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History of Optical Fibre in BT Part 2 – 1980s and 1990s

BT's early achievements in optical fibre technology included a laboratory demonstration of multimode fibre to HM Queen Elizabeth in 1975 through to the World's first commercial deployment of single mode fibre in 1983. Throughout the 1980s and 1990s, subsequent BT research led to technologies of fundamental importance in today's networks including coherent fibre transmission, erbium fibre amplifiers, wavelength switching and passive optical networks (PONs).

Extending the reach of single mode optical fibre

As described in a previous article in this Journal [1], BT's 1982 single-mode fibre field trials around Martlesham in Suffolk showed that a 30 km reach was achievable and that single-mode fibre could be deployed in an operational environment. This reach was important because it avoided the need to install repeaters in underground manholes. In 1983, BT went on to deliver the world's first commercial deployment of single-mode fibre between Luton and Milton Keynes, after which the wider industry adopted single-mode fibre as the basis for optical networks worldwide. BT research then turned to extending transmission distance by moving the operating wavelength from 1300 nm to 1550 nm. Although single-mode fibre has lower loss at 1550 nm, this required suitable transmitters and receivers to be developed and an effect called chromatic dispersion to be mitigated.

By 1985, using the trial cables already installed around Martlesham, BT had demonstrated a 1550 nm system operating at 140 Mbit/s over 90.5 km — three times the original target. Over time, 1550 nm became the standard wavelength for longer-distance optical fibre systems, while 1300 nm remains common on shorter links.

BT research then looked at further extending the reach and bitrate of optical fibre transmission. Work to date had used direct detection in which the optical signals exiting the optical fibre link are converted to electronic signals using a semiconductor photodiode. Noise arises within the receiver and limits the reach of a direct detection system. The first avenue explored was coherent transmission which had long been used in radio systems. In coherent transmission the weak optical signal exiting the optical fibre is combined with a second much larger optical signal (known as the local oscillator) before entering the receiver. This effectively amplifies the signal without increasing the noise, improves the receiver sensitivity and allows longer reaches. A second benefit of coherent transmission is it allows not only the amplitude but also the phase of the light to be modulated, thus increasing the amount of information that can be carried (measured in bits/s/Hz).

There were three challenges to overcome to allow coherent transmission in optical fibres. Firstly, it was necessary to achieve far narrower semiconductor laser linewidths than had been used for direct detection. Secondly, optical components needed to be developed such as external modulators and couplers. Thirdly, the polarisation stability of deployed optical fibres needed to be confirmed. In the early 1980s the BT team led by David W Smith performed groundbreaking experiments to demonstrate coherent optical transmission and this was recognised with the Rank Prize for Optoelectronics in 1984 [2]. The Rank Prize certificate states: "No group were able to translate this concept into practice. Smith and his co-workers overcame the crucial problems and showed how such systems can be made. The work is a significant step in the continuing improvement of world communications and is of real benefit to mankind".



(a) (b)

Figure 1: (a) The BT team receiving The Rank Prize for Optoelectronics for groundbreaking research on coherent optical fibre transmission in 1984. From left David W Smith, Derek Malyon, Sir John Davies (chair Rank Prize Fund), Richard Wyatt, Terry Hodgkinson. (b) Equipment used in first field deployment of coherent optical fibre transmission between Cambridge and Bedford in 1988

In 1988 BT were the first in the world to take coherent transmission out of the laboratory and into the field with a 176 km link operating at 565 Mbit/s between Cambridge and Bedford [3]. Figure 1 shows the BT team receiving their Rank Prize along with the equipment used in the later field trial.

However, coherent transmission did not see immediate widespread commercial deployment, primarily because an alternative way to extend the reach of optical fibres was being researched – the erbium doped fibre amplifier (EDFA).

EDFAs were first reported by Southampton University in 1987, using a large gas laser to provide the pump. Laboratories worldwide including BT then began research into making erbium doped fibres and using them to build optical amplifiers. In 1988 Tim Whitley of BT reported the first experiment to pump an EDFA with a semiconductor laser diode, which was an essential step to make a commercial amplifier [4]. The basic idea is shown in figure 2. A few metres of single mode optical fibre are lightly doped with erbium ions and pumped using a semiconductor laser diode. The excited erbium ions can then amplify a weak incoming signal at 1550 nm - exactly the wavelength region where single mode optical fibres have their minimum loss. EDFAs avoid the need convert the signal back to electronics, as was the case for earlier repeaters, and furthermore can simultaneously amplify several signals (each at different wavelengths). BT went on to produce a prototype EDFA packaged for commercial deployment, which featured on the BBC's Tomorrow's World television programme in 1990 and was runner-up in the Prince of Wales Award for Innovation and Production. By deploying EDFAs as intermediate line amplifiers – typically spaced up to 80 km in terrestrial networks - it became possible to build optical fibre transmission systems hundreds or even thousands of kilometres long.

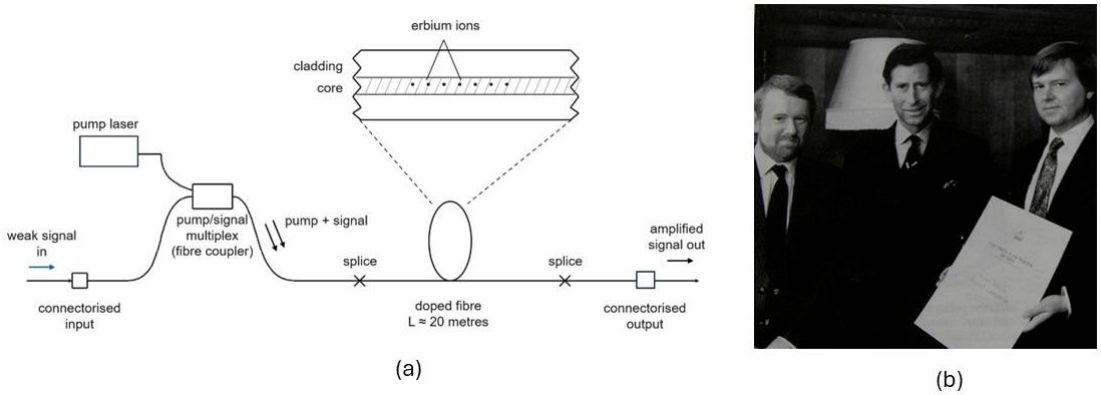


Figure 2: (a) Schematic of a diode-pumped erbium doped fibre amplifier (b) BT team (Colin Millar (left); Paul Wheatley (right) receiving award from HRH Prince Charles in 1990 for developing prototype erbium doped fibre amplifier

The path to optical networking

Widespread deployment of single mode transmission systems took place between BT exchanges throughout the late 1980s and 1990s using direct detection and without optical fibre amplification. The first generation was known as Plesiochronous Digital Hierarchy (PDH) and this was followed by a second generation known as Synchronous Digital Hierarchy (SDH). SDH was deployed at 2.5G bit/s and later 10 Gbit/s and typically used optoelectronic repeaters every 40 km (1300 nm wavelength) or 80 km (1550 nm wavelengths).

By 1998 EDFAs were commercially available and BT used them to deploy Wavelength Division Multiplexing (WDM) for the first time in its network. WDM uses multiple lasers, each at a slightly different precisely defined wavelength within the 1550 nm wavelength region. These wavelengths are all combined (multiplexed) onto one fibre at the transmit end using a passive optical filter and then demultiplexed at the far end using a similar passive filter – rather like how a prism splits white light into the colours of the rainbow. EDFAs are used at the terminals and at intermediate locations spaced by approximately 80 km. The first live BT deployments of WDM were on the Edinburgh-Newcastle and Belfast-Carlisle routes in 1998. They could support 16 wavelengths each carrying up to 2.5 Gbit/s. They also supported 1+1 optical protection switching in the event of a cable cut, which was very innovative. A second generation of WDM was widely deployed in BT's core network through the 2000s, operating with up to 80 wavelengths each carrying 10 Gbit/s. They used EDFAs with direct detection.

By 2010 physics dictated that the pioneering work performed on coherent transmission in the 1980s was about to have its day! At 10 Gbit/s chromatic dispersion was causing the optical pulses carrying the digital data to broaden as they went along the fibre. To ensure error free transmission it was necessary to periodically deploy special dispersion compensating fibres to reverse the effect of dispersion. The take-up of broadband services was causing significant traffic growth. It was inevitable that BT would need to move to higher bitrates but that a more practical way to overcome chromatic dispersion would be needed. The answer was to use coherent transmission combined with EDFAs and the advanced signal processing made possible by the massive strides made in silicon electronics. In this way 100 Gbit/s WDM was deployed throughout the BT core network.

There is one key technical component of today's network we have yet to mention and this too traces its roots back to BT research in the 1980s and 1990s. Until 2010 BT deployed point-to-point WDM systems connecting two electronic switch/router nodes. In 1986 Dave Payne and Jeff Stern of BT demonstrated using wavelengths to passively connect multiple nodes in a network [5]. In 1988 Goff Hill of BT proposed multi-wavelength switching in which WDM is combined with all-optical switches to build a circuit switched network with a wavelength providing the end-to-end circuits [6]. Building on these ideas, the RACE Multi-Wavelength Transport Network (MWTN) Project started in 1992 led by BT working alongside ten European manufacturers and operators. Its ambition: to demonstrate a *managed*, transparent, multi-wavelength optical transport layer—far beyond the capacity of the PDH and SDH systems of the day. The project developed prototype components, and BT contributed to optical network standardisation. In Sweden MWTN built the world's first field trial of transparent, multiwavelength optical networking with management systems and demonstrated two nodes at BT's 'Innovation '94' exhibition. In 1995, BT received the RACE Award for Technological Progress, shown in figure 3, in recognition of MWTN's achievements—a significant milestone

at the close of the decade-long RACE programme.



Figure 3: Award won by the MWTN project on optical switching

The BT core network today is the “motorway network” for broadband Britain. Deployed between 106 exchanges in the major cities it uses EDFAs, coherent transmission and optical switching to provide 100 Gbit/s, 200 Gbit/s and 400 Gbit/s wavelength networking all-optically across the length of the country. The signals leaving any UK city are carried as light all the way to their destination passing through multiple all-optical wavelength switches along the way, and without ever being converted to electronics. This is a remarkable technical achievement which can be traced back to pioneering BT research in the 1980s and 1990s.

Fibre-to-the-premises and Passive Optical Fibre Networks

As soon as optical fibres began to be deployed between telephone exchanges, researchers began to dream about deploying optical fibre all the way to people’s homes. This part of the network is highly cost sensitive. The first BT trial of fibre-to-the-home ran from 1982 to 1984 in Milton Keynes [7]. Known as “Fibrevision” it connected eighteen homes with optical fibre and allowed customers to select from a range of pay TV and radio programmes. In contrast to how things are done today, each fibre carried only one television channel! A “switched star” configuration was used in which the content was distributed from a central hub over a ten-fibre cable to an electronic switch situated up to 200 m from the customers. Each home was connected to the switch via an optical fibre cable.

The switched star approach used in Milton Keynes illustrated the quandary that to deploy fibre-to-the-home in volume would require either enormous amounts of dedicated optical fibres from the exchange to each home, or large numbers of active switching nodes in the street. At the IEEE Conference on Communications (ICC) in Amsterdam in May 1984, Jeff Stern of BT proposed an answer to this quandary [8]. The first deployments of single mode fibre between exchanges had demonstrated reaches greatly exceeding the approximate 5 km maximum needed in the access network. This allowed ample optical budget to introduce passive optical splitters into the network to form a “passive star” network. A single shared fibre from the exchange feeds a passive optical splitter in the street which is connected to multiple homes via dedicated fibres. This concept would go onto be known as a Passive Optical Network (PON) and is widely deployed to millions of homes today.

PONs greatly reduce the amount of optical fibre that needs to be deployed in the access network while also avoiding the need for active electronics in the street with associated operational costs. The ICC paper also raised the possibility that upstream transmission from the customers to the exchange could be achieved over a common wavelength using some contention or polling protocol. Again, this principle is exactly how the PONs deployed today work (e.g. ITU-T GPON and XGS-PON). In the downstream direction a continuous

bitstream is broadcast to all customers, with encryption used to ensure each customer can only read the data intended for them. In the upstream a protocol ensures each customer sends a burst of data at allocated times so that the bursts of data from different customers do not collide when they arrive at the exchange.

By 1987 BT had focussed PON research onto cost-effectively meeting the needs of telephony customers and reported early laboratory demonstrations of what became known as TPON (Telephony on Passive Optical Network) [9]. In 1991 and 1992 BT deployed a field trial of optical fibre access in the small town of Bishop's Stortford to the north of London. Unlike most overseas optical fibre access trials it was not aimed at greenfield sites but rather used a mixture of housing types and ages. The Bishop's Stortford trial included an active switched star approach but unlike overseas field trials Bishop's Stortford also included TPON and in fact one of the objectives of the trial was to compare the active and passive approaches. As shown in figure 4, the TPON system shared a 20 Mbit/s optical signal between customer end points via a 128-way passive optical split. The trial deployed both "house TPON" with a fibre connection all the way to the home and "street TPON" in which the final connection to the home uses copper pairs with an electrical unit in the street to interface between the fibre and multiple copper pairs.

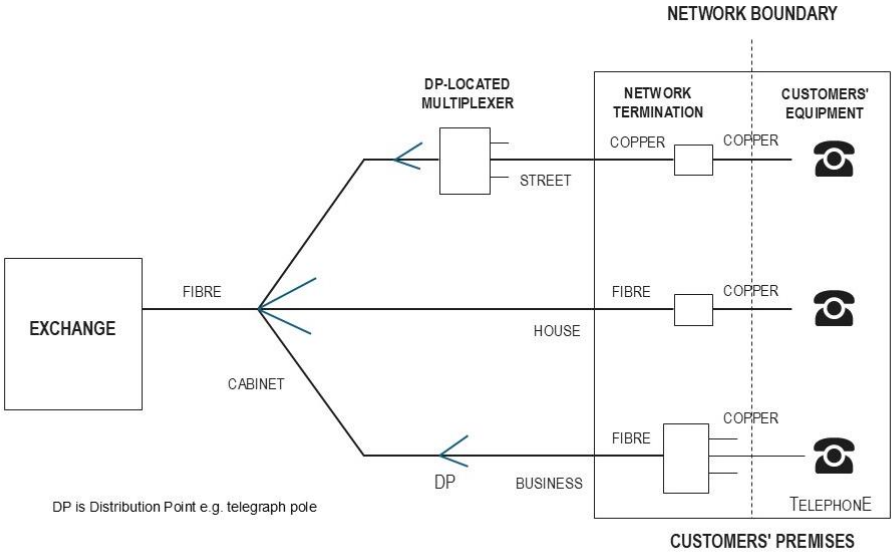


Figure 4: Network architecture for first deployment of passive optical networks for fibre-to-the-premises at Bishop's Stortford in 1991.

TPON operated at wavelengths around 1310 nm to deliver the narrowband services. Wavelengths around 1500 nm were reserved for future broadband services such as television. The two wavelengths could then coexist over the same fibre, and broadband could be added later without disrupting existing telephony traffic.

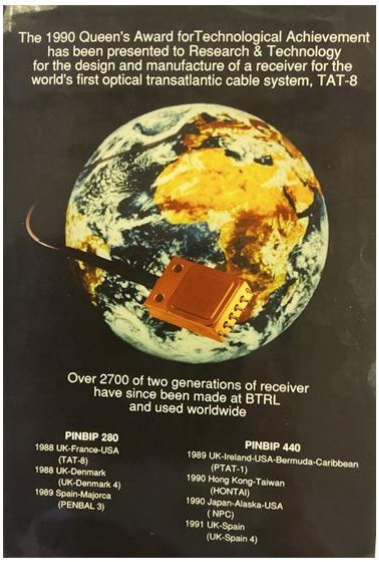
The Bishop's Stortford trial achieved a great deal in terms of understanding the business, operational and technical challenges of an optical access network. However, it was recognised that at the time (before the widespread use of the internet) the economics of wide scale fibre access could not be justified. To reduce costs BT set up an international collaboration with other major operators which became known as the Full-Service Access Network (FSAN) group. This resulted in international standardisation of cost-effective PON equipment. The PON equipment deployed today to deliver fibre to hundreds of millions of premises around the world has arisen from the work of FSAN and the early research at BT. The first generation of deployment by BT Group to millions of homes follows the GPON standard with 2.5 Gbit/s downstream and 1.2 Gbit/s upstream and typically 32-way split. Individual customers can be upgraded to higher speed XGS-PON (10 Gbit/s symmetrical) over the same fibres as GPON using the elegant wavelength reservation scheme first proposed for Bishop's Stortford.

Queen's awards for TAT-8, MOVPE and Blown Fibre

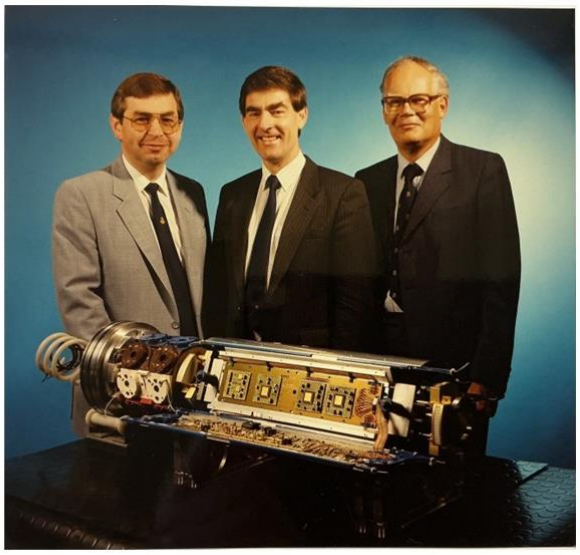
The quality of BT optical research in the 1990s is illustrated by the award of three Queen's Awards for Technological Achievement

TAT8 was the first transatlantic subsea optical fibre cable. It entered service in 1988, operating at a 1300 nm wavelength carrying 280 Mbit/s (8000 voice channels). EDFAs were not yet commercially available and so subsea optoelectronic repeaters were periodically deployed along the route to detect the weak optical signal,

regenerate it and modulate a laser for ongoing transmission. Subsea systems require very high reliability and the world-class technical capabilities of the BT laboratories, including reliable silicon integrated circuits, meant that contracts were placed with BT for the design and manufacture of the receiver used in the subsea repeaters for TAT-8. BT would go on to manufacture over 2,700 receivers for use in seven other subsea cables worldwide. In 1990 BT received the Queens's Award for Technological Achievement for the design and manufacture of the TAT-8 receiver. Figure 5(a) shows the certificate and figure 5(b) shows the proud winners along with an example of a subsea repeater. TAT-8 used cables from multiple vendors and so the BT team developed cable jointing techniques which would later lead to universal cable joints which are vital today in the repair of international subsea cables



(a)



(b)

Figure 5: (a) Queen's Award for TAT8 subsea receiver. (b) Some of the team with the TAT8 repeater. From left Peter Cochrane, Tom Rowbotham and Derek King (Technical Lead).

From the outset of optical research in 1966, BT's laboratories had researched how to make suitable semiconductor-based light sources and receivers for use with optical fibres. Indeed, many of the technical challenges lay in this area. In the 1970s & 1980s, the technique of Metal Organic Vapour Phase Epitaxy (MOVPE) was being developed across the world for various applications. BT researchers worked collaboratively on MOVPE with universities and companies like Plessey and STL and this was commercialised through the BT&D joint venture with Du Pont. In 1993, BT received the Queens's Award for Technological Achievement for the development of MOVPE for making semiconductor devices for the optoelectronics industry, and the technique is widely used today.



(a) (b)

Figure 6: (a) The MOVPE equipment developed at BT's laboratories (b) the Queen's Award for MOVPE

In 1982 Steve Cassidy and Mick Reeve of BT were investigating ways to install fibre in ducts without putting it under strain. They tried blowing fibre along a tube with air by attaching a parachute at the end. It worked – but worked even better when the parachute came out of the end. This prompted them to study the theory of fluid flow and find that the speeds, density and dimensions involved in their experiment were orders of magnitude beyond the point at which standard Newtonian fluid flow breaks down. They therefore assumed the flow was chaotic and devised a simple theory which agreed well with experiments and allowed optimisation of the design of the tubes and blowing equipment. Patents arose from their research plus a field trial in 1984 and licensing to suppliers. Blown fibre was used in the Bishop's Stortford fibre to the premise (FTTP) trial. In 1994 BT received the Queens's Award for Technological Achievement for blown fibre and today BT fibres and fibre cables are often installed using this technique.

Author's Conclusions

Following the world-changing deployment of single mode optical fibre in 1982, BT research based at its Martlesham Heath laboratories near Ipswich continued to push the boundaries of optical fibre technology throughout the 1980s and 1990s. This was recognised with multiple awards. The technologies developed are central to the optical fibre networks which are ubiquitously deployed today and are central to all our lives and to the economy. Optical fibre has changed the world and BT's research in the field has made a key contribution to that revolution.

Acknowledgements

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Abbreviations

EDFA	Erbium Doped Fibre Amplifier
GPON	Gigabit Passive Optical Network
MOVPE	Metal Organic Vapour Phase Epitaxy
PDH	Plesiochronous Digital Hierarchy
PON	Passive Optical Network
SDH	Synchronous Digital Hierarchy
TPON	Telephony over Passive Optical Network

WDM	Wavelength Division Multiplexing
XGS-PON	10 Gbit/s- capable Symmetric Passive Optical Network

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