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BT's laboratories at Martlesham Heath where pioneering work on optical fibres took place

# HISTORY OF OPTICAL FIBRE IN BT
## PART 1 – 1966 TO 1983

**It is striking to note the vital, ubiquitous role optical fibre plays in the network of major operators such as BT. Without deployment of optical fibre, none of the high-speed internet services we all use in our everyday lives would be possible and the same is true for the emerging AI services. Optical fibre has truly transformed the world.**

**RUSSELL DAVEY**

Marking a major milestone – optical fibre

This year marks the 60th anniversary of the Kao and Hockham paper which is generally recognised as the birth of optical fibre communications and so it is timely to reflect on the history and impact of optical fibre.

### Optical fibre today

At the heart of the BT network today are approximately 1000 exchange buildings which house equipment used to deliver fibre-to-the-premises (FTTP) to millions of customers. The same exchanges contain high-capacity packet routers for onward connection to the rest of the world. The packet routers across the country are connected using high-capacity optical fibre transmission. Each fibre carries up to 88 wavelengths at 100-400 Gbit/s and optical amplifiers are used to extend the reach. When customers use 4G/5G mobile services, radio signals are used to connect them wirelessly to the nearest mobile base station, which is then connected directly or indirectly with optical fibre to the packet routers in exchange buildings.

While many organisations contributed to the development of optical fibre and its associated active components, this article

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gives a BT perspective on the deployment of optical fibre and the historic and challenging research that has made it possible. BT became independent of the British Post Office in 1981.

The Post Office research station was first located at Dollis Hill in London. Construction of new laboratories at Martlesham Heath near Ipswich began in 1968 and the new research centre was opened by HM Queen Elizabeth II in November 1975. The early pioneering Post Office work on optical fibres overlapped with the move from Dollis Hill to Martlesham Heath.



**Figure 1:** (a) FF Roberts, first leader of optical fibre research in BT. (b) The 50 mm diameter copper waveguides which were the lead candidate for transmission before optical fibres were invented.

## The early years 1966 to 1970

Optical fibres rely on total internal reflection: when light passes from a medium of higher to lower refractive index (e.g. glass to air or water to air) then for a range of angles all the light is reflected at the boundary. Nineteenth century scientists used this to demonstrate guiding light within a jet of water. The concept could be extended to guide light within a glass fibre and the first application of optical fibres was in the 1950s when bundles of optical fibres were used to make gastroscopes to view inside the human body. However, the loss within optical fibres at that time was far too high for useful communications.

Kao and Hockham published their paper in July 1966 showing that it was theoretically possible to make optical fibres with a loss better than the target of 20 dB/km required for telecommunications. Kao was awarded the Nobel Prize for Physics in 2009 for his work on optical fibre. In his Nobel lecture Kao says he presented the substance of his paper at an IEE conference on 27 January, 1966 and that the only people who took notice were the British Post Office and the UK Ministry of Defence, who both immediately launched their own optical fibre research programmes in parallel to Kao's work at STC in Harlow. The Ministry of Defence work was in collaboration with Southampton University. It is interesting to note that this early era is a very British story.

The Kao and Hockham paper gave no background to the 20 dB/km loss target. The early Post Office work on optical fibre was led by FF Roberts. In a February 1977 publication, he says he became aware of Kao's work in late 1965 and so a Post Office target loss of less than 20 dB/km was set early in 1966 and quoted to all interested parties. A loss of 20 dB/km means that after 1 km of fibre, 99% of the signal has been lost. In 1966 coaxial copper cables were used to connect Post Office telephone exchanges at 34 Mbit/s and 140 Mbit/s with repeaters needed every 1-2 km. Powered buildings were up to 30 km apart and so the repeaters needed to be deployed underground and powered remotely. A higher bandwidth solution was needed to support rapid growth in telephony. The generally accepted lead candidate for the future were highly engineered millimetre copper waveguides of 50 mm diameter, as shown in Figure 1(b), for which a Post Office field trial ran in Suffolk between Martlesham Heath and Wickham Market until 1977. FF Roberts saw optical fibres as a better alternative to both coaxial cables and millimetre copper waveguides, but if their loss was higher than 20 dB/km then optical fibre repeater spacings would be no better than for the deployed coaxial copper cables.

Kao and Roberts were both very active evangelising optical fibres as the future. They often worked together, which is not surprising given their laboratories were close together. Internal Post Office memos show that in March 1966 FF Roberts visited multiple British organisations to discuss making low loss optical fibres. He then proceeded to set up a Low Loss Optical Fibre Consortium in which the Post Office funded research contracts with Kao at STL, Barr & Stroud, British Titan Products and Sheffield University and worked with BICC on putting optical fibres into cables. It is also documented that Post Office engineers visited Corning in the mid-1960s seeking their assistance in making low loss optical fibres, which as we will see turned out to be an especially important visit.

A breakthrough in optical fibres was announced at an IEE conference on Trunk Telecommunications and Guided Waves in London in October 1970. Most of the papers were about millimetre copper waveguides with just a few on optical fibres, including notably one from Corning announcing that they had made a breakthrough in low loss optical fibres. In the discussion at the end of the conference the chairman asked the audience whether the solution was going to be optical fibres or millimetre copper waveguides. Most thought the answer was the more mature copper waveguides. However, Dick Dyott of the British Post Office infamously said: "we can wait for the waveguide to be laid in the ground and then come along and fill it with optical fibres". His sentiment turned out to be correct in that the network today relies

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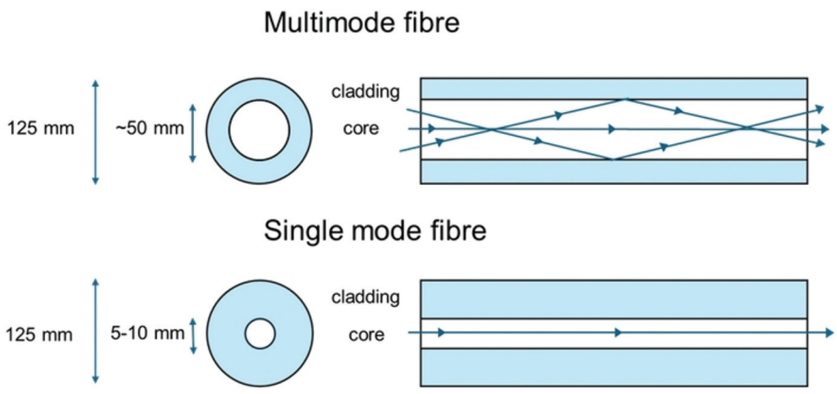



**Figure 2:** Principles of multimode and single mode fibre

on circular ducts filled with many optical fibres, albeit the ducts are not made of copper! However, it would be another seven years before optical fibres finally won the argument.

A few weeks later Corning took a sample of their optical fibre to the Post Office laboratories where its loss was measured to be 15 dB/km (at a wavelength of 633 nm). The target of 20 dB/km had therefore been met, albeit significant progress remained to get to the 0.2 dB/km which we routinely expect today. This breakthrough by Corning was recognised by the IEEE with a Milestone plaque.

## First multimode deployments in the 1970s

Data is transmitted along an optical fibre as a series of optical pulses representing digital "1s" interleaved with dark periods representing digital "0s". As shown in Figure 2, optical fibres typically consist of a solid core surrounded by a cladding of slightly lower refractive index. By total internal reflection the light is guided within the core. In a multimode step-index fibre the core is approximately 50 μm in diameter and the guided light can follow multiple paths (modes) as it passes along the fibre, which causes the digital "1s" to broaden along the fibre and eventually leads to a degradation in transmission. This is known as inter-modal dispersion. In a graded index multimode fibre, the refractive index varies gradually across the fibre which reduces the inter-modal dispersion. By contrast in a single mode optical fibre the core diameter is smaller at approximately 5 μm and so the light can only propagate in a single mode directly along the core, which eliminates inter-modal dispersion.

The early 1970s was an exciting time for optical communications research within the Post Office. The teams knew they were working on a truly revolutionary project that had massive implications for the future of communications. At the time semiconductor lasers at the wavelengths of interest were very immature. Device lifetimes were very short and room temperature operation a distant goal. The Post Office research teams had a long history in reliability engineering and expertise in semiconductor materials. Through collaboration with wider industry, they were able to eventually demonstrate that semiconductor optical transmitters and receivers would be able meet the rigorous reliability requirements for telecommunications. Equally, it was necessary to understand and address the propagation effects in optical fibres. Loss mechanisms had to be understood, including Rayleigh scattering and absorption, plus chromatic dispersion and inter-modal dispersion. A lot of time was spent addressing the challenges of launching light efficiently into fibres and joining them with connectors and by fusion splicing. Both the Kao and Hockham paper and the 1970 Corning breakthrough considered single mode optical fibre. However, in the early 1970s the world moved towards multimode fibre because it was easier to couple the light into the fibre and to join two pieces of fibre together.

John Midwinter took over from FF Roberts leading the Post Office optical fibre research and when HM Queen Elizabeth II opened the new Post Office laboratories at Martlesham Heath on 21 November 1975, he was able to demonstrate transmission at 8 Mbit/s over 6 km of multimode optical fibre (Figure 3). This was made possible by




**Figure 3:** John Mindwinter demonstrating optical fibre to Her Majesty Queen Elizabeth II on 21 November 1975

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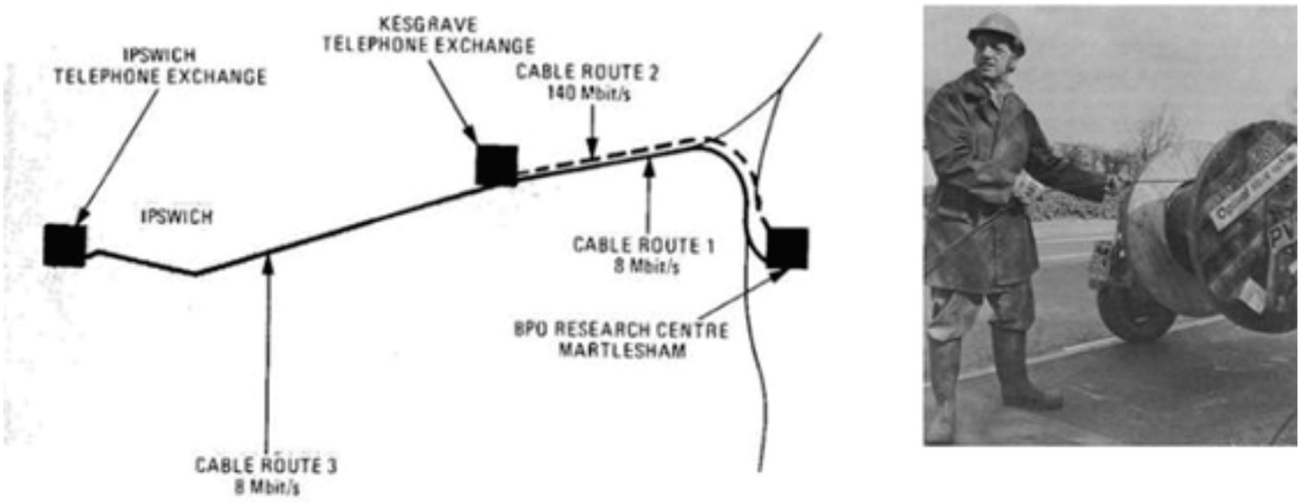



**Figure 4:** First Post Office field deployment of multimode optical fibre in 1977

the culmination of years of exciting, challenging research into both the fibres and semiconductor optical transmitters and receivers.

In 1976 planning began in the Post Office for a field trial of optical fibre using one-kilometre lengths of cables made by BICC, each containing two graded index multimode fibres manufactured by Corning. During winter 1976/77, several lengths of this cable were pulled into existing crowded ducts by local Post Office field engineers and the fibres were jointed together by researchers (often working in snow or rain) to connect the Post Office laboratories at Martlesham Heath to the nearest telephone exchange at Kesgrave. The total route distance was just under 6 km and the loss of the installed, jointed fibre was less than 4.5 dB/km at the operating wavelength of approximately 840 nm. A bit rate of 140 Mbit/s (a common telecoms bitrate at the time) was comfortably achieved without any intermediate repeaters. In fact, 140 Mbit/s was achieved even when the cable length was extended to 8 km without repeaters. As shown in Figure 4, the route was extended to Ipswich telephone exchange giving a total route length of 13 km. For this longer route a bit rate of 8 Mbit/s (another common telecoms bitrate) was achieved.

These results sent a shockwave through the planning departments in the Post Office because they meant optical fibres could be deployed in crowded, operational ducts without needing repeaters every 1-2 km as was the case with coaxial copper cables. Furthermore, the coaxial copper cables were causing problems when upgraded to high digital bandwidths. While the previously preferred future solution of 50 mm diameter copper waveguides was at an advanced stage of development and could carry up to 20 Gbit/s, they needed to be deployed under tension in special steel ducting on straight routes (minimum 100 m bend radius) and filled with nitrogen gas, making them complex and expensive to deploy. The economic case suddenly seemed overwhelmingly in favour of optical fibre and plans to deploy millimetre copper waveguides were immediately dropped. In a similar timeframe to the Martlesham Heath-Kesgrave-Ipswich trial, STL also installed a 140 Mbit/s multimode fibre link in the Post Office network between Stevenage and Hitchin. This worked over a total length of 9 km but needed a repeater in a manhole every 3 km along the 9 km route so its impact was less.

In 1978 BT moved quickly to commercial deployment by inviting tenders. In the absence of standards, it was decided to buy Proprietary Optical Line Systems (POLs) in which both the multimode fibre cable and equipment were purchased from the same vendor. In 1979 contracts were placed with three vendors (STC, GEC, Plessey) for 15 routes operating at a mixture of 8, 34 and 140 Mbit/s. The first multimode fibre route between Brownshill and Walsall went live in 1980 with further deployments following in 1980 and 1981. The first deployments operated at wavelengths of 850nm where semiconductor light sources were first developed but some of the later multimode deployments moved to wavelengths of 1300 nm where the fibre losses were lower. Deployment of multimode fibre by overseas network operators was also underway.

## The change to single mode fibre in the early 1980s

In 1981, British Telecom became independent of the Post Office and the Martlesham Heath research site became BT Laboratories. During this period, work within BT Laboratories showed that significant cost savings could be achieved by moving to 140 Mbit/s and having a repeater spacing of more than 30 km, since this would eliminate the need for intermediate repeaters to be deployed in manholes with the associated operational costs such as providing remote electrical power. The 140 Mbit/s multimode fibre systems of the time needed repeaters at least every 10 km.

In 1979 NTT had reported a 2.2 km length of single mode fibre with a loss of 0.6 dB/km at

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1270 nm and just 0.2 dB/km at 1550 nm. Research within BT focussed on producing longer lengths of low loss single mode fibre and optimising its design. The plenary talk at the Optical Fibre Communications (OFC) conference in 1982 was given by Ainslie and Day of BT Labs on "Current world-wide status of single-mode fibres". This presentation and BT publications from the same period show it is possible to simultaneously optimise fibre loss and chromatic dispersion and describe a "type B" design with low loss at both 1300 nm wavelengths (0.38 dB/km) and at 1550 nm wavelengths (0.22 dB/km). This dual-window design is typical of that now widely deployed.

Single mode fibre was lower loss than multimode, was cheaper to produce and did not suffer from the inter-mode dispersion which limited the bit rate and regenerator spacing on multimode fibre systems. However, the smaller core meant it was more difficult to launch the light into the core and to join lengths of optical fibre. Sydney O'Hara, deputy director of research, chaired a meeting at BT Laboratories where the world-changing decision to focus on single mode fibre was made. The first BT laboratories open week in 1980 included a lab demonstration of 140 Mbit/s operating over 37 km of single mode fibre without any intermediate repeaters.

The world's first field trial of single mode optical fibre was performed by BT Laboratories in February 1982 over a 7.5 km length of cable installed between the Martlesham Heath labs and the nearby town of Woodbridge. The Martlesham-Woodbridge trial used a mixture of BT's own fibre along with other fibre produced by GEC. In both cases the fibres were of an experimental basis made from a range of glass preforms and not tightly toleranced. The fibres were put into four-fibre cables by Telephone Cable Limited (TCL) who used conventional cable installation methods to deploy six 1-2 km lengths of cable into operational duct already containing copper cables.

One of the main objectives of the trial was to confirm that fusion splicing of single




**Figure 5:** Single mode fibre work at BT Laboratories. (a) Keith Beales and George Newns with an optical fibre preform (b) Fusion splicing fibres in 1982 on the world's first deployment of single mode fibre between Martlesham and Woodbridge (c) Single mode fibre team with 1985 Queen's Award for Technological Achievement

model optical fibres could be performed not only in the laboratory but in a field environment – in a vehicle or in a tent above a manhole. This objective was successfully met with a mean splice loss of approximately 0.22 dB at the operating wavelength of 1310nm, in line with theoretical predictions. Using all 4 fibres in the 7.5 km cables deployed between Martlesham and Woodbridge, systems experiments were successfully performed over 31.5 km of fibre at both 140 Mbit/s and 650 Mbit/s at the operating wavelength of 1310 nm. At 140 Mbit/s the experiment was extended to 62 km by adding in an additional length of laboratory cable. This was double the initial target of a 30 km spacing between repeaters!

In the same year a second single mode field trial was deployed in collaboration between BT and STL on a 15 km cable route from BT Laboratories to Ipswich exchange. The fibres for this route were produced by STC/STL in a pilot manufacturing facility and so were more tightly toleranced than those used for Martlesham-Woodbridge, achieving a lower mean splice loss of 0.11 dB at 1310 nm. System experiments on the Martlesham-Ipswich route achieved 565 Mbit/s over 61 km operating at 1310 nm.

The two Martlesham trials of single mode fibre convinced BT to use single mode for one of the next phases of Proprietary Optical Line Systems. This deployment between Luton and Milton Keynes took place in 1983 and was the world's first commercial deployment of single mode fibre. The system was purchased from STC and operated at 140 Mbit/s over a distance of 27 km without any intermediate regeneration. By 1984 BT had become the first operator in the world to move to single mode fibre for volume deployment. History shows that the world followed this direction.

Figure 5 shows that the pioneering work in BT on single mode optical fibre ranging from design and fabrication through to practical challenges like splicing fibres in the field won a Queen's Award in 1985.

## AUTHOR'S CONCLUSIONS

Looking back, the speed of progress in BT on optical fibre deployment was remarkable, from a lab demonstration of multimode fibre to HM Queen Elizabeth in 1975 to volume deployment of single mode fibre in 1985. John Midwinter led the work throughout most of this period, wrote a seminal textbook and was awarded an OBE and FRS. When in 1984 he left to take up a BT chair at University College London his colleagues presented him with a mini coffin, shown in Figure 6, inscribed with "laid to rest by optical

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**Figure 6:** Mini coffin presented to John Midwinter by BT colleagues as a leaving gift, containing the copper technologies "laid to rest by optical communications".

communications" and containing samples of the alternative media, such as coaxial cables and millimetre waveguides which had been replaced by optical fibres. The development of optical fibre technology was far from over. Significant further developments would follow such as coherent transmission and erbium fibre amplifiers along with networking techniques like wavelength switching and passive optical networks (PONs). However, the development of optical fibres in the first place was the fundamental first step to enable the high-speed internet we all take for granted today and this was only possible due to the vision of Sir Charles Kao and FF Roberts in 1966 and the teams of researchers who worked through the subsequent years to make their vision a reality.

**Acknowledgements**

The author is grateful for invaluable discussions with many retired colleagues from the BT optical fibre community, including Jim Ainslie, Keith Beales, Steve Hornung, Colin Millar, Dave Payne, Mick Reeve, David W Smith, Jeff Stern, Tim Whitley, John Wright, and to the family of John Midwinter for sharing photographs and memorabilia.

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