesting. That year another Royal Society meeting was held, entitled Optical Bistability, Dynamical Nonlinearity and Photonic Logic [14], [16] and looking back at the Proceedings is highly revealing. Many of the papers happily discuss "optical logic" with the clear implication that it is the future of digital processing and will surpass silicon, yet show a terrifying unawareness of what silicon was already capable of. The glaring exception is a paper by P. W. Smith [15], [17] which looks at exactly this issue and shows with admirable clarity that optics can expect to have serious problems competing with electronics in so far as dense, highly complex logic is concerned. This is because it will be extremely difficult for it to compete in terms of the power–speed product per logical operation. It was through exactly this type of thinking that Kao

Authorized licensed use limited to: British Telecommunications via the BT Library. Downloaded on July 21,2025 at 16:18:17 UTC from IEEE Xplore. Restrictions apply.

had earlier guided the optical communications program along hugely productive directions. However, the optical computing community seemed unwilling to take note, and despite P. W. Smith's thought-provoking observations, enthusiasts continued to proclaim that such mundane considerations could not stop the development of the massively parallel optical computer.

During the following few years, work on GaAs MQW SEED devices built up at UCL, paralleling similar work at Bell Labs, and my own interest in how or where they might be exploited grew, as did my skepticism for massively parallel photonic switching. By 1988, it was rather painfully clear that digital optical switching and computing of the form being proposed was a nonstarter precisely because of the issues raised by Smith [15], [17], and that optics was supreme only as an interconnect technology. The exception, again as identified by Smith [15], [17], was at logical processing speeds above the electronic range. However, as we had suspected, the MQW device and materials technology opened up new possibilities for optoelectronic devices from which we benefit today. It is far less obvious that the massive spending on the "engineering" of parallel optical processing systems yielded any comparable spin-off. Yet, despite all this, the observation that optical transmission was increasingly limited by the electronic switching interfaces remained true, and one was tantalized by the fact that only a vanishingly small fraction of the optical fiber transmission spectral window was actually being used. By the late 1980s, it was obvious that WDM provided real potential to solve this and the technology to do it was starting to fall into place, further burying "photonic switching."

V. Summary

The subsequent development of optical communications from 1985 is well known and still evolving rapidly. The development of the EDFA probably is the single most influential since 1985 and has opened up possibilities that not even Kao envisaged in terms of the unrepeatered distance accessible as well as spectral utilization via WDM technology. The future seems now to firmly include DWDM optical networks and routing in the wavelength domain as a realistic means of exploiting the optical spectrum of the fiber in a way that is compatible with the electronic and network technologies that must always be interworked with. Massively parallel optical processing, by comparison, appears to be dead although, as P. W. Smith [15], [17] indicated, ultrafast optical logic may well have a future role since, at least in the picosecond response time region, there is much weaker competition from electronics.

The message to me from all of this formative period is overwhelmingly clear. Studying fundamental physics can usually be justified on the basis that it may lead to an unexpected breakthrough. But once one strays into the territory of systems and devices, much tougher constraints must be applied. One should never lose sight of one's "system" target, nor of what the competition is doing. When the competition is far ahead, much more than enthusiasm and a bit more physics and hype will be needed to win through, so that adhering to the "mundane" views of people like Kao [1] and Smith [15], [17] is essential.

References

[1] K. C. Kao and G. A. Hockham, "Dielectric surface waveguides for optical frequencies," *Proc. IEE*, vol. 113, pp. 1151–1158, 1966.

[2] K. C. Kao and T. W. Davies, "Spectrophotometric studies of ultra low-loss optical glasses—I: Single beam method," *J. Sci. Instrum.*, vol. 1, pp. 1063–1068, 1968.

[3] M. W. Jones and K. C. Kao, "Spectrophotometric studies of ultra low-loss optical glasses—II: Double beam method," *J. Sci. Instrum.*, vol. 2, pp. 331–335, 1969.

[4] C. R. Day, J. E. Midwinter, G. R. Newns, R. W. J. Uffen, and R. Worthington, "Optical properties of sodium-borosilicate glass fibers," *Electron. Lett. (GB)*, vol. 10, pp. 450–451, 1974.

[5] F. P. Kapron, D. B. Keck, and R. D. Maurer, "Radiation losses in glass optical waveguides," in *IEE Conf. Trunk Telecommunications by Guided Waves*, London, U.K., Sept.–Oct. 1970.

[6] R. W. Berry, D. J. Brace, and I. A. Ravenscroft, "Optical fiber system trials at 8 Mbit/s and 140 Mbit/s," *IEEE Trans. Commun.*, vol. COM-26, pp. 1020–1027, 1978.

[7] J. E. Midwinter and J. R. Stern, "Propagation studies of 40 km of graded-index fiber installed in cable in an operational duct route," *IEEE Trans. Commun.*, vol. COM-26, pp. 1015–1020, 1978.

[8] C. F. Davidson, "Millimetric Waveguide Systems," *Phil. Trans. Royal Soc.*, vol. A.289, pp. 123–134, 1978.

[9] D. N. Payne and W. A. Gambling, "Zero material dispersion in optical fibers," *Electron. Lett.*, vol. 11, pp. 176–178, 1975.

[10] B. J. Ainslie, C. R. Day, P. W. France, K. J. Beales, and G. R. Newnsa, "Preparation of long lengths of ultra-low-loss single-mode fiber," *Electron. Lett.*, vol. 15, pp. 411–413, 1979.

[11] J. E. Midwinter, "Studies of monomode long wavelength fiber systems at the British Telecom Research Laboratories," *IEEE J. Quantum Electron.*, vol. QE-17, pp. 911–918, 1981.

[12] D. W. Smith and D. Malyon, "Experimental 1.51 micron monomode fiber link containing an injection locked repeater," *Electron. Lett.*, vol. 18, pp. 43–45, 1982.

[13] R. J. Mears, "Low noise Erbium doped fiber amplifier operating at 1.54 micron," *Electron. Lett.*, vol. 23, p. 1026, 1987.

[14] *Proc. Royal Society Meeting Optical Bistability, Dynamical Nonlinearity, and Photonic Logic*, London, U.K., Mar. 1984.

[15] P. W. Smith, "Applications of all-optical switching and logic," in *Proc. Royal Society Meeting Optical Bistability, Dynamical Nonlinearity, and Photonic Logic*, London, U.K., 1984.

[16] "Optical bistability, dynamical nonlinearity and photonic logic," *Phil. Trans. Royal Soc.*, vol. A313, pp. 191–451, 1984.

[17] P. W. Smith, "Applications of all-optical switching and logic," *Phil. Trans. Royal Soc.*, vol. A313, pp. 349–355, 1984.

John E. Midwinter (M'69–SM'81–F'83) was born in Newbury, U.K., in 1938. He received the B.Sc. degree from King's College London in 1961 and the Ph.D. degree from the University of London in 1968, both in physics.

He has worked in laser, nonlinear optics, and optical fiber communications research at the Royal Radar Establishment, Malvern, U.K., from 1961 to 1967, Perkin Elmer and Allied Chemical Corporations from 1968 to 1971, the British Post Office and British Telecom from 1971 to 1984, and at the University College London since 1984, where he holds the Pender Chair of electrical engineering. His current interests are focused mainly on all-optical networks as well as the problems of professional education both at first and higher degree levels, and throughout life in fast-moving fields such as IT and communications. He has authored over 200 papers and numerous books.

Dr. Midwinter has served on numerous conference and other organizing committees for the IEEE, the IEE, and others, and became President of the IEE (London) in 2000.

Authorized licensed use limited to: British Telecommunications via the BT Library. Downloaded on July 21,2025 at 16:18:17 UTC from IEEE Xplore. Restrictions apply.